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Project Technical Information

Comparison of Organic and Inorganic Ion Exchangers for Removal of Cesium and Strontium from Simulated and Actual Hanford 241-AW-101 DSSF Tank Waste

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April 1996

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest National Laboratory
Richland, Washington 99352
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Summary

Pacific Northwest National Laboratory (PNL) conducted this study as a joint effort between the "Develop and Test Sorbents" task for the Efficient Separations and Processing Cross-Cutting Program (ESP) and the "Batch Testing of Crystalline Silico-Titanates (CSTs)" subtask which is part of the PNL Tank Waste Remediation System (TWRS) Pretreatment Technology Development Project. The objective of the study is to investigate radionuclide uptake of the newly produced CST materials under a variety of solution conditions and compare the results obtained for this material with those obtained for other commercial and experimental exchangers.

A number of organic and inorganic exchangers are being developed and evaluated for the removal of ^{137}Cs, ^{90}Sr and other radionuclides from Hanford tank wastes. The exchangers investigated in this work include powdered (IONSIV® IE-910; referred to as IE-910) and two batches of the engineered (IONSIV® IE-911; referred to as IE-911 (08) and IE-911 (38B)) forms of the inorganic CST sorbent developed by Sandia National Laboratories/Texas A&M and prepared by UOP; a phenol-formaldehyde resin (CS-100) developed by Rohm and Haas; a resorcinol-formaldehyde (R-F) polymer developed at the Westinghouse Savannah River Company and produced by Boulder Scientific; an inorganic zeolite exchanger produced by UOP (IONSIV® TIE-96; referred to as TIE-96); an inorganic sodium titanate produced by Allied Signal/Texas A&M (NaTi); and a macrocyclic organic resin developed and produced by IBC Advanced Technologies (SuperLig® 644; referred to as SL-644). Several of these materials are still under development and may not be in the optimal form. UOP has further developed the IE-911 with improved kinetics and samples are expected to be available in January 1996.

The work described in this report involves the direct comparison of these materials for the pretreatment of actual and simulated Hanford tank waste. Cs and Sr K_d's, column distribution ratios ($\lambda = K_d \times \rho_b$), and decontamination factors (DF) are compared as a function of contact duration, solution composition, supernate:exchanger phase ratio, and multiple sequential contacts. The actual double shell slurry feed waste is a volume composite from tanks 101-AW (70%), 106-AP (20%) and 102-AP (10%). The actual waste tests were conducted at 4.96 ± 0.19 M sodium and 23°C with Na/Cs mole ratios that ranged from 100 to 500,000. The simulant composition was formulated based on previous analytical characterization of the actual waste and tests were conducted at dilutions ranging from 7 to 0.2 M Na, over a wide range of Na/Cs mole ratios (50 to 500,000).

The following specific conclusions resulted from the study:

- For the multiple contact experiment, a maximum Cs-137 DF of 421 was obtained with the SL-644 material. This corresponds to a Cs-137 level of 0.46 Ci m^{-3} at 5 M sodium which is lower than the NRC Class A limit of 1 Ci m^{-3}. The maximum DF for Sr-90 of 239 was obtained using the IE-911 material. This corresponds to an effluent concentration of 6.7E-04 Ci m^{-3} which is significantly lower than the NRC Class A limit of 0.04 Ci m^{-3}. These DFs are a general reflection of the λ values and are not an indication of the DFs that could be obtained in a column type operation. For both Cs and Sr, it is likely that additional contacts with any material would have provided additional decontamination.

- For all of the ion exchange materials examined, the calculated cesium λ values increase with Na/Cs ratio (decreasing cesium concentration) and decrease with increasing sodium concentration. Cs λ values varied from 2 to 6.0E+04 with the following order over most solution conditions: IE-910 ≈ IE-911 > SL-644 ≈ R-F > TIE-96 > CS-100. In general, the organic exchangers exhibited lower Cs λ values than IE-910 or IE-911. Since they will most likely be used in a

number of load/elute cycles can be minimized by processing concentrated waste streams regenerable column configuration, a high Cs λ is not as important as it is with the inorganic exchangers. Material stability and the ease with which the exchangers can be eluted and regenerated are more important and were not addressed in this study.

- In general, there was agreement between the Cs λ results obtained with the simulated and actual wastes. However, for all of the materials, the actual waste results were lower than those obtained in the simulant. At feed conditions (5 M Na and Na/Cs = 78,000), the difference between the simulant and actual waste Cs λ values were -4%, -50%, -14%, -35%, -21%, and -24%, for CS-100, R-F, SL-644, IE-910, IE-911, and TIE-96, respectively.

- The CST sorbent (powdered IE-910 and engineered IE-911) demonstrated high affinity for cesium and strontium in the actual and simulated waste solutions. The Cs λ of the IE-911 (38B) material was virtually identical to that of the IE-910 during the actual and simulant waste tests (at 5 M Na) and only 20% to 30% lower at 0.2 M Na in the simulant. Evidently, fabrication into an engineered form did not severely impact the equilibrium Cs distribution.

- Comparison of Cs and Sr λ values from batch contacts at different phase ratios do not indicate the presence of interfering components that might foul the exchanger surface or exchange sites.

- Based on the actual waste ICP results, the organic ion exchangers remove chromium (SL-644 > R-F > CS-100). In addition, zirconium was removed by all of the materials except IE-911, with the following order: NaTi ≈ TIE-96 >> SL-644 > R-F ≈ CS-100 > IE-910. These data suggest that future testing will be necessary to address the issue of significant metals uptake.

- All of the materials demonstrated an affinity for strontium with the NaTi providing the greatest removal followed by IE-911, IE-910, and TIE-96. The organic exchangers exhibited relatively low affinities and would not be useful for strontium removal.

- For every ion exchange material, the Sr λ results were much lower in the actual waste experiment than those obtained during the simulant tests. This is most likely due to reduced strontium levels in the simulant with respect to the actual waste and the presence of organic materials in the actual waste that were not present in simulant. The exact nature of these organics is not known but they are generally complexant materials that would react with the Sr to form neutral or anionic complexes, thereby reducing the extent to which the cation exchange takes place.

- Based on the simulant testing results, a 25-fold dilution of the waste from 5 M Na to 0.2 M Na increases the CST cesium loading 12-14%, doubles the loading on the TIE-96, and decreases the cesium loading 40-45% for the organic exchangers. The process implication is that for inorganic materials, the amount of exchanger required can be minimized by processing dilute streams (e.g., before evaporative concentration of the waste). Conversely, if organic exchangers are used, the number of load/elute cycles can be minimized by processing concentrated waste streams.

The actual waste results are summarized in Table S.1 at the initial feed conditions of 5.0 M Na, 0.48 M K, 23°C, and a Na/Cs mole ratio of 78,000. The equilibrium data are given as K_d (exchanger mass basis) and λ values (exchanger volume basis) to illustrate the effect of the bed density on the apparent performance. The λ value is useful for sizing ion exchange columns and the K_d value is pertinent for assessing the impact of converting the loaded materials into a final waste form.

Table S.1. Actual Waste Testing Results at Feed Conditions (5 M Na, 0.48 M K, and Na/Cs = 78,000)

Exchanger Description	Material Composition	Material Producer	Density[(a)] g mL^{-1}	Cs K_d mL g^{-1}	Cs λ	Sr K_d mL g^{-1}	Sr λ
IONSIV® IE-911	Silicotitanate	UOP	1.13	710	800	900	1000
IONSIV® IE-910	Silicotitanate	UOP	0.77[(b)]	910	700	700	540
IONSIV® TIE-96	Zeolite	UOP	0.77	21	16	250	190
NaTi	Sodium titanate	Allied Signal	0.58[(b)]	NA[(d)]	NA	2100	1200
SuperLig® 644	Polymeric macrocycle	IBC Advanced Technologies	0.22[(c)]	500	110	90	20
R-F	Resorcinol-formaldehyde	Boulder Scientific	0.30	220	65	60	18
Duolite® CS-100	Phenol-formaldehyde	Rohm & Haas	0.24	88	21	13	3

(a) ion exchange material density measured on a dry weight basis in 2 M NaOH unless otherwise noted
(b) bulk powder density (dry weight basis)
(c) measured in NCAW waste simulant
(d) not applicable, Sr ion exchange material

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1.0 Introduction

1.1 Background

The contents of Hanford's 177 double- and single-shell waste tanks include a mixture of sludge, salt cake, and alkaline supernatant liquid. The supernate consists of concentrated aqueous solutions of sodium nitrate/nitrite salts with smaller quantities of hydroxide, aluminum, potassium, carbonate, sulfate, and phosphate. The salt cake, generated by extensive evaporation of aqueous solution, consists primarily of dried sodium salts. The bulk of the water soluble radionuclides such as ^{137}Cs are contained in the interstitial liquid, salt cake, and supernatant solutions. The insoluble sludge fraction consists of metal oxides/hydroxides and contains the bulk of the ^{90}Sr and many of the transuranic radionuclides (TRU).

Although the pretreatment and disposal strategy is still being defined, one of the first steps in most pretreatment scenarios will be a separation of the supernatant and dissolved salt cake from the sludges. It is envisioned that cesium will be removed from the aqueous solutions using an ion exchange process and the decontaminated solutions will be immobilized as a low-activity waste. The specific cesium decontamination requirements will depend on waste composition and the disposal requirements for the low-activity waste. The separated cesium will be concentrated and vitrified with the HLW sludge for disposal in the high-level waste repository.

1.2 Scope

A number of organic and inorganic exchangers are being developed and evaluated for cesium removal from Hanford tank wastes. The exchangers of interest that are investigated in this work include powdered (IONSIV® IE-910; referred to as IE-910) and engineered (IONSIV® IE-911; referred to as IE-911) forms of the crystalline silico-titanate (CST) inorganic sorbent developed by Sandia National Laboratories (SNL)/Texas A&M and prepared by UOP; a phenol-formaldehyde (CS-100) resin developed by Rohm and Haas; a resorcinol-formaldehyde (R-F) polymer developed at the Westinghouse Savannah River Company (WSRC) and produced by Boulder Scientific; an inorganic zeolite exchanger produced by UOP (IONSIV® TIE-96; referred to as TIE-96); an inorganic sodium titanate produced by Allied Signal/Texas A&M (NaTi); and a macrocyclic organic resin developed and produced by IBC Advanced Technologies (SuperLig® 644; referred to as SL-644). Several of these materials are still under development and may not be in the optimal form.

The testing described in this report is a joint effort with the project "Develop and Test Sorbents" which is funded by the Efficient Separations Cross-Cutting Program (EM-50) and the "Batch Testing of Crystalline Silico-Titanates" subtask which is part of the PNL TWRS Pretreatment Technology Development Project (funded by EM-30). Funding for the investigation of the IE-910, TIE-96, NaTi and SL-644 is provided by the EM-50 program and funding for the testing of the IE-911, CS-100, and R-F is provided by the EM-30 program. These two efforts have been combined in order to have a common testing protocol, share actual waste samples, share data, and facilitate the transfer of technology from the Efficient Separations Program to the implementing organization (EM-30). This common testing will allow a side by side comparison of all of the exchangers under investigation.

The work described in this report involves the direct comparison of the ion exchange materials for the pretreatment of actual and simulated Hanford tank waste. Data on the performance of all of the exchangers with simulated and actual double shell slurry feed (DSSF) is included. The DSSF waste is a mixture of the supernate from tanks 101-AW (70%), 106-AP (20%) and 102-AP (10%).

The comparative parameters include radionuclide removal efficiency under a variety of conditions and material properties (e.g., bed density and percent removable water). Cesium and strontium distribution (K_d), lambda ($\lambda = K_d \times \rho_b$), and decontamination factors (DF) are compared as a function of exchanger contact duration, solution composition (Na and Cs concentration), exchanger/waste phase ratio, and multiple sequential contacts.

1.3 Objectives

The overall objective of the cesium ion exchange task is, 1) to evaluate available materials for the ion exchange recovery of cesium and strontium from alkaline wastes, 2) to determine the loading and elution efficiency of these processes, 3) to determine the physical life cycle (including radiation and chemical stability) of these materials, and 4) to determine if basic ion exchange data can be applied to a broad range of tank wastes. The intent is to provide the technology to produce a LLW effluent with radioactivity suitable for treatment in the LLW glass vitrification facility.

Specific experimental objectives of the batch testing work described in this report include:

- obtain information on the equilibrium behavior of the ion exchangers under consideration
- investigate the achievable decontamination factor for cesium and other radionuclides
- verify the results of simulant testing by conducting tests with actual wastes
- investigate the behavior of waste components that may interfere with the ion exchange process either by surface fouling or site specific competition
- investigate waste/exchanger chemistry (i.e. dissolution, precipitation, etc.)

1.4 Strategy

The objective of the batch contact testing is to obtain screening information concerning the suitability of exchangers for specific treatment applications. The basic experimental operation involves batch contacts between the exchangers and the simulant and actual waste solutions. The advantage of batch testing relative to column testing is that a large amount of equilibrium data (i.e. K_d or λ) can be obtained with relatively small amounts of waste at reduced unit cost (i.e. cost per data point). Simulant testing was conducted at several dilutions ([Na] = 0.2, 1.0, 3.0, 5.0, and 7.0 $\underline{M}$) and cesium concentrations (Na/Cs = 50, 500, 5000, 50000, and 500,000) to develop procedures for contacting the actual waste and to provide additional equilibrium data over a large number of experimental conditions. Trace amounts of ^{137}Cs and ^{85}Sr were used for analytical purposes.

During the actual waste testing, three separate contacting methods were used to provide information over a wide range of supernate:exchanger phase ratios and are discussed below.

Cesium Addition Method - Four separate contacts involving 10 mL of waste and 0.067 g of exchanger were conducted with the actual 70% 101-AW DSSF composite waste. In three of these contacts, different amounts of non-radioactive cesium were added into the actual waste supernate to provide equilibrium data at four different cesium concentrations. The amounts were chosen so that the equilibrium Na/Cs ratios of the tests bounded the Na/Cs ratio of the actual 70% 101-AW DSSF waste composite.

High DF Method - The supernate from the previous method (without additional cesium) was contacted with an additional 0.5 g of exchanger in order to investigate the achievable decontamination factor. The large amount of exchanger was necessary to efficiently remove most of the ^{137}Cs.

High Phase Ratio Method - In order to adequately investigate the effect that interfering components have on Cs K_d, the supernate:exchanger phase ratio was increased to match the expected distribution coefficient. The high phase ratio provides a large amount of interfering components relative to the number of exchanger sites and increases the impact of these components on equilibrium behavior.

2.0 Experimental Approach

This section contains a description of the exchanger materials, waste solutions, and experimental procedures that were used.

2.1 Material Selection and Preparation

A listing of the exchangers under consideration along with selected manufacturing information is displayed in Table 2.1. Several of these materials are still under development and may not be in the optimal form. The SuperLig®644 polymer resin is the latest version of the covalently bound SuperLig® macrocycle family of sequestering ligands from IBC Advanced Technologies (American Fork, UT) and has been shown to be highly selective for cesium even in the presence of excess sodium or potassium (Brown et al. 1995b). The inorganic sodium titanate (NaTi) is a powder produced by Allied Signal (Des Plaines, IL) in collaboration with Professor A. Clearfield at Texas A&M, primarily for Sr removal.

CS-100 and resorcinol-formaldehyde (R-F) are two organic ion exchange resins that are commercially available and under consideration for cesium removal from Hanford tank wastes (Brown et al. 1995a; Brown et al. 1995b; Brown et al. 1995c; Eager et al. 1994; Penwell et al. 1994).[1] CS-100 is a granular (20 to 50 mesh) phenol-formaldehyde condensate polymer ion exchange resin which is commercially available from Rohm & Haas. R-F, originally developed by J. P. Bibler and R. M. Wallace at WSRC and currently produced by Boulder Scientific (Mead, CO), has been shown to exhibit a much greater loading for Cs and selectivity over sodium or potassium than the CS-100 resin (Bibler et al. 1989; Bibler 1991; Bibler 1994; Bray et al. 1990; Kurath et al. 1994).

IE-96 is a high capacity aluminosilicate zeolite produced by UOP (Des Plaines, IL) with relatively little selectivity for cesium over other alkali metals. TIE-96 is a modified version of the IE-96 which is capable of removing Sr and Pu from alkaline solutions in addition to cesium.

Also produced by UOP on an experimental basis, IE-910 and IE-911 are the powdered and engineered forms of the CSTs, respectively. The engineered CST (IONSIV® IE-911) is being developed by UOP (Des Plaines, IL) under a Cooperative Research and Development Agreement (CRADA) with SNL. The CSTs were originally developed in a powdered form by R. G. Dosch at SNL and Professor R. G. Anthony at Texas A&M. Two batches of engineered IE-911 (-08 and -38B) were investigated in these experiments. UOP has further developed the IE-911 with improved kinetics and samples are expected to be available in January 1996.

Because of different manufacturing processes, each material does not contain the same counter ion when received from the manufacturer. CS-100 and SuperLig® 644 are in the H^+-form, R-F is in the K^+-form, and TIE-96, IE-910, IE-911, and NaTiA are likely in the Na^+-form. It is possible that due to the variation in counter ion form and material capacity could change the equilibrium composition of the waste after the exchange process has been completed. For example, as solution-phase cesium exchanges with K^+ in the R-F resin, the concentration of the K^+ in solution must concurrently increase. In most

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[1] Gallagher, S. A. 1986. *Report of Current NCAW Ion Exchange Laboratory Data*. Internal Letter #65453-86-088, Rockwell International, Richland, Washington.

cases, the quantity of solid material, and hence counter ion, is such that this increase is insignificant. In the worst case, assuming a total capacity of 6 meq g^{-1} for a high capacity material (e.g., R-F), a phase ratio of 150 (0.067 g and 10 mL solution), and a potassium concentration of 0.48 M, one can calculate less than a 10% change in the equilibrium of K^+ level if all of the K^+ were exchanged. Under the conditions tested, the majority of the material capacity is utilized by sodium exchange. A similar argument can be made for the H^+-form exchangers. In the current experimental solution these effects can be deemed insignificant due to the high potassium and free hydroxide levels of the actual and simulated 70% 101-AW DSSF simulant waste.

Table 2.1. Selected Properties of Cesium and Strontium Selective Materials

Material	ID	Batch Number	Date of Manufacture	Particle Size (Mesh)
Duolite CS-100	CS	6-8144 Lot 2-850001	Nov 1991	20 - 50
IONSIV® TIE-96	ZE	975791000012-A	Sept 1995	20 - 50
Resorcinol-Formaldehyde	RF	BSC-187-210	Aug 1991	40 - 70
SuperLig®644	SL	10-SM-171	Nov 1994	25 - 45
IONSIV® IE-910	CP	993794040002	Sept 1994	< 400
IONSIV® IE-911	CE	07398-38B	Jun 1995	40 - 70
IONSIV® IE-911		8671-08	Jun 1995	20 - 50
Sodium Titanate	TI	8104-170	May 1994	< 400

All materials were used "as received" without additional processing. However, the K_d data (Section 2.3) have been mass corrected to account for the fraction of easily removed water using the F-Factor. Approximately 0.5 g of each material was weighed before and after drying at 105°C for 24 hours. In order to ensure that a constant weight had been achieved, the materials were dried for a second 24 hour period and re-weighed.

In an attempt to compare the cesium uptake for each material on a volume basis, the bed density was determined in 2 M NaOH. Each material was accurately weighed by difference into a 100-mL graduated cylinder containing 2 M NaOH. The cylinders were tapped lightly and allowed to settle for approximately 24 hours. This provides a uniform basis for determining each materials' bed density. It is important to note that many of the organic materials shrink and swell depending on the solution pH. The bed density in other waste solutions may be significantly different than in 2 M NaOH.

2.2 Waste Simulant Selection and Preparation

The primary wastes requiring Cs treatment at Hanford are Neutralized current acid waste (NCAW), double shell slurry feed (DSSF), complexant concentrate (CC) waste, salt cake and sludge wash solutions. Each of these major waste types contains a unique characteristic that influences cesium ion exchange. The NCAW contains a relatively high amount of cesium (Na/Cs mole ratio of 10,000) with only a modest amount of potassium. This waste has the greatest cesium decontamination factor (DF) requirements and will provide the greatest cesium concentrations during processing. The DSSF contains a relatively large amount of potassium (Na/K mole ratio as low as 10) which is known to interfere with cesium ion exchange via the competing cation effect. The CC waste contains relatively large amounts of organic complexants, attendant chemical and radiolytic degradation products. These organics are not expected to interfere directly with the cesium ion exchange process although the expected large variety of constituents presents an uncertainty with respect to fouling of the exchangers. The dissolved saltcake and sludge wash solutions represent the bulk of the waste volume expected to require cesium removal. The sodium to cesium ratio is expected to generally be high (i.e. > 250,000) and the DF requirements correspondingly low.

The simulant chosen for the testing described in this report models an actual DSSF waste composite. The specific composition and method of preparation are displayed in Appendix A and was used because of availability of a sample of actual waste with this composition. The actual waste sample does not necessarily represent a distinctive or characteristic waste but rather is a composite of several DSSF tanks (70% 101-AW, 20% 106-AP, and 10% 102-AP on a volume basis). This waste will be referred to as 70% 101-AW DSSF composite simulant to distinguish it from other DSSF compositions. The simulants were formulated to mimic the cesium ion exchange properties of the actual waste and were prepared from a set of concentrated stock solutions with variable amounts of cesium and diluted with water to sodium concentrations of 0.2, 1.0, 3.0, and 5.0 M. The 70% 101-AW DSSF simulant at 7.0 M sodium was prepared separately and did not require dilution. The method provides an easy method of preparing a wide variety of tank compositions for cesium ion exchange testing. In effect, the solutions predict variable dilutions or evaporator concentrates of a single waste stream. The approach is designed to provide useful process engineering data in the absence of precise ion exchange feed specifications. A similar approach has been taken previously for testing with CC and NCAW simulant (Bray et al. 1993; Kurath et al. 1994). Since the dilutions were prepared with water, the relative abundances of all of the species except cesium remain constant (i.e., for the 70% 101-AW DSSF simulant; Na/K = 10.5 and Na/Al = 10.1). However, it should be noted that the free hydroxide concentration and solution pH is not constant during dilution (theoretical pH = 12.9 and 13.6 at 0.2 and 1.0 M Na, respectively).

Trace amounts of cesium-137 or strontium-85 were added to the simulants for analytical purposes. The ^{137}Cs tracer solution was purchased as CsCl in 1 M HCl and contains about 0.4 mg ^{137}Cs mL^{-1}. The radiochemical activity of the "as received" material is usually 12 mCi mL^{-1} or 440 MBq mL^{-1}. For the sodium iodide well crystal radiochemical detector used in the laboratory, approximately 1 μL (12 μCi) of the stock tracer is used per liter of feed. Similar trace amounts of ^{85}Sr were added to selected solutions to facilitate strontium analyses for testing of NaTi.

2.3 Batch Distribution Coefficient

The batch distribution coefficient (K_d) is an equilibrium measure of the overall ability of the solid phase ion exchange material to remove an ion from solution under the particular experimental conditions which exist during the contact. The batch K_d is an indicator of the selectivity, capacity, and affinity of an ion for the ion exchange material in the presence of a complex matrix of competing ions. The addition of a small quantity of ion exchange material into a small volume of supernatant solution is an extremely rapid and cost effective method for comparing a wide variety of such materials. However, this method does not normally provide information about ion exchange kinetics but is useful for measuring ion exchange under the particular conditions of the test. Accurate comparison of K_d results requires identical experimental conditions (volume:mass ratio, equilibrium solution composition, material pretreatment, temperature, duration, etc.) because all of these factors are known to affect K_d.

In the batch K_d tests, a known quantity of ion exchange material is placed in contact with a known volume of waste. The material is allowed to contact the solution at constant temperature for sufficient time to reach equilibrium, after which the solid ion exchange material and liquid supernate are separated. The concentration of the species of interest is determined in the solution and in the solid phase. In practice it is easier to measure the concentration of the particular ion of interest in the solution instead of in the solid. Therefore, the equation for the determination of the batch distribution can be simplified by determining the concentration of the analyte before and after contact and calculating the quantity of analyte on the ion exchanger by difference (Equation 1).

$$K_d = \frac{(C_0 - C_1)}{C_1} * \frac{V}{M*F} \tag{1}$$

where;

C_0 is the initial concentration of the ion of interest in the feed solution prior to contact,
C_1 is the concentration after contact, V is the solution volume, M is the exchanger mass and,
F is the mass of dry ion exchanger divided by the mass of wet exchanger (F-factor).

The column distribution ratio λ, is obtained by multiplying K_d by the exchanger bed density, ρ_b (g of resin per mL of resin in solution) as shown in Equation 2.

$$\lambda = K_d * \rho_b \tag{2}$$

The lambda value provides a method of comparing the ion exchange performance of a wide variety of materials on a volume basis. Comparison of materials on a volume basis provides the process engineer an estimate of the cesium loading with respect to the column size required. However, the bed density of each material is highly variable depending upon solution conditions, column size, and loading methods and has a large effect on the cesium loading per material volume (lambda). Other methods of comparison (e.g., mass, cost, cycles, effluent composition, waste generation, ease of use, etc.) may also be important, but have not been attempted in this study. In particular, use of certain materials in a column may not be possible (e.g., finely powdered solids) and comparison on a mass basis may be more meaningful. Such comparisons are better suited for engineering trade studies.

The experimental equipment required to complete the batch K_d determinations included an analytical balance, a constant temperature water bath, an oven for F-Factor determinations, a variable speed shaker table, 20-mL scintillation vials, 0.2 μm syringe filters, the appropriate ion exchanger, and simulant solutions. Samples were placed into a controlled temperature environment at 25°C and agitated with either a "ping-pong" type shaker table at approximately 2 Hz or a Maxi Mix III orbital shaker at 400 to 600 Hz. After reaching the appropriate contact duration (normally 72 hours), the samples were removed from the shaker table and the solids were separated from the liquid by filtration through a 0.2 μm syringe filter. The filtered solutions were analyzed for ^{137}Cs or ^{85}Sr by gamma counting using a NaI crystal. Each 3 mL sample was counted for 20 minutes. Control blanks were prepared with no sorbent material added and were treated in the same manner as the samples.

In general the uncertainties associated with the λ and K_d values are estimated to be less than 10%. Calculation of standard deviations (σ) for each pair of λ values (duplicate samples) shows that σ is generally less than 10% of the λ value and usually less than 5%. Some pairs of λ values exhibit remarkable similarity, being the same value to 4 digits.

The values of K_d and λ will exhibit the greatest uncertainty at very high and very low values. In the former case, the concentration C_1 in Equation 1 begins to approach zero and the analytical uncertainty of this value increases. For example, the error associated with each individual ICP analytical result is expected to exceed 15% within ten times the detection limit. During the actual waste test, the radioanalytical uncertainty was 5% for Cs-137 and 3% to 12 % for Sr-85. In the latter case where only small amounts of the radionuclide are removed and the K_d and λ values are low, the small difference in concentration (C_0 - C_1) becomes a significant source of error.

Another probable source of uncertainty in λ is that associated with each material's dry bed density. Solution composition, sample size/dimensions, and time will all affect the apparent bed density. In addition, the organic exchangers exhibit variations from other reported bed densities of as much as 50%. This does not affect the determination of K_d but would affect the Cs λ values determined using Equation 2.

2.4 Kinetic Batch Distribution

Due to the extensive variety of ion exchange and sorbent materials used in the current experiment, the extent of cesium uptake as a function of time was investigated in order to ensure equilibrium could be reached for every material tested. The materials exhibit a wide variability of particle sizes ranging from submicron powders to macro porous polymers.. The different particle sizes and material structures affect the diffusion rates in the particle and can greatly influence the length of time required to achieve equilibrium.

The objective of this method is to demonstrate that adequate contact time was allowed for equilibrium to be attained. The general experimental conditions were the same as described in Section 2.3 except that the contact time was varied from 1 min to 120 hours. Approximately 0.067 g of each material was contacted with 10 mL of 70% 101-AW DSSF simulant (5 M Na, 1.00E-04 M Cs, initial Na/Cs = 5.00E+04). A separate sample was prepared for each material at each contact time (variable from 1 min to 120 hr). The one minute samples were manually swirled in an attempt to mimic the action of the shaker table. All other samples were placed into a controlled temperature environment at 25°C and agitated with a "ping-pong" type shaker table at approximately 2 Hz. Immediately after reaching the appropriate contact duration, the samples were removed from the shaker table and the solids were separated from the liquid by filtration through a 0.2 μm syringe filter. The filtered solutions were analyzed for ^{137}Cs by gamma counting. Control blanks were prepared with no sorbent material added and were treated in the same manner as the samples. The cesium K_d and λ values were determined using equation 1. No attempt was made to ensure diffusion rate limited ion exchange (i.e. maximum mixing for the greatest mass transfer) and hence the data cannot be used to model the kinetics of ion exchange.

2.5 Simulant Test Conditions

In order to obtain a wide range of equilibrium data and estimate exchanger performance with the actual DSSF composite, a series of batch distribution tests were completed using the 70% 101-AW DSSF simulant waste at the conditions shown in Table 2.2.

Table 2.2. Simulant Testing Conditions

Experimental Parameter	Experimental Conditions
Exchangers:	SL-644, R-F, CS-100, NaTi, IE-910, IE-911, TIE-96
Waste simulant:	70% 101-AW DSSF simulant
Sodium concentration:	0.2, 1, 3, 5 M Na (7 M, IE-911 only)
Initial Na/Cs ratio:	50, 500, 5000, 50,000, 500,000
Waste Volume:	10 mL
Exchanger mass:	ca. 0.067 g
Contact time/temperature:	72 hrs, 25°C
Tracers:	^{137}Cs, ^{85}Sr

2.6 Actual Waste Test Configurations and Conditions

Three separate types of contacts were performed with the actual waste to provide a range of phase ratios (solution:exchanger) and to minimize the amount of actual waste required. These methods were the cesium addition method, the high DF method and the high phase ratio method.

2.6.1 Cesium Addition Method

For the actual waste testing, the actual waste solution (previously diluted to 5 M Na total) was subdivided into four stock solutions. Solid nonradioactive cesium nitrate was added to three of these solutions bringing the total concentration to approximately 5.00E-02, 5.00E-03, and 5.00E-04 M Cs. No cesium was added to the fourth solution and its concentration remained at approximately 6.33E-05 M Cs. A ^{85}Sr spike (8.6 μCi mL^{-1}) was added for analytical purposes.

The reason for performing the contacts with several wastes each with different starting Cs levels is to effectively bracket the initial waste feed (6.33E-05 M Cs) with the final equilibrium cesium concentrations of the four solutions. Since by definition all cesium-selective materials will remove cesium from solution and decrease the equilibrium concentration, additional cesium must be added to the initial solution to compensate for this removal. The result will be a method to predict the column loading for each material using actual waste without performing a large-scale column experiment.

The batch contacts with the cesium addition method were conducted in the same manner as the simulant tests. Each contact involved 10 mL of solution with about 0.067 g of exchanger and was agitated with an orbital shaker at about 400 rpm. This motion was sufficiently gentle that the exchangers were not degraded (i.e. reduced to fines). The contact time was 72 hours at the ambient temperature of the hotcell (23°C). At the completion of the solid/liquid contact, the solution was separated from the exchanger by filtration through a 0.2 μm syringe filter and two 0.5 mL aliquots of solution were withdrawn for analytical purposes.

2.6.2 Multiple Contact (High DF) Method

In order to demonstrate the achievable DF, multiple batch contacts were performed with relatively large amounts (0.5 g) of exchanger. Each additional contact removes cesium and strontium and provides an estimate of the achievable DF along with data at additional phase ratios. While this experiment does not predict the DFs that might be achieved by a column operation it at least indicates the decontamination limits that may result from non-exchangeable forms of the cesium.

In order to reduce the quantity of actual waste required for these tests, residual solution (containing no additional cesium) from previous tests (Section 2.6.1) were used. In those cases 0.067 g of each material was separately contacted with 10 mL of actual waste. After performing the solid/liquid separation and removing aliquots for analytical samples, the residual solutions (ca. 9 mL) were contacted with 0.5 g of fresh material under the same conditions as was previously described (72 hr contact, 25°C). After the second solid/liquid separation and analytical samples had been removed, a third contact with 0.5 g of fresh resin and the residual solution (ca. 8 mL) was proposed but not completed. Although the solid/liquid phase ratio was not constant over the course of the testing, the data can still be used to indicate the ability of each material to achieve a high DF.

2.6.3 High Phase Ratio Method

In order to adequately investigate the effect of interfering components on cesium uptake, it is necessary to contact the exchangers with a relatively high ratio of supernate to exchanger. This high phase ratio simulates the inlet portion of the exchanger bed where the exchanger encounters a relatively large amount of waste. It is expected that components which foul or preferentially exchange will concentrate in this region.

It is desirable to have a phase ratio at least as high as the K_d and preferably 2-3 times higher. The phase ratio in the cesium addition method (Section 2.6.1) is 10 mL:0.067 g or 150 mL g^{-1}. Of the materials to be tested only CS-100 and TIE-96 had K_d's significantly less than this. Due to the limited quantity of actual waste available for the current experiments, a phase ratio of 1000 was used. In the tests described in this section, a smaller quantity of material (i.e., 10 mg IE-910, 10 mg IE-911, 20 mg R-F, and 20 mg SL-644) was individually contacted with fresh (10 mL) portions of the actual waste. All other variables were the same as described in Section 2.3 (e.g., 23°C and 72 hour contact).

2.7 Chemical and Radionuclide Analysis

While the removal of Cs-137 is the primary radionuclide of interest, information on the ion exchange behavior of strontium, TRU components (Pu, Am), and other cations may also be obtained from the actual waste testing. The performed analyses included gamma energy analysis (GEA), alpha total (AT), and ICP-AES (for the non spiked solutions). In order to reduce costs, radioactive strontium-85 was added into the stock solutions at 8.6 μCi mL^{-1} to allow the strontium concentration to be tracked by GEA. The relatively inexpensive AT analyses were performed to determine the total alpha levels in the solutions. ICP-AES analysis was performed to provide an indication of what interfering species might be removed by the ion exchange materials.

3.0 Results and Discussion

3.1 Exchanger Properties

The materials examined in this test exhibit a wide variety of physical, chemical, and ion exchange properties which can greatly affect their ability to remove cesium and/or strontium from solution. An estimate of the bed density was obtained by adding each material to a 25 mL graduated cylinder containing 2 M NaOH and allowing the mixture to settle for approximately 24 hours. The results of this test are displayed in Table 3.1. The cylinder was gently tapped to facilitate packing of the materials. The density of the finely powdered materials (e.g., NaTi and IE-910) was determined in the absence of 2 M NaOH. In practice the bed density of a large scale ion exchange column will probably differ slightly from these results due to size, wall, or solution effects. The density of some materials is more sensitive to solution composition changes than other materials and may differ in an actual waste matrix from that obtained in 2 M NaOH. For example, the density of the organic materials may vary widely (especially with changing pH) whereas the density of the inorganic materials generally does not change.

In general, the organic materials exhibited a lower density than the inorganic materials in the 2 M NaOH solution. In particular, the density of the SuperLig®644 material was such that it floated on top of the waste matrix for several hours during the solid/liquid contact. Adequate contact was achieved as the material eventually swelled and sank to the bottom of the container. Also, the two powdered exchangers (e.g., NaTi and IE-910) consist of sub-micron particles. The dry bed densities of these materials will depend on how vigorously the column packing procedure is completed and hence exhibits a large uncertainty. Although such small particles would not be practical in a large-scale column process, these materials were added to the current experiment for comparison purposes. A mass basis (K_d) rather than the volume basis (λ) comparison is probably more meaningful for these materials.

Table 3.1. Physical Properties of Exchangers

Material	F factor	Dry density, g mL^{-1}
CS-100	0.6148	0.2434
TIE-96	0.8338	0.7672
R-F	0.8070	0.3044
SL-644	0.9751	0.2238[a]
IE-910	0.9680	0.7738[b]
IE-911 (38B)	0.8870	1.1300
IE-911 (08)	0.8990	0.8999
NaTi	0.9764	0.5812[b]

[a] Density obtained from Brown et al. (1995) in NCAW simulant.
[b] Density obtained from dry material (no solution added).

3.2 Actual Waste Preparation

The actual waste solution used in this experiment was a composite mixture from three DSSF tanks (70% 101-AW, 20% 106-AP, and 10% 102-AP) prepared by volume. Two bottles (identified by WHC as J-1278 and J-1279) of concentrated (ca. 8.55 M Na) waste were received from D. L. Herting (WHC) in March, 1994. The samples were archived in the 325 B hotcell at PNL on March 15, 1994, as 94-002537 (J-1278) and 94-002538 (J-1279). A separate volume of the original waste solution was characterized by WHC personnel for other purposes. The results of these analyses are displayed in Table 3.2 and are described in a WHC internal letter.[2]

Ion exchange batch testing as described in this report was completed in September, 1995. The original waste was reanalyzed at PNL (Table 3.3) for sodium and potassium concentration by inductively coupled plasma atomic emission spectroscopy (ICP-AES), for cesium-137 by gamma energy analysis (GEA), and for cesium isotopic ratios by thermal ionization mass spectroscopy (TIMS). Following this analytical confirmation, the contents of the two shipping containers were combined to form a single actual waste stock solution which was spiked with 5 mCi of a ^{85}Sr tracer and diluted with water to approximately 5 M Na. Subsequent sodium analyses on control samples (N = 16) indicated the solution had a sodium concentration of 4.96 ± 0.19 M after the dilution. The diluted solution had a specific gravity (SpG) of 1.261 g mL^{-1}. The SpG of the undiluted waste was 1.416 g mL^{-1}.

The solution was mixed overnight to achieve isotopic exchange equilibrium and then filtered through a 0.2 μm filter yielding 0.85% weight percent residual solids. After the dilution, Sr-85 addition, and filtration steps, the filtrate solution was crystal clear with no visible color or solids present. The waste contains relatively high concentrations of phosphate and carbonate which might result in the formation of insoluble strontium phosphate or carbonate. Addition of strontium-85 tracer, even in minute molar quantities, may exceed the solubility product and result in the precipitation of total strontium. For this reason, the strontium-85 tracer was allowed to equilibrate overnight with stirring and was filtered prior to use. This eliminates the possibility of precipitation during the experimental contacts and isolates the process to ion exchange and/or sorption only.

The previously prepared stock solution (spiked with Sr-85, filtered, and diluted to ≈5 M Na) was then subsampled into four separate bottles each containing a different amount of solid $CsNO_3$. These bottles were prepared by evaporating a standardized 0.09782 M Cs solution of cesium nitrate (0.00, 0.26, 3.25, and 33.15 mL). The mixtures were stirred for a minimum of eight hours to ensure that the cesium had completely dissolved providing a series of homogenous solutions. The cesium concentration of these subsamples was calculated to be 6.33E-05, 5.00E-04, 5.00E-03, 5.00E-02 respectively.

Blank samples, in which no ion exchange material was added to the sample vial, were used to determine the initial starting cesium concentration (Cs C_0) as described in Section 2.3 for each of the four stock solutions. In this way, the blank solutions followed identical process steps as the actual samples (e.g., glass vials, 72 hour contact, 0.2 μm filtration, sample dilution, and analysis), thus ensuring that analytes were not inadvertently removed by unknown processes.

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[2] D.L. Herting. 1994. Strontium Removal Study--Feed Characterization. Internal letter #12110-PCL94-017, February 16, 1994. WHC, Richland, WA.

Table 3.2. Comparison of DSSF Actual and Simulant Waste Solutions

Analyte	Units	Room Temp.[a]	Tank Temp.[a]	Diluted to 5 M Na[a]	PNL Simulant	PNL Analysis
Solids	Wt %	5.8[b]	3.5[b]	1.3[b]	NR[c]	0.85[d]
SpG	g g^{-1}	1.39	1.42	1.21	1.26	1.261
% H_2O	Wt %	54.2	50.9	72.4	NR	NR
AT	μCi mL^{-1}	1.24E-02	2.30E-02	7.0E-03	NA[e]	< 3E-03
^{137}Cs	μCi mL^{-1}	2.5E+02	4.40E+02	1.50E+02	NA	1.99E+02
^{90}Sr	μCi mL^{-1}	2.7E-01	4.6E-01	1.6E-01	NA	NR
TOC	g L^{-1}	4.2E+00	3.72E+01	2.16E+00	NA	NR
TIC	M	2.1E-01	2.3E-01	1.3E-01	1.40E-01	NR
OH^-	M	4.41E+00	5.39E+01	2.01E+00	2.17E+00	NR
F^-	M	7.0E-02	--[f]	--	4.33E-02	NR
Cl^-	M	1.2E-01	1.6E-01	0.6E-03	6.50E-02	NR
NO_2^-	M	1.62E+00	2.07E+00	8.1E-01	9.40E-01	NR
NO_3^-	M	2.54E+00	3.27E+00	1.34E+00	1.49E+00	NR
PO_4^{3-}	M	< 4E-03	--	1.6E-02	1.75E-02	NR
SO_4^{2-}	M	1.5E-02	1.5E-02	1.0E-02	1.26E-02	NR
Na	M	9.64E+00	1.07E+01	4.67E+00	5.00E+00	(4.96±0.19)E+00
K	M	9.2E-01	9.5E-01	4.4E-01	4.75E-01	(4.78±0.13)E-01
Al	M	8.6E-01	9.5E-01	4.6E-01	4.97E-01	(4.71±0.12)E-01
S	M	1.7E-02	1.8E-02	9.1E-03	NA	NR
P	M	9.0E-03	8.8E-03	1.8E-02	1.75E-02	(1.43±0.05)E-02
Cr	M	3.1E-03	3.4E-03	1.9E-03	NA	(2.11±0.03)E-03
Si	M	4.3E-03	3.6E-03	1.9E-03	NA	(3.90±0.1)E-03
Sr	M	--	--	--	7.14E-08	(1.31±0.08)E-05
B	M	9.2E-03	1.04E-02	5.8E-03	NA	(1.24±0.2)E-02
Mo	M	4.6E-04	5.0E-04	2.7E-04	NA	(3.02±0.2)E-04
Pb	M	1.1E-04	1.2E-04	0.5E-04	NA	(1.29±0.6)E-04
Ni	M	2.4E-04	2.6E-04	1.4E-04	NA	(1.49±0.1)E-04
Ca	M	3.4E-04	3.2E-04	2.4E-04	2.41E-04	(8±4)E-04
Zr	M	1.2E-04	1.4E-04	0.7E-04	NA	(5.55±0.5)E-05
Zn	M	3.1E-04	1.3E-04	0.9E-04	NA	(8.0±1.3)E-05
Sb	M	5.0E-05	8.0E-05	--	NA	--
Fe	M	1.1E-04	2.0E-04	0.7E-04	NA	--
Mn	M	0.8E-04	1.3E-04	--	NA	--
Cd	M	2.7E-05	3.0E-05	2.0E-05	NA	(1.22±0.9)E-04
Be	M	2.1E-04	2.3E-04	1.3E-04	NA	(1.22±0.04)E-04
Ba	M	1.1E-06	0.2E-05	--	5.91E-07	< 1.45E-05

(a) WHC pre-transport analysis
(b) Centrifuged solids
(c) Analysis not requested
(d) Filtered (0.2 μm) solids
(e) Species not added to simulant
(f) Analyte below detection limit

Table 3.3. Additional Characterization of Actual DSSF Composite

Analysis	Analytical Results
Density:	1.409 g mL^{-1}
Sodium:	8.55 M Na by ICP-AES (1.94E+05 and 1.99E+05 μg mL^{-1})
Potassium:	0.821 M K by ICP-AES (3.21E+04 and 3.19E+04 μg mL^{-1})
^{137}Cs:	239 μCi g^{-1} by GEA (2.38E+02 and 2.40E+02 μCi g^{-1})
^{137}Cs:	25.98% isotopic by TIMS
Total Cs:	1.09E-04 M
Na/Cs:	7.84E+04
Na/K:	1.04E+01
K/Cs:	7.50E+03

3.3 Time-Dependent Cesium Distribution

The results for the time-dependent cesium batch distribution tests with simulated 70% 101-AW DSSF composite are displayed in Figure 3.1 for each ion exchange or sorbent material. The material lambda values are displayed as a function of time from 1 minutes to 120 hours. Each data point is a separate measurement and duplicates were not completed. In general, the low distribution materials (e.g., TIE-96 and CS-100) achieved a steady-state cesium uptake (K_d or λ) in approximately 2 to 20 hours. Materials with intermediate (e.g., R-F and SuperLig 644) or relatively high cesium uptake (e.g., IE-910 and IE-911) reach steady-state in 20 hours. In addition, the particle size has a large effect on the cesium uptake as a function of time. At relatively short times (i.e., less than 2 hours), the IE-910 powdered CST demonstrated a much higher cesium uptake than the engineered forms (IE-911) of this same material. However, all materials appear to reach equilibrium at approximately 20 hours of contact time.

The data also indicate that solid/solution mixing has a measurable effect on the kinetics of the cesium uptake process. For example, the first two data points were completed at 1 and 2 minutes, respectively. The 1 minute samples were shaken manually and the remaining samples (greater than 1 minute) were placed into a ping-pong style shaker table. In several cases, the cesium uptake was greater at 1 minutes than at 2 minutes. Evidently, manual swirling in the first samples resulted in greater mixing and mass transport of cesium to the ion exchange site.

The data collected at 72 hours were obtained with a slightly different mixing style using an orbital shaker equipped with spring feet. In this particular case, the solution movement was much less and evidently resulted in slightly decreased cesium uptake. The actual waste tests took place in a hotcell and required the smaller orbital shaker due to size constraints. A modification of the orbital shaker was completed and the spring feet were replaced with solid rubber corks. The resulting shaking motion was sufficient to swirl the solution and solid materials without excessive particle/particle interactions which might physically grind the materials to a fine powder. The results from testing the three shaking methods are compared in Figure 3.1 at the 120 hour time. The data

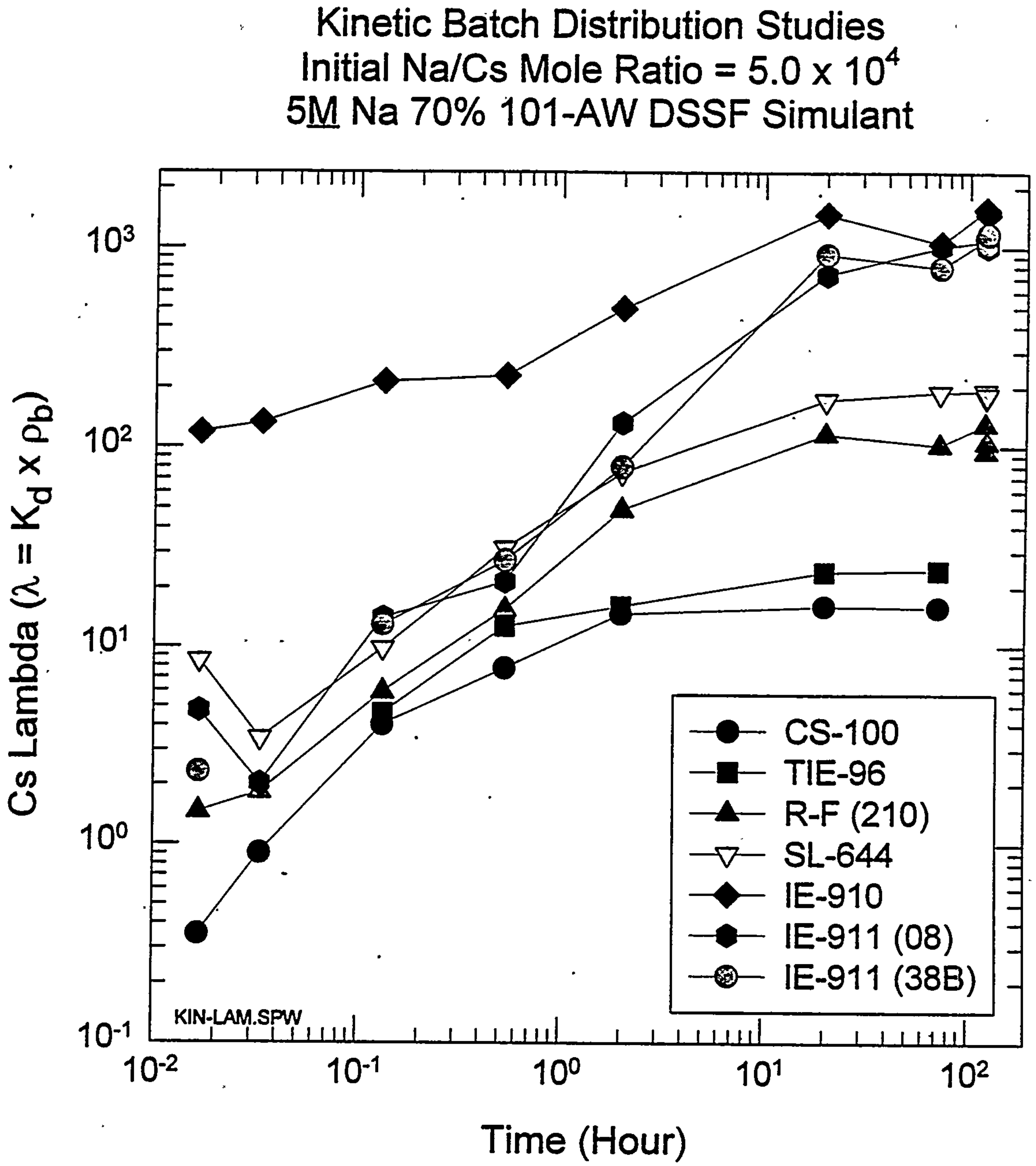

Figure 3.1. Kinetic Batch Distribution Cesium Uptake in Simulated 70% 101-AW DSSF Composite at 5 M Na, 1.00E-04 M Cs (Initial Na/Cs = 5.00E+04), and 25°C.

indicate that there is very little difference between the three methods and for all practical purposes equilibrium is reached during this period.

It is important to note that the cesium ion exchange rates in these experiments are limited significantly by diffusion in the liquid phase and cannot be directly used to model ion exchange kinetics. More vigorous shaking will result in increased mass transfer and higher cesium uptake at shorter contact times. In any case, the flow patterns in the liquid do not easily correlate with those found in ion exchange columns.

3.4 Cesium Distribution in Simulated DSSF

The results for the cesium ion exchange batch distribution experiments in the 70% 101-AW DSSF simulant are displayed in Figures 3.2 through Figure 3.8 for CS-100, TIE-96, R-F, SL-644, IE-910, IE-911(38B), and IE-911(08), respectively. The cesium lambda ($\lambda = K_d \times \rho_b$) results are displayed as a function of equilibrium Na/Cs ratio at several waste dilutions ([Na] = 0.2, 1.0, 3.0, 5.0, and 7.0). As displayed, the data demonstrate, on a single graph, a material's cesium uptake over a wide range of waste dilutions and cesium concentrations. For example, at Na/Cs ratios greater than about 10^6 (e.g., low cesium concentrations expected in sludge washes, tank rinses, process condensate, or ground water) the volume of solution which can be processed per volume of exchanger does not change appreciably. In other words, one cannot expect to necessarily process larger volumes of dilute solutions based on extrapolation of data from more concentrated solutions.

Direct comparison of the various materials can be completed using these data representations, though the process is rather tedious. For example, TIE-96 demonstrates a greater cesium loading than the CS-100 resin under all solution conditions tested (e.g., [Na] and Na/Cs ratios), <u>except</u>, perhaps at 5 <u>M</u> Na and 7.0E+05 Na/Cs. A direct point by point evaluation of the data is required to make such a comparison and such small differences can be easily overlooked.

As another example, the data suggest that dilution of this waste prior to processing would be beneficial for certain materials (e.g., inorganics like TIE-96, IE-910, and IE-911), but not for others (e.g, organics like R-F and SL-644). For TIE-96, the λ value is approximately 20 and 1000 at 5 <u>M</u> and 0.2 <u>M</u> Na, respectively. Therefore, this 25-fold dilution yields a 50-fold increase in the diluted waste volume which can be processed per volume of zeolite material. In contrast, for R-F, the λ value is about 52 and 850 at 5 <u>M</u> and 0.2 <u>M</u> Na (Na/Cs = 1.0E+04 Na/Cs), respectively. This 25-fold dilution results in only a 16-fold increase in volume processed per volume of resin material. Clearly, dilution would not be advantageous in this particular case.

Three forms of the crystalline silicotitanate sorbent material (powdered IE-910 and two batches of engineered IE-911) were tested in the current experiments. A direct comparison of the cesium uptake (λ) for these materials is shown in Figure 3.9 and 3.10 as a function of Na/Cs ratio. Direct comparison on a volume basis is difficult because of the uncertainty in the IE-910 bed density. However, it appears that the performance of the engineered IE-911 materials is fairly similar to that of the IE-910 powder under the conditions of the simulant testing.

By vertically intersecting the data displayed in Figures 3.2 through 3.8 at a constant Na/Cs ratio, the cesium loading can be displayed as a function of sodium concentration from 0.2 <u>M</u> to 7 <u>M</u> Na for each individual material. The data can be combined into a single graph for rapid comparison

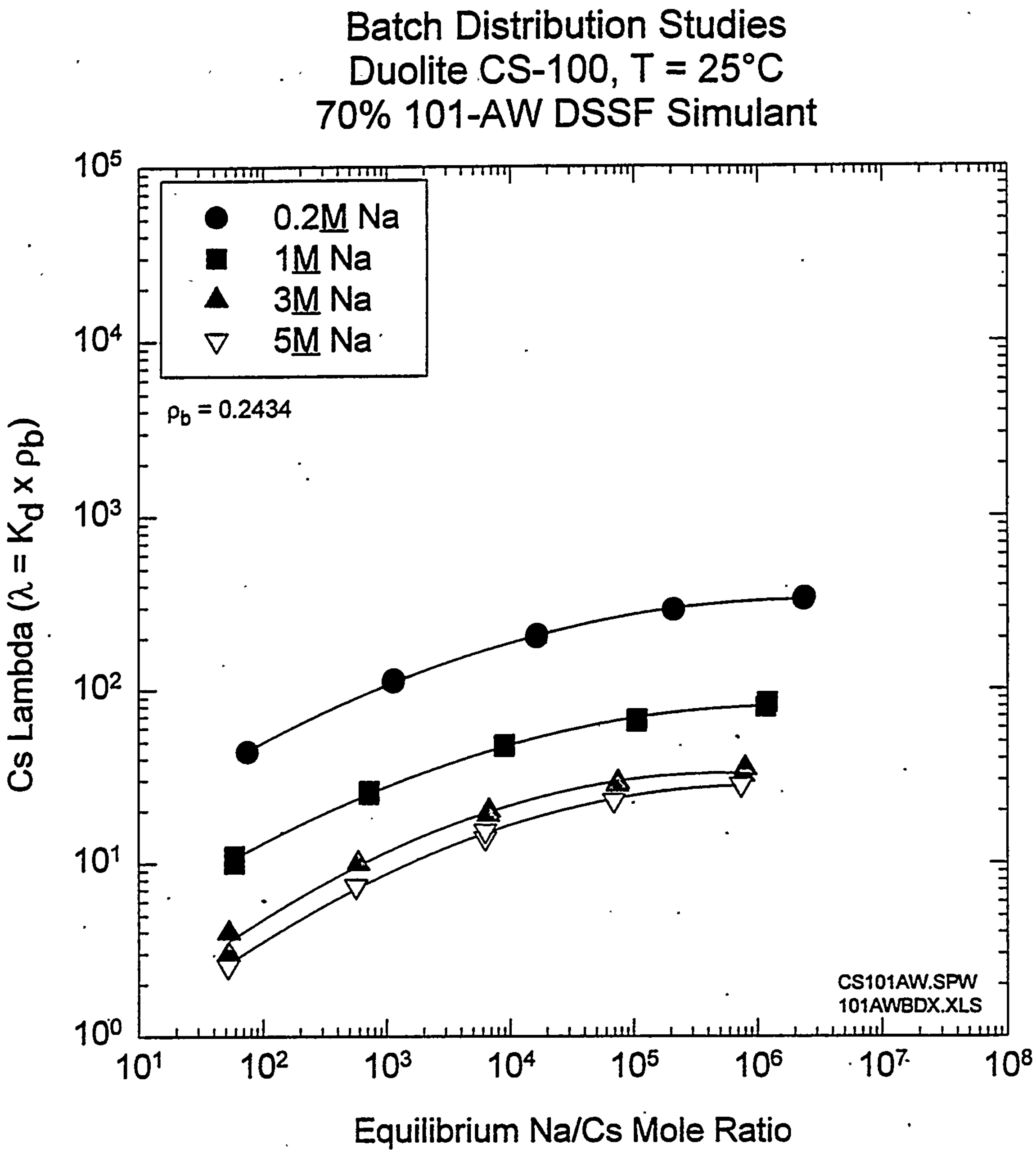

Figure 3.2. Cs λ Values for CS-100 in Simulated 70% 101-AW DSSF Composite at 25°C.

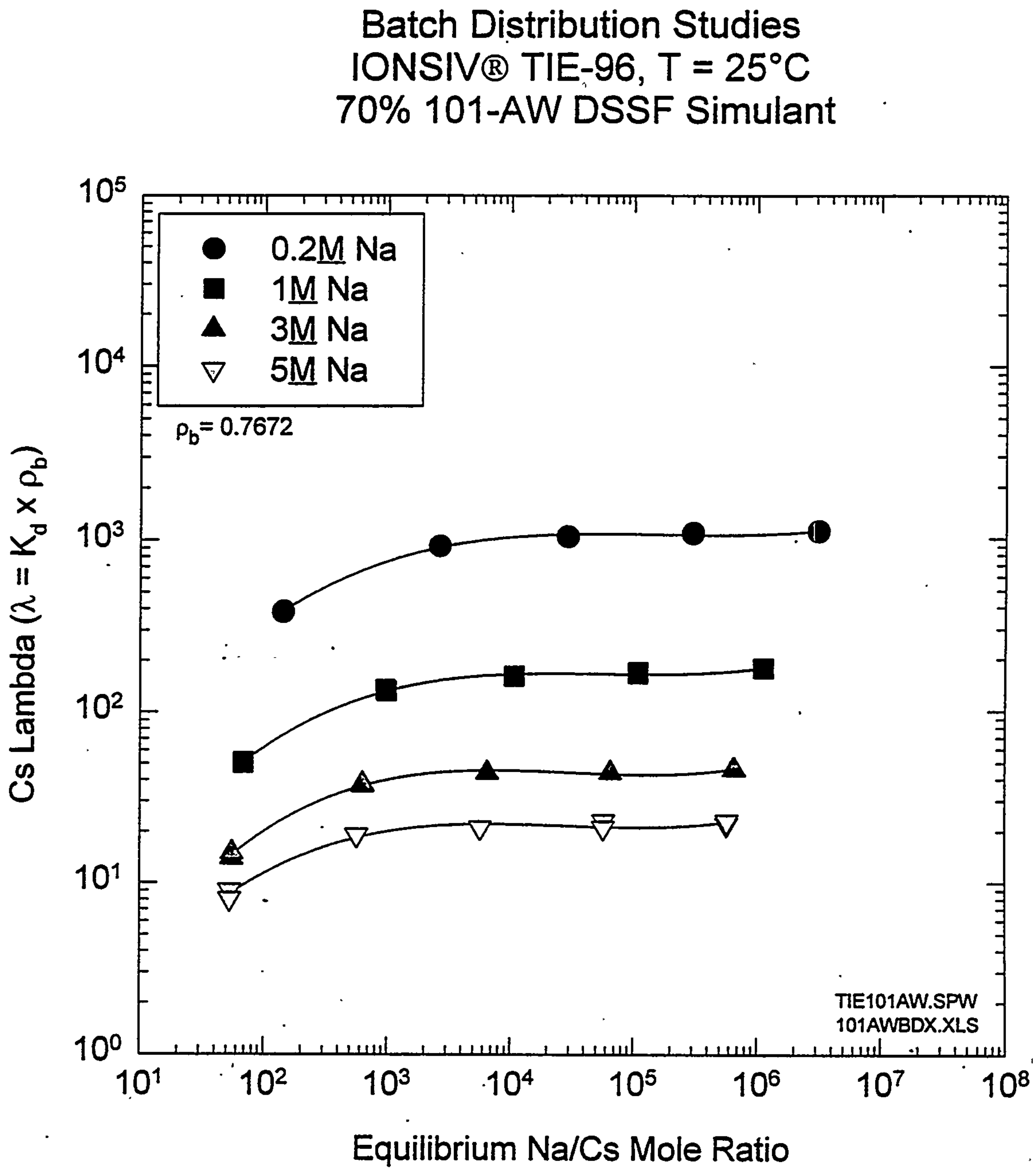

Figure 3.3. Cs λ Values for TIE-96 in Simulated 70% 101-AW DSSF Composite at 25°C.

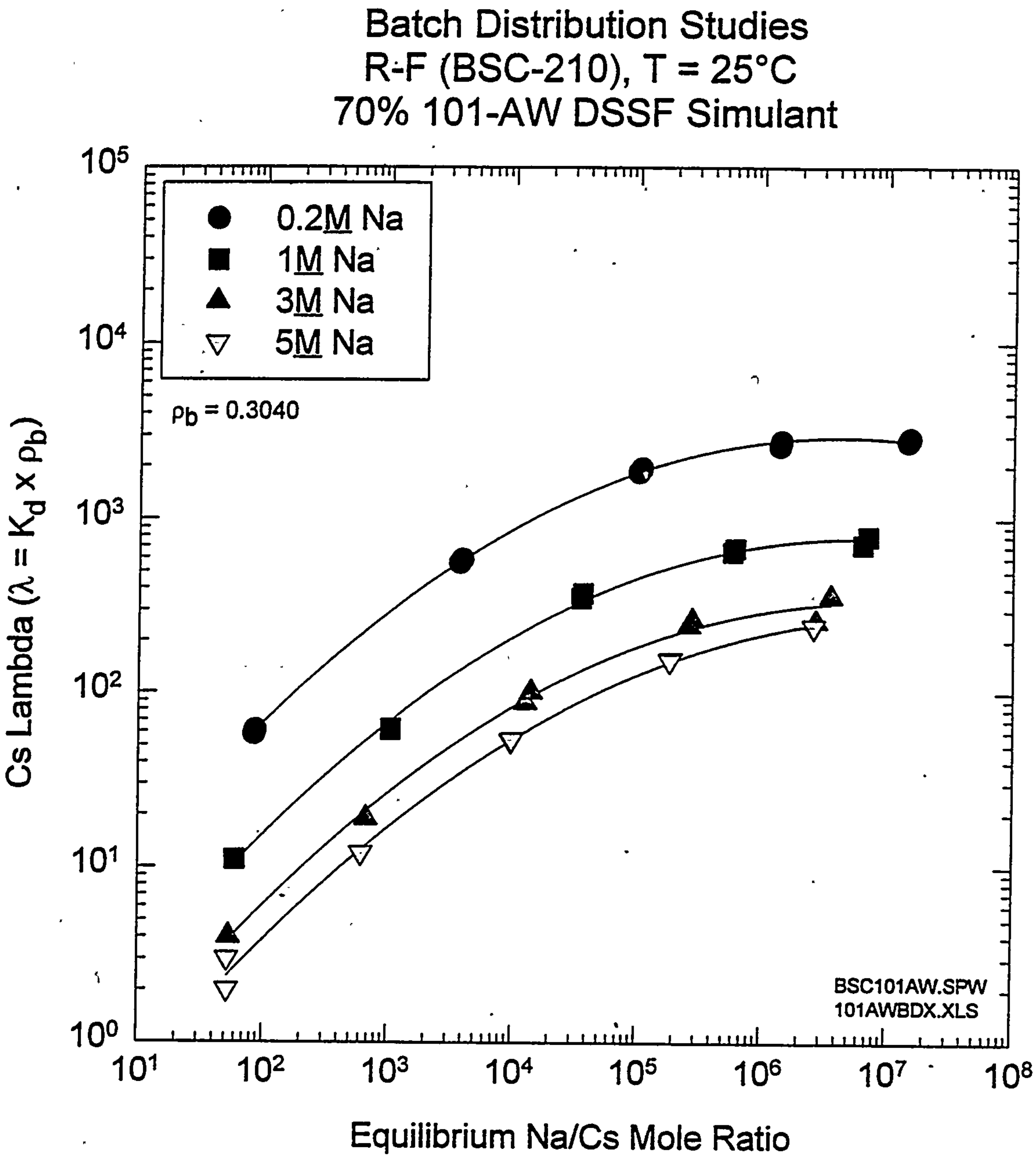

Figure 3.4. Cs λ Values for R-F in Simulated 70% 101-AW DSSF Composite at 25°C.

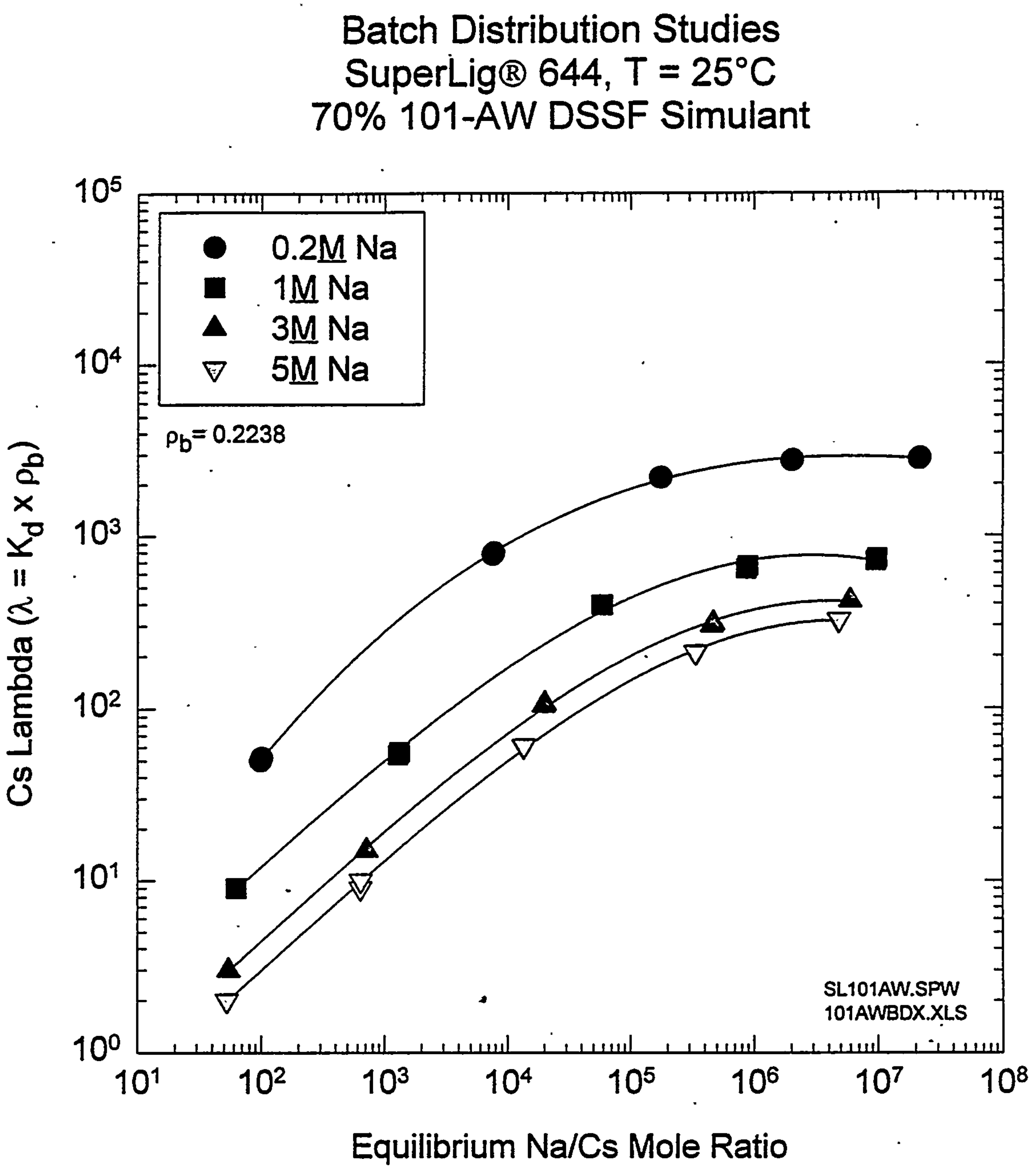

Figure 3.5. Cs λ Values for SL-644 in Simulated 70% 101-AW DSSF Composite at 25°C.

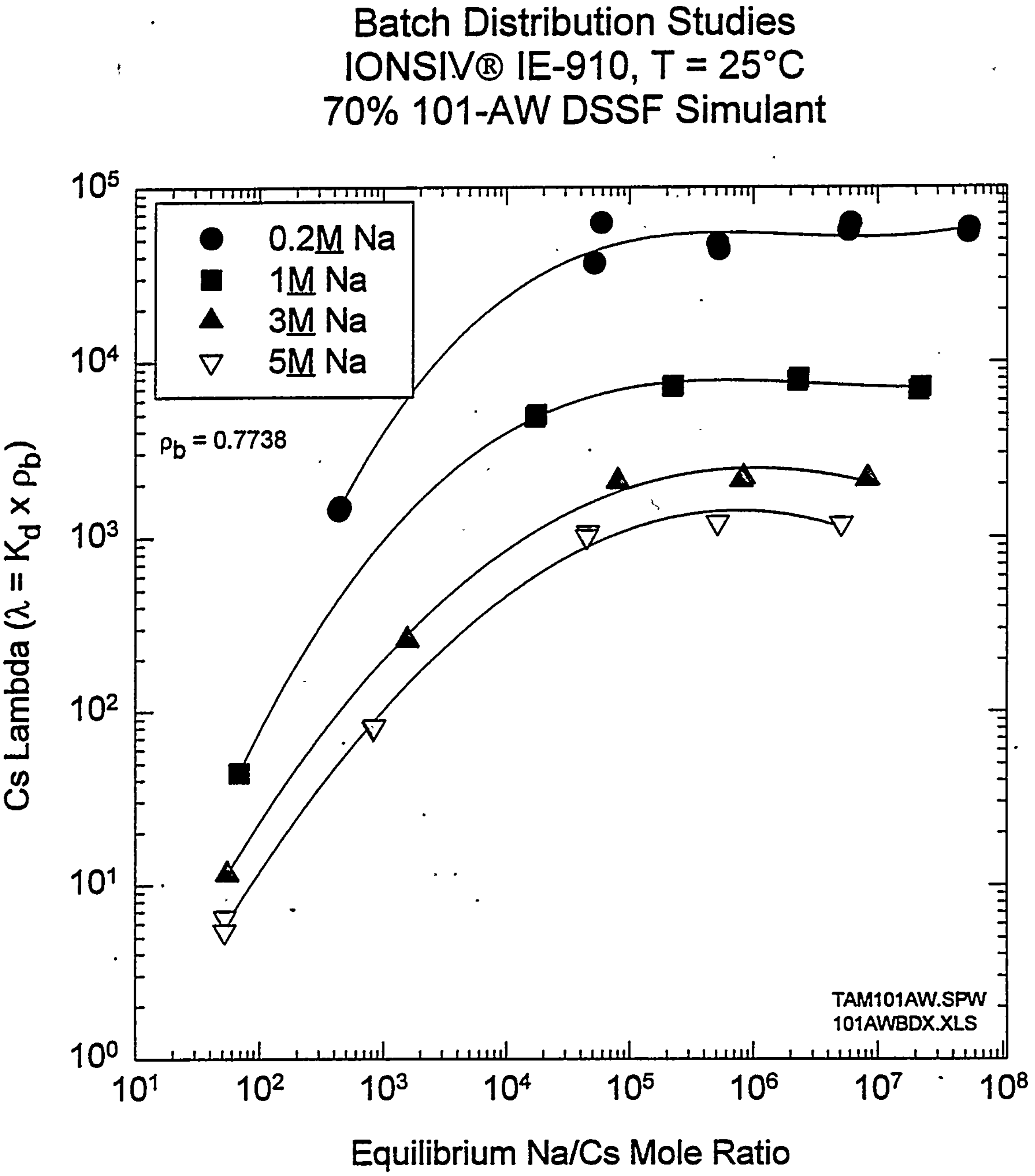

Figure 3.6. Cs λ Values for IE-910 in Simulated 70% 101-AW DSSF Composite at 25°C.

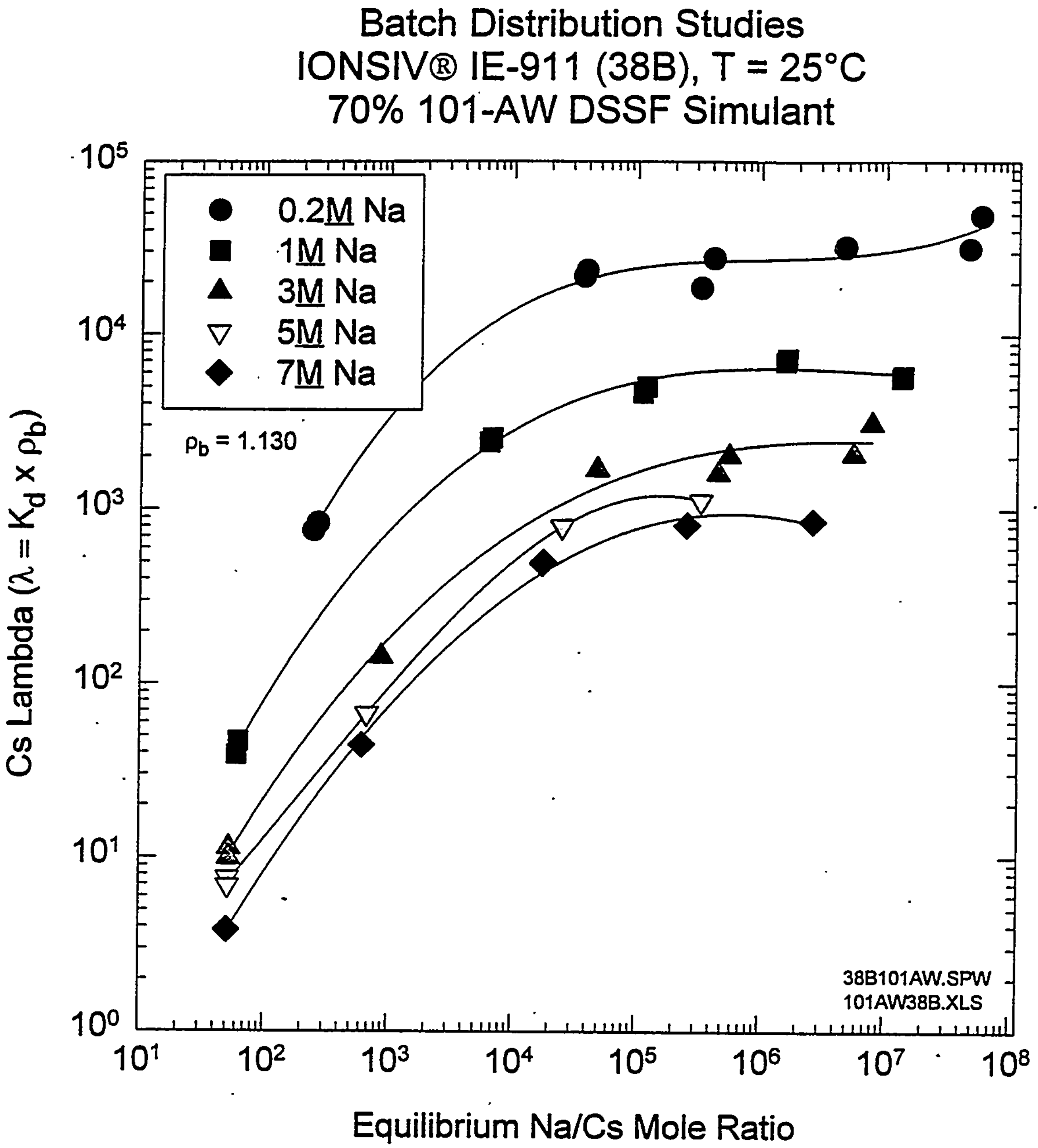

Figure 3.7. Cs λ Values for IE-911 (38b) in Simulated 70% 101-AW DSSF Composite at 25°C.

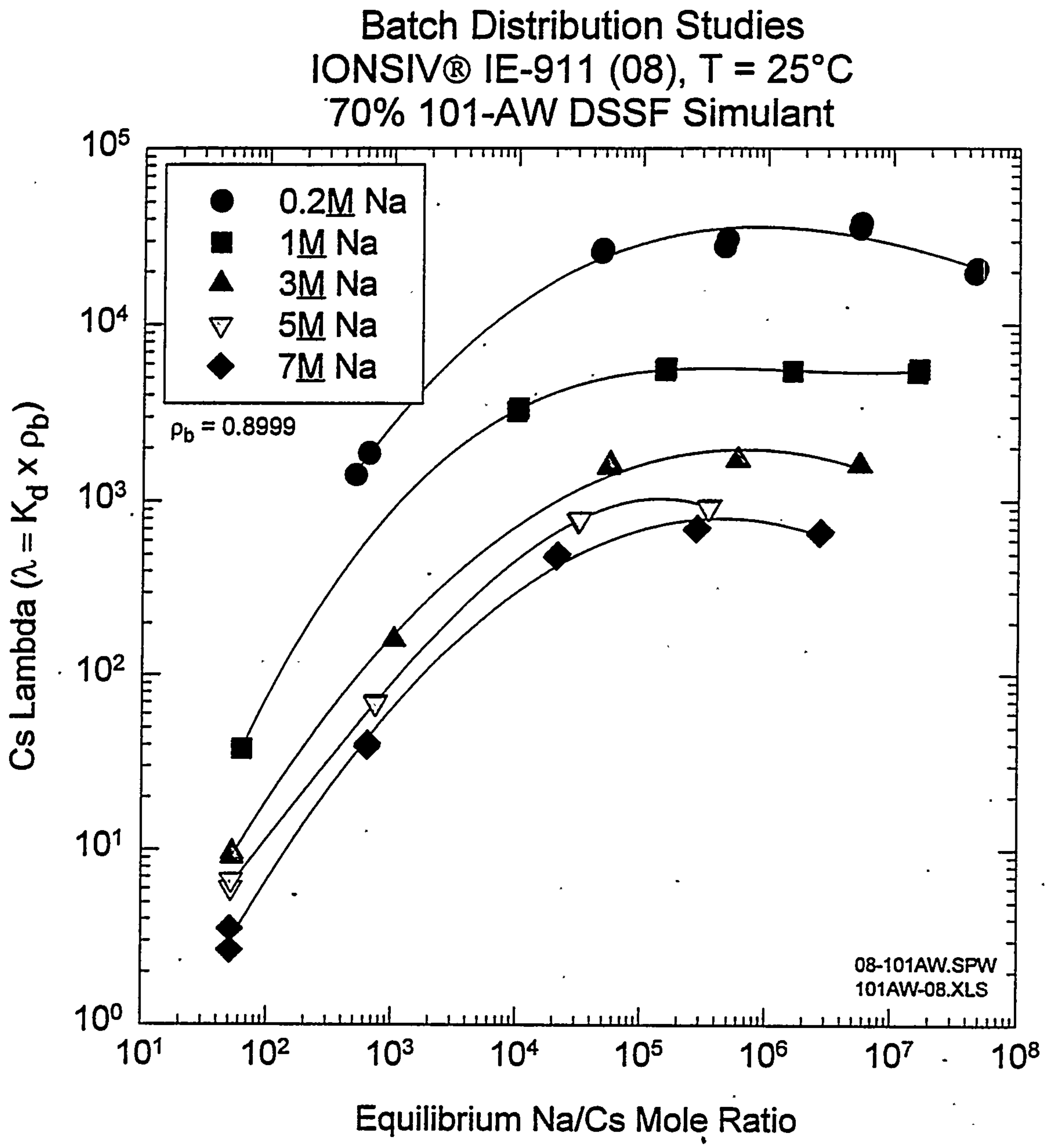

Figure 3.8. Cs λ Values for IE-911 (08) in Simulated 70% 101-AW DSSF Composite at 25°C.

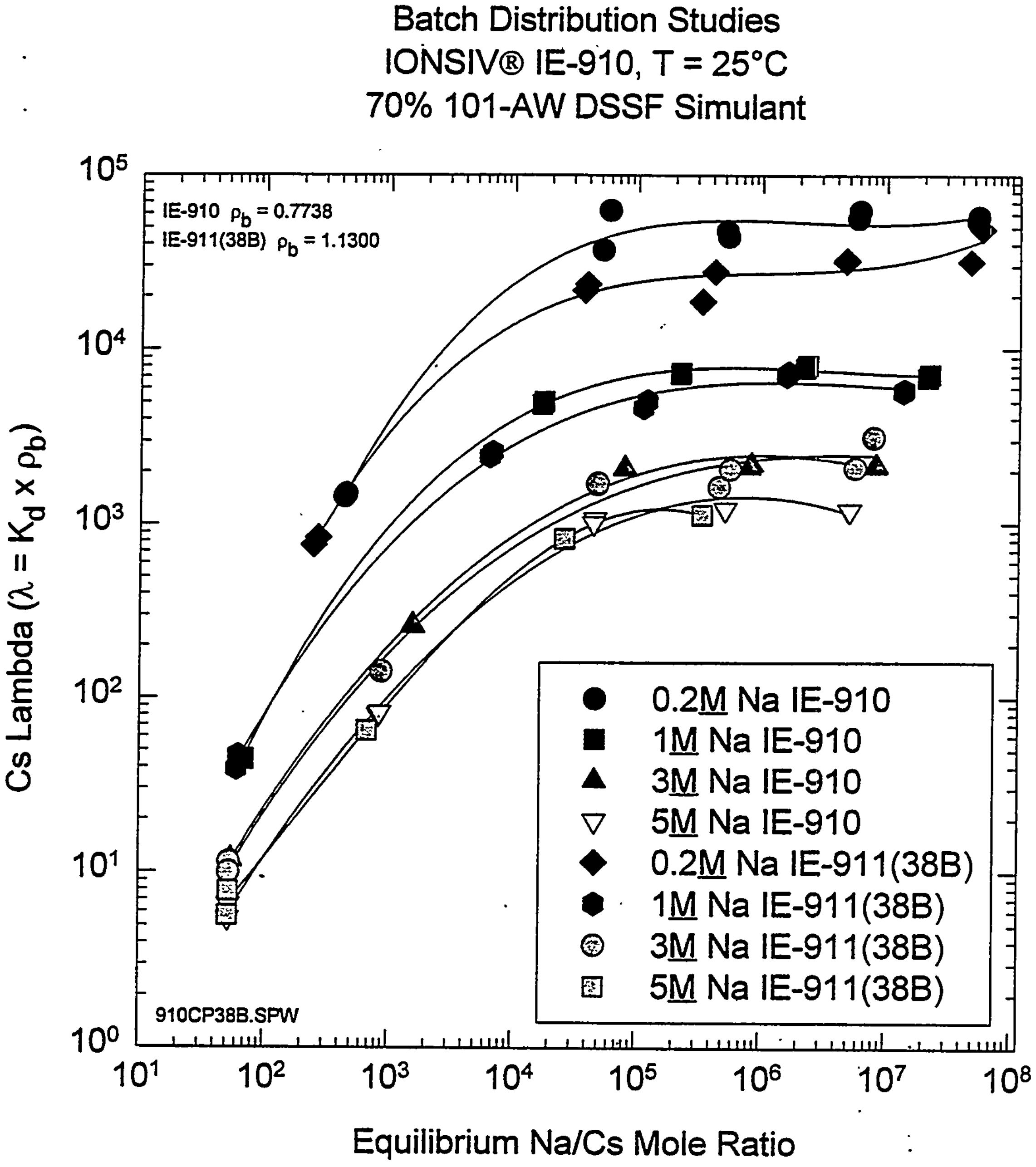

Figure 3.9. Comparison of Cs λ Values for Powdered (IE-910) and Engineered (IE-911[38B]) Forms of the Crystalline Silico-Titanate Sorbent Material in Simulated 70% 101-AW DSSF Composite at 25°C.

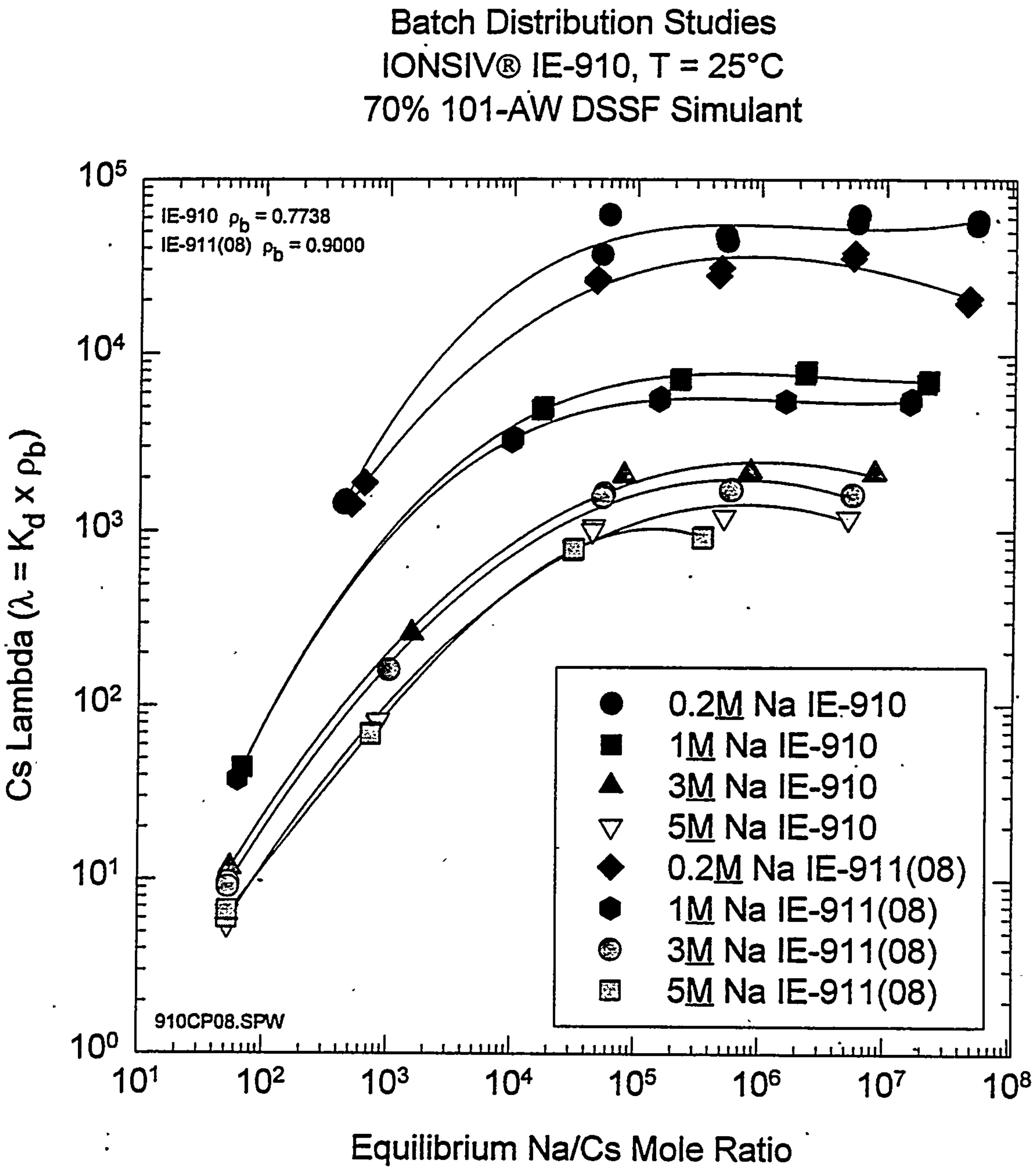

Figure 3.10. Comparison of Cs λ Values for Powdered (IE-910) and Engineered (IE-911[08]) Forms of the Crystalline Silico-Titanate Sorbent Material in Simulated 70% 101-AW DSSF Composite at 25°C.

of all materials as a function of sodium concentration. Figures 3.11 and 3.12 display these results at an equilibrium Na/Cs ratio of 1.0E+04 and 1.0E+06, respectively. In these plots the benefit of waste dilution on cesium uptake for the inorganic materials (TIE-96, IE-910, and IE-911) is clearly demonstrated by the slopes of the curves relative to the organic materials. An additional perspective on the data is displayed in Figure 3.13 by comparing the cesium uptake as a function of Na/Cs mole ratio for all of the materials on a single plot at 5 M Na.

3.5 Cesium Distribution in Actual 70% 101-AW DSSF Composite

The results of the Cs batch distribution experiments in actual 70% 101-AW DSSF waste are displayed in Figure 3.14 as a function of equilibrium Na/Cs ratio at a single sodium concentration (4.96±0.19 M Na). Under all cesium concentrations tested, the CST materials (IE-910 and IE-911) exhibited greater cesium loading than any other material. As described in Section 2.6.1, the actual waste solution was subdivided into four subsamples and various quantities of additional nonradioactive cesium were added to three of the solutions. One subsample remained unchanged and exhibited an initial Na/Cs ratio of 7.8E+05. Assuming that these batch distribution experiments provide an accurate prediction of the column behavior of these materials, the column volumes (CV) of actual 70% 101-AW DSSF composite waste required to reach 0.5 C/C_0 is estimated to be 16, 21, 65, 110, 700, and 800 CV for TIE-96, CS-100, R-F, SL-644, IE-910, and IE-911(38B), respectively.

In addition, these actual waste results can be compared to those obtained previously for the 70% 101-AW DSSF simulant at 5 M Na from Figures 3.2 through 3.8. For visual clarity, the data are subdivided into two graphs (Figures 3.15 and 3.16), each with three materials, comparing the results for the actual and simulated wastes. In general, the actual waste results are lower than those obtained for the simulant. For the R-F and TIE-96 exchangers, the actual waste results were significantly lower than the simulant results, -50% and -25%, respectively. The results for the CST materials were very close at low Na/Cs mole ratios but deviated by as much as -30% at high Na/Cs ratios. The SL-644 and CS-100 deviations (-14% and -4%) were not as great as those of the other materials. Evidently, some chemical constituents were not accurately modelled in the simulant. It is interesting to note that the effect is different for each of the various materials suggesting that the interfering components affect each material in a slightly different way. Material differences (e.g, degradation) between the hotcell and simulant testing might also explain these results.

3.6 Strontium Distribution in Actual and Simulated DSSF

The removal of strontium from simulated and actual 70% 101-AW DSSF waste was investigated by determining the strontium batch distribution coefficient (Sr K_d) and lambda (Sr λ) under a limited set of conditions. The actual and simulated waste solutions were traced with Sr-85 and the strontium concentration was determined by GEA. For the simulant experiments (5 M Na and 5.00E+05 Na/Cs initially), the sodium titanate and crystalline silicotitanate materials removed essentially all of the strontium giving Sr K_d and λ values greater than 1E+06. The zeolite TIE-96 gave a Sr K_d (λ) of 4.13E+03 (3.16E+03). The organic materials generally produced much lower λ values between 18 and 38. The strontium distribution results for the simulated 70% 101-AW DSSF waste are displayed in Table 3.4 at 5 M Na, 1.0E-05 M Cs, and 25°C.

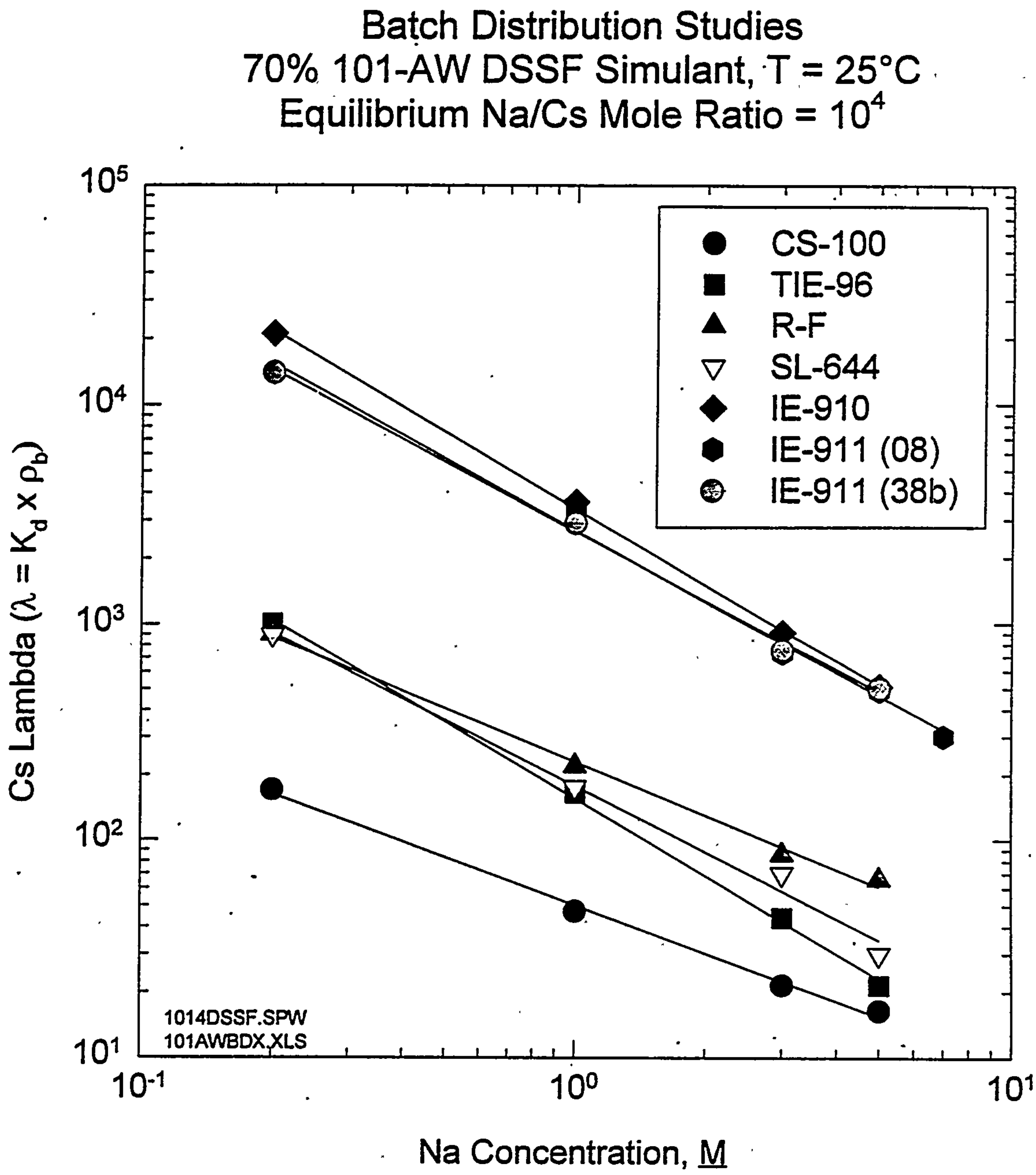

Figure 3.11. Comparison of Cs λ Values for Cesium-Selective Materials as a Function of Sodium Concentration in Simulated 70% 101-AW DSSF Composite at 25°C and an Equilibrium Na/Cs Ratio of 1.00E+04.

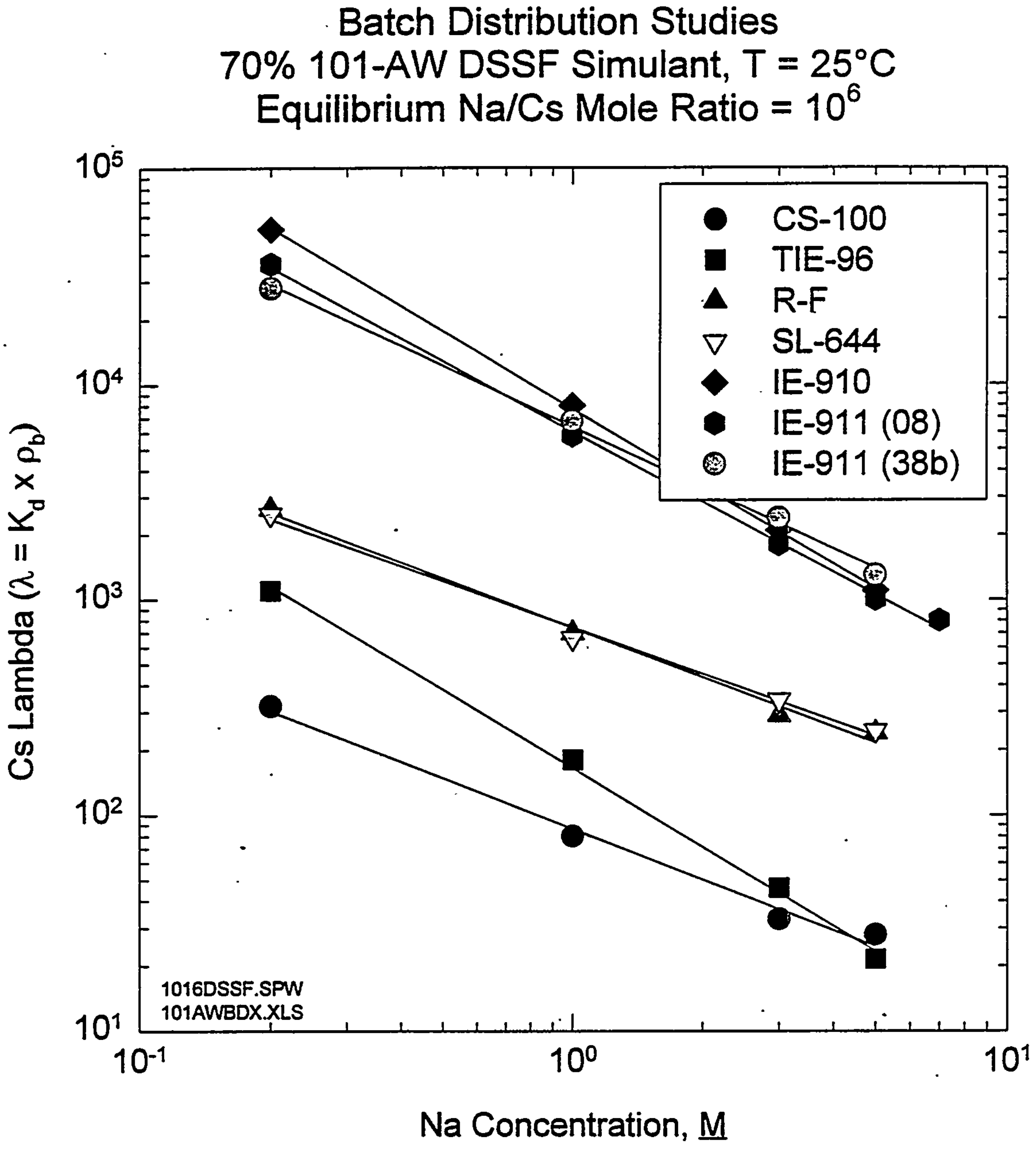

Figure 3.12. Comparison of Cs λ Values for Cesium-Selective Materials as a Function of Sodium Concentration in Simulated 70% 101-AW DSSF Composite at 25°C and an Equilibrium Na/Cs Ratio of 1.00E+06.

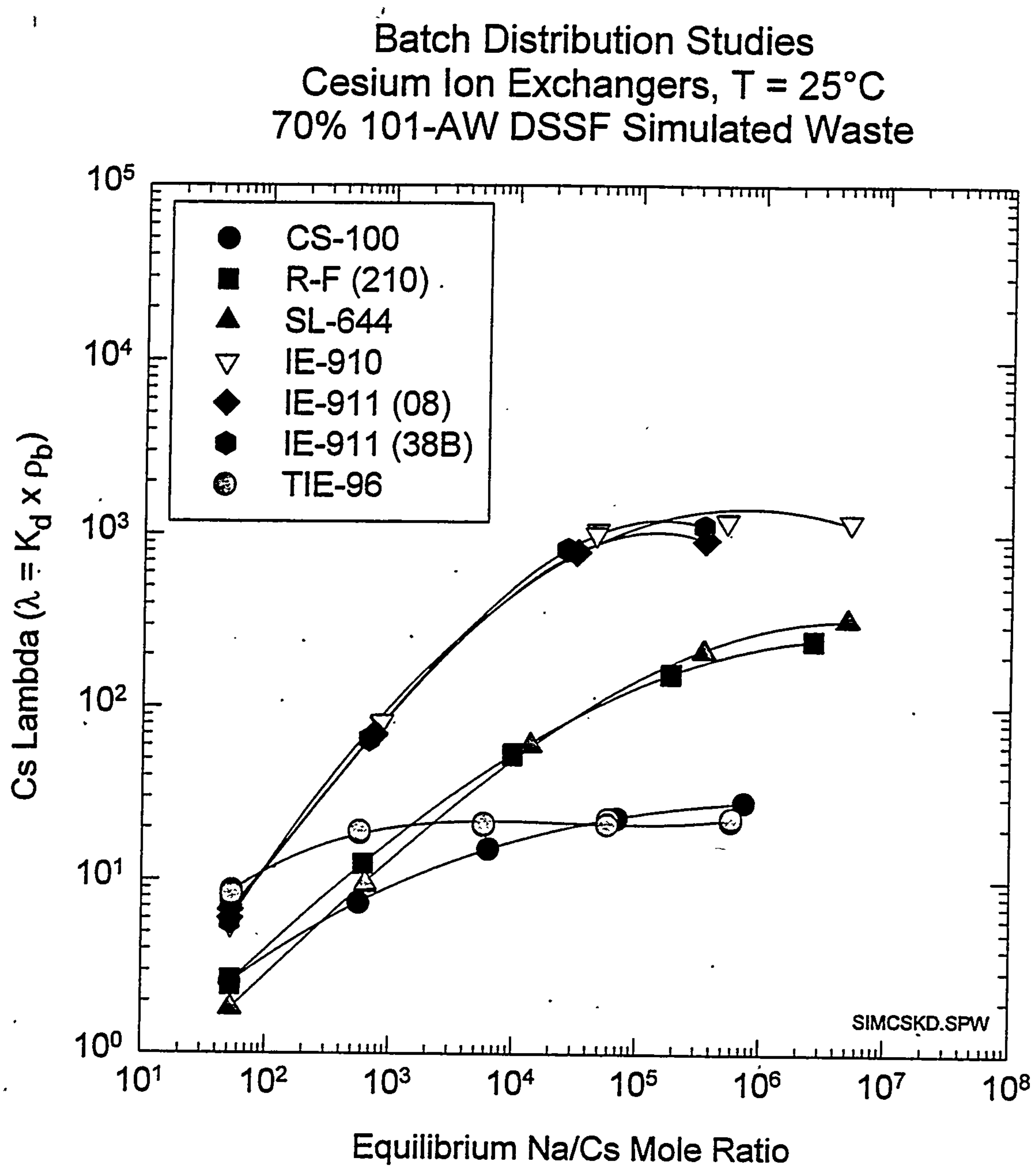

Figure 3.13. Comparison of Cs λ Values for Cesium Selective Materials in Simulated 70% 101-AW DSSF Composite at 5 M Na and 25°C.

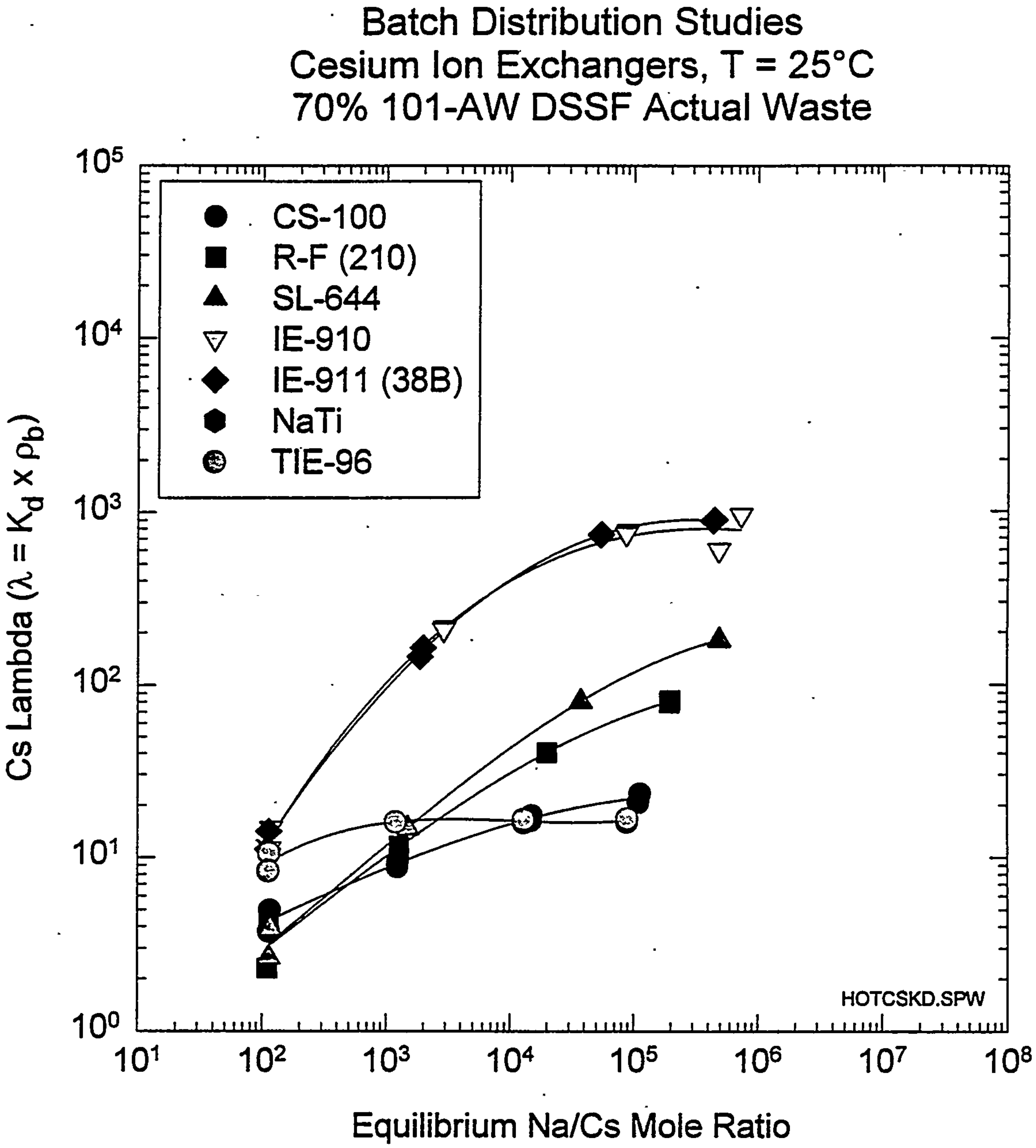

Figure 3.14. Comparison of Cs λ Values for Cesium Selective Materials in Actual 70% 101-AW DSSF Composite at 5 M Na and 25°C.

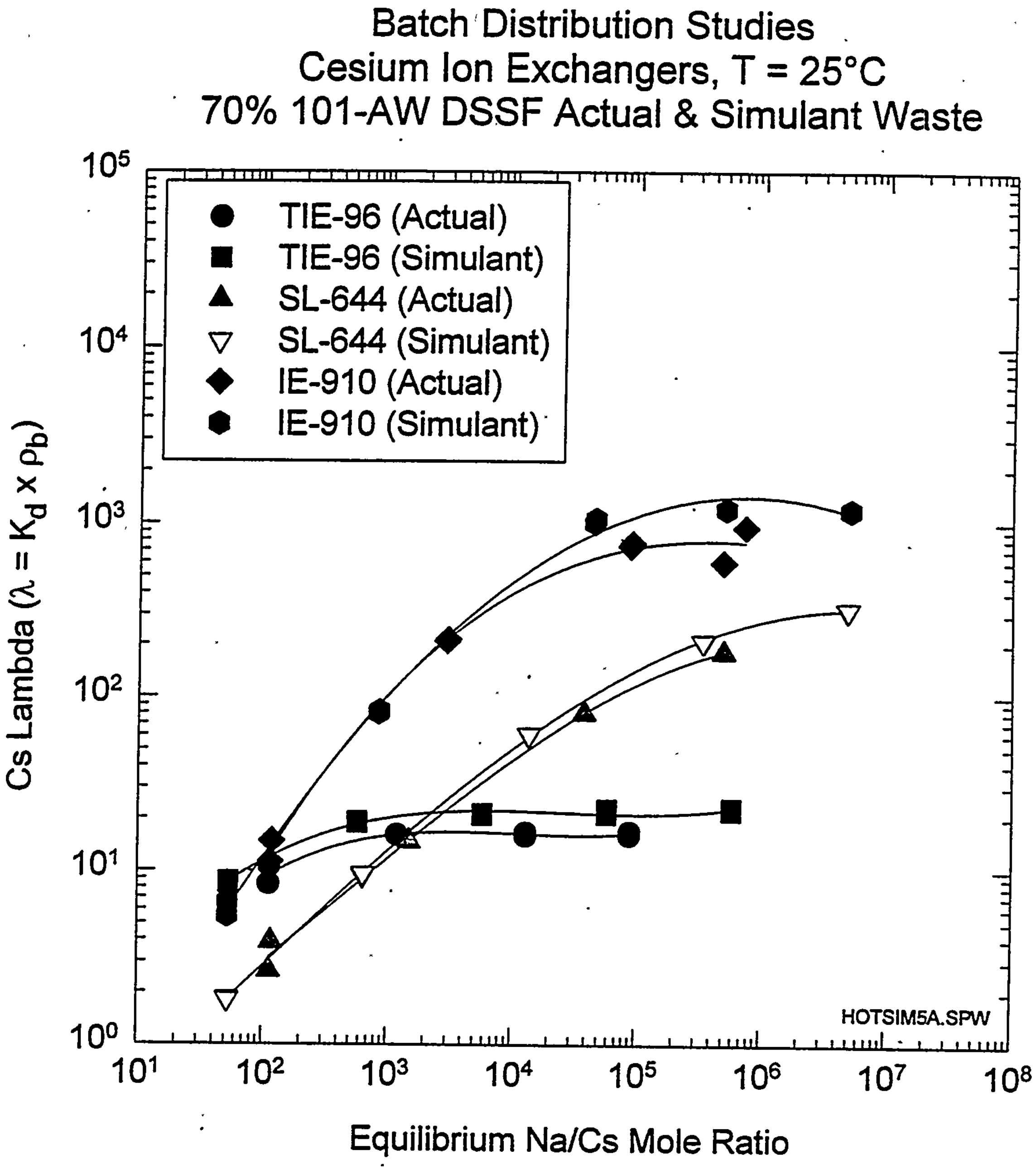

Figure 3.15. Comparison of Cs λ Values for Actual and Simulated 70% 101-AW DSSF Composite at 5 M Na and 25°C (TIE-96, SL-644, IE-910).

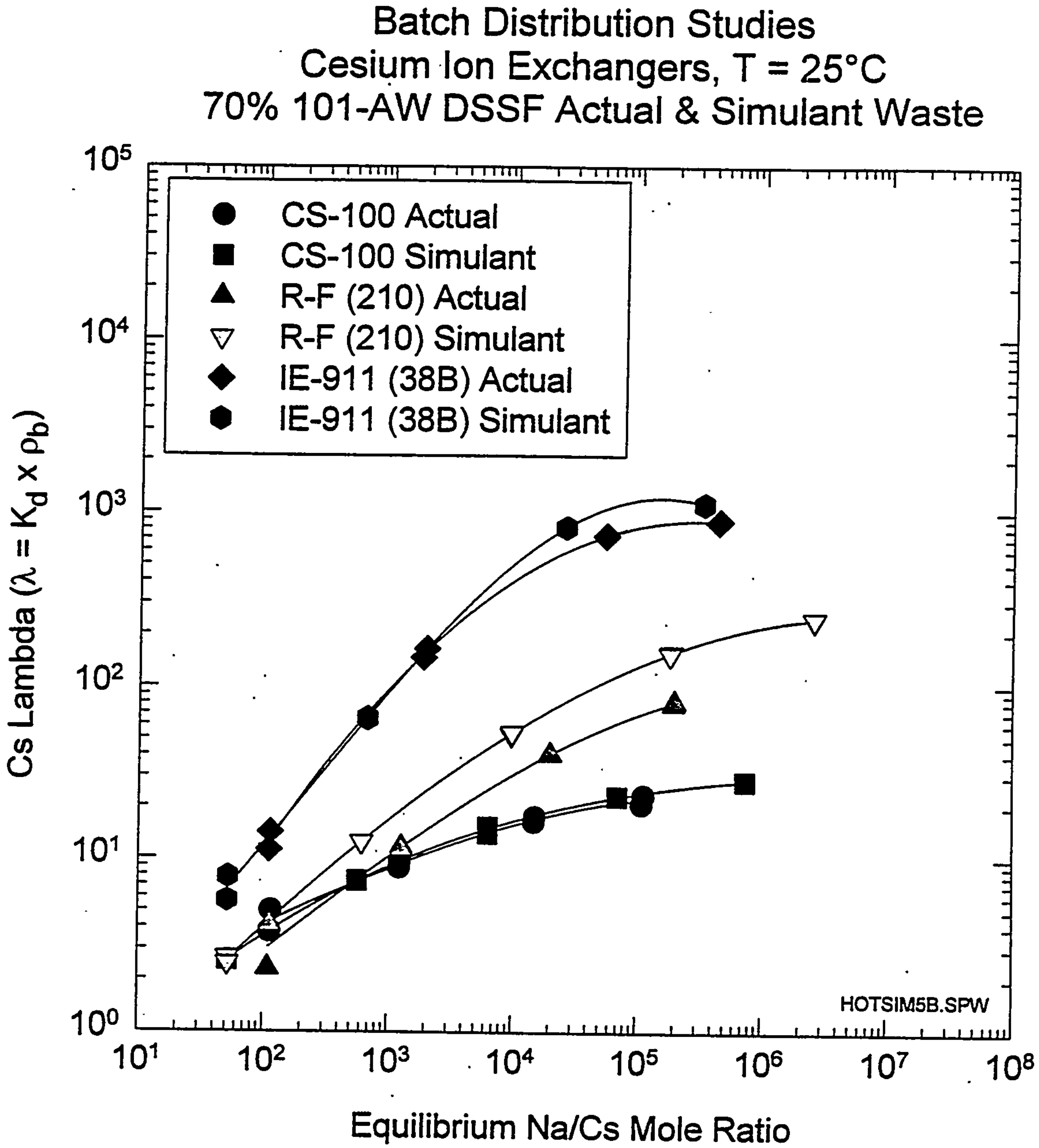

Figure 3.16. Comparison of Cs λ Values for Actual and Simulated 70% 101-AW DSSF Composite at 5 M Na and 25°C (CS-100, R-F, IE-911 (38B)).

Table 3.4. Strontium Distribution Results in Simulated 70% 101-AW DSSF Waste.

Material	Sr K_d	Sr K_d [a]	Sr λ	Sr λ [a]
CS-100	7.37E+01	6.82E+01	1.79E+01	1.66E+01
TIE-96	3.99E+03	4.27E+03	3.06E+03	3.27E+03
R-F	8.42E+01	1.25E+02	2.56E+01	3.82E+01
SL-644	8.15E+01	8.46E+01	1.82E+01	1.89E+01
IE-910	>5.93E+06	>5.93E+06	>4.58E+06	>4.58E+06
IE-911(08)	NA[b]	NA	NA	NA
IE-911(38B)	NA	NA	NA	NA
NaTi	>5.79E+06	>5.88E+06	>3.37E+06	>3.42E+06

[a] Duplicate

[b] Not available

The Sr λ values obtained from the actual waste tests are displayed in Figure 3.17 as a function of equilibrium Na/Cs mole ratio. In general, strontium removal was not affected by the concentration of cesium in the waste although both the CS-100 resin and the IE-910 exhibit a slight dependency. This lack of dependency is not surprising since both cesium and strontium are present in low concentrations relative to the sodium and have little opportunity to interact. The equilibrium is therefore approximated by a pair of binary ion exchange interactions; one between sodium and cesium and the other between sodium and strontium. Interestingly, the Sr K_d for the engineered CST (IE-911[38B]) was higher than for the powdered CST (IE-910) and was not affected by the cesium concentration. The NaTi powder exhibited the highest Sr λ but only slightly above the IE-911. The actual waste results generally followed those of the simulant work in the following order for Sr λ: NaTi > IE-911 > IE-910 > TIE-96 > SL-644 > R-F > CS-100.

As shown in Table 3.5, the Sr λ values obtained in the actual waste tests were several orders of magnitude lower than those obtained using the simulant. These data indicate significant differences between the actual and simulated wastes with respect to strontium removal by ion exchange/sorption. Based on the chemical compositions of the simulated and actual wastes displayed in Table 3.2, it seems plausible that the differences are related to the strontium concentration, the organic components, the trace metal interferences, or differences between experimental operations between the two test facilities.

The Sr level of the simulant was determined from Sr-90 radiochemical analysis and assuming approximately 20% of the total strontium was Sr-90. ICP analysis of the actual waste indicates that the actual strontium concentration is nearly 200 times that of the simulant. However, the Sr level cannot account for the entire difference since some Sr λ values are more than 8000 times lower suggesting additional contributing factors.

Perhaps the most significant difference between the actual and simulant wastes is the level of soluble organic matter which may complex to the strontium. The actual waste contains 2.16 g C L^{-1}

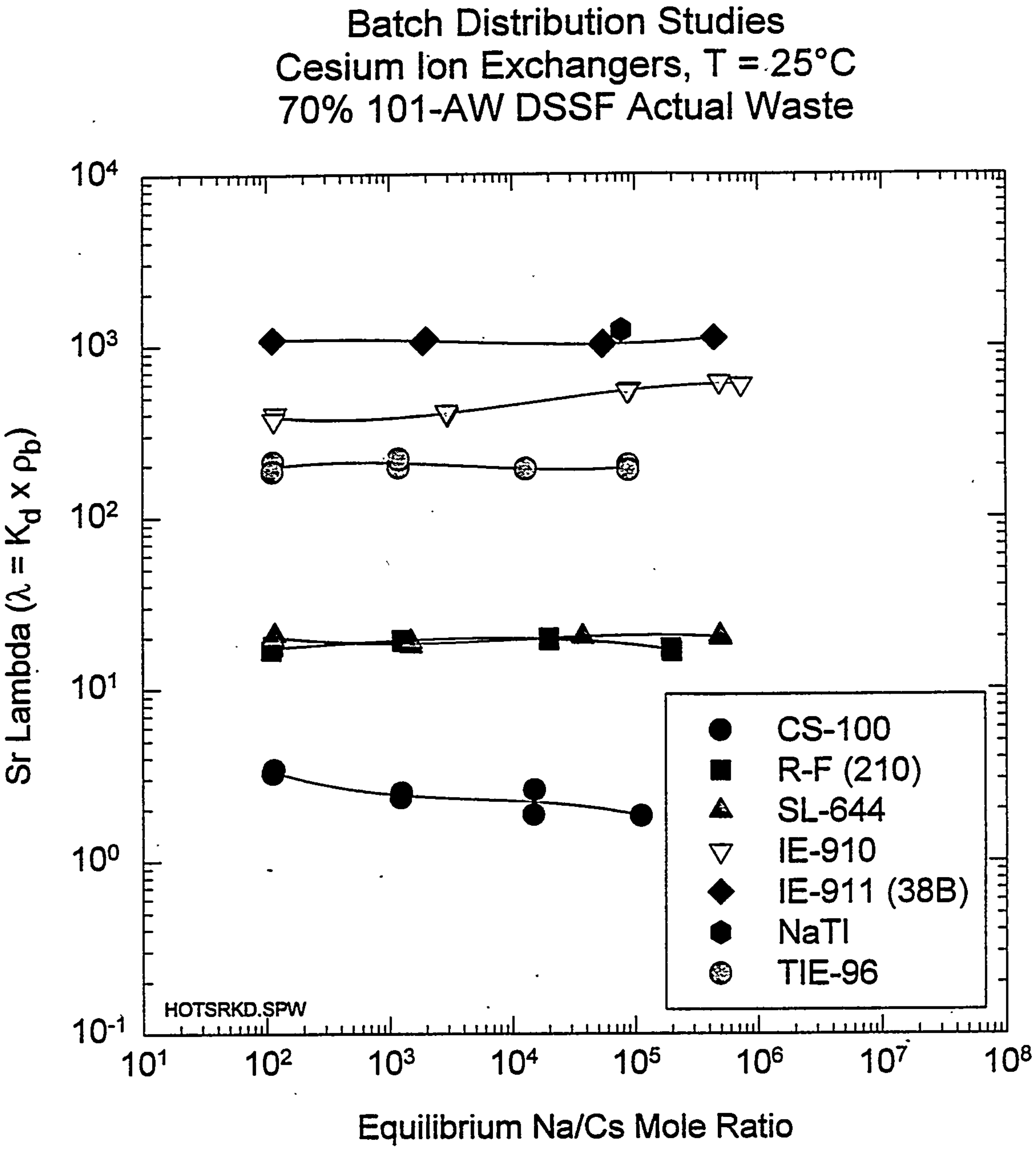

Figure 3.17. Sr λ Values in Actual 70% 101-AW DSSF Composite at 5 M Na and 25°C.

TOC while no organics were added to the simulant due to a lack of compositional analysis. The exact nature of these organics is not known but may consist of complexants capable of binding strontium in such a form (chelated anionic metal complex) that is difficult to remove by these cationic ion exchange materials (Brown et al. 1994; Marsh et al. 1995; Orth and Kurath 1993; Samuelson 1953; Samuelson 1963).

It is also possible that differences in the trace metals (primarily Ca and Ba, but possibly Cd, Cr, Fe, Ni, Mn, Zn, Zr, etc.) concentrations between the two solutions could account for the Sr λ variations. As displayed in Table 3.2, only Ca and Ba trace metals were added to the simulant.

Table 3.5. Comparison of Sr λ values in Actual and Simulant 70% 101-AW DSSF Waste

	Average Strontium λ		
Material	Simulant	Actual	Simulant/Actual
CS-100	1.7E+01	3.7E+00	5.6E+00
R-F	3.2E+01	1.7E+01	1.9E+00
SL-644	1.9E+01	2.0E+01	9.5E-01
IE-910	>4.6E+06	5.7E+02	>8.1E+03
IE-911(38B)	NA[a]	1.1E+03	NA
IE-911(08)	NA	NA	NA
TIE-96	3.2E+03	2.0E+02	1.6E+01
NaTi	>3.4E+06	1.2E+03	>2.8E+03

[a] Not available

3.7 Distribution of Other Species in Actual DSSF

The removal of 44 other metals from the actual 70% 101-AW DSSF composite waste was investigated by ICP-AES solution analysis before and after solid/liquid contact. A vast majority of the metals were either not detected (e.g., Ag, As, Ba, Bi, Ce, etc.), did not change appreciably during the ion exchange process (e.g., Al, B, K, Mo, Na, P, Pb, Zn), or the data were too scattered to infer a statistically significant difference (e.g., Ca and Ni). However, in spite of the preponderance of irrelevant data, a number of important results, including the removal of chromium, strontium, beryllium, and zirconium, were uncovered and are displayed in Table 3.6.

Perhaps the most significant result is the chromium uptake (Cr K_d) by the organic resins (SL-644 > R-F > CS-100). Similar results have been described previously (Brown et al. 1995; Svitra et al. 1994) indicating possible chromium removal for the CS-100 and R-F resins. The current data confirm this hypothesis and suggest that additional efforts should be made to quantify the extent of Cr loading during future column ion exchange experiments. Another surprising result is the slight removal of beryllium by the organic ion exchangers. The extent of strontium removal was calculated from the ICP-AES data and the results generally mirror those obtained from GEA (Section 3.6). Accurate calculation of the Sr K_d's is hampered by the relatively high ICP detection limit and data scatter. However, the following general trend is noted: (IE-911 ≈ IE-910 ≈ NaTi > TIE-96 > SL-644 > R-F > CS-100). All of the materials except IE-911 remove zirconium to some extent (NaTI and TIE-96 removed Zr to below the detection limit).

In addition to metals removal, certain materials appeared to generate some metals during the solid/liquid contact which could possibly indicate material instability. The solution in contact with the zeolite TIE-96 had three times the silicon that the blank had (341 vs 109 ppm Si). This result is not too surprising since many zeolites are known to be unstable in caustic solution. In addition, all of the inorganic materials (IE-910, IE-911, NaTi, and TIE-96) generated greater than detectable quantities of titanium after contact. Stability or instability of the organic resins (CS-100, R-F, and SL-644) cannot be ascertained from these data since Total Organic Carbon (TOC) or other organic analyses were not completed. These results do not necessarily indicate lack of stability or suggest that the inorganic materials should not be employed in similar radionuclide removal processes. Instead, addition chemical stability experiments should be devised using these results for guidance.

Table 3.6. Selected Metal Distribution Results in Actual 70% 101-AW DSSF Waste

Material	Cr K_d	Sr K_d	Zr K_d
CS-100	9.39E+00	9.88E+00	8.37E+01
R-F	1.17E+02	5.33E+01	9.73E+01
SL-644	1.37E+02	7.53E+01	1.50E+02
IE-910	--[(a)]	> 1.91E+02	2.88E+01
IE-911	--	> 2.20E+02	-8.44E+01
TIE-96	--	1.52E+02	> 6.76E+02
NaTi	--	> 1.94E+02	> 6.08E+02

(a) No statistically significant metals removal

3.8 Multiple Contact Cesium Distribution in Actual DSSF

A comparison of the overall DFs achieved during the two contact experiment is displayed in Table 3.7. A maximum DF of 421 for Cs-137 was obtained with the SL-644 material. This corresponds to a Cs-137 concentration of 0.46 Ci m^{-3} at 5 M sodium. This is lower than the NRC Class A limit and the pretreatment level currently assumed in the TWRS process flowsheet (Orme, 1995). The maximum DF for Sr-90 of 239 was obtained using the IE-911 material. Applying this DF to the feed concentration of 0.16 μCi mL^{-1}, gives an effluent concentration of 6.7E-04 Ci m^{-3} which is much lower than the NRC Class A limit of 0.04 Ci m^{-3}. These DFs are a general reflection of the λ values and are not an indication of the DFs that could be obtained in a column type operation. For both cesium and strontium, it is likely that additional contacts with any of the materials would have provided additional decontamination.

Table 3.7. Cumulative Cs and Sr Decontamination Factors in Actual 70% 101-AW DSSF Waste

Material	Cs DF	Sr DF
CS-100	1.99E+00	1.12E+00
R-F	4.21E+01	2.53E+00
SL-644	4.30E+02	8.23E+00
IE-910	2.84E+02	9.45E+01
IE-911 (38B)	1.89E+02	2.42E+02
NaTi	NA[a]	NA[a]
TIE-96	2.60E+00	3.66E+01

[a] Not applicable

3.9 High Phase Ratio Cesium Distribution in Actual DSSF

High phase ratio Cs and Sr batch tests were completed to investigate the effect that potential interferences have on the Cs and Sr lambda values. In this experiment, with more solution contacted per mass of exchanger, reduced removal of cesium could result if there is a significant amount of interfering components. Samples were submitted for GEA (Cs-137 and Sr-85) and ICP analysis (interferant metals). The ICP results have not been received and therefore information about potential interferences must be inferred from the cesium and strontium GEA data.

The Cs and Sr λ values are compared in Table 3.8 for the high and average phase ratio tests. The Cs λ values for the high phase ratio test are generally higher than results from the lower phase ratio. This tends to indicate a lack of interfering components although even higher phase ratio tests would be required to dismiss this possibility. The results for Sr are mixed with 2 Sr λ values from the high phase ratio test higher than those of the average phase ratio test and 2 are lower. These results do not provide any indication of interfering components, although again, higher phase ratio tests would be required to eliminate this possibility.

Table 3.8. Comparison of Cs and Sr Distribution Results at Two Phase Ratios

Ion Exchange Material	Na/Cs ratio	High Phase Ratio			Average Phase ratio		
		phase ratio mL g^{-1}	Cs λ	Sr λ	phase ratio mL g^{-1}	Cs λ	Sr λ
R-F	1.08E+05	480	77	35	150	70	17
SL-644	1.55E+05	480	120	18	150	130	20
IE-910	1.67E+05	920	875	695	150	780	605
IE-911	1.09E+05	885	900	900	150	850	1000

4.0 Conclusions

Based on the results of the batch testing with simulants and actual waste, the following observations and conclusions are made:

Processing considerations

- A maximum DF of 421 for Cs-137 was obtained with the SL-644 material. This corresponds to a Cs-137 concentration of 0.46 Ci m^{-3} at 5 $\underline{M}$ sodium which is lower than the NRC Class A limit of 1 Ci m^{-3}. Maximum Sr-90 DF (239) was obtained using the IE-911 material. This corresponds to an effluent concentration of 6.7E-04 Ci m^{-3} which is significantly lower than the NRC Class A limit of 0.04 Ci m^{-3}. These DFs are a general reflection of the λ values and are not indicative of the DFs that could be obtained in a column type operation. It is likely that additional contacts with any material would have provided additional Cs and Sr decontamination.

- Comparison of Cs and Sr λ values from batch contacts at different phase ratios do not indicate the presence of interfering species that might foul the exchanger surface or exchange sites.

Cesium equilibrium results

- In general, there was agreement between the Cs λ results obtained with the simulated and actual wastes. However, for all of the materials the actual waste results were lower than those obtained in the simulant. At feed conditions (5 $\underline{M}$ Na and Na/Cs = 78,000), the difference between the simulant and actual waste Cs λ values were -4%, -50%, -14%, -35%, -21%, and -24%, for CS-100, R-F, SL-644, IE-910, IE-911, and TIE-96, respectively.

- The general order of Cs λ values is: IE-910 $\approx$ IE-911 (08 and 38B) > R-F, Superlig 644 > TIE-96 > CS-100.

- All forms of the CST sorbent (powdered IE-910 and engineered IE-911) demonstrate high affinity for cesium and strontium in the actual and simulated waste solutions. The cesium lambda for the IE-911 (38B) material was nearly identical to that of the IE-910 during the actual and simulant waste tests at 5 $\underline{M}$ Na and only 20% to 30% lower during the simulant testing at low ionic strength (0.2 $\underline{M}$ Na). Evidently, fabrication into an engineered form did not severely impact the equilibrium Cs batch distribution for the CSTs.

- Since the CST materials are nonregenerable and must be used on a once through basis and possibly vitrified, it may be more appropriate to evaluate these materials on a mass (K_d) rather than a unit volume basis. Depending on the conditions chosen, the K_d's for the IE-911 (38B) material ranged from about 70-80% of those for the IE-910 at 5 $\underline{M}$ Na while the K_d's for the IE-911 (08) material were approximately 80% that of the IE-910 material.

- Based on the simulant results, a 25-fold dilution of the waste from 5 $\underline{M}$ Na to 0.2 $\underline{M}$ Na increases the CST cesium loading 12-14%, doubles the loading on the TIE-96, and decreases the cesium loading 40-45% for the organic exchangers. The process implication is that for inorganic materials, the amount of exchanger required can be minimized by processing dilute streams (e.g., before evaporative concentration of the waste). Conversely, if organic exchangers are used, the number of load/elute cycles can be minimized by processing concentrated waste streams.

Strontium equilibrium behavior

- All of the materials have an affinity for strontium with NaTi providing the greatest removal followed by IE-911, IE-910, and TIE-96. The organic exchangers exhibited relatively low affinities (SL-644 > R-F > CS-100) and would not be useful for strontium removal.

- For every ion exchange material, the Sr λ results were much lower in the actual waste experiment than those obtained during the simulant tests. This is most likely due to reduced strontium levels in the simulant with respect to the actual waste and the presence of organic materials in the actual waste that were not present in simulant. The exact nature of these organics is not known but they are generally complexant materials that would react with the Sr to form neutral or anionic complexants and thereby reduce the extent to which cation exchange takes place.

- The CST and NaTi materials exhibited very large Sr λ values (> 1E+06) for the simulated waste. The organic exchangers had much lower Sr λ values which ranged from 18-38. During actual waste testing, the calculated Sr λ values for the IE-911 (38B) and NaTi materials were nearly identical (ca. 1000). Surprisingly, the value for IE-910 was about 500, less than the engineered IE-911. The organic exchangers all exhibited much lower Sr λ values, ranging from about 3 for CS-100 to 20 for the R-F and SuperLig® materials.

- Over the range of conditions investigated, the concentration of cesium generally had little effect on Sr λ. This is not surprising since both cesium and strontium are present in low concentrations and generally do not compete for the same exchange sites. This means that the equilibrium system can be approximated as if it is two binary ion exchange interactions.

Other components

- The removal of chromium by the organic resins (SL-644 > R-F > CS-100) and zirconium by all of the exchangers except IE-911 (NaTi ≈ TIE-96 > SL-644 > R-F > CS-100 > IE-910) suggests that additional column loading and elution experiments will be needed to determine the quantity of these metals in the process solutions.

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Appendix A

Test Instructions for DSSF Waste Preparation

Attachment A: Test Instructions for DSSF Waste Preparation

Objective: To prepare a synthetic stock DSSF test feed (diluted to 5 M sodium) based on the analytical results of actual Hanford DSSF.

1. Test Solution Make-Up, Synthetic 101-AW DSSF Stock Solution

Component	FW,g	Molarity	g/L	g/ 2 L	Weight	Date	Initials
KOH	56.11	0.6650	37.31	74.63			
Na_2SO_4	142.05	0.0152	2.15	4.31			
$Na_2HPO_4 \bullet 7H_2O$	268.07	0.0245	6.57	13.14			
NaOH	40.00	5.1567	206.27	412.53			
$Al(NO_3)_3 \bullet 9H_2O$	375.15	0.6953	260.85	521.71			
Na_2CO_3	105.99	0.1960	20.77	41.55			
NaCl	58.45	0.0910	5.32	10.64			
NaF	41.99	0.0607	2.55	5.10			
$NaNO_2$	69.00	1.2250	84.53	169.05			
$Ba(NO_3)_2$	261.35	8.28E-07	2.16E-04	4.33E-04			
$Ca(NO_3)_2 \bullet 4H_2O$	236.18	3.62E-04	8.54E-02	1.71E-01			
$Sr(NO_3)_2$	211.64	1.00E-07	2.12E-05	4.25E-05			

After preparation the solution should have the following composition:

Species	Stock 101-AW, M	Diluted 101-AW, M
Na	7.00E+00	5.00E+00
Al	6.95E-01	4.97E-01
Ba	8.28E-07	5.91E-07
Ca	3.62E-04	2.41E-04
K	6.65E-01	4.75E-01
Sr	1.00E-07	7.14E-08
SO_4	1.52E-02	1.26E-02
OH	5.82E+00	4.16E+00
OH (Free)	3.04E+00	2.17E+00
Theoretical pH	1.51E+01	1.48E+01
Cl	9.10E-02	6.50E-02
CO_3	1.96E-01	1.40E-01
F	6.07E-02	4.33E-02
NO_2	1.23E+00	9.40E-01
NO_3	2.09E+00	1.49E+00
PO_4	2.45E-02	1.75E-02
Cs	Variable	Variable

Appendix B

Cs and Sr λ Values for the Simulant Experiments

Waste - DSSF composite (70% 101-AW, 20% 10%)				Temperature = 25 C												
ID Number	AEUC	AEUC-1	AEVC	AEVC-1	AEWC	AEWC-1	AEXC	AEXC-1	AEYC	AEYC-1	AEZC	AEZC-1	1	2	61	62
Material	CST:	IE-910	AS NaTi:	8104-170	Superlig 644		Cs-100		R-F:	BSC210	Zeolite:	TIE-96	IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01
Na/Cs Final	4.348E+02	4.489E+02	5.161E+01	5.167E+01	1.006E+02	9.798E+01	7.473E+01	7.492E+01	8.590E+01	8.403E+01	1.425E+02	1.441E+02	5.022E+02	6.387E+02	2.471E+02	2.681E+02
Cs Kd, mL/g	1.857E+03	1.923E+03	7.328E+00	7.659E+00	2.305E+02	2.215E+02	1.813E+02	1.815E+02	2.009E+02	1.918E+02	4.975E+02	5.028E+02	1.571E+03	2.081E+03	6.735E+02	7.438E+02
Density, g/mL	7.738E-01	7.738E-01	5.812E-01	5.812E-01	2.238E-01	2.238E-01	2.434E-01	2.434E-01	3.044E-01	3.044E-01	7.672E-01	7.672E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	1.437E+03	1.488E+03	4.259E+00	4.452E+00	5.158E+01	4.957E+01	4.413E+01	4.419E+01	6.114E+01	5.839E+01	3.817E+02	3.858E+02	1.414E+03	1.873E+03	7.581E+02	8.372E+02
ID Number	AFUC	AFUC-1	AFVC	AFVC-1	AFWC	AFWC-1	AFXC	AFXC-1	AFYC	AFYC-1	AFZC	AFZC-1	3	4	63	64
Material	CST:	IE-910	AS NaTi:	8104-170	Superlig 644		Cs-100		R-F:	BSC210	Zeolite:	TIE-96	IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02
Na/Cs Final	5.850E+04	5.139E+04	5.235E+02	5.232E+02	7.538E+03	7.724E+03	1.128E+03	1.140E+03	3.874E+03	3.693E+03	2.679E+03	2.678E+03	4.717E+04	4.622E+04	3.679E+04	3.871E+04
Cs Kd, mL/g	8.063E+04	4.778E+04	1.090E+01	1.053E+01	3.492E+03	3.575E+03	4.581E+02	4.675E+02	1.930E+03	1.838E+03	1.194E+03	1.193E+03	2.997E+04	2.871E+04	1.919E+04	2.076E+04
Density, g/mL	7.738E-01	7.738E-01	5.812E-01	5.812E-01	2.238E-01	2.238E-01	2.434E-01	2.434E-01	3.044E-01	3.044E-01	7.672E-01	7.672E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	6.239E+04	3.697E+04	6.333E+00	6.120E+00	7.814E+02	8.001E+02	1.115E+02	1.138E+02	5.876E+02	5.596E+02	9.164E+02	9.151E+02	2.697E+04	2.583E+04	2.160E+04	2.336E+04
ID Number	AGUC	AGUC-1	AGVC	AGVC-1	AGWC	AGWC-1	AGXC	AGXC-1	AGYC	AGYC-1	AGZC	AGZC-1	5	6	65	66
Material	CST:	IE-910	AS NaTi:	8104-170	Superlig 644		Cs-100		R-F:	BSC210	Zeolite:	TIE-96	IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03
Na/Cs Final	5.287E+05	4.348E+02	4.348E+02	4.348E+02	4.348E+02	4.348E+02	4.348E+02	4.348E+02	4.348E+02	4.348E+02	4.348E+02	4.348E+02	4.502E+05	4.718E+05	4.120E+05	3.263E+05
Cs Kd, mL/g	5.710E+04	6.157E+04	9.962E+00	9.773E+00	9.853E+03	9.852E+03	8.305E+02	8.527E+02	6.148E+03	6.441E+03	1.350E+03	1.355E+03	3.116E+04	3.443E+04	2.462E+04	1.663E+04
Density, g/mL	7.738E-01	7.738E-01	5.812E-01	5.812E-01	2.238E-01	2.238E-01	2.434E-01	2.434E-01	3.044E-01	3.044E-01	7.672E-01	7.672E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	4.418E+04	4.764E+04	5.790E+00	5.680E+00	2.205E+03	2.205E+03	2.021E+02	2.076E+02	1.872E+03	1.961E+03	1.035E+03	1.040E+03	2.804E+04	3.098E+04	2.772E+04	1.871E+04
ID Number	AHUC	AHUC-1	AHVC	AHVC-1	AHWC	AHWC-1	AHXC	AHXC-1	AHYC	AHYC-1	AHZC	AHZC-1	7	8	67	68
Material	CST:	IE-910	AS NaTi:	8104-170	Superlig 644		Cs-100		R-F:	BSC210	Zeolite:	TIE-96	IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04
Na/Cs Final	5.834E+06	6.036E+06	5.252E+04	5.256E+04	2.025E+06	2.048E+06	2.098E+05	2.099E+05	1.408E+06	1.367E+06	3.036E+05	3.073E+05	5.397E+06	5.557E+06	4.706E+06	4.676E+06
Cs Kd, mL/g	7.275E+04	8.026E+04	1.160E+01	1.189E+01	1.228E+04	1.240E+04	1.185E+03	1.195E+03	9.208E+03	8.666E+03	1.403E+03	1.425E+03	3.935E+04	4.206E+04	2.870E+04	2.818E+04
Density, g/mL	7.738E-01	7.738E-01	5.812E-01	5.812E-01	2.238E-01	2.238E-01	2.434E-01	2.434E-01	3.044E-01	3.044E-01	7.672E-01	7.672E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	5.629E+04	6.210E+04	6.744E+00	6.910E+00	2.748E+03	2.776E+03	2.884E+02	2.909E+02	2.803E+03	2.638E+03	1.076E+03	1.093E+03	3.541E+04	3.785E+04	3.230E+04	3.172E+04
ID Number	AJUC	AJUC-1	AJVC	AJVC-1	AJWC	AJWC-1	AJXC	AJXC-1	AJYC	AJYC-1	AJZC	AJZC-1	9	10	69	70
Material	CST:	IE-910	AS NaTi:	8104-170	Superlig 644		Cs-100		R-F:	BSC210	Zeolite:	TIE-96	IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01	2.000E-01
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05
Na/Cs Final	5.250E+07	5.372E+07	5.264E+05	5.252E+05	2.169E+07	2.143E+07	2.390E+06	2.354E+06	1.449E+07	1.489E+07	3.138E+06	3.145E+06	4.612E+07	4.424E+07	5.731E+07	4.636E+07
Cs Kd, mL/g	7.084E+04	7.493E+04	1.212E+01	1.169E+01	1.271E+04	1.252E+04	1.397E+03	1.360E+03	9.188E+03	9.538E+03	1.434E+03	1.453E+03	2.322E+04	2.181E+04	4.360E+04	2.814E+04
Density, g/mL	7.738E-01	7.738E-01	5.812E-01	5.812E-01	2.238E-01	2.238E-01	2.434E-01	2.434E-01	3.044E-01	3.044E-01	7.672E-01	7.672E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	5.482E+04	5.798E+04	7.043E+00	6.794E+00	2.844E+03	2.802E+03	3.399E+02	3.310E+02	2.797E+03	2.903E+03	1.100E+03	1.114E+03	2.090E+04	1.963E+04	4.907E+04	3.167E+04

ID Number	BEUC	BEUC-1	BEVC	BEVC-1	BEWC	BEWC-1	BEXC	BEXC-1	BEYC	BEYC-1	BEZC	BEZC-1	11	12	71	72
Material	CST: IE-910		AS NaTi: 8104-170		Superlig 644		Cs-100		R-F: BSC210		Zeolite: TIE-96		IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01
Na/Cs Final	6.847E+01	6.836E+01	5.074E+01	5.163E+01	6.251E+01	6.254E+01	5.865E+01	5.879E+01	5.939E+01	5.992E+01	6.798E+01	6.828E+01	6.261E+01	6.270E+01	6.024E+01	6.225E+01
Cs Kd, mL/g	5.733E+01	5.689E+01	2.249E+00	5.031E+00	3.806E+01	3.827E+01	4.142E+01	4.335E+01	3.514E+01	3.722E+01	6.542E+01	6.586E+01	4.191E+01	4.214E+01	3.451E+01	4.111E+01
Density, g/mL	7.738E-01	7.738E-01	5.812E-01	5.812E-01	2.238E-01	2.238E-01	2.434E-01	2.434E-01	3.044E-01	3.044E-01	7.672E-01	7.672E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	4.436E+01	4.402E+01	1.307E+00	2.924E+00	8.518E+00	8.565E+00	1.008E+01	1.055E+01	1.070E+01	1.133E+01	5.019E+01	5.052E+01	3.771E+01	3.792E+01	3.884E+01	4.627E+01
ID Number	BFUC	BFUC-1	BFVC	BFVC-1	BFWC	BFWC-1	BFXC	BFXC-1	BFYC	BFYC-1	BFZC	BFZC-1	13	14	73	74
Material	CST: IE-910		AS NaTi: 8104-170		Superlig 644		Cs-100		R-F: BSC210		Zeolite: TIE-96		IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02
Na/Cs Final	1.763E+04	1.700E+04	5.081E+02	5.077E+02	1.323E+03	1.276E+03	7.143E+02	7.189E+02	1.045E+03	1.042E+03	9.922E+02	9.752E+02	1.012E+04	9.781E+03	6.456E+03	6.791E+03
Cs Kd, mL/g	6.463E+03	6.243E+03	2.480E+00	2.349E+00	2.508E+02	2.416E+02	1.046E+02	1.049E+02	2.026E+02	2.013E+02	1.726E+02	1.761E+02	3.725E+03	3.580E+03	2.159E+03	2.280E+03
Density, g/mL	7.738E-01	7.738E-01	5.812E-01	5.812E-01	2.238E-01	2.238E-01	2.434E-01	2.434E-01	3.044E-01	3.044E-01	7.672E-01	7.672E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	5.001E+03	4.831E+03	1.442E+00	1.365E+00	5.612E+01	5.408E+01	2.545E+01	2.554E+01	6.166E+01	6.128E+01	1.324E+02	1.351E+02	3.352E+03	3.222E+03	2.430E+03	2.566E+03
ID Number	BGUC	BGUC-1	BGVC	BGVC-1	BGWC	BGWC-1	BGXC	BGXC-1	BGYC	BGYC-1	BGZC	BGZC-1	15	16	75	76
Material	CST: IE-910		AS NaTi: 8104-170		Superlig 644		Cs-100		R-F: BSC210		Zeolite: TIE-96		IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03
Na/Cs Final	2.250E+05	2.212E+05	5.101E+03	5.064E+03	5.934E+04	5.823E+04	9.014E+03	8.886E+03	3.644E+04	3.516E+04	1.092E+04	1.085E+04	1.548E+05	1.510E+05	1.117E+05	1.199E+05
Cs Kd, mL/g	9.493E+03	9.293E+03	3.098E+00	1.975E+00	1.775E+03	1.770E+03	1.979E+02	1.918E+02	1.229E+03	1.152E+03	2.110E+02	2.102E+02	6.333E+03	6.149E+03	4.125E+03	4.493E+03
Density, g/mL	7.738E-01	7.738E-01	5.812E-01	5.812E-01	2.238E-01	2.238E-01	2.434E-01	2.434E-01	3.044E-01	3.044E-01	7.672E-01	7.672E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	7.346E+03	7.191E+03	1.800E+00	1.148E+00	3.972E+02	3.962E+02	4.816E+01	4.669E+01	3.741E+02	3.505E+02	1.619E+02	1.613E+02	5.699E+03	5.533E+03	4.643E+03	5.057E+03
ID Number	BHUC	BHUC-1	BHVC	BHVC-1	BHWC	BHWC-1	BHXC	BHXC-1	BHYC	BHYC-1	BHZC	BHZC-1	17	18	77	78
Material	CST: IE-910		AS NaTi: 8104-170		Superlig 644		Cs-100		R-F: BSC210		Zeolite: TIE-96		IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04
Na/Cs Final	2.248E+06	2.323E+06	5.068E+04	5.099E+04	8.952E+05	8.685E+05	1.058E+05	1.050E+05	6.081E+05	5.816E+05	1.109E+05	1.102E+05	1.587E+06	1.582E+06	1.586E+06	1.635E+06
Cs Kd, mL/g	1.010E+04	1.050E+04	2.077E+00	3.002E+00	2.983E+03	2.869E+03	2.749E+02	2.664E+02	2.253E+03	2.150E+03	2.210E+02	2.179E+02	6.082E+03	6.048E+03	6.263E+03	6.535E+03
Density, g/mL	7.738E-01	7.738E-01	5.812E-01	5.812E-01	2.238E-01	2.238E-01	2.434E-01	2.434E-01	3.044E-01	3.044E-01	7.672E-01	7.672E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	7.813E+03	8.127E+03	1.207E+00	1.745E+00	6.676E+02	6.420E+02	6.691E+01	6.485E+01	6.858E+02	6.544E+02	1.696E+02	1.672E+02	5.474E+03	5.443E+03	7.049E+03	7.356E+03
ID Number	BJUC	BJUC-1	BJVC	BJVC-1	BJWC	BJWC-1	BJXC	BJXC-1	BJYC	BJYC-1	BJZC	BJZC-1	19	20	79	80
Material	CST: IE-910		AS NaTi: 8104-170		Superlig 644		Cs-100		R-F: BSC210		Zeolite: TIE-96		IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05
Na/Cs Final	2.121E+07	2.207E+07	5.155E+05	5.186E+05	9.873E+06	9.633E+06	1.156E+06	1.204E+06	6.384E+06	7.041E+06	1.155E+06	1.145E+06	1.615E+07	1.559E+07	1.357E+07	1.387E+07
Cs Kd, mL/g	8.875E+03	9.296E+03	4.766E+00	5.706E+00	3.306E+03	3.189E+03	3.238E+02	3.470E+02	2.369E+03	2.639E+03	2.334E+02	2.336E+02	6.208E+03	5.921E+03	5.056E+03	5.180E+03
Density, g/mL	7.738E-01	7.738E-01	5.812E-01	5.812E-01	2.238E-01	2.238E-01	2.434E-01	2.434E-01	3.044E-01	3.044E-01	7.672E-01	7.672E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	6.867E+03	7.193E+03	2.770E+00	3.317E+00	7.400E+02	7.138E+02	7.881E+01	8.446E+01	7.211E+02	8.034E+02	1.791E+02	1.792E+02	5.586E+03	5.329E+03	5.691E+03	5.830E+03

ID Number	CEUC	CEUC-1	CEVC	CEVC-1	CEWC	CEWC-1	CEXC	CEXC-1	CEYC	CEYC-1	CEZC	CEZC-1	21	22	81	82
Material	CST: IE 910		AS NaTi: 8104-170		Superlig 644		Cs-100		R-F: BSC210		Zeolite: TIE-96		IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01
Na/Cs Final	5.468E-02	5.465E-02	6.003E-02	6.012E-02	5.528E-02	5.526E-02	5.654E-02	5.675E-02	5.611E-02	5.594E-02	5.431E-02	5.412E-02	5.319E+01	5.301E+01	5.298E+01	5.263E+01
Cs Kd, mL/g	1.491E+01	1.512E+01	-6.503E-02	-3.066E-01	1.315E+01	1.302E+01	1.502E+01	1.411E+01	1.281E+01	1.352E+01	1.879E+01	1.973E+01	1.066E+01	1.008E+01	1.006E+01	8.785E+00
Density, g/mL	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	1.154E+01	1.170E+01	-5.032E-02	-2.372E-01	1.017E+01	1.008E+01	1.162E+01	1.091E+01	9.913E+00	1.046E+01	1.454E+01	1.527E+01	9.590E+00	9.074E+00	1.132E+01	9.889E+00
ID Number	CFUC	CFUC-1	CFVC	CFVC-1	CFWC	CFWC-1	CFXC	CFXC-1	CFYC	CFYC-1	CFZC	CFZC-1	23	24	83	84
Material	CST: IE 910		AS NaTi: 8104-170		Superlig 644		Cs-100		R-F: BSC210		Zeolite: TIE-96		IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02
Na/Cs Final	1.912E-03	1.898E-03	6.000E-03	6.004E-03	4.222E-03	4.217E-03	5.109E-03	5.126E-03	4.509E-03	4.506E-03	4.734E-03	4.719E-03	1.031E+03	1.028E+03	8.766E+02	8.748E+02
Cs Kd, mL/g	3.407E+02	3.355E+02	6.593E-03	-9.066E-02	6.545E+01	6.497E+01	4.204E+01	4.136E+01	6.092E+01	6.175E+01	4.911E+01	4.822E+01	1.779E+02	1.785E+02	1.266E+02	1.270E+02
Density, g/mL	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	2.636E+02	2.596E+02	5.102E-03	-7.016E-02	5.065E+01	5.028E+01	3.253E+01	3.200E+01	4.714E+01	4.778E+01	3.800E+01	3.731E+01	1.601E+02	1.606E+02	1.425E+02	1.429E+02
ID Number	CGUC	CGUC-1	CGVC	CGVC-1	CGWC	CGWC-1	CGXC	CGXC-1	CGYC	CGYC-1	CGZC	CGZC-1	25	26	85	86
Material	CST: IE 910		AS NaTi: 8104-170		Superlig 644		Cs-100		R-F: BSC210		Zeolite: TIE-96		IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03
Na/Cs Final	3.756E-05	3.756E-05	5.974E-04	6.002E-04	1.486E-04	1.528E-04	4.470E-04	4.537E-04	2.374E-04	2.163E-04	4.561E-04	4.564E-04	5.563E+04	5.388E+04	4.807E+04	4.854E+04
Cs Kd, mL/g	2.709E+03	2.681E+03	6.790E-01	-3.986E-02	4.772E+02	4.638E+02	8.274E+01	7.928E+01	2.901E+02	3.306E+02	5.681E+01	5.690E+01	1.824E+03	1.740E+03	1.502E+03	1.519E+03
Density, g/mL	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	2.096E+03	2.074E+03	5.254E-01	-3.084E-02	3.693E+02	3.589E+02	6.402E+01	6.135E+01	2.245E+02	2.558E+02	4.396E+01	4.403E+01	1.641E+03	1.566E+03	1.690E+03	1.710E+03
ID Number	CHUC	CHUC-1	CHVC	CHVC-1	CHWC	CHWC-1	CHXC	CHXC-1	CHYC	CHYC-1	CHZC	CHZC-1	27	28	87	88
Material	CST: IE 910	AS NaTi: 8104-170			Superlig 644		Cs-100		R-F: BSC210		Zeolite: TIE-96		IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04
Na/Cs Final	3.589E-06	3.740E-06	6.019E-05	6.000E-05	6.402E-06	6.545E-06	4.032E-05	4.078E-05	1.088E-05	1.152E-05	4.546E-05	4.548E-05	5.936E+05	5.808E+05	4.589E+05	5.661E+05
Cs Kd, mL/g	2.845E+03	2.735E+03	-4.990E-01	-6.873E-03	1.387E+03	1.345E+03	1.199E+02	1.137E+02	8.715E+02	8.087E+02	5.774E+01	5.766E+01	1.922E+03	1.909E+03	1.440E+03	1.826E+03
Density, g/mL	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	2.201E+03	2.117E+03	-3.861E-01	-5.319E-03	1.073E+03	1.041E+03	9.276E+01	8.802E+01	6.744E+02	6.257E+02	4.468E+01	4.461E+01	1.729E+03	1.718E+03	1.621E+03	2.056E+03
ID Number	CJUC	CJUC-1	CJVC	CJVC-1	CJWC	CJWC-1	CJXC	CJXC-1	CJYC	CJYC-1	CJZC	CJZC-1	29	30	89	90
Material	CST: IE 910		AS NaTi: 8104-170		Superlig 644		Cs-100		R-F: BSC210		Zeolite: TIE-96		IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00	3.000E+00
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05
Na/Cs Final	3.680E-07	3.608E-07	6.002E-06	6.014E-06	4.999E-07	4.985E-07	3.922E-06	3.774E-06	1.110E-06	8.416E-07	4.514E-06	4.492E-06	5.443E+06	5.580E+06	5.652E+06	7.938E+06
Cs Kd, mL/g	2.749E+03	2.791E+03	-4.989E-02	-3.589E-01	1.861E+03	1.859E+03	1.297E+02	1.434E+02	8.567E+02	1.188E+03	5.959E+01	5.968E+01	1.791E+03	1.791E+03	1.853E+03	2.773E+03
Density, g/mL	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	7.738E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	2.127E+03	2.160E+03	-3.861E-02	-2.777E-01	1.440E+03	1.439E+03	1.004E+02	1.110E+02	6.629E+02	9.194E+02	4.611E+01	4.618E+01	1.612E+03	1.612E+03	2.085E+03	3.122E+03

ID Number	DEUC	DEUC-1	DEVC	DEVC-1	DEWC	DEWC-1	DEXC	DEXC-1	DEYC	DEYC-1	DEZC	DEZC-1	31	32	DE1	DE2
Material	CST: IE-910		AS NaTi: 8104-170		Superlig 644		Cs-100		R-F: BSC210		Zeolite: TIE-96		IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01	5.000E+01
Na/Cs Final	5.273E+01	5.229E+01	4.992E+01	4.986E+01	5.269E+01	5.265E+01	5.217E+01	5.217E+01	5.236E+01	5.216E+01	5.315E+01	5.302E+01	5.195E+01	5.222E+01	5.198E+01	5.181E+01
Cs Kd, mL/g	8.439E+00	7.030E+00	-2.323E-01	-4.435E-01	8.199E+00	8.067E+00	1.052E+01	1.054E+01	8.748E+00	8.087E+00	1.128E+01	1.082E+01	6.672E+00	7.417E+00	6.738E+00	6.069E+00
Density, g/mL	7.738E-01	7.738E-01	5.812E-01	5.812E-01	2.238E-01	2.238E-01	2.434E-01	2.434E-01	3.044E-01	3.044E-01	7.672E-01	7.672E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	6.530E+00	5.440E+00	-1.350E-01	-2.578E-01	1.835E+00	1.805E+00	2.560E+00	2.566E+00	2.663E+00	2.462E+00	8.650E+00	8.304E+00	6.004E+00	6.674E+00	7.584E+00	6.832E+00
ID Number	DFUC	DFUC-1	DFVC	DFVC-1	DFWC	DFWC-1	DFXC	DFXC-1	DFYC	DFYC-1	DFZC	DFZC-1	33	34	DF1	DF2
Material	CST: IE-910		AS NaTi: 8104-170		Superlig 644		Cs-100		R-F: BSC210		Zeolite: TIE-96		IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02
Na/Cs Final	8.323E+02	8.469E+02	4.990E+02	5.018E+02	6.367E+02	6.389E+02	5.630E+02	5.624E+02	6.098E+02	6.090E+02	5.701E+02	5.674E+02	7.375E+02	7.346E+02	6.736E+02	6.750E+02
Cs Kd, mL/g	1.036E+02	1.062E+02	-2.885E-01	5.369E-01	4.159E+01	4.268E+01	3.018E+01	3.042E+01	4.066E+01	4.062E+01	2.428E+01	2.493E+01	7.763E+01	7.598E+01	5.881E+01	5.917E+01
Density, g/mL	7.738E-01	7.738E-01	5.812E-01	5.812E-01	2.238E-01	2.238E-01	2.434E-01	2.434E-01	3.044E-01	3.044E-01	7.672E-01	7.672E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	8.013E+01	8.220E+01	-1.677E-01	3.121E-01	9.307E+00	9.553E+00	7.345E+00	7.403E+00	1.238E+01	1.236E+01	1.863E+01	1.913E+01	6.986E+01	6.838E+01	6.620E+01	6.660E+01
ID Number	DGUC	DGUC-1	DGVC	DGVC-1	DGWC	DGWC-1	DGXC	DGXC-1	DGYC	DGYC-1	DGZC	DGZC-1	35	36	DG1	DG2
Material	CST: IE-910		AS NaTi: 8104-170		Superlig 644		Cs-100		R-F: BSC210		Zeolite: TIE-96		IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03	5.000E+03
Na/Cs Final	4.590E+04	4.489E+04	4.983E+03	4.994E+03	1.352E+04	1.360E+04	6.252E+03	6.284E+03	9.665E+03	9.758E+03	5.763E+03	5.764E+03	3.102E+04	3.183E+04	2.516E+04	2.549E+04
Cs Kd, mL/g	1.373E+03	1.305E+03	-5.115E-01	-1.699E-01	2.681E+02	2.710E+02	6.189E+01	6.273E+01	1.728E+02	1.775E+02	2.701E+01	2.763E+01	8.673E+02	8.831E+02	7.003E+02	7.114E+02
Density, g/mL	7.738E-01	7.738E-01	5.812E-01	5.812E-01	2.238E-01	2.238E-01	2.434E-01	2.434E-01	3.044E-01	3.044E-01	7.672E-01	7.672E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	1.062E+03	1.010E+03	-2.973E-01	-9.874E-02	6.000E+01	6.065E+01	1.506E+01	1.527E+01	5.259E+01	5.404E+01	2.072E+01	2.120E+01	7.805E+02	7.947E+02	7.883E+02	8.007E+02
ID Number	DHUC	DHUC-1	DHVC	DHVC-1	DHWC	DHWC-1	DHXC	DHXC-1	DHYC	DHYC-1	DHZC	DHZC-1	37	38	DH1	DH2
Material	CST: IE-910		AS NaTi: 8104-170		Superlig 644		Cs-100		R-F: BSC210		Zeolite: TIE-96		IE-911, (8671- 08)		IE-911, (0739-38B)	
[Na], Mol.	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04	5.000E+04
Na/Cs Final	5.160E+05	5.152E+05	5.000E+04	4.977E+04	3.444E+05	3.369E+05	6.902E+04	6.922E+04	1.865E+05	1.830E+05	5.818E+04	5.765E+04	3.528E+05	3.438E+05	3.365E+05	3.350E+05
Cs Kd, mL/g	1.574E+03	1.568E+03	-9.754E-03	-7.037E-01	9.406E+02	9.361E+02	9.401E+01	9.381E+01	5.143E+02	5.050E+02	2.943E+01	2.736E+01	1.041E+03	1.024E+03	9.984E+02	1.001E+03
Density, g/mL	7.738E-01	7.738E-01	5.812E-01	5.812E-01	2.238E-01	2.238E-01	2.434E-01	2.434E-01	3.044E-01	3.044E-01	7.672E-01	7.672E-01	8.999E-01	8.999E-01	1.126E+00	1.126E+00
Cs Lambda	1.218E+03	1.214E+03	-5.669E-03	-4.090E-01	2.105E+02	2.095E+02	2.288E+01	2.283E+01	1.566E+02	1.537E+02	2.258E+01	2.099E+01	9.370E+02	9.211E+02	1.124E+03	1.127E+03
ID Number	DJUC	DJUC-1	DJVC	DJVC-1	DJWC	DJWC-1	DJXC	DJXC-1	DJYC	DJYC-1	DJZC	DJZC-1	39	40		
Material	CST: IE-910		AS NaTi: 8104-170		Superlig 644		Cs-100		R-F: BSC210		Zeolite: TIE-96		IE-911, (8671- 08)			
[Na], Mol.	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00		
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01	8.990E-01	8.990E-01		
Na/Cs Start	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05	5.000E+05		
Na/Cs Final	5.076E+06	5.120E+06	4.974E+05	5.003E+05	4.841E+06	4.925E+06	7.352E+05	7.355E+05	2.602E+06	2.603E+06	5.804E+05	5.819E+05				
Cs Kd, mL/g	1.545E+03	1.545E+03	-8.155E-01	9.343E-02	1.439E+03	1.448E+03	1.161E+02	1.155E+02	7.986E+02	8.071E+02	2.872E+01	2.979E+01	Not enough solution.			
Density, g/mL	7.738E-01	7.738E-01	5.812E-01	5.812E-01	2.238E-01	2.238E-01	2.434E-01	2.434E-01	3.044E-01	3.044E-01	7.672E-01	7.672E-01				
Cs Lambda	1.195E+03	1.196E+03	-4.740E-01	5.430E-02	3.221E+02	3.241E+02	2.825E+01	2.811E+01	2.431E+02	2.457E+02	2.203E+01	2.286E+01				

ID Number	41	42	43	44	45	46	47	48	49	·50
Material	IE-911, (8671- 08)		IE-911, (8671- 08)		IE-911, (8671- 08)		IE-911, (8671- 08)		IE-911, (8671- 08)	
[Na], Mol.	7.000E+00	7.000E+00	7.000E+00	7.000E+00	7.000E+00	7.000E+00	7.000E+00	7.000E+00	7.000E+00	7.000E+00
F Factor	8.990E-01	8.990E-01	8.990E-01	8.990E-01	8.990E-01	8.990E-01	8.990E-01	8.990E-01	8.990E-01	8.990E-01
Na/Cs Start	5.000E+01	5.000E+01	5.000E+02	5.000E+02	5.000E+03	5.000E+03	5.000E+04	5.000E+04	5.000E+05	5.000E+05
Na/Cs Final	5.118E+01	5.089E+01	6.347E+02	6.299E+02	2.120E+04	2.070E+04	2.789E+05	2.741E+05	2.645E+06	2.708E+06
Cs Kd, mL/g	3.908E+00	2.952E+00	4.494E+01	4.323E+01	5.532E+02	5.354E+02	7.918E+02	7.728E+02	7.287E+02	7.521E+02
Density, g/mL	8.999E-01	8.999E-01	8.999E-01	8.999E-01	8.999E-01	8.999E-01	8.999E-01	8.999E-01	8.999E-01	8.999E-01
Cs Lambda	3.517E+00	2.656E+00	4.044E+01	3.891E+01	4.978E+02	4.818E+02	7.125E+02	6.955E+02	6.557E+02	6.768E+02

ID Number	EE1	EE2	EF1	EF2	EG1	EG2	EH1	EH2	EJ1	EJ2
Material	UOP: IE-911, batch # 0739-38B									
[Na], Mol.	7.000E+00	7.000E+00	7.000E+00	7.000E+00	7.000E+00	7.000E+00	7.000E+00	7.000E+00	7.000E+00	7.000E+00
F Factor	8.870E-01	8.870E-01	8.870E-01	8.870E-01	8.870E-01	8.870E-01	8.870E-01	8.870E-01	8.870E-01	8.870E-01
Na/Cs Start	5.000E+01	5.000E+01	5.000E+02	5.000E+02	5.000E+03	5.000E+03	5.000E+04	5.000E+04	5.000E+05	5.000E+05
Na/Cs Final	5.101E+01	5.100E+01	6.149E+02	6.155E+02	1.754E+04	1.786E+04	2.564E+05	2.596E+05	2.682E+06	2.679E+06
Cs Kd, mL/g	3.397E+00	3.388E+00	3.916E+01	3.911E+01	4.348E+02	4.422E+02	7.194E+02	7.242E+02	7.588E+02	7.646E+02
Density, g/mL	1.126E+00	1.126E+00	1.126E+00	1.126E+00	1.126E+00	1.126E+00	1.126E+00	1.126E+00	1.126E+00	1.126E+00
Cs Lambda	3.824E+00	3.814E+00	4.407E+01	4.402E+01	4.894E+02	4.978E+02	8.098E+02	8.151E+02	8.541E+02	8.606E+02

Waste - DSSF composite (70% 101-AW, 20% 10%)				Temperature = 25 C			Strontium Kd's at 5M Na, Na/Cs=500,000					
ID Number	DJUS	DJUS-1	DJVS	DJVS-1	DJWS	DJWS-1	DJXS	DJXS-1	DJYS	DJYS-1	DJZS	DJZS-1
Material	CST: IE-910		AS NaTi: 8104-170		Superlig 644		Cs-100		R-F: BSC210		Zeolite: TIE-96	
[Na], Mol.	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00
F Factor	9.680E-01	9.680E-01	9.764E-01	9.764E-01	9.751E-01	9.751E-01	6.148E-01	6.148E-01	8.070E-01	8.070E-01	8.338E-01	8.338E-01
Na/Sr Start	7.000E+07	7.000E+07	7.000E+07	7.000E+07	7.000E+07	7.000E+07	7.000E+07	7.000E+07	7.000E+07	7.000E+07	7.000E+07	7.000E+07
Na/Sr Final	2.682E+12	2.682E+12	2.682E+12	2.682E+12	1.079E+08	1.089E+08	9.147E+07	8.998E+07	1.020E+08	1.177E+08	1.756E+09	1.629E+09
Sr Kd, mL/g	5.930E+06	5.925E+06	5.791E+06	5.881E+06	8.151E+01	8.462E+01	7.368E+01	6.819E+01	8.418E+01	1.255E+02	3.993E+03	4.268E+03
Density	7.738E-01	7.738E-01	5.812E-01	5.812E-01	2.238E-01	2.238E-01	2.434E-01	2.434E-01	3.044E-01	3.044E-01	7.672E-01	7.672E-01
Sr Lambda	4.588E+06	4.585E+06	3.366E+06	3.418E+06	1.824E+01	1.894E+01	1.793E+01	1.660E+01	2.562E+01	3.819E+01	3.063E+03	3.274E+03

Appendix C

Cs and Sr λ Values for the Actual Waste Experiments

	Phase I Experiment Phase Ratio = 150 mL/g, Cs lambdas							
ID Number	CS1D	CS1Q	CS2D	CS2Q	CS3D	CS3Q	CS4D	CS4Q
Material	CS-100	CS-100	CS-100	CS-100	CS-100	CS-100	CS-100	CS-100
[Na], Mol.	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
F Factor	0.6671	0.6671	0.6671	0.6671	0.6671	0.6671	0.6671	0.6671
Na/Cs Start	1.05E+02	1.05E+02	1.05E+03	1.05E+03	1.14E+04	1.14E+04	7.84E+04	7.84E+04
Na/Cs Final	1.15E+02	1.13E+02	1.24E+03	1.23E+03	1.48E+04	1.51E+04	1.13E+05	1.09E+05
Cs Kd Value	2.04E+01	1.54E+01	3.92E+01	3.62E+01	6.68E+01	7.17E+01	9.52E+01	8.51E+01
Density	0.2434	0.2434	0.2434	0.2434	0.2434	0.2434	0.2434	0.2434
Cs Lambda	4.96E+00	3.75E+00	9.54E+00	8.82E+00	1.63E+01	1.74E+01	2.32E+01	2.07E+01
ID Number	RF1D	RF1Q	RF2D	RF2Q	RF3D	RF3Q	RF4D	RF4Q
Material	R-F (210)	R-F (210)	R-F (210)	R-F (210)	R-F (210)	R-F (210)	R-F (210)	R-F (210)
[Na], Mol.	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
F Factor	0.8109	0.8109	0.8109	0.8109	0.8109	0.8109	0.8109	0.8109
Na/Cs Start	1.05E+02	1.05E+02	1.05E+03	1.05E+03	1.14E+04	1.14E+04	7.84E+04	7.84E+04
Na/Cs Final	1.13E+02	1.10E+02	1.27E+03	1.27E+03	1.99E+04	2.00E+04	1.96E+05	1.99E+05
Cs Kd Value	1.35E+01	7.56E+00	3.82E+01	3.69E+01	1.32E+02	1.33E+02	2.60E+02	2.68E+02
Density	0.3044	0.3044	0.3044	0.3044	0.3044	0.3044	0.3044	0.3044
Cs Lambda	4.11E+00	2.30E+00	1.16E+01	1.12E+01	4.02E+01	4.04E+01	7.90E+01	8.15E+01
ID Number	SL1D	SL1Q	SL2D	SL2Q	SL3D	SL3Q	SL4D	SL4Q
Material	SL-644	SL-644	SL-644	SL-644	SL-644	SL-644	SL-644	SL-644
[Na], Mol.	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
F Factor	0.9436	0.9436	0.9436	0.9436	0.9436	0.9436	0.9436	0.9436
Na/Cs Start	1.05E+02	1.05E+02	1.05E+03	1.05E+03	1.14E+04	1.14E+04	7.84E+04	7.84E+04
Na/Cs Final	1.17E+02	1.13E+02	1.49E+03	1.49E+03	3.76E+04	3.78E+04	4.92E+05	4.96E+05
Cs Kd Value	1.73E+01	1.19E+01	6.56E+01	6.56E+01	3.58E+02	3.60E+02	8.05E+02	8.11E+02
Density	0.2238	0.2238	0.2238	0.2238	0.2238	0.2238	0.2238	0.2238
Cs Lambda	3.88E+00	2.66E+00	1.47E+01	1.47E+01	8.01E+01	8.05E+01	1.80E+02	1.82E+02
ID Number	CP1D	CP1Q	CP2D	CP2Q	CP3D	CP3Q	CP4D	CP4Q
Material	IE-910	IE-910	IE-910	IE-910	IE-910	IE-910	IE-910	IE-910
[Na], Mol.	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
F Factor	0.9841	0.9841	0.9841	0.9841	0.9841	0.9841	0.9841	0.9841
Na/Cs Start	1.05E+02	1.05E+02	1.05E+03	1.05E+03	1.14E+04	1.14E+04	7.84E+04	7.84E+04
Na/Cs Final	1.18E+02	1.15E+02	2.98E+03	2.93E+03	9.05E+04	8.76E+04	4.91E+05	7.36E+05
Cs Kd Value	1.89E+01	1.45E+01	2.76E+02	2.69E+02	9.96E+02	9.59E+02	7.72E+02	1.23E+03
Density	0.7738	0.7738	0.7738	0.7738	0.7738	0.7738	0.7738	0.7738
Cs Lambda	1.47E+01	1.12E+01	2.14E+02	2.08E+02	7.71E+02	7.42E+02	5.98E+02	9.54E+02
ID Number	CE1D	CE1Q	CE2D	CE2Q	CE3D	CE3Q	CE4D	CE4Q
Material	11, (0739-38B)		IE-911, (0739-38B)		IE-911, (0739-38B)		IE-911, (0739-38B)	
[Na], Mol.	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
F Factor	0.8695	0.8695	0.8695	0.8695	0.8695	0.8695	0.8695	0.8695
Na/Cs Start	1.05E+02	1.05E+02	1.05E+03	1.05E+03	1.14E+04	1.14E+04	7.84E+04	7.84E+04
Na/Cs Final	1.13E+02	1.11E+02	1.99E+03	1.88E+03	5.44E+04	5.51E+04	4.41E+05	4.49E+05
Cs Kd Value	1.26E+01	9.82E+00	1.46E+02	1.29E+02	6.46E+02	6.56E+02	7.82E+02	7.97E+02
Density	1.1256	1.1256	1.1256	1.1256	1.1256	1.1256	1.1256	1.1256
Cs Lambda	1.41E+01	1.11E+01	1.64E+02	1.46E+02	7.27E+02	7.38E+02	8.80E+02	8.97E+02

ID Number	TI4D	TI4Q
Material	AS NaTi	AS NaTi
[Na], Mol.	4.96	4.96
F Factor	1.0051	1.0051
Na/Cs Start	7.84E+04	7.84E+04
Na/Cs Final	7.77E+04	7.77E+04
Cs Kd Value	-1.49E+00	-1.49E+00
Density	0.5812	0.5812
Cs Lambda	-8.63E-01	-8.63E-01

ID Number	ZE1D	ZE1Q	ZE2D	ZE2Q	ZE3D	ZE3Q	ZE4D	ZE4Q
Material	TIE-96	TIE-96	TIE-96	TIE-96	TIE-96	TIE-96	TIE-96	TIE-96
[Na], Mol.	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
F Factor	0.8952	0.8952	0.8952	0.8952	0.8952	0.8952	0.8952	0.8952
Na/Cs Start	1.05E+02	1.05E+02	1.05E+03	1.05E+03	1.14E+04	1.14E+04	7.84E+04	7.84E+04
Na/Cs Final	1.14E+02	1.12E+02	1.19E+03	1.19E+03	1.29E+04	1.29E+04	8.83E+04	8.87E+04
Cs Kd Value	1.36E+01	1.08E+01	2.08E+01	2.08E+01	2.07E+01	2.15E+01	2.09E+01	2.17E+01
Density	0.7672	0.7672	0.7672	0.7672	0.7672	0.7672	0.7672	0.7672
Cs Lambda	1.05E+01	8.32E+00	1.60E+01	1.60E+01	1.59E+01	1.65E+01	1.60E+01	1.67E+01

Phase II Experiment: Multiple Cycle High DF, Cs lambdas

ID Number	CS4G	CS4R	RF4G	RF4R	SL4G	SL4R	CP4G	CP4R
Material	CS-100	CS-100	R-F (210)	R-F (210)	SL-644	SL-644	IE-910	IE-910
[Na], Mol.	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
F Factor	0.6671	0.6671	0.8109	0.8109	0.9436	0.9436	0.9841	0.9841
Na/Cs Start	1.07E+05	1.07E+05	1.91E+05	1.91E+05	4.78E+05	4.78E+05	5.69E+05	5.69E+05
Na/Cs Final	1.52E+05	1.50E+05	3.14E+06	3.26E+06	3.27E+07	3.27E+07	2.14E+07	2.17E+07
Cs Kd Value	1.00E+01	9.67E+00	3.06E+02	3.18E+02	1.15E+03	1.15E+03	6.12E+02	6.19E+02
Density	0.2434	0.2434	0.3044	0.3044	0.2238	0.2238	0.7738	0.7738
Cs Lambda	2.44E+00	2.35E+00	9.31E+01	9.69E+01	2.58E+02	2.58E+02	4.73E+02	4.79E+02

ID Number	CE4G	CE4R	ZE4G	ZE4R
Material	11, (0739-38B)		TIE-96	TIE-96
[Na], Mol.	4.96	4.96	4.96	4.96
F Factor	0.8695	0.8695	0.8952	0.8952
Na/Cs Start	4.30E+05	4.30E+05	8.56E+04	8.56E+04
Na/Cs Final	1.43E+07	1.43E+07	1.96E+05	1.96E+05
Cs Kd Value	6.15E+02	6.15E+02	2.38E+01	2.37E+01
Density	1.1256	1.1256	0.7672	0.7672
Cs Lambda	6.92E+02	6.92E+02	1.82E+01	1.82E+01

Phase III: High Phase Ratio Experiment, Cs lambdas

ID Number	RF0P	RF0U	SL0P	SL0U	CP0P	CP0U	CE0P	CE0U
Material	R-F (210)	R-F (210)	SL-644	SL-644	IE-910	IE-910	11, (0739-38B)	
[Na], Mol.	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
F Factor	0.8109	0.8109	0.9436	0.9436	0.9841	0.9841	0.8695	0.8695
Na/Cs Start	7.59E+04	7.59E+04	7.59E+04	7.59E+04	7.59E+04	7.59E+04	7.59E+04	7.59E+04
Na/Cs Final	1.08E+05	1.08E+05	1.54E+05	1.54E+05	1.65E+05	1.67E+05	1.30E+05	1.30E+05
Cs Kd Value	2.52E+02	2.53E+02	5.32E+02	5.33E+02	1.12E+03	1.14E+03	7.31E+02	7.28E+02
Density	3.04E-01	3.04E-01	2.24E-01	2.24E-01	7.74E-01	7.74E-01	1.13E+00	1.13E+00
Cs Lambda	7.67E+01	7.69E+01	1.19E+02	1.19E+02	8.66E+02	8.82E+02	8.23E+02	8.19E+02

	Phase I Experiment: Phase Ratio = 150 mL/g, Sr lambdas							
ID Number	CS1D	CS1Q	CS2D	CS2Q	CS3D	CS3Q	CS4D	CS4Q
Material	CS-100	CS-100	CS-100	CS-100	CS-100	CS-100	CS-100	CS-100
[Na], Mol.	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
F Factor	0.6671	0.6671	0.6671	0.6671	0.6671	0.6671	0.6671	0.6671
Na/Cs Start	1.05E+02	1.05E+02	1.05E+03	1.05E+03	1.14E+04	1.14E+04	7.84E+04	7.84E+04
Na/Cs Final	1.12E+02	1.11E+02	1.10E+03	1.10E+03	1.18E+04	1.19E+04	8.43E+04	7.80E+04
Sr Kd Value	1.40E+01	1.32E+01	1.02E+01	9.51E+00	7.69E+00	1.07E+01	1.63E+01	-1.29E+00
Density	0.2434	0.2434	0.2434	0.2434	0.2434	0.2434	0.2434	0.2434
Sr Lambda	3.40E+00	3.22E+00	2.48E+00	2.32E+00	1.87E+00	2.60E+00	3.97E+00	-3.15E-01
ID Number	RF1D	RF1Q	RF2D	RF2Q	RF3D	RF3Q	RF4D	RF4Q
Material	R-F (210)	R-F (210)	R-F (210)	R-F (210)	R-F (210)	R-F (210)	R-F (210)	R-F (210)
[Na], Mol.	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
F Factor	0.8109	0.8109	0.8109	0.8109	0.8109	0.8109	0.8109	0.8109
Na/Cs Start	1.05E+02	1.05E+02	1.05E+03	1.05E+03	1.14E+04	1.14E+04	7.84E+04	7.84E+04
Na/Cs Final	1.40E+02	1.38E+02	1.42E+03	1.42E+03	1.56E+04	1.55E+04	1.04E+05	1.03E+05
Sr Kd Value	5.87E+01	5.54E+01	6.28E+01	6.40E+01	6.51E+01	6.34E+01	5.69E+01	5.40E+01
Density	0.3044	0.3044	0.3044	0.3044	0.3044	0.3044	0.3044	0.3044
Sr Lambda	1.79E+01	1.69E+01	1.91E+01	1.95E+01	1.98E+01	1.93E+01	1.73E+01	1.64E+01
ID Number	SL1D	SL1Q	SL2D	SL2Q	SL3D	SL3Q	SL4D	SL4Q
Material	SL-644	SL-644	SL-644	SL-644	SL-644	SL-644	SL-644	SL-644
[Na], Mol.	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
F Factor	0.9436	0.9436	0.9436	0.9436	0.9436	0.9436	0.9436	0.9436
Na/Cs Start	1.05E+02	1.05E+02	1.05E+03	1.05E+03	1.14E+04	1.14E+04	7.84E+04	7.84E+04
Na/Cs Final	1.67E+02	1.65E+02	1.59E+03	1.62E+03	1.80E+04	1.80E+04	1.25E+05	1.24E+05
Sr Kd Value	9.25E+01	8.82E+01	8.03E+01	8.51E+01	9.03E+01	9.02E+01	9.09E+01	8.83E+01
Density	0.2238	0.2238	0.2238	0.2238	0.2238	0.2238	0.2238	0.2238
Sr Lambda	2.07E+01	1.97E+01	1.80E+01	1.90E+01	2.02E+01	2.02E+01	2.03E+01	1.98E+01
ID Number	CP1D	CP1Q	CP2D	CP2Q	CP3D	CP3Q	CP4D	CP4Q
Material	IE-910	IE-910	IE-910	IE-910	IE-910	IE-910	IE-910	IE-910
[Na], Mol.	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
F Factor	0.9841	0.9841	0.9841	0.9841	0.9841	0.9841	0.9841	0.9841
Na/Cs Start	1.05E+02	1.05E+02	1.05E+03	1.05E+03	1.14E+04	1.14E+04	7.84E+04	7.84E+04
Na/Cs Final	4.70E+02	4.45E+02	4.68E+03	4.82E+03	6.86E+04	6.77E+04	1.28E+05	4.89E+05
Sr Kd Value	5.19E+02	4.83E+02	5.19E+02	5.38E+02	7.20E+02	7.08E+02	9.24E+01	7.69E+02
Density	0.7738	0.7738	0.7738	0.7738	0.7738	0.7738	0.7738	0.7738
Sr Lambda	4.02E+02	3.73E+02	4.01E+02	4.16E+02	5.57E+02	5.48E+02	7.15E+01	5.95E+02
ID Number	CE1D	CE1Q	CE2D	CE2Q	CE3D	CE3Q	CE4D	CE4Q
Material	11, (0739-38B)		IE-911, (0739-38B)		IE-911, (0739-38B)		IE-911, (0739-38B)	
[Na], Mol.	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
F Factor	0.8695	0.8695	0.8695	0.8695	0.8695	0.8695	0.8695	0.8695
Na/Cs Start	1.05E+02	1.05E+02	1.05E+03	1.05E+03	1.14E+04	1.14E+04	7.84E+04	7.84E+04
Na/Cs Final	7.19E+02	7.07E+02	7.33E+03	7.02E+03	7.11E+04	7.37E+04	5.40E+05	5.37E+05
Sr Kd Value	9.74E+02	9.56E+02	9.76E+02	9.28E+02	8.96E+02	9.35E+02	9.93E+02	9.87E+02
Density	1.1256	1.1256	1.1256	1.1256	1.1256	1.1256	1.1256	1.1256
Sr Lambda	1.10E+03	1.08E+03	1.10E+03	1.04E+03	1.01E+03	1.05E+03	1.12E+03	1.11E+03

ID Number	TI4D	TI4Q						
Material	AS NaTi	AS NaTi						
[Na], Mol.	4.96	4.96						
F Factor	1.0051	1.0051						
Na/Cs Start	7.84E+04	7.84E+04						
Na/Cs Final	1.19E+06	1.20E+06						
Sr Kd Value	2.11E+03	2.13E+03						
Density	0.5812	0.5812						
Sr Lambda	1.23E+03	1.24E+03						
ID Number	ZE1D	ZE1Q	ZE2D	ZE2Q	ZE3D	ZE3Q	ZE4D	ZE4Q
Material	TIE-96	TIE-96	TIE-96	TIE-96	TIE-96	TIE-96	TIE-96	TIE-96
[Na], Mol.	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
F Factor	0.8952	0.8952	0.8952	0.8952	0.8952	0.8952	0.8952	0.8952
Na/Cs Start	1.05E+02	1.05E+02	1.05E+03	1.05E+03	1.14E+04	1.14E+04	7.84E+04	7.84E+04
Na/Cs Final	2.77E+02	2.56E+02	2.74E+03	2.95E+03	2.95E+04	2.97E+04	2.03E+05	1.94E+05
Sr Kd Value	2.75E+02	2.42E+02	2.57E+02	2.88E+02	2.50E+02	2.53E+02	2.64E+02	2.46E+02
Density	0.7672	0.7672	0.7672	0.7672	0.7672	0.7672	0.7672	0.7672
Sr Lambda	2.11E+02	1.86E+02	1.97E+02	2.21E+02	1.92E+02	1.94E+02	2.03E+02	1.88E+02
	Phase II Experiment: Multiple Cycle High DF, Sr lambdas							
ID Number	CS4G	CS4R	RF4G	RF4R	SL4G	SL4R	CP4G	CP4R
Material	CS-100	CS-100	R-F (210)	R-F (210)	SL-644	SL-644	IE-910	IE-910
[Na], Mol.	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
F Factor	0.6671	0.6671	0.8109	0.8109	0.9436	0.9436	0.9841	0.9841
Na/Cs Start	1.07E+05	1.07E+05	1.91E+05	1.91E+05	4.78E+05	4.78E+05	5.69E+05	5.69E+05
Na/Cs Final	1.52E+05	1.50E+05	3.14E+06	3.26E+06	3.27E+07	3.27E+07	2.14E+07	2.17E+07
Sr Kd Value	1.98E+00	1.84E+00	1.74E+01	1.89E+01	7.15E+01	7.15E+01	2.34E+02	2.32E+02
Density	0.2434	0.2434	0.3044	0.3044	0.2238	0.2238	0.7738	0.7738
Sr Lambda	4.82E-01	4.48E-01	5.30E+00	5.75E+00	1.60E+01	1.60E+01	1.81E+02	1.80E+02
ID Number	CE4G	CE4R	ZE4G	ZE4R				
Material	11, (0739-38B)		TIE-96	TIE-96				
[Na], Mol.	4.96	4.96	4.96	4.96				
F Factor	0.8695	0.8695	0.8952	0.8952				
Na/Cs Start	4.30E+05	4.30E+05	8.56E+04	8.56E+04				
Na/Cs Final	1.43E+07	1.43E+07	1.96E+05	1.96E+05				
Sr Kd Value	6.68E+02	6.41E+02	2.57E+02	2.38E+02				
Density	1.1256	1.1256	0.7672	0.7672				
Sr Lambda	7.52E+02	7.21E+02	1.97E+02	1.83E+02				
	Phase III: High Phase Ratio Experiment, Sr lambdas							
ID Number	RF0P	RF0U	SL0P	SL0U	CP0P	CP0U	CE0P	CE0U
Material	R-F (210)	R-F (210)	SL-644	SL-644	IE-910	IE-910	IE-911, (0739-38B)	
[Na], Mol.	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
F Factor	0.8109	0.8109	0.9436	0.9436	0.9841	0.9841	0.8695	0.8695
Na/Cs Start	7.84E+04	7.84E+04	7.84E+04	7.84E+04	7.84E+04	7.84E+04	7.84E+04	7.84E+04
Na/Cs Final	1.08E+05	1.08E+05	1.54E+05	1.54E+05	1.65E+05	1.67E+05	1.30E+05	1.30E+05
Sr Kd Value	1.23E+02	1.07E+02	8.47E+01	7.51E+01	9.20E+02	8.75E+02	8.09E+02	7.85E+02
Density	0.3044	0.3044	0.2238	0.2238	0.7738	0.7738	1.1256	1.1256
Sr Lambda	3.76E+01	3.25E+01	1.90E+01	1.68E+01	7.12E+02	6.77E+02	9.10E+02	8.84E+02

Appendix D

Cr, Zr, and Sr ICP λ Values for the Actual Waste Experiments

Phase I Experiment: ICP metals Kd's and Lambda's (Phase Ratio = 150 mL/g)

ID Number	CS4D	CS4Q-1	CS4Q-2	RF4D	RF4Q-1	RF4Q-2	SL4D	SL4Q-1	SL4Q-2
Material	CS-100	CS-100	CS-100	R-F (210)	R-F (210)	R-F (210)	SL-644	SL-644	SL-644
Tracer	Cr ICP	Cr ICP	Cr ICP	Cr ICP	Cr ICP	Cr ICP	Cr ICP	Cr ICP	Cr ICP
[Na], Mol.	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00
F Factor	6.671E-01	6.671E-01	6.671E-01	8.109E-01	8.109E-01	8.109E-01	9.436E-01	9.436E-01	9.436E-01
Na/Cr Start	2.368E+03	2.368E+03	2.368E+03	2.368E+03	2.368E+03	2.368E+03	2.368E+03	2.368E+03	2.368E+03
Na/Cr Final	2.622E+03	2.374E+03	2.428E+03	3.994E+03	3.955E+03	3.926E+03	4.584E+03	4.465E+03	4.439E+03
Kd Value	2.332E+01	5.755E-01	5.520E+00	1.194E+02	1.165E+02	1.144E+02	1.428E+02	1.352E+02	1.334E+02
Density	2.434E-01	2.434E-01	2.434E-01	3.044E-01	3.044E-01	3.044E-01	2.238E-01	2.238E-01	2.238E-01
Lambda Valu	5.675E+00	1.401E-01	1.344E+00	3.634E+01	3.546E+01	3.482E+01	3.196E+01	3.025E+01	2.987E+01

ID Number	CS4D	CS4Q	RF4Q	SL4Q	CP4Q	CE4Q	TI4Q	ZE4Q	BL4-Avg
Material	CS-100	CS-100	R-F (210)	SL-644	IE-910	IE-911 (38b)	NaTi	TIE-96	Blank
Tracer	Sr ICP	Sr ICP	Sr ICP	Sr ICP	Sr ICP	Sr ICP	Sr ICP	Sr ICP	Sr ICP
[Na], Mol.	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00
F Factor	6.671E-01	6.671E-01	8.109E-01	9.436E-01	9.841E-01	8.695E-01	1.005E+00	8.952E-01	
Na/Sr Start	3.810E+05	3.810E+05	3.810E+05	3.810E+05	3.810E+05	3.810E+05	3.810E+05	3.810E+05	3.810E+05
Na/Sr Final	4.295E+05	3.744E+05	4.978E+05	5.690E+05	8.762E+05	8.762E+05	8.762E+05	7.302E+05	3.810E+05
Kd Value	2.770E+01	-3.715E+00	5.332E+01	7.529E+01	1.911E+02	2.196E+02	1.940E+02	1.523E+02	#DIV/0!
Density	2.434E-01	2.434E-01	3.044E-01	2.238E-01	7.738E-01	1.126E+00	5.812E-01	7.672E-01	2.190E+01
Lambda Valu	6.741E+00	-9.041E-01	1.623E+01	1.685E+01	1.478E+02	2.471E+02	1.128E+02	1.168E+02	#DIV/0!

ID Number	CS4D	CS4Q	RF4Q	RF4Q	SL4Q	SL4Q	CP4Q	CP4Q	CE4Q	CE4Q	CE4Q	TI4Q	ZE4Q	BL4-Avg
Material	CS-100	CS-100	R-F (210)	R-F (210)	SL-644	SL-644	IE-910	IE-910	IE-911 (38b)	IE-911 (38b)	IE-911 (38b)	NaTi	TIE-96	Blank
Tracer	Zr ICP	Zr ICP	Zr ICP	Zr ICP	Zr ICP	Zr ICP	Zr ICP	Zr ICP	Zr ICP	Zr ICP	Zr ICP	Zr ICP	Zr ICP	Zr ICP
[Na], Mol.	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00	5.000E+00
F Factor	6.671E-01	6.671E-01	8.109E-01	8.109E-01	9.436E-01	9.436E-01	9.841E-01	9.841E-01	8.695E-01	8.695E-01	8.695E-01	1.005E+00	8.952E-01	
Na/Zr Start	8.996E+04	8.996E+04	8.996E+04	8.996E+04	8.996E+04	8.996E+04	8.996E+04	8.996E+04	8.996E+04	8.996E+04	8.996E+04	8.996E+04	8.996E+04	8.996E+04
Na/Zr Final	1.353E+05	1.158E+05	1.486E+05	1.334E+05	1.949E+05	1.641E+05	1.115E+05	1.039E+05	4.390E+04	4.736E+04	4.386E+04	4.561E+05	4.561E+05	8.996E+04
Kd Value	1.096E+02	6.232E+01	1.132E+02	8.385E+01	1.780E+02	1.257E+02	3.522E+01	2.277E+01	-8.648E+01	-7.997E+01	-8.656E+01	6.075E+02	6.762E+02	#DIV/0!
Density	2.434E-01	2.434E-01	3.044E-01	3.044E-01	2.238E-01	2.238E-01	7.738E-01	7.738E-01	1.126E+00	1.126E+00	1.126E+00	5.812E-01	7.672E-01	
Lambda Valu	2.668E+01	1.517E+01	3.446E+01	2.552E+01	3.984E+01	2.813E+01	2.725E+01	1.762E+01	-9.734E+01	-9.002E+01	-9.743E+01	3.531E+02	5.188E+02	#DIV/0!