*Effects of Soluble Organic Complexants and
Their Degradation Products on the Removal of
Selected Radionuclides from High-Level Waste*

*Part III: Distributions of Sr, Cs, Tc, Pu, and Am onto
33 Absorbers from Four Variations of a 3:1 Dilution
of Hanford Complexant Concentrate (CC)
Simulant Solution*

*Part IV: The Effects of Varying Dilution Ratios on the
Distributions of Sr, Cs, Tc, Pu, and Am onto 12 Absorbers
from Hanford Complexant Concentrate (CC)
Simulant Solution*

*S. Fredric Marsh**

Zita V. Svitra

Scott M. Bowen

MASTER

**Sandia National Laboratories/New Mexico, Albuquerque, NM 87185-0734.*

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CONTENTS

LIST OF TABLES	vii
TRADEMARKS	ix
ABSTRACT	1
EXECUTIVE SUMMARY	2
1.0 OVERVIEW	3
2.0 PART III: DISTRIBUTIONS OF Sr, Cs, Tc, Pu, AND Am ONTO 33 ABSORBERS FROM FOUR VARIATIONS OF A 3:1 DILUTION OF HANFORD COMPLEXANT CONCENTRATE (CC) SIMULANT SOLUTION	4
2.1 Experimental Parameters	4
2.1.1 Simulant Solutions	4
2.1.2 Radiotracers	5
2.1.3 Absorbers	6
2.1.4 Solution/Absorber Contacts	7
2.1.5 Calculation of Kd Values	7
2.1.6 Corrections	8
2.1.7 Measurement Precision	8
2.1.8 Data Transfer and Processing	8
2.1.9 Calculation of Detection Limits	8
2.2. Results and Discussion	9
2.2.1 Individual Elements	9
Strontium	10
Cesium	11
Technetium	12
Plutonium	13
Americium	14
2.2.2 Individual Absorbers	15
2.2.2.1 Commercially Available Absorbers	15
Amberlite™ IRC-718 Cation Exchange Resin	15
Bone Char	16
Clinoptilolite	17
Diphonix™ Cation Exchange Resin	18
Duolite™ C-467 Cation Exchange Resin	19
Duolite™ CS-100 Cation Exchange Resin	20
Ionac™ SR-6 Anion Exchange Resin	21
IONSIV™ IE-910 (CST) Powder	22
IONSIV™ IE-96 Zeolite	23
IONSIV™ TIE-96 Titanium-Loaded Zeolite	24
Monosodium Titanate (BSC-265-0106)	25
Nusorb™ Ferroc carbon A	26
Purolite™ A-520-E Anion Exchange Resin	27
Reillex™ HPQ Anion Exchange Resin	28
Resorcinol/Formaldehyde Resin (BSC-210)	29
Tannin	30

TEVA-Spec™ Extractant Resin	31
TRU-Spec™ Extractant Resin	32
UTEVA-Spec™ Extractant Resin	33
2.2.2.2 Developmental Absorbers	34
CSbA-PAN (Crystalline Antimonic Acid) Composite	34
KCoFC (Potassium Hexacyanoferrate) Crystals	35
KCoFC-PAN (Potassium Hexacyanoferrate) Composite	36
NiFC-PAN (Nickel Hexacyanoferrate) Composite	37
Sodium Nanotitanate (8104-170)	38
Sodium Nanotitanate (8225-127)	39
SuperLig™ 644 Particles	40
2.2.2.3 Experimental Absorbers	41
Aliquat™ 336 Extractant Beads	41
Cyanex™ 923 Extractant Beads	42
Dow™ XFS-4195 Chelating Resin	43
Isobutyl-HP Anion Exchange Resin	44
N-Butyl-HP Anion Exchange Resin	45
N-Hexyl-HP Anion Exchange Resin	46
SNL/HTO Monosodium Titanate	47
 3.0 PART IV: THE EFFECTS OF VARYING DILUTION RATIOS ON THE DISTRIBUTIONS OF Sr, Cs, Tc, Pu, AND Am ONTO 12 ABSORBERS FROM HANFORD COMPLEXANT CONCENTRATE (CC) SIMULANT SOLUTION	 48
3.1 Introduction	48
3.2 Results and Discussion	48
3.2.1 Sorption of Am, Cs, Pu, Sr, and Tc onto 12 Selected Absorbers from 1:1 Diluted Simulant Solution	48
Aliquat™ 336 Extractant Beads	48
Bone Char	49
CSbA-PAN Composite	49
Duolite™ CS-100 Cation Exchange Resin	50
Ionac™ SR-6 Anion Exchange Resin	50
IONSIV™ IE-910 (CST) Powder	51
Monosodium Titanate (BSC-265-0106)	51
Purolite™ A-520-E Anion Exchange Resin	52
Resorcinol/Formaldehyde Resin (BSC-210)	52
Sodium Nanotitanate (8225-127)	53
SNL/HTO Monosodium Titanate	53
SuperLig™ 644 Particles	54
3.2.2 Sorption of Sr, Cs, Tc, Pu, and Am onto Three Selected Absorbers from Undiluted and 0.5:1, 1:1, 2:1, and 3:1 Dilutions of CC Simulant Solution	55
Strontium	57
Cesium	58
Technetium	59
Plutonium	60
Americium	61
 4.0 CONCLUSIONS	 62
5.0 FUTURE STUDIES	62
ACKNOWLEDGMENTS	63
REFERENCES	63

TABLES

Table 1.	Compositions of the Four Variations of Diluted Generic Hanford CC Simulant Solutions	5
Table 2.	Radiotracers	5
Table 3.	Absorbers	6
Table 4.	Ratio of Air-Dried Weight to Oven-Dried Weight for Each Dried Absorber	7

Part III Individual Elements

Table 5.	Strontium Distribution Data	10
Table 6.	Cesium Distribution Data	11
Table 7.	Technetium Distribution Data	12
Table 8.	Plutonium Distribution Data	13
Table 9.	Americium Distribution Data	14

Individual Absorbers

Commercially Available Absorbers

Table 10.	Amberlite™ IRC-718 Cation Exchange Resin	15
Table 11.	Bone Char	16
Table 12.	Clinoptilolite	17
Table 13.	Diphonix™ Cation Exchange Resin	18
Table 14.	Duolite™ C-467 Cation Exchange Resin	19
Table 15.	Duolite™ CS-100 Cation Exchange Resin	20
Table 16.	Ionac™ SR-6 Anion Exchange Resin	21
Table 17.	IONSIV™ IE-910 (CST) Powder	22
Table 18.	IONSIV™ IE-96 Zeolite	23
Table 19.	IONSIV™ TIE-96 Titanium-Loaded Zeolite	24
Table 20.	Monosodium Titanate (BSC-265-0106)	25
Table 21.	Nusorb™ Ferrocen A	26
Table 22.	Purolite™ A-520-E Anion Exchange Resin	27
Table 23.	Reillex™ HPQ Anion Exchange Resin	28
Table 24.	Resorcinol/Formaldehyde Resin (BSC-210)	29
Table 25.	Tannin	30
Table 26.	TEVA-Spec™ Extractant Resin	31
Table 27.	TRU-Spec™ Extractant Resin	32
Table 28.	UTEVA-Spec™ Extractant Resin	33

Developmental Absorbers

Table 29.	CSbA-PAN Composite	34
Table 30.	KCoFC Crystals	35
Table 31.	KCoFC-PAN Composite	36
Table 32.	NiFC-PAN Composite	37
Table 33.	Sodium Nanotitanate (8104-170)	38
Table 34.	Sodium Nanotitanate (8225-127)	39
Table 35.	SuperLig™ 644 Particles	40

Experimental Absorbers

Table 36.	Aliquat™ 336 Extractant Beads	41
Table 37.	Cyanex™ 923 Extractant Beads	42
Table 38.	Dow™ XFS-4195 Chelating Resin	43
Table 39.	Isobutyl-HP Anion Exchange Resin	44
Table 40.	N-Butyl-HP Anion Exchange Resin	45
Table 41.	N-Hexyl-HP Anion Exchange Resin	46
Table 42.	SNL/HTO Monosodium Titanate	47

Part IV

Twelve Selected Absorbers

Table 43.	Aliquat™ 336 Extractant Beads	48
Table 44.	Bone Char	49
Table 45.	CSbA-PAN Composite	49
Table 46.	Duolite™ CS-100 Cation Exchange Resin	50
Table 47.	Ionac™ SR-6 Anion Exchange Resin	50
Table 48.	IONSIV™ IE-910 (CST) Powder	51
Table 49.	Monosodium Titanate (BSC-265-0106)	51
Table 50.	Purolite™ A-520-E Anion Exchange Resin	52
Table 51.	Resorcinol/Formaldehyde Resin (BSC-210)	52
Table 52.	Sodium Nanotitanate (8225-127)	53
Table 53.	SNL/HTO Monosodium Titanate	53
Table 54.	SuperLig™ 644 Particles	54

Three Selected Absorbers

Table 55.	Compositions of the Five Concentrations of Unirradiated Generic Hanford CC Simulant Used in Part IV of This Study	55
Table 56.	Compositions of the Five Concentrations of Gamma-Irradiated Generic Hanford CC Simulant Used in Part IV of This Study	56
Table 57.	Strontium Distribution Data	57
Table 58.	Cesium Distribution Data	58
Table 59.	Technetium Distribution Data	59
Table 60.	Plutonium Distribution Data	60
Table 61.	Americium Distribution Data	61

FIGURE

Fig. 1. Visible absorbance spectra of the four variations of generic Hanford complexant concentrate (CC) simulant solution. 4

TRADEMARKS

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EFFECTS OF SOLUBLE ORGANIC COMPLEXANTS AND THEIR DEGRADATION PRODUCTS ON THE REMOVAL OF SELECTED RADIONUCLIDES FROM HIGH-LEVEL WASTE

**Part III: Distributions of Sr, Cs, Tc, Pu, and Am onto 33 Absorbers from Four Variations
of a 3:1 Dilution of Hanford Complexant Concentrate (CC) Simulant Solution**

**Part IV: The Effects of Varying Dilution Ratios on the Distributions of Sr, Cs, Tc, Pu, and Am
onto 12 Absorbers from Hanford Complexant Concentrate (CC) Simulant Solution**

by

S. Fredric Marsh, Zita V. Svitra, and Scott M. Bowen

ABSTRACT

Many of the radioactive waste storage tanks at U. S. Department of Energy facilities contain organic compounds that have been degraded by radiolysis and chemical reactions during decades of storage. The objective of this study was to measure the effects of soluble organic complexants and their degradation products on the sorption of strontium, cesium, technetium, plutonium, and americium onto 33 absorbers that in the absence of these organic compounds offer high sorption of these elements. The elements were in a generic simulant for Hanford complexant concentrate supernate that initially contained six organic complexants: EDTA, HEDTA, NTA, citrate, gluconate, and iminodiacetate. This simulant was tested as prepared and after gamma-irradiation to approximately 34 Mrads. Two other variations consisted of the unirradiated and irradiated simulants after treatment at 450°C and 15,000 psi in a hydrothermal organic-destruction process. These experiments were conducted with a 3:1 water-to-simulant dilution of each of the four simulant variations.

To determine the effects of varying dilution ratios on the sorption of these five elements from the unirradiated and gamma-irradiated simulants that were not treated with the hydrothermal process, we measured their distribution from a 1:1 dilution, using 1 M NaOH as the diluent, onto the 12 best-performing absorbers. We then measured the sorption of these five elements from solutions having diluent-to-simulant ratios of 0, 0.5, 2.0, and 3.0 onto the three absorbers that performed best for sorbing strontium, plutonium, and americium from the 1:1 dilution.

For each of 900 element/absorber/solution combinations, we measured distribution coefficients (Kd values) twice for each period for dynamic contact periods of 30 min, 2 h, and 6 h to obtain information about absorber stability and sorption kinetics. The 5400 measured Kd values indicate that the sorption of strontium, plutonium, and americium is significantly decreased by the organic complexants in these simulant solutions, whereas the sorption of cesium and technetium is much less affected.

EXECUTIVE SUMMARY

Successful remediation of the large quantities of radioactive hazardous waste stored in underground tanks at the Hanford Reservation near Richland, Washington, requires the identification of reliable partitioning agents and suitable technologies. To address this need, we previously completed four screening studies that collectively provide nearly 16,000 measured distribution coefficients (Kd values) for the sorption of 16 elements onto more than 100 absorber materials from 9 simulated Hanford tank waste solutions. The simulants we tested were acid-dissolved sludge (pH 0.6), acidified supernate (pH 3.5), and alkaline supernate (pH 13.9) solutions for Hanford Tank 102-SY;¹ Hanford double-shell slurry feed (DSSF);² Hanford neutralized current-acid waste (NCAW);³ and four variations of an organic-containing simulant for Hanford Tank 101-SY.⁴

Of these previously tested simulant solutions, only those representing Tank 101-SY contained any of the degraded organic compounds known to be present in numerous other Hanford waste tanks.⁵ Because many of the organic compounds in Hanford waste interact with multivalent cations, such organic compounds are expected to interfere with the removal of certain radionuclides by forming aqueous-soluble complexes with metal ions that would otherwise be sorbed.

A preliminary study⁶ of the effects of ethylenediaminetetraacetic acid (EDTA) and its radiolysis products on the sorption of strontium, cesium, and technetium tested 18 absorbers that had shown high sorption of strontium in our previous studies.¹⁻³ In that study,⁶ we used the leachate from an irradiated simulated slurry for Hanford Tank 101-SY to demonstrate that degraded organic complexants dramatically decrease the sorption of strontium onto even the best absorbers for this element.

Our most recently published study,⁴ which reported the results of experiments using unirradiated and irradiated Tank 101-SY simulant, before and after hydrothermal organic-destruction treatment, demonstrated that EDTA and its degradation products seriously interfere with the sorption of strontium and americium onto absorbers that otherwise perform well.

For our present study, we used a generic simulant for Hanford complexant concentrate supernate, which is the most challenging simulant we have tested because it initially contains six different organic complexants: EDTA, HEDTA, NTA, citrate, gluconate, and iminodiacetate. In addition to the as-prepared complexant concentrate (CC) simulant, we studied three variations of this simulant. The first variation is the initial simulant solution after gamma-irradiation to 34

Mrads with ⁶⁰Co. The second variation is the unirradiated simulant after treatment with a hydrothermal organic-destruction process.⁷ The final variation is the irradiated simulant after treatment with the hydrothermal process. Thus, these four simulant solutions represent a wide spectrum of organic-containing Hanford waste from which key radionuclides must be removed.

Our present study examines the sorption of strontium, cesium, technetium, plutonium, and americium, the five most hazardous elements. The absorbers included in our tests either are already commercially available or could be produced in commercial quantities within a reasonable time.

We measured distribution coefficients for each element/absorber/solution combination after dynamic contact periods of 30 min, 2 h, and 6 h to obtain information about absorber stability and sorption kinetics for each system. Moreover, each element/absorber/solution/contact-time combination was measured twice to estimate the reproducibility of our measurements.

From these data we have identified absorbers that strongly sorb each of five tested elements from CC simulant that has been subjected to hydrothermal organic-destruction treatment. Cesium and technetium are strongly sorbed by selected absorbers in the presence or absence of organic complexants.

Many absorbers sorb strontium well in the absence of organic complexants; moreover, three offer triple-digit Kd values for removing strontium from even the organic-containing solutions, and three other absorbers perform nearly as well.

Thus, existing absorbers appear capable of removing cesium, technetium, and strontium from organic-containing waste with no prior organic-destruction treatment.

Plutonium and americium are strongly sorbed from simulant solutions subjected to the hydrothermal organic-destruction treatment but are much less sorbed than strontium from organic-containing solutions; the lower Kd values reflect the stable complexes these actinides form with many organic complexants. However, the sorption of these two actinides increased significantly as the simulant was diluted with 1 M NaOH.

These findings demonstrate the effectiveness of the hydrothermal organic-destruction process developed at Los Alamos National Laboratory⁷ and provide a basis for conducting the final series of absorber evaluations. We plan to test the best absorbers with actual Hanford organic-containing waste within the next year to confirm their suitability for removing selected radioactive elements from Hanford waste. Identification of reliable partitioning agents could allow processing of Hanford high-level-waste (HLW) tanks that contain soluble

organic complexants to begin and be completed sooner, and at a lower cost, than would otherwise be possible. Thus, the findings of our experimental studies could benefit radioactive waste processing, environmental remediation, and decommissioning efforts at Hanford and elsewhere within the U. S. Department of Energy (DOE) complex.

1.0 OVERVIEW

The Hanford Reservation near Richland, Washington, harbors 177 underground tanks that store more than 65 million gallons of radioactive waste containing some 165 million curies. These HLWs are a byproduct of the production of nuclear materials for national defense needs during the past half-century. Because Hanford operating contractors used numerous chemical processes during this period and procedures for storing the resulting waste were not standardized, many different reagents and waste streams were combined in these underground tanks. The resulting mixtures of sludges, salt-cakes, slurries, and supernates are complex and unstable wastes whose disposal is a serious environmental challenge. Adding significantly to the stored-waste problem is the fact that 68 of these underground waste storage tanks are known, or are presumed, to have leaked.⁵

DOE has directed Los Alamos National Laboratory (LANL) and Sandia National Laboratories/New Mexico (Sandia/NM) to support the Hanford Tank Waste Remediation Systems (TWRS) mission, which is to store, treat, and dispose of all tank waste in a safe, cost-effective, and environmentally sound manner. An essential prerequisite for achieving this goal is the identification of suitable partitioning agents and technologies.

In support of the TWRS mission, we previously completed four absorber screening studies that collectively provide nearly 16,000 measured distribution coefficients (K_d values) for sorption of 16 elements onto more than 100 commercially available and experimental absorber materials from 9 simulated Hanford waste solutions. The individual simulants we tested were acid-dissolved sludge (pH 0.6), acidified supernate (pH 3.5), and alkaline supernate (pH 13.9) solutions for Hanford Tank 102-SY;¹ Hanford double-shell slurry feed (DSSF);² Hanford neutralized current-acid waste (NCAW);³ and four variations of an organic-containing simulant for Hanford Tank 101-SY.⁴

Although identification of specific organic compounds present in the organic-containing simulant solutions was far beyond the scope of our study, other investigators have identified many of the organic

compounds that form under conditions that simulate the storage of nuclear waste in underground waste tanks. More than 60% of the initial organic compounds were found to degrade during the storage of an alkaline simulant solution containing EDTA, nitrilotriacetic acid (NTA), N-(2-hydroxyethyl) ethylenediaminetriacetic acid (HEDTA), and citrate at ambient temperature for 171 days.⁸ The effects of gamma-irradiation on simulated mixed waste containing EDTA, NTA, HEDTA, and citrate have been reported,⁹ and the effects of radiolysis and chemical forces on the degradation of citric acid in simulated mixed nuclear waste have been compared.¹⁰ Measurements of actual Hanford radioactive waste¹¹ resulted in the successful characterization of nearly 95% of the total organic carbon (TOC) in neutralized cladding removal waste (NCRW) but only 1.2% of the TOC in double-shell slurry (DSS) waste. Recent reanalysis of the organics in a Hanford organic complexant waste resulted in the identification of 58 individual organic compounds that account for more than 80% of the TOC.¹²

Because many of the organic complexants in Hanford waste alter the chemistry of multivalent cations by forming aqueous-soluble complexes, these complexants directly compete with sorption processes that would otherwise occur. We documented⁶ the effects of EDTA and its radiolysis products on the sorption of strontium, cesium, and technetium by 18 absorbers that had shown high sorption of strontium in our earlier screening studies.¹⁻³ In that preliminary study,⁶ we tested a simulated leachate from an irradiated simulated slurry for Hanford Tank 101-SY that had been prepared from a simplified recipe.¹³

In a subsequent study,⁴ we used a realistic simulant for the contents of Hanford Tank 101-SY and three variations of this simulant. The first variation is the initial simulant solution after gamma-irradiation to 34 Mrads with ⁶⁰Co. The second variation is the unirradiated simulant after treatment with a hydrothermal organic-destruction process.⁷ The final variation is the irradiated simulant after treatment with the hydrothermal process. Thus, we used four simulant solutions that represent the wide spectrum of organic-containing Hanford tank waste from which key radionuclides must be removed.

Because most solutions stored in Hanford HLW tanks are saturated with inorganic salts, such waste solutions are poorly suited for processing in their undiluted form. We can safely assume that these waste solutions will require dilution before they are processed with the designated partitioning option. Moreover, the radioactive solutions generated by planned sludge-washing operations are likely to be combined with the initial waste solution to produce a diluted feed that meets process

specifications. Although most HLW solutions will probably require dilution before they can be processed, the appropriate ratio of diluent to HLW solution cannot be selected until relevant tests have been completed. To provide a preliminary basis for selecting the appropriate dilution ratio for CC waste, we measured the distribution of strontium, cesium, technetium, plutonium, and americium onto selected absorbers from solutions whose diluent-to-simulant ratio ranged from zero to 3.0.

In Part III of this study (section 2.0), we measured the distribution of these three major fission products and two actinides onto all 33 absorbers from a 3:1 dilution, using water as the diluent, of each of the four variations of the generic CC simulant solution.

In Part IV of this study (section 3.0), we measured the distribution of these same elements onto 12 selected absorbers from 1:1 dilutions of unirradiated and gamma-irradiated portions of the CC simulant. We then performed additional measurements on three of the best-performing absorbers from unirradiated and gamma-irradiated CC simulant variations that had diluent-to-simulant ratios of 0, 0.5, 2.0, and 3.0. We used 1 M NaOH to prepare all 10 of the diluted simulant solutions tested in Part IV.

2.0 PART III: DISTRIBUTIONS OF Sr, Cs, Tc, Pu, AND Am ONTO 33 ABSORBERS FROM FOUR VARIATIONS OF A 3:1 DILUTION OF HANFORD COMPLEXANT CONCENTRATE (CC) SIMULANT SOLUTION

2.1 Experimental Parameters

2.1.1 Simulant Solutions. The four simulant solutions were prepared as follows.

- (1) *Unirradiated/untreated.* The accepted recipe¹⁴ was used to prepare a generic Hanford CC simulant solution.
- (2) *Irradiated/Untreated.* A portion of the simulant solution described in (1) subsequently was gamma-irradiated, while exposed to air, at 1.35 Mrads/h to a total of 34 Mrads with ⁶⁰Co in the Gamma Irradiation Facility at Sandia/NM. Irradiation is known to degrade most organic compounds into simpler compounds and carbon dioxide, which forms carbonate in alkaline solutions. Moreover, the solution heating that occurred during the gamma-irradiation may have contributed to the organic degradation. Although we obtained no temperature profile during the irradiation, the solution temperature at the end of the 24-h irradiation was measured to be 50°C.

- (3) *Unirradiated/hydrothermal-treated.* A portion of the unirradiated simulant solution described in (1) was treated with a hydrothermal organic-destruction process.⁷ The small-scale hydrothermal unit used to process this solution consisted of a 5-ft reactor operating at 450°C and 15,000 psi. The typical residence time of solution passing through this reactor was approximately 25 s.
- (4) *Irradiated/hydrothermal-treated.* A portion of the irradiated simulant solution described in (2) was treated with the same hydrothermal organic-destruction process described in (3).

These four variations of the CC simulant solution differed significantly in appearance. Whereas the unirradiated solution appeared light tan, the gamma-irradiated portion seemed slightly darker. Both hydrothermal-treated portions were nearly colorless. These differences are reflected in the UV-visible absorbance spectra of the four solutions in Fig. 1. Note the differences in the UV spectra between the treated and untreated solutions; these differences reflect the organic-destruction efficiency of the hydrothermal process. If hydrothermal processing is used to destroy organic components in actual waste, an on-line UV absorbance measurement might indicate when the required degree of organic destruction has been reached.

The compositions of the initial simulant solution and the three variations of the initial simulant solution are presented in Table 1. Because the accuracy of the TOC can be questionable when many unusual organic compounds are present, the analytical technique used for TOC was tailored to the specific compositions of organics in Hanford tank waste.¹⁵

Fig. 1. Visible absorbance spectra of the four variations of generic Hanford complexant concentrate (CC) simulant solution.

Table 1. Compositions of the Four Variations of Diluted^a Generic Hanford CC Simulant Solutions

Constituent	Concentration (M)			
	Unirradiated/ untreated	Irradiated/ untreated	Unirradiated/ hydrothermal-treated	Irradiated/ hydrothermal-treated
Cations^b				
Na	2.2	2.1	1.9	1.6
K	0.009	0.009	0.013	0.014
Rb	1.3×10^{-5}	1.2×10^{-5}	9×10^{-6}	1.0×10^{-5}
Cs	1.4×10^{-4}	1.3×10^{-4}	1.0×10^{-4}	1.3×10^{-4}
Al	0.16	0.16	0.024	0.012
Ca	0.002	0.002	0.0001	0.0001
Fe	0.003	0.005	6×10^{-5}	7×10^{-5}
Sr	1.3×10^{-4}	1.3×10^{-4}	3×10^{-5}	3×10^{-5}
Anions^c				
Cl	0.04	0.012	0.012	0.013
NO ₃	0.9	0.9	0.5	0.7
NO ₂	0.3	0.3	0.1	0.1
PO ₄	0.009	0.009	BDL ^d	BDL
SO ₄	0.006	0.007	0.003	0.003
CO ₃	0.19	0.23	0.49	0.62
TOC ^e	1.0	0.9	0.13	0.14
pH	13.2	13.2	11.9	12.1

^aDilutions consisted of three volumes of water to one volume of undiluted simulant.

^bCations, except Na and K, were measured by inductively coupled plasma/mass spectrometry (ICP/MS).

^cAnions, as well as Na and K cations, were measured by ion chromatography (IC).

^dBelow detection limit.

^eTotal organic carbon.

2.1.2 Radiotracers. Because gamma spectrometry would be used to measure the K_d values of the four elements, we added appropriate quantities of radiotracers for strontium, cesium, technetium, plutonium, and americium to each simulant solution. The five radiotracers and their gamma

energies, branching ratios, and concentrations are shown in Table 2. Each simulant solution was initially passed through an AcrodiscTM LC13 PVDF 0.45-μm filter to remove any insoluble materials, and the five radiotracers were then added. The simulant and radiotracers were stirred thoroughly

Table 2. Radiotracers

Radiotracer	Gamma Energy (MeV)	Gamma Branching (%) ^a	Estimated Concentration
⁸⁵ Sr	0.514	100	3 μg/L
¹³⁷ Cs	0.662	85	6 μg/L
^{95m} Tc	0.204	100	2 pg/L
²³⁸ Pu	0.152	1×10^{-3}	10 mg/L
²⁴¹ Am	0.0595	35.3	30 μg/L

^aGamma branching information is provided to indicate the assay sensitivity.

and then left undisturbed for at least one week to allow adequate time for soluble complexes or insoluble compounds to form. Every radiotracer-containing simulant solution was refiltered through an Acrodisc™ filter just before its absorber-contact phase began.

2.1.3 Absorbers. The 33 selected absorbers (see Table 3) offer high sorption of the five elements from previously tested alkaline simulant solutions.¹⁻⁴ Their suppliers or preparation details are included in the tables for the individual absorbers (section 2.2.2).

To put all absorbers on a comparable basis, we intentionally air-dried all moist resins and composites at room temperature before testing. Air-drying also

prevented unintentional dilution. Had we added as-received wet resins, they could have diluted the simulant solution by as much as 23%. Although several of our colleagues expressed concern that air-drying might have adverse effects, our earlier studies demonstrated that the air-dried absorbers performed well.¹⁻⁴

Because air-drying these absorbers under other temperature, humidity, and altitude conditions could yield different moisture contents, knowing the ratio of the weight of each air-dried absorber to its weight after oven-drying at 110°C for 18 h is important (see Table 4). Resins dried at 110°C will have the same moisture content in any laboratory; therefore, these ratios reflect the relative quantities of easily lost water in the air-dried

Table 3. Absorbers

Absorber Type/Source	Trademark ^a or Other Identification
Commercially Available Absorbers	Amberlite™ IRC-718 cation exchange resin
	Bone char
	Clinoptilolite
	Diphonix™ cation exchange resin
	Duolite™ C-467 cation exchange resin
	Duolite™ CS-100 cation exchange resin
	Ionac™ SR-6 anion exchange resin
	IONSIV™ IE-910 (CST) powder
	IONSIV™ IE-96 zeolite
	IONSIV™ TIE-96 titanium-loaded zeolite
	Monosodium titanate (BSC-265-0106)
	Nusorb™ Ferroc carbon A
	Purolite™ A-520-E anion exchange resin
	Reillex™ HPQ anion exchange resin
	Resorcinol/formaldehyde resin (BSC-210)
	Tannin
	TEVA-Spec™ extractant resin
	TRU-Spec™ extractant resin
	UTEVA-Spec™ extractant resin
Developmental Absorbers	CSbA-PAN (crystalline antimonite acid) composite
	KCoFC (potassium hexacyanoferrate) crystals
	KCoFC-PAN (potassium hexacyanoferrate) composite
	NiFC-PAN (nickel hexacyanoferrate) composite, improved
	Sodium nanotitanate (8104-170)
	Sodium nanotitanate (8225-127)
	SuperLig™ 644 particles
Experimental Absorbers	Aliquat™ 336 extractant beads
	Cyanex™ 923 extractant beads
	Dow™ XFS-4195 chelating resin
	Isobutyl-HP anion exchange resin
	N-butyl-HP anion exchange resin
	N-hexyl-HP anion exchange resin
	SNL/HTO monosodium titanate

^aTrademark owners are identified on p. ix.

Table 4. Ratio of Air-Dried Weight to Oven-Dried Weight for Each Dried Absorber

Absorber	Air-dried weight/110°C-dried weight
Amberlite™ C-467	1.136
Amberlite™ IRC-718	1.100
CSbA-PAN	1.052
Diphonix™	1.100
Dow™ XFS-4195	1.031
Duolite™ CS-100	1.033
Ionac™ SR-6	1.060
Isobutyl-HP	1.060
KCoFC-PAN	1.071
Monosodium titanate (BSC-265-0106)	1.141
N-butyl-HP	1.132
N-hexyl-HP	1.113
NiFC-PAN (improved)	1.192
Purolite™ A-520-E	1.137
Resorcinol/formaldehyde (BSC-210)	1.205
Reillex™ HPQ	1.076

absorbers we used and provide a basis for normalizing our data to those of other studies done with absorbers having different moisture contents.

2.1.4 Solution/Absorber Contacts. In most cases, a 250-mg portion of each air-dried absorber was contacted with a measured 6-mL volume of the simulant solution in a specially modified 20-mL disposable hypodermic syringe. We modified these syringes by inserting cylindrical plugs cut from 0.25-in.-thick porous Kynar™ (obtained from Porex Technologies, Fairburn, Georgia) into the tapered tips as filters, which permitted only liquid to pass through.

For each set of experiments, we prepared six syringes, each containing an absorber. A measured volume of the simulant solution was transferred by pipet into a disposable 15-mL plastic beaker and then drawn into a syringe through the Kynar™ filter. We then sealed the tip of each syringe with a solid Luer cap and placed the syringes on a 48-rpm tube rotator for dynamic contact periods of 30 min, 2 h, and 6 h. At the end of each contact period, approximately 25% of the total solution volume was expelled through an attached Acrodisc™ LC13 PVDF 0.45-μm filter into a tared counting vial. The weight of the dispensed solution was used in the calculation of the Kd values.

The described filter-tip syringes were unsuitable for those absorbers whose particle size was smaller than the pores of the Kynar™ filters. For these finely divided materials, we transferred 6 mL of solution by pipet directly into a 30-mL centrifuge tube that contained 250 mg of absorber and mixed each absorber/solution on the rotator for the prescribed time. At the end of each

contact period, the tubes were centrifuged at high speed for 5 min. We then transferred approximately 1.5 mL of the centrifuged solution into a 3-mL hypodermic syringe with an Acrodisc™ LC13 PVDF 0.45-μm filter attached to its Luer-lock tip. The centrifuged solution was expelled through this filter into a tared counting vial, from which we determined the solution weight.

2.1.5 Calculation of Kd Values. Distribution coefficients (Kd values) normally are calculated in terms of the dry absorber weight;¹⁶ optionally, Kd values can be calculated in terms of the wet-absorber volume. Because most of the absorbers we tested were received in dry form, we tested all absorbers on a comparable dry basis to conform to a consistent Kd convention. We recognize that air-drying moist absorbers to constant weight at room temperature causes some polymers to temporarily shrink as they lose physically sorbed water; however, such polymers swell again when they recontact aqueous solution. Therefore, the only adverse effect of air-drying might be a temporary decrease in polymer porosity that could result in slower kinetics until the polymer regains its lost water. To protect the air-dried absorbers from any irreversible damage, we never applied heat while drying the absorbers tested in this study.

Each portion of postcontact solution was assayed by gamma spectrometry using the characteristic gamma energies of the added radionuclides. The fraction of each element sorbed was determined indirectly from the difference in the measured gamma activity of the selected radionuclide before and after contact with each specified absorber.

All Kd values were calculated as follows:

$$K_d = \frac{Pr - Po}{Po} \frac{S}{A},$$

where Pr = measured precontact activity per milliliter,
Po = measured postcontact activity per milliliter,
S = milliliters of solution contacted, and
A = grams of dry absorber contacted.

2.1.6 Corrections. Because the solution weight of the postcontact assay portion usually differed slightly from that of the precontact standard solution, each postcontact solution was normalized to the same weight basis as the standard.

We also made appropriate corrections to account for the fact that the liquid-to-solid ratio and the remaining activity of every radionuclide decreased as successive assay portions were removed.

To determine the quantities of sorbed radionuclides, we compared the activity of each radionuclide in the postcontact solution with the activity of that radionuclide in the precontact standard. Because most absorbers were initially added in air-dried form, the aqueous solvent was often preferentially sorbed, thereby decreasing the aqueous volume and simultaneously increasing the concentration of the solutes. Consequently, the activity of certain radionuclides was at times slightly higher in the postcontact solution than in the precontact solution. Whenever the postcontact/precontact solution activity ratio of a radionuclide exceeded unity, we assigned a value of 1.000 to the ratio having the highest value and normalized all other radionuclides in that portion of solution accordingly.

2.1.7 Measurement Precision. We measured each of the 1,980 element/absorber/solution/contact-time combinations twice for each contact period and calculated the standard deviation for each pair of measurements. We then used these individual relative standard deviations to compute pooled standard deviations for three ranges of Kd values. Because the lower gamma energies of 59.5 and 100 keV of ²⁴¹Am and ²³⁸Pu, respectively, had larger associated uncertainties, we calculated the measurement precision for these two actinides separately.

The resulting pooled relative standard deviation for a single measurement of americium or plutonium was 88% for Kd values between 0.1 and 0.25, 48% for Kd values between 0.25 and 1.0, and 12% for Kd values higher than 1.0. Pooled relative standard deviations for a single measurement of strontium, cesium, or technetium were 56% for Kd values between 0.1 and 0.25, 38% for Kd values between 0.25 and 1.0, and 11% for Kd values higher than 1.0. Although we report only the average Kd

value for each pair of measurements for selected absorbers in section 2.2.1, the average and associated (absolute) standard deviation for every pair of measurements is provided in section 2.2.2.

We did not measure Kd values in duplicate during our earlier studies.^{1-3,6} However, because the experimental technique we used then was essentially identical to the one we used in this study, the pooled standard deviations derived in the present study should also provide a reliable estimate of the precision of the Kd values obtained in previous studies.

2.1.8 Data Transfer and Processing. To save time and minimize the human errors that can be introduced in transcribing large quantities of data, we automated the data transfer and calculation process. We used the *Gamanal*¹⁷ computer program to determine the area of each gamma peak from the raw data in the multichannel analyzer memory. *Gamanal* provides a complete qualitative and quantitative analysis of mixtures of radionuclides by interpreting high-resolution gamma spectra. *Gamanal* determines background, fits and resolves complex peak groupings, determines the energies and absolute intensities of the gamma rays, and calculates the quantities of the source radionuclides. All interferences are resolved by a least-squares solution of the matrix of equations for the gamma intensities.

The *Gamanal* output was electronically imported into an EXCELTM spreadsheet in which the described calculations and corrections were applied. Finally, all calculated Kd values were combined into one master spreadsheet and converted to a database to provide tabulated comparisons of the measured Kd values according to element and absorber. Because small Kd values always have large associated uncertainties, we rounded all Kd values to not more than one place beyond the decimal point.

2.1.9 Calculation of Detection Limits. When peaks in a gamma spectrum were too small to be detected by the *Gamanal* program, we used a simple method¹⁸ to calculate the appropriate detection limits. First, for each radionuclide of interest, we used the same detector to determine the gamma-peak position and full width at half maximum (FWHM) from a spectrum with a strong gamma signal. We then doubled the FWHM to include the entire gamma-peak region (always rounding up to the next integer), which defines the position and width of the region of interest to be applied to the background spectra. After summing the number of background counts in this region, we multiplied the square root of the sum by a confidence-limit scale factor. Finally, we applied a scale-factor value of 2.772 to ensure that 95% of the signal peaks of this magnitude would be detected on the observed background.

The scale factor was determined as follows. Counting statistics dictate that the square root of the number of counts in a region is an estimate of the standard deviation uncertainty of those counts. The detection of a peak requires that the background in the region of interest be subtracted; the single standard deviation of their difference is the square root of the sum of the squares of the single-standard-deviation values for each of the two spectra. Thus, the standard deviation is the square root of the sums of the counts in the two corresponding regions of interest.

Because the hypothetical sample spectrum contains no detectable peak signal, the number of counts in the sample region of interest is equal to the number of counts in the background. Therefore, an estimate of the single-standard-deviation uncertainty (the confidence limits of detection) is the square root of twice the number of background counts, or 1.414 times the square root of the number of background counts. Scaling to exactly two standard deviations (95.44% confidence) would yield a scale factor of 2.828. Standard math tables permit the scale factor to be calculated to any desired confidence limit.

Using these calculated minimum peak area values that could be detected with a 95% confidence level to calculate the corresponding minimum Kd values, we report Kd values in terms of *greater than* (>) the computed minimum Kd values.

2.2. Results and Discussion

2.2.1 Individual Elements. Tables 5 through 9 list some of the best absorbers for sorbing each element from the four simulant solutions; the absorbers are ranked in order of their measured Kd values for sorption from the initial Hanford CC simulant solution. Although absorbers that perform poorly generally are omitted from Tables 5 through 9, the tables in sections 2.2.2 through 2.2.4 provide averages and standard deviations for each of the 1,980 sets of duplicate measurements that include all five elements.

Strontium. The sorption of strontium onto absorbers is dramatically decreased by the organic complexants in the two untreated simulant solutions. The fact that Kd values are generally higher in the irradiated/untreated solution indicates that many of the organic compounds that interfere with sorption of strontium are destroyed or decomposed into simpler compounds by the gamma

irradiation. However, even in the unirradiated/untreated simulant solutions where the organic-caused interference appears greatest, four of the tested absorbers provide triple-digit Kd values for sorbing strontium. Thus, we have identified several absorbers that might remove strontium from organic-containing waste solutions without prior organic-destruction treatment.

Table 5. Strontium Distribution Data—Kd Values for Sorption of Strontium from Four Variations of 3:1 Diluted Generic Hanford CC Simulant Solution

Absorber	Unirradiated/ untreated			Irradiated/ untreated			Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h	30 min	2 h	6 h	30 min	2 h	6 h
SNL/HTO	313	457	535	164	242	325	10550	10976	12627	6200	6058	8468
Na nanotitanate (8225-127)	100	179	238	80	133	169	4776	7384	10967	3639	4331	9025
CSbA-PAN	48	88	111	47	79	94	2434	3722	4027	2254	3732	4957
Na nanotitanate (8104-170)	40	70	99	38	67	91	5072	7733	13036	3710	6393	6414
Monosodium titanate (BSC)	37	61	69	74	121	135	3152	3617	4474	3221	3633	5305
Bone char	36	78	119	35	66	105	834	1886	3519	707	1502	2592
Amberlite™ IRC-718	13	15	15	17	20	21	977	1717	2189	833	1362	1866
KCoFC crystals	3.7	3.5	2.9	3.1	3.6	3.4	62	81	93	54	67	77
IONSIV™ IE-910 (CST)	3.1	5.1	7.8	5.5	8.0	11	1533	2434	3054	754	1320	1720
Duolite™ C-467	2.9	3.2	3.1	3.4	3.7	3.8	420	695	809	256	405	456
IONSIV™ TIE-96	2.9	5.3	7.3	2.7	5.0	7.1	30	74	139	25	58	107
KCoFC-PAN	1.5	1.4	1.7	0.5	1.1	1.2	5.9	8.7	13	4.7	7.1	9.9
Diphonix™	1.4	1.2	1.2	1.8	2.3	2.3	525	548	585	329	354	377

Cesium. Kd values were relatively constant for sorption of cesium from hydrothermal-treated or untreated solutions in our previous study⁶ of a Hanford Tank 101-SY simulant that contained EDTA as the only organic complexant. From these four variations of the CC simulant, however, the cesium Kd values, while acceptably high for sorption from untreated solutions, often are much higher for sorption from the hydrothermal-treated solutions. It seems unlikely that an organic compound in the untreated solutions is complexing cesium because those cesium Kd values are not suppressed. Instead, it appears that the cesium Kd values from the hydrothermal-treated solutions are enhanced by a pH change or the higher levels of carbonate that result from the hydrothermal destruction of organic compounds.

The sorption of cesium on NiFC-PAN and KCoFC-PAN generally decreases with increased contact time. We attribute these decreasing Kd values to an accelerated dissolution of these absorbers in the presence of organic complexants, as evidenced by the rapid appearance of the characteristic colors of the nickel or cobalt ions, respectively. We note, but cannot explain, the slow kinetics of Superlig™ 644 and its significantly lower Kd values for sorbing cesium from hydrothermal-treated solutions. We also note that Duolite™ CS-100, whose performance in untreated solutions is one of the poorest, performs even worse in hydrothermal-treated solutions.

Table 6. Cesium Distribution Data—Kd Values for Sorption of Cesium from Four Variations of 3:1 Diluted Generic Hanford CC Simulant Solution

Absorber	Unirradiated/ untreated			Irradiated/ untreated			Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h	30 min	2 h	6 h	30 min	2 h	6 h
IONSIV™ IE-910 (CST)	5224	6788	7794	5010	7396	9069	>61K	>74K	>80K	>40K	>80K	>91K
RF resin (BSC-210) ^a	1266	3571	6947	1055	3282	5506	1449	3759	6996	1226	2952	5341
KCoFC crystals	1097	552	66	1500	960	332	23K	73K	62K	27K	64K	63K
Superlig™ 644	713	2452	4482	342	1563	2935	36	209	624	30	186	590
NiFC-PAN	673	382	221	538	255	153	13K	>92K	>94K	8875	>100K	>100K
KCoFC-PAN	255	205	263	337	180	180	9419	>87K	>89K	10K	>99K	>98K
Duolite™ CS-100	116	131	126	93	111	104	45	50	50	41	46	47
IONSIV™ IE-96	112	198	247	105	200	259	226	421	503	183	336	413
Clinoptilolite	90	88	90	95	94	93	194	191	188	151	149	146
IONSIV™ TIE-96	76	159	217	74	156	217	153	313	422	129	254	326

^aRF is resorcinol formaldehyde.

Technetium. The absorbers that sorb technetium best are either anion exchange resins or compounds that incorporate functionalities that are closely related to those of anion exchange resins. Ten of the tested absorbers provide at least triple-digit Kd values for sorption of technetium from all four solutions. Although the Kd values for sorption from the untreated solutions are more than adequate, those for sorption from the hydrothermal-treated solutions are always

higher. TEVA-Spec™ and the LANL-prepared Aliquat™ 336 extractant beads offer the highest Kd values for technetium sorption at the 2-h and 6-h contact times. Because Aliquat™ 336 is the sorbed extractant in both absorber materials, the major difference is the cost of the LANL-prepared beads, which is only 1% that of TEVA-Spec™.

Table 7. Technetium Distribution Data—Kd Values for Sorption of Technetium from Four Variations of 3:1 Diluted Generic Hanford CC Simulant Solution

Absorber	Unirradiated/ untreated			Irradiated/ untreated			Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h	30 min	2 h	6 h	30 min	2 h	6 h
TEVA-Spec™	1129	1348	1277	1202	1439	1437	2709	4368	3681	2479	4226	4402
N-Butyl-Reillex™ HP	633	1007	1024	619	924	1087	1415	2389	2561	1226	1899	2970
Aliquat™ 336	600	1149	1271	827	1345	1418	1298	4798	3792	1236	3184	6033
N-Hexyl-Reillex™ HP	570	963	1090	571	909	1091	1277	2337	2977	1030	1749	2461
Isobutyl-Reillex™ HP	482	728	809	609	830	919	1128	2207	2025	1014	1569	1987
Purolite™ A-520-E	435	775	1033	526	939	1112	1212	3209	3629	990	2218	4231
Reillex™ HPQ	373	497	490	381	493	490	846	1088	1181	692	1048	1081
Ionac™ SR-6	288	634	958	305	659	950	723	1929	2683	696	1439	2314
Cyanex™ 923	111	151	147	110	149	130	157	201	194	150	181	171
Dow™ XFS-4195	65	142	214	53	136	216	142	303	461	124	262	403

Plutonium. No absorber provides even double-digit Kd values for sorption of plutonium from the untreated solutions. For sorption from the hydrothermal-treated solutions, however, five absorbers offer Kd values of at least 200. The fact that Kd values for sorption of plutonium from hydrothermal-treated

solution are lower for the irradiated solution indicates that plutonium sorption from this solution is suppressed by some of the radiolyzed complexants that survive the hydrothermal treatment.

Table 8. Plutonium Distribution Data—Kd Values for Sorption of Plutonium from Four Variations of 3:1 Diluted Generic Hanford CC Simulant Solution

Absorber	Unirradiated/ untreated			Irradiated/ untreated			Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h	30 min	2 h	6 h	30 min	2 h	6 h
Duolite™ CS-100	2.2	3.7	5.3	2.0	3.7	5.2	9.2	13	16	4.9	6.6	8.8
Ionsiv™ IE-910 (CST)	1.0	2.1	3.7	0.8	1.7	3.0	0.3	0.2	0.3	0.2	0.3	0.4
SNL/HTO	0.7	1.2	2.4	0.1	0.1	0.8	564	753	1036	271	349	430
Bone char	0.5	0.4	0.4	<0.1	0.3	0.1	138	357	519	81	169	265
KCoFC crystals	0.5	0.4	0.5	<0.1	0.1	0.2	6.9	7.4	8.0	2.9	3.0	3.6
KCoFC-PAN	0.5	0.5	0.6	<0.1	<0.1	<0.1	2.8	4.4	6.3	0.4	1.3	1.7
Aliquat™ 336	0.4	0.3	0.3	<0.1	<0.1	<0.1	0.5	0.3	0.2	<0.1	<0.1	<0.1
NiFC-PAN	0.4	0.3	0.4	<0.1	<0.1	<0.1	1.2	2.0	3.6	<0.1	0.3	0.9
Cyanex™ 923	0.4	0.3	0.3	<0.1	<0.1	<0.1	0.3	0.4	0.3	0.3	0.3	0.2
Clinoptilolite	0.3	0.4	0.3	<0.1	0.2	0.2	2.3	2.2	2.2	0.9	0.7	0.7
Na nanotitanate (8104-170)	0.3	0.4	0.5	0.2	<0.1	<0.1	269	439	656	98	168	244
Tannin	0.2	<0.1	0.2	0.5	0.2	0.4	43	378	1714	22	170	552
Na nanotitanate (8225-127)	<0.1	0.3	0.3	<0.1	<0.1	0.1	201	350	477	97	160	201
UTEVA-Spec™	<0.1	<0.1	<0.1	0.5	0.6	0.7	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
TRU-Spec™	<0.1	<0.1	<0.1	0.1	0.4	0.3	<0.1	<0.1	<0.1	0.2	0.1	0.1

Americium. As is the case with the other multivalent cations whose distributions we measured, the sorption of americium is dramatically decreased by the organic complexants in the two untreated simulant solutions. Although

no absorber provides even double-digit Kd values for sorption of americium from the untreated solutions, seven absorbers offer at least four-digit Kd values for its sorption from the hydrothermal-treated solutions.

Table 9. Americium Distribution Data—Kd Values for Sorption of Americium from Four Variations of 3:1 Diluted Generic Hanford CC Simulant Solution

Absorber	Unirradiated/ untreated			Irradiated/ untreated			Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h	30 min	2 h	6 h	30 min	2 h	6 h
SNL/HTO	2.3	3.3	4.1	0.6	1.0	1.4	4534	>4935	>4946	5201	>5231	>5223
Na nanotitanate (8225-170)	0.9	1.4	2.1	1.0	1.2	1.2	7256	>4824	>4831	5878	>4815	>7053
UTEVA-Spec TM	0.5	0.3	0.3	<0.1	<0.1	<0.1	0.6	0.5	0.5	<0.1	0.1	0.1
Na nanotitanate (8225-127)	0.5	1.1	1.4	0.3	0.4	0.5	>4549	>5567	7995	>2919	>5131	5199
Diphonix TM	0.4	0.6	0.7	0.4	0.6	0.6	942	1646	3647	1962	2665	3038
CSbA-PAN	0.4	0.4	0.4	0.6	0.7	0.7	2397	>4618	>4773	2167	>4503	>4584
Bone char	0.3	0.3	0.6	0.4	0.6	0.7	1514	3880	>4723	1409	3424	>4638
Monosodium titanate	0.2	0.6	0.6	0.8	0.8	0.8	8064	>5061	>6056	2629	>5065	>5006

2.2.2 Individual Absorbers. Tables 10 through 42 present Kd values for sorption of the five measured elements onto each of the 33 tested absorbers from each of the four variations of generic Hanford CC simulant. Sorption data for five elements in each of these tables often provide information about the selectivity for one of the elements in the presence of the other four. Because we present three different contact times, these tables also provide information about sorption kinetics for each element on specific absorbers and sometimes indicate absorber stability problems as well.

2.2.2.1 Commercially Available Absorbers. Nineteen commercially available absorbers were included in our study.

Amberlite™ IRC-718 Cation Exchange Resin. Amberlite™ IRC-718, manufactured by Rohm & Haas, Philadelphia, Pennsylvania, is a weak-acid cation exchange resin consisting of a styrene/divinylbenzene copolymer with iminodiacetic acid functionality. We air-dried this resin for reasons detailed in section 2.1.3.

Only strontium is sorbed with even low double-digit Kd values from the two untreated solutions. After hydrothermal treatment, americium and strontium are both well sorbed. (The ">" assigned to Kd values of less than 5000 in our report is a consequence of the low initial concentration of americium in the two hydrothermal-treated solutions; the reported Kd values are based on detection limits calculated as described in section 2.1.9.)

Table 10. Distribution of Five Elements onto Amberlite™ IRC-718 Cation Exchange Resin from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.1
Cs	1.0 ± 0.1	0.8 ± 0.1	0.9 ± 0.1	0.6 ± 0.1	0.7 ± 0.1	0.8 ± 0.1
Pu	0.2 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	<0.1 ± 0.0	0.2 ± 0.0	0.1 ± 0.0
Sr	13 ± 0.0	15 ± 0.0	15 ± 0.2	17 ± 0.5	20 ± 0.3	21 ± 0.4
Tc	2.4 ± 0.0	2.4 ± 0.1	2.5 ± 0.3	2.6 ± 0.1	2.6 ± 0.1	2.7 ± 0.1

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	2257 ± 495	4013 ± 467	>4774 ± 7.3	1288 ± 14	5K ± 0.5K	>4748 ± 57
Cs	1.6 ± 0.1	1.4 ± 0.3	1.4 ± 0.0	1.6 ± 0.1	1.2 ± 0.1	1.3 ± 0.1
Pu	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
Sr	977 ± 4.0	1717 ± 34	2189 ± 171	833 ± 58	1362 ± 47	1866 ± 165
Tc	9.7 ± 0.4	9.4 ± 0.6	8.4 ± 0.2	9.5 ± 0.1	8.8 ± 0.0	8.4 ± 0.0

Bone Char. Bone char, produced by calcining cattle bones in the absence of air, was obtained from Stauffer Chemical Company, Westport, Connecticut. This absorber, which is predominantly calcium phosphate, was used as received.

Bone char sorbs strontium moderate to well from the two untreated simulants and considerably better from the two hydrothermal-treated solutions. Americium and

plutonium also sorb well from the hydrothermal-treated solutions. The fact that the Kd values for these three elements are lower for sorption from the irradiated/treated than from the unirradiated/treated solution indicates that their sorption is suppressed by some of the radiolyzed complexants that survive the hydrothermal treatment.

Table 11. Distribution of Five Elements onto Bone Char from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.3 ± 0.1	0.3 ± 0.1	0.6 ± 0.0	0.4 ± 0.2	0.6 ± 0.2	0.7 ± 0.1
Cs	$<0.1 \pm 0.0$	0.1 ± 0.1	0.1 ± 0.1	0.6 ± 0.3	0.3 ± 0.0	0.5 ± 0.1
Pu	0.5 ± 0.2	0.4 ± 0.2	0.4 ± 0.2	$<0.1 \pm 0.0$	0.3 ± 0.3	0.1 ± 0.1
Sr	36 ± 1.8	78 ± 4.1	119 ± 0.0	35 ± 1.3	66 ± 0.1	105 ± 4.9
Tc	2.0 ± 0.1	2.2 ± 0.1	2.2 ± 0.0	2.2 ± 0.2	2.4 ± 0.1	3.1 ± 0.4

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	1514 ± 203	3880 ± 415	$>4723 \pm 5.3$	1409 ± 149	3424 ± 277	$>4638 \pm 192$
Cs	0.1 ± 0.0	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	0.1 ± 0.1	0.1 ± 0.1	$<0.1 \pm 0.0$
Pu	138 ± 1.8	357 ± 38	519 ± 37	81 ± 12	169 ± 21	265 ± 26
Sr	834 ± 52	1886 ± 52	3519 ± 205	707 ± 60	1502 ± 174	2592 ± 62
Tc	8.3 ± 0.0	9.5 ± 0.1	11 ± 0.1	6.9 ± 0.3	8.1 ± 0.5	8.8 ± 0.6

Clinoptilolite. Clinoptilolite, a natural zeolite mineral from Castle Creek, Idaho (batch #27034), obtained from Minerals Research, Clarkson, New Jersey, was ball-milled to <200 mesh before use.

Clinoptilolite sorbs cesium well from all four solutions. Americium and strontium sorb well from these solutions only after hydrothermal treatment.

Table 12. Distribution of Five Elements onto Clinoptilolite from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.1	0.3 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
Cs	90 ± 1.4	88 ± 0.9	90 ± 1.3	95 ± 0.9	94 ± 1.5	93 ± 2.7
Pu	0.3 ± 0.0	0.4 ± 0.0	0.3 ± 0.1	<0.1 ± 0.0	0.2 ± 0.2	0.2 ± 0.1
Sr	0.3 ± 0.0	0.4 ± 0.1	0.4 ± 0.0	0.6 ± 0.1	0.5 ± 0.2	0.5 ± 0.3
Tc	<0.1 ± 0.0	0.3 ± 0.2	0.3 ± 0.1	0.4 ± 0.2	0.6 ± 0.3	0.5 ± 0.1

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
	30 min	2 h	6 h	30 min	2 h	6 h
Am	>6K ± 0.1K	>7K ± 0.1K	>7K ± 0.1K	>3664 ± 963	>6K ± 0.2K	>6K ± 0.1K
Cs	194 ± 2.1	191 ± 3.5	188 ± 2.6	151 ± 2.6	149 ± 0.6	146 ± 1.0
Pu	2.3 ± 0.3	2.2 ± 0.5	2.2 ± 0.0	0.9 ± 0.4	0.7 ± 0.1	0.7 ± 0.1
Sr	114 ± 1.4	180 ± 0.7	237 ± 2.3	76 ± 0.1	136 ± 0.4	182 ± 0.1
Tc	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.1	<0.1 ± 0.0

Diphonix™ Cation Exchange Resin. Diphonix™, a polyfunctional cation exchange resin with diphosphonic acid, sulfonic acid, and carboxylic acid functional groups, was obtained from Eichrom Industries, Darien, Illinois. We air-dried this resin before testing for reasons detailed in section 2.1.3.

None of the five elements sorbs at useful levels from the two untreated solutions. Plutonium, americium, and strontium sorb with at least triple-digit Kd values from the two hydrothermal-treated solutions.

Table 13. Distribution of Five Elements onto Diphonix™ Cation Exchange Resin from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.4 ± 0.1	0.6 ± 0.0	0.7 ± 0.4	0.4 ± 0.0	0.6 ± 0.1	0.6 ± 0.1
Cs	3.3 ± 0.1	3.3 ± 0.1	3.4 ± 0.2	3.3 ± 0.1	3.5 ± 0.1	3.4 ± 0.1
Pu	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
Sr	1.4 ± 0.0	1.2 ± 0.1	1.2 ± 0.2	1.8 ± 0.0	2.3 ± 0.1	2.3 ± 0.2
Tc	1.9 ± 0.0	1.7 ± 0.3	1.8 ± 0.4	2.3 ± 0.1	2.2 ± 0.0	2.1 ± 0.1

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	942 ± 276	1646 ± 668	3647 ± 1844	1962 ± 243	2665 ± 254	3038 ± 133
Cs	3.9 ± 0.1	3.7 ± 0.1	3.5 ± 0.1	2.7 ± 0.1	2.9 ± 0.0	2.7 ± 0.1
Pu	>3118 ± 43	>3171 ± 13	>3212 ± 26	>1683 ± 122	>4106 ± 1385	>6K ± 0.4K
Sr	525 ± 19	548 ± 4.9	585 ± 11	329 ± 12	354 ± 4.4	377 ± 7.9
Tc	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.4 ± 0.1	0.6 ± 0.1	0.5 ± 0.2

Duolite™ C-467 Cation Exchange Resin. Duolite™ C-467, a chelating cation exchange resin composed of a polystyrene/divinylbenzene copolymer with aminophosphonic acid functionality, is manufactured by Rohm & Haas, Philadelphia, Pennsylvania. We air-dried this resin before testing for reasons detailed in section 2.1.3.

None of these five elements sorbs at a useful level from the two untreated solutions. Americium and strontium sorb well from the hydrothermal-treated solutions.

Table 14. Distribution of Five Elements onto Duolite™ C-467 Cation Exchange Resin from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	$<0.1 \pm 0.0$	0.2 ± 0.2	0.1 ± 0.1	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$
Cs	0.5 ± 0.0	0.6 ± 0.5	0.5 ± 0.2	0.6 ± 0.1	0.5 ± 0.0	0.6 ± 0.1
Pu	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.2	0.1 ± 0.0	$<0.1 \pm 0.0$	0.1 ± 0.1
Sr	2.9 ± 0.1	3.2 ± 0.3	3.1 ± 0.1	3.4 ± 0.1	3.7 ± 0.1	3.8 ± 0.0
Tc	3.7 ± 0.0	5.7 ± 0.2	7.4 ± 0.1	4.1 ± 0.2	5.3 ± 0.8	6.7 ± 1.5

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	1491 ± 21	2425 ± 232	4269 ± 2140	672 ± 36	2108 ± 551	3254 ± 293
Cs	0.2 ± 0.2	0.2 ± 0.0	0.2 ± 0.0	0.1 ± 0.1	0.3 ± 0.1	0.2 ± 0.0
Pu	3.5 ± 0.1	6.7 ± 0.1	11 ± 0.3	1.1 ± 0.1	2.1 ± 0.2	3.4 ± 0.0
Sr	420 ± 28	695 ± 37	809 ± 13	256 ± 2.5	405 ± 2.1	456 ± 3.4
Tc	17 ± 1.1	21 ± 3.0	25 ± 5.5	15 ± 0.2	17 ± 1.0	18 ± 1.2

Duolite™ CS-100 Cation Exchange Resin. Duolite™ CS-100, a phenol-formaldehyde condensate cation exchange resin, was manufactured by Rohm & Haas, Philadelphia, Pennsylvania. We air-dried this resin before testing for reasons detailed in section 2.1.3.

Cesium sorbs with at least double-digit Kd values from all four solutions; however, strontium and americium sorb more strongly than cesium from the hydrothermal-treated solutions at the longest contact

time. Duolite™ CS-100 resin was one of the few tested absorbers whose performance was poorer in the hydrothermal-treated solutions.

During all contacts with Duolite™ CS-100 resin, we observed a dark color in the simulant solutions whose intensity was proportional to the length of the contact time. The change in color is in accord with the reported degradation of this absorber in strong alkaline solution.¹⁹

Table 15. Distribution of Five Elements onto Duolite™ CS-100 Cation Exchange Resin from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	$<0.1 \pm 0.0$	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.3 ± 0.3	0.2 ± 0.2
Cs	116 ± 1.9	131 ± 1.2	126 ± 0.2	93 ± 0.0	111 ± 0.5	104 ± 2.6
Pu	0.3 ± 0.1	$<0.1 \pm 0.0$	0.1 ± 0.1	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$
Sr	0.7 ± 0.1	0.9 ± 0.0	1.0 ± 0.0	0.4 ± 0.2	1.1 ± 0.2	1.1 ± 0.1
Tc	0.5 ± 0.1	0.6 ± 0.0	0.6 ± 0.0	0.5 ± 0.2	1.0 ± 0.3	0.8 ± 0.0

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	12 ± 0.4	84 ± 19	571 ± 55	5.9 ± 0.0	41 ± 5.6	292 ± 14
Cs	45 ± 0.5	50 ± 0.8	50 ± 0.3	41 ± 0.1	46 ± 0.2	47 ± 0.5
Pu	9.2 ± 0.5	13 ± 0.8	16 ± 1.0	4.9 ± 0.2	6.6 ± 0.1	8.8 ± 0.0
Sr	21 ± 0.3	44 ± 5.0	77 ± 6.5	14 ± 0.3	34 ± 1.6	63 ± 2.1
Tc	0.3 ± 0.3	0.2 ± 0.0	0.2 ± 0.0	0.3 ± 0.1	0.6 ± 0.1	0.7 ± 0.0

Ionac™ SR-6 Anion Exchange Resin. Ionac™ SR-6, a macroporous anion exchange resin with tributyl amine as the functional group, is manufactured by Sybron Chemicals, Inc., Birmingham, New Jersey. We air-dried this resin before testing for reasons detailed in section 2.1.3.

Technetium sorbs strongly and selectively from all four solutions.

Table 16. Distribution of Five Elements onto Ionac™ SR-6 Anion Exchange Resin from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
Cs	0.4 ± 0.1	0.4 ± 0.0	0.5 ± 0.1	0.5 ± 0.1	0.3 ± 0.1	0.4 ± 0.0
Pu	<0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.4 ± 0.4	0.3 ± 0.0	0.4 ± 0.1
Sr	0.5 ± 0.1	0.6 ± 0.1	0.7 ± 0.0	0.5 ± 0.1	0.5 ± 0.1	0.6 ± 0.1
Tc	288 ± 4.1	634 ± 54	958 ± 32	305 ± 6.0	659 ± 7.1	950 ± 25

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.4 ± 0.1	0.6 ± 0.3	0.5 ± 0.2	<0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.1
Cs	0.3 ± 0.0	<0.1 ± 0.0	0.3 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.1	0.1 ± 0.0
Pu	<0.1 ± 0.0	0.2 ± 0.2	0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.1	<0.1 ± 0.0
Sr	0.5 ± 0.1	0.2 ± 0.1	0.5 ± 0.1	<0.1 ± 0.0	0.2 ± 0.1	0.3 ± 0.0
Tc	723 ± 27	1929 ± 62	2683 ± 215	696 ± 4.5	1439 ± 2.6	2314 ± 369

IONSIV™ IE-910 (CST) Powder. IONSIV™ IE-910 is a crystalline silico-titanate powder manufactured by UOP Molecular Sieves Division, Des Plaines, Illinois, under license from its developers at Sandia National Laboratories/NM and Texas A&M University. This absorber was used as received.

Cesium sorbs with at least four-digit Kd values from all four solutions. Americium and strontium also sorb well from the hydrothermal-treated solution. The fact that Kd values for sorption of americium and strontium from hydrothermal-treated solution are lower from irradiated solution indicates that their sorption is suppressed by some of the radiolyzed complexants that survive the hydrothermal treatment.

Table 17. Distribution of Five Elements onto IONSIV™ IE-910 (CST) Powder from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	0.3 ± 0.3	0.1 ± 0.1	0.1 ± 0.1
Cs	$5K \pm 0.4K$	$6K \pm 1K$	$7K \pm 0.3K$	$5K \pm 0.3K$	$7K \pm 0.2K$	$9K \pm 2K$
Pu	0.3 ± 0.1	0.2 ± 0.1	0.2 ± 0.0	$<0.1 \pm 0.1$	0.2 ± 0.0	0.2 ± 0.1
Sr	3.1 ± 0.2	5.1 ± 0.2	7.8 ± 0.0	5.5 ± 0.2	8.0 ± 0.0	11 ± 0.1
Tc	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	0.1 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	136 ± 2.3	231 ± 2.7	333 ± 13	42 ± 1.2	68 ± 1.1	93 ± 0.4
Cs	$>62K \pm 24K$	$>75K \pm 10K$	$>81K \pm 0.7K$	$>40K \pm 2.5K$	$>81K \pm 6K$	$>92K \pm 1.6K$
Pu	0.3 ± 0.3	0.2 ± 0.2	0.3 ± 0.0	0.2 ± 0.2	0.3 ± 0.1	0.4 ± 0.0
Sr	1533 ± 42	2434 ± 98	3054 ± 26	754 ± 20	1320 ± 64	1720 ± 14
Tc	$<0.1 \pm 0.0$	0.1 ± 0.1	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	0.1 ± 0.1	$<0.1 \pm 0.0$

IONSIV™ IE-96 Zeolite. IONSIV™ IE-96 is a zeolite absorber manufactured by UOP Molecular Sieves Division, Des Plaines, Illinois. This absorber was used as received.

Cesium sorbs well from all four solutions, with the Kd values somewhat higher for sorption from the hydrothermal-treated solutions. Americium and strontium also sorb well from the two treated solutions.

Table 18. Distribution of Five Elements onto IONSIV™ IE-96 Zeolite from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.3 ± 0.4	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Cs	112 ± 2.1	198 ± 4.5	247 ± 2.7	105 ± 0.9	200 ± 2.1	259 ± 1.1
Pu	0.1 ± 0.1	<0.1 ± 0.0	0.2 ± 0.2	0.3 ± 0.3	0.1 ± 0.0	0.1 ± 0.1
Sr	0.5 ± 0.2	0.6 ± 0.0	0.6 ± 0.1	0.3 ± 0.1	0.5 ± 0.1	0.5 ± 0.1
Tc	0.5 ± 0.2	0.6 ± 0.0	0.7 ± 0.2	0.5 ± 0.0	0.8 ± 0.1	0.8 ± 0.2

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	1536 ± 365	>6K ± 1.4K	5K ± 0.6K	144 ± 42	>4144 ± 851	7K ± 0.1K
Cs	226 ± 1.8	421 ± 0.7	503 ± 1.6	183 ± 8.9	336 ± 12	413 ± 2.9
Pu	1.0 ± 0.1	1.1 ± 0.0	1.6 ± 0.0	0.4 ± 0.0	0.6 ± 0.1	0.7 ± 0.2
Sr	74 ± 0.9	310 ± 2.3	662 ± 0.9	37 ± 6.4	218 ± 12	471 ± 32
Tc	0.1 ± 0.1	<0.1 ± 0.0	0.2 ± 0.0	0.3 ± 0.4	0.4 ± 0.0	0.4 ± 0.1

IONSIV™ TIE-96 Titanium-Loaded Zeolite.

IONSIV™ TIE-96 is a titanium-loaded zeolite absorber manufactured by UOP Molecular Sieves Division, Des Plaines, Illinois. This absorber was used as received.

Cesium sorbs well from all four solutions, but the Kd values are somewhat higher for sorption from the hydrothermal-treated solutions. Americium and strontium also sorb well from the two treated solutions.

Table 19. Distribution of Five Elements onto IONSIV™ TIE-96 Titanium-Loaded Zeolite from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.1 ± 0.1	0.2 ± 0.1	<0.1 ± 0.0	0.4 ± 0.2	0.3 ± 0.3	0.4 ± 0.4
Cs	76 ± 0.4	159 ± 1.5	217 ± 3.2	74 ± 4.7	156 ± 10	217 ± 11
Pu	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
Sr	2.9 ± 0.0	5.3 ± 0.3	7.3 ± 0.1	2.7 ± 0.3	5.0 ± 0.3	7.1 ± 0.5
Tc	0.3 ± 0.1	0.4 ± 0.1	0.3 ± 0.0	0.4 ± 0.3	0.5 ± 0.3	0.8 ± 0.4

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	50 ± 1.8	173 ± 3.0	428 ± 7.8	28 ± 2.3	90 ± 7.5	217 ± 14
Cs	153 ± 2.2	313 ± 2.5	422 ± 3.1	129 ± 6.6	254 ± 11	326 ± 8.0
Pu	4.3 ± 0.4	7.6 ± 0.0	11 ± 0.1	1.5 ± 0.2	2.6 ± 0.1	3.9 ± 0.1
Sr	30 ± 0.5	74 ± 0.7	139 ± 1.1	25 ± 0.9	58 ± 1.2	107 ± 1.7
Tc	0.3 ± 0.0	0.3 ± 0.0	0.2 ± 0.0	0.1 ± 0.1	0.2 ± 0.1	0.3 ± 0.0

Monosodium Titanate (BSC-265-0106). Monosodium titanate (BSC-265-0106) was obtained from Boulder Scientific Company, Mead, Colorado, as a slurry in 0.5% NaOH solution. We removed the bulk of the solution by vacuum filtration and then air-dried the solid absorber to constant weight before use.

Strontium sorbs well from the two untreated solutions but sorbs much more strongly from the hydrothermal-treated solutions. Americium and plutonium also sorb well from the two treated solutions.

Table 20. Distribution of Five Elements onto Monosodium Titanate (BSC-265-0106) from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.2 ± 0.1	0.6 ± 0.3	0.6 ± 0.2	0.8 ± 0.1	0.8 ± 0.3	0.8 ± 0.0
Cs	1.9 ± 0.2	2.0 ± 0.4	1.7 ± 0.2	2.0 ± 0.0	1.9 ± 0.3	1.6 ± 0.1
Pu	$<0.1 \pm 0.0$	0.3 ± 0.3	0.1 ± 0.1	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	0.1 ± 0.1
Sr	37 ± 0.7	61 ± 1.5	69 ± 1.6	74 ± 1.1	121 ± 3.0	135 ± 0.4
Tc	$<0.1 \pm 0.0$	0.2 ± 0.2	0.2 ± 0.0	0.4 ± 0.1	0.4 ± 0.2	0.3 ± 0.0

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	$8K \pm 0.3K$	$>5K \pm 0.1K$	$>6K \pm 1.4K$	2629 ± 550	$>5K \pm 0.1K$	$>5K \pm 0.1K$
Cs	7.7 ± 0.1	7.3 ± 0.0	7.3 ± 0.0	5.6 ± 0.1	5.3 ± 0.0	4.9 ± 0.1
Pu	91 ± 5.7	220 ± 12	379 ± 31	43 ± 4.1	92 ± 8.0	166 ± 14
Sr	3152 ± 290	3617 ± 545	4474 ± 139	3221 ± 152	3633 ± 129	$5K \pm 1.2K$
Tc	0.2 ± 0.0	$<0.1 \pm 0.0$	0.2 ± 0.1	$<0.1 \pm 0.0$	0.1 ± 0.1	$<0.1 \pm 0.0$

Nusorb™ Ferrocabon A. Nusorb™ Ferrocabon A is a carbon/iron oxide composite manufactured by Nucon International, Inc., Columbus, Ohio. This absorber was used as received.

All five elements sorb with lower than double-digit Kd values from the untreated solutions; however, americium and strontium sorb well, whereas technetium sorbs slightly, from the two treated solutions.

Table 21. Distribution of Five Elements onto Nusorb™ Ferrocabon A from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	0.1 ± 0.1	$<0.1 \pm 0.0$	0.1 ± 0.1
Cs	1.9 ± 0.2	2.9 ± 0.3	3.7 ± 0.2	1.8 ± 0.1	2.7 ± 0.2	3.3 ± 0.1
Pu	0.2 ± 0.2	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.2	0.2 ± 0.2	0.2 ± 0.0
Sr	0.5 ± 0.1	0.8 ± 0.2	1.7 ± 0.1	0.4 ± 0.1	1.0 ± 0.1	1.6 ± 0.1
Tc	2.5 ± 0.1	4.9 ± 0.1	7.8 ± 0.1	2.0 ± 0.1	4.5 ± 0.0	7.8 ± 0.0

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	156 ± 18	563 ± 91	1431 ± 404	45 ± 1.2	164 ± 8.1	433 ± 7.4
Cs	2.8 ± 0.0	4.5 ± 0.1	5.4 ± 0.1	2.3 ± 0.1	3.4 ± 0.1	4.1 ± 0.1
Pu	0.6 ± 0.0	1.4 ± 0.3	3.1 ± 0.6	0.2 ± 0.1	0.7 ± 0.3	1.1 ± 0.2
Sr	213 ± 18	506 ± 57	831 ± 8.8	88 ± 3.5	266 ± 3.7	493 ± 13
Tc	5.0 ± 0.1	9.5 ± 0.5	16 ± 0.5	4.6 ± 0.4	8.2 ± 0.1	13 ± 0.5

Purolite™ A-520-E Anion Exchange Resin. Purolite™ A-520-E, a macroporous strong-base anion exchange resin with triethyl amine as the functional group, was obtained from the Purolite Company, Bala Cynwyd, Pennsylvania. We air-dried this resin before testing for reasons detailed in section 2.1.3.

Technetium is strongly and selectively sorbed from all four solutions with Kd values increasing somewhat for sorption from the hydrothermal-treated solutions.

Table 22. Distribution of Five Elements onto Purolite™ A-520-E Anion Exchange Resin from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.2	0.9 ± 0.1	0.8 ± 0.4	0.8 ± 0.2
Cs	0.6 ± 0.1	0.6 ± 0.1	0.6 ± 0.2	0.8 ± 0.1	0.7 ± 0.4	0.8 ± 0.2
Pu	0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
Sr	0.7 ± 0.0	0.7 ± 0.0	0.7 ± 0.1	0.9 ± 0.0	1.0 ± 0.4	1.0 ± 0.1
Tc	435 ± 20	775 ± 32	1033 ± 76	526 ± 85	939 ± 85	1112 ± 25

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.4 ± 0.2	0.4 ± 0.1	0.5 ± 0.0	0.3 ± 0.3	0.2 ± 0.2	0.2 ± 0.2
Cs	0.4 ± 0.1	0.5 ± 0.1	0.4 ± 0.0	0.3 ± 0.2	0.3 ± 0.1	0.4 ± 0.1
Pu	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	<0.1 ± 0.0
Sr	0.4 ± 0.2	0.5 ± 0.2	0.6 ± 0.2	0.5 ± 0.3	1.1 ± 0.1	1.2 ± 0.3
Tc	1212 ± 22	3209 ± 1109	3629 ± 527	990 ± 133	2218 ± 110	4231 ± 721

Reillex™ HPQ Anion Exchange Resin. Reillex™ HPQ anion exchange resin, a copolymer of 1-methyl-4-vinylpyridine and divinylbenzene, was manufactured by Reilly Industries, Inc., Indianapolis, Indiana. We air-dried this resin before testing for reasons detailed in section 2.1.3.

Technetium is strongly and selectively sorbed from all four solutions, but the Kd values more than double for sorption from the hydrothermal-treated solution.

Table 23. Distribution of Five Elements onto Reillex™ HPQ Anion Exchange Resin from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.2 ± 0.2	0.1 ± 0.1	<0.1 ± 0.0	0.5 ± 0.2	0.5 ± 0.1	0.4 ± 0.1
Cs	0.4 ± 0.3	0.3 ± 0.1	0.3 ± 0.0	0.6 ± 0.3	0.6 ± 0.2	0.6 ± 0.1
Pu	<0.1 ± 0.0	0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
Sr	0.3 ± 0.2	0.3 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	0.5 ± 0.2	0.5 ± 0.0
Tc	373 ± 17	497 ± 0.1	490 ± 0.9	381 ± 40	493 ± 34	490 ± 17

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.1	0.3 ± 0.2	0.4 ± 0.2	0.3 ± 0.2
Cs	0.3 ± 0.1	0.3 ± 0.0	0.2 ± 0.0	0.5 ± 0.1	0.6 ± 0.1	0.6 ± 0.2
Pu	0.3 ± 0.3	0.2 ± 0.0	0.2 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
Sr	0.2 ± 0.1	0.2 ± 0.0	0.2 ± 0.0	0.5 ± 0.0	0.7 ± 0.2	0.6 ± 0.2
Tc	846 ± 46	1088 ± 30	1181 ± 97	692 ± 13	1048 ± 151	1081 ± 12

Resorcinol/Formaldehyde Resin (BSC-210). Resorcinol/formaldehyde resin (BSC-210), manufactured by Boulder Scientific Company, Mead, Colorado, was provided to us by Jane Bibler of Westinghouse Savannah River Company, whose directions we followed to convert it from the as-received potassium form to a sodium form. We air-dried this resin before testing for reasons detailed in section 2.1.3.

Cesium sorbs strongly from all four solutions. From the two hydrothermal-treated solutions, strontium also sorbs at useful levels.

During all contacts with the resorcinol/formaldehyde resin, the simulant solutions acquired a dark color whose intensity was proportional to the length of the contact time. The change in color indicates some leaching of this absorber in strong alkaline solution.

Table 24. Distribution of Five Elements onto Resorcinol/Formaldehyde Resin (BSC-210) from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.1 ± 0.1	0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
Cs	1266 ± 46	3571 ± 34	6K ± 0.6K	1055 ± 120	3282 ± 159	5K ± 0.1K
Pu	0.2 ± 0.3	0.2 ± 0.3	0.1 ± 0.1	0.4 ± 0.0	0.3 ± 0.0	0.4 ± 0.1
Sr	0.5 ± 0.4	0.8 ± 0.1	0.9 ± 0.0	0.3 ± 0.1	0.6 ± 0.1	0.8 ± 0.0
Tc	0.9 ± 0.2	1.3 ± 0.1	1.8 ± 0.3	0.8 ± 0.1	1.1 ± 0.1	1.3 ± 0.1

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	9.4 ± 0.0	12 ± 0.4	13 ± 0.2	3.7 ± 0.3	4.6 ± 0.0	4.9 ± 0.1
Cs	1449 ± 7.1	3759 ± 71	6K ± 0.3K	1226 ± 91	2952 ± 9.3	5K ± 0.3K
Pu	<0.1 ± 0.0	0.1 ± 0.1	0.3 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
Sr	48 ± 0.2	47 ± 0.2	46 ± 0.2	27 ± 0.3	27 ± 0.7	26 ± 0.1
Tc	0.1 ± 0.1	0.2 ± 0.0	0.4 ± 0.0	0.5 ± 0.2	0.8 ± 0.1	0.7 ± 0.1

Tannin. Tannin absorber was obtained from Mitsubishi Nuclear Fuels Corporation, Japan. We air-dried this absorber before testing for reasons detailed in section 2.1.3.

Cesium sorbs at low double-digit Kd values from all four solutions. Americium and plutonium sorb well and strontium sorbs moderately from the hydrothermal-

treated solutions. The fact that Kd values for the multivalent cations from hydrothermal-treated solution are lower for irradiated solution indicates that their sorption is suppressed by some of the radiolyzed complexants that survive the hydrothermal treatment.

Table 25. Distribution of Five Elements onto Tannin from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	$<0.1 \pm 0.0$	0.2 ± 0.2	0.1 ± 0.1	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$
Cs	23 ± 0.7	31 ± 1.1	34 ± 0.7	18 ± 1.3	25 ± 0.9	28 ± 0.6
Pu	0.2 ± 0.0	0.1 ± 0.1	0.2 ± 0.1	0.5 ± 0.1	0.2 ± 0.1	0.4 ± 0.0
Sr	0.4 ± 0.2	1.3 ± 0.2	2.3 ± 0.1	0.7 ± 0.0	1.5 ± 0.1	3.0 ± 0.1
Tc	3.0 ± 0.1	8.1 ± 0.6	18 ± 1.0	2.5 ± 0.2	6.9 ± 0.1	21 ± 0.6

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	23 ± 0.6	100 ± 5.4	249 ± 1.0	11 ± 2.1	41 ± 8.5	115 ± 14
Cs	13 ± 0.1	14 ± 0.1	13 ± 0.2	12 ± 0.1	13 ± 0.1	13 ± 0.1
Pu	43 ± 2.0	378 ± 54	1714 ± 301	22 ± 5.0	170 ± 59	552 ± 5.7
Sr	19 ± 0.2	27 ± 0.3	31 ± 0.3	14 ± 0.2	21 ± 0.2	23 ± 0.2
Tc	1.8 ± 0.1	3.6 ± 0.2	5.9 ± 0.2	1.7 ± 0.5	3.7 ± 0.8	6.6 ± 0.4

TEVA-Spec™ Extractant Resin. TEVA-Spec™, an aliphatic quaternary ammonium salt (Aliquat™ 336) on an acrylic ester nonionic polymeric adsorbent, was obtained from Eichrom Industries, Inc., Darien, Illinois. These extractant beads were used as received.

Technetium sorbs well and selectively from all four solutions, as it does with the low-cost, LANL-prepared Aliquat™ 336 extractant beads (see section 2.2.2.3).

Table 26. Distribution of Five Elements onto TEVA-Spec™ Extractant Resin from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.6 ± 0.2	0.3 ± 0.1	0.4 ± 0.2	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
Cs	0.9 ± 0.1	0.8 ± 0.2	0.8 ± 0.1	0.4 ± 0.1	0.3 ± 0.1	0.4 ± 0.1
Pu	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.4 ± 0.0	0.3 ± 0.2	0.4 ± 0.0
Sr	0.9 ± 0.1	0.9 ± 0.2	0.9 ± 0.1	0.3 ± 0.0	0.3 ± 0.0	0.4 ± 0.0
Tc	1129 ± 5.8	1348 ± 41	1277 ± 38	1202 ± 40	1439 ± 74	1437 ± 41

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.5 ± 0.0	0.5 ± 0.1	0.8 ± 0.1	0.2 ± 0.2	0.3 ± 0.2	0.4 ± 0.0
Cs	0.4 ± 0.2	0.3 ± 0.1	0.5 ± 0.1	0.1 ± 0.0	0.2 ± 0.2	0.2 ± 0.1
Pu	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
Sr	0.6 ± 0.2	0.6 ± 0.1	0.8 ± 0.1	0.2 ± 0.1	0.4 ± 0.1	0.5 ± 0.1
Tc	2709 ± 47	4368 ± 515	3681 ± 1127	2470 ± 298	4226 ± 506	4402 ± 465

TRU-Spec™ Extractant Resin. TRU-Spec™ extractant resin, a mixture of 13% CMPO (octylphenyl-N, N-diisobutylcarbamoylmethylphosphine oxide) and 27% TBP (tributyl phosphate) on polyacrylic beads, was obtained

from Eichrom Industries, Inc., Darien, Illinois. This absorber was used as received.

Only technetium sorbs even slightly from the four solutions.

Table 27. Distribution of Five Elements onto TRU-Spec™ Extractant Resin from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.2 ± 0.2	0.1 ± 0.0	0.2 ± 0.0	<0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0
Cs	0.4 ± 0.1	0.4 ± 0.0	0.5 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	0.4 ± 0.0
Pu	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.1	0.4 ± 0.2	0.3 ± 0.1
Sr	0.6 ± 0.1	0.5 ± 0.0	0.7 ± 0.0	0.3 ± 0.2	0.4 ± 0.1	0.4 ± 0.0
Tc	10 ± 0.0	10 ± 0.1	10 ± 0.1	11 ± 0.0	11 ± 0.1	11 ± 0.2

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.4 ± 0.4	1.0 ± 0.5	0.6 ± 0.2	<0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.1
Cs	0.4 ± 0.3	0.4 ± 0.4	0.2 ± 0.1	0.2 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0
Pu	<0.1 ± 0.0	0.1 ± 0.1	<0.1 ± 0.0	0.2 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Sr	0.6 ± 0.3	0.6 ± 0.4	0.5 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.3 ± 0.1
Tc	12 ± 0.6	13 ± 1.4	11 ± 0.1	11 ± 0.4	11 ± 0.6	10 ± 0.3

UTEVA-Spec™ Extractant Resin. UTEVA-Spec™, a dipentylphosphonate on an acrylic ester nonionic polymeric adsorbent, was obtained from Eichrom Industries, Inc., Darien, Illinois. This absorber was used as received.

UTEVA-Spec™ sorbs none of the five elements from the four solutions with useful Kd values.

Table 28. Distribution of Five Elements onto UTEVA-Spec™ Extractant Resin from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.5 ± 0.1	0.3 ± 0.0	0.3 ± 0.2	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
Cs	0.7 ± 0.3	0.6 ± 0.2	0.5 ± 0.3	0.2 ± 0.0	0.2 ± 0.2	0.2 ± 0.2
Pu	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.1	0.5 ± 0.1	0.6 ± 0.6	0.7 ± 0.6
Sr	0.8 ± 0.3	0.6 ± 0.2	0.5 ± 0.3	0.1 ± 0.1	0.2 ± 0.2	0.2 ± 0.2
Tc	4.9 ± 0.4	4.2 ± 0.0	4.2 ± 0.3	4.1 ± 0.1	4.1 ± 0.1	3.9 ± 0.3

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.6 ± 0.0	0.5 ± 0.1	0.5 ± 0.1	<0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.1
Cs	0.5 ± 0.0	0.3 ± 0.1	0.4 ± 0.2	0.1 ± 0.1	<0.1 ± 0.0	0.1 ± 0.1
Pu	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.1	<0.1 ± 0.0	0.1 ± 0.1
Sr	0.8 ± 0.1	0.7 ± 0.1	0.7 ± 0.2	0.3 ± 0.0	0.3 ± 0.0	0.4 ± 0.1
Tc	5.7 ± 0.1	5.4 ± 0.1	5.1 ± 0.2	5.0 ± 0.0	4.9 ± 0.2	4.6 ± 0.1

2.2.2.2 Developmental Absorbers. Our study included seven developmental absorbers.

CSbA-PAN (Crystalline Antimonic Acid) Composite. CSbA-PAN crystalline antimonic acid composite was prepared and supplied by Ferdinand Sebesta of the Czech Technical University, Prague, Czech Republic. This composite was air-dried before use for reasons detailed in section 2.1.3.

Only strontium sorbs well from the two untreated solutions. From the hydrothermal-treated solutions, both americium and strontium sorb strongly. The fact that K_d values for sorption of plutonium are lower from irradiated hydrothermal-treated solution than from unirradiated/hydrothermal-treated solution indicates that some of the complexants produced by gamma radiolysis survive the hydrothermal treatment and interfere with sorption.

Table 29. Distribution of Five Elements onto CSbA-PAN Composite from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.4 ± 0.3	0.4 ± 0.1	0.4 ± 0.0	0.6 ± 0.1	0.7 ± 0.2	0.7 ± 0.0
Cs	$<0.1 \pm 0.0$	0.4 ± 0.1	0.3 ± 0.3	0.7 ± 0.1	0.7 ± 0.2	0.8 ± 0.1
Pu	0.1 ± 0.1	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$
Sr	48 ± 2.8	88 ± 3.5	111 ± 4.3	47 ± 0.2	79 ± 1.9	94 ± 0.5
Tc	0.8 ± 0.1	1.2 ± 0.1	1.3 ± 0.3	1.5 ± 0.0	2.2 ± 0.8	2.1 ± 0.2

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	2397 ± 58	$>4618 \pm 42$	$>4773 \pm 131$	2167 ± 363	$>4503 \pm 18$	$>4584 \pm 40$
Cs	0.4 ± 0.0	0.3 ± 0.1	0.3 ± 0.1	$<0.1 \pm 0.0$	0.1 ± 0.1	$<0.1 \pm 0.0$
Pu	6.9 ± 0.6	14 ± 1.5	30 ± 1.9	1.5 ± 0.1	2.4 ± 0.2	4.0 ± 0.1
Sr	2434 ± 29	3722 ± 340	4027 ± 915	2254 ± 58	3732 ± 177	4957 ± 581
Tc	1.5 ± 0.3	1.6 ± 0.1	1.7 ± 0.1	1.0 ± 0.2	1.1 ± 0.3	1.3 ± 0.1

KCoFC (Potassium Hexacyanoferrate) Crystals. This inorganic absorber, consisting of 150- to 600- μ m crystals, was prepared at Oak Ridge National Laboratory using the procedure described by Prout²⁰ with a minor modification. This absorber was used as received.

Cesium sorbs well from all four solutions. It sorbs much more strongly, and americium and strontium also sorb, from the two hydrothermal-treated solutions. For cesium, the decreasing Kd values with increased contact time may reflect a complexant-induced dissolution of the absorber that explains the rapid appearance of the characteristic red color of cobalt that we observed when it was contacted with the untreated solutions.

Table 30. Distribution of Five Elements onto KCoFC Crystals from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	<0.1 $\pm$ 0.0	<0.1 $\pm$ 0.0	0.1 $\pm$ 0.1	0.2 $\pm$ 0.1	<0.1 $\pm$ 0.0	<0.1 $\pm$ 0.0
Cs	1097 $\pm$ 47	552 $\pm$ 7.6	66 $\pm$ 16	1500 $\pm$ 119	960 $\pm$ 22	332 $\pm$ 23
Pu	0.5 $\pm$ 0.4	0.4 $\pm$ 0.1	0.5 $\pm$ 0.3	<0.1 $\pm$ 0.0	0.1 $\pm$ 0.1	0.2 $\pm$ 0.1
Sr	3.7 $\pm$ 0.1	3.5 $\pm$ 0.0	2.9 $\pm$ 0.1	3.1 $\pm$ 0.1	3.6 $\pm$ 0.1	3.4 $\pm$ 0.1
Tc	0.1 $\pm$ 0.0	0.3 $\pm$ 0.0	0.4 $\pm$ 0.1	0.2 $\pm$ 0.0	0.4 $\pm$ 0.2	0.4 $\pm$ 0.1

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	263 $\pm$ 20	556 $\pm$ 28	928 $\pm$ 15	127 $\pm$ 5.3	269 $\pm$ 5.8	443 $\pm$ 17
Cs	23K $\pm$ 4.5K	74K $\pm$ 13K	63K $\pm$ 41K	28K $\pm$ 5K	64K $\pm$ 46K	63K $\pm$ 51K
Pu	6.9 $\pm$ 0.2	7.4 $\pm$ 0.1	8.0 $\pm$ 0.2	2.9 $\pm$ 0.1	3.0 $\pm$ 0.1	3.6 $\pm$ 0.0
Sr	62 $\pm$ 1.5	81 $\pm$ 0.7	93 $\pm$ 0.7	54 $\pm$ 1.2	67 $\pm$ 0.6	77 $\pm$ 0.3
Tc	<0.1 $\pm$ 0.0	<0.1 $\pm$ 0.0	<0.1 $\pm$ 0.0	<0.1 $\pm$ 0.0	0.4 $\pm$ 0.4	0.3 $\pm$ 0.1

KCoFC-PAN (Potassium Hexacyanoferrate)

Composite. This potassium hexacyanoferrate-polyacrylonitrile composite was prepared by Ferdinand Sebesta of the Czech Technical University, Prague, Czech Republic. We air-dried this composite before testing for reasons detailed in section 2.1.3.

The behavior of this composite is generally similar to that of the KCoFC crystals although these Kd values for sorption of cesium from the untreated solutions, and for sorption of americium and strontium from the hydrothermal-treated solutions, are lower. The fact that these Kd values decrease less with increased contact time in the untreated solutions suggests that this material may be less affected by organic complexants.

Table 31. Distribution of Five Elements onto KCoFC-PAN Composite from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	0.1 ± 0.1	0.3 ± 0.0	0.2 ± 0.1
Cs	255 ± 4.2	205 ± 6.6	263 ± 6.7	337 ± 6.0	180 ± 3.2	180 ± 2.2
Pu	0.5 ± 0.1	0.5 ± 0.1	0.6 ± 0.2	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	0.1 ± 0.1
Sr	1.5 ± 0.4	1.4 ± 0.2	1.7 ± 0.1	0.5 ± 0.2	1.1 ± 0.1	1.2 ± 0.2
Tc	1.3 ± 0.5	1.3 ± 0.3	1.4 ± 0.2	0.8 ± 0.1	1.3 ± 0.2	1.4 ± 0.1

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	20 ± 0.0	38 ± 0.3	79 ± 1.1	8.9 ± 0.3	16 ± 0.2	26 ± 0.5
Cs	$9K \pm 0.5K$	$>88K \pm 0.1K$	$>90K \pm 1.5K$	$11K \pm 1.3K$	$>100K \pm 3K$	$>98K \pm 0.9K$
Pu	2.8 ± 0.0	4.4 ± 0.1	6.3 ± 0.2	0.4 ± 0.2	1.3 ± 0.0	1.7 ± 0.1
Sr	5.9 ± 0.2	8.7 ± 0.1	13 ± 0.0	4.7 ± 0.1	7.1 ± 0.1	9.9 ± 0.1
Tc	0.9 ± 0.0	1.3 ± 0.0	1.4 ± 0.1	1.0 ± 0.1	1.0 ± 0.0	1.1 ± 0.1

NiFC-PAN (Nickel Hexacyanoferrate) Composite.

This nickel hexacyanoferrate polyacrylonitrile composite, an improved version of the NiFC-PAN we tested in our earlier studies, was prepared by Ferdinand Sebesta of the Czech Technical University, Prague, Czech Republic. We air-dried this composite before testing for reasons detailed in section 2.1.3.

Cesium sorbs well from all four solutions, although the K_d values are much higher for sorption from the hydrothermal-treated solutions. Americium and strontium also sorb at useful levels from the treated solutions. The decreasing K_d values for cesium with increased contact time in the untreated solutions coincide with the rapid appearance of the characteristic green color of nickel, which indicates poor stability of this absorber in the presence of organic complexants.

Table 32. Distribution of Five Elements onto NiFC-PAN Composite (improved) from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	$<0.1 \pm 0.0$	0.1 ± 0.1	$<0.1 \pm 0.0$	0.3 ± 0.1	0.2 ± 0.0	0.2 ± 0.0
Cs	673 ± 6.9	382 ± 15	221 ± 8.5	538 ± 8.6	255 ± 4.6	153 ± 6.2
Pu	0.4 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	$<0.1 \pm 0.0$	0.1 ± 0.1	0.1 ± 0.1
Sr	0.7 ± 0.0	0.8 ± 0.1	1.0 ± 0.1	0.8 ± 0.1	0.9 ± 0.1	0.8 ± 0.1
Tc	1.0 ± 0.1	1.3 ± 0.0	1.4 ± 0.2	1.0 ± 0.0	1.6 ± 0.6	1.6 ± 0.6

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	77 ± 0.0	177 ± 1.0	358 ± 7.9	34 ± 0.7	76 ± 0.2	154 ± 6.0
Cs	$14K \pm 4.6K$	$>93K \pm 1K$	$>94K \pm 0.4K$	$9K \pm 0.2K$	$>101K \pm 0.1K$	$>100K \pm 3K$
Pu	1.2 ± 0.1	2.0 ± 0.3	3.6 ± 0.1	$<0.1 \pm 0.0$	0.3 ± 0.1	0.9 ± 0.1
Sr	20 ± 0.2	26 ± 0.2	34 ± 0.4	17 ± 0.0	22 ± 0.2	27 ± 0.3
Tc	1.0 ± 0.1	1.0 ± 0.4	1.4 ± 0.0	1.1 ± 0.2	1.2 ± 0.2	1.1 ± 0.0

Sodium Nanotitanate (8104-170). A sodium nanotitanate absorber (8104-170, <100 mesh) of proprietary composition was provided by Allied Signal, Inc., Research and Technology, Des Plaines, Illinois. This absorber was used as received.

Although strontium sorbs reasonably well even from the untreated solutions, its K_d values for sorption from the hydrothermal-treated solutions are two orders of

magnitude higher. Americium and plutonium also sorb well from the two treated solutions. The fact that K_d values for sorption of plutonium from hydrothermal-treated solution are lower for sorption from the irradiated solution indicates that its sorption is suppressed by some of the radiolyzed complexants that survive the hydrothermal treatment.

Table 33. Distribution of Five Elements onto Sodium Nanotitanate (8104-170) from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.9 ± 0.1	1.4 ± 0.2	2.1 ± 0.1	1.0 ± 0.2	1.2 ± 0.1	1.2 ± 0.1
Cs	1.2 ± 0.1	1.1 ± 0.0	1.3 ± 0.0	1.7 ± 0.3	1.8 ± 0.1	1.7 ± 0.1
Pu	0.3 ± 0.1	0.4 ± 0.3	0.5 ± 0.0	0.2 ± 0.2	0.1 ± 0.1	0.1 ± 0.1
Sr	40 ± 2.4	70 ± 3.9	99 ± 6.3	38 ± 0.7	67 ± 0.1	91 ± 0.7
Tc	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.4 ± 0.2	0.4 ± 0.1	0.3 ± 0.1

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	7K ± 1.7K	>4824 ± 57	>4831 ± 67	6K ± 1.3K	>4815 ± 5.0	>7K ± 2.7K
Cs	4.7 ± 0.0	4.8 ± 0.2	4.9 ± 0.1	3.1 ± 0.0	3.2 ± 0.0	3.4 ± 0.0
Pu	269 ± 33	439 ± 8.0	656 ± 179	98 ± 2.1	168 ± 4.7	244 ± 1.4
Sr	5K ± 0.7K	8K ± 1.3K	13K ± 0.4K	3710 ± 387	6K ± 1.4K	6K ± 0.2K
Tc	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.1

Sodium Nanotitanate (8225-127). A sodium nanotitanate (8225-127, <40 mesh) absorber of proprietary composition was provided by Allied Signal, Inc., Research and Technology, Des Plaines, Illinois. This absorber was used as received.

Strontium is sorbed well from the two untreated solutions. Americium, strontium, and plutonium sorb well from the hydrothermal-treated solutions. Of the 33 absorbers tested, this is one of the best for sorbing strontium from the untreated organic-containing simulants.

Table 34. Distribution of Five Elements onto Sodium Nanotitanate (8225-127) from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.5 ± 0.3	1.1 ± 0.1	1.4 ± 0.0	0.3 ± 0.2	0.4 ± 0.2	0.5 ± 0.1
Cs	2.7 ± 0.1	2.9 ± 0.0	2.8 ± 0.0	3.0 ± 0.1	3.2 ± 0.1	3.1 ± 0.1
Pu	0.1 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.1 ± 0.1	<0.1 ± 0.0	0.1 ± 0.0
Sr	100 ± 1.4	179 ± 2.5	238 ± 2.1	80 ± 0.8	133 ± 3.2	169 ± 0.3
Tc	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.0	0.2 ± 0.2	0.1 ± 0.1

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	>4549 ± 894	>6K ± 0.5K	8K ± 1.6K	>2929 ± 666	>5K ± 0.1K	5K ± 0.1K
Cs	14 ± 0.2	14 ± 0.3	14 ± 0.1	9.0 ± 0.0	9.0 ± 0.2	9.2 ± 0.0
Pu	201 ± 4.0	350 ± 8.2	477 ± 30	97 ± 1.5	160 ± 0.9	201 ± 3.4
Sr	4776 ± 566	7K ± 1.4K	11K ± 0.2K	3639 ± 130	4331 ± 614	9K ± 0.9K
Tc	<0.1 ± 0.0	0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0

SuperLig™ 644 Particles. SuperLig™ 644, a proprietary macrocycle absorber, was prepared by IBC Advanced Technologies, Inc., American Fork, Utah, and was provided to us by 3M Industrial and Consumer Sector, New Products Department, St. Paul, Minnesota. This absorber was used as received.

Cesium is consistently sorbed well from all four solutions. At the longest contact times, americium and strontium are also sorbed at useful levels from the two

hydrothermal-treated solutions. The observed pattern of higher sorption from the unirradiated treated solutions, whether they are hydrothermal-treated or not, is unusual. The exceptionally slow sorption kinetics for americium, cesium, and strontium also are unusual. To be fair, however, we should state that the developers of this absorber propose that it be used as fine particles embedded in membranes rather than as the coarse particles we used in this test.

Table 35. Distribution of Five Elements onto SuperLig™ 644 Particles from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.2 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	0.2 ± 0.2	0.1 ± 0.1	0.1 ± 0.1
Cs	713 ± 104	2452 ± 192	4482 ± 412	342 ± 15	1563 ± 18	2935 ± 158
Pu	<0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.2	0.2 ± 0.1	0.2 ± 0.2
Sr	0.5 ± 0.1	0.6 ± 0.1	0.8 ± 0.1	0.4 ± 0.3	0.4 ± 0.0	0.6 ± 0.2
Tc	0.6 ± 0.1	0.7 ± 0.1	0.8 ± 0.2	0.5 ± 0.2	0.6 ± 0.1	0.7 ± 0.1

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.4 ± 0.2	2.3 ± 0.1	1392 ± 652	<0.1 ± 0.0	1.3 ± 0.2	211 ± 7.6
Cs	36 ± 0.6	209 ± 13	624 ± 35	30 ± 1.6	186 ± 4.2	590 ± 23
Pu	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0
Sr	1.3 ± 0.2	4.5 ± 0.1	68 ± 4.9	1.0 ± 0.1	3.3 ± 0.3	56 ± 1.8
Tc	0.7 ± 0.1	0.7 ± 0.1	0.8 ± 0.0	0.6 ± 0.2	0.4 ± 0.2	0.7 ± 0.0

2.2.2.3 Experimental Absorbers. Six experimental absorbers were included in our study.

Aliquat™ 336 Extractant Beads. We combined one volume of Aliquat™ 336 (methyltricaprylammonium chloride), obtained from Aldrich Chemical Co., Milwaukee, Wisconsin, with one volume of hexane and added Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas, Philadelphia, Pennsylvania, to absorb the liquid. After evaporation of the volatile hexane, the dry-appearing loaded beads contained 0.277 g of Aliquat™ 336 per gram of beads.

These extractant beads sorb technetium strongly and selectively from all four solutions. Although the cost of these easily prepared beads is two orders of magnitude lower, the performance is comparable to that of TEVA-Spec™, the commercial equivalent (see section 2.2.2.1). We attribute the difference in the 30-min Kd values to the much smaller size of the TEVA-Spec™ resin.

Table 36. Distribution of Five Elements onto Aliquat™ 336 Extractant Beads from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.2 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.6 ± 0.0	0.5 ± 0.4	0.7 ± 0.2
Cs	<0.1 ± 0.0	0.3 ± 0.1	0.4 ± 0.1	0.7 ± 0.0	0.6 ± 0.2	0.8 ± 0.1
Pu	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
Sr	0.2 ± 0.0	0.5 ± 0.2	0.6 ± 0.1	0.9 ± 0.1	0.8 ± 0.2	1.0 ± 0.2
Tc	600 ± 10	1149 ± 20	1271 ± 25	827 ± 11	1345 ± 38	1418 ± 11

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	<0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.2	0.4 ± 0.0	0.4 ± 0.1
Cs	0.3 ± 0.1	0.3 ± 0.2	0.2 ± 0.0	0.2 ± 0.1	0.2 ± 0.0	0.3 ± 0.0
Pu	0.5 ± 0.2	0.3 ± 0.3	0.2 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
Sr	0.5 ± 0.0	0.5 ± 0.2	0.6 ± 0.1	0.3 ± 0.2	0.5 ± 0.1	0.6 ± 0.0
Tc	1298 ± 75	4798 ± 671	3792 ± 284	1236 ± 105	3184 ± 247	6K ± 1K

Cyanex™ 923 Extractant Beads. We combined one volume of Cyanex™ 923 (trialkylphosphine oxide), obtained from American Cyanamid Company, Wayne, New Jersey, with two volumes of cyclohexane and added Amborsorb™ porous carbon beads, obtained from Rohm & Haas,

Philadelphia, to absorb the liquid. After evaporation of the volatile cyclohexane, the dry-appearing loaded beads contained 0.27 mL of Cyanex™ 923 per gram of beads.

Technetium sorbs well and selectively from all four solutions.

Table 37. Distribution of Five Elements into Cyanex™ 923 Extractant Beads from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	0.3 ± 0.1	0.6 ± 0.5	0.3 ± 0.1
Cs	$<0.1 \pm 0.1$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	0.5 ± 0.1	0.5 ± 0.3	0.4 ± 0.1
Pu	0.4 ± 0.4	0.3 ± 0.0	0.3 ± 0.1	$<0.1 \pm 0.0$	0.1 ± 0.1	$<0.1 \pm 0.0$
Sr	0.4 ± 0.0	0.4 ± 0.1	0.4 ± 0.0	0.6 ± 0.1	0.5 ± 0.5	0.4 ± 0.2
Tc	111 ± 9.1	151 ± 3.4	147 ± 0.6	110 ± 7.9	149 ± 4.0	130 ± 0.8

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$
Cs	0.1 ± 0.0	0.1 ± 0.1	$<0.1 \pm 0.0$	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Pu	0.3 ± 0.0	0.4 ± 0.1	0.3 ± 0.0	0.3 ± 0.1	0.3 ± 0.1	0.2 ± 0.1
Sr	0.3 ± 0.1	0.4 ± 0.1	0.4 ± 0.1	0.2 ± 0.1	0.3 ± 0.0	0.3 ± 0.0
Tc	157 ± 7.3	201 ± 8.5	194 ± 2.6	150 ± 1.0	181 ± 1.2	171 ± 3.8

Dow™ XFS-4195 Chelating Resin. Dow™ XFS-4195, a chloromethylated polymer of styrene and divinylbenzene with bis-picolyamine functionality, is an experimental chelating resin formerly available from Dow Chemical

U.S.A., Midland, Michigan. We air-dried this composite before testing for reasons detailed in section 2.1.3.

Technetium sorbs well and selectively from all four solutions.

Table 38. Distribution of Five Elements onto Dow™ XFS-4195 Chelating Resin from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	$<0.1 \pm 0.0$	0.2 ± 0.1	0.1 ± 0.1	0.2 ± 0.2	$<0.1 \pm 0.0$	0.1 ± 0.1
Cs	0.1 ± 0.1	0.3 ± 0.1	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.1	0.2 ± 0.0
Pu	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	0.6 ± 0.2	0.3 ± 0.1	0.3 ± 0.0
Sr	0.3 ± 0.0	0.5 ± 0.1	0.5 ± 0.0	0.5 ± 0.1	0.4 ± 0.0	0.3 ± 0.0
Tc	65 ± 5.0	142 ± 5.8	214 ± 6.1	53 ± 4.6	136 ± 7.9	216 ± 6.0

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	1.2 ± 0.1	1.0 ± 0.1	0.8 ± 0.0	0.6 ± 0.0	0.4 ± 0.0	0.5 ± 0.1
Cs	0.1 ± 0.1	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$
Pu	0.9 ± 0.4	0.8 ± 0.4	0.6 ± 0.2	0.6 ± 0.1	0.6 ± 0.1	0.7 ± 0.1
Sr	0.2 ± 0.2	0.3 ± 0.1	0.4 ± 0.1	0.3 ± 0.1	0.3 ± 0.0	0.3 ± 0.0
Tc	142 ± 0.4	303 ± 16	461 ± 21	124 ± 4.1	262 ± 14	403 ± 14

Isobutyl-HP Anion Exchange Resin. Isobutyl-HP anion exchange resin is the isobutyl derivative of Reillex™ HP (poly-4-vinylpyridine) prepared by Donald McQuigg of Reilly Industries, Inc., Indianapolis, Indiana. On the basis of measured chloride exchange capacities, the product was quaternized to 48% of the theoretical maximum. We air-dried

this composite before testing for reasons detailed in section 2.1.3.

Technetium is sorbed strongly and selectively from all four solutions, with Kd values approximately double for sorption from the hydrothermal-treated solutions.

Table 39. Distribution of Five Elements onto Isobutyl-HP Anion Exchange Resin from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.5 ± 0.3	0.4 ± 0.2	0.5 ± 0.1	0.9 ± 0.3	0.8 ± 0.1	0.7 ± 0.3
Cs	0.8 ± 0.2	0.7 ± 0.1	0.8 ± 0.0	1.0 ± 0.3	1.0 ± 0.2	1.0 ± 0.2
Pu	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
Sr	0.9 ± 0.2	0.8 ± 0.0	0.9 ± 0.1	1.1 ± 0.4	1.1 ± 0.3	1.1 ± 0.3
Tc	482 ± 19	728 ± 18	809 ± 0.1	609 ± 5.1	830 ± 29	919 ± 2.5

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	0.2 ± 0.0	0.3 ± 0.1	0.3 ± 0.1
Cs	0.3 ± 0.1	0.4 ± 0.1	0.3 ± 0.0	0.3 ± 0.1	0.2 ± 0.0	0.3 ± 0.1
Pu	0.2 ± 0.2	0.3 ± 0.3	0.2 ± 0.2	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
Sr	0.4 ± 0.1	0.5 ± 0.2	0.4 ± 0.1	0.5 ± 0.1	0.4 ± 0.1	0.5 ± 0.0
Tc	1128 ± 1.1	2207 ± 54	2025 ± 207	1014 ± 29	1569 ± 221	1987 ± 45

N-Butyl-HP Anion Exchange Resin. N-Butyl-HP is the 1-butyl derivative of Reillex™ HP (poly-4-vinylpyridine) prepared by Donald McQuigg of Reilly Industries, Indianapolis, Indiana. On the basis of measured chloride exchange capacities, the product was quaternized to 43% of the theoretical maximum. We air-dried this composite before testing for reasons detailed in section 2.1.3.

Technetium is strongly and selectively sorbed from all four solutions with the K_d values approximately double for sorption from the hydrothermal-treated solutions.

Table 40. Distribution of Five Elements onto N-Butyl-HP Anion Exchange Resin from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	K _d Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.9 ± 0.2	0.7 ± 0.0	0.8 ± 0.1
Cs	0.1 ± 0.1	0.2 ± 0.1	0.2 ± 0.0	0.8 ± 0.3	0.6 ± 0.1	0.8 ± 0.1
Pu	0.3 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
Sr	0.2 ± 0.0	0.2 ± 0.0	0.3 ± 0.0	0.9 ± 0.2	0.8 ± 0.1	0.9 ± 0.1
Tc	633 ± 13	1007 ± 4.2	1024 ± 47	619 ± 31	924 ± 0.2	1087 ± 89

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.7 ± 0.3	0.5 ± 0.1	0.4 ± 0.1	<0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.0
Cs	0.8 ± 0.1	0.4 ± 0.1	0.4 ± 0.1	0.3 ± 0.0	0.4 ± 0.1	0.4 ± 0.1
Pu	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0
Sr	0.8 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	0.4 ± 0.0	0.5 ± 0.1	0.9 ± 0.1
Tc	1415 ± 204	2389 ± 267	2561 ± 17	1226 ± 58	1899 ± 139	2970 ± 252

N-Hexyl-HP Anion Exchange Resin. N-Hexyl-HP is the 1-hexyl derivative of Reillex™ HP (poly-4-vinylpyridine) prepared by Donald McQuigg of Reilly Industries, Indianapolis, Indiana. On the basis of measured chloride exchange capacities, the product was quaternized to 45% of the theoretical maximum. We air-dried this composite before testing for reasons detailed in section 2.1.3.

Technetium is strongly and selectively sorbed from all four solutions with the Kd values approximately double for sorption from the hydrothermal-treated solutions.

Table 41. Distribution of Five Elements onto N-Hexyl-HP Anion Exchange Resin from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	$<0.1 \pm 0.0$	0.1 ± 0.1	$<0.1 \pm 0.0$	1.0 ± 0.2	1.2 ± 0.2	1.0 ± 0.2
Cs	0.2 ± 0.2	0.2 ± 0.0	0.2 ± 0.0	0.8 ± 0.3	1.0 ± 0.4	0.9 ± 0.2
Pu	0.2 ± 0.2	0.2 ± 0.2	0.3 ± 0.1	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$
Sr	0.2 ± 0.1	0.2 ± 0.0	0.3 ± 0.0	1.0 ± 0.2	1.1 ± 0.3	1.0 ± 0.3
Tc	570 ± 5.3	963 ± 15	1090 ± 25	571 ± 32	909 ± 30	1091 ± 36

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.5 ± 0.4	0.6 ± 0.0	0.5 ± 0.0	0.4 ± 0.1	0.3 ± 0.3	0.2 ± 0.1
Cs	0.3 ± 0.2	0.5 ± 0.0	0.4 ± 0.1	0.5 ± 0.1	0.5 ± 0.2	0.5 ± 0.1
Pu	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	0.1 ± 0.1	$<0.1 \pm 0.0$
Sr	0.3 ± 0.3	0.5 ± 0.0	0.5 ± 0.0	0.7 ± 0.2	0.9 ± 0.6	1.2 ± 0.1
Tc	1277 ± 94	2337 ± 358	2977 ± 455	1030 ± 51	1749 ± 2.8	2461 ± 355

SNL/HTO Monosodium Titanate. SNL/HTO is an amorphous monosodium titanate (8.5 wt.% Na) prepared by Sandia/NM. This absorber was used as received.

Strontium is sorbed from the two untreated solutions with at least triple-digit Kd values. Strontium and

americium are sorbed strongly and plutonium is sorbed well from the two hydrothermal-treated solutions. Of the 33 absorbers tested, this absorber provides the highest sorption of strontium from untreated organic-containing simulants.

Table 42. Distribution of Five Elements onto SNL/HTO Monosodium Titanate from a 3:1 Dilution of Four Variations of Generic Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/ untreated			Irradiated/ untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	2.3 ± 1.0	3.3 ± 1.1	4.1 ± 1.3	0.6 ± 0.2	1.0 ± 0.2	1.4 ± 0.2
Cs	2.5 ± 0.1	2.3 ± 0.2	2.1 ± 0.1	2.5 ± 0.1	2.4 ± 0.1	2.5 ± 0.0
Pu	0.7 ± 0.3	1.2 ± 0.2	2.4 ± 0.9	0.1 ± 0.0	0.1 ± 0.1	0.8 ± 0.2
Sr	313 ± 20	457 ± 14	535 ± 32	164 ± 0.8	242 ± 2.3	325 ± 7.0
Tc	0.3 ± 0.3	0.3 ± 0.0	0.2 ± 0.1	<0.1 ± 0.0	0.1 ± 0.1	0.2 ± 0.0

Element	Unirradiated/ hydrothermal-treated			Irradiated/ hydrothermal-treated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	4534 ± 863	>4935 ± 341	>4946 ± 387	5K ± 0.1K	>5K ± 0.1K	>5K ± 0.1K
Cs	14 ± 0.4	15 ± 0.1	15 ± 0.3	10 ± 0.0	10 ± 0.2	10 ± 0.0
Pu	564 ± 31	753 ± 158	1036 ± 99	271 ± 20	349 ± 24	430 ± 7.9
Sr	11K ± 3K	11K ± 1K	13K ± 2.1K	6K ± 0.3K	6K ± 0.7K	8K ± 1.3K
Tc	0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.1

3.0 PART IV: THE EFFECTS OF VARYING DILUTION RATIOS ON THE DISTRIBUTIONS OF Sr, Cs, Tc, Pu, AND Am ONTO 12 ABSORBERS FROM HANFORD COMPLEXANT CONCENTRATE (CC) SIMULANT SOLUTION

3.1 Introduction

Because most solutions stored in Hanford HLW tanks are saturated with inorganic salts, such waste solutions are poorly suited for processing in their undiluted form. We can safely assume that these waste solutions will require dilution before they are processed with the selected partitioning option. It is also probable that the radioactive solutions that result from planned sludge-washing operations will be combined with the initial supernate solution to produce a diluted feed that meets process specifications.

Although some dilution is likely to be needed before most HLW solutions can be processed, the appropriate ratio of diluent to HLW solution cannot be selected until relevant tests have been completed. To provide a preliminary basis for selecting an appropriate dilution ratio for the CC waste, we measured the distribution of strontium, cesium, technetium, plutonium, and americium onto selected absorbers from solutions whose diluent-to-simulant ratio covered the range from 0 to 3.0.

Section 2.0 (Part III) reports the distribution of these three major fission products and two actinides onto 33 absorbers from a 3:1 dilution of each of the four variations of the generic CC simulant solution. Water was always the diluent for Part III.

In this section (Part IV) we report the measured distributions of the same five elements onto 12 selected absorbers from 1:1 dilutions (using 1 M NaOH as the diluent) of unirradiated and gamma-irradiated portions of the CC simulant. We also report the measured distributions of these elements onto the three best-performing absorbers from unirradiated and gamma-irradiated CC simulant variations that were diluted with 1 M NaOH at diluent-to-simulant ratios of 0, 0.5, 1.0, 2.0, and 3.0.

3.2 Results and Discussion

We selected the 12 best-performing absorbers from the 33 reported in section 2.2.2 for additional testing with a 1:1 dilution of the CC simulant, using 1 M NaOH as the diluent. We selected the three best-performing absorbers for sorption of multivalent cations. We tested these absorbers for sorption of the same five elements from solutions with diluent-to-simulant ratios of 0.5, 1.0, 2.0, and 3.0, again using 1 M NaOH as the diluent. These tests were limited to the unirradiated and gamma-irradiated variations of the CC simulant that had not been subjected to hydrothermal treatment.

3.2.1 Sorption of Am, Cs, Pu, Sr, and Tc onto 12 Selected Absorbers from 1:1 Diluted Simulant Solution. Details concerning the composition of these absorbers and their suppliers are provided in section 2.2.2 of this report. Tables 43 through 54 report the K_d values obtained for sorption of the five elements onto the 12 selected absorbers.

Aliquat™ 336 Extractant Beads. Technetium is strongly and selectively sorbed, but the K_d values are lower than those obtained for sorption from the 3:1 dilution, as described in section 2.2.2.

Table 43. Distribution of Am, Cs, Pu, Sr, and Tc onto Aliquat™ 336 Extractant Beads from 1:1 Dilutions of Irradiated and Unirradiated Hanford CC Simulant Solution

Element	K _d Value for Specified Time					
	Unirradiated/untreated			Irradiated/untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	<0.1 ± 0.1	<0.1 ± 0.0	0.1 ± 0.1	0.2 ± 0.2	0.4 ± 0.2	0.2 ± 0.0
Cs	0.3 ± 0.0	0.2 ± 0.1	0.2 ± 0.0	0.1 ± 0.1	0.3 ± 0.1	0.2 ± 0.1
Pu	<0.1 ± 0.1	0.2 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.1
Sr	0.4 ± 0.1	0.4 ± 0.1	0.4 ± 0.0	0.2 ± 0.1	0.4 ± 0.1	0.4 ± 0.1
Tc	328 ± 33	734 ± 64	786 ± 31	280 ± 3.0	637 ± 6.4	718 ± 0.2

Bone Char. Strontium is sorbed at low double-digit Kd values, which are 4- to 5-fold lower than those obtained for sorption from the 3:1 dilution, as described in section 2.2.2.

Table 44. Distribution of Am, Cs, Pu, Sr, and Tc onto Bone Char from 1:1 Dilutions of Irradiated and Unirradiated Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/untreated			Irradiated/untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	$<0.1 \pm 0.0$	0.2 ± 0.0	0.3 ± 0.1	0.2 ± 0.2	0.1 ± 0.1	0.2 ± 0.0
Cs	0.3 ± 0.1	0.4 ± 0.0	0.4 ± 0.1	0.1 ± 0.1	$<0.1 \pm 0.0$	0.1 ± 0.0
Pu	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	0.3 ± 0.4	0.3 ± 0.2	0.3 ± 0.2
Sr	8.8 ± 0.1	17 ± 0.1	29 ± 0.5	7.5 ± 0.3	16 ± 0.3	27 ± 0.1
Tc	2.1 ± 0.0	3.2 ± 0.0	3.7 ± 0.0	2.1 ± 0.3	2.6 ± 0.5	3.9 ± 0.5

CSbA-PAN Composite. Strontium is sorbed at low to moderate Kd values, which are several times lower than those obtained for sorption from the 3:1 dilution, as described in section 2.2.2.

Table 45. Distribution of Am, Cs, Pu, Sr, and Tc onto CSbA-PAN Composite from 1:1 Dilutions of Irradiated and Unirradiated Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/untreated			Irradiated/untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	0.1 ± 0.1	0.2 ± 0.0	0.3 ± 0.1	0.2 ± 0.0
Cs	0.1 ± 0.1	$<0.1 \pm 0.0$	0.2 ± 0.2	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Pu	0.1 ± 0.1	0.1 ± 0.1	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$
Sr	16 ± 0.3	34 ± 0.8	57 ± 0.3	15 ± 0.3	32 ± 0.4	49 ± 0.4
Tc	0.6 ± 0.2	0.8 ± 0.0	1.6 ± 0.7	1.2 ± 0.4	1.3 ± 0.1	1.4 ± 0.1

Duolite™ CS-100 Cation Exchange Resin. These low double-digit Kd values for cesium are slightly higher than those obtained for sorption from the 3:1 dilution, as described in section 2.2.2.

Table 46. Distribution of Am, Cs, Pu, Sr, and Tc onto Duolite™ CS-100 Cation Exchange Resin from 1:1 Dilutions of Irradiated and Unirradiated Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/untreated			Irradiated/untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.2 ± 0.1	0.3 ± 0.0	0.2 ± 0.1	<0.1 ± 0.0	0.1 ± 0.1	<0.1 ± 0.0
Cs	122 ± 0.4	144 ± 0.6	139 ± 2.6	112 ± 2.2	135 ± 0.1	136 ± 0.2
Pu	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.2	0.1 ± 0.1
Sr	1.0 ± 0.1	1.0 ± 0.0	1.1 ± 0.1	0.6 ± 0.0	0.7 ± 0.0	0.7 ± 0.1
Tc	1.1 ± 0.1	1.2 ± 0.2	1.3 ± 0.2	0.8 ± 0.1	0.9 ± 0.0	0.9 ± 0.0

Ionac™ SR-6 Anion Exchange Resin. These Kd values for technetium sorption are about half those obtained for sorption from the 3:1 dilution, as described in section 2.2.2.

Table 47. Distribution of Am, Cs, Pu, Sr, and Tc onto Ionac™ SR-6 Anion Exchange Resin from 1:1 Dilutions of Irradiated and Unirradiated Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/untreated			Irradiated/untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.1	0.3 ± 0.1	0.2 ± 0.2	0.2 ± 0.2
Cs	0.4 ± 0.1	0.6 ± 0.0	0.5 ± 0.1	0.4 ± 0.2	0.4 ± 0.1	0.4 ± 0.2
Pu	0.1 ± 0.2	0.4 ± 0.1	0.2 ± 0.2	<0.1 ± 0.0	0.1 ± 0.1	<0.1 ± 0.0
Sr	0.4 ± 0.1	0.7 ± 0.1	0.6 ± 0.2	0.3 ± 0.2	0.3 ± 0.1	0.5 ± 0.1
Tc	143 ± 0.3	297 ± 2.4	466 ± 13	150 ± 0.6	300 ± 6.2	467 ± 11

IONSIV™ IE-910 (CST) Powder. Although cesium is strongly sorbed, these Kd values are only about one-third those obtained for sorption from the 3:1 dilution, as described in section 2.2.2.

Table 48. Distribution of Am, Cs, Pu, Sr, and Tc onto IONSIV™ IE-910 (CST) Powder from 1:1 Dilutions of Irradiated and Unirradiated Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/untreated			Irradiated/untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.3 ± 0.1	0.4 ± 0.1	0.3 ± 0.0	0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0
Cs	1740 ± 10	2403 ± 59	2687 ± 105	1630 ± 51	2253 ± 1.0	2777 ± 62
Pu	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1
Sr	1.5 ± 0.1	1.9 ± 0.1	2.5 ± 0.1	1.7 ± 0.2	2.5 ± 0.1	3.3 ± 0.1
Tc	0.4 ± 0.1	0.5 ± 0.1	0.4 ± 0.0	0.1 ± 0.1	0.2 ± 0.1	0.2 ± 0.1

Monosodium Titanate (BSC-265-0106). These Kd values for sorption of strontium are only about half those for sorption from the 3:1 dilution, as described in section 2.2.2; however, these Kd values for sorption of americium are significantly higher.

Table 49. Distribution of Am, Cs, Pu, Sr, and Tc onto Monosodium Titanate (BSC-265-0106) from 1:1 Dilutions of Irradiated and Unirradiated Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/untreated			Irradiated/untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	1.2 ± 0.1	3.0 ± 0.2	5.6 ± 0.1	0.9 ± 0.1	2.1 ± 0.0	3.8 ± 0.1
Cs	0.9 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	0.4 ± 0.0	0.3 ± 0.0	0.2 ± 0.0
Pu	0.8 ± 0.1	3.0 ± 0.2	11 ± 0.9	0.3 ± 0.2	1.9 ± 0.1	7.6 ± 0.7
Sr	23 ± 0.3	37 ± 0.5	39 ± 0.8	23 ± 0.0	40 ± 0.6	46 ± 1.1
Tc	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0

Purolite™ A-520-E Anion Exchange Resin. Although technetium is well sorbed, these Kd values are little more than half those obtained for sorption from the 3:1 dilution, as described in section 2.2.2.

Table 50. Distribution of Am, Cs, Pu, Sr, and Tc onto Purolite™ A-520-E Anion Exchange Resin from 1:1 Dilutions of Irradiated and Unirradiated Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/untreated			Irradiated/untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.4 ± 0.0	0.5 ± 0.2	0.4 ± 0.1	0.1 ± 0.2	0.1 ± 0.0	<0.1 ± 0.0
Cs	0.7 ± 0.1	0.6 ± 0.2	0.6 ± 0.2	0.2 ± 0.0	0.3 ± 0.1	0.3 ± 0.0
Pu	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.1	<0.1 ± 0.0	0.1 ± 0.0
Sr	0.5 ± 0.1	0.6 ± 0.2	0.6 ± 0.3	0.2 ± 0.0	0.4 ± 0.0	0.4 ± 0.0
Tc	287 ± 26	556 ± 57	717 ± 67	259 ± 22	506 ± 59	638 ± 0.9

Resorcinol/Formaldehyde Resin (BSC-210). Although cesium Kd values are only about half those for sorption from the 3:1 dilution, as described in section 2.2.2, these Kd values for technetium sorption from the 1:1 dilution are much higher for the longest contact time.

Table 51. Distribution of Am, Cs, Pu, Sr, and Tc onto Resorcinol/Formaldehyde Resin (BSC-210) from 1:1 Dilutions of Irradiated and Unirradiated Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/untreated			Irradiated/untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.1	0.2 ± 0.2	0.2 ± 0.0
Cs	500 ± 4.0	1428 ± 9.8	2732 ± 0.3	509 ± 26	1411 ± 32	2690 ± 89
Pu	0.3 ± 0.1	0.4 ± 0.2	0.4 ± 0.2	<0.1 ± 0.0	0.1 ± 0.1	<0.1 ± 0.0
Sr	0.9 ± 0.0	1.2 ± 0.0	1.3 ± 0.0	0.7 ± 0.1	0.9 ± 0.2	1.1 ± 0.0
Tc	2.6 ± 0.1	9.9 ± 0.1	77 ± 3.3	2.5 ± 0.3	11 ± 0.4	113 ± 6.7

Sodium Nanotitanate (8225-127). These Kd values for sorption of strontium are only about one-third those obtained for sorption from the 3:1 dilution, as described in section 2.2.2.

Table 52. Distribution of Am, Cs, Pu, Sr, and Tc onto Sodium Nanotitanate (8225-127) from 1:1 Dilutions of Irradiated and Unirradiated Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/untreated			Irradiated/untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	0.7 ± 0.0	1.6 ± 0.1	2.7 ± 0.1	0.6 ± 0.2	1.2 ± 0.2	2.0 ± 0.1
Cs	0.7 ± 0.1	0.7 ± 0.0	0.7 ± 0.1	0.8 ± 0.2	0.7 ± 0.1	0.7 ± 0.1
Pu	0.2 ± 0.0	0.6 ± 0.1	1.9 ± 0.1	0.4 ± 0.2	0.8 ± 0.0	2.0 ± 0.1
Sr	32 ± 0.4	57 ± 0.8	63 ± 0.4	29 ± 0.9	52 ± 0.1	63 ± 0.2
Tc	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0

SNL/HTO Monosodium Titanate. Although strontium is well sorbed, its Kd values are only about one-third those obtained for sorption from the 3:1 dilution, as described in section 2.2.2.

Table 53. Distribution of Am, Cs, Pu, Sr, and Tc onto SNL/HTO Monosodium Titanate from 1:1 Dilutions of Irradiated and Unirradiated Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/untreated			Irradiated/untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	1.9 ± 0.1	3.1 ± 0.1	4.1 ± 0.1	1.1 ± 0.0	2.1 ± 0.0	3.3 ± 0.1
Cs	0.7 ± 0.1	0.5 ± 0.0	0.3 ± 0.0	0.5 ± 0.0	0.4 ± 0.0	0.4 ± 0.0
Pu	0.8 ± 0.2	3.8 ± 0.2	9.3 ± 0.1	0.8 ± 0.1	3.7 ± 0.3	8.8 ± 0.4
Sr	123 ± 1.1	149 ± 2.9	140 ± 1.1	93 ± 0.3	119 ± 1.0	127 ± 0.5
Tc	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0

SuperLig™ 644 Particles. These high Kd values for cesium are fairly comparable to those obtained for sorption from the 3:1 dilution, as described in section 2.2.2.

Table 54. Distribution of Am, Cs, Pu, Sr, and Tc onto SuperLig™ 644 Particles from 1:1 Dilutions of Irradiated and Unirradiated Hanford CC Simulant Solution

Element	Kd Value for Specified Time					
	Unirradiated/untreated			Irradiated/untreated		
	30 min	2 h	6 h	30 min	2 h	6 h
Am	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	0.2 ± 0.3	0.2 ± 0.1	0.2 ± 0.1
Cs	359 ± 9.6	1761 ± 107	3837 ± 346	326 ± 60	1630 ± 259	3559 ± 623
Pu	0.3 ± 0.4	0.3 ± 0.0	0.4 ± 0.0	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$	$<0.1 \pm 0.0$
Sr	0.9 ± 0.2	1.3 ± 0.1	1.5 ± 0.1	0.9 ± 0.3	1.0 ± 0.0	1.4 ± 0.1
Tc	0.9 ± 0.3	1.8 ± 0.0	3.6 ± 0.1	2.0 ± 1.1	1.9 ± 0.2	4.2 ± 0.1

3.2.2 Sorption of Sr, Cs, Tc, Pu, and Am onto Three Selected Absorbers from Undiluted and 0.5:1, 1:1, 2:1, and 3:1 Dilutions of CC Simulant Solution. Three of the twelve absorbers tested with the 1:1 dilution of CC simulant (section 3.2.1) showed significant increases over those described in section 2.2.2 (from 3:1 dilutions using water) in sorbing plutonium and americium. On the basis of that enhanced performance, we tested these three absorbers with undiluted CC simulant and with additional dilutions (using

1 M NaOH in all cases) at diluent-to-simulant ratios of 0.5, 2.0, and 3.0. Data obtained from the 1:1 dilution, as well as from the 3:1 water dilutions described in section 2.0, are included to facilitate comparisons. The compositions of the undiluted and the four 1 M NaOH dilutions of unirradiated and irradiated CC simulants are shown in Tables 55 and 56, respectively. The measured K_d values for sorption from these ten solutions are presented in Tables 57 through 61.

Table 55. Compositions of the Five Concentrations of Unirradiated Generic Hanford CC Simulant Used in Part IV of This Study

Constituent	Concentration (M)				
	Diluted (Diluent-to-Simulant Ratio) ^a				
	Undiluted	0.5:1	1:1	2:1	3:1
Cations^b					
Na	8.9	6.6	5.0	3.6	3.0
K	0.035	0.023	0.018	0.012	0.009
Rb	5×10^{-5}	3.3×10^{-5}	2.5×10^{-5}	1.7×10^{-5}	1.3×10^{-5}
Cs	5.6×10^{-4}	3.7×10^{-4}	2.8×10^{-4}	1.9×10^{-4}	1.4×10^{-4}
Al	0.64	0.43	0.32	0.21	0.16
Ca	0.008	0.005	0.004	0.003	0.002
Fe	0.012	0.008	0.006	0.004	0.003
Sr	5.2×10^{-4}	3.5×10^{-4}	2.6×10^{-4}	1.7×10^{-4}	1.3×10^{-4}
Anions^c					
Cl	0.15	0.10	0.075	0.05	0.04
NO ₃	3.6	2.4	1.8	1.2	0.9
NO ₂	1.3	0.8	0.6	0.4	0.3
PO ₄	0.036	0.024	0.018	0.012	0.009
SO ₄	0.024	0.016	0.012	0.008	0.006
CO ₃	0.74	0.50	0.37	0.25	0.19
TOC ^d	3.8	2.5	1.9	1.3	1.0
pH	13.7	13.8	13.8	13.9	13.9

^aDilutions shown are parts (by volume) of 1 M NaOH added to the undiluted simulant.

^bCations, except Na and K, were measured by inductively coupled plasma/mass spectrometry (ICP/MS).

^cAnions, as well as Na and K cations, were measured by ion chromatography (IC).

^dTotal organic carbon.

Table 56. Compositions of the Five Concentrations of Gamma-Irradiated Generic Hanford CC Simulant Used in Part IV of This Study

Constituent	Concentration (M)				
	Undiluted	Diluted (Diluent-to-Simulant Ratio) ^a			
		0.5:1	1:1	2:1	3:1
Cations^b					
Na	8.5	6.0	4.8	3.5	2.9
K	0.035	0.023	0.018	0.012	0.009
Rb	4.8×10^{-5}	3.2×10^{-5}	2.4×10^{-5}	1.6×10^{-5}	1.2×10^{-5}
Cs	5.2×10^{-4}	3.5×10^{-4}	2.6×10^{-4}	1.7×10^{-4}	1.3×10^{-4}
Al	0.64	0.43	0.32	0.21	0.16
Ca	0.008	0.005	0.004	0.003	0.002
Fe	0.019	0.013	0.010	0.006	0.005
Sr	5.2×10^{-4}	3.5×10^{-4}	2.6×10^{-4}	1.7×10^{-4}	1.3×10^{-4}
Anions^c					
Cl	0.048	0.032	0.024	0.016	0.012
NO ₃	3.4	2.3	1.7	1.1	0.9
NO ₂	1.3	0.8	0.6	0.4	0.3
PO ₄	0.036	0.024	0.018	0.012	0.009
SO ₄	0.028	0.019	0.014	0.009	0.007
CO ₃	0.90	0.60	0.45	0.30	0.23
TOC^d	3.7	2.4	1.8	1.2	0.9
pH	13.6	13.8	13.8	13.9	13.9

^aDilutions shown are parts (by volume) of 1 M NaOH added to the undiluted simulant.

^bCations, except Na and K, were measured by inductively coupled plasma/mass spectrometry (ICP/MS).

^cAnions, as well as Na and K cations, were measured by ion chromatography (IC).

^dTotal organic carbon.

Strontium. Strontium Kd values increase with increasing dilution ratio, whether the diluent is 1 M NaOH or water.

Table 57. Strontium Distribution Data—Kd Values for Sorption of Strontium onto Three Selected Absorbers from Five Different Concentrations of Unirradiated and Gamma-Irradiated Generic Hanford CC Simulant Solution

Kd Value for Specified Time						
Sodium Nanotitanate (8225-127)—Developmental						
Dilution ^a	Unirradiated			Irradiated		
	30 min	2 h	6 h	30 min	2 h	6 h
none	3.7 ± 0.2	6.9 ± 0.2	10 ± 0.2	3.4 ± 0.0	6.7 ± 0.5	9.6 ± 0.1
0.5:1	14 ± 0.1	28 ± 0.4	39 ± 0.2	14 ± 0.3	27 ± 0.3	40 ± 0.2
1:1	32 ± 0.4	57 ± 0.8	63 ± 0.4	29 ± 0.9	52 ± 0.1	63 ± 0.2
2:1	63 ± 0.8	99 ± 1.0	100 ± 1.4	49 ± 0.3	78 ± 0.3	88 ± 0.8
3:1	105 ± 2.3	181 ± 3.9	202 ± 4.1	85 ± 1.2	140 ± 1.8	165 ± 2.3
3:1 (H ₂ O)	100 ± 1.4	179 ± 2.5	238 ± 2.1	80 ± 0.8	133 ± 3.2	169 ± 0.3
SNL/HTO Monosodium Titanate—Experimental						
Dilution ^a	Unirradiated			Irradiated		
	30 min	2 h	6 h	30 min	2 h	6 h
none	16 ± 0.1	27 ± 0.0	35 ± 0.1	16 ± 0.3	24 ± 0.0	31 ± 0.4
0.5:1	65 ± 1.3	94 ± 1.5	99 ± 0.6	59 ± 0.9	87 ± 1.3	101 ± 0.5
1:1	123 ± 1.1	149 ± 2.9	140 ± 1.1	93 ± 0.3	119 ± 1.0	127 ± 0.5
2:1	190 ± 2.6	227 ± 2.4	184 ± 2.5	126 ± 0.4	160 ± 0.7	152 ± 1.0
3:1	327 ± 0.3	372 ± 2.6	278 ± 2.4	190 ± 0.1	242 ± 1.2	228 ± 3.3
3:1 (H ₂ O)	313 ± 20	457 ± 14	535 ± 32	164 ± 0.8	242 ± 2.3	325 ± 7.0
Monosodium Titanate (BSC-265-0106)—Commercially Available						
Dilution ^a	Unirradiated			Irradiated		
	30 min	2 h	6 h	30 min	2 h	6 h
none	2.5 ± 0.2	4.5 ± 0.0	7.0 ± 0.0	1.9 ± 0.0	4.1 ± 0.1	6.8 ± 0.1
0.5:1	9.9 ± 0.8	18 ± 0.0	25 ± 0.2	9.3 ± 0.5	19 ± 0.3	27 ± 0.0
1:1	23 ± 0.3	37 ± 0.5	39 ± 0.8	23 ± 0.0	40 ± 0.6	46 ± 1.1
2:1	47 ± 0.1	75 ± 1.3	70 ± 2.3	44 ± 0.5	73 ± 2.2	72 ± 1.1
3:1	76 ± 0.4	113 ± 0.1	121 ± 0.7	78 ± 0.5	110 ± 2.1	120 ± 0.7
3:1 (H ₂ O)	37 ± 0.7	61 ± 1.5	69 ± 1.6	74 ± 1.1	121 ± 3.0	135 ± 0.4

^aDiluent is 1 M NaOH unless otherwise noted.

Cesium. Cesium Kd values are low for sorption onto all three absorbers from all dilutions, as expected, because these absorbers were selected for their ability to sorb the multivalent cations.

Table 58. Cesium Distribution Data—Kd Values for Sorption of Cesium onto Three Selected Absorbers from Five Different Concentrations of Unirradiated and Gamma-Irradiated Generic Hanford CC Simulant Solution

Kd Value for Specified Time						
Sodium Nanotitanate (8225-127)—Developmental						
Dilution ^a	Unirradiated			Irradiated		
	30 min	2 h	6 h	30 min	2 h	6 h
none	0.4 ± 0.1	0.3 ± 0.1	0.3 ± 0.0	0.3 ± 0.1	0.4 ± 0.4	0.2 ± 0.1
0.5:1	0.6 ± 0.1	0.4 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	0.4 ± 0.1	0.4 ± 0.0
1:1	0.7 ± 0.1	0.7 ± 0.0	0.7 ± 0.1	0.8 ± 0.2	0.7 ± 0.1	0.7 ± 0.1
2:1	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.0	1.0 ± 0.2	0.7 ± 0.2	0.7 ± 0.1
3:1	1.3 ± 0.3	1.2 ± 0.1	1.3 ± 0.0	1.2 ± 0.1	1.1 ± 0.1	1.1 ± 0.1
3:1 (H ₂ O)	2.7 ± 0.1	2.9 ± 0.0	2.8 ± 0.0	3.0 ± 0.1	3.2 ± 0.1	3.1 ± 0.1
SNL/HTO Monosodium Titanate—Experimental						
Dilution ^a	Unirradiated			Irradiated		
	30 min	2 h	6 h	30 min	2 h	6 h
none	0.2 ± 0.1	0.1 ± 0.0	0.1 ± 0.1	0.3 ± 0.3	<0.1 ± 0.1	0.1 ± 0.0
0.5:1	0.1 ± 0.0	<0.1 ± 0.1	0.1 ± 0.0	0.3 ± 0.1	0.3 ± 0.0	0.3 ± 0.1
1:1	0.7 ± 0.1	0.5 ± 0.0	0.3 ± 0.0	0.5 ± 0.0	0.4 ± 0.0	0.4 ± 0.0
1:0	0.1 ± 0.0	0.2 ± 0.1	0.4 ± 0.1	0.8 ± 0.0	0.7 ± 0.0	0.5 ± 0.1
3:1	1.1 ± 0.2	0.9 ± 0.0	0.8 ± 0.1	1.0 ± 0.1	0.9 ± 0.1	0.9 ± 0.0
3:1 (H ₂ O)	2.5 ± 0.1	2.3 ± 0.2	2.1 ± 0.1	2.5 ± 0.1	2.4 ± 0.1	2.5 ± 0.0
Monosodium Titanate (BSC-265-0106)—Commercially Available						
Dilution ^a	Unirradiated			Irradiated		
	30 min	2 h	6 h	30 min	2 h	6 h
none	0.4 ± 0.2	0.2 ± 0.0	0.2 ± 0.1	0.3 ± 0.1	<0.1 ± 0.0	0.1 ± 0.0
0.5:1	0.5 ± 0.4	0.2 ± 0.0	0.2 ± 0.1	0.3 ± 0.2	0.2 ± 0.0	0.3 ± 0.0
1:1	0.9 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	0.4 ± 0.0	0.3 ± 0.0	0.2 ± 0.0
2:1	<0.1 ± 0.0	<0.1 ± 0.0	0.2 ± 0.1	0.7 ± 0.1	0.6 ± 0.1	0.5 ± 0.0
3:1	1.0 ± 0.1	0.8 ± 0.1	0.8 ± 0.1	0.8 ± 0.1	0.7 ± 0.0	0.6 ± 0.1
3:1 (H ₂ O)	1.9 ± 0.2	2.0 ± 0.4	1.7 ± 0.2	2.0 ± 0.0	1.9 ± 0.3	1.6 ± 0.1

^aDiluent is 1 M NaOH unless otherwise noted.

Technetium. Technetium Kd values are low for sorption onto all three absorbers from all dilutions, as expected, because these absorbers were selected for their ability to sorb the multivalent cations.

Table 59. Technetium Distribution Data—Kd Values for Sorption of Technetium onto Three Selected Absorbers from Five Different Concentrations of Unirradiated and Gamma-Irradiated Generic Hanford CC Simulant Solution

Kd Value for Specified Time						
Sodium Nanotitanate (8225-127)—Developmental						
Dilution ^a	Unirradiated			Irradiated		
	30 min	2 h	6 h	30 min	2 h	6 h
none	<0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	0.4 ± 0.3	0.5 ± 0.5	0.3 ± 0.3
0.5:1	0.3 ± 0.5	0.3 ± 0.4	0.2 ± 0.3	0.2 ± 0.3	0.5 ± 0.3	0.3 ± 0.2
1:1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
2:1	0.8 ± 0.0	0.8 ± 0.1	0.7 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
3:1	<0.1 ± 0.0	<0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.1	0.1 ± 0.2
3:1 (H ₂ O)	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.0	0.2 ± 0.2	<0.1 ± 0.1
SNL/HTO Monosodium Titanate—Experimental						
Dilution ^a	Unirradiated			Irradiated		
	30 min	2 h	6 h	30 min	2 h	6 h
none	0.5 ± 0.4	0.2 ± 0.0	0.5 ± 0.6	0.3 ± 0.4	0.2 ± 0.2	0.1 ± 0.1
0.5:1	<0.1 ± 0.0	0.2 ± 0.2	0.3 ± 0.1	0.2 ± 0.1	0.5 ± 0.1	0.3 ± 0.1
1:1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
2:1	0.6 ± 0.1	0.6 ± 0.1	0.5 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
3:1	<0.1 ± 0.0	<0.1 ± 0.0	0.2 ± 0.0	<0.1 ± 0.1	<0.1 ± 0.0	0.1 ± 0.1
3:1 (H ₂ O)	0.3 ± 0.4	0.3 ± 0.0	0.2 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.1	0.2 ± 0.0
Monosodium Titanate (BSC-265-0106)—Commercially Available						
Dilution ^a	Unirradiated			Irradiated		
	30 min	2 h	6 h	30 min	2 h	6 h
none	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.1	<0.1 ± 0.1	<0.1 ± 0.0
0.5:1	0.7 ± 0.4	0.4 ± 0.0	0.2 ± 0.1	1.5 ± 1.1	0.7 ± 0.5	0.7 ± 0.2
1:1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
2:1	0.6 ± 0.0	0.4 ± 0.1	0.5 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
3:1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	<0.1 ± 0.0
3:1 (H ₂ O)	<0.1 ± 0.0	0.2 ± 0.3	0.2 ± 0.0	0.4 ± 0.1	0.4 ± 0.2	0.3 ± 0.0

^aDiluent is 1 M NaOH unless otherwise noted.

Plutonium. Plutonium Kd values increase as the fraction of 1 M NaOH diluent increases, but not when the diluent is water.

Table 60. Plutonium Distribution Data—Kd Values for Sorption of Plutonium onto Three Selected Absorbers from Five Different Concentrations of Unirradiated and Gamma-Irradiated Generic Hanford CC Simulant Solution

Kd Value for Specified Time						
Sodium Nanotitanate (8225-127)—Developmental						
Dilution ^a	Unirradiated			Irradiated		
	30 min	2 h	6 h	30 min	2 h	6 h
none	0.1 ± 0.1	0.3 ± 0.0	0.3 ± 0.2	0.2 ± 0.2	0.4 ± 0.6	0.3 ± 0.0
0.5:1	0.3 ± 0.4	0.8 ± 0.1	1.9 ± 0.4	0.4 ± 0.3	0.8 ± 0.8	1.5 ± 0.2
1:1	0.2 ± 0.0	0.6 ± 0.1	1.9 ± 0.1	0.4 ± 0.2	0.8 ± 0.0	2.0 ± 0.1
2:1	0.3 ± 0.1	1.9 ± 0.1	4.4 ± 0.0	0.5 ± 0.1	1.4 ± 0.1	3.5 ± 0.1
3:1	1.7 ± 0.3	3.4 ± 0.2	5.1 ± 0.0	0.9 ± 0.1	2.5 ± 0.0	4.0 ± 0.2
3:1 (H ₂ O)	<0.1 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	<0.1 ± 0.1	<0.1 ± 0.0	0.1 ± 0.0
SNL/HTO Monosodium Titanate—Experimental						
Dilution ^a	Unirradiated			Irradiated		
	30 min	2 h	6 h	30 min	2 h	6 h
none	0.2 ± 0.3	1.1 ± 0.1	2.4 ± 0.1	0.1 ± 0.2	0.9 ± 0.0	1.9 ± 0.3
0.5:1	0.9 ± 0.3	3.5 ± 1.0	9.2 ± 0.5	0.8 ± 0.0	3.6 ± 0.2	7.0 ± 0.0
1:1	0.8 ± 0.2	3.8 ± 0.2	9.3 ± 0.1	0.8 ± 0.1	3.7 ± 0.3	8.8 ± 0.4
2:1	1.9 ± 0.1	9.0 ± 0.4	15 ± 0.0	2.0 ± 0.3	7.8 ± 0.1	13 ± 0.4
3:1	4.2 ± 0.1	9.8 ± 0.1	14 ± 0.2	3.6 ± 0.1	8.8 ± 0.1	13 ± 0.1
3:1 (H ₂ O)	0.7 ± 0.3	1.2 ± 0.2	2.4 ± 0.9	0.1 ± 0.0	0.1 ± 0.2	0.8 ± 0.2
Monosodium Titanate (BSC-265-0106)—Commercially Available						
Dilution ^a	Unirradiated			Irradiated		
	30 min	2 h	6 h	30 min	2 h	6 h
none	<0.1 ± 0.1	0.3 ± 0.2	1.1 ± 0.0	0.4 ± 0.1	0.7 ± 0.0	0.7 ± 0.5
0.5:1	<0.1 ± 0.0	1.8 ± 0.3	8.2 ± 0.8	1.5 ± 0.2	2.0 ± 0.5	4.7 ± 0.2
1:1	0.8 ± 0.1	3.0 ± 0.2	11 ± 0.9	0.3 ± 0.2	1.9 ± 0.1	7.6 ± 0.7
2:1	0.8 ± 0.0	4.0 ± 0.4	16 ± 1.4	0.8 ± 0.1	3.4 ± 0.1	11 ± 1.1
3:1	3.1 ± 0.0	7.4 ± 0.1	15 ± 0.0	2.3 ± 0.1	6.8 ± 0.0	14 ± 0.5
3:1 (H ₂ O)	<0.1 ± 0.0	0.3 ± 0.3	0.1 ± 0.1	<0.1 ± 0.0	<0.1 ± 0.0	0.1 ± 0.2

^aDiluent is 1 M NaOH unless otherwise noted.

Americium. Americium Kd values increase as the fraction of 1 M NaOH diluent increases, but not when the diluent is water.

Table 61. Americium Distribution Data—Kd Values for Sorption of Americium onto Three Selected Absorbers from Five Different Concentrations of Unirradiated and Gamma-Irradiated Generic Hanford CC Simulant Solution

Kd Value for Specified Time						
Sodium Nanotitanate (8225-127)—Developmental						
Dilution ^a	Unirradiated			Irradiated		
	30 min	2 h	6 h	30 min	2 h	6 h
none	0.7 ± 0.5	0.4 ± 0.2	0.4 ± 0.1	0.2 ± 0.3	0.7 ± 0.4	0.8 ± 0.2
0.5:1	0.4 ± 0.1	1.0 ± 0.0	1.6 ± 0.2	0.1 ± 0.0	1.1 ± 0.1	1.3 ± 0.1
1:1	0.7 ± 0.0	1.6 ± 0.1	2.7 ± 0.1	0.6 ± 0.2	1.2 ± 0.2	2.0 ± 0.1
2:1	1.2 ± 0.1	2.7 ± 0.1	4.4 ± 0.0	1.3 ± 0.3	2.2 ± 0.2	3.8 ± 0.1
3:1	2.1 ± 0.3	3.7 ± 0.1	5.9 ± 0.0	2.0 ± 0.1	3.6 ± 0.1	5.8 ± 0.2
3:1 (H ₂ O)	0.5 ± 0.3	1.1 ± 0.1	1.4 ± 0.0	0.3 ± 0.2	0.4 ± 0.2	0.5 ± 0.1
SNL/HTO Monosodium Titanate—Experimental						
Dilution ^a	Unirradiated			Irradiated		
	30 min	2 h	6 h	30 min	2 h	6 h
none	0.3 ± 0.2	0.6 ± 0.1	0.8 ± 0.0	0.5 ± 0.2	1.0 ± 0.1	1.3 ± 0.1
0.5:1	0.9 ± 0.1	2.4 ± 0.4	2.7 ± 0.1	1.0 ± 0.5	2.2 ± 0.3	2.4 ± 0.2
1:1	1.9 ± 0.1	3.1 ± 0.1	4.1 ± 0.1	1.1 ± 0.0	2.1 ± 0.0	3.3 ± 0.1
2:1	2.6 ± 0.2	4.5 ± 0.1	6.5 ± 0.0	2.5 ± 0.2	4.0 ± 0.0	5.9 ± 0.1
3:1	3.8 ± 0.3	6.0 ± 0.1	8.2 ± 0.2	3.5 ± 0.1	5.7 ± 0.2	8.3 ± 0.0
3:1 (H ₂ O)	2.3 ± 1.0	3.3 ± 1.1	4.1 ± 1.3	0.6 ± 0.2	1.0 ± 0.2	1.4 ± 0.2
Monosodium Titanate (BSC-265-0106)—Commercially Available						
Dilution ^a	Unirradiated			Irradiated		
	30 min	2 h	6 h	30 min	2 h	6 h
none	0.3 ± 0.1	0.2 ± 0.0	0.5 ± 0.2	<0.1 ± 0.0	0.5 ± 0.1	0.7 ± 0.1
0.5:1	1.1 ± 0.4	1.8 ± 0.0	3.1 ± 0.1	1.0 ± 0.2	1.2 ± 0.7	2.1 ± 0.3
1:1	1.2 ± 0.1	3.0 ± 0.2	5.6 ± 0.1	0.9 ± 0.1	2.1 ± 0.0	3.8 ± 0.1
2:1	1.6 ± 0.1	3.7 ± 0.4	6.6 ± 0.3	2.0 ± 0.1	3.6 ± 0.0	5.7 ± 0.4
3:1	3.1 ± 0.2	5.0 ± 0.0	8.0 ± 0.2	3.3 ± 0.1	5.4 ± 0.1	8.9 ± 0.1
3:1 (H ₂ O)	0.2 ± 0.1	0.6 ± 0.3	0.6 ± 0.2	0.8 ± 0.1	0.8 ± 0.3	0.8 ± 0.0

^aDiluent is 1 M NaOH unless otherwise noted.

Americium. Americium Kd values increase as the fraction of 1 M NaOH diluent increases, but not when the diluent is water.

Table 61. Americium Distribution Data—Kd Values for Sorption of Americium onto Three Selected Absorbers from Five Different Concentrations of Unirradiated and Gamma-Irradiated Generic Hanford CC Simulant Solution

Kd Value for Specified Time						
Sodium Nanotitanate (8225-127)—Developmental						
Dilution ^a	Unirradiated			Irradiated		
	30 min	2 h	6 h	30 min	2 h	6 h
none	0.7 ± 0.5	0.4 ± 0.2	0.4 ± 0.1	0.2 ± 0.3	0.7 ± 0.4	0.8 ± 0.2
0.5:1	0.4 ± 0.1	1.0 ± 0.0	1.6 ± 0.2	0.1 ± 0.0	1.1 ± 0.1	1.3 ± 0.1
1:1	0.7 ± 0.0	1.6 ± 0.1	2.7 ± 0.1	0.6 ± 0.2	1.2 ± 0.2	2.0 ± 0.1
2:1	1.2 ± 0.1	2.7 ± 0.1	4.4 ± 0.0	1.3 ± 0.3	2.2 ± 0.2	3.8 ± 0.1
3:1	2.1 ± 0.3	3.7 ± 0.1	5.9 ± 0.0	2.0 ± 0.1	3.6 ± 0.1	5.8 ± 0.2
3:1 (H ₂ O)	0.5 ± 0.3	1.1 ± 0.1	1.4 ± 0.0	0.3 ± 0.2	0.4 ± 0.2	0.5 ± 0.1
SNL/HTO Monosodium Titanate—Experimental						
Dilution ^a	Unirradiated			Irradiated		
	30 min	2 h	6 h	30 min	2 h	6 h
none	0.3 ± 0.2	0.6 ± 0.1	0.8 ± 0.0	0.5 ± 0.2	1.0 ± 0.1	1.3 ± 0.1
0.5:1	0.9 ± 0.1	2.4 ± 0.4	2.7 ± 0.1	1.0 ± 0.5	2.2 ± 0.3	2.4 ± 0.2
1:1	1.9 ± 0.1	3.1 ± 0.1	4.1 ± 0.1	1.1 ± 0.0	2.1 ± 0.0	3.3 ± 0.1
2:1	2.6 ± 0.2	4.5 ± 0.1	6.5 ± 0.0	2.5 ± 0.2	4.0 ± 0.0	5.9 ± 0.1
3:1	3.8 ± 0.3	6.0 ± 0.1	8.2 ± 0.2	3.5 ± 0.1	5.7 ± 0.2	8.3 ± 0.0
3:1 (H ₂ O)	2.3 ± 1.0	3.3 ± 1.1	4.1 ± 1.3	0.6 ± 0.2	1.0 ± 0.2	1.4 ± 0.2
Monosodium Titanate (BSC-265-0106)—Commercially Available						
Dilution ^a	Unirradiated			Irradiated		
	30 min	2 h	6 h	30 min	2 h	6 h
none	0.3 ± 0.1	0.2 ± 0.0	0.5 ± 0.2	<0.1 ± 0.0	0.5 ± 0.1	0.7 ± 0.1
0.5:1	1.1 ± 0.4	1.8 ± 0.0	3.1 ± 0.1	1.0 ± 0.2	1.2 ± 0.7	2.1 ± 0.3
1:1	1.2 ± 0.1	3.0 ± 0.2	5.6 ± 0.1	0.9 ± 0.1	2.1 ± 0.0	3.8 ± 0.1
2:1	1.6 ± 0.1	3.7 ± 0.4	6.6 ± 0.3	2.0 ± 0.1	3.6 ± 0.0	5.7 ± 0.4
3:1	3.1 ± 0.2	5.0 ± 0.0	8.0 ± 0.2	3.3 ± 0.1	5.4 ± 0.1	8.9 ± 0.1
3:1 (H ₂ O)	0.2 ± 0.1	0.6 ± 0.3	0.6 ± 0.2	0.8 ± 0.1	0.8 ± 0.3	0.8 ± 0.0

^aDiluent is 1 M NaOH unless otherwise noted.

4.0 CONCLUSIONS

Our study of the effectiveness of 33 absorbers for removing selected elements from four variations of organic-containing simulant for generic Hanford Complexant Concentrate has met the initial objective of measuring the effects of degraded organic compounds on the sorption of strontium, cesium, technetium, plutonium, and americium.

Cesium is sorbed very strongly onto several absorbers, even from the CC simulant solutions that contain the highest concentrations of organic complexants. After these organic compounds are destroyed by hydrothermal treatment, cesium is even more strongly sorbed onto crystalline silico-titanate, cobalt hexacyanoferrate, and nickel hexacyanoferrate. However, the hexacyanoferrate absorbers appear to decompose in the presence of organic complexants. Two of the tested absorbers, SuperLig™ 644 and Duolite™ CS-100, sorb cesium less effectively from simulants that have undergone hydrothermal treatment; we have no explanation for these decreased Kd values.

Technetium is strongly sorbed from the four tested CC simulant solutions by many anion exchange resins and extractants that offer tetraalkylammonium functionality. Although the Kd values for technetium sorption are always higher from simulant solutions that have been hydrothermally treated, five absorbers offer at least triple-digit Kd values for technetium sorption, even from CC simulant solutions that contain the highest concentrations of organic complexants.

For strontium, plutonium, and americium (the multivalent cations tested), the presence of the six organic complexants and their degradation products in the simulant solutions seriously interferes with their sorption onto absorbers that sorb these elements well from organic-free simulant solutions. Nevertheless, several of the tested absorbers offer at least triple-digit Kd values for removing strontium from all four simulant solutions. The best-performing absorbers for these multivalent cations include bone char and several varieties of sodium titanate.

We have, therefore, identified specific existing absorbers that appear to be capable of removing cesium, technetium, and strontium from organic-containing waste with no prior organic-destruction treatment.

However, plutonium and americium are less strongly sorbed onto the 33 tested absorbers than strontium. Because several absorbers offer high single-digit or low double-digit Kd values for removing plutonium and americium from 1:1 dilutions (using 1 M NaOH as

the diluent) of the organic-containing waste, we tested the three best absorbers for removing these actinides from four other dilution levels. Based on these tests, the sorption of plutonium and americium increases with increasing dilution. Although a 3:1 dilution (with water as the diluent) provides Kd values for strontium sorption similar to those obtained with 1 M NaOH as the diluent, the Kd values for plutonium and americium are much lower for sorption from water-diluted simulants.

Our measured Kd values for sorbing the three multivalent cations from irradiated solutions are often lower than from the unirradiated counterparts, whether hydrothermal-treated or not. This indicates that the radiolysis products can be more effective complexants than the original compounds.

The Los Alamos hydrothermal treatment process⁷ has been demonstrated to very effectively destroy much of the organic carbon and convert the remainder to simpler organic compounds that interfere much less than the initial complexants with the sorption of multivalent cations. The measured Kd values for strontium, plutonium, and americium are often several orders of magnitude higher for sorption of these elements from simulant solutions that have been treated with the hydrothermal organic-destruction process.

On the basis of solution coloration, KCoFC and NiFC-PAN absorbers appear to rapidly degrade in the presence of some organic compounds. Duolite™ CS-100 and the resorcinol/formaldehyde (BSC-210) resin both darken the simulant solutions with intensities that appear to parallel the contact times. These observations indicate that the effect of strong alkaline solutions and soluble organic compounds on absorber stability should be evaluated in future absorber-stability studies.

Measurements of important radionuclides from actual organic-containing Hanford waste solutions are needed to confirm our simulant-solution results and should be performed as soon as such waste samples are available.

5.0 FUTURE STUDIES

This investigation demonstrates that degraded organic complexants affect the sorption of strontium, plutonium, and americium onto absorbers that perform well in the absence of such organics. Therefore, we plan to test the best-performing absorbers from this study with actual waste from Hanford HLW Tanks 101-SY and 103-SY.

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