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Mixing of Process Heels, Process Solutions, and Recycle Streams: Small-Scale Active Tests

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Summary

Within the planned facility for treating High and Low Activity Waste at Hanford, several process tanks will receive internal recycle wastes or waste originating from more than one underground storage tank. Adverse effects of mixing different tank wastes, such as solids formation and the conversion of extractable pertechnetate to non-pertechnetate form, were investigated using samples from Envelope C (AN-102), Envelope A (AN-103), and Envelope B (AZ-102). This was done by observation of solution mixture behavior over a period of 14 days, and measuring the batch distribution coefficient values for technetium at two intervals (4 hours and 14 days). One objective of the tests was to report on formation of solids and other evidence of adverse reactions (i.e., foaming, gassing, and color change) upon mixing Envelope C with A or B, as well as when mixing Envelope C with Sr/TRU precipitate wash solution. Another objective was to examine the postulated effect concerning conversion of pertechnetate to the non-pertechnetate species upon mixing Envelope C with Envelopes A or B.

The test results indicated that mixing Envelope C with A or B waste solutions did not result in adverse reactions and no visible solids were formed in the solutions. Similarly, no solids formation/precipitation occurred by mixing Envelope C with Sr/TRU wash solution. Technetium Kd values of the solution mixture (Envelope C with A) after 4 hours and after aging for 14 days, decreased by 30 and 38%, respectively. Once corrected for the amount of non-pertechnetate in Envelope C, the K_d values of the pertechnetate-only species decreased by only 5.5 and 17.8%, after 4 hours and after 14 days, respectively. For the solution mixtures of C with B, the total technetium K_d values decreased by 50% and 33% after 4 hours and after 14 days. The increase in Kd for this sample after 14 days suggests that Envelope B oxidizes the non-pertechnetate in Envelope C to pertechnetate. While these decreases in Kd may seem large, the projected impact on the facility is expected to be minimal.

Additional test results indicated no appreciable reduction of the Tc K_d values for effluent solutions of Envelope C (large) when measured 1 day and 14 days after Cs ion exchange column loading. A negligible reduction (13%) was observed in the technetium distribution coefficient values for the 14 day-old Envelope B effluent solution. A summary of the results is shown in Table 1 and Figures 1 and 2.

1.0 Introduction

The pretreatment process for BNFL, Inc.'s Hanford River Protection Project is to provide decontaminated low activity waste and concentrated eluate streams for vitrification into low and high activity waste glass, respectively. The pretreatment includes sludge washing, filtration, precipitation, and ion exchange processes to remove entrained solids, cesium, transuranics, technetium, and strontium. Within the planned facility, several process tanks will receive internal recycle wastes or waste originating from more than one underground storage tank. Mixing of various solutions with the feed solution in process tank heels may promote unfavorable conditions for the pretreatment and vitrification processes. Several potential problems resulting from mixing have already been identified.[1] The primary concern is the formation of solids as a result of mixing the tank heel of one envelope with another. A second concern is dilution of process streams, which could lower the solution pH, resulting in solids precipitation. Solids are undesirable in the RPP pretreatment and vitrification processes because they can clog filters, reduce the efficiency of ion exchange resins, and increase the amount of non-radioactive material ultimately transferred to the high activity vitrification process. Envelope C contains molar concentrations of total organic carbon (TOC) and may have the capacity to induce reductive precipitation as well as induce precipitation of salts not normally expected to precipitate from Envelope A or B.

Another concern is the speciation of various radionuclides, which could be adversely affected by stream mixing. For example, technetium is largely in the form of pertechnetate in Envelope A tanks, but largely non-pertechnetate in Envelope C tanks. Mixing these two envelopes may convert pertechnetate in "A" into a non-extractable (non-pertechnetate) species, thereby increasing technetium content in LAW glass.[2]

The addition of organic compounds into the effluent solutions from deteriorating Cs ion exchange resin (SuperLig 644) may increase the proportion of non-pertechnetate species. Such a postulated effect was not observed in previous tests performed on Hanford wastes samples at Savannah River Technology Center, [(3-5)] although those tests were not geared specifically to examine this phenomenon.

The objectives of this study were as follows:

1. Determine through qualitative observations if adverse chemical reactions (i.e. color change, foaming, gassing) or precipitation occurs from mixing of Envelope C with A or B, as well as A with B.
2. Determine the technetium batch distribution coefficient values for solution mixtures of Envelope C with A or B and Envelope A with B, after storage for 4 hours and 14 days.
3. Determine the technetium batch distribution coefficient values of effluent solutions of Envelope B and C after 24 hours and 14 days following the Cs ion exchange column loading.
4. Determine through qualitative observations if chemical reactions (e.g., color change, foaming, gassing) or precipitation occurs from mixing of Sr/TRU precipitate wash solution with Envelope C.

The radioactive waste solutions used in these tests were from Hanford tanks (241-) AN-103 (A), AN-102 (C), and AZ-102 (B).

2.0 Experimental

2.1 Materials

Radioactive solution mixtures of Envelope C with A or B were used for determination of technetium batch distribution coefficient values. Envelope C sample was retrieved from Hanford tank AN-102 and subjected to dilution, Sr/TRU precipitation and cross-flow filtration processes. The sample was diluted during Sr/TRU precipitation filtration processes to ~ 6 M [Na^+]. Envelopes A and B were retrieved from Hanford tanks AN-103 and AZ-102, respectively. Both samples were filtered to remove entrained solids. Envelope A had been diluted to 5.25M Na^+ prior to filtration. Table 2 shows the chemical and radionuclide compositions of Envelopes A, B, and C samples.

The ion exchange material used for determination of technetium distribution coefficient values was SuperLig^{Ò} 639 (batch # 981015DHC720011). The resin is composed of polystyrene beads with an attached proprietary organic compound. IBC Advanced Technologies, American Fort, Utah, supplied the resin for testing. The resin particle size and the F-factor was previously reported.[7]

2.2 Equipment

The equipment used for batch contact tests consists of 15-mL polyethylene bottles, a Mix-Max^{Ò} orbital shaker, nylon filter units (0.45 mm), plastic filter holders, and an analytical balance accurate to ± 0.001 g. All experiments were performed in the shielded Intermediate Level Cell, allowing remote handling of materials.

2.3 Procedure

2.3.1 Tc Batch Distribution Coefficients

Radioactive solution mixtures of Envelope C with A or B were prepared by adding small aliquots of 3.0 ± 0.1 mL C into 30 ± 1 mL of A or B in sealed polyethylene bottles. Similarly small aliquots of 3.0 ± 0.1 mL B was added to 30 ± 1 mL of A in 60-mL polyethylene

bottles. Upon addition, the solutions were mixed by gently shaking the bottles in 15- minute intervals for 4 hours and observed for physical changes. Four hours after initial mixing of each solution, a 24-hour batch contact experiment was initiated to measure Tc batch distribution coefficient values. Twenty-four hours after initial solution mixing, the solution mixtures were again visually examined for physical changes (foaming, gas bubbling, color change, and visible solids formation). Two weeks after initial mixing of the solutions, a second 24-hour batch distribution coefficient measurement was conducted on each solution. In the batch K_d tests, a known volume of solution mixture (~5 ± 0.1 mL) was added into polyethylene bottle with a known quantity of SuperLigÒ 639 ion exchange resin (~0.05 ± 0.005 g) to maintain a solution-to-resin ratio of ~100:1 for most tests. The bottles containing the solution and the resin were placed on the orbital shaker and gently shaken for 24 ± 1 hours at cell ambient temperature (26 ± 1°C). The tests were conducted in duplicate. Control samples (~5 ± 0.1 mL of solution mixtures) in which no ion exchange resin was added, were treated in the same process steps as the actual test samples. The concentration of Tc in the control samples were used as the starting initial concentrations to determine the K_d values and percent removed by the resin. The ambient cell temperature was recorded at the beginning and end of each test. After the contact period, the resin was separated from the sample solution by filtration through individual 0.45-micron nylon filter units. A 1-mL sub-sample of the filtrate was removed from the cell and analyzed by the Analytical Development Section of the Savannah River Technology Center. Sub-samples were often diluted (10:1) with de-ionized water to reduce the radiation dose rate before the samples are transferred from the shielded cell to analytical laboratories. All dilutions and measurements were performed based on mass and corrected for density of the solution to ensure accuracy. The concentration of technetium (Tc-99) in filtered solutions before and after contact with the resin was analyzed by inductively coupled plasma-mass spectroscopy (ICP-MS) at mass 99; the quantity of Tc-99 on the exchange resin was determined by difference. No correction for any ruthenium isotope was needed, based on the distribution of masses 100-104. Results were corrected for dilution, where appropriate.

In a similar manner, Tc batch distribution coefficient values were measured for solution effluents of Envelope C (large) and B after Cs ion exchange column loading. The measurements were performed 24 hours and 14 days after the Cs ion exchange column loading was completed for each sample. In these tests, 5 ± 0.1 mL of effluents solution added to ~0.05 ± 0.005 g of resin in 30-mL polyethylene bottles. The solutions were periodically examined for solid precipitate formation. The distribution coefficient values and percent removed were determined according to the equations:

$$K_d = \frac{(C_i / C_f - 1) * V}{(M * F)} \qquad (1)$$

and

$$\% R = \frac{100 * (C_i - C_f)}{C_i} \qquad (2)$$

where C_i is the initial concentration of salt solution, C_f is the final (equilibrium) concentration, V is the volume of liquid sample, M is the "as received" mass of the resin, and F is the mass of dried resin divided by the mass of ²as received² resin (i.e., the dry weight correction or F-factor). A matrix of experimental mixing tests performed on radioactive samples are shown in Table 3. The radioactive mixing tests were conducted under an approved task and quality assurance plan.[7] The quality control checks and the minimum reportable quantities (MRQ) met the requirement of the task quality assistance plan.

3.0 Results and Discussion

To examine conversion of pertechnetate to a non-pertechnetate species, absorption studies were performed with SuperLigÒ 639 resin, which only removes the pertechnetate ion. The distribution coefficient values (K_d values) of total technetium were measured and the corresponding pertechnetate fraction was calculated. This was done with solution mixtures of Envelope C (AN-102) with A (AN-103) or B (AZ-102), as well as the effluent solutions after Cs ion exchange column loading. The K_d results for the 4 hours and 14 days old solutions mixtures are presented in Figures 1 and 2, respectively. The Tc K_d values measured for Envelope A (AN-103) mixed with Envelope B are shown in Table 4. Attempts to measure the pertechnetate (TcO_4^-) species by liquid scintillation were unsuccessful due to high Cs content in the solution mixtures. The values of the TcO_4^- species shown in Tables 1 and 4 were calculated from total technetium in solution mixtures, weight percent of each envelope in the solution mixture, and the weight percent pertechnetate in each envelope. To perform these calculations, it was assumed that the pertechnetate fraction does not change upon mixing. The amount of pertechnetate in Envelope A was determined using multiple batch contacts, as previously reported.[8] The percent pertechnetate in each envelope is shown in Table 1A. The Envelope A sample was assumed to contain 100% pertechnetate, although the multiple batch contacts only confirmed that at least 97.6% was pertechnetate.

The Tc K_d values of the solution mixtures of Envelope A with Envelope B were 542 and 530 mL/g for the 4 hours and 14 days old solution mixtures, respectively. This compares to the standard K_d value of 471 mL/g for Envelope A. The increase in Kd is attributable to

an increase in the Tc:nitrate ratio for the mixture (Table 1A). The slight drop (i.e., ~2.5%) in the K_d value for the 14 days old solution mixture as compared to that of the 4 hours is not significant. The addition of Envelope B into A resulted in no visible solids formation and no solid precipitants were observed during the 14 days of solution storage and monitoring. Therefore, no further analyses of the solution mixture, such as turbidity measurements, were performed.

Table 5 shows the technetium K_d values of Envelope C (AN-102) mixed with Envelope A (AN-103) after 4 hours and 14 days. The Tc K_d values were 330 and 292 mL/g and the calculated TcO_4^- only species were 513 and 446 mL/g for the 4 hours and 14 days old solution mixtures, respectively. The total Tc Kd values are lower than the standard K_d value 471 mL/g, but compare well once corrected for the fraction of pertechnetate (513 vs. 471 mL/g). A subsequent 13% drop of the TcO_4^- only K_d values was noted for the14-day-old solution mixture as compared to the 4 hours old solution. Closer inspection of the actual measurements (Table 5) shows that the measured final Tc concentrations actually overlap, indicating that the changes are not considered significant. The addition of Envelope C (AN-102) into A (AN-103) did not result in an adverse chemical reaction (i.e., foaming, gassing, color change etc.) or cause the formation of any visible solids. Consequently, no further analyses were performed on the solution mixtures.

The Tc K_d values of Envelope C (AN-102) mixed with Envelope B (AZ-102) after 4 hours and 14 days are presented in Table 6. The Tc K_d values of the solution mixture measured after 4 hours and 14 days were 444 and 588 mL/g, respectively; the corresponding calculated TcO_4^- only K_d values were 707 and 1135 mL/g. The total Tc Kd of the 4-hours-old mixture dropped 50% (883 vs. 444 mL/g) while the calculated TcO_4^- species only dropped 20% (883 vs. 707 mL/g). This is consistent with a substantial portion of non-pertechnetate technetium in Envelope C, but is still better than expected based on the pertechnetate to nitrate ratio (Table 1) which decreases from 5.81E-4 to 1.45E-4. Furthermore, the TcO_4^- species for the 14 days old solution mixture increased by 28.5%. This latter finding is inconsistent with previous observations, and suggests that Envelope B is oxidizing the non-pertechnetate to pertechnetate.

Table 7 shows the Tc K_d values of Envelope C (AN-102) and Envelope B (AZ-102) effluent solutions after Cs ion exchange column loading. The K_d values of Envelope C effluent solution was measured after 24 hours and 14 days following the Cs ion exchange column loading the values and the measured values were 40.8 and 39.7 mL/g, respectively. These values compare very well with the standard Tc K_d value (42 mL/g) for large C (AN-102). The K_d value of the TcO_4^- was 317 mL/g vs. 334 mL/g for the standard TcO_4^- for Envelope C (large). For Envelope B effluent solution, the Tc K_d value measured 14 days after Cs ion exchange column loading was 765 mL/g. vs. 883 mL/g for the standard Tc K_d of Envelope B. These results indicate no adverse effects of the Cs ion exchange resin loading on the Tc K_d values.

Sr/TRU precipitate wash solution mixed with Envelope C large (AN-102) did not result in visible solids precipitate formation or evidence of adverse reactions. Dark solids, however, were found in polyethylene bottles containing Envelope C (large) filtrate solution prior to initiating the mixing tests. The solids were filtered and the large C filtrate was used for the mixing tests. Apparently, the Sr/TRU removal process resulted in post-filtration precipitate formation. These solids were also apparently responsible for fouling the cesium ion exchange column. The solid precipitate was dissolved in 0.5 M HCl and analyzed by ICP-ES. The analytical samples were filtered due to the presence of a noticeable amount of solids. The results of the analyses of dissolved samples are shown in Table 8. The solids bubbled vigorously upon initial exposure to acid (presumably due to the presence of carbonate). Much, but not all, of the solid dissolved.

4.0 Conclusions

Small radioactive mixing tests were performed to evaluate the effects of mixing, in particular the formation of solids and occurrence of adverse reactions, Envelope C (AN-102) with Envelope A (AN-103) or Envelope B (AZ-102), and Sr/TRU precipitate wash solution. The tests also examined the postulated effect of deteriorating Cs ion exchange resin causing conversion of pertechnetate to non-pertechnetate species.

Envelope C solutions mixed with Envelope A, B, or Sr/TRU precipitate wash solution did not result in the formation of visible solids or the occurrence of adverse reactions, such as gassing, foaming, and color change. However, mixing Envelope C into Envelope A or B significantly reduced the K_d values of total technetium, but the reduction of pertechnetate K_d values was significantly lower than that of total technetium. The data suggests that Envelope B slowly converts non-pertechnetate present in "C" to pertechnetate. It was not possible to perform a liquid-liquid extraction of the pertechnetate, which would have aided in speciating the technetium, due to presence of high Cs concentrations. The lower Tc K_d values of the solution mixtures is probably attributable to the very high nitrate concentration in Envelope C, which would have increased the nitrate concentration in the mixture compared to the individual A or B samples. Nitrate ion competes with pertechnetate for sites on the resin. On the other hand, the K_d results of Envelope C and Envelope B effluent solutions after Cs ion exchange column loading showed no significant overall effect from deterioration of Cs ion exchange resin indicating no conversion of pertechnetate to non-pertechnetate species. Future mixing studies using chemical technetium speciation techniques should be able to provide more direct evidence of technetium behavior.

5.0 References

1. 1. Johnson, M. E, Mixing of Process Heels, Process Solutions, and Recycle Streams: Small-Scale Radioactive Mixing Test Specification, 001579, Rev. 0, January 29, 1999.
2. Oak Ridge National Laboratory, Jack Collins, unpublished data
3. Hassan, N. M. and McCabe, D. J., Hanford Envelope A Tank Waste Ion Exchange, SRTC-BNF-019, Rev. 0, October 24, 1997.
4. Hassan, N. M. and McCabe, D. J., Hanford Envelope C Tank Waste Ion Exchange, SRTC-BNF-018, Rev. 0, October 24, 1997.
5. Hassan, N. M. and McCabe, D. J., Hanford Envelope B Tank Waste Ion Exchange, SRTC-BNF-017, Rev. 1, December 5, 1997.
6. Nash, C. A., Rosencrance, S. W., and Wilmarth, B. R., Strontium-Transuranic Precipitation, and crossflow filtration of AN102 Small C, SRT-RPP-2000-00003, August 20000.
7. Hassan, N. M., Kaplan, I. D. , and McCabe, D. J., Task Technical and Quality Assurance Plan in Support of BNFL PartB, Task Tile: Mixing of Process Heels, Process Solutions, and Recycle Streams: Small-Scale Active Tests, March, 2000.
8. Hassan, N. M., McCabe, D. J., and King, W. D., Small-Scale Ion exchange Removal of Cesium and Technetium from Hanford Tank 241-AN-103, BNF-003-98-0146, Rev. 1, April 12, 2000.

Table 1. Summary of Results (Active Process Heel Mixing)

Standard batch K_d values (mL/g) at 26 ± 1 °C	Tc-99 Kd (mL/g)	% Removed	TcO_4 Kd (mL/g)	% Removed
Envelope A (AN-103)	471	82	na	na
Envelope B (AZ-102)	883	89	na	na
Envelope C (AN-102) –large C	42	29	334	77
Mixed Radioactive solution K_d values (mL/g) at 26 ± 1 °C	Tc-99 Kd Solution age: 4 hrs	Tc-99 Kd Solution age: 14 days	TcO_4 Kd Solution age: 4 hrs	TcO_4 Kd Solution age: 14 days
Envelope A with B (10:1 v/v)	542	530	na	na
Envelope A with C (10:1 v/v)	330	292	513	446
Envelope B with C (10:1 v/v)	444	588	707	1135
Envelope C (large), Cs IX effluent	41	40	317	317
Envelope B, Cs IX effluent solution	nm	765	nm	765

nm = not measured
na = not applicable, 100% pertechnetate

Table 1A. Initial Tc to nitrate ratios

	A	B	C
NO3 (M)	1.04	0.273	1.89
Tc (mg/L)	1.94	15.7	4.59
Tc (M)	1.96E-05	1.59E-04	4.64E-05
Tc/NO3	1.88E-05	5.81E-04	2.45E-05
% TcO4	100.0	100.0	22.5
Mix	A (10%B)	A (10%C)	B (10%C)
NO3 (M)	0.9633	1.125	0.4347
Tc (M)	3.22E-05	2.20E-05	1.48E-04
Tc/NO3	3.35E-05	1.96E-05	3.41E-04
TcO4 (M)	3.22E-05	1.88E-05	1.45E-04
TcO4/NO3	3.35E-05	1.67E-05	3.34E-04
%TcO4	100	85.17	97.80

Table 2. Characterization of Hanford Tank Waste Samples (Envelope A, B, and C)

Constituent	Envelope A (AN-103)	Envelope B (AZ-102)	Envelope C (AN-102)
Cations, M			
[Na^+]	5.25E+00	2.65E+00	5.98E+00
[Al]	7.0E-01	2.79E-02	2.72E-01
[Ca]	< 1.51E-04	2.70E-03	5.14E-03
[Cr]	1.44E-03	1.48E-02	1.69E-03
[Pb]	9.7E-03	< 3.98E-05	4.03E-04
[Zn]	< 6.81E-06	< 1.53E-05	< 5.05E-05
[K^+]	1.21E-01	8.10E-02	2.92E-02
U (mg/L)	nm	5.33E+00	5.59E+00
Anions, M			
[NO_3^-]	1.04E+00	2.73E-01	1.89E+00
[NO_2^-]	1.57E+00	8.32E-01	8.32E-01
[SO_4^{--}]	8.0E-03	1.72E-01	6.20E-02
[PO_4^{---}]	6.90E-03	< 3.0E-03	< 1.26E-02
[Cl^-]	8.5E-02	<1.00E-03	4.35E-02
[F^-]		5.09E-02	4.11E-02
OH^- (Free)	2.176E+00	1.09E-01	1.69E+00
Radionuclides, µCi/mL			
Cs-137	1.94E+02	1.14E+03	1.90E+02
Am-241	nm	<1.64E-02	1.50E-02
Sr-90	nm	2.07E+00	1.65E+00
alpha	nm	nm	1.78E-02
Tc (calc'd, mass 99), µCi/mL	3.30E-02	2.67E-01	7.80E-02
TIC (mg/L)	2.52E+03	6.14E+03	7.80E+03
TOC (mg/L)	3.76E+02	6.04E+03	2.25E+04
Density (g/mL)	1.27E+00	1.15E+00	1.23E+00

Table 3. Active Mixing Tests Performed

Feeds[a]	Mixing Ratios (ml/ml)	Mixture Age	**Treatment**
Envelope A diluted w/ B	30/3	<4 hr	4-hr old mixture in 24-hr contact with SuperLig 639
Envelope A diluted w/ B	30/3	14 day	14-day old mixture in 24-hr contact with SuperLig 639
Envelope A diluted w/ C	30/3	<4 hr	Put 4-hr old mixture in 24-hr contact with SuperLig 639
Envelope A diluted w/ C	30/3	14 day	14-day old mixture in 24-hr contact with SuperLig 639
Envelope B diluted w/ C	30/3	<4 hr	4-hr old mixture in 24-hr contact with SuperLig 639
Envelope B diluted w/ C	30/3	14 day	14-day old mixture in 24-hr contact with SuperLig 639
LC after Cs-IX processing	n/a	<1 day	<1-day after contact with Cs-IX, 24-hr contact with SuperLig 639.
LC after Cs-IX processing	n/a	14 day	14-days after contact with Cs-IX, 24-hr contact with SuperLig 639.
Envelope B after Cs-IX processing	n/a	14 day	14-days after contact with Cs-IX, a 24-hr contact with SuperLig 639.
Sr&TRU ppt. wash/LC filtrate	2/20	1-14 day	Mixture observation for 14 days.
Sr&TRU ppt. wash/LC filtrate	10/10	1-14 day	Mixture observation for 14 days.

Table 4. K_d values for Envelope A Mixed with Envelope B Heel

Envelope A mixed with B (solution age: 4 hr)	Sample wt. (g)	Density (g/mL)	Resin wt. (g)	Phase ratio	Tc-99 (ug/L)	Dilution Factor	Tc-99 (ug/L)			K_d values (mL/g) Tc-99	
BNF-B103-B/A-S639-4hr-1	6.112	1.255	0.0502	97.0	51.59	11.35	585			548	
BNF-B103-B/A-S639-4hr-1D	6.229	1.255	0.0504	98	53.27	11.36	605			535	
BNF-B103-B/A-CTR-1	6.161	1.255	na	na	341.18	11.29	3852		avg. >>	542	
Envelope A mixed with B (solution age: 14 days)	Sample wt. (g)	Density (g/mL)	Resin wt. (g)	Phase ratio	Tc-99 (ug/L)	Dilution Factor	Tc-99 (ug/L)			Kd Tc-99	Values TcO_4
BNF-B103-B/A-S639-2W-1	6.222	1.255	0.0503	98.5	59.45	12.14	721.7			487	
BNF-B103-B/A-S639-2W-1D	6.229	1.255	0.0515	96.4	51.89	11.94	619.3			572	
BNF-B103-B/A-CTR-2W-1	5.088	1.255	na	na	352.1	12.06	4246		avg. >>	530	

"CTR" refers to the control sample, i.e., no resin
"-1D" refers to duplicate sample

Table 5. K_d values for Envelope A Mixed with Envelope C Heel

Envelope A mixed with C (solution age: 4 hr)	Sample wt. (g)	Density (g/mL)	Resin wt. (g)	Phase ratio	Tc-99 (ug/L)	Dilution Factor	Tc-99 (ug/L) dil. corrected	TcO_4 (ug/L)	TcO_4 removed	K_d value Tc-99	(mL/g) TcO_4
BNF-B103-C/A-S639-4hr-1	6.229	1.264	0.051	96.7	61.11	10.96	669.7	428	2275	333	521
BNF-B103-C/A-S639-4hr-1D	6.276	1.264	0.0502	98.9	62.73	11.0	690.2	448	2254	327	504
BNF-B103-C/A-CTR-1	6.173	1.264	na	na	243.01	12.12	2944	na	avg. >>	330	513
Envelope A mixed with C (solution age: 14 days)	Sample wt. (g)	Density (g/mL)	Resin wt. (g)	Phase ratio	Tc-99 (ug/L)	Dilution Factor	Tc-99 (ug/L) dil. corrected	TcO_4 (ug/L)	TcO_4 removed	K_d value Tc-99	(mL/g) TcO4
BNF-B103-C/A-S639-2W-1	6.314	1.264	0.0519	96.3	60.1	13.31	800.4	563	2087	254	371
BNF-B103-C/A-S639-2W-1D	6.384	1.264	0.0514	98.3	55.7	12.03	670.7	433	2217	329	521
BNF-B103-C/A-CTR-2W-1	9.566	1.264	na	na	232.3	12.43	2888	na	avg.	292	446

Table 6. K_d Results for Envelope B Mixed with Envelope C Heel

Envelope B mixed with C (solution age: 4 hr)	Sample wt. (g)	Density (g/mL)	Resin wt. (g)	Phase ratio	Tc-99 (ug/L)	Dilution Factor	Tc-99 (ug/L) dil. corrected	TcO4 (ug/L)	TcO4 removed	K_d value Tc-99	(mL/g) TcO4
BNF-B103-C/B-S639-4hr-1	5.600	1.1584	0.0504	95.9	112.8	22.1	2497	1547	11482	446.9	721
BNF-B103-C/B-S639-4hr-1D	5.778	1.1584	0.0502	99.4	113.1	23.0	2602	1652	11377	440.2	693
BNF-B103-C/B-CTR-1	5.786	1.1584	na	na	634.1	22.0	13979	na	avg. >>	443.6	707
Envelope B mixed with C (solution age: 2 weeks)	Sample wt. (g)	Density (g/mL)	Resin wt. (g)	Phase ratio	Tc-99 (ug/L)	Dilution Factor	Tc-99 (ug/L) dil. corrected	TcO4 (ug/L)	TcO4 removed	K_d value Tc-99	(mL/g) TcO4
BNF-B102-C/B-S639-2W-1	5.688	1.1584	0.050	98.2	160.0	13.2	2119	1179	11715	550	1000
BNF-B102-C/B-S639-2W-1D	5.664	1.1584	0.0505	96.8	142.0	13.2	1874	934	11959	626	1270
BNF-B102-C/B-CTR-2W-1	5.707	1.1584	na	na	1050	13.2	13833	na	avg. >>	588	1135

Table 7. K_d Results for Envelope B and C (large) Effluent After Cs Ion Exchange Column Loading

Envelope large C effluent - 24 hrs after ion exchange column run	sample wt. (g)	density (g/mL)	resin wt. (g)	Phase ratio	Tc-99 (ug/L)	Tc-99 (removed)	K_d value (mL/g)
BNF-C300-S639-1	12.381	1.234	0.1014	98.9	2971	1212	40.9
BNF-C300-S639-1D	12.565	1.234	0.1018	100	2982	1201	40.8
BNF-C300-AN102-LC-1	12.181	1.234	na	na	4110	<<avg. >>	40.8
BNF-C300-AN102-LC-1D	12.180	1.234	na	na	4255	4183	
Envelope large C effluent – 14 days after Cs ion exchange column run	sample wt. (g)	density (g/mL)	resin wt. (g)	Phase ratio	Tc-99 (ug/L)	Tc-99 (removed)	Kd value (mL/g)
BNF-C300-S639-2W-1	12.155	1.234	0.1023	96.3	2977	1252	41.0
BNF-C300-S639-2W-1D	12.077	1.234	0.1034	94.7	3021	1208	38.3
BNF-C300-AN102-LC-2D	12.907	1.234	na	na	4229	avg. >>	39.7
Envelope large C effluent – 14 days after Cs ion exchange column run	sample wt. (g)	density (g/mL)	resin wt. (g)	Phase ratio	Tc-99 (ug/L)	Tc-99 (removed)	Kd value (mL/g)
BNF-B300-S639-1	10.571	1.15	0.1034	88.9	1085	8929	741.1
BNF-B300-S639-1D	10.865	1.15	0.1012	93.4	1071	8943	789.6
BNF-B300-AZ102-D-1	10.849	1.15	na	na	10014	avg. >>	765.3

Table 8. Envelope C (large) post-filtration precipitate solid analysis

ANALYTE:		Results (mg/L)
Al		24.499
B		3.526
Ba		0.032
Ca		28.598
Cd		6.159
Co		0.369
Cr		17.657
Cu		2.591
Fe		1.488
La	<	0.110
Li	<	0.020
Mg		0.080
Mn		23.727
Mo		5.798
Na		55041.387
Ni		43.783
P		66.124
Pb		14.003
Si		11.087
Sn		2.264
Sr		21.501
Ti	<	0.020
V	<	0.030
Zn		0.447
Zr		11.458

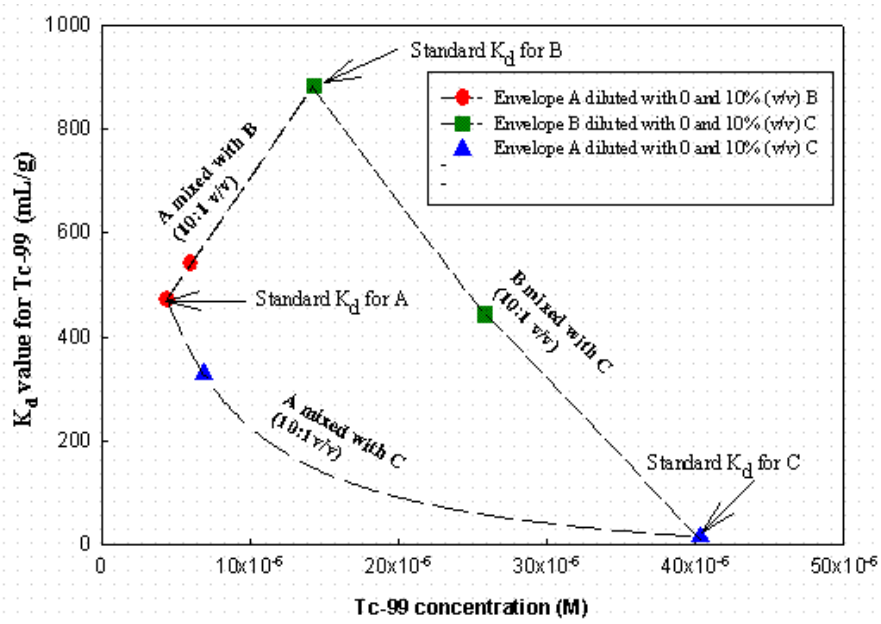

Figure 1. The K_d values for Envelope A mixed with B and C solutions
(Mixed solution age ~ 4-hrs; contact time ~ 24 hrs.; temperature ~ 25 deg. C)

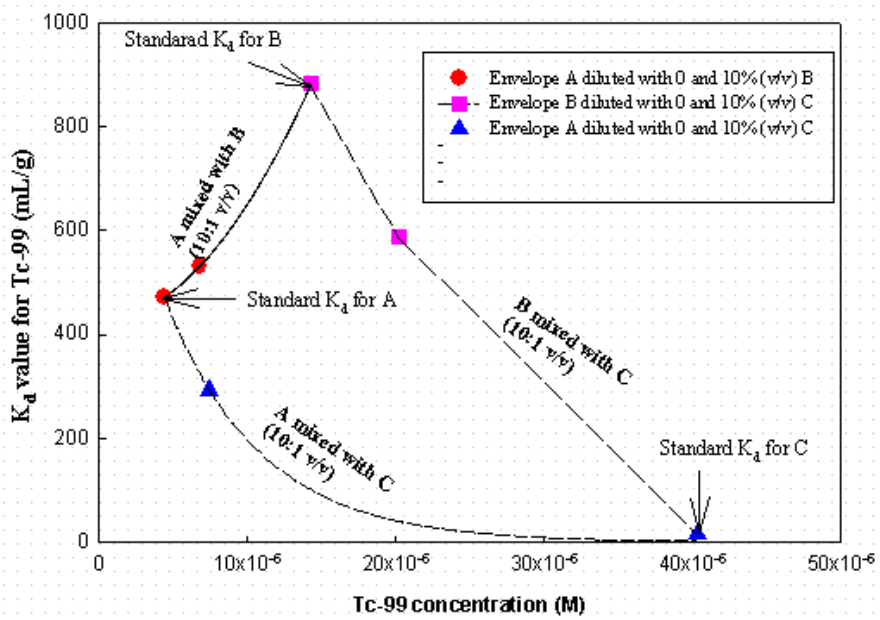

Figure 2. The K_d values for Envelopes A mixed with B or C solutions
(mixed solution age = 2 weeks; contact time ~ 24 hrs.; temperature ~ 25 deg. C)