*Distributions of 12 Elements on
64 Absorbers from Simulated Hanford
Neutralized Current Acid Waste (NCAW)*

*Zita V. Svitra
S. Fredric Marsh*
Scott M. Bowen*

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

MASTER

Los Alamos

NATIONAL LABORATORY

Los Alamos, New Mexico 87545

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DISTRIBUTIONS OF 12 ELEMENTS ON 64 ABSORBERS FROM SIMULATED HANFORD NEUTRALIZED CURRENT ACID WASTE (NCAW)

by

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

ABSTRACT

As part of the Hanford Tank Waste Remediation System program at Los Alamos, we evaluated 64 commercially available or experimental absorber materials for their ability to remove hazardous components from high-level waste. These absorbers included cation and anion exchange resins, inorganic exchangers, composite absorbers, and a series of liquid extractants sorbed on porous support-beads. We tested these absorbers with a solution that simulates Hanford neutralized current acid waste (NCAW) (pH 14.2). To this simulant solution we added the appropriate radionuclides and used gamma spectrometry to measure fission products (Cs, Sr, Tc, and Y) and matrix elements (Cr, Co, Fe, Mn, Ni, V, Zn, and Zr). For each of 768 element/absorber combinations, we measured distribution coefficients for dynamic contact periods of 30 min, 2 h, and 6 h to obtain information about sorption kinetics. On the basis of these 2304 measured distribution coefficients, we determined that many of the tested absorbers may be suitable for processing NCAW solutions.

EXECUTIVE SUMMARY

Successful remediation of the large quantities of hazardous waste stored in underground tanks at the Hanford Reservation near Richland, Washington, requires the identification of reliable partitioning agents and the development of suitable technologies. To address this need, we measured the sorption of 12 elements onto 64 different absorbers from a simulant that represents a generic Hanford neutralized current acid waste (NCAW) solution.

After each completed segment of our absorber screening studies, we review the performance of the tested absorbers, eliminate those that perform poorly, and replace them with other absorbers. Thus, although this study using NCAW simulant solution may resemble our previous studies, it includes 30 absorbers not tested in our Hanford Tank 102-SY study¹ and 13 absorbers not tested in our double-shell slurry feed (DSSF) study.² We also add or eliminate specific radiotracers depending on their availability and solubility in the simulant solution being studied.

The results from this absorber screening study, our previous studies of three simulant solutions for Hanford Tank 102-SY,¹ and our studies of alkaline supernate for Hanford generic DSSF simulant² indicate that many existing partitioning agents may be suitable for high-level waste (HLW) tank remediation. We also found numerous inexpensive commercial materials that outperform specialty products costing much more. The identification of reliable partitioning agents could allow the processing of HLW in Hanford tanks to begin and be completed sooner, and at a lower cost, than would otherwise be possible. Thus, the findings of our studies could have a major beneficial impact on decommissioning and environmental remediation efforts at Hanford and elsewhere within the U.S. Department of Energy (DOE) complex.

Our screening studies, intended to identify the most promising absorbers and extractants, include mainly absorbers that either are already commercially available or could be produced in commercial quantities at acceptable cost and within a reasonable time. Distribution coefficients (K_ds) for each element/absorber

combination were measured for dynamic contact periods of 30 min, 2 h, and 6 h to provide information about the sorption kinetics of each system.

In many cases, the observed behavior of the element/absorber combination in the simulant solution was significantly different from the expected behavior, based on published measurements from solutions having relatively simple chemical compositions. We attribute such differences to the effects of other cations that compete for absorber sites, as well as the competition from anions that form soluble complexes with metal ions that would otherwise be sorbed. Such matrix-dependent differences in absorber performance demonstrate the value of using realistic simulant solutions for such measurements.

Table 1 summarizes the number of absorbers identified as effective in each of six Kd ranges.

From simulated NCAW solution, all elements except vanadium show at least one absorber for which the Kd value is 300 or more. Cesium, strontium, iron, manganese, and zirconium are sorbed with Kd values greater than 1000 by many absorbers.

Absorbers that perform well in this and previous^{1,2} screening studies will be evaluated with increasingly realistic simulants that contain degraded organic ligands that form competing complexes with multivalent cations. We plan to evaluate the best identified absorbers with actual radioactive waste solutions as soon as such waste can be obtained. We also suggest an accelerated effort to identify or develop partitioning agents to achieve separations for which we have identified no satisfactory absorbers.

I. INTRODUCTION

The Hanford Reservation near Richland, Washington, incorporates 177 underground tanks that store more than 65 million gallons of radioactive waste containing some 165 million curies. These high-level wastes (HLWs) are a byproduct of the production of nuclear materials for national defense needs during the past half-century. Because Hanford operating contractors used

Table 1. Number of Absorbers Capable of Sorbing Each of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Values					
	>1000	301-1000	101-300	21-100	11-20	5-10
Cs	6	1	2	7	1	0
Sr	31	4	9	8	1	1
Tc	1	7	2	3	0	3
Y	2	18	14	14	2	4
Cr	1	2	0	1	0	0
Co	0	1	1	9	4	2
Fe	13	12	5	6	4	3
Mn	8	7	12	10	1	5
Ni	1	0	2	15	10	12
V	0	0	1	2	0	1
Zn	3	4	2	16	1	5
Zr	7	7	10	11	3	1

numerous chemical processes during this period, many different reagents and waste streams were generated and combined in underground tanks. The resulting wastes consist of complex and sometimes unstable mixtures of sludges, saltcakes, slurries, and supernates. Adding significantly to the stored-waste problem is the fact that 67 of these underground waste storage tanks are known, or are presumed, to have leaked.

The U.S. Department of Energy (DOE) is committed to the remediation of hazardous wastes stored at Hanford and has directed Los Alamos National Laboratory (LANL) and Sandia National Laboratories/New Mexico (SNL) to support the Hanford Tank Waste Remediation System (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.

Ion exchange is a partitioning technology that has been extensively used in the nuclear industry. Anion exchange has been used for many decades to recover plutonium³ and neptunium⁴ from a wide variety of impure nuclear materials. Cation exchange resins also have been used in the nuclear industry,⁵ although they generally are considered to be less selective than anion exchange resins.

Although most of the absorbers we tested in this study and in our previous studies with three simulant solutions for Hanford Tank 102-SY¹ and one generic simulant solution for double-shell slurry feed² (DSSF) are cation exchangers, we also included anion exchange resins, inorganic exchangers, composite resins, and a series of liquid ion exchangers (sorbed on porous carbon beads). Our intent was to obtain more comprehensive data as well as to supply convenient reference points for other studies. We also included some experimental absorbers to provide guidance for future research activities.

Some of the absorbers included in our study have been reported by others to offer high selectivity for specific ions; however, few of these absorbers have been evaluated with media approaching the complexity of the HLW solutions stored at Hanford. Nor have any other investigators, to our knowledge, measured the distribution of as many elements (12) onto so many different absorber materials (64) from a realistic Hanford neutralized current acid waste (NCAW) simulant solution under identical test conditions. Moreover, because we measured the sorption of so many different elements, our study provides selectivity information that specifies which unwanted elements are most likely to interfere by competing for absorber sites.

After each completed segment of our absorber screening studies, we review the performance of the tested absorbers, eliminate those that perform poorly, and replace them with other absorbers. Thus, although this study using NCAW simulant solution may resemble our previous studies, it includes 30 absorbers not tested in our Hanford Tank 102-SY study¹ and 13 absorbers not tested in our DSSF study.² We also add or eliminate specific radiotracers depending on their availability and solubility in the simulant solution being studied.

Our objective was to evaluate numerous potentially useful absorber materials, including some not previously studied, for their ability to recover selected elements from a realistic NCAW simulant solution. Because no simulant can accurately represent the contents of any HLW storage tank, the most promising absorbers eventually must be tested with actual waste. However, because actual waste samples are expensive and difficult to obtain, we continue to advocate preliminary screening of candidate absorbers with simulants before testing with actual tank waste solutions.

Although we include comments and observations about our experimental data, we intentionally do not recommend specific absorbers. Our purpose is to identify options from which the designated engineers can develop reliable process flow sheets. Which partitioning options they select will, of course, depend on the specific objectives of their flow sheet.

II. EXPERIMENTAL PARAMETERS

A. Simulant Solution

The simulated NCAW solution was prepared and provided by Garrett Brown of Battelle Pacific Northwest Laboratory (PNL). The composition of this solution supplied by PNL is given in Table 2.

We initially passed the NCAW simulant solution through a 0.45- μ m filter to remove any suspended solids and then refiltered it after adding the radiotracers to remove any portion not truly in solution. Finally, we filtered each portion of precontacted and postcontacted simulant solution again through a 0.45- μ m filter before gamma-spectrometric assay.

Table 2. Composition of Simulated Hanford NCAW Solution Used in This Study

	Concentration (M)
Cations	
Na	4.987
K	0.120
Rb	5.0×10^{-5}
Cs	5.0×10^{-4}
Al	0.430
Anions	
F	0.089
NO ₃	1.669
NO ₂	0.43
PO ₄	0.025
SO ₄	0.15
CO ₃	0.23
OH ⁻ (total)	3.4
OH ⁻ (free)	1.68
Theoretical pH = 14.52	
Measured pH = 14.2	

B. Radiotracers

Having selected gamma spectrometry as the technique for measuring the distribution of the selected elements, we obtained suitable radiotracers to be added to the simulant solutions. The selected tracers and the gamma energies measured are listed in Table 3.

We purchased ⁶⁰Co, ¹³⁷Cs, ⁵⁹Fe, ⁵⁴Mn, and ⁵¹Cr from DuPont New England Nuclear Products, Boston, Massachusetts. The Medical Isotopes Program of the Brookhaven National Laboratory Medical Department supplied ⁵⁶Ni and ⁴⁸V. The ⁸⁵Sr, ^{95m}Tc, ⁶⁵Zn, ⁸⁸Zr, and ⁸⁸Y were obtained from the Nuclear and Radiochemistry Group at Los Alamos.

To minimize interference among gamma rays with similar energies, we divided the 12 radiotracers into two easily resolved groups. One group consisted of ⁵¹Cr, ¹³⁷Cs, ⁸⁵Sr, and ^{95m}Tc. The other group contained ⁶⁰Co, ⁵⁹Fe, ⁵⁴Mn, ⁵⁶Ni, ⁴⁸V, ⁸⁸Y, ⁶⁵Zn, and ⁸⁸Zr. We divided the simulant solution into two equal portions and added four tracers to one portion and eight tracers to a separate portion. Both portions were tested with all 64 absorbers.

Table 3. Radiotracers Used in This Study

Radiotracer	Gamma Energy (MeV)	Gamma Branching (%) ^a	Estimated Concentration ^b
⁵⁶ Ni	0.158	100	60 pg/L
^{95m} Tc	0.204	100	2 pg/L
⁵¹ Cr	0.320	10	0.3 μg/L
⁸⁸ Zr	0.394	97	50 μg/L
⁸⁵ Sr	0.514	100	3 μg/L
¹³⁷ Cs	0.662	85	6 μg/L
⁵⁴ Mn	0.835	100	3 μg/L
⁸⁸ Y	0.898	92	50 μg/L
⁴⁸ V	0.983	100	80 pg/L
⁵⁹ Fe	1.099	56	20 μg/L
⁶⁵ Zn	1.115	51	6 μg/L
⁶⁰ Co	1.173	100	2 μg/L

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

^bThe elemental concentrations given for the radiotracers are based on the best information available from suppliers; however, these values do not account for low levels of these elements that could have been unintentionally added as impurities in the reagents used to prepare the simulant.

C. Absorbers

The absorbers evaluated in this study are listed in Table 4. Details about the supplier or preparation of each absorber are provided in Section III.B. These absorbers, which encompassed a wide range of particle sizes and porosities, were used as received except where otherwise noted.

Although the suppliers of the polyacrylonitrile (PAN) composites, tannin, and Diphonix™ prefer that their absorbers not be dried, we intentionally air-dried all wet absorbers before testing to put them all on a directly comparable basis. We also sought to avoid diluting the simulant solution by adding as-received wet resins, which in the worst case would have diluted the simulant by 23%. Because the NCAW simulant was essentially saturated with various salts, large dilutions could significantly change the chemical properties of the solution, which could substantially affect the performance of many absorbers.

The concern expressed by a few colleagues about the adverse effects of air-drying absorbers appears to be overstated. Specifically, our study using air-dried absorbers yielded a distribution coefficient (K_d) of 17,000 for one element with Diphonix™ (Section III.B.1.f), 3 triple-digit K_d values and 3 four-digit K_d values with tannin (Section III.B.1.z), and four-digit or higher K_d values with 13 of 16 PAN absorbers (Sections III.B.4.c and III.B.4.e through III.B.4.p). Moreover, these high K_d values may qualify the cited absorbers for future column tests, in which none of the tested absorbers will require drying.

D. Solution/Absorber Contacts

In most cases, a 250-mg portion of each dry absorber was contacted with a measured 6-mL volume of simulant solution in a specially modified 20-mL disposable hypodermic syringe. We modified these syringes by inserting cylindrical plugs cut from 1/4-in.-thick porous Kynar™, obtained from Porex Technologies, Fairburn, Georgia, into the tapered tips as filters, which permitted only liquid to pass through (Fig. 1).

A typical group of experiments consisted of a different absorber in each of six syringes. A measured volume of 0.45- μ m-filtered simulant solution was transferred by pipet into a 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 (Fig. 2) 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 the filtered tip of the syringe into a tared counting vial. The weight of the dispensed solution was determined and used in the calculation of K_d values.

The described filter-tip syringes were unsuitable for the crystalline silico-titanate (CST) absorbers from Sandia/NM because these small particles often plugged these filters. For finely divided materials, we pipetted 6 mL of solution 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 10 min. We then transferred approximately 1.5 mL of the centrifuged solution into a 2.5-mL hypodermic syringe with a 0.45-mm filter (center left in Fig. 1) attached to the Luer-lock tip. The centrifuged solution was expelled through this filter into a tared counting vial, from which we determined the solution weight.

E. Calculation of K_d Values

Distribution coefficients (K_d s) normally are calculated in terms of the dry absorber weight;⁶ optionally, K_d s can be calculated in terms of the wet absorber volume. Because most of absorbers we tested were received in dry form, we tested all absorbers on a comparable, dry basis to conform to a consistent K_d 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 lasting damage, we never applied heat during the drying cycles.

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.

Table 4. Absorbers Evaluated in This Study

Absorber Type/Source	Trademark^a or Other Identification
Commercial Absorbers	Amberlite™ DP-1 cation resin Amberlite™ IRC-76 cation resin Amberlite™ IRC-718 cation resin Bone char absorber Chelex™ 100 cation resin (iminodiacetic acid) Diphonix™ cation resin (polyfunctional) Duolite™ CS-100 cation resin (phenolic) Duolite™ C-467 cation resin (phosphonic acid) Durasil™ 190 resin Durasil™ 230 resin Ionac™ SR-3 anion resin (trimethyl amine) Ionac™ SR-6 anion resin (tributyl amine) Ionsiv™ TIE-96 (TiO ₂ -loaded zeolite) Ionsiv™ TIE-96, modified (TiO ₂ -loaded zeolite) Lewatit™ CNP 80 W resin Lewatit™ TP 207 resin Nusorb™ Ferroc carbon A absorber Nusorb™ LP-70-S absorber Nusorb™ Magnetite absorber Nusorb™ Unitane absorber Purolite™ A-520-E anion resin (triethyl amine) Reillex™ HPQ anion resin (polyvinylpyridine) Resin Tech™ 3972 resin SRS RF BSC-187 (resorcinol/formaldehyde) resin SRS RF BSC-210 (resorcinol/formaldehyde) resin Tannin absorber TEVA-Spec™ absorber UTEVA-Spec™ absorber
Experimental Absorbers	Blaylock clay Fithian clay KCoFC crystals (150–600 μm) KCoFC powder KW-3-85x (tantalum tungstate) MgAlHT (hydrotalcite) RC-2-62A (sodium nanotitanate) PS-CATS (functionalized polymer) PS-3,3-LICAMS (functionalized polymer) Sybron (Et) ₃ N anion resin Sybron (Pr) ₃ N anion resin
Composite Absorbers F. Sebesta, Czech Republic (polyacrylonitrile matrix)	AMP-PAN ammonium molybdophosphate Ba(Ca)SO ₄ -PAN barium/calcium sulfate CSbA-PAN crystalline polyantimonic acid M315-PAN synthetic mordenite MgO-PAN magnesium oxide MnO-PAN manganese dioxide NaTiO-PAN sodium titanate NiFC-PAN nickel hexacyanoferrate NM-PAN nickel hexacyanoferrate/manganese dioxide SnSbA-PAN stannic antimonate TiO-PAN titanium dioxide TiP-PAN titanium phosphate

Table 4. Absorbers Evaluated in This Study (Cont.)

Absorber Type/Source	Trademark^a or Other Identification
Composite Absorbers (cont.)	TiSbA-PAN titanium antimonate
F. Sebesta, Czech Republic	ZrO-PAN zirconium oxide
(polyacrylonitrile matrix)	ZrOP-PAN zirconium oxide/zirconium phosphate
	ZrP-PAN zirconium phosphate
J. Narbutt, Poland	CoFC-PSF cobalt hexacyanoferrate
(phenolsulfonic- formaldehyde matrix)	TiFC-PSF titanium hexacyanoferrate
LANL-Prepared	Aliquat TM 336 (methyltricaprylammonium chloride)
Extractant Beads	Cyanex TM 923 (trialkylphosphine oxide)
	LIX TM -54 (a beta diketone)
Sandia/NM	SNL/CST 120 crystalline silico-titanate
Absorbers	SNL/CST 141 crystalline silico-titanate
	SNL/CST 149 crystalline silico-titanate
	SNL/HTO amorphous hydrous titanium dioxide

^aTrademark owners are identified on page x.

Fig. 1. Hypodermic syringe, with porous KynarTM filter in tip, as used for solution/absorber contacts. An uninstalled KynarTM filter is shown below the syringe.

Fig. 2. Tube rotator used to mix the solution/absorber combinations.

The Kd value for each element was calculated as follows:

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

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

Uncertainties are larger when Kd values are very low (when the numerator of the first fraction represents a small difference between two large numbers), as well as when Kd values are very high (when the denominator of the first fraction becomes very small). However, the objective of this screening study was to identify absorbers that sorb specific elements poorly or very well.

Although we report most Kd values below 5000 as calculated, this obviously should not be taken to indicate that all four figures are significant. The uncertainty associated with our highest and lowest Kd values appears to be within a factor of 2 or 3. We estimate the uncertainty associated with our best Kd values to range from 10% to 20%. To avoid implying more precision than is justified, we report Kd values above 5000 as the next lower thousand (K) value. In some cases where we feel the uncertainty is unusually high, even though the Kd value is less than 5000, we report the Kd as the next lower hundred value.

The need for highly precise Kd values decreases as the Kd values increase. For example, the difference between a Kd value of 5000 (99.98% sorbed) and a Kd value of 10,000 (99.99% sorbed) is only 0.01%. We therefore elected to evaluate a larger number of candidate absorbers, rather than spend a comparable effort trying to increase the number of significant figures in our measured Kd values. If it is necessary to determine Kd values with higher accuracy, such data can be obtained in follow-up studies, which would be limited to the most promising absorbers identified in our screening studies.

F. Corrections

Because the solution weights of the postcontact assay portions 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/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 same radionuclide in the precontact standard. Because absorbers were initially added in dry form, the aqueous solvent was often preferentially sorbed, which decreased the liquid volume and simultaneously increased the concentration of the solutes. Consequently, the activity of nonsorbed 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 same portion of solution accordingly.

We also made time-dependent corrections for the decay of ⁵⁶Ni (6.1-day half-life) and ⁴⁸V (16-day half-life) during the gamma assay period. All calculations and corrections were performed in an EXCEL™ spreadsheet.

G. Other Sources of Uncertainty

Each combination of element/absorber/contact time was measured only once. The absence of duplicates is offset by the fact that we measured individual Kd values for three consecutive contact periods. Any abrupt change in the expected smooth trend of these three data points indicates an unreliable point.

Poor precision is also indicated by excessive variation within a set of three data points where no trend is evident. For very low or very high Kd values, the variation is expected to be large for reasons already discussed.

H. Data Transfer and Processing

To save time and also minimize the human errors that can be introduced in transcribing large quantities of data, we automated the data transfer and calculation process. We used *Gamanal*⁷ 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 computer interpretation of 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 EXCEL™ spreadsheet in which all 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.

I. Calculation of Detection Limits

When peaks in a gamma spectrum were too small to be detected by the *Gamanal* program, we used a simple method⁸ to calculate the appropriate detection limits. First, for each radionuclide of interest, the same detector was used to determine the peak position and full width at half maximum (FWHM) from a spectrum with a strong gamma signal. The FWHM then was doubled to include the entire gamma-peak region (and always rounded up to the next integer) to define the position and width of the region of interest to be applied to the background spectra. The number of background counts in this region was summed, and the square root of the sum multiplied by a confidence-limit scale factor. A scale-factor value of 2.772 was used to ensure that 95% of the signal peaks of this magnitude would be statistically 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.

III. RESULTS AND DISCUSSION

A. Individual Elements

Tables 5 through 16 list some of the most promising absorbers for each element, ranked in order of Kd value, for sorption from simulated NCAW solution. Partitioning agents that sorb the specified element poorly are generally omitted from these tables, although absorbers designated as baseline technologies for the TWRS are always included, even when they perform poorly. A complete listing for all elements for each absorber is presented in Section III.B, Individual Absorbers.

1. Cesium. Nine absorbers sorb cesium with Kd values greater than 100. Although the KCoFC (powder) and KCoFC (crystals) offer five-digit Kd values for sorbing cesium from NCAW simulant, the decrease in Kd values with increased contact time reflects instability of these materials in solutions of pH greater than 12.

Table 5. Cesium Distribution Data

Absorber	Kd Value for Specified Time		
	30 min	2 h	6 h
KCoFC powder	31K	17K	5K
KCoFC crystals	18K	17K	5K
SNL/CST 141	1812	1990	2071
SNL/CST 149	1301	1759	1829
SRS RF BSC-210	283	712	1142
NiFC-PAN	261	158	115
CoFC-PSF	237	1072	1488
SRS RF BSC-187	169	423	666
NM-PAN	147	101	77
M315-PAN	94	99	91
Duolite™ CS-100	89	97	96
SNL/CST 120	71	95	101
TiFC-PSF	35	44	45
Durasil™ 230	32	46	48
Tannin	28	29	29
Ionsiv™ TIE-96 (mod.)	23	38	45
Ionsiv™ TIE-96	23	38	43

2. Strontium. The number of effective absorbers for removing strontium from alkaline solution is especially large. More than 30 absorbers offer four-digit Kd values for sorbing strontium from NCAW simulant.

Table 6. Strontium Distribution Data

Absorber	Kd Value for Specified Time		
	30 min	2 h	6 h
SNL/HTO	>34K	>35K	>35K
KCoFC powder	21K	25K	>35K
SNL/CST 120	18K	21K	23K
ZrP-PAN	16K	>38K	>37K
RC-2-62A	15K	>36K	>36K
MnO-PAN	12K	>40K	>39K
CSbA-PAN	7K	>36K	>37K
TiP-PAN	7K	14K	>37K
KCoFC crystals	7K	11K	24K
NM-PAN	5K	>56K	>56K
TiO-PAN	5K	17K	>42K
NaTiO-PAN	3487	9K	14K
Diphonix™	3338	8K	17K
SNL/CST 149	2950	6K	8K
TiSbA-PAN	2812	7K	12K
SnSbA-PAN	2084	8K	>36K
NiFC-PAN	1952	5K	11K
SNL/CST 141	1581	2082	3001
TiFC-PSF	1216	4402	7K
Bone char	825	2812	7K
MgO-PAN	808	1276	1458
Amberlite™ IRC-718	474	992	1633
MgAlHT	453	778	921
Ionsiv™ TIE-96	407	965	1696
Duolite™ C-467	361	706	1010
Lewatit™ TP 207	344	874	1519
Tannin	324	672	1081
Ionsiv™ TIE-96 (mod.)	294	781	1322
Nusorb™ Ferrocabon A	282	1427	2784
KW-3-85x	238	243	246
Chelex™ 100	213	374	384
PS-CATS	131	318	497
Duolite™ CS-100	91	123	135
Fithian clay	81	152	242
CoFC-PSF	76	531	1199
Ba(Ca)SO ₄ -PAN	68	119	166
PS-3,3-LICAMS	64	153	236
SRS RF BSC-187	64	106	134
SRS RF BSC-210	64	100	113
ZrO-PAN	52	659	2999
ZrOP-PAN	22	207	1495

3. Technetium. Many anion exchange resins and several extractants whose structures mimic anion exchange functional groups provide at least triple-digit Kd values for sorbing technetium from NCAW simulant.

Table 7. Technetium Distribution Data

Absorber	Kd Value for Specified Time		
	30 min	2 h	6 h
TEVA-Spec™	1101	1259	1209
Aliquat™ 336	455	679	775
Reillex™ HPQ	382	459	445
Purolite™ A-520-E	329	660	782
Sybron (Et) ₃ N	303	571	739
Ionac™ SR-3	227	385	407
Sybron (Pr) ₃ N	218	488	705
Cyanex™ 923	185	212	188
Ionac™ SR-6	127	308	544
Nusorb™ LP-70-S	31	46	47
SRS RF BSC-187	5.0	33	232
Tannin	4.7	15	62

4. Yttrium. More than 30 absorbers offer at least triple-digit Kd values for sorbing yttrium from NCAW simulant.

Table 8. Yttrium Distribution Data

Absorber	Kd Value for Specified Time		
	30 min	2 h	6 h
NiFC-PAN	248	587	1141
SNL/HTO	237	474	718
KCoFC powder	222	379	707
Fithian clay	212	321	510
NM-PAN	178	436	852
MnO-PAN	163	399	748
RC-2-62A	158	391	700
TiP-PAN	139	338	549
ZrP-PAN	138	670	1184
TiO-PAN	130	397	686
KCoFC crystals	128	262	485
Bone char	115	304	456
MgO-PAN	114	282	433
MgAlHT	107	229	358
TiSbA-PAN	100	264	592
Ionsiv™ TIE-96 (mod.)	89	245	405
Blaylock clay	86	157	243
Duolite™ CS-100	79	153	232
NaTiO-PAN	70	223	433
Ionsiv™ TIE-96	69	183	331
SNL/CST 120	67	170	321
Nusorb™ Ferrocabon A	50	160	368
Ba(Ca)SO ₄ -PAN	44	136	252
TiFC-PSF	43	109	228
PS-CATS	38	89	175
CSbA-PAN	38	101	298
Durasil™ 230	35	124	285
SRS RF BSC-210	33	70	86
LIX™-54	31	79	236
Amberlite™ DP-1	31	62	103
Tannin	29	81	149
SnSbA-PAN	26	66	203
AMP-PAN	24	68	130
Diphonix™	18	28	41
Nusorb™ Unitane	12	42	174
ZrOP-PAN	8	35	140
CoFC-PSF	7	22	44

5. Chromium. Only four absorbers sorb chromium with Kd values higher than 10.

Table 9. Chromium Distribution Data

Absorber	Kd Value for Specified Time		
	30 min	2 h	6 h
Nusorb™ Ferrocabon A	20	24	7.4
Tannin	13	184	3004
SRS RF BSC-187	7	90	789
SRS RF BSC-210	1	15	397

6. Cobalt. Only Nusorb™ LP-70-S and Nusorb™ Ferrocabon A sorb cobalt with triple-digit Kd values, although a number of other absorbers offer high double-digit Kd values.

Table 10. Cobalt Distribution Data

Absorber	Kd Value for Specified Time		
	30 min	2 h	6 h
Nusorb™ LP-70-S	47	283	854
NiFC-PAN	32	64	92
Duolite™ CS-100	23	43	69
NM-PAN	21	38	45
Bone char	12	19	26
KCoFC powder	12	12	11
KCoFC crystals	10	12	11
SRS RF BSC-187	8.6	25	51
Nusorb™ Ferrocabon A	7.1	27	102
SRS RF BSC-210	6.1	15	30
Tannin	4.7	16	31
PS-CATS	4.6	15	34
TiFC-PSF	2.3	7	12
CoFC-PSF	1.9	6.1	11

7. Iron. The high Kd values for sorbing iron on many absorbers from NCAW solution may preclude their use for sorbing other elements of interest.

Table 11. Iron Distribution Data

Absorber	Kd Value for Specified Time		
	30 min	2 h	6 h
KCoFC powder	>4100	>4200	>4100
MnO-PAN	2534	>5K	>5K
RC-2-62A	1450	1970	>3800
TiO-PAN	1233	5K	>5K
KCoFC crystals	927	>5K	>4900
NiFC-PAN	682	2686	>8K
SNL/HTO	616	648	636
ZrP-PAN	572	>6K	>6K
NM-PAN	569	1749	3164
Duolite™ CS-100	392	672	1709
MgO-PAN	283	598	676
TiP-PAN	267	472	723
Tannin	265	925	2672
TiSbA-PAN	162	599	959
NaTiO-PAN	133	756	2343
SRS RF BSC-187	102	236	387
MgAlHT	100	182	270
Nusorb™ Ferrocabon A	78	405	1059
PS-CATS	78	285	599
Ionsiv™ TIE-96	73	300	725
SRS RF BSC-210	73	143	232
TiFC-PAN	69	269	507
Ionsiv™ TIE-96 (mod.)	53	343	1117
Diphonix™	47	86	126
PS-3,3-LICAMS	43	259	574
Fithian clay	39	122	364
ZrO-PAN	15	85	580
CoFC-PSF	8.6	51	351
ZrOP-PAN	7.9	32	216

8. Manganese. Many absorbers offer high Kd values for sorbing manganese from NCAW simulant, which may preclude the use of these absorbers for removing other elements of interest.

Table 12. Manganese Distribution Data

Absorber	Kd Value for Specified Time		
	30 min	2 h	6 h
MnO-PAN	1560	>7K	>8K
KCoFC powder	1030	>6K	>6K
Duolite™ CS-100	334	705	1016
KCoFC crystals	279	933	2991
ZrP-PAN	173	3973	>10K
TiO-PAN	121	456	1257
Tannin	90	333	796
SNL/HTO	79	146	239
RC-2-62A	71	190	430
SRS RF BSC-210	62	103	138
PS-CATS	57	360	696
TiP-PAN	54	101	173
TiFC-PSF	53	251	642
Nusorb™ Ferrocabon A	45	286	1180
SRS RF BSC-187	41	112	168
MgO-PAN	38	68	99
NaTiO-PAN	34	81	146
MgAlHT	29	63	129
Fithian clay	28	234	1366
NiFC-PAN	28	74	184
TiSbA-PAN	27	77	195
Ionsiv™ TIE-96 (mod.)	26	114	343
NM-PAN	23	77	282
Ionsiv™ TIE-96	21	62	150
Blaylock clay	14	101	458
CoFC-PSF	14	93	255
ZrO-PAN	11	45	127
Durasil™ 230	7.1	43	465
ZrOP-PAN	6.3	24	79
Nusorb™ Unitane	4.7	16	75

9. Nickel. Three absorbers offer at least triple-digit Kd values for sorbing nickel from NCAW simulant.

Table 13. Nickel Distribution Data

Absorber	Kd Value for Specified Time		
	30 min	2 h	6 h
NiFC-PAN	84	732	1023
NM-PAN	59	217	240
Nusorb™ LP-70-S	51	100	143
Bone char	51	62	56
Duolite™ CS-100	33	44	54
KCoFC powder	14	16	21
TiFC-PSF	12	27	37
PS-CATS	12	24	33
KCoFC crystals	10	14	16
SRS RF BSC-187	9.8	23	37
LIX™-54	8.6	23	51
SRS RF BSC-210	7.5	14	24
MgO-PAN	7.1	20	55
Nusorb™ Ferrocabon A	7.0	20	34
Fithian clay	6.8	13	26
Amberlite™ IRC-718	6.7	16	29
Chelex™ 100	3.6	12	27

10. Vanadium. Very few absorbers sorb vanadium at useful Kd values. Only ZrP-PAN offers triple-digit Kd values for sorbing vanadium from NCAW solution.

Table 14. Vanadium Distribution Data

Absorber	Kd Value for Specified Time		
	30 min	2 h	6 h
TiP-PAN	83	89	83
ZrP-PAN	21	119	129
ZrO-PAN	3.6	19	32
ZrOP-PAN	2.3	3.9	5.7

11. Zinc. Three absorbers offer four-digit Kd values for sorbing zinc and another six absorbers offer triple-digit values from NCAW simulant.

Table 15. Zinc Distribution Data

Absorber	Kd Value for Specified Time		
	30 min	2 h	6 h
NiFC-PAN	726	1922	2623
MgO-PAN	376	649	646
TiO-PAN	337	527	636
NM-PAN	333	823	1049
TiP-PAN	287	788	1519
SNL/HTO	164	367	621
MnO-PAN	109	198	348
MgAlHT	38	68	107
Diphonix™	22	32	36
ZrP-PAN	18	136	199
KCoFC powder	18	33	50
KCoFC crystals	18	31	50
Bone char	13	19	21
ZrO-PAN	8.7	29	60
NaTiO-PAN	8.4	20	43
SnSbA-PAN	8.1	17	43
TiFC-PSF	7.8	22	33
Tannin	7.5	16	23
RC-2-62A	7.5	14	28
TiSbA-PAN	6.9	17	58
Ionsiv™ TIE-96	6.3	14	24
ZrOP-PAN	5.2	15	40

12. Zirconium. Seven absorbers offer at least four-digit Kd values for sorbing zirconium from NCAW simulant. Numerous others offer three-digit Kd values.

Table 16. Zirconium Distribution Data

Absorber	Kd Value for Specified Time		
	30 min	2 h	6 h
SNL/HTO	1512	>2200	>2200
TiO-PAN	1506	2018	>3000
TiP-PAN	854	>4500	>4700
ZrP-PAN	725	>4500	>4600
RC-2-62A	509	>2100	>2200
MnO-PAN	165	278	377
TiSbA-PAN	141	1278	>2600
Duolite™ CS-100	91	181	288
NaTiO-PAN	86	482	1298
Fithian clay	70	298	691
Tannin	68	277	485
Diphonix™	61	159	292
MgO-PAN	54	102	166
Bone char	54	95	115
Ionsiv™ TIE-96	44	210	390
SNL/CST 120	42	72	136
Ionsiv™ TIE-96 (mod.)	37	243	767
TiFC-PSF	34	206	303
SNL/CST 149	33	45	45
SRS RF BSC-187	24	57	107
PS-CATS	20	80	217
ZrO-PAN	16	114	684
Durasil™ 230	10	33	120
Nusorb™ Ferrocen A	9.9	58	109
ZrOP-PAN	7.8	35	272
PS-3,3-LICAMS	6.6	33	130

B. Individual Absorbers

Tables 17 through 80 present Kd values for sorption of 12 elements onto each of the 64 absorbers from simulated NCAW solution. Because we measured the sorption of 12 different elements, these tables often provide information about which unwanted elements are most likely to interfere with the targeted element by competing for absorber sites. Therefore, Tables 17 through 80 may be used to predict the selectivity of each individual absorber for any of these elements. Because we provide Kd values for three different contact times, these tables also provide information about sorption kinetics for each element on specific absorbers.

Although long-term stability is an essential attribute of any absorber that would be seriously considered for waste processing, we made no attempt to evaluate the stability of these absorbers in the simulated NCAW solution. Each candidate absorber was included in our tests unless there was an obvious reason not to, such as noticeable degradation of the absorber. We recommend that the absorbers that appear most promising for application to HLW tank processing be evaluated for long-term chemical stability and also for radiation resistance if these properties are not already known.

1. Commercially Available Absorbers. The 28 commercially available absorbers listed in Table 4 were included in our study.

a. Amberlite™ DP-1 Cation Exchange Resin. Amberlite™ DP-1, manufactured by Rohm & Haas, Philadelphia, Pennsylvania, is a weak-acid cation exchanger consisting of a crosslinked methacrylic polymer with carboxylic acid functionality. This resin was air-dried before use.

Amberlite™ DP-1 sorbs yttrium with triple-digit Kd values and strontium and zirconium at useful levels from NCAW simulant.

Table 17. Amberlite™ DP-1 Cation Exchange Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.7	0.6	0.5
Sr	16	24	29
Tc	0.3	0.5	0.2
Y	31	62	103
Cr	<0.1	<0.1	<0.1
Co	0.1	0.2	0.2
Fe	3.6	5.0	6.8
Mn	1.6	2.3	2.8
Ni	0.5	1.4	3.9
V	<0.1	<0.1	<0.1
Zn	0.8	1.5	2.0
Zr	6.0	11	18

b. Amberlite™ IRC-76 Cation Exchange Resin.

Amberlite™ IRC-76, manufactured by Rohm & Haas, Philadelphia, Pennsylvania, is a weak-acid cation exchanger consisting of a crosslinked acrylic acid polymer with carboxylic acid functionality. This resin was air-dried before use.

Only strontium and manganese are sorbed with even double-digit Kd values.

Table 18. Amberlite™ IRC-76 Cation Exchange Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	1.2	0.9	1.0
Sr	35	64	89
Tc	0.2	<0.1	<0.1
Y	2.9	4.7	7.5
Cr	<0.1	<0.1	<0.1
Co	0.4	0.5	0.7
Fe	3.0	3.4	3.0
Mn	4.4	7.6	11
Ni	1.3	2.1	3.2
V	0.2	0.4	0.6
Zn	0.3	0.4	0.6
Zr	1.6	2.0	2.2

c. Amberlite™ IRC-718 Cation Exchange Resin.

Amberlite™ IRC-718, manufactured by Rohm & Haas, Philadelphia, Pennsylvania, is a weak-acid cation exchanger consisting of a styrene/divinylbenzene copolymer with iminodiacetic acid functionality. This resin was air-dried before use.

Amberlite™ IRC-718 sorbs strontium well and yttrium and nickel at useful, but much lower, Kd values.

Table 19. Amberlite™ IRC-718 Cation Exchange Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.3	<0.1	0.1
Sr	474	992	1633
Tc	3.8	3.6	3.3
Y	12	26	43
Cr	<0.1	<0.1	<0.1
Co	0.3	0.3	0.3
Fe	2.9	3.5	3.4
Mn	2.2	3.5	4.9
Ni	6.7	16	29
V	<0.1	<0.1	<0.1
Zn	2.2	2.3	2.1
Zr	1.3	1.6	2.0

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

Bone char sorbs strontium, yttrium, and zirconium with at least triple-digit Kd values. Five other elements are sorbed with double-digit Kd values.

Table 20. Bone Char Absorber: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.2	0.1	0.3
Sr	825	2812	7K
Tc	1.1	1.3	1.3
Y	115	304	456
Cr	<0.1	0.2	0.4
Co	12	19	26
Fe	15	25	31
Mn	22	39	69
Ni	51	62	56
V	0.1	<0.1	<0.1
Zn	13	19	21
Zr	54	95	115

e. Chelex™ 100 Cation Exchange Resin. Chelex™ 100, manufactured by the Dow Chemical Company, Midland, Michigan, is a weak-acid cation exchanger that consists of a styrene/divinylbenzene copolymer with iminodiacetic acid functionality. This resin was air-dried before use.

Chelex™ 100 provides high selectivity for sorbing strontium from NCAW simulant, with nickel the only other element sorbed with even a double-digit Kd value.

Table 21. Chelex™ 100 Cation Exchange Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.4	0.2	0.2
Sr	213	374	384
Tc	1.4	1.3	1.2
Y	0.8	1.1	1.2
Cr	<0.1	<0.1	<0.1
Co	0.2	0.2	0.1
Fe	0.2	0.4	0.3
Mn	<0.1	0.2	0.1
Ni	3.6	12	27
V	0.2	0.3	0.2
Zn	0.3	0.3	0.2
Zr	0.1	<0.1	0.2

f. Diphonix™ Cation Exchange Resin. Diphonix™, a polyfunctional resin that contains diphosphonic acid, sulfonic acid, and carboxylic acid functional groups, was obtained from EIChroM Industries, Inc., Darien, Illinois. We air-dried this resin before testing for reasons detailed in Section II.C.

Diphonix™ resin sorbs strontium well from NCAW simulant and sorbs five other elements with double-digit or triple-digit Kd values from NCAW simulant.

Table 22. Diphonix™ Cation Exchange Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	1.0	1.0	0.8
Sr	3338	8K	17K
Tc	2.7	2.4	2.0
Y	18	28	41
Cr	<0.1	<0.1	<0.1
Co	0.2	0.3	0.3
Fe	47	86	126
Mn	4.4	6.6	9.0
Ni	5.3	7.0	10
V	<0.1	<0.1	<0.1
Zn	22	32	36
Zr	61	159	292

g. Duolite™ CS-100 Cation Exchange Resin. Duolite™ CS-100 is a phenol-formaldehyde condensate cation exchange resin manufactured by Rohm & Haas, Philadelphia, Pennsylvania. (However, Rohm & Haas has recently discontinued CS-100 as one of its standard products.) This resin was air-dried before use.

Duolite™ CS-100 resin, the current baseline technology for removing cesium from Hanford waste, sorbs cesium with only a double-digit Kd value. Strontium and yttrium sorb with triple-digit Kd values. Moreover, the high-concentration matrix elements iron, manganese, and zirconium are much more strongly sorbed than cesium and would be expected to seriously interfere with cesium sorption.

Table 23. Duolite™ CS-100 Cation Exchange Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	89	97	96
Sr	91	123	135
Tc	0.4	0.1	0.3
Y	79	153	232
Cr	0.2	1.0	3.0
Co	23	43	69
Fe	392	672	1709
Mn	334	705	1016
Ni	33	44	54
V	<0.1	<0.1	<0.1
Zn	4.2	5.9	8.3
Zr	91	181	288

h. 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. This resin was air-dried before use.

Duolite™ C-467 provides high selectivity for strontium from NCAW simulant, with a Kd value 20-fold higher than that for yttrium, the only other element with even a double-digit Kd value. The commercial availability of this resin at low cost makes it an attractive candidate for removing strontium from alkaline solution.

Table 24. Duolite™ C-467 Cation Exchange Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.4	0.3	0.3
Sr	361	706	1010
Tc	3.8	5.1	6.4
Y	15	29	51
Cr	<0.1	<0.1	<0.1
Co	0.1	<0.1	<0.1
Fe	0.5	0.5	0.7
Mn	1.9	2.4	2.7
Ni	2.3	3.9	7.4
V	<0.1	<0.1	<0.1
Zn	1.4	1.5	1.5
Zr	0.8	0.4	0.4

i. Durasil™ 190 Resin. Durasil™ 190, a vitreous glass absorber obtained from the Duratek Corporation, Beltsville, Maryland, was used as received.

Durasil™ 190 sorbs none of the 12 elements from NCAW simulant at useful levels.

Table 25. Durasil™ 190 Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.2	0.2	0.7
Sr	0.3	0.6	3.0
Tc	0.6	0.6	0.6
Y	1.0	2.0	2.7
Cr	<0.1	0.1	<0.1
Co	0.4	0.8	0.4
Fe	0.5	1.0	0.8
Mn	0.6	0.8	0.6
Ni	0.5	1.1	1.0
V	0.5	0.8	0.5
Zn	0.2	0.5	0.3
Zr	0.2	0.7	0.6

j. Durasil™ 230 Resin. Durasil™ 230, an aluminosilicate absorber obtained from the Duratek Corporation, Beltsville, Maryland, was used as received.

Durasil™ 230 sorbs manganese, yttrium, and zirconium with triple-digit Kd values and sorbs cesium, strontium, and iron moderately.

Table 26. Durasil™ 230 Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	32	46	48
Sr	17	40	69
Tc	<0.1	<0.1	<0.1
Y	35	124	285
Cr	<0.1	0.2	0.2
Co	<0.1	<0.1	0.2
Fe	6.2	14	49
Mn	7.1	43	465
Ni	2.7	3.7	4.8
V	<0.1	<0.1	<0.1
Zn	2.5	3.9	5.0
Zr	10	33	120

k. Ionac™ SR-3 Anion Exchange Resin. Ionac™ SR-3, a macroporous strong-base anion exchange resin with trimethyl amine as the functional group, was obtained from Sybron Chemicals, Inc., Birmingham, New Jersey. This resin was air-dried before use.

Ionac™ SR-3 sorbs technetium strongly and selectively from NCAW simulant.

Table 27. Ionac™ SR-3 Anion Exchange Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.3	0.2	0.2
Sr	<0.1	<0.1	<0.1
Tc	227	385	407
Y	0.6	0.7	1.0
Cr	0.3	0.2	0.2
Co	0.3	0.3	0.3
Fe	0.3	0.3	0.6
Mn	0.5	0.6	0.7
Ni	0.5	0.6	0.9
V	0.1	<0.1	0.1
Zn	<0.1	<0.1	<0.1
Zr	0.4	0.3	0.4

l. Ionac™ SR-6 Anion Exchange Resin. Ionac™ SR-6, a macroporous strong-base anion exchange resin with tributyl amine as the functional group, was obtained from Sybron Chemicals, Inc., Birmingham, New Jersey. Ionac™ SR-6 resin has been reported⁹ to offer greatly increased selectivity for nitrate ion from groundwater. This resin was air-dried before use.

Ionac™ SR-6 sorbs technetium selectively from NCAW simulant.

Table 28. Ionac™ SR-6 Anion Exchange Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	<0.1	0.1	<0.1
Sr	0.2	0.5	0.4
Tc	127	308	544
Y	1.5	1.7	2.3
Cr	0.1	0.3	0.4
Co	0.4	0.3	0.4
Fe	0.8	0.8	1.0
Mn	0.7	0.6	0.8
Ni	0.6	0.6	1.3
V	0.5	0.4	0.4
Zn	0.4	0.2	0.3
Zr	0.3	0.4	0.4

m. Ionsiv™ TIE-96 Absorber. Ionsiv™ TIE-96 is a titanium-loaded zeolite manufactured by UOP Molecular Sieves Division, Moorestown, New Jersey. This absorber was used as received.

Ionsiv™ TIE-96 sorbs strontium, iron, zirconium, yttrium, and manganese well from NCAW simulant. Several other elements are sorbed at lower, but useful, levels.

Table 29. Ionsiv™ TIE-96 Absorber: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	23	38	43
Sr	407	965	1696
Tc	<0.1	<0.1	<0.1
Y	69	183	331
Cr	0.1	<0.1	0.1
Co	0.2	0.3	0.5
Fe	73	300	725
Mn	21	62	150
Ni	2.7	4.2	6.3
V	<0.1	<0.1	<0.1
Zn	6.3	14	24
Zr	44	210	390

n. Ionsiv™ TIE-96 (Modified) Absorber. Ionsiv™ TIE-96 (modified) is an improved version of the Ionsiv™ TIE-96 titanium-loaded zeolite manufactured by UOP Molecular Sieves Division, Moorestown, New Jersey. This absorber was used as received.

This absorber generally shows the same sorption patterns as the unmodified Ionsiv™ TIE-96.

Table 30. Ionsiv™ TIE-96 (Modified)
Absorber: Distribution of 12 Elements from
Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	23	38	45
Sr	294	781	1322
Tc	0.3	<0.1	0.1
Y	89	245	405
Cr	<0.1	<0.1	<0.1
Co	<0.1	0.4	0.5
Fe	53	343	1117
Mn	26	114	343
Ni	3.1	4.8	8.3
V	<0.1	<0.1	<0.1
Zn	4.8	11	21
Zr	37	243	767

o. Lewatit™ CNP 80 W Resin. Lewatit™ CNP 80 W, a cation exchange resin consisting of a copolymer of acrylic acid, divinylbenzene, and an aliphatic diene with carboxylic acid anchor groups in the H⁺ form, is manufactured by Miles Inc., Organic Product Division, Pittsburgh, Pennsylvania. This absorber was air-dried before use.

Lewatit™ CNP 80 W is selective for strontium with a moderate Kd value.

Table 31. Lewatit™ CNP 80 W Resin:
Distribution of 12 Elements from Simulated
Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.2	0.8	1.1
Sr	7.7	22	55
Tc	<0.1	<0.1	<0.1
Y	0.8	1.2	1.5
Cr	<0.1	0.1	0.4
Co	0.1	0.2	0.1
Fe	0.2	0.4	0.7
Mn	0.7	1.2	2.3
Ni	0.3	0.5	0.9
V	0.3	0.5	0.4
Zn	<0.1	<0.1	<0.1
Zr	<0.1	0.1	0.3

p. Lewatit™ TP 207 Resin. Lewatit™ TP 207, a weakly acidic, macroporous cation exchange resin of crosslinked polystyrene with chelating iminodiacetate groups, is manufactured by Miles Inc., Organic Product Division, Pittsburgh, Pennsylvania. This material was air-dried before use.

Lewatit™ TP 207 strongly and selectively sorbs strontium.

**Table 32. Lewatit™ TP 207 Resin:
Distribution of 12 Elements from Simulated
Hanford NCAW Solution**

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.1	<0.1	<0.1
Sr	344	874	1519
Tc	0.6	0.5	0.4
Y	3.3	5.3	8.6
Cr	<0.1	0.2	0.2
Co	0.4	0.2	0.3
Fe	0.6	0.5	0.5
Mn	0.9	0.9	0.9
Ni	1.7	3.0	6.0
V	0.7	0.5	0.4
Zn	6.3	11	14
Zr	0.1	<0.1	<0.1

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

Nusorb™ Ferrocabon A sorbs strontium, manganese, iron, yttrium, zirconium, and cobalt with at least triple-digit Kd values.

**Table 33. Nusorb™ Ferrocabon A Absorber:
Distribution of 12 Elements from Simulated
Hanford NCAW Solution**

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	1.8	3.6	3.4
Sr	282	1427	2784
Tc	5.1	5.5	5.8
Y	50	160	368
Cr	20	24	7.4
Co	7.1	27	102
Fe	78	405	1059
Mn	45	286	1180
Ni	7.0	20	34
V	0.2	0.4	1.0
Zn	4.0	11	30
Zr	9.9	58	109

r. Nusorb™ LP-70-S Absorber. Nusorb™ LP-70-S, an activated carbon whose surface provides cation exchange functionality, is manufactured by Nucon International, Inc., Columbus, Ohio. This material was used as received.

Nusorb™ LP-70-S strongly sorbs cobalt and nickel, both of which have radioisotopes of environmental concern. Several other elements also are sorbed at useful levels.

**Table 34. Nusorb™ LP-70-S Absorber:
Distribution of 12 Elements from Simulated
Hanford NCAW Solution**

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	2.1	1.7	1.6
Sr	7.2	13	23
Tc	31	46	47
Y	4.2	9.4	19
Cr	<0.1	<0.1	<0.1
Co	47	283	854
Fe	2.6	4.6	7.9
Mn	9.2	22	57
Ni	51	100	143
V	<0.1	<0.1	0.2
Zn	<0.1	0.2	0.4
Zr	0.8	1.7	3.5

s. Nusorb™ Magnetite Absorber. Nusorb™ Magnetite, a porous low-density single-phase Fe_3O_4 , is manufactured by Nucon International, Inc., Columbus, Ohio. This material was used as received.

Even the elements sorbed best from NCAW simulant by Nusorb™ Magnetite sorb only at low to moderate levels.

**Table 35. Nusorb™ Magnetite Absorber:
Distribution of 12 Elements from Simulated
Hanford NCAW Solution**

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	<0.1	<0.1	<0.1
Sr	3.8	7.7	15
Tc	0.1	0.2	0.3
Y	2.3	5.7	13
Cr	<0.1	0.2	0.3
Co	<0.1	<0.1	<0.1
Fe	1.9	4.8	11
Mn	0.7	1.7	4.1
Ni	<0.1	0.4	1.1
V	<0.1	<0.1	<0.1
Zn	0.2	0.2	0.3
Zr	0.9	0.9	1.1

t. Nusorb™ Unitane Absorber. Nusorb™ Unitane, titanium oxide beads with pores in the 1- to 10- μ m range, is manufactured by Nucon International, Inc., Columbus, Ohio. This material was used as received.

Nusorb™ Unitane sorbs strontium and yttrium with triple-digit Kd values, and several other elements are sorbed with useful, but lower, Kd values.

**Table 36. Nusorb™ Unitane Absorber:
Distribution of 12 Elements from Simulated
Hanford NCAW Solution**

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	<0.1	<0.1	<0.1
Sr	28	175	694
Tc	0.3	0.5	0.5
Y	12	42	174
Cr	<0.1	0.3	0.2
Co	0.6	1.7	5.1
Fe	6.2	20	61
Mn	4.7	16	75
Ni	0.9	2.2	3.8
V	0.1	<0.1	<0.1
Zn	1.9	2.2	2.5
Zr	4.3	8.9	17

u. 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. This resin was air-dried before use.

Purolite™ A-520-E sorbs technetium strongly and selectively from NCAW simulant.

**Table 37. Purolite™ A-520-E Anion Exchange
Resin: Distribution of 12 Elements from
Simulated Hanford NCAW Solution**

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.1	0.2	0.1
Sr	<0.1	<0.1	<0.1
Tc	329	660	782
Y	1.4	1.5	1.6
Cr	0.1	0.2	0.2
Co	0.6	0.7	0.6
Fe	0.7	1.2	1.2
Mn	0.9	1.3	1.3
Ni	0.6	0.7	0.4
V	0.6	0.7	0.6
Zn	0.5	0.6	0.5
Zr	0.8	0.9	0.8

v. Reillex™ HPQ Anion Exchange Resin. Reillex™ HPQ, a strong-base polyvinylpyridine anion exchange resin, was obtained from Reilly Industries, Inc., Indianapolis, Indiana. This resin was converted from the as-received chloride form to the nitrate form and air-dried before use.

Reillex™ HPQ sorbs technetium strongly and quite selectively from NCAW simulant.

Table 38. Reillex™ HPQ Anion Exchange Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.1	<0.1	<0.1
Sr	0.2	0.3	0.3
Tc	382	459	445
Y	2.3	3.4	4.0
Cr	<0.1	<0.1	<0.1
Co	0.2	0.2	0.3
Fe	1.1	1.0	1.0
Mn	1.5	1.9	2.3
Ni	2.2	2.5	5.1
V	<0.1	<0.1	<0.1
Zn	<0.1	0.1	0.1
Zr	0.4	0.8	0.8

w. Resin Tech™ 3972 Resin. Resin Tech™ 3972, a styrene/divinylbenzene copolymer with phosphorous acid functionality, is manufactured by Resin Tech, Inc., Cherry Hill, New Jersey. This resin was air-dried before use.

Resin Tech™ 3972 offers useful Kd values for sorbing strontium, yttrium, manganese, and iron from NCAW simulant.

Table 39. Resin Tech™ 3972 Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.7	0.7	0.6
Sr	14	46	84
Tc	0.5	0.5	0.4
Y	4.6	16	26
Cr	<0.1	<0.1	<0.1
Co	0.1	0.3	0.6
Fe	2.6	8.9	21
Mn	2.6	9.4	22
Ni	0.9	2.1	4.4
V	<0.1	<0.1	<0.1
Zn	<0.1	<0.1	0.2
Zr	0.1	1.3	2.4

x. SRS Resorcinol/Formaldehyde (BSC-187) Resin.

Jane Bibler of Westinghouse Savannah River Company provided this sample of batch BSC-187 resin and recommended that we convert it from the as-received potassium form to a sodium form. We did so by passing 10 volumes of 10% NaOH solution through a column of potassium-form resin, rinsed the column with 15 column volumes of water. The resin was air-dried before use.

This SRS resorcinol/formaldehyde resin sorbs many elements with triple-digit Kd values. Several others are sorbed with double-digit Kd values.

Table 40. SRS Resorcinol/Formaldehyde (BSC-187) Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	169	423	666
Sr	64	106	134
Tc	5.0	33	232
Y	16	38	63
Cr	7.0	90	789
Co	8.6	25	51
Fe	102	236	387
Mn	41	112	168
Ni	9.8	23	37
V	<0.1	<0.1	<0.1
Zn	1.1	1.4	1.6
Zr	24	57	107

y. SRS Resorcinol/Formaldehyde (BSC-210) Resin.

Jane Bibler of Westinghouse Savannah River Company provided this sample of batch BSC-210 resin and recommended that we convert it from the as-received potassium form to a sodium form. We did so by passing 10 volumes of 10% NaOH solution through a column of potassium-form resin, rinsed the column with 15 column volumes of water. The resin was air-dried before use.

This SRS resorcinol/formaldehyde resin sorbs cesium with a four-digit Kd; chromium, iron, manganese, and strontium are sorbed with triple-digit Kd values; and five other elements are sorbed with double-digit Kd values.

Table 41. SRS Resorcinol/Formaldehyde (BSC-210) Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	283	712	1142
Sr	64	100	113
Tc	0.7	3.1	35
Y	33	70	86
Cr	1.0	15	397
Co	6.1	15	30
Fe	73	143	232
Mn	62	103	138
Ni	7.5	14	24
V	<0.1	<0.1	<0.1
Zn	0.6	1.1	1.3
Zr	16	31	49

z. Tannin Absorber. Tannin absorber was obtained from Mitsubishi Nuclear Fuels Corporation, Japan. We air-dried this absorber before testing for reasons detailed in Section II.C.

Tannin sorbs chromium, iron, and strontium with four-digit Kd values. All 12 elements except vanadium are sorbed with at least a double-digit Kd value.

Table 42. Tannin Absorber: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	28	29	29
Sr	324	672	1081
Tc	4.7	15	62
Y	29	81	149
Cr	13	184	3004
Co	4.7	16	31
Fe	265	925	2672
Mn	90	333	796
Ni	8.5	15	11
V	<0.1	<0.1	<0.1
Zn	7.5	16	23
Zr	68	277	485

aa. TEVA-Spec™ Absorber. TEVA-Spec™, an aliphatic quaternary ammonium salt (Aliquat™ 336) on an acrylic ester nonionic polymeric adsorbent, was prepared by EIChroM Industries, Inc., Darien, Illinois. This absorber was used as received.

The strong and selective sorption of technetium by TEVA-Spec™ is similar to the performance of the LANL-prepared absorber that consists of Aliquat™ 336 sorbed into Ambersorb™ beads.

Table 43. TEVA-Spec™ Absorber: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	<0.1	<0.1	<0.1
Sr	0.1	0.3	0.3
Tc	1101	1259	1209
Y	2.1	2.6	2.9
Cr	0.1	0.3	0.4
Co	0.3	0.3	0.3
Fe	0.4	0.3	0.5
Mn	0.7	0.9	1.1
Ni	4.2	9.6	15
V	0.4	0.3	0.3
Zn	<0.1	0.2	<0.1
Zr	<0.1	<0.1	<0.1

bb. UTEVA-Spec™ Absorber. UTEVA-Spec™, a dipentyl pentylphosphonate on an acrylic ester nonionic polymeric adsorbent, is manufactured by Eichrom Industries, Inc., Darien, Illinois. This absorber was used as received.

UTEVA Spec™ offers no useful Kd values from NCAW simulant.

**Table 44. UTEVA-Spec™ Absorber:
Distribution of 12 Elements from Simulated
Hanford NCAW Solution**

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	<0.1	<0.1	<0.1
Sr	0.3	0.2	0.3
Tc	5.5	5.0	4.5
Y	1.3	1.5	1.9
Cr	0.6	0.4	0.7
Co	0.3	0.3	0.2
Fe	0.5	0.7	0.6
Mn	0.6	0.8	1.1
Ni	1.0	1.3	1.8
V	0.2	0.4	0.3
Zn	<0.1	<0.1	<0.1
Zr	0.2	<0.1	0.1

2. Experimental Inorganic Materials. The seven experimental inorganic exchangers tested were primarily materials sent to us from other DOE laboratories or universities. We welcome such materials and look forward to receiving other potentially useful absorbers to test in our future studies.

a. Blaylock Clay. Blaylock clay is a sample of Rivers Bend Illite clay from the Blaylock formation, McCurtain County, Oklahoma. This fraction of the milled material that passed through a 1-mm screen was used as received.

Blaylock clay offers at least triple-digit Kd values for manganese, yttrium, strontium, and iron from NCAW simulant. However, the high sorption of manganese by this material may preclude the use of this material for sorbing other elements of interest.

**Table 45. Blaylock Clay: Distribution of
12 Elements from Simulated Hanford NCAW
Solution**

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	2.2	2.3	2.7
Sr	51	87	118
Tc	<0.1	<0.1	<0.1
Y	86	157	243
Cr	0.3	<0.1	<0.1
Co	0.2	0.2	0.9
Fe	15	42	114
Mn	14	101	458
Ni	2.3	5.0	12
V	<0.1	<0.1	<0.1
Zn	2.8	4.4	6.9
Zr	4.1	6.7	9.9

b. Fithian Clay. Fithian clay is a sample from Fithian, Illinois. This fraction of the milled material that passed through a 1-mm screen was used as received.

The observed sorption pattern for the elements is similar to that of Blaylock clay, except that now zirconium sorption is significantly higher.

Table 46. Fithian Clay: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	3.2	3.2	3.3
Sr	81	152	242
Tc	<0.1	<0.1	<0.1
Y	212	321	510
Cr	0.4	1.0	1.3
Co	1.5	1.9	2.4
Fe	39	122	364
Mn	28	234	1366
Ni	6.8	13	26
V	<0.1	<0.1	<0.1
Zn	4.6	7.0	8.7
Zr	70	298	691

c. KCoFC Crystals (150–600 μm). This inorganic ion exchanger was prepared at Oak Ridge National Laboratory (ORNL) using the procedure described by Prout¹⁰ with a minor modification. The absorber was used as received.

KCoFC crystals (150–600 μm) sorb strontium, cesium, iron, and manganese with at least four-digit Kd values. Yttrium is sorbed with a triple-digit Kd value. The decreasing Kd values for cesium with increasing contact time reflects an instability of this material in solutions of pH greater than 12.

Table 47. KCoFC Crystals (150–600 μm): Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	18K	17K	5K
Sr	7K	11K	24K
Tc	<0.1	<0.1	0.2
Y	128	262	485
Cr	0.7	0.7	0.8
Co	10	12	11
Fe	927	>5K	>4900
Mn	279	933	2991
Ni	10.0	14	16
V	1.3	1.5	1.4
Zn	18	31	50
Zr	13	22	36

d. KCoFC Powder. This inorganic ion exchanger was prepared as a fine powder at ORNL using the procedure described by Prout¹⁰ with a minor modification. The absorber was used as received.

KCoFC powder sorbs iron, strontium, manganese, and cesium with at least four-digit Kd values. Yttrium is sorbed with a triple-digit Kd value. The decreasing Kd values for cesium with increasing contact time reflects an instability of this material in solutions of pH greater than 12.

Table 48. KCoFC Powder: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	31K	17K	5K
Sr	21K	25K	35K
Tc	0.1	0.2	0.2
Y	222	379	707
Cr	2	2.4	2.3
Co	12	12	11
Fe	>41K	>42K	>41K
Mn	1030	>6K	>6K
Ni	14	16	21
V	1.5	0.6	0.5
Zn	18	33	50
Zr	20	32	51

e. KW-3-85x Absorber. KW-3-85x is crystalline tantalum tungstate with a d-spacing of 10.5 Å. This absorber was prepared as an unpillared reference material by K. L. Wade of LANL and was used as received.

KW-3-85x sorbs strontium with a triple-digit Kd value and four other elements with double-digit Kd values.

Table 49. KW-3-85x Absorber: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	<0.1	0.1	<0.1
Sr	238	243	246
Tc	<0.1	<0.1	<0.1
Y	43	82	95
Cr	0.2	0.4	0.6
Co	<0.1	<0.1	0.4
Fe	11	14	15
Mn	5.2	14	22
Ni	1.1	0.9	0.4
V	<0.1	<0.1	0.3
Zn	0.2	0.1	0.5
Zr	13	23	20

f. MgAlHT Absorber. MgAlHT, a hydrotalcite, is an inorganic layered double-hydroxide compound that was expected to offer an affinity for multivalent anions. This material, provided by Jim Amonette of PNL, was hydrated overnight with 0.1 M NaCl solution (per Amonette's instructions) before use.

MgAlHT sorbs strontium, yttrium, iron, manganese, and zinc with triple-digit Kd values from NCAW simulant. The absence of anion exchange behavior may be due to the very high pH of this simulant.

Table 50. MgAlHT Absorber: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	1.4	0.9	0.8
Sr	453	778	921
Tc	1.6	0.9	0.6
Y	107	229	358
Cr	2.5	2.2	2.1
Co	0.8	1.2	1.1
Fe	100	182	270
Mn	29	63	129
Ni	4.2	8.9	20
V	1.6	1.9	1.8
Zn	38	68	107
Zr	13	18	29

g. RC-2-62A Absorber. RC-2-62A, a layered crystalline sodium nanotitanate ($\text{Na}_4\text{Ti}_9\text{O}_{20}$) with a d-spacing of 10.0 Å, was prepared by Professor A. Clearfield of Texas A&M University.

RC-2-62A sorbs strontium, iron, and zirconium with Kd values of at least four digits and sorbs yttrium and manganese with three-digit Kd values.

Table 51. RC-2-62A Absorber: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	<0.1	<0.1	<0.1
Sr	15K	>36K	>36K
Tc	<0.1	0.3	<0.1
Y	158	391	700
Cr	0.3	0.5	0.5
Co	0.2	0.4	0.7
Fe	1450	1970	>3800
Mn	71	190	430
Ni	2.0	4.5	8.5
V	<0.1	0.1	<0.1
Zn	7.5	14	28
Zr	509	>2100	>2200

3. Experimental Resins. Four experimental resins were included in our study. Two of these were prepared at Lawrence Berkeley Laboratory (LBL) and two were prepared by Sybron Chemicals, Inc.

a. PS-CATS Resin. This experimental resin was prepared and provided by Richard H. Fish of LBL, who asked us not to provide structural information until he secures his patent. This resin was air-dried before use.

PS-CATS resin sorbs manganese, iron, strontium, zirconium, and yttrium with triple-digit Kd values.

Table 52. PS-CATS Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	11	12	11
Sr	131	318	497
Tc	0.8	0.5	0.4
Y	38	89	175
Cr	<0.1	<0.1	<0.1
Co	4.6	15	34
Fe	78	285	599
Mn	57	360	696
Ni	12	24	33
V	<0.1	<0.1	<0.1
Zn	2.7	4.4	5.5
Zr	20	80	217

b. PS-3,3-LICAMS Resin. This experimental resin was prepared and provided by Richard H. Fish of LBL, who asked us not to provide structural information until he secures his patent. This resin was air-dried before use.

Iron, strontium, and zirconium are sorbed with triple-digit Kd values.

Table 53. PS-3,3-LICAMS Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	1.6	1.5	1.4
Sr	64	153	236
Tc	3.0	3.1	3.1
Y	15	49	94
Cr	<0.1	<0.1	<0.1
Co	1.5	3.4	4.9
Fe	43	259	574
Mn	6.6	18	27
Ni	6.1	15	21
V	<0.1	<0.1	<0.1
Zn	0.2	0.3	0.3
Zr	6.6	33	130

c. Sybron (Et)₃N Anion Exchange Resin. This experimental, macroporous strong-base anion exchange resin with triethyl amine as the functional group was obtained from Sybron Chemicals, Inc., Birmingham, New Jersey. A previous study¹¹ reported that this resin offers a significant increase over (Me)₃N resin for sorbing Pu(IV) from dilute nitric acid. This resin was air-dried before use.

The behavior of this experimental resin in NCAW simulant is fairly similar to that of Purolite™ A-520-E resin (its commercial equivalent).

Table 54. Sybron (Et)₃N Anion Exchange Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.2	<0.1	<0.1
Sr	5.2	5.2	4.6
Tc	303	571	739
Y	12	21	29
Cr	<0.1	0.2	0.1
Co	0.1	0.1	0.2
Fe	2.2	2.9	3.2
Mn	1.6	2.3	2.8
Ni	0.7	1.8	3.3
V	<0.1	0.1	<0.1
Zn	0.1	<0.1	<0.1
Zr	<0.1	0.4	0.5

d. Sybron (Pr)₃N Anion Exchange Resin. This experimental, macroporous strong-base anion exchange resin with tripropyl amine as the functional group was obtained from Sybron Chemicals, Inc., Birmingham, New Jersey. This resin was air-dried before use.

This resin sorbs technetium well with high selectivity, similar to most other anion exchange resins.

Table 55. Sybron (Pr)₃N Anion Exchange Resin: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.2	<0.1	<0.1
Sr	0.6	0.5	0.5
Tc	218	488	705
Y	2.7	3.9	4.7
Cr	<0.1	<0.1	0.1
Co	0.3	0.2	0.3
Fe	0.7	0.8	1.0
Mn	0.5	0.8	1.1
Ni	0.4	0.9	1.9
V	0.2	0.2	0.3
Zn	<0.1	0.2	0.3
Zr	0.2	0.4	0.4

4. Polyacrylonitrile (PAN) Composite Absorbers.

Although inorganic ion exchangers are known to offer high selectivity, high capacity, and rapid kinetics, their granular and mechanical properties often make them unsuitable for column applications. One way to circumvent these limitations is to incorporate the inorganic exchange materials in beads of a suitable porous polymer.¹²

The 16 composite absorbers prepared for LANL by Dr. Ferdinand Sebesta of the Czech Technical University in Prague consist of various inorganic exchange materials dispersed in modified-binding-polymer beads of PAN, which have been described in detail.¹³

Although Dr. Sebesta asked that these PAN composites be kept wet because their performance could be seriously degraded if they were dried, we chose to air-dry them to put them on an equivalent basis with the other absorbers. We therefore note that the excellent performance obtained with many PAN composites might be even better had we followed Dr. Sebesta's instructions. Specifically, the frequently observed slow sorption kinetics might be faster.

a. AMP-PAN Ammonium Molybdophosphate Composite. The ammonium molybdophosphate content of the dry composite was 81%. We air-dried this composite before testing for reasons detailed in Section II.C.

The AMP-PAN composite sorbs yttrium well from NCAW simulant.

Table 56. AMP-PAN Composite: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.7	0.8	0.7
Sr	21	27	30
Tc	2.5	2.7	3.0
Y	24	68	130
Cr	1.0	1.1	1.2
Co	0.8	0.7	0.6
Fe	2.7	3.6	3.9
Mn	2.0	3.4	6.1
Ni	1.2	1.8	4.1
V	0.6	0.7	1.1
Zn	0.8	0.8	0.7
Zr	2.0	3.2	3.9

b. Ba(Ca)SO₄-PAN Barium/Calcium Sulfate Composite. The barium/calcium sulfate content of the dry Ba(Ca)SO₄-PAN composite was 85%. We air-dried this composite before testing for reasons detailed in Section II.C.

The Ba(Ca)SO₄-PAN composite sorbs yttrium and strontium well and zirconium at useful levels from NCAW simulant.

Table 57. Ba(Ca)SO₄-PAN Composite: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	<0.1	0.2	0.1
Sr	68	119	166
Tc	1.2	1.2	1.5
Y	44	136	252
Cr	0.7	1.0	1.3
Co	<0.1	0.1	0.1
Fe	4.3	6.7	9.1
Mn	3.3	5.1	7.1
Ni	0.6	1.2	3.0
V	0.1	<0.1	0.1
Zn	<0.1	<0.1	<0.1
Zr	11	17	29

c. CSbA-PAN Crystalline Polyantimonic Acid Composite. The polyantimonic acid content of the dry composite was 86%. We air-dried this composite before testing for reasons detailed in Section II.C.

The CSbA-PAN composite offers very high sorption for strontium from NCAW simulant. Yttrium sorbs with a Kd value of almost 300.

Table 58. CSbA-PAN Composite: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	<0.1	<0.1	<0.1
Sr	7401	>36K	>37K
Tc	0.9	1.2	1.3
Y	38	101	298
Cr	<0.1	0.2	0.3
Co	<0.1	<0.1	<0.1
Fe	1.3	1.6	2.2
Mn	1.1	1.3	2.4
Ni	0.1	1.4	8.5
V	0.2	0.2	<0.1
Zn	0.3	0.2	0.3
Zr	4.7	5.1	4.6

d. M315-PAN Synthetic Mordenite Composite. The synthetic mordenite content of the dry M315-PAN composite was 93%. We air-dried this composite before testing for reasons detailed in Section II.C.

The M315-PAN composite offers useful Kd values for cesium, yttrium, and strontium from NCAW simulant.

Table 59. M315-PAN Composite: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	94	99	91
Sr	8.2	17	37
Tc	0.7	0.4	0.4
Y	22	44	67
Cr	<0.1	0.1	0.3
Co	0.1	<0.1	<0.1
Fe	1.1	1.5	2.0
Mn	0.9	1.3	1.8
Ni	1.4	3.0	8.9
V	<0.1	<0.1	<0.1
Zn	0.1	<0.1	0.1
Zr	2.2	2.5	3.3

e. MgO-PAN Magnesium Oxide Composite. The magnesium oxide content of the dry MgO-PAN composite was 80%. We air-dried this composite before testing for reasons detailed in Section II.C.

The MgO-PAN composite sorbs many elements from NCAW simulant with at least triple-digit Kd values.

Table 60. MgO-PAN Composite: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	<0.1	<0.1	<0.1
Sr	808	1276	1458
Tc	2.1	1.7	1.9
Y	114	282	433
Cr	0.5	0.4	0.5
Co	0.4	0.5	0.6
Fe	283	598	676
Mn	38	68	99
Ni	7.1	20	55
V	0.1	<0.1	<0.1
Zn	376	649	646
Zr	54	102	166

f. MnO-PAN Manganese Dioxide Composite. The manganese dioxide content of the dry MnO-PAN composite was 85%. We air-dried this composite before testing for reasons detailed in Section II.C.

The MnO-PAN composite sorbs strontium, manganese, and iron with at least four-digit Kd values and yttrium, zirconium, and zinc with triple-digit Kd values.

Table 61. MnO-PAN Composite: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	<0.1	<0.1	<0.1
Sr	12K	>40K	>39K
Tc	1.4	1.4	1.5
Y	163	399	748
Cr	<0.1	0.2	0.3
Co	1.6	3.7	7.4
Fe	2534	>5K	>5K
Mn	1560	>7K	>8K
Ni	2.1	2.4	1.0
V	0.7	1.5	2.4
Zn	109	198	348
Zr	165	278	377

g. NaTiO-PAN Sodium Titanate Composite. The sodium titanate content of the dry NaTiO-PAN composite was 92%. We air-dried this composite before testing for reasons detailed in Section II.C.

The NaTiO-PAN composite sorbs strontium strongly from NCAW simulant. Iron, zirconium, yttrium, and manganese also sorb well.

Table 62. NaTiO-PAN Composite: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.6	0.4	0.4
Sr	3487	9K	14K
Tc	0.7	0.2	0.5
Y	70	223	433
Cr	0.1	<0.1	0.2
Co	<0.1	<0.1	0.1
Fe	133	756	2343
Mn	34	81	146
Ni	1.5	2.7	8.8
V	<0.1	<0.1	<0.1
Zn	8.4	20	43
Zr	86	482	1298

h. NiFC-PAN Nickel Hexacyanoferrate Composite. The nickel hexacyanoferrate content of the dry NiFC-PAN composite was 85%. We air-dried this composite before testing for reasons detailed in Section II.C.

The NiFC-PAN composite sorbs strontium, iron, zinc, yttrium, and nickel with at least four-digit Kd values.

Table 63. NiFC-PAN Composite: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	261	158	115
Sr	1952	5K	11K
Tc	0.9	0.8	0.9
Y	248	587	1141
Cr	1.6	1.6	1.8
Co	32	64	92
Fe	682	2686	>8K
Mn	28	74	184
Ni	84	732	1023
V	1.9	1.8	2.0
Zn	726	1922	2623
Zr	19	21	26

i. NM-PAN Nickel Hexacyanoferrate/Manganese Dioxide Composite. The nickel hexacyanoferrate content and the manganese dioxide content of the dry composite were each 42.8%. We air-dried this composite before testing for reasons detailed in Section II.C.

The NM-PAN composite sorbs six elements with at least triple-digit Kd values. Strontium sorbs especially well.

Table 64. NM-PAN Composite: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	147	101	77
Sr	>5K	>56K	>56K
Tc	1.0	1.3	1.2
Y	178	436	852
Cr	1.0	1.4	1.5
Co	21	38	45
Fe	569	1749	3164
Mn	23	77	282
Ni	59	217	240
V	1.0	1.4	1.1
Zn	333	823	1049
Zr	17	25	33

j. SnSbA-PAN Stannic Antimonate Composite. The stannic antimonate content of the dry composite was 86%. We air-dried this composite before testing for reasons detailed in Section II.C.

The SnSbA-PAN composite sorbs strontium strongly and selectively; the Kd values for other sorbed elements are at least two orders of magnitude lower.

Table 65. SnSbA-PAN Composite: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	<0.1	<0.1	<0.1
Sr	2084	8K	>36K
Tc	0.6	1.2	0.9
Y	26	66	203
Cr	<0.1	0.8	0.9
Co	<0.1	0.1	0.1
Fe	25	52	90
Mn	7.8	17	36
Ni	0.5	2.3	9.6
V	0.1	0.2	<0.1
Zn	8.1	17	43
Zr	9.6	17	24

k. TiO-PAN Titanium Dioxide Composite. The titanium dioxide content of the dry TiO-PAN composite was 85%. We air-dried this composite before testing for reasons detailed in Section II.C.

This composite sorbs four elements with at least four-digit Kd values from NCAW simulant.

Table 66. TiO-PAN Composite: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.1	0.2	0.2
Sr	5K	17K	>42K
Tc	1.0	1.1	1.2
Y	130	397	686
Cr	<0.1	<0.1	0.2
Co	0.6	0.7	1.0
Fe	1233	5K	>5K
Mn	121	456	1257
Ni	6.9	10	18
V	0.5	0.3	0.4
Zn	337	527	636
Zr	1506	2018	>3000

l. TiP-PAN Titanium Phosphate Composite. The titanium phosphate content of the dry composite was 92%. We air-dried this composite before testing for reasons detailed in Section II.C.

The TiP-PAN composite sorbs strontium with a five-digit Kd value; zinc and zirconium with four-digit Kd values; and iron, yttrium, and manganese with triple-digit Kd values.

Table 67. TiP-PAN Composite: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	<0.1	<0.1	<0.1
Sr	7K	14K	>37K
Tc	0.2	<0.1	0.5
Y	139	338	549
Cr	0.2	0.6	0.7
Co	<0.1	0.4	1.4
Fe	267	472	723
Mn	54	101	173
Ni	1.7	4.3	11
V	83	89	83
Zn	287	788	1519
Zr	854	>4500	>4700

m. TiSbA-PAN Titanium Antimonate Composite. The titanium antimonate content of the dry composite was 86%. We air-dried this composite before testing for reasons detailed in Section II.C.

The TiSbA-PAN composite sorbs strontium with a five-digit Kd value and sorbs four other elements with at least triple-digit Kd values.

Table 68. TiSbA-PAN Composite: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.3	<0.1	<0.1
Sr	2812	7K	12K
Tc	0.5	0.9	0.9
Y	100	264	592
Cr	<0.1	0.5	0.6
Co	<0.1	<0.1	0.2
Fe	162	599	959
Mn	27	77	195
Ni	1.8	4.4	12
V	0.1	<0.1	<0.1
Zn	6.9	17	58
Zr	141	1278	>2600

n. ZrO-PAN Zirconium Oxide Composite. The zirconium oxide content of the dry composite was 75%. We air-dried this composite before testing for reasons detailed in Section II.C.

The ZrO-PAN composite sorbs strontium with a four-digit Kd value and three other elements with triple-digit Kd values.

Table 69. ZrO-PAN Composite: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.2	<0.1	<0.1
Sr	52	659	2999
Tc	1.4	1.8	2.1
Y	10	35	99
Cr	0.3	0.7	0.8
Co	1.2	2.6	4.6
Fe	15	85	580
Mn	11	45	127
Ni	1.5	5.8	14
V	3.6	19	32
Zn	8.7	29	60
Zr	16	114	684

o. ZrOP-PAN Zirconium Oxide/Zirconium Phosphate Composite. The zirconium oxide content and the zirconium phosphate content of the dry composite were 60% and 15%, respectively. We air-dried this composite before testing for reasons detailed in Section II.C.

The ZrOP-PAN composite sorbs strontium best of the four elements whose Kd values are at least triple-digit.

Table 70. ZrOP-PAN Composite: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.1	<0.1	<0.1
Sr	22	207	1495
Tc	1.3	2.0	2.2
Y	8.0	35	140
Cr	<0.1	0.3	0.5
Co	1.1	2.2	4.2
Fe	7.9	32	216
Mn	6.3	24	79
Ni	1.1	3.3	10
V	2.3	3.9	5.7
Zn	5.2	15	40
Zr	7.8	35	272

p. ZrP-PAN Zirconium Phosphate Composite. The zirconium phosphate content of the dry composite was 92%. We air-dried this composite before testing for reasons detailed in Section II.C.

The ZrP-PAN composite sorbs five elements with at least four-digit Kd values from NCAW simulant.

Table 71. ZrP-PAN Composite: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	<0.1	<0.1	<0.1
Sr	16K	>38K	>37K
Tc	0.1	0.6	0.5
Y	138	670	1184
Cr	<0.1	0.7	0.8
Co	1.8	3.6	4.3
Fe	572	>6K	>6K
Mn	173	3973	>10K
Ni	5.3	9.2	11
V	21	119	129
Zn	18	136	199
Zr	725	>4500	>4600

5. Phenolsulfonic-Formaldehyde (PSF) Composite Absorbers. These two composites were prepared and provided to us by Dr. Jerzy Narbutt, Head of the Department of Radiochemistry, Institute of Nuclear Chemistry and Technology, Warsaw, Poland. In these two composite resins, the inorganic exchange material is dispersed in a phenolsulfonic-formaldehyde matrix.¹⁴ These composites were used as received.

a. CoFC-PSF Cobalt Hexacyanoferrate Composite. The cobalt hexacyanoferrate content of the CoFC-PSF composite was approximately 20%.

This composite sorbs cesium and strontium with four-digit Kd values. Iron and manganese also sorb well from NCAW simulant.

Table 72. CoFC-PSF Composite: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	237	1072	1488
Sr	76	531	1199
Tc	0.8	0.5	0.6
Y	7.0	22	44
Cr	<0.1	0.2	0.6
Co	1.9	6.1	11
Fe	8.6	51	351
Mn	14	93	255
Ni	3.0	5.6	9.4
V	<0.1	<0.1	<0.1
Zn	1.6	7.4	24
Zr	2.5	6.7	17

b. TiFC-PSF Titanium Hexacyanoferrate Composite. The titanium hexacyanoferrate content of the TiFC-PSF composite was approximately 17%.

Strontium sorbs most strongly of the five elements sorbed with at least triple-digit Kd values.

Table 73. TiFC-PSF Composite: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	35	44	45
Sr	1216	4402	7K
Tc	0.6	0.6	0.6
Y	43	109	228
Cr	0.5	2.2	2.8
Co	2.3	7.0	12
Fe	69	269	507
Mn	53	251	642
Ni	12	27	37
V	<0.1	<0.1	<0.1
Zn	7.8	22	33
Zr	34	206	303

6. Sorbed Liquid Extractants. We prepared and evaluated porous beads impregnated with three different liquid extractants.

a. Aliquat™ 336 Absorber. We diluted 5 g of Aliquat™ 336 (methyltricaprylammonium chloride), obtained from Aldrich Chemical Co., Milwaukee, Wisconsin, with 10 mL of hexane and added 17.32 g of Amborsorb™ 563 porous carbon beads, obtained from Rohm & Haas, Philadelphia, Pennsylvania, to absorb the liquid. The cyclohexane evaporated to yield 26.2 g of the loaded Amborsorb™ beads.

This extractant sorbs technetium strongly and selectively from NCAW simulant. Its very low sorption of technetium from acidic solution, determined in a previous study,¹ indicates that technetium could be stripped by nitric acid.

Table 74. Aliquat™ 336 Absorber: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	<0.1	0.1	0.1
Sr	0.4	0.8	1.1
Tc	455	679	775
Y	3.5	5.7	7.2
Cr	<0.1	0.3	0.3
Co	0.2	0.1	0.1
Fe	0.6	0.7	1.1
Mn	0.6	0.7	1.0
Ni	0.3	0.3	0.8
V	<0.1	<0.1	<0.1
Zn	0.1	<0.1	0.1
Zr	<0.1	0.3	0.5

b. Cyanex™ 923 Absorber. We diluted 10 mL of Cyanex™ 923 (trialkylphosphine oxide), obtained from the American Cyanamid Company, Wayne, New Jersey, with 20 mL of cyclohexane and added 26.83 g of Amborsorb™ 563 porous carbon beads, obtained from Rohm & Haas, Philadelphia, Pennsylvania, to absorb the liquid. The cyclohexane evaporated to yield 36.8 g of the loaded Amborsorb™ beads.

This extractant selectively sorbs technetium from NCAW simulant.

Table 75. Cyanex™ 923 Absorber: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	<0.1	<0.1	<0.1
Sr	0.7	1.2	1.6
Tc	185	212	188
Y	2.9	4.7	5.9
Cr	<0.1	<0.1	0.1
Co	<0.1	<0.1	<0.1
Fe	0.5	0.8	1.0
Mn	0.2	0.5	0.6
Ni	1.0	1.2	1.4
V	<0.1	0.1	<0.1
Zn	0.1	0.2	0.2
Zr	0.2	<0.1	0.3

c. LIX™-54 Absorber. We diluted 10 mL of LIX™-54 (a beta diketone), obtained from the Henkel Corporation, Tucson, Arizona, with 20 mL of cyclohexane and added 26.80 g of Amborsorb™ 563 porous carbon beads, obtained from Rohm & Haas, Philadelphia, Pennsylvania, to absorb the liquid. The cyclohexane evaporated to yield 34.6 g of the loaded Amborsorb™ beads.

This extractant sorbs yttrium and strontium well and nickel and iron at lower levels from NCAW simulant.

Table 76. LIX™-54 Absorber: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	<0.1	<0.1	<0.1
Sr	37	101	178
Tc	0.5	0.5	0.7
Y	31	79	236
Cr	<0.1	0.2	0.2
Co	0.4	0.8	1.4
Fe	2.7	7.5	17
Mn	0.8	1.5	2.2
Ni	8.6	23	51
V	0.1	0.3	0.5
Zn	0.4	0.5	0.7
Zr	0.5	0.7	0.9

7. Sandia/NM Absorbers. Materials designated as SNL/CST are a new class of inorganic ion exchangers called crystalline silico-titanates (CSTs). These materials, jointly invented by Sandia National Laboratories/New Mexico (SNL) and Texas A&M University, show a significant potential for removing cesium from defense wastes that contain more than 5 M Na⁺ and more than 1 M OH⁻. CST materials are very fine powders composed of cuboidal crystals with particle sizes of several hundred angstroms. Different numerical values in the absorber designations represent different synthesis procedures.

Because the composition of these various CST materials is proprietary, we can provide only general information. As the development effort progressed, however, a baseline composition was selected for larger-scale synthesis, characterization, and evaluation of properties. SNL/CST 141 and 149 are baseline materials that are being developed for the removal of cesium and other radionuclides from a wide range of waste solutions.

SNL/CST 141 powder has already been prepared in commercial quantities by the UOP Corporation, Des Plaines, Illinois, Sandia/NM's partner in a cooperative research and development agreement (CRADA). An engineered form of CST suitable for use in ion exchange columns is scheduled to be commercially available in 1995.

a. SNL/CST 120 Crystalline Silico-Titanate. SNL/CST 120 strongly and selectively sorbs strontium from NCAW simulant. The Kd value for yttrium, the next most strongly extracted element, is nearly two orders of magnitude lower.

Table 77. SNL/CST 120: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	71	95	101
Sr	18K	21K	23K
Tc	0.2	<0.1	<0.1
Y	67	170	321
Cr	<0.1	0.2	0.5
Co	<0.1	0.4	0.5
Fe	11	18	30
Mn	5.5	10	53
Ni	<0.1	<0.1	<0.1
V	<0.1	0.6	0.7
Zn	1.4	1.4	1.4
Zr	42	72	136

b. SNL/CST 141 Crystalline Silico-Titanate.

SNL/CST 141 strongly sorbs both strontium and cesium from NCAW simulant. None of the other 10 elements sorb with Kd values higher than 33.

Table 78. SNL/CST 141: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	1812	1990	2071
Sr	1581	2082	3001
Tc	<0.1	<0.1	<0.1
Y	33	30	32
Cr	0.5	0.5	0.6
Co	1.1	1.2	2.7
Fe	6.8	11	18
Mn	3.1	4.7	8.5
Ni	1.2	0.3	0.3
V	1.1	1.2	2.7
Zn	1.3	1.5	2.9
Zr	27	30	24

c. SNL/CST 149 Crystalline Silico-Titanate.

SNL/CST 149 strongly sorbs both strontium and cesium from NCAW simulant, whereas yttrium and zirconium sorb moderately.

Table 79. SNL/CST 149: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	1301	1759	1829
Sr	2950	6K	8K
Tc	<0.1	<0.1	<0.1
Y	46	62	83
Cr	0.4	0.5	0.8
Co	0.9	0.9	2.1
Fe	6.6	9.3	15
Mn	2.7	3.8	7.3
Ni	1.1	0.3	0.3
V	1.0	1.0	2.3
Zn	1.2	1.2	2.6
Zr	33	45	45

d. SNL/HTO Amorphous Hydrrous Titanium Dioxide.

As expected, the behavior of hydrrous titanium dioxide is very different from that of the crystalline silico-titanates. Strontium and many other elements sorb strongly from NCAW simulant.

Table 80. SNL/HTO: Distribution of 12 Elements from Simulated Hanford NCAW Solution

Element	Kd Value for Specified Time		
	30 min	2 h	6 h
Cs	0.2	0.3	0.3
Sr	>34K	>35K	>35K
Tc	<0.1	<0.1	<0.1
Y	237	474	718
Cr	0.3	0.6	0.8
Co	0.3	1.1	2.3
Fe	616	648	636
Mn	79	146	239
Ni	4.5	9.9	22
V	0.1	0.3	0.3
Zn	164	367	621
Zr	1512	>2200	>2200

IV. FUTURE STUDIES

This screening study met its objective of identifying specific absorbers that seem capable of partitioning targeted elements from Hanford NCAW solution. The best absorbers and promising new materials identified in our screening studies will be evaluated with realistic simulant compositions (especially those containing organic constituents) that represent other Hanford tanks. We will continue to use radiotracers, which provide a rapid, reliable, and inexpensive way to obtain large quantities of distribution data.

Because even the best simulant solutions cannot accurately represent the contents of any HLW storage tank, we are anxious to obtain and test actual samples from the Hanford waste tanks. Only by testing genuine waste solutions can we obtain sorption data that are sufficiently reliable to permit the design of full-scale partitioning processes to begin. We recognize that even tests with actual wastes will not be conclusive because the compositions of the Hanford tanks vary greatly and that even individual tanks exhibit large heterogeneities in their horizontal and vertical compositions. However, as we obtain sorption data for the most promising absorbers with samples from various HLW tanks, we hope to identify absorbers that sorb the target elements well from a wide variety of waste compositions.

Finally, chemical and radiation stabilities are important factors to consider when selecting materials for processing radioactive waste solutions. The long-term chemical stability and the effect of radiation on the most promising absorbers from our screening studies should be determined (if such information is not already available) before absorbers are selected for use in large-scale recovery processes.

V. CONCLUSIONS

Our screening study of many absorbers from a realistic simulant for Hanford NCAW has met the initial objective of identifying many promising absorbers. Moreover, because we measured the sorption of so many different elements, our study provides important selectivity information about which unwanted elements are most likely to compete for absorber sites. Based on our experimental data, it appears that many of the separations required for processing HLW from Hanford NCAW solution, and perhaps HLW in other underground storage tanks as well, can be achieved using available absorbers and existing, proven technology.

A. Experimental Procedure

Radiotracers, as used in our study, provide a fast, reliable, and cost-effective way to obtain large quantities of distribution data. Follow-on studies should measure the distribution of key elements from other Hanford waste tank compositions that contain degraded organic components, using the most promising absorbers identified by completed screening studies.

B. Individual Elements

From simulated NCAW solution, all elements except vanadium show at least one absorber where the Kd value is 300 or more. Cesium, strontium, iron, manganese, and zirconium are sorbed with Kd values greater than 1000 by many absorbers.

C. Individual Absorbers

- The performance of the 64 absorbers tested with this PNL-prepared NCAW simulant solution is often much different from the performance reported for similar absorbers tested in solutions having relatively simple chemical compositions.

- Low-cost partitioning agents such as Aliquat™ 336, Duolite™ C-467, and Reillex™ HPQ often outperform other materials whose cost is many times higher.
- The silico-titanate absorbers from Sandia/NM show high sorption of cesium and strontium from simulated Hanford NCAW solution. Because the sorption of cesium on silico-titanates appears to be irreversible, this material should be considered for interim storage of radioactive waste, for incorporation into HLW glass, or for use as a final waste form.

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