*Distributions of 14 Elements on 63 Absorbers
from Three Simulant Solutions (Acid-Dissolved
Sludge, Acidified Supernate, and Alkaline
Supernate) for Hanford HLW Tank 102-SY*

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**DISTRIBUTIONS OF 14 ELEMENTS ON 63 ABSORBERS
FROM THREE SIMULANT SOLUTIONS (ACID-DISSOLVED SLUDGE, ACIDIFIED
SUPERNATE, AND ALKALINE SUPERNATE) FOR HANFORD HLW TANK 102-SY**

by

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

ABSTRACT

As part of the Hanford Tank Waste Remediation System program at Los Alamos, we evaluated 63 commercially available or experimental absorber materials for their ability to remove hazardous components from high-level waste (HLW). 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 three solutions prepared to simulate acid-dissolved sludge (pH 0.6), acidified supernate (pH 3.5), and alkaline supernate (pH 13.9) from underground storage tank 102-SY at the Hanford Reservation near Richland, Washington. To these simulants we added the appropriate radionuclides and used gamma spectrometry to measure fission products (Ce, Cs, Sr, Tc, and Y), actinides (U, Pu, and Am), and matrix elements (Cr, Co, Fe, Mn, Zn, and Zr). For each of more than 2500 element/absorber/solution combinations, we measured distribution coefficients for dynamic contact periods of 30 min, 2 h, and 6 h to obtain information about sorption kinetics. Because we measured the sorption of many different elements, the tabulated results indicate those elements most likely to interfere with the sorption of elements of greater interest. On the basis of nearly 7500 measured distribution coefficients, we determined that many of these absorbers appear suitable for processing HLW. This study supersedes the previous version of LA-12654, in which results attributed to a solution identified as an alkaline supernate simulant were misleading because that solution contained insufficient hydroxide.

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 14 elements onto more than 60 different absorbers from simulants that represent acid-dissolved sludge, acidified supernate, and alkaline supernate solutions from Hanford Tank 102-SY.

Our results indicate that many existing partitioning agents may be suitable for HLW tank remediation. 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. The findings of our study 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.

This screening study, intended to identify the most promising absorbers and extractants, included 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 for each element/absorber/solution 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.

The observed behavior of the absorber/element combination often was significantly different from the published behavior of the same combination with relatively clean solutions. We attribute such differences to the effects of other cations that compete for absorber sites, as well as to 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.

We also found numerous inexpensive commercial materials that outperform specialty products costing much more.

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

Table 1. Number of Absorbers Capable of Sorbing Each of 14 Elements from Three Simulant Solutions

Solution	Element	Kd Values					
		>1000	300-1000	100-300	20-100	10-20	5-10
Acid-Dissolved Sludge	Ce	0	0	0	5	1	1
	Cs	7	0	0	11	1	4
	Sr	0	0	0	0	0	0
	Tc	0	0	1	8	2	5
	Y	0	0	0	0	0	0
	Cr	0	0	0	0	0	0
	Co	0	0	0	0	1	0
	Fe	0	0	0	0	0	0
	Mn	0	0	0	0	0	0
	Zn	0	0	0	0	0	0
	Zr	0	1	3	10	4	3
	U	0	0	0	6	8	5
	Pu	2	5	6	2	8	2
	Am	0	0	0	0	0	6
Acidified Supernate	Ce	1	3	3	10	3	6
	Cs	8	1	5	2	4	2
	Sr	0	0	0	0	3	4
	Tc	0	7	7	9	3	1
	Y	1	0	1	9	0	5
	Cr	0	0	0	2	2	5
	Co	0	0	0	1	3	4
	Fe	0	0	0	0	0	3
	Mn	0	0	0	0	1	5
	Zn	0	0	0	5	3	2
	Zr	0	0	0	1	4	3
	U	0	1	4	15	8	8
	Pu	0	0	0	0	0	1
	Am	0	3	2	13	1	5
Alkaline Supernate	Ce	1	4	4	5	3	15
	Cs	5	3	6	2	2	2
	Sr	12	6	4	7	8	7
	Tc	0	6	2	4	1	3
	Y	0	1	3	20	7	6
	Cr	0	0	0	2	0	0
	Co	0	0	0	1	5	1
	Fe	6	2	10	10	3	3
	Mn	3	5	9	5	6	5
	Zn	8	5	5	3	2	2
	Zr	3	13	7	6	2	0
	U	2	1	5	5	4	3
	Am	1	5	1	4	3	1

From acid-dissolved sludge solution, cerium, cesium, technetium, zirconium, uranium, and plutonium show good to excellent sorption, whereas strontium, yttrium, chromium, cobalt, iron, manganese, zinc, and americium show poor sorption.

From acidified supernate solution, cerium, cesium, technetium, yttrium, zinc, uranium, and americium show good to excellent sorption, whereas strontium, chromium, cobalt, iron, manganese, zirconium, and plutonium show poor to marginal sorption.

From alkaline supernate solution, cerium, cesium, strontium, yttrium, iron, manganese, zinc, zirconium, uranium, and americium show good to excellent sorption, whereas chromium and cobalt show low to moderate sorption.

Those absorbers identified as acceptable on the basis of these initial tests are being evaluated to determine their effectiveness in sorbing many elements from solutions that simulate the contents of other underground storage tanks at Hanford. Moreover, we plan to begin studies using actual radioactive waste solutions as soon as we can obtain them. We also suggest an accelerated effort to identify or develop partitioning agents for specific needs, such as sorbing strontium from acidic solution, for which we identified no satisfactory absorbers.

This report supersedes, corrects, and expands the previously published Los Alamos National Laboratory report LA-12654, which included distribution data from an acidified supernate solution incorrectly identified as an alkaline supernate solution. Readers should destroy any copies of LA-12654 in their possession.

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 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, many different reagents and waste streams were generated and combined in underground tanks, often with insufficient concern about the compatibility of the various components. 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 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) 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 plutonium¹ and neptunium² from a wide variety of impure nuclear materials. Although cation exchange resins also have been used in the nuclear industry,³ they generally are considered to be less selective than anion exchange resins.

Although most of the absorbers we tested 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 (14) onto so many different absorber materials (60) under identical test conditions. Moreover, because we measured the sorption of so many different elements, our study provides selectivity information that identifies which unwanted elements are most likely to interfere by competing for absorber sites.

Our objective was to evaluate numerous potentially useful absorber materials, including many not previously studied, for their ability to recover selected elements from realistic simulants of acid-dissolved sludge, acidified supernate, and alkaline supernate solutions for Hanford Tank 102-SY. 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 advocate preliminary screening of promising candidate absorbers with realistic simulant solutions before testing with actual tank waste solutions.

Our study initially was intended to support the Los Alamos flow sheet development program for Hanford Tank 102-SY;⁴ however, many of our experimental findings apply to other flow sheet proposals, such as the so-called "Clean Option."⁵ 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 scientists can

develop reliable process flow sheets. The preferred partitioning options will depend on the objectives of the specific flow sheet. Decisions about whether the targeted elements should be recovered individually or grouped for subsequent disposal are properly left to the flow sheet designers. No matter which flow sheet is adopted, however, our experimental data will enable HLW tank processing to begin and be completed sooner and at a lower cost than would otherwise be possible.

II. EXPERIMENTAL PARAMETERS

A. Simulant Solutions

The compositions of the simulant solutions for Hanford HLW Tank 102-SY were based on consultation with and recommendations from Westinghouse Hanford Company (WHC) and Battelle Pacific Northwest Laboratories (PNL) personnel.⁶ The sludge composition was based on the assumption that soluble components had been leached out during thorough mixing with the supernate solutions. Our assumptions about tank contents were checked against composition data obtained by reconstruction of the tank contents from all available records for transfers into and out of each tank during its entire operating history.⁷

The sludge components that are expected to dissolve during sludge-washing operations⁸ were subtracted from our best estimate of the initial sludge composition. We dissolved those components assumed to remain in the sludge in a minimum quantity of nitric acid. The simulated acid-dissolved sludge was filtered to remove insoluble residue.

The alkaline supernate and acidified supernate solutions were similar in their initial composition, but the alkaline supernate solution contained substantially more hydroxide and generated much more precipitate. To ensure that the alkaline supernate solution was truly saturated with relatively insoluble salts, we diluted the initial liter of solution/solids with another three liters of water and heated this diluted solution in a stainless steel container while stirring continuously until the volume was reduced to the initial one liter. Bulk solids were separated by centrifugation; any remaining suspended solids were removed by passing the alkaline supernate solution through a 0.45- μ m filter.

The compositions of the simulated acid-dissolved sludge, acidified supernate, and alkaline supernate solutions for Hanford Tank 102-SY are presented in Table 2.

Table 2. Compositions of Hanford Tank 102-SY Simulant Solutions

	Acid-Dissolved Sludge	Acidified Supernate	Alkaline Supernate
Cations^a			
Na	0.65 M	1.40 M	2.2 M
Mg	0.060 M	0.032 M	none
Al	0.43 M	0.44 M	0.16 M
Si	0.125 M	0.29 M	0.0024 M
Ca	0.044 M	0.028 M	0.0069 M
Cr(III)	0.33 M	0.072 M	none
Cr(VI)	none	0.007 M	0.0051 M
Mn	0.143 M	0.043 M	none
Fe	0.36 M	0.101 M	0.0061 M
Ni	0.010 M	BDL ^c	BDL
Cu	0.016 M	BDL	BDL
Se	0.027 M	BDL	BDL
Sr	0.0009 M	BDL	BDL
Pb	0.012 M	BDL	BDL
Th	0.027 M	BDL	BDL
U	0.023 M	BDL	BDL
²³⁹ Pu	3 g/L	—	BDL
²³⁸ Pu	60 mg/L	60 mg/L	none
Anions^b			
F	0.027 M	0.024	0.21 M
Cl	0.006 M	0.021	0.102 M
NO ₃	5.24 M	1.95	1.31 M
PO ₄	0.006 M	<0.002	0.061 M
SO ₄	0.009 M	0.015	0.022 M
pH	0.58	3.5	13.85
calculated H ⁺	0.5 M	—	—
calculated OH ⁻	—	—	0.7 M
^a Determined by inductively coupled plasma/mass spectrometry (ICP/MS). ^b Determined by ion chromatography (IC). ^c Below detection limit.			

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.

Actinides were isolated and purified in the Los Alamos Plutonium Facility. We purchased ^{51}Cr , ^{141}Ce , and ^{60}Co from DuPont New England Nuclear Products, Boston, MA. All other radioisotopes were obtained from the Medical Radioisotopes and Reactor Applications Group (CST-15) at Los Alamos National Laboratory.

To minimize interference among gamma rays with similar energies, we divided the 14 radiotracers into two easily resolved groups. One group consisted of ^{141}Ce , ^{60}Co , ^{51}Cr , ^{137}Cs , ^{85}Sr , $^{95\text{m}}\text{Tc}$, ^{88}Y , and ^{88}Zr . The other group contained ^{241}Am , ^{59}Fe , ^{54}Mn , either ^{238}Pu or ^{239}Pu , ^{237}U , and ^{65}Zn . Each group of tracers was added to a separate portion of each simulant solution. We then divided each simulant solution into two equal portions and added eight tracers to one portion and six tracers to the other portion of each simulant. (Plutonium was measured only in the two acidic solutions because its solubility was known to be very low in alkaline solution.)

Table 3. Radiotracers Used in this Study

Radiotracer	Gamma Energy (MeV)	Gamma Branching (%) ^a	Estimated Concentration ^b
^{241}Am	0.0595	35.9	30 $\mu\text{g/L}$
^{239}Pu	0.1293	6.2×10^{-3}	3 g/L
$^{238}\text{Pu}^c$	0.153	1.0×10^{-3}	60 mg/L
^{141}Ce	0.145	48	50 pg/L
$^{95\text{m}}\text{Tc}$	0.204	100	2 pg/L
^{237}U	0.208	23.3	20 mg/L
^{51}Cr	0.320	10	—
^{88}Zr	0.394	97	50 $\mu\text{g/L}$
^{85}Sr	0.514	100	3 $\mu\text{g/L}$
^{137}Cs	0.662	85	6 $\mu\text{g/L}$
^{54}Mn	0.835	100	—
^{88}Y	0.898	92	50 $\mu\text{g/L}$
^{59}Fe	1.099	56	—
^{65}Zn	1.115	51	6 $\mu\text{g/L}$
^{60}Co	1.173	100	2 $\mu\text{g/L}$

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

^bThe elemental concentrations added with ^{51}Cr , ^{54}Mn , and ^{59}Fe were insignificant when compared with the large quantities of these same elements in the simulant matrix (see Table 2). The elemental concentrations given for the other radiotracers are based on the best information available from suppliers; however, these values do not account for low levels of these elements, which could have been unintentionally added as impurities during simulant preparation.

^c ^{238}Pu was used at a concentration of 60 mg/L with all absorbers tested in acidified supernate solution and with a few selected absorbers in acid-dissolved sludge solution. For all other acid-dissolved sludge solutions, ^{239}Pu was used at 3 g/L (a 50-fold higher concentration than when ^{238}Pu was used).

C. Absorbers

The absorbers evaluated in this study are listed in Table 4. Details about the supplier or preparation of the absorbers are provided in section III.B. These absorbers, which encompassed a wide range of particle sizes and porosities, were air-dried and used without further treatment except where otherwise noted.

Although the suppliers of the PAN composites, tannin, and Diphonix™ requested that their absorbers not be dried, we intentionally air-dried all absorbers before testing to put them all on a comparable basis. We also sought to avoid diluting the simulant solution by the addition of as-received wet absorbers; in the worst case the water in the as-received absorbers would have diluted the simulant by 23%. Because our three simulant

solutions were essentially saturated with various salts, large dilutions could significantly change the chemical properties of the simulant, thereby substantially affecting the performance of many absorbers. Nevertheless, we recognize that air-drying some of the absorbers also could adversely affect their performance, especially the sorption kinetics. We recommend that the K_d values we report for the PAN composites, tannin, and Diphonix™ be considered as minimum values that might have been higher had we not air-dried these absorbers.

Some absorbers were not compatible with all three simulant solutions, whereas others became available to us only after the study was under way. For these reasons, we did not measure all possible element/absorber/solution combinations.

Table 4. Absorbers Evaluated in this Study^a

Absorber Type/Source	Tradename or Other Identification
Commercial	Amberlyst™ 15 cation resin (sulfonic acid)
	Amberlyst™ XN-1010 cation resin (sulfonic acid)
	Duolite™ C-467 cation resin (phosphonic acid)
	Diphonix™ cation resin (polyfunctional)
	Ionsiv™ TIE-96 (TiO ₂ -loaded zeolite)
	Ionsiv™ TIE-96, modified (TiO ₂ -loaded zeolite)
	Duolite™ CS-100 resin
	Tannin (Mitsubishi)
	Sr-Spec™ resin (EiChrom)
	TRU-Spec™ resin (EiChrom)
	Durasil™ 190 resin
	Durasil™ 230 resin
	Bone char
	Reillex™ HPQ anion resin
	Ionac™ SR-3 anion resin
	Purolite™ A-520-E (Et) ₃ N anion resin
	Ionac™ SR-6 anion resin
	SRS (Savannah River Site) resorcinol/formaldehyde resin, batch BSC-187
Experimental	Sybron™ (Et) ₃ N anion resin
	Sybron™ (Pr) ₃ N anion resin
	JSK-1 anion resin
	JSK-2 anion resin
	JSK-3 anion resin
	Crypt-DER polymer resin
Composites Sebesta, Czech Republic (polyacrylonitrile matrix)	PK-01-244 phosphinic acid resin
	TiO-PAN titanium dioxide
	NiFC-PAN nickel ferrocyanide
	MgO-PAN magnesium oxide
	MnO-PAN manganese dioxide
	NaY-PAN synthetic zeolite
	M315-PAN synthetic mordenite
	NaTiO-PAN sodium titanate
	Ba(Ca)SO ₄ -PAN barium/calcium sulfate
	AMP-PAN ammonium molybdate

Table 4. Absorbers Evaluated in this Study^a (Cont.)

Absorber Type/Source	Tradename or Other Identification
Narbutt, Poland (phenolsulfonic-formaldehyde matrix)	TiFC-PSF titanium hexacyanoferrate CoFC-PSF cobalt hexacyanoferrate
Los Alamos	LANL-ZrP zirconium phosphate LANL-TiP titanium phosphate LANL-TiO titanium dioxide LANL-ZrO zirconium dioxide LANL-NbO niobium pentoxide
Extractant Beads	
Los Alamos	LIX TM -1010 (di-2-ethylhexylphosphoric acid) LIX TM -54 (a beta diketone) LIX TM -84 (a ketoxime) LIX TM -26 (8-hydroxyquinoline) Cyanex TM 923 (trialkylphosphine oxide) Cyanex TM 272 (trimethylpentylphosphoric acid) DHDECMP DHDECMP-diisopropylbenzene CMPO-diisopropylbenzene Aliquat TM 336 Czech cobalt dicarbollide Los Alamos-synthesized cobalt dicarbollide
Inorganics	
Sandia National Laboratories	SNL/CST 35 crystalline silico-titanate SNL/CST 48 crystalline silico-titanate SNL/CST 35 crystalline silico-titanate SNL/CST 68 crystalline silico-titanate SNL/CST 69 crystalline silico-titanate SNL/CST 84 crystalline silico-titanate SNL/CST 111 crystalline silico-titanate SNL/CST 120 crystalline silico-titanate SNL/CST 141 crystalline silico-titanate SNL/CST 149 crystalline silico-titanate SNL/HTO amorphous hydrous titanium oxide

^aTrademarks are identified on page x.

D. Solution/Absorber Contacts

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

For each set of experiments, we selected six syringes, each containing a different absorber. A measured volume of the selected 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. We then weighed the dispensed solution and used that figure in the calculation of K_d values.

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

The filter-tip syringes were unsuitable for the crystalline silico-titanate (CST) absorbers from Sandia National Laboratories because the CST particles were smaller than the pores in the Kynar filters. For these very finely divided materials, we achieved dynamic contact by placing each absorber/solution combination in a 20-mL centrifuge tube. At the end of each contact period, the tubes were centrifuged at high speed for 10 min. We then transferred 1.55 mL of solution from each 30-mL tube into a smaller centrifuge tube. The smaller tubes then were centrifuged at high speed for 10 min. Finally, we transferred approximately 1.5 mL of solution from the smaller centrifuge tube into a 2.5-mL hypodermic syringe with a 0.45- μ m filter (center left in Fig. 1) attached to the Luer-lock tip. The twice-centrifuged solution was expelled through this filter into a tared counting vial, from which we determined the solution weight.

The unusually large variation in Kd values obtained with the CST absorbers indicates that, in spite of our efforts to exclude them, some very small particles entered the solutions taken for gamma spectrometric assay. This problem was particularly apparent with strongly sorbed elements such as cesium. Even a few such particles on which cesium was strongly sorbed could have

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

introduced a significant amount of activity into a nearly cesium-free solution. However, in all such cases the resulting error would cause us to understate the actual Kd values for removing cesium from solution. Our reported Kd values for the CST materials should, therefore, be considered as minimum values.

E. Calculation of Kd Values

Each portion of postcontact solution was assayed by gamma spectrometry for specific 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.

The Kd value for each element was calculated as follows:

$$K_d = \left(\frac{Pr - Po}{Po} \right) \left(\frac{S}{A} \right),$$

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

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

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 percent. To avoid implying more precision than is justified, we report Kd values above 5000 as *greater than* (>) 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 *greater than* (>) the next lower hundred value.

F. Corrections

The actinide-containing group of radiotracers exhibited direct interference between the gamma ray energies of two radionuclides. In addition to the measured 208-keV gamma ray, ^{237}U has a 59.5-keV gamma whose energy coincides with that of the gamma we measured for ^{241}Am . To correct for this interference, we determined the 59.5-keV/208-keV ratio from a pure ^{237}U spectrum and used that ratio to correct the 59.5-keV contribution from ^{237}U in all assay portions (including precontact solutions) that contained both actinides.

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

We also made appropriate corrections to account for the fact that the liquid/solid ratio and the remaining activity of every radionuclide decreased as each sequential assay portion was 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 radio-

nuclide in the precontact solution. Because most absorbers were initially added in air-dried form, the aqueous solvent was often preferentially sorbed, thereby decreasing the aqueous volume while 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 same portion of solution accordingly.

We also made time-dependent corrections for the decay of ^{237}U (6.8-day half-life) during the gamma assay period. We used an EXCELTM spreadsheet to perform all Kd calculations and corrections.

G. Other Sources of Error

Each combination of element/absorber/solution/contact time was measured only once. The absence of duplicates is somewhat offset by the fact that we measured individual Kd values for three consecutive contact periods. An 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 sorption, the variation is expected to be high for reasons already discussed.

At times, Kd values are highest for the 30-min contact and decrease thereafter. Several scenarios could explain decreasing Kd values: (1) The element in question might sorb rapidly and then be displaced by another slower-sorbing species. (2) Some of the strongly complexing anions in the simulants could be participating in slow competitive reactions with the cations being measured. (3) The absorber could be uniformly or selectively dissolving, releasing previously sorbed cations in the process (slow dissolution of an amorphous phase within the crystalline silico-titanates may explain decreasing Kd values of some of the initially sorbed non-cesium cations). (4) The decreasing Kd values could be entirely due to experimental error.

The difficulties in accurately correcting for the complex background under the low-energy (59.5-keV) gamma peak of ^{241}Am resulted in Kd values with unusually large uncertainties.

H. Data Transfer and Processing

To save time and minimize the introduction of human errors inherent in manually transcribing large amounts of data, we automated the data transfer and calculation process. We used *Gamanal*⁹ to determine the area of each gamma peak of interest 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 EXCELTM 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, absorber, and solution type. 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 method¹⁰ 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 essentially 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 was 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; a single standard deviation of the 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, the single-standard-deviation uncertainty estimate (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 18 list the most promising absorbers for each element, ranked in order of Kd value, for sorption from simulated acid-dissolved sludge, acidified supernate, and alkaline supernate solutions. Partitioning agents that sorb the specified element poorly are generally omitted from these tables, although absorbers designated as baseline technologies for the Hanford Tank Waste Remediation System (TWRS) are always included, even when they perform poorly. A complete listing of the Kd values for all elements is presented in section III.B, Individual Absorbers.

1. Cerium. For sorption from acid-dissolved sludge solution, only the JSK experimental anion exchange resins outperform commercial Reillex™ HPQ during short contact periods.

For sorption from acidified supernate solution, Cyanex™ 923, a low-cost commercial extractant, outperforms specialty products costing much more.

For sorption from alkaline solution, bone char and the Sandia absorbers offer high Kd values.

Table 5. Cerium Distribution Data

Solution	Absorber	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	JSK-1 resin	28	29	27
	JSK-2 resin	27	26	24
	JSK-3 resin	23	23	22
	Reillex™ HPQ	14	13	13
	Purolite™ A-520-E	7.8	14	21
	Ionac™ SR-3	6.6	13	21
	Crypt-DER	3.0	2.9	2.8
	Duolite™ C-467	2.4	1.5	2.2
	Amberlyst™ 15	2.0	1.7	1.8
Acidified Supernate	Cyanex™ 923	744	988	1596
	TRU-Spec™	547	594	644
	SNL/HTO	265	320	512
	CMPO-DIPB	78	370	499
	Amberlyst™ 15	42	77	132
	LIX™-26	32	40	42
	DHDECMP	26	45	51
	MgO-PAN	26	59	222
	MnO-PAN	24	25	26
	Diphonix™	22	23	22
	Bone char	19	33	53
	DHDECMP-DIPB	18	28	28
	SNL/CST 111	17	32	57
	SRS resorcinol resin	14	26	42
	Amberlyst™ XN-1010	13	38	114
	AMP-PAN	12	22	28
	SNL/CST 68	8.6	16	38
	SNL/CST 48	6.4	8.6	17
	Duolite™ C-467	6.3	4.3	3.6
	Ba(Ca)SO ₄ -PAN	5.4	6.1	8.6
	Purolite™ A-520-E	4.8	5.3	6.1
	NaY-PAN	4.6	4.0	3.3
Alkaline Supernate	Bone char	914	>1400	>1500
	SNL/CST 149	797	948	701
	SNL/CST 69	205	>290	298
	SNL/HTO	184	>280	>290
	SNL/CST 141	177	199	296
	SNL/CST 35	153	>300	191
	SNL/CST 111	139	>300	>300
	SNL/CST 120	106	230	150
	LANL-TiP	30	61	22
	MgO-PAN	11	27	35
	Tannin	9.4	13	22
	LANL-ZrP	6.4	37	114
	M315-PAN	5.3	13	53
	Ba(Ca)SO ₄ -PAN	5.3	12	24

2. **Cesium.** For sorption from all three solutions, the Sandia CSTs are among the best performers.

AMP-PAN sorbs cesium well from acid-dissolved sludge and acidified supernate solutions. NiFC-PAN also sorbs cesium well from acidified supernate; however, the decreasing Kd values in alkaline supernate are

puzzling. The fact that other elements exhibit increasing Kd values on NiFC-PAN with longer contact times indicates that this absorber is not deteriorating.

For sorption from acidified supernate and alkaline supernate solutions, SRS resorcinol resin outperforms Duolite™ CS-100.

Table 6. Cesium Distribution Data

Solution	Absorber	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	SNL/CST 35	4485	1011	3416
	SNL/CST 111	3420	>5K	>5K
	SNL/CST 69	2884	2279	3252
	SNL/CST 84	1849	>8K	>11K
	AMP-PAN	1626	4073	>5K
	SNL/CST 48	794	758	1180
	SNL/CST 68	688	2307	1049
	M315-PAN	50	64	61
	NiFC-PAN	45	49	49
	Durasil™ 230	11	14	19
	Ionsiv™ TIE-96 (mod.)	7.7	9.0	9.4
	Ionsiv™ TIE-96	7.6	7.9	8.3
	Duolite™ CS-100	0.5	1.1	1.3
Acidified Supernate	SNL/CST 35	>13K	>12K	4195
	SNL/CST 69	>8K	>10K	>20K
	SNL/CST 84	5484	3953	3098
	SNL/CST 111	4938	2713	1864
	SNL/CST 68	4072	2453	722
	SNL/CST 48	3951	2820	1031
	NiFC-PAN	3533	>11K	>5K
	AMP-PAN	2133	4636	>8K
	M315-PAN	191	227	231
	Durasil™ 230	78	135	148
	SRS resorcinol resin	75	85	66
	Ionsiv™ TIE-96 (mod.)	63	110	139
	Ionsiv™ TIE-96	58	97	122
	SNL/HTO	10	8.9	8.5
	Duolite™ CS-100	1.3	1.2	1.3
Alkaline Supernate	SNL/CST 141	2521	2521	2312
	SNL/CST 111	2323	2708	3076
	NiFC-PAN	2090	943	76
	SNL/CST 149	1866	2402	3084
	CoFC-PSF	1154	3793	3575
	SNL/CST 120	570	786	898
	SRS resorcinol resin	314	599	847
	Duolite™ CS-100	196	225	233
	SNL/CST 35	165	277	385
	M315-PAN	161	177	177
	Durasil™ 230	66	106	118
	Tannin	64	66	66
	TiFC-PSF	59	102	102
	Ionsiv™ TIE-96 (mod.)	49	86	107
	Ionsiv™ TIE-96	47	84	103
	Amberlyst™ XN-1010	13	14	15
	SNL/CST 69	10	13	16
	NaY-PAN	8.0	7.8	7.5

3. Strontium. Although Sr-SpecTM sorbs strontium from both acid-dissolved sludge and acidified supernate solutions better than the other absorbers, in neither case is the sorption very high.

For sorption from acidified supernate solution, AmberlystTM 15, whose cost is hundreds of times lower, performs nearly as well as Sr-SpecTM. The poor to marginal performance of all the studied absorbers for sorbing

strontium from these two solutions indicates that better partitioning agents are needed to remove this important fission product from acidic waste solutions.

For sorption from alkaline supernate solution, many absorbers offer excellent performance; the silico-titanates and hydrous titanium oxide from Sandia and the bone char are among the best.

Table 7. Strontium Distribution Data

Solution	Absorber	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Sr-Spec TM	3.0	3.1	2.9
	Diphonix TM	2.0	1.7	1.3
	Ionsiv TM TIE-96	1.9	1.0	1.5
	Ba(Ca)SO ₄ -PAN	1.5	1.7	1.5
	MgO-PAN	1.4	1.6	2.0
Acidified Supernate	Sr-Spec TM	18	18	17
	Amberlyst TM 15	12	13	13
	Ba(Ca)SO ₄ -PAN	7.3	8.1	12
	Amberlyst TM XN-1010	5.9	7.8	8.3
	NaTiO-PAN	4.9	5.3	5.0
	SRS resorcinol resin	4.9	2.6	1.5
	SNL/CST 111	4.2	4.2	3.5
	SNL/CST 69	3.4	2.9	6.6
	MgO-PAN	3.0	4.8	7.4
	SNL/CST 84	2.2	2.0	4.4
	SNL/CST 35	1.6	1.3	3.3
	SNL/HTO	1.5	1.4	3.6
Alkaline Supernate	SNL/CST 149	>9K	>9K	>9K
	Bone char	>5K	>11K	>11K
	SNL/CST 111	4660	>4500	>4600
	SNL/CST 35	>4200	>4400	>4600
	SNL/CST 120	>4400	>4500	>4600
	SNL/HTO	>4000	>4100	>4200
	SNL/CST 69	3839	1332	1659
	SNL/CST 141	2755	>4300	>4400
	NiFC-PAN	1121	3736	4651
	Duolite TM C-467	1051	2734	>5K
	TiO-PAN	917	1627	2856
	Diphonix TM	546	696	918
	MgO-PAN	499	768	689
	NaTiO-PAN	314	410	296
	Ionsiv TM TIE-96 (mod.)	286	405	421
	TiFC-PSF	144	260	254
	Ionsiv TM TIE-96	118	140	159
	CoFC-PSF	84	293	1270
	LANL-TiP	76	117	16
	Ba(Ca)SO ₄ -PAN	76	116	146
	LANL-ZrO	60	164	526
	Tannin	50	58	102
	M315-PAN	22	165	432

4. Technetium. Reillex™ HPQ offers the highest Kd value for sorbing technetium from acid-dissolved sludge and an even higher Kd value for sorption from acidified supernate solution. Although Reillex™ HPQ provides Kd values of at least 250 for sorption from acidified supernate, two experimental resins and two commercial extractants outperform it.

Aliquat™ 336 is especially interesting because it is nearly selective for sorbing technetium from acidified supernate and alkaline supernate solutions; moreover, its

much lower Kd values for sorption from acid-dissolved sludge indicates that acid should be an effective stripping agent.

Most anion exchange resins sorb technetium well from acidic and alkaline solutions. Ionac™ SR-6, however, sorbs technetium well from acidified supernate and alkaline supernate solutions but not from acid-dissolved sludge solution. Thus, nitric acid may effectively elute technetium from this resin (see section IV, Elution Considerations).

Table 8. Technetium Distribution Data

Solution	Absorber	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved	Reillex™ HPQ	76	90	93
	Ionac™ SR-3	32	44	43
Sludge	Purolite™ A-520-E	32	57	77
	Sybron™ (Et) ₃ N resin	31	51	53
	LANL-TiO	19	40	57
	LANL-ZrO	17	41	60
	Duolite™ C-467	12	12	13
	Sybron™ (Pr) ₃ N resin	11	26	45
	Tannin	10	39	136
	LANL-NbO	6.9	17	31
	Duolite™ CS-100	4.8	6.3	6.4
	Ionac™ SR-6	2.1	4.6	8.4
	SRS resorcinol resin	2.1	4.6	11
	Aliquat™ 336	0.7	0.8	1.0
Acidified Supernate	Sybron™ (Pr) ₃ N resin	401	777	992
	Cyanex™ 923	300	551	582
	Aliquat™ 336	295	443	572
	Sybron™ (Et) ₃ N resin	264	405	440
	Reillex™ HPQ	250	280	274
	Purolite™ A-520-E	205	320	380
	Ionac™ SR-6	151	394	618
	Ionac™ SR-3	121	123	125
	TRU-Spec™	90	78	74
	LANL-TiO	54	185	290
	LIX™-26	54	112	190
	Sr-Spec™	45	42	39
	DHDECMP	43	112	222
	CMPO-DIPB	41	111	196
	Duolite™ C-467	40	42	44
	LANL-ZrO	35	148	258
	LANL-NbO	28	134	271
	Crypt-DER	25	25	25

Table 8. Technetium Distribution Data (Cont.)

Solution	Absorber	Kd Value for Specified Time		
		30 min	2 h	6 h
Alkaline Supernate	Aliquat TM 336	417	614	651
	Purolite TM A-520-E	371	585	620
	Reillex TM HPQ	314	372	370
	Sybron TM (Et) ₃ N resin	279	446	521
	Sybron TM (Pr) ₃ N resin	262	277	554
	Ionac TM SR-3	222	272	258
	Ionac TM SR-6	191	385	520
	Sr-Spec TM	82	81	76
	Cyanex TM 923	80	116	110
	Crypt-DER	31	38	38
	DHDECMP	21	23	21
	LIX TM -26	21	23	22
	DHDECMP-DIPB	14	14	13
	TRU-Spec TM	7.6	7.5	7.2
	CMPO-DIPB	4.5	6.8	7.6
	Tannin	4.3	5.4	4.0
	Bone char	2.9	5.1	4.9

5. Yttrium. None of the absorbers sorbs yttrium well from acid-dissolved sludge solution.

From acidified supernate solution, Cyanex™ 923, a low-cost commercial extractant, sorbs yttrium at least tenfold better than much costlier alternatives.

From alkaline supernate solution, bone char sorbs yttrium best, although several other absorbers offer usable Kd values.

Table 9. Yttrium Distribution Data

Solution	Absorber	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Duolite™ C-467	1.8	0.9	1.6
	JSK-1 resin	1.7	1.3	1.1
	JSK-2 resin	1.6	1.7	1.4
	Ionac™ SR-3	1.5	1.7	1.4
	Ionsiv™ TIE-96	1.5	0.9	1.2
	Amberlyst™ XN-1010	1.4	1.4	1.5
	Purolite™ A-520-E	1.4	1.1	1.1
	Reillex™ HPQ	1.2	0.5	0.8
Acidified Supernate	Tannin	1.2	1.2	0.7
	Cyanex™ 923	1078	2014	2981
	TRU-Spec™	98	94	92
	SNL/HTO	53	59	52
	Diphonix™	28	31	31
	Amberlyst™ 15	27	45	66
	MgO-PAN	26	59	258
	CMPO-DIPB	15	45	89
	AMP-PAN	15	27	34
	SRS resorcinol resin	12	21	36
Alkaline Supernate	Bone char	11	18	26
	Amberlyst™ XN-1010	11	26	64
	Bone char	172	253	339
	SNL/CST 149	81	77	104
	NiFC-PAN	48	72	99
	TiO-PAN	39	64	102
	SNL/HTO	37	68	93
	MgO-PAN	35	58	98
	Ionsiv™ TIE-96 (mod.)	28	41	47
	LANL-TiO	20	31	20
	Duolite™ C-467	19	40	85
	NaTiO-PAN	17	40	68
	MnO-PAN	17	151	229
	Diphonix™	16	20	28
	Ionsiv™ TIE-96	16	20	23
	SNL/CST 69	16	26	38
	Ba(Ca)SO ₄ -PAN	16	34	61
	SNL/CST 141	13	16	22
	Tannin	12	18	34
	M315-PAN	11	31	67
	Duolite™ CS-100	10	14	21
	NaY-PAN	10	23	40
	TiFC-PSF	9.7	25	37
	LIX™-54	9.3	24	56
	SNL/CST 35	8.9	17	37
	SNL/CST 120	8.3	12	21
	Sr-Spec™	7.9	8.5	6.7
	Durasil™ 230	7.3	9.8	11

6. Chromium. None of the tested absorbers removes chromium adequately from acid-dissolved sludge solution.

For sorption from acidified supernate and alkaline supernate solutions, several absorbers offer double-digit Kd values after 6-h contacts; however, the Kd values are

significantly lower for shorter contact periods. The poor to marginal sorption of chromium by all the absorbers indicates that better partitioning agents are needed if this important matrix element is to be removed.

Table 10. Chromium Distribution Data

Solution	Absorber	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	MgO-PAN	1.5	1.4	1.6
	LANL-ZrP	1.4	1.1	1.3
	Ionsiv™ TIE-96	1.4	0.8	1.1
	LANL-TiP	1.2	1.1	0.8
	Ba(Ca)SO ₄ -PAN	1.1	0.9	0.9
	Duolite™ C-467	1.1	0.4	1.0
	Diphonix™	1.1	0.6	0.8
	SNL/CST 111	1.0	1.0	1.2
	Amberlyst™ 15	1.0	0.7	0.9
Acidified Supernate	SNL/HTO	5.9	7.8	21
	Amberlyst™ 15	4.2	7.9	14
	MgO-PAN	4.0	5.9	36
	LANL-TiO	4.0	4.4	5.4
	MnO-PAN	3.0	4.3	4.8
	SNL/CST 69	2.8	3.8	14
	NaY-PAN	2.3	4.1	4.8
	SNL/CST 111	2.1	1.9	1.7
	SNL/CST 68	1.7	2.4	6.6
	SNL/CST 84	1.4	1.7	8.8
	Sr-Spec™	1.3	1.6	2.0
	SNL/CST 48	1.3	1.7	6.0
	TRU-Spec™	1.3	1.9	2.5
	SNL/CST 35	1.1	1.9	9.6
	Duolite™ CS-100	1.0	2.3	3.5
Alkaline Supernate	SRS resorcinol resin	3.9	16	71
	Tannin	1.9	7.3	27
	Ba(Ca)SO ₄ -PAN	1.7	2.2	2.6

7. Cobalt. Only tannin sorbs cobalt from acid-dissolved sludge solution with a double-digit Kd value, and achieving that requires a 6-h contact period.

From acidified supernate solution, four partitioning agents sorb cobalt with double-digit Kd values; however, only MgO-PAN offers a Kd value higher than 15, and achieving that requires a 6-h contact.

For sorption from alkaline supernate solution, five absorbers offer double-digit Kd values of borderline usefulness. More effective absorbers are needed for all three solutions if ^{60}Co , an important activation product, is to be recovered.

Table 11. Cobalt Distribution Data

Solution	Absorber	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Diphonix™	1.4	1.7	2.1
	MgO-PAN	1.3	1.4	1.4
	Duolite™ C-467	1.3	0.4	0.8
	M315-PAN	1.3	1.0	1.1
	LANL-ZrP	1.3	1.3	1.1
	Tannin	1.3	3.5	13
	Amberlyst™ XN-1010	1.3	0.9	1.2
	Ionsiv™ TIE-96	1.2	0.7	0.8
Acidified Supernate	Duolite™ C-467	14	13	12
	SRS resorcinol resin	12	15	7.7
	MgO-PAN	9.4	15	33
	NiFC-PAN	8.9	10	11
	NaTiO-PAN	6.2	7.9	9.5
	SNL/CST 68	5.3	5.4	2.3
	SNL/CST 48	4.5	4.6	2.0
	Bone char	4.4	5.5	6.9
	Amberlyst™ XN-1010	4.0	3.5	3.4
	Amberlyst™ 15	3.6	3.5	3.1
	Crypt-DER	2.1	2.1	2.1
Alkaline Supernate	Bone char	14	17	18
	Duolite™ CS-100	8.1	12	16
	LANL-TiO	6.4	12	18
	NiFC-PAN	5.7	7.0	8.4
	LANL-NbO	5.7	15	22
	LANL-ZrO	4.3	7.6	10
	SRS resorcinol resin	2.9	7.5	13

8. Iron. Iron is poorly sorbed from both acid-dissolved sludge and acidified supernate solutions by all absorbers. Because iron is present at high concentrations in many waste solutions, we had expected it to interfere with the sorption of other elements whose removal is critical to the HLW cleanup effort. However, its low Kd values indicate that its effect on

other elements may be less than anticipated. Nevertheless, when iron is present at high concentration, significant amounts may load even on absorbers with low Kd values for iron.

The high Kd values for sorbing iron from alkaline supernate on many absorbers may preclude their use for sorbing other elements of interest.

Table 12. Iron Distribution Data

Solution	Absorber	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	NaY-PAN	2.2	1.6	1.5
	LIX™-84	1.0	0.5	0.8
	Duolite™ CS-100	0.8	0.8	1.4
	SNL/CST 35	0.8	0.5	0.8
	M315-PAN	0.8	0.5	0.5
	Duolite™ C-467	0.8	0.2	0.4
	TRU-Spec™	0.8	0.8	0.8
	SNL/CST 68	0.7	0.7	0.9
	LIX™-54	0.7	0.3	0.4
	SNL/CST 48	0.7	1.0	1.0
	Ionsiv™ TIE-96	0.7	0.4	0.8
	MgO-PAN	0.7	0.8	1.0
	MnO-PAN	0.7	1.2	1.0
	CMPO-DIPB	0.6	0.6	0.5
	Amberlyst™ 15	0.5	1.2	0.8
Acidified Supernate	MnO-PAN	3.1	4.5	5.8
	LIX™-54	2.8	3.4	4.7
	SNL/CST 69	2.2	2.0	2.2
	SNL/HTO	2.2	3.1	3.9
	Diphonix™	2.1	2.7	3.1
	Duolite™ CS-100	1.8	2.6	3.2
	NiFC-PAN	1.4	1.7	2.3
	TiO-PAN	1.4	3.8	5.2
	Amberlyst™ 15	1.2	3.4	5.8
	TRU-Spec™	0.8	1.4	2.5
	Reillex™ HPQ	0.7	0.8	1.2
	SNL/CST 111	0.6	1.6	1.9
	SNL/CST 84	0.6	1.2	1.4
	Sr-Spec™	0.3	0.8	1.5
Alkaline Supernate	SNL/HTO	4235	>7K	>26K
	TiO-PAN	2368	4447	3523
	NiFC-PAN	1524	3676	>6K
	Diphonix™	865	1762	2988
	MgO-PAN	754	1620	2048
	NaTiO-PAN	537	1350	1703
	Ionsiv™ TIE-96 (mod.)	216	515	430
	Ionsiv™ TIE-96	166	139	124
	MnO-PAN	107	244	>1000
	LANL-TiP	75	53	>1000
	Bone char	68	202	310
	TiFC-PSF	62	159	257
	Tannin	56	90	160

Table 12. Iron Distribution Data (Cont.)

Solution	Absorber	Kd Value for Specified Time		
		30 min	2 h	6 h
Alkaline Supernate (cont.)	SNL/CST 35	55	113	181
	SNL/CST 120	52	104	166
	Duolite™ CS-100	52	75	110
	SNL/CST 69	45	80	145
	LIX™-54	41	72	135
	LANL-TiO	41	83	128
	SNL/CST 141	37	63	89
	SNL/CST 149	37	58	94
	LIX™-84	36	50	67
	SNL/CST 111	36	60	93
	LANL-ZrO	35	71	92
	SRS resorcinol resin	33	40	46
	CoFC-PSF	30	82	110
	LANL-ZrP	26	162	195
	AMP-PAN	16	17	15
	Ba(Ca)SO ₄ -PAN	12	19	25
	LANL-NbO	11	23	35
	Durasil™ 230	11	25	48
	Amberlyst™ 15	8.2	14	22

9. Manganese. Manganese is moderately sorbed from acidified supernate solution by Duolite™ C-467 and NaTiO-PAN but is not sorbed from acid-dissolved sludge by any of the absorbers tested in this study. As in the case of iron, this suggests that the risk of interference posed by the competitive

sorption of manganese from these solutions may be less than expected.

For sorption from alkaline supernate solution, many absorbers offer high K_d values for manganese. Thus, these absorbers may be useless for removing other elements of greater interest from this solution.

Table 13. Manganese Distribution Data

Solution	Absorber	K _d Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Diphonix™	1.8	3.2	3.8
	Duolite™ C-467	1.3	1.3	1.4
	Amberlyst™ XN-1010	1.1	0.5	0.4
	PK-01-244 resin	1.0	0.3	0.3
	LIX™-84	0.9	0.3	0.5
	Crypt-DER	0.8	0.7	0.4
	NaTiO-PAN	0.4	0.4	0.4
Acidified Supernate	Duolite™ C-467	15	17	17
	NaTiO-PAN	6.0	7.3	7.6
	SRS resorcinol resin	5.9	4.7	2.2
	Amberlyst™ 15	5.2	4.7	4.5
	LIX™-1010	4.9	5.7	5.3
	Amberlyst™ XN-1010	4.3	4.9	5.0
	LIX™-54	2.4	2.1	2.6
	SNL/CST 48	2.0	1.7	1.2
	SNL/CST 68	1.9	1.9	1.6
	Bone char	1.8	2.5	2.9
	MnO-PAN	1.8	1.9	2.2
	CMPO-DIPB	1.6	1.6	2.1
Alkaline Supernate	Tannin	1.3	0.4	0.5
	SNL/HTO	1969	4777	>9K
	TiO-PAN	774	1859	3110
	MgO-PAN	172	373	623
	NaTiO-PAN	142	319	616
	Diphonix™	128	200	296
	Ionsiv™ TIE-96 (mod.)	121	280	322
	Ionsiv™ TIE-96	103	115	126
	SNL/CST 141	102	178	275
	SNL/CST 35	95	375	635
	SNL/CST 149	69	134	235
	Bone char	62	927	3963
	NiFC-PAN	59	167	363
	Duolite™ C-467	52	80	93
	SNL/CST 111	52	109	225
	SNL/CST 69	50	101	167
	LANL-TiP	47	49	>1000
	MnO-PAN	25	76	>1000
	SNL/CST 120	24	117	215
	Ba(Ca)SO ₄ -PAN	17	58	104
	Reillex™ HPQ	14	18	26
	LANL-ZrP	12	106	96
	TiFC-PSF	9.9	33	87
	Amberlyst™ 15	8.3	13	21
	Tannin	7.1	16	34
	NaY-PAN	6.9	14	28
	Duolite™ CS-100	4.8	9.7	14

10. Zinc. None of the absorbers removes significant amounts of zinc from acid-dissolved sludge solution.

Several absorbers offer usable Kd values for sorption from acidified supernate solution.

From alkaline supernate solution, many absorbers offer very high sorption of zinc. The observed pH effect suggests that zinc could easily be sorbed from alkaline solution and eluted with acid.

Table 14. Zinc Distribution Data

Solution	Absorber	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	JSK-2 resin	2.8	1.9	1.1
	JSK-3 resin	1.7	1.3	0.7
	JSK-1 resin	1.6	1.0	0.9
	Diphonix™	1.2	2.1	2.1
	Duolite™ C-467	0.9	0.7	0.8
	PK-01-244 resin	0.8	0.4	0.4
	SNL/CST 111	0.8	0.6	0.6
	Crypt-DER resin	0.7	0.5	0.3
Acidified Supernate	NiFC-PAN	61	94	90
	SNL/CST 68	33	44	43
	Duolite™ C-467	24	46	89
	SNL/CST 48	23	32	34
	NaTiO-PAN	21	44	71
	SNL/HTO	18	18	19
	SRS resorcinol resin	9.3	11	9.0
	Bone char	8.3	14	18
	LIX™-1010	3.6	4.0	4.0
	Amberlyst™ XN-1010	3.2	3.4	3.6
Alkaline Supernate	SNL/HTO	4625	>11K	>25K
	NiFC-PAN	3800	>11K	>17K
	TiO-PAN	2875	>6K	>9K
	MgO-PAN	2051	4193	4040
	MnO-PAN	1519	3806	>10K
	Diphonix™	792	1616	2406
	Duolite™ C-467	292	617	910
	LANL-TiP	173	118	>1000
	Duolite™ CS-100	122	286	490
	NaTiO-PAN	115	540	1117
	Bone char	86	153	215
	Tannin	60	143	251
	LANL-TiO	51	215	448
	Ionsiv™ TIE-96	49	130	227
	AMP-PAN	34	37	29
	TiFC-PSF	30	211	335
	Ionsiv™ TIE-96 (mod.)	29	96	198
	LANL-ZrO	19	37	53
	CoFC-PSF	11	85	471
	Durasil™ 230	12	23	35
	LANL-ZrP	8.8	30	104

11. Zirconium. Many absorbers offer moderate to high sorption of zirconium from acid-dissolved sludge solution. Of particular interest is TiO-PAN, which is highly selective for zirconium. We attribute the erratic K_d values for SNL/CST 69 to incomplete exclusion of very small absorber particles from the assay solution, and those for SNL/CST 84 to dissolution of an amorphous phase that appears to preferentially sorb zirconium.

For sorption from acidified supernate solution, only MgO-PAN offers a double-digit K_d value for zirconium. However, because the K_d value for MgO-PAN for a contact time of 6 h is significantly higher than values obtained for shorter contact times, this high value is suspect.

Many absorbers offer very high sorption of zirconium from alkaline supernate solution. Because zirconium is a major matrix element in many HLW solutions, it may present serious interference problems for the cited absorbers.

Table 15. Zirconium Distribution Data

Solution	Absorber	K _d Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	NaY-PAN	107	191	196
	SNL/CST 69	91	14	116
	Durasil™ 230	75	220	205
	SNL/CST 84	70	87	19
	TiO-PAN	51	323	899
	Ionsiv™ TIE-96 (mod.)	35	88	115
	SNL/CST 68	31	119	103
	Ionsiv™ TIE-96	28	64	85
	M315-PAN	27	67	96
	SNL/CST 48	15	49	51
	SNL/CST 111	11	14	18
	Duolite™ CS-100	9.2	16	22
	SNL/CST 35	8.2	26	76
	Cyanex™ 272	8.0	32	199
Acidified Supernate	Amberlyst™ 15	2.8	4.6	8.4
	MgO-PAN	1.7	2.9	28
	SNL/HTO	1.7	2.7	6.4
	SNL/CST 69	1.7	2.5	5.5
	MnO-PAN	1.7	2.2	2.3
	Sr-Spec™	1.6	1.8	2.1
	TiO-PAN	1.5	2.0	3.2
	TRU-Spec™	1.4	1.9	2.6
	Duolite™ CS-100	1.1	2.1	3.1

Table 15. Zirconium Distribution Data (Cont.)

Solution	Absorber	Kd Value for Specified Time		
		30 min	2 h	6 h
Alkaline Supernate	SNL/HTO	1037	2220	4276
	TiO-PAN	615	1187	2092
	Diphonix™	359	759	927
	MnO-PAN	270	925	1543
	MgO-PAN	233	460	643
	Bone char	204	339	506
	NaTiO-PAN	189	526	833
	NiFC-PAN	179	375	474
	Ba(Ca)SO ₄ -PAN	161	327	482
	SNL/CST 120	147	283	449
	Ionsiv™ TIE-96 (mod.)	146	379	327
	Duolite™ CS-100	142	222	304
	Tannin	131	231	372
	Ionsiv™ TIE-96	117	151	129
	SNL/CST 35	113	280	504
	SNL/CST 149	94	104	95
	LANL-TiP	88	106	34
	SNL/CST 111	83	85	68
	TiFC-PSF	73	192	222
	SNL/CST 141	64	62	53
	LANL-ZrO	58	273	611
	SRS resorcinol resin	41	81	123
	LANL-TiO	35	205	570
	Durasil™ 230	35	86	148
	SNL/CST 69	32	87	141
	M315-PAN	19	34	50
	LANL-ZrP	18	52	159
	CoFC-PSF	13	46	129
	NaY-PAN	12	18	21

12. Uranium. Many absorbers offer moderate Kd values for sorbing uranium from acid-dissolved sludge solution. Note that all 60 absorbers were evaluated for sorbing uranium from acid-dissolved sludge that contained 3 g ²³⁹Pu/L. A few selected absorbers also were evaluated for sorbing uranium from a similar solution that contained ²³⁸Pu at a 50-fold lower concentration to determine how the lower plutonium concentration affected the Kd values of other actinides.

For sorbing uranium from acidified supernate solution, Cyanex™ 923 outperforms other much costlier partitioning agents.

For sorbing uranium from alkaline supernate solution, TiO-PAN and SNL/HTO offer very high Kd values, whereas numerous other absorbers offer moderate to high Kd values.

Table 16. Uranium Distribution Data

Solution	Absorber	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge, 3 g Pu/L	TRU-Spec™	25	26	27
	JSK-2 resin	19	19	19
	JSK-3 resin	18	18	17
	Reillex™ HPQ	16	19	18
	JSK-1 resin	14	13	12
	Sybron™ (Et) ₃ N resin	13	22	22
	Ionac™ SR-3	12	21	37
	Purolite™ A-520-E	9.9	24	35
	Sr-Spec™	4.9	5.1	5.7
	Duolite™ C-467	3.8	5.0	6.0
	Amberlyst™ 15	3.1	6.4	7.2
	DHDECMP-DIPB	1.2	2.3	2.7
	Diphonix™	0.4	1.5	2.8
	CMPO-DIPB	0.4	0.8	1.4
Acid-Dissolved Sludge, 60 mg Pu/L	Reillex™ HPQ	20	23	23
	JSK-2 resin	20	17	17
	JSK-3 resin	18	17	17
	JSK-1 resin	13	12	11
	Purolite™ A-520-E	10	22	39
	Cyanex™ 923	2.7	6.5	14
Acidified Supernate	Cyanex™ 923	122	233	356
	Diphonix™	96	153	214
	TRU-Spec™	70	107	164
	TiO-PAN	67	115	185
	SNL/HTO	52	69	90
	CMPO-DIPB	49	183	291
	SNL/CST 35	25	45	54
	Cyanex™ 272	23	41	58
	SNL/CST 68	23	38	45
	DHDECMP	22	31	32
	Duolite™ C-467	19	38	63
	Amberlyst™ 15	15	30	58
	Duolite™ CS-100	12	19	25
	Reillex™ HPQ	8.4	8.9	8.9
	SRS resorcinol resin	7.5	13	22
	Bone char	6.1	9.6	13
	Sr-Spec™	4.8	4.9	5.2

Table 16. Uranium Distribution Data (Cont.)

Solution	Absorber	Kd Value for Specified Time		
		30 min	2 h	6 h
Alkaline Supernate	TiO-PAN	2350	>6K	>9K
	SNL/HTO	2127	>9K	>17K
	Diphonix TM	124	115	87
	LANL-TiP	80	51	79
	SNL/CST 120	73	77	101
	NaTiO-PAN	48	183	403
	SNL/CST 35	31	56	72
	TiFC-PSF	25	93	135
	Ionsiv TM TIE-96	22	77	204
	Bone char	18	24	28
	SNL/CST 111	16	30	43
	Ionsiv TM TIE-96 (mod.)	16	64	195
	CoFC-PSF	7.6	36	92

13. Plutonium. Apart from the outstanding performance of the experimental JSK resins for all contact periods and Sybron™ (Et)₃N resin for a 6-h contact period, Reillex™ HPQ sorbs plutonium from acid-dissolved sludge solution better than all other partitioning agents. The performance of JSK-3 resin, which greatly exceeds that of Reillex™ HPQ, is particularly impressive.

The poor removal of plutonium from acidified supernate solution may not be a serious problem because the solubility of plutonium is expected to decrease sharply as the acidity decreases. Sorption was not measured from alkaline supernate solution, in which plutonium solubility is expected to be very low.

Table 17. Plutonium Distribution Data

Solution	Absorber	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge, 3 g Pu/L	JSK-3 resin	1053	1035	1173
	JSK-2 resin	142	278	422
	JSK-1 resin	83	143	196
	Reillex™ HPQ	78	274	485
	TRU-Spec™	57	58	60
	Sybron™ (Et) ₃ N resin	24	114	839
	Ionac™ SR-3	21	64	207
	Sr-Spec™	14	14	14
	Purolite™ A-520-E	13	51	415
	DHDECMP	4.4	8.2	15
	Duolite™ CS-100	4.0	6.7	10
	Cyanex™ 923	3.0	7.6	21
Acid-Dissolved Sludge, 60 mg Pu/L	JSK-3 resin	870	1650	2185
	JSK-2 resin	329	337	261
	JSK-1 resin	178	249	254
	Reillex™ HPQ	132	184	205
	Purolite™ A-520-E	45	186	260
	Cyanex™ 923	21	100	199
Acidified Supernate	MnO-PAN	2.8	3.3	3.8
	Duolite™ CS-100	2.7	3.4	4.4
	Amberlyst™ 15	2.3	4.9	8.5
	LIX™-54	2.2	2.8	3.0
	Cyanex™ 923	1.4	1.9	2.0
	TRU-Spec™	1.2	2.0	2.8
	Diphonix™	1.0	1.2	1.0
	Reillex™ HPQ	0.7	0.9	0.7
	DHDECMP-DIPB	0.7	0.6	0.4

14. Americium. Americium is sorbed from acid-dissolved sludge solution by the JSK resins and by Reillex™ HPQ but only with single-digit Kd values.

For sorption from acidified supernate solution, many absorbers offer high Kd values for americium. Cyanex™ 923 sorbs americium better than any other partitioning agent studied, including specialty products costing much more.

For sorption from alkaline supernate solution, several absorbers offer triple-digit Kd values for americium. Bone char is particularly effective at the two longer contact times.

Table 18. Americium Distribution Data

Solution	Absorber	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge, 3 g Pu/L	JSK-2 resin	8.4	7.9	7.6
	JSK-1 resin	7.4	6.5	5.9
	JSK-3 resin	6.2	5.3	5.0
	Reillex™ HPQ	3.9	2.4	2.4
	TRU-Spec™	0.3	<0.1	<0.1
	Diphonix™	<0.1	0.3	0.4
Acid-Dissolved Sludge, 60 mg Pu/L	JSK-2 resin	9.4	7.7	7.2
	JSK-1 resin	8.3	7.0	6.6
	JSK-3 resin	7.9	6.3	6.0
	Reillex™ HPQ	4.6	3.6	3.8
Acidified Supernate	Cyanex™ 923	538	751	802
	TRU-Spec™	495	598	671
	SNL/HTO	229	264	168
	CMPO-DIPB	49	355	472
	LIX™-54	34	32	30
	Amberlyst™ 15	33	68	93
	MnO-PAN	32	30	26
	Diphonix™	28	25	22
	SNL/CST 111	25	52	107
	DHDECMP	25	34	35
	AMP-PAN	24	50	86
	LIX™-26	23	33	30
	Bone char	16	35	62
	Amberlyst™ XN-1010	10	27	66
	LIX™-1010	10	27	64
Alkaline Supernate	SNL/HTO	200	510	779
	TiO-PAN	109	490	750
	NiFC-PAN	65	189	407
	SNL/CST 35	63	123	138
	Bone char	57	730	3084
	SNL/CST 141	54	41	20
	SNL/CST 111	47	92	53
	LANL-TiP	40	44	>100
	SNL/CST 69	24	67	135
	MnO-PAN	21	65	>1000
	SNL/CST 120	15	43	71
	Ba(Ca)SO ₄ -PAN	14	71	171
	SNL/CST 149	12	11	12
	MgO-PAN	10	46	121
	LANL-ZrP	9.4	102	75
	Ionsiv™ TIE-960 (mod.)	6.3	20	29
	Ionsiv™ TIE-960	5.8	14	22
	TiFC-PSF	4.9	21	53
	Reillex™ HPQ	4.5	7.5	21
	Tannin	2.9	9.0	21
	Duolite™ CS-100	1.6	6.3	13
	NaTiO-PAN	1.4	18	55
	NaY-PAN	1.3	12	35
	M315-PAN	<0.1	4.8	8.6
	Diphonix™	<0.1	1.9	9.6

B. Individual Absorbers

Tables 19 through 81 present K_d values for sorption of each of the 14 elements onto each of the 63 absorbers from simulated acid-dissolved sludge, acidified supernate, and alkaline supernate solutions. As mentioned earlier, not all absorbers were tested with all three simulant solutions.

Because we measured the sorption of 14 different elements, these tables provide information about unwanted elements most likely to interfere with the target element by competing for absorber sites. Tables 19 through 81, therefore, may be used to predict the selectivity of each absorber for any element.

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 three simulant solutions. The absorbers were tested for sorption from all three simulant solutions unless there was an obvious reason not to, such as apparent 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. Eighteen commercially available absorbers, listed in Table 4, were included in our study.

a. Amberlyst™ 15 Cation Exchange Resin. Amberlyst™ 15, manufactured by Rohm & Haas, Philadelphia, PA, is a macroporous, strong-acid cation exchange resin with sulfonic acid functional groups. Air-drying the as-received resin before use resulted in a weight loss of 45.4%.

Table 19 shows that surprisingly few elements sorb from acid-dissolved sludge solution onto this resin and that lanthanides and trivalent actinides sorb reasonably well from acidified supernate solution. Amberlyst™ 15 is outperformed by only one other absorber for sorbing strontium from acidified supernate solution. From alkaline supernate solution, cesium, strontium, yttrium, iron, manganese, zinc, and zirconium are weakly to moderately sorbed.

Table 19. Amberlyst™ 15 Cation Exchange Resin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	2.0	1.7	1.8
	Cs	1.5	1.3	1.6
	Sr	1.2	0.9	1.2
	Tc	1.0	0.7	1.2
	Y	2.3	1.7	2.1
	Cr	1.0	0.7	0.9
	Co	0.9	0.6	0.6
	Fe	0.5	1.2	0.8
	Mn	0.3	0.6	0.4
	Zn	<0.1	<0.1	<0.1
	Zr	1.2	1.3	1.3
	U	3.1	6.4	7.2
	Pu	1.1	1.9	1.8
	Am	0.7	0.7	0.6
Acidified Supernate	Ce	42	77	132
	Cs	9.7	9.1	9.0
	Sr	12	13	13
	Tc	<0.1	<0.1	<0.1
	Y	27	45	66
	Cr	4.2	7.9	14
	Co	3.6	3.5	3.1
	Fe	1.2	3.4	5.8
	Mn	5.2	4.7	4.5
	Zn	2.4	2.0	1.8
	Zr	2.8	4.6	8.4
	U	15	30	58
	Pu	2.3	4.9	8.5
	Am	33	68	93
Alkaline Supernate	Ce	<0.1	0.2	0.5
	Cs	7.0	6.5	6.4
	Sr	10	14	16
	Tc	0.7	0.3	0.4
	Y	3.1	7.0	14
	Cr	0.7	0.3	0.4
	Co	1.2	1.1	1.4
	Fe	8.2	14	22
	Mn	8.3	13	21
	Zn	5.1	6.9	8.2
	Zr	3.6	6.3	11
	U	<0.1	0.2	0.3
	Am	<0.1	<0.1	2.5

b. Amberlyst™ XN-1010 Cation Exchange Resin. Amberlyst™ XN-1010, a macroporous, strong-acid cation exchange resin with sulfonic acid functional groups, is manufactured by Rohm & Haas, Philadelphia, PA. The manufacturer states that Amberlyst™ XN-1010 has a particularly high surface area and is suitable for nonaqueous

applications. Air-drying the as-received resin before use resulted in a weight loss of 4.4%.

Table 20 shows that the behavior of Amberlyst™ XN-1010 in all three solutions is generally similar to that of Amberlyst™ 15, as would be expected.

Table 20. Amberlyst™ XN-1010 Cation Exchange Resin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	1.3	1.4	1.5
	Cs	2.4	2.2	2.5
	Sr	0.9	0.9	1.1
	Tc	1.2	1.1	1.3
	Y	1.4	1.4	1.5
	Cr	0.9	0.6	1.3
	Co	1.3	0.9	1.2
	Fe	0.3	1.1	0.8
	Mn	1.1	0.5	0.4
	Zn	0.3	<0.1	<0.1
	Zr	1.2	1.8	3.3
	U	1.2	2.4	4.6
	Pu	<0.1	0.7	1.3
	Am	0.2	0.4	0.2
Acidified Supernate	Ce	13	38	114
	Cs	13	15	15
	Sr	5.9	7.8	8.3
	Tc	1.3	1.0	1.0
	Y	11	26	64
	Cr	0.5	0.8	1.3
	Co	4.0	3.5	3.4
	Fe	<0.1	<0.1	<0.1
	Mn	4.3	4.9	5.0
	Zn	3.2	3.4	3.6
	Zr	<0.1	<0.1	<0.1
	U	4.0	6.7	15
	Pu	0.3	0.1	0.4
	Am	10	27	66
Alkaline Supernate	Ce	5.0	5.4	4.7
	Cs	13	14	15
	Sr	10	16	15
	Tc	0.3	0.3	0.4
	Y	3.4	4.9	4.8
	Cr	<0.1	<0.1	<0.1
	Co	<0.1	0.6	1.3
	Fe	3.8	10	25
	Mn	2.3	1.8	3.3
	Zn	1.9	6.1	22
	Zr	3.2	8.3	25
	U	0.6	1.0	2.1
	Am	0.4	0.1	0.1

d. 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, IL. Air-drying the as-received resin before use resulted in an unusually large weight loss of 72%.

Diphonix™ resin sorbs none of the 14 elements significantly from acid-dissolved sludge solution, whereas it sorbs uranium, lanthanides, and americium from acidified supernate solution. Strontium, iron, zinc, zirconium, manganese, and uranium are strongly sorbed from alkaline supernate solution.

Table 22. Diphonix™ Cation Exchange Resin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	1.3	1.1	1.2
	Cs	1.7	1.4	1.3
	Sr	2.0	1.7	1.3
	Tc	2.0	1.6	1.8
	Y	1.1	1.1	1.0
	Cr	1.1	0.6	0.8
	Co	1.4	1.7	2.1
	Fe	0.2	0.6	0.3
	Mn	1.8	3.2	3.8
	Zn	1.2	2.1	2.1
	Zr	1.0	0.6	1.0
	U	0.4	1.5	2.8
	Pu	<0.1	<0.1	<0.1
	Am	<0.1	0.3	0.4
Acidified Supernate	Ce	22	23	22
	Cs	1.5	1.0	1.1
	Sr	0.6	0.2	0.2
	Tc	1.0	1.0	1.4
	Y	28	31	31
	Cr	0.9	1.7	3.1
	Co	1.1	1.2	0.9
	Fe	2.1	2.7	3.1
	Mn	0.6	0.7	0.6
	Zn	0.4	<0.1	<0.1
	Zr	<0.1	<0.1	0.3
	U	96	153	214
	Pu	1.0	1.2	1.0
	Am	28	25	22
Alkaline Supernate	Ce	<0.1	3.9	9.7
	Cs	3.0	1.6	1.7
	Sr	546	696	918
	Tc	2.4	1.1	1.2
	Y	16	20	28
	Cr	1.4	0.4	0.3
	Co	0.9	0.2	0.4
	Fe	865	1762	2988
	Mn	121	200	296
	Zn	792	1616	2406
	Zr	359	759	927
	U	124	115	87
	Am	<0.1	1.9	9.6

c. Duolite™ C-467 Cation Exchange Resin. Duolite™ C-467, a chelating cation exchange resin composed of a polystyrene/divinylbenzene copolymer with aminophosphonic acid functional groups, is manufactured by Rohm & Haas, Philadelphia, PA. Air-drying the as-received resin before use resulted in a weight loss of 34.1%.

Table 21 shows moderate sorption of technetium and zirconium from acid-dissolved sludge solution. From

acidified supernate solution, technetium, zinc, and uranium sorb reasonably well, whereas cobalt, manganese, americium, and lanthanides sorb moderately. Strontium and zinc sorb exceptionally well from alkaline supernate, and yttrium, manganese, and americium also sorb well. The much-higher sorption of yttrium suggests that this resin may separate yttrium from cerium in alkaline solution.

Table 21. Duolite™ C-467 Cation Exchange Resin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	2.4	1.5	2.2
	Cs	0.9	0.2	0.7
	Sr	1.4	0.6	0.9
	Tc	12	12	13
	Y	1.8	0.9	1.6
	Cr	1.1	0.4	1.0
	Co	1.3	0.4	0.8
	Fe	0.8	0.2	0.4
	Mn	1.3	1.3	1.4
	Zn	0.9	0.7	0.8
	Zr	5.4	7.7	13
	U	3.8	5.0	6.0
	Pu	2.4	3.2	3.9
	Am	0.8	0.7	0.7
Acidified Supernate	Ce	6.3	4.2	3.6
	Cs	<0.1	<0.1	0.1
	Sr	1.4	0.7	0.5
	Tc	40	42	44
	Y	7.2	5.6	4.5
	Cr	0.5	0.7	1.1
	Co	14	13	12
	Fe	<0.1	0.6	0.8
	Mn	15	17	17
	Zn	24	46	89
	Zr	<0.1	0.1	0.3
	U	19	38	63
	Pu	0.7	1.0	1.3
	Am	6.9	6.2	5.4
Alkaline Supernate	Ce	0.4	1.5	2.0
	Cs	0.4	0.2	0.2
	Sr	1051	2734	>5K
	Tc	2.5	3.7	4.7
	Y	19	40	85
	Cr	<0.1	<0.1	0.1
	Co	1.0	1.0	1.2
	Fe	6.6	7.0	8.0
	Mn	52	80	93
	Zn	292	617	910
	Zr	1.0	1.4	1.6
	U	0.2	<0.1	0.3
	Am	1.2	7.5	12

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

Ionsiv™ TIE-96 sorbs zirconium well and cesium slightly from acid-dissolved sludge solution. From acidified supernate solution, it sorbs cesium well and uranium somewhat. It sorbs cesium, strontium, iron, manganese, zinc, zirconium, and uranium well from alkaline supernate solution.

Table 23. Ionsiv™ TIE-96: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	1.8	1.1	1.5
	Cs	7.6	7.9	8.3
	Sr	1.9	1.0	1.4
	Tc	1.7	1.6	1.5
	Y	1.5	0.9	1.2
	Cr	1.4	0.8	1.1
	Co	1.2	0.7	0.8
	Fe	0.7	0.4	0.8
	Mn	0.1	0.1	0.1
	Zn	0.4	0.2	0.3
	Zr	28	64	85
	U	<0.1	0.4	0.1
	Pu	1.5	2.5	4.4
	Am	0.2	<0.1	0.3
Acidified Supernate	Ce	0.1	1.2	1.6
	Cs	58	97	122
	Sr	0.5	0.7	0.4
	Tc	<0.1	<0.1	<0.1
	Y	0.9	1.3	1.1
	Cr	<0.1	0.9	0.9
	Co	0.2	0.6	0.4
	Fe	0.5	0.4	0.5
	Mn	0.4	0.3	0.3
	Zn	0.6	0.2	0.4
	Zr	<0.1	0.6	0.5
	U	5.4	7.6	12
	Pu	<0.1	0.3	0.3
	Am	1.5	1.9	2.2
Alkaline Supernate	Ce	2.3	4.4	7.1
	Cs	47	84	103
	Sr	118	140	159
	Tc	0.3	0.3	0.3
	Y	16	20	23
	Cr	<0.1	0.3	0.4
	Co	0.9	1.6	1.9
	Fe	166	139	124
	Mn	103	115	126
	Zn	49	130	227
	Zr	117	151	129
	U	22	77	204
	Am	5.8	14	22

f. 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, NJ. This absorber was used as received.

The modified form of Ionsiv™ TIE-96 provides a generally improved version of the sorption pattern of

unmodified Ionsiv™ TIE-96, with the Kd values of lanthanides, uranium, and americium for sorption from acidified supernate solution approximately doubled.

The sorption pattern from alkaline supernate solution also is similar to that of unmodified Ionsiv™ TIE-96, but the Kd values generally are higher.

Table 24. Ionsiv™ TIE-96 (Modified): Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.9	1.1	1.3
	Cs	7.7	9.0	9.4
	Sr	1.4	1.4	1.4
	Tc	1.0	1.0	1.5
	Y	1.2	1.0	1.0
	Cr	0.4	0.9	1.1
	Co	0.7	0.8	0.6
	Fe	0.2	0.7	0.6
	Mn	0.3	0.1	0.1
	Zn	0.3	0.2	0.1
	Zr	35	88	115
	U	<0.1	0.2	0.3
	Pu	1.8	3.0	4.9
	Am	0.3	0.1	0.3
Acidified Supernate	Ce	2.3	3.0	2.9
	Cs	63	110	139
	Sr	0.9	1.0	0.7
	Tc	<0.1	<0.1	<0.1
	Y	2.2	2.2	1.9
	Cr	1.0	1.6	1.3
	Co	1.0	0.8	0.8
	Fe	0.5	0.6	0.8
	Mn	0.3	0.4	0.5
	Zn	0.8	0.3	0.5
	Zr	0.6	0.8	0.6
	U	7.3	14	26
	Pu	<0.1	0.4	0.2
	Am	4.6	5.6	5.7
Alkaline Supernate	Ce	2.6	5.9	11
	Cs	49	86	107
	Sr	286	405	421
	Tc	0.2	0.2	0.2
	Y	28	41	47
	Cr	<0.1	0.2	0.3
	Co	1.2	1.6	2.1
	Fe	216	515	430
	Mn	121	280	322
	Zn	29	96	198
	Zr	146	379	327
	U	16	64	195
	Am	6.3	20	29

g. Duolite™ CS-100 Resin. Duolite™ CS-100 is a carboxy methylated phenol formaldehyde polymer manufactured by Rohm & Haas, Philadelphia, PA. Air-drying the as-received resin before use resulted in a weight loss of 55%.

Duolite™ CS-100 resin moderately sorbs zirconium, plutonium, and technetium (but not cesium) from

acid-dissolved sludge solution. Only uranium is sorbed to a useful extent from acidified supernate solution.

Zinc, zirconium, cesium, and iron are strongly sorbed from alkaline supernate solution. During contact with this resin, the alkaline supernate solution turned brown, indicating possible resin instability.

Table 25. Duolite™ CS-100 Cation Exchange Resin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.2	0.5	0.5
	Cs	0.5	1.1	1.3
	Sr	<0.1	<0.1	<0.1
	Tc	4.8	6.3	6.4
	Y	0.2	0.3	0.2
	Cr	0.1	0.1	0.2
	Co	0.3	0.5	0.4
	Fe	0.8	0.8	1.4
	Mn	0.1	0.1	0.3
	Zn	<0.1	<0.1	0.2
	Zr	9.2	16	22
	U	1.2	1.6	2.4
	Pu	4.0	6.7	10
	Am	0.1	<0.1	<0.1
Acidified Supernate	Ce	2.6	2.5	3.0
	Cs	1.3	1.2	1.3
	Sr	<0.1	<0.1	<0.1
	Tc	2.2	2.6	2.8
	Y	2.4	2.4	2.4
	Cr	1.0	2.3	3.5
	Co	0.5	0.4	0.5
	Fe	1.8	2.6	3.2
	Mn	<0.1	<0.1	<0.1
	Zn	1.1	0.9	0.8
	Zr	1.1	2.1	3.1
	U	12	19	25
	Pu	2.7	3.4	4.4
	Am	3.1	3.0	2.9
Alkaline Supernate	Ce	3.7	4.0	5.4
	Cs	196	225	233
	Sr	26	29	40
	Tc	<0.1	<0.1	<0.1
	Y	10	14	21
	Cr	0.3	0.4	0.6
	Co	8.1	12	16
	Fe	52	75	110
	Mn	4.8	9.7	18
	Zn	122	286	490
	Zr	142	222	304
	U	15	14	18
	Am	1.6	6.3	13

h. Tannin Absorber. Tannin absorber was obtained from Mitsubishi Nuclear Fuels Corporation, Japan. Air-drying the as-received tannin resulted in an unusually high weight loss of 82.2%.

Tannin sorbs technetium and zirconium from acid-dissolved sludge solution, although the sorption kinetics

are slow. Only uranium is sorbed from acidified supernate solution with a K_d value higher than 5, and again the sorption kinetics appear slow. Zirconium, zinc, iron, strontium, and cesium sorb well from alkaline supernate solution.

Table 26. Tannin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	1.0	0.6	0.5
	Cs	1.8	1.5	1.3
	Sr	0.9	0.6	0.3
	Tc	10	39	136
	Y	1.2	1.2	0.7
	Cr	0.6	0.6	0.3
	Co	1.3	3.4	13
	Fe	0.3	0.2	0.7
	Mn	0.2	0.3	0.2
	Zn	0.4	0.3	0.2
	Zr	4.3	12	33
	U	<0.1	0.6	1.0
	Pu	<0.1	0.6	2.5
	Am	0.2	0.1	0.2
Acidified Supernate	Ce	1.9	3.7	4.1
	Cs	2.4	2.2	2.4
	Sr	1.0	0.9	0.7
	Tc	2.1	2.7	2.7
	Y	1.8	3.3	4.1
	Cr	0.1	0.3	0.6
	Co	1.6	1.6	1.0
	Fe	<0.1	<0.1	0.2
	Mn	1.3	0.4	0.5
	Zn	0.6	0.2	0.2
	Zr	<0.1	<0.1	<0.1
	U	2.2	4.2	8.8
	Pu	0.4	0.2	0.4
	Am	1.1	2.0	3.1
Alkaline Supernate	Ce	9.4	13	22
	Cs	64	66	66
	Sr	50	58	102
	Tc	4.3	5.4	4.0
	Y	12	18	34
	Cr	1.9	7.3	27
	Co	<0.1	1.1	2.5
	Fe	56	90	160
	Mn	7.1	16	34
	Zn	60	143	251
	Zr	131	231	372
	U	9.1	24	46
	Am	2.9	9.0	21

i. Sr-Spec™ Resin. Sr-Spec™ resin, a crown-ether-based material, was obtained from EIChrom Industries, Inc., Darien, IL. This resin was used as received.

The Kd value of only 3 for sorbing strontium from acid-dissolved sludge is nearly matched by the Kd value of 2.8 for technetium and is exceeded by the Kd values for uranium and plutonium.

Technetium, strontium, and uranium sorb from acidified supernate solution. Solution discoloration, observed in acidified supernate solution, indicated that Sr-Spec™ may be somewhat unstable in that medium. Only technetium sorbs well from alkaline supernate solution.

Table 27. Sr-Spec™ Resin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.3	0.1	0.3
	Cs	0.3	0.1	0.1
	Sr	3.0	3.1	2.9
	Tc	2.8	2.7	2.8
	Y	0.6	0.4	0.5
	Cr	<0.1	0.1	0.2
	Co	0.4	0.1	0.2
	Fe	<0.1	0.2	0.2
	Mn	0.2	0.1	0.3
	Zn	0.1	0.2	0.2
	Zr	1.1	1.5	1.6
	U	4.9	5.1	5.7
	Pu	14	14	14
	Am	0.1	0.2	0.1
Acidified Supernate	Ce	1.0	0.8	0.8
	Cs	0.9	0.9	0.9
	Sr	18	18	17
	Tc	45	42	39
	Y	<0.1	<0.1	<0.1
	Cr	1.3	1.6	2.0
	Co	1.1	0.8	0.8
	Fe	0.3	0.8	1.5
	Mn	0.1	0.3	0.4
	Zn	<0.1	<0.1	<0.1
	Zr	1.6	1.8	2.1
	U	4.8	4.9	5.2
	Pu	0.4	0.7	1.0
	Am	0.1	0.5	0.3
Alkaline Supernate	Ce	6.4	7.6	5.7
	Cs	0.2	<0.1	0.1
	Sr	11	11	9.3
	Tc	82	81	76
	Y	7.9	8.5	6.7
	Cr	0.3	0.3	0.6
	Co	0.3	<0.1	0.2
	Fe	0.5	0.9	2.6
	Mn	<0.1	0.9	4.3
	Zn	<0.1	<0.1	0.1
	Zr	1.4	1.5	1.9
	U	<0.1	0.5	0.6
	Am	<0.1	<0.1	3.3

j. TRU-Spec™ Resin. TRU-Spec™ resin, a mixture of 13% CMPO (octylphenyl-N, N-diisobutylcarbamoylmethylphosphine oxide) and 27% TBP (tributyl phosphate) sorbed on polyacrylic ester beads, was obtained from EIChroM Industries, Inc., Darien, IL. This absorber was used as received.

This resin sorbs plutonium and uranium reasonably well from acid-dissolved sludge, whereas it sorbs technetium and zirconium weakly. It sorbs lanthanides, americium, uranium, and technetium well from acidified supernate solution. No elements sorb on this resin with even double-digit Kd values from alkaline supernate solution.

Table 28. TRU-Spec™ Resin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.1	0.2	0.4
	Cs	0.2	0.3	0.3
	Sr	0.2	0.2	0.3
	Tc	4.1	4.0	4.1
	Y	0.1	0.3	0.4
	Cr	0.6	0.6	0.8
	Co	<0.1	<0.1	<0.1
	Fe	0.8	0.8	0.8
	Mn	<0.1	0.1	0.4
	Zn	0.6	0.5	0.6
	Zr	3.8	4.3	4.9
	U	25	26	27
	Pu	57	58	60
	Am	0.3	0.1	0.1
Acidified Supernate	Ce	548	594	644
	Cs	1.5	1.8	2.0
	Sr	0.5	0.2	0.1
	Tc	90	78	74
	Y	98	94	92
	Cr	1.3	1.9	2.5
	Co	<0.1	<0.1	<0.1
	Fe	0.8	1.4	2.5
	Mn	0.3	0.3	0.3
	Zn	<0.1	<0.1	<0.1
	Zr	1.4	1.9	2.6
	U	70	107	164
	Pu	1.2	2.0	2.8
	Am	495	598	671
Alkaline Supernate	Ce	5.9	4.6	6.7
	Cs	<0.1	<0.1	<0.1
	Sr	4.9	4.5	6.6
	Tc	7.6	7.5	7.2
	Y	5.9	5.6	8.2
	Cr	<0.1	0.3	0.1
	Co	0.2	0.2	0.2
	Fe	0.4	0.7	1.7
	Mn	<0.1	0.2	2.4
	Zn	0.3	0.2	0.1
	Zr	0.7	1.1	1.2
	U	<0.1	0.3	0.5
	Am	<0.1	<0.1	0.9

k. Durasil™ 190 Resin. Durasil™ 190 resin, obtained from Duratek Corporation, Beltsville, MD, was used as received. The air-dried weight, per water-wet milliliter, was 0.969 g.

This resin sorbs none of the 14 elements significantly from acid-dissolved sludge solution. It sorbs cesium from acidified supernate solution. Only cerium, strontium, and yttrium approach even low double-digit Kd values for sorption from alkaline supernate solution.

Table 29. Durasil™ 190 Resin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.4	0.5	0.7
	Cs	1.2	1.7	2.5
	Sr	0.1	<0.1	0.3
	Tc	0.5	0.5	0.7
	Y	<0.1	0.3	0.1
	Cr	0.1	<0.1	0.1
	Co	0.3	0.3	0.3
	Fe	0.3	0.6	0.7
	Mn	0.3	0.4	0.2
	Zn	0.4	0.6	0.5
	Zr	0.7	1.3	1.7
	U	0.4	0.1	0.2
	Pu	0.2	0.2	0.2
	Am	<0.1	0.3	0.4
Acidified Supernate	Ce	0.3	0.1	0.4
	Cs	9.4	21	34
	Sr	0.1	<0.1	<0.1
	Tc	0.4	0.3	0.4
	Y	<0.1	0.2	0.3
	Cr	0.1	0.1	0.3
	Co	0.4	0.3	0.3
	Fe	0.3	0.8	0.8
	Mn	<0.1	<0.1	<0.1
	Zn	0.4	0.6	0.6
	Zr	0.3	0.2	0.3
	U	0.2	0.7	0.8
	Pu	0.8	1.0	0.9
	Am	0.1	0.6	0.6
Alkaline Supernate	Ce	5.6	9.8	9.4
	Cs	0.4	0.8	1.6
	Sr	6.6	11	12
	Tc	0.2	<0.1	<0.1
	Y	5.2	9.3	11
	Cr	0.4	0.6	0.4
	Co	<0.1	<0.1	<0.1
	Fe	0.5	0.5	0.4
	Mn	<0.1	<0.1	<0.1
	Zn	0.6	0.3	0.3
	Zr	0.6	1.1	1.3
	U	0.7	0.8	1.0
	Am	<0.1	<0.1	<0.1

I. Durasil™ 230 Resin. Durasil™ 230 resin, obtained from Duratek Corporation, Beltsville, MD, was used as received. The air-dried weight, per water-wet milliliter, was 0.749 g.

This resin sorbs zirconium and cesium from acid-dissolved sludge solution, and cesium selectively from acidified supernate solution. Cesium, zirconium, iron, strontium, zinc, americium, manganese, and yttrium all sorb with at least double-digit Kd values from alkaline supernate solution.

Table 30. Durasil™ 230 Resin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.3	0.5	0.5
	Cs	11	14	13
	Sr	0.5	0.1	0.2
	Tc	0.5	0.7	0.6
	Y	0.2	0.2	0.2
	Cr	<0.1	<0.1	<0.1
	Co	0.4	0.3	0.4
	Fe	<0.1	0.1	0.2
	Mn	<0.1	<0.1	<0.1
	Zn	0.1	0.1	0.1
	Zr	75	220	205
	U	0.4	0.3	0.3
	Pu	1.2	2.8	3.4
	Am	0.3	0.1	0.2
Acidified Supernate	Ce	<0.1	0.1	<0.1
	Cs	78	135	148
	Sr	0.3	0.3	0.2
	Tc	0.4	0.5	0.6
	Y	0.3	0.3	0.3
	Cr	0.4	0.6	0.7
	Co	0.1	<0.1	0.3
	Fe	<0.1	0.4	0.9
	Mn	0.3	0.3	0.3
	Zn	0.4	0.4	0.7
	Zr	0.4	0.7	0.9
	U	0.7	0.5	0.9
	Pu	<0.1	0.3	0.7
	Am	0.1	<0.1	0.1
Alkaline Supernate	Ce	5.4	5.8	6.4
	Cs	66	106	118
	Sr	15	20	22
	Tc	<0.1	<0.1	<0.1
	Y	7.3	9.8	11
	Cr	0.5	0.6	0.7
	Co	1.0	1.3	1.3
	Fe	11	25	48
	Mn	4.2	12	19
	Zn	12	23	35
	Zr	35	86	148
	U	2.2	2.8	3.3
	Am	0.9	7.8	14

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

Bone char sorbs none of the 14 elements at useful levels from acid-dissolved sludge solution. It sorbs

lanthanides, americium, technetium, cobalt, and zinc from acidified supernate solution, and it sorbs many elements well from alkaline supernate solution. Strontium, cerium, manganese, zirconium, yttrium, iron, and americium are especially well sorbed from alkaline supernate solution.

Table 31. Bone Char: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	1.1	1.4	1.2
	Cs	1.1	1.0	0.9
	Sr	0.7	0.6	0.8
	Tc	4.0	4.0	3.9
	Y	0.6	0.4	0.5
	Cr	0.7	0.5	0.7
	Co	0.7	1.0	1.0
	Fe	0.4	0.2	0.3
	Mn	0.3	0.1	0.3
	Zn	0.4	0.2	0.3
	Zr	2.0	2.5	2.6
	U	1.5	0.9	1.1
	Pu	2.0	1.6	1.6
	Am	0.6	0.4	0.3
Acidified Supernate	Ce	19	33	53
	Cs	0.2	0.1	0.2
	Sr	1.6	2.0	1.9
	Tc	12	14	15
	Y	11	18	26
	Cr	0.2	0.4	0.7
	Co	4.4	5.5	6.9
	Fe	0.1	0.5	0.7
	Mn	1.8	2.5	2.9
	Zn	8.3	14	18
	Zr	<0.1	0.2	0.3
	U	6.1	9.6	13
	Pu	0.1	0.2	1.1
	Am	16	35	62
Alkaline Supernate ^a	Ce	914	>1400	>1500
	Cs	1.1	3.1	2.9
	Sr	>5K	>11K	>11K
	Tc	2.9	5.1	4.9
	Y	172	253	339
	Cr	1.2	2.9	2.9
	Co	14	17	18
	Fe	68	202	310
	Mn	62	927	3963
	Zn	86	153	215
	Zr	204	339	506
	U	18	24	28
	Am	57	730	3084

^a After the absorber/solution contacts, all alkaline supernate solutions were passed through a 0.45- μ m filter to remove fine particles.

n. Reillex™ HPQ Anion Exchange Resin. Reillex™ HPQ, a strong-base polyvinylpyridine anion exchange resin, was obtained from Reilly Industries, Inc., Indianapolis, IN. This resin was converted from the as-received chloride form to the nitrate form and air-dried before use. The air-dried weight, per water-wet milliliter, was 0.352 g.

This resin sorbs technetium well from all three solutions. It sorbs plutonium well and uranium and cerium moderately from acid-dissolved sludge solution. It sorbs americium surprisingly well from alkaline supernate solution. This higher than expected sorption of americium suggests that trivalent actinides might separate from lanthanides in such a solution.

Table 32. Reillex™ HPQ Anion Exchange Resin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge, 3 g Pu/L	Ce	14	13	13
	Cs	0.8	0.3	0.6
	Sr	1.1	0.6	0.7
	Tc	76	90	93
	Y	1.2	0.5	0.8
	Cr	0.8	0.2	0.6
	Co	0.9	0.2	0.2
	Fe	0.5	0.5	0.5
	Mn	<0.1	<0.1	<0.1
	Zn	0.3	0.2	0.2
	Zr	4.3	4.2	4.2
	U	17	19	18
	Pu	78	274	485
	Am	3.9	2.4	2.4
Acid-Dissolved Sludge, 60 mg Pu/L	U	20	23	23
	Pu	131	184	205
	Am	4.6	3.6	3.8
Acidified Supernate	Ce	0.4	0.6	0.5
	Cs	1.0	0.8	0.8
	Sr	0.1	0.3	0.1
	Tc	250	280	274
	Y	0.8	1.0	0.6
	Cr	<0.1	<0.1	<0.1
	Co	0.9	1.0	0.8
	Fe	0.7	0.8	1.2
	Mn	<0.1	<0.1	<0.1
	Zn	0.6	0.5	0.6
	Zr	0.2	0.4	0.4
	U	8.4	8.9	8.9
	Pu	0.7	0.9	0.7
	Am	1.0	0.9	0.8
Alkaline Supernate	Ce	<0.1	0.7	1.0
	Cs	<0.1	<0.1	<0.1
	Sr	0.4	0.6	0.6
	Tc	314	372	370
	Y	2.3	3.4	4.1
	Cr	0.1	0.2	0.2
	Co	2.2	2.7	2.7
	Fe	3.4	3.7	4.4
	Mn	14	18	26
	Zn	<0.1	<0.1	<0.1
	Zr	1.3	1.5	1.8
	U	0.2	0.4	0.7
	Am	4.5	7.5	21

o. 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, NJ. The air-dried weight, per water-wet milliliter, was 0.359 g.

This resin sorbs plutonium, technetium, uranium, and cerium from acid-dissolved sludge solution. Technetium sorbs well from the other two solutions.

Table 33. Ionac™ SR-3 Anion Exchange Resin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	6.6	13	21
	Cs	<0.1	<0.1	<0.1
	Sr	0.2	0.6	0.3
	Tc	32	44	43
	Y	1.5	1.7	1.4
	Cr	0.5	0.9	0.7
	Co	<0.1	0.3	0.3
	Fe	0.3	0.5	0.6
	Mn	<0.1	<0.1	<0.1
	Zn	0.1	0.2	0.5
	Zr	1.4	2.8	2.4
	U	12	21	37
	Pu	21	64	207
	Am	2.6	3.7	4.3
Acidified Supernate	Ce	3.5	3.5	3.4
	Cs	0.5	0.5	0.4
	Sr	1.0	0.7	0.9
	Tc	121	123	125
	Y	0.7	0.6	0.7
	Cr	<0.1	<0.1	<0.1
	Co	0.8	0.8	0.7
	Fe	<0.1	0.3	0.1
	Mn	0.3	0.5	0.3
	Zn	0.3	0.4	0.4
	Zr	0.5	0.2	0.3
	U	1.2	1.6	1.7
	Pu	0.5	0.1	0.2
	Am	0.5	0.9	0.8
Alkaline Supernate	Ce	<0.1	<0.1	0.4
	Cs	0.8	0.4	0.3
	Sr	0.7	1.3	1.4
	Tc	222	272	258
	Y	0.6	1.2	1.3
	Cr	1.1	0.6	0.8
	Co	0.5	0.3	0.2
	Fe	0.4	0.4	0.8
	Mn	0.1	0.1	0.6
	Zn	<0.1	<0.1	<0.1
	Zr	0.9	0.4	0.6
	U	0.5	0.4	0.9
	Am	<0.1	<0.1	<0.1

p. 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, PA. The air-dried weight, per water-wet milliliter, was 0.351 g.

This resin sorbs plutonium, technetium, uranium, and cerium from acid-dissolved sludge solution. It sorbs technetium well from the other two solutions.

Table 34. Purolite™ A-520-E Anion Exchange Resin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge, 3 g Pu/L	Ce	7.8	14	21
	Cs	<0.1	<0.1	0.1
	Sr	<0.1	0.1	<0.1
	Tc	32	57	77
	Y	1.4	1.1	1.1
	Cr	0.5	0.4	0.5
	Co	0.2	0.2	0.3
	Fe	0.2	0.4	0.4
	Mn	<0.1	<0.1	<0.1
	Zn	0.3	0.3	0.3
	Zr	2.1	2.4	2.3
	U	10.1	24	35
	Pu	13	51	415
	Am	2.9	4.2	3.2
Acid-Dissolved Sludge, 60 mg Pu/L	U	9.9	22	39
	Pu	45	186	260
	Am	2.7	4.2	3.7
Acidified Supernate	Ce	4.8	5.3	6.1
	Cs	0.7	0.2	0.3
	Sr	0.6	0.4	0.5
	Tc	205	320	380
	Y	0.6	0.4	0.5
	Cr	<0.1	<0.1	<0.1
	Co	0.9	0.5	0.6
	Fe	0.5	0.6	0.5
	Mn	<0.1	0.2	0.2
	Zn	0.5	0.4	0.2
	Zr	0.7	0.3	0.3
	U	3.3	4.6	4.3
	Pu	0.3	0.1	0.2
	Am	0.6	0.7	0.6
Alkaline Supernate	Ce	<0.1	0.2	<0.1
	Cs	0.8	0.2	0.3
	Sr	0.5	1.2	1.5
	Tc	371	585	620
	Y	0.5	1.2	2.0
	Cr	0.8	0.3	0.6
	Co	1.0	0.3	0.4
	Fe	0.4	0.4	1.0
	Mn	<0.1	0.2	1.1
	Zn	0.3	<0.1	<0.1
	Zr	0.8	0.3	0.6
	U	0.8	0.7	0.8
	Am	<0.1	<0.1	<0.1

q. 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, NJ. The air-dried weight, per water-wet milliliter, was 0.462 g. Ionac™ SR-6 resin has been reported¹¹ to offer greatly increased selectivity for sorbing nitrate ion from groundwater.

This resin quite selectively sorbs technetium from all three solutions; however, the much-lower K_d value for sorption from acid-dissolved sludge solution suggests that technetium may elute more easily with nitric acid from this resin than from other anion exchange resins.

Table 35. Ionac™ SR-6 Anion Exchange Resin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	K _d Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.6	0.7	0.7
	Cs	0.3	0.3	0.4
	Sr	0.1	0.7	0.4
	Tc	2.2	4.6	8.3
	Y	0.1	0.4	0.3
	Cr	0.2	0.3	0.5
	Co	<0.1	<0.1	<0.1
	Fe	0.1	0.3	0.8
	Mn	<0.1	<0.1	<0.1
	Zn	0.2	0.2	0.3
	Zr	<0.1	0.5	0.6
	U	0.2	0.8	0.7
	Pu	0.3	0.5	0.5
	Am	0.1	0.3	0.3
Acidified Supernate	Ce	<0.1	0.2	0.1
	Cs	0.3	0.1	0.1
	Sr	0.1	0.3	0.3
	Tc	151	394	619
	Y	0.4	0.5	0.4
	Cr	0.4	0.6	0.8
	Co	0.2	0.4	0.6
	Fe	0.1	<0.1	0.2
	Mn	0.5	0.2	0.2
	Zn	0.2	0.3	0.5
	Zr	0.2	0.3	0.3
	U	0.6	1.3	1.7
	Pu	0.7	0.2	0.5
	Am	<0.1	<0.1	<0.1
Alkaline Supernate	Ce	<0.1	1.0	2.0
	Cs	0.3	<0.1	<0.1
	Sr	0.6	3.2	4.4
	Tc	191	385	520
	Y	0.8	3.4	5.4
	Cr	0.4	0.3	0.2
	Co	0.1	0.1	0.1
	Fe	0.4	0.6	0.7
	Mn	<0.1	<0.1	<0.1
	Zn	0.3	0.3	0.3
	Zr	0.5	0.5	0.7
	U	0.3	0.6	0.8
	Am	<0.1	<0.1	<0.1

r. SRS Resorcinol/Formaldehyde Resin. Dr. 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 this by passing ten volumes of 10% NaOH solution through a column of potassium-form resin, rinsing the column with 15 column volumes of water, and finally air-drying the resin. The air-dried weight, per water-wet milliliter, was 0.254 g.

This resin sorbs technetium and cesium somewhat from acid-dissolved sludge solution. It sorbs cesium well from acidified supernate solution, but cesium is accompanied by significant levels of many other elements. Sorption of cesium from alkaline supernate solution is even higher; however, many other elements cosorb with moderate to high Kd values.

Table 36. SRS Resorcinol/Formaldehyde Resin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.8	1.0	1.1
	Cs	2.7	4.5	5.9
	Sr	1.2	0.8	1.1
	Tc	2.7	4.5	11
	Y	0.7	1.0	1.1
	Cr	0.8	0.9	1.0
	Co	1.0	1.2	1.3
	Fe	0.2	0.5	0.3
	Mn	0.3	0.4	0.5
	Zn	0.2	0.5	0.5
	Zr	1.3	0.9	1.5
	U	0.2	<0.1	0.3
	Pu	<0.1	0.1	0.1
	Am	<0.1	0.4	0.1
Acidified Supernate	Ce	14	26	42
	Cs	75	85	66
	Sr	4.8	2.6	1.5
	Tc	1.0	1.5	1.8
	Y	12	21	36
	Cr	0.3	1.0	0.8
	Co	12	15	7.7
	Fe	0.2	0.5	0.7
	Mn	5.9	4.7	2.2
	Zn	9.3	11	9.0
	Zr	<0.1	<0.1	0.1
	U	7.5	13	22
	Pu	0.2	0.9	1.2
	Am	11	19	27
Alkaline Supernate	Ce	1.1	1.1	1.4
	Cs	314	599	847
	Sr	20	31	76
	Tc	<0.1	<0.1	<0.1
	Y	4.0	8.0	19
	Cr	3.9	16	71
	Co	2.9	7.5	13
	Fe	33	40	46
	Mn	<0.1	0.5	1.0
	Zn	6.8	16	31
	Zr	41	81	123
	U	7.2	15	41
	Am	<0.1	<0.1	<0.1

2. Experimental Absorbers. Seven experimental absorbers were included in our study. Two of these are experimental resins produced by Sybron Chemicals, one is a cryptand polymer developed at Los Alamos, and one is a phosphinic acid resin developed at the University of Tennessee.

The remaining three JSK experimental anion exchange resins were custom-synthesized as part of a Los Alamos effort to develop new plutonium-selective resins. Their composition cannot be disclosed until the

development program is complete and the Laboratory's patent position is secured. We can state, however, that although these resins involve a new concept for anion exchange, they can be produced by modifying existing commercial resins. For this reason, production on a commercial scale may be considerably less difficult than would be the case for an entirely new resin. Because these three resins were not stable in alkaline solution, they were studied only for sorption from acid-dissolved sludge and acidified supernate solutions.

a. 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, Birmingham, NJ. The air-dried weight, per water-wet milliliter, was 0.365 g. A previous study¹² found that this resin offers a significant increase over (Me)₃N resin for sorbing Pu(IV) from dilute nitric acid.

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

Table 37. Sybron (Et)₃N Anion Exchange Resin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	7.4	9.6	7.5
	Cs	0.2	0.1	0.2
	Sr	0.1	0.2	0.3
	Tc	31	51	53
	Y	0.6	0.6	0.3
	Cr	0.3	0.1	0.4
	Co	<0.1	<0.1	<0.1
	Fe	0.1	0.1	0.4
	Mn	<0.1	<0.1	0.3
	Zn	0.3	0.2	0.5
	Zr	2.4	2.6	2.0
	U	13	22	22
	Pu	24	114	839
	Am	2.6	1.4	0.8
Acidified Supernate	Ce	0.7	0.7	0.8
	Cs	<0.1	<0.1	<0.1
	Sr	0.2	0.4	0.3
	Tc	264	405	440
	Y	0.2	0.5	0.4
	Cr	0.8	0.9	0.8
	Co	0.2	0.5	0.4
	Fe	0.1	0.2	0.2
	Mn	0.3	0.3	0.4
	Zn	0.5	0.5	0.3
	Zr	0.1	0.1	0.3
	U	2.8	3.1	3.1
	Pu	<0.1	<0.1	0.2
	Am	0.3	0.4	0.2
Alkaline Supernate	Ce	0.3	0.8	2.0
	Cs	0.1	<0.1	<0.1
	Sr	5.3	5.6	7.3
	Tc	279	446	521
	Y	1.6	2.9	7.4
	Cr	<0.1	<0.1	<0.1
	Co	0.2	<0.1	0.3
	Fe	4.4	5.2	6.7
	Mn	<0.1	<0.1	0.6
	Zn	0.4	0.1	0.1
	Zr	2.0	3.3	4.6
	U	<0.1	0.3	0.3
	Am	<0.1	<0.1	<0.1

b. 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, Birmingham, NJ. The air-dried weight, per water-wet milliliter, was 0.406 g.

This resin sorbs technetium from all three solutions. The lower Kd value for sorption from acid-dissolved sludge solution suggests that nitric acid may elute technetium more easily from this resin than from most other anion exchange resins.

Table 38. Sybron (Pr)₃N Anion Exchange Resin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	1.2	1.7	2.2
	Cs	0.1	0.5	0.3
	Sr	<0.1	0.4	0.2
	Tc	11	26	45
	Y	0.2	0.5	0.3
	Cr	<0.1	0.8	0.6
	Co	0.3	0.1	0.1
	Fe	0.1	0.3	0.3
	Mn	0.1	<0.1	<0.1
	Zn	<0.1	0.4	0.2
	Zr	0.5	1.0	1.8
	U	1.9	3.5	7.1
	Pu	0.7	1.7	3.2
	Am	0.3	0.7	0.9
Acidified Supernate	Ce	0.4	0.1	0.2
	Cs	<0.1	<0.1	<0.1
	Sr	0.3	0.2	0.3
	Tc	401	777	992
	Y	0.4	0.5	0.4
	Cr	0.6	0.6	0.6
	Co	0.4	0.6	0.4
	Fe	0.3	0.2	0.1
	Mn	<0.1	0.2	0.1
	Zn	0.7	0.4	0.4
	Zr	1.2	0.4	0.7
	U	3.5	4.2	5.4
	Pu	0.5	0.4	0.3
	Am	0.3	0.1	0.1
Alkaline Supernate	Ce	1.5	1.3	1.2
	Cs	0.3	<0.1	<0.1
	Sr	2.2	3.0	3.5
	Tc	262	477	554
	Y	1.9	2.8	4.0
	Cr	<0.1	0.1	0.2
	Co	<0.1	<0.1	<0.1
	Fe	1.4	1.7	2.8
	Mn	<0.1	0.9	2.8
	Zn	0.2	<0.1	<0.1
	Zr	0.5	0.9	1.2
	U	0.4	0.4	0.4
	Am	<0.1	<0.1	1.1

c. JSK-1 Anion Exchange Resin. From acid-dissolved sludge solution, this resin sorbs plutonium strongly, whereas it sorbs cerium, technetium, and uranium at lower, but useful levels. It sorbs zirconium and yttrium poorly from both

solutions. From acidified supernate solution, it sorbs only technetium well. This resin could not be studied with alkaline supernate solution because it is unstable in strongly basic solution.

Table 39. JSK-1 Anion Exchange Resin: Distribution of 14 Elements from Two Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge, 3 g Pu/L	Ce	28	29	27
	Cs	0.4	0.1	0.2
	Sr	1.2	1.3	1.1
	Tc	32	32	30
	Y	1.7	1.2	1.1
	Cr	0.5	0.4	0.4
	Co	<0.1	0.3	0.1
	Fe	0.1	0.1	0.2
	Mn	<0.1	<0.1	<0.1
	Zn	1.6	1.0	0.9
	Zr	4.7	4.4	2.8
	U	14	13	12
	Pu	83	143	196
	Am	7.4	6.5	5.9
Acid-Dissolved Sludge, 60 mg Pu/L	U	13	12	11
	Pu	178	249	254
	Am	8.3	7.0	6.6
Acidified Supernate	Ce	0.7	0.6	0.5
	Cs	<0.1	<0.1	<0.1
	Sr	0.6	0.6	0.5
	Tc	63	63	61
	Y	0.4	0.4	0.3
	Cr	0.4	0.7	0.7
	Co	1.0	0.7	0.6
	Fe	<0.1	<0.1	<0.1
	Mn	1.0	1.0	0.9
	Zn	2.6	2.8	2.5
	Zr	0.4	0.3	0.3
	U	1.8	1.7	1.7
	Pu	1.5	0.9	0.8
	Am	1.8	1.8	1.7

d. JSK-2 Anion Exchange Resin. This resin sorbs plutonium well from acid-dissolved sludge solution and also sorbs cerium, technetium, uranium, and americium, but at lower levels. It sorbs only technetium at a useful level from

acidified supernate solution. This resin could not be studied with alkaline supernate solution because it is unstable in strongly basic solution.

Table 40. JSK-2 Anion Exchange Resin: Distribution of 14 Elements from Two Simulant Solutions for Hanford Tank 102-SY

Solution	Absorber	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge, 3 g Pu/L	Ce	27	26	24
	Cs	0.3	0.1	0.1
	Sr	0.6	0.5	0.6
	Tc	28	28	27
	Y	1.6	1.7	1.4
	Cr	0.4	0.4	0.5
	Co	<0.1	<0.1	0.1
	Fe	<0.1	<0.1	0.3
	Mn	0.3	0.1	0.1
	Zn	2.8	1.9	1.1
	Zr	5.5	5.6	5.8
	U	19	19	19
	Pu	142	278	422
	Am	8.4	7.9	7.6
Acid-Dissolved Sludge, 60 mg/L	U	20	17	17
	Pu	329	337	261
	Am	9.4	7.7	7.2
Acidified Supernate	Ce	0.6	not measured	1.2
	Cs	0.1	not measured	0.3
	Sr	0.2	not measured	0.5
	Tc	50	not measured	51
	Y	<0.1	not measured	0.5
	Cr	<0.1	not measured	0.6
	Co	0.1	not measured	0.4
	Fe	<0.1	0.1	0.3
	Mn	0.7	0.2	0.3
	Zn	1.9	1.8	1.8
	Zr	<0.1	not measured	0.5
	U	1.3	1.2	1.2
	Pu	0.2	0.3	0.1
	Am	1.8	1.2	1.1

e. JSK-3 Anion Exchange Resin. This resin sorbs plutonium from acid-dissolved sludge solution significantly better than any other absorber, whereas its sorption of other elements from both acidic solutions is similar to that of JSK-2 resin. The exceptionally high sorption of plutonium

from acid-dissolved sludge solution exceeds that of the next best absorber, Reillex™ HPQ resin, by an order of magnitude. This resin could not be studied with alkaline supernate solution because it is unstable in strongly basic solution.

Table 41. JSK-3 Anion Exchange Resin: Distribution of 14 Elements from Two Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge, 3 G Pu/L	Ce	23	23	22
	Cs	0.4	0.1	0.4
	Sr	1.0	1.3	1.3
	Tc	24	24	22
	Y	1.2	1.1	1.3
	Cr	0.4	0.6	0.7
	Co	<0.1	0.3	0.1
	Fe	0.4	0.1	0.3
	Mn	<0.1	0.2	0.4
	Zn	1.7	1.3	0.7
	Zr	3.7	3.3	3.0
	U	18	18	17
	Pu	1053	1035	1173
	Am	6.2	5.3	5.0
Acid-Dissolved Sludge, 60 mg Pu/L	U	18	17	17
	Pu	870	1650	2185
	Am	7.9	6.3	6.0
Acidified Supernate	Ce	1.4	1.4	1.4
	Cs	<0.1	<0.1	0.1
	Sr	0.8	0.8	0.8
	Tc	48	49	50
	Y	0.6	0.7	0.5
	Cr	0.6	0.5	0.6
	Co	1.1	1.3	0.9
	Fe	<0.1	<0.1	<0.1
	Mn	0.8	0.9	0.5
	Zn	1.7	1.3	1.5
	Zr	0.3	0.2	0.1
	U	2.0	1.4	1.5
	Pu	0.7	0.4	0.4
	Am	1.7	1.3	1.1

f. Crypt-DER Polymer Resin. Crypt-DER polymer resin is a novel absorber prepared by the Materials Technology: Polymers and Coatings Group at Los Alamos National Laboratory. The granular solid is obtained by polymerizing an octaazacryptand compound with a commercially available di-epoxide resin (DER). The cryptand and functionality contained in the polymer selectively sorbs certain metal ions, such as Hg(II) and Cd(II), from solutions having a pH above 3. However, when the amine nitrogens of the cryptand are protonated at a lower pH, the cationic

functionality binds fluoride ions quite selectively. We included the Crypt-DER polymer resin in this study to obtain additional information about its metal-sorption properties.

It sorbs plutonium, technetium, and uranium at useful levels from acid-dissolved sludge solution, whereas it sorbs cerium and zirconium weakly. It sorbs only technetium at useful K_d values from acidified supernate solution. Technetium, zinc, and strontium are all sorbed with double-digit K_d values from alkaline supernate solution.

Table 42. Crypt-DER Polymer Resin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Absorber	K _d Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	3.0	2.9	2.8
	Cs	0.1	0.3	0.2
	Sr	0.8	0.5	0.4
	Tc	9.8	9.9	9.8
	Y	1.0	0.7	0.6
	Cr	<0.1	<0.1	<0.1
	Co	0.3	0.3	0.3
	Fe	<0.1	<0.1	0.1
	Mn	0.8	0.7	0.4
	Zn	0.7	0.5	0.3
	Zr	3.2	3.6	3.9
	U	3.6	6.3	8.3
	Pu	4.1	8.0	19
	Am	1.0	0.9	1.0
Acidified Supernate	Ce	0.9	0.7	0.7
	Cs	0.8	0.8	1.0
	Sr	0.7	0.3	0.4
	Tc	25	25	25
	Y	1.0	0.6	0.8
	Cr	0.5	0.1	0.1
	Co	2.1	2.1	2.1
	Fe	0.1	0.2	0.4
	Mn	0.8	0.8	1.1
	Zn	1.2	1.3	1.4
	Zr	<0.1	0.3	0.2
	U	1.6	1.7	1.9
	Pu	<0.1	<0.1	<0.1
	Am	1.2	1.4	1.5
Alkaline Supernate	Ce	5.2	6.7	6.4
	Cs	<0.1	<0.1	0.1
	Sr	3.1	12	15
	Tc	31	38	38
	Y	6.2	7.5	8.5
	Cr	0.2	0.3	0.5
	Co	<0.1	<0.1	<0.1
	Fe	0.6	1.6	2.7
	Mn	0.3	0.4	0.8
	Zn	4.1	11	27
	Zr	<0.1	0.8	1.0
	U	<0.1	<0.1	0.3
	Am	<0.1	<0.1	<0.1

g. PK-01-244 Phosphinic Acid Resin. Professor Spiro Alexandratos at the University of Tennessee, who prepared the PK-01-244 phosphinic acid cation exchanger, advised us that its water content was 45% and it should not be dried. For this absorber only we did not air-dry the resin but took 455-mg portions that should have contained 250 mg of the dry resin.

Only cesium and technetium exhibit Kd values consistently higher than unity for sorption from acid-dissolved sludge or acidified supernate solutions. Zirconium, strontium, iron, cerium, yttrium, and manganese are sorbed with double-digit Kd values from alkaline supernate solution.

Table 43. PK-01-244 Resin: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.8	0.8	0.5
	Cs	1.0	0.9	0.5
	Sr	0.6	0.6	0.5
	Tc	1.5	1.7	1.9
	Y	0.6	0.8	0.6
	Cr	0.6	0.6	0.4
	Co	0.9	0.7	0.5
	Fe	0.7	0.2	0.2
	Mn	1.0	0.3	0.3
	Zn	0.8	0.4	0.4
	Zr	1.1	0.6	1.0
	U	<0.1	0.3	0.3
	Pu	0.6	0.3	0.2
	Am	0.8	0.4	0.3
Acidified Supernate	Ce	0.5	0.5	0.8
	Cs	1.4	1.4	1.7
	Sr	0.3	0.3	0.7
	Tc	0.9	0.8	1.4
	Y	0.7	0.4	0.7
	Cr	<0.1	0.1	0.1
	Co	0.7	0.4	1.0
	Fe	0.2	0.1	0.1
	Mn	0.5	0.3	0.3
	Zn	0.2	0.2	0.2
	Zr	0.5	0.1	0.1
	U	0.5	0.4	0.5
	Pu	0.3	0.3	0.2
	Am	<0.1	<0.1	0.1
Alkaline Supernate	Ce	10	16	7.2
	Cs	2.1	1.9	1.8
	Sr	33	31	19
	Tc	1.8	1.6	1.7
	Y	11	13	7.0
	Cr	0.1	0.2	0.2
	Co	<0.1	<0.1	<0.1
	Fe	8.3	15	19
	Mn	3.7	10	13
	Zn	1.3	2.0	2.8
	Zr	86	90	98
	U	<0.1	0.5	1.1
	Am	2.1	5.5	8.9

3. 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.¹³

Nine composite absorbers prepared for us by Dr. Ferdinand Sebesta of the Czech Technical University in Prague consist of various inorganic exchange materials dispersed in modified-binding-polymer beads of polyacrylonitrile (PAN).

Although Dr. Sebesta asked that these composites be kept wet because their performance would be seriously degraded if they were dried, we chose to air-dry them to put them on an equal 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. In particular, the frequently observed slow sorption kinetics might be faster.

a. TiO-PAN Titanium Dioxide Composite. The titanium dioxide content of the dry TiO-PAN composite was 85%. The air-dried weight of this composite, per water-wet milliliter, was 0.231 g.

TiO-PAN composite sorbs zirconium strongly from acid-dissolved sludge solution, albeit with slow kinetics;

only plutonium offers even weak competitive sorption from this solution. It sorbs uranium strongly from acidified supernate solution and uranium, zinc, iron, manganese, strontium, zirconium, and americium strongly from alkaline supernate solution.

Table 44. TiO-PAN Composite: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.7	0.4	0.5
	Cs	0.3	0.1	0.4
	Sr	1.1	0.4	0.8
	Tc	1.0	0.7	0.9
	Y	0.8	0.6	0.6
	Cr	0.5	0.4	0.5
	Co	0.6	0.3	0.4
	Fe	0.4	0.4	0.8
	Mn	0.1	0.1	0.2
	Zn	<0.1	0.2	0.3
	Zr	51	323	899
	U	0.3	0.3	0.6
	Pu	6.3	7.7	8.6
	Am	0.1	<0.1	<0.1
Acidified Supernate	Ce	1.6	1.9	1.6
	Cs	0.6	1.0	0.6
	Sr	0.2	0.5	0.4
	Tc	1.3	1.5	1.6
	Y	1.5	2.0	1.8
	Cr	4.0	4.4	5.4
	Co	<0.1	<0.1	<0.1
	Fe	1.4	3.8	5.2
	Mn	<0.1	<0.1	0.1
	Zn	<0.1	0.2	0.1
	Zr	1.5	2.0	3.2
	U	67	115	185
	Pu	1.1	1.5	2.0
	Am	2.1	2.8	3.2
Alkaline Supernate	Ce	4.6	13	57
	Cs	0.5	0.5	0.4
	Sr	917	1627	2856
	Tc	0.8	0.7	0.8
	Y	39	64	102
	Cr	<0.1	<0.1	0.1
	Co	1.4	1.5	1.6
	Fe	2368	4447	3523
	Mn	774	1859	3110
	Zn	2875	>6K	>9K
	Zr	615	1187	2092
	U	2350	>6K	>9K
	Am	109	490	750

b. NiFC-PAN Nickel Ferrocyanide Composite. The nickel ferrocyanide content of the dry NiFC-PAN composite was 85%. The air-dried weight of this composite, per water-wet milliliter, was 0.231 g.

NiFC-PAN appears to be selective for sorbing cesium from acid-dissolved sludge solution. From acidified supernate solution, it sorbs cesium strongly, zinc

well, and cobalt moderately. From alkaline supernate solution, it sorbs zinc, iron, strontium, cesium, zirconium, manganese, and americium very well. We do not understand why the sorption of cesium decreases with increasing time, whereas the sorption of all other elements on NiFC-PAN increases with time.

Table 45. NiFC-PAN Composite: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.5	0.3	0.5
	Cs	45	49	49
	Sr	0.5	0.6	0.7
	Tc	0.4	0.8	0.7
	Y	0.5	0.7	0.6
	Cr	0.5	0.5	0.6
	Co	1.1	1.1	1.1
	Fe	0.4	0.3	0.5
	Mn	0.3	0.3	0.4
	Zn	0.3	0.4	0.4
	Zr	1.0	1.1	1.7
	U	0.6	0.4	0.2
	Pu	0.2	0.7	0.4
	Am	<0.1	<0.1	0.1
Acidified Supernate	Ce	0.3	0.3	0.2
	Cs	3533	>11K	>6K
	Sr	<0.1	<0.1	<0.1
	Tc	1.0	0.7	0.8
	Y	<0.1	0.2	0.2
	Cr	0.9	0.8	1.2
	Co	8.9	10	11
	Fe	1.4	1.7	2.3
	Mn	0.5	0.7	0.5
	Zn	61	94	90
	Zr	0.5	0.5	0.7
	U	2.1	2.2	2.0
	Pu	<0.1	<0.1	0.2
	Am	0.4	0.3	0.2
Alkaline Supernate	Ce	2.6	4.9	6.4
	Cs	2090	943	76
	Sr	1121	3736	4651
	Tc	0.2	0.4	1.6
	Y	48	72	99
	Cr	1.1	1.3	2.5
	Co	5.7	7.0	8.4
	Fe	1524	3676	>6K
	Mn	59	167	363
	Zn	3800	>11K	>17K
	Zr	179	375	474
	U	7.0	8.9	9.0
	Pu	65	189	407
	Am			

c. MgO-PAN Magnesium Oxide Composite. The magnesium oxide content of the dry MgO-PAN composite was 80%. The air-dried weight of this composite, per water-wet milliliter, was 0.226 g.

MgO-PAN sorbs zirconium and several other elements slightly from acid-dissolved sludge solution. This composite sorbs zinc, iron, strontium, zirconium,

manganese, and americium well from alkaline supernate solution.

Because this absorber was unstable in acidified supernate solution, we were unable to obtain Kd values for sorption from that solution. Resin swelling and solution discoloration indicated some instability in all solutions.

Table 46. MgO-PAN Composite: Distribution of 14 Elements from Two Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	1.5	1.5	1.5
	Cs	0.8	1.1	1.1
	Sr	1.4	1.6	2.0
	Tc	1.4	1.7	1.9
	Y	1.2	1.5	1.5
	Cr	1.5	1.4	1.6
	Co	1.3	1.4	1.4
	Fe	0.7	0.8	1.0
	Mn	0.3	0.3	0.3
	Zn	0.4	0.4	0.4
	Zr	2.2	3.2	4.7
	U	0.1	0.3	0.5
	Pu	0.9	1.3	1.6
	Am	0.3	0.3	0.3
Alkaline Supernate	Ce	11	27	25
	Cs	<0.1	<0.1	<0.1
	Sr	499	768	689
	Tc	1.3	1.3	1.6
	Y	35	58	98
	Cr	0.2	0.1	0.4
	Co	1.0	1.0	1.1
	Fe	754	1620	2048
	Mn	172	373	623
	Zn	2051	4193	4040
	Zr	233	460	643
	U	4.0	6.4	9.5
	Am	10	46	121

d. MnO-PAN Manganese Dioxide Composite. The manganese dioxide content of the dry MnO-PAN composite was 85%. The air-dried weight of this composite, per water-wet milliliter, was 0.210 g.

MnO-PAN sorbs zirconium and plutonium somewhat from acid-dissolved sludge solution. Cerium and americium show an order-of-magnitude higher sorption than yttrium from acidified supernate solution. Strontium, zinc, zirconium, cerium, iron, and yttrium all sorb well from alkaline supernate solution.

Kd values for several elements for the 30-min contact period are much lower than Kd values for the 2-h and 6-h contact periods. We believe these differences are a result of the filtration of most 2-h and 6-h postcontact solutions, but not the 30-min postcontact solutions, through a 0.45- μ m filter before the gamma spectrometric assay.

Table 47. MnO-PAN Composite: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	1.1	1.0	0.9
	Cs	1.2	1.2	1.1
	Sr	0.9	0.6	0.6
	Tc	1.2	1.3	1.0
	Y	1.1	1.1	0.8
	Cr	0.6	0.9	0.6
	Co	0.9	0.8	0.7
	Fe	0.7	1.2	1.0
	Mn	0.3	0.3	0.5
	Zn	<0.1	0.2	0.2
	Zr	4.0	6.0	6.8
	U	0.5	0.1	0.5
	Pu	2.5	2.7	2.8
	Am	0.2	0.2	0.1
Acidified Supernate	Ce	24	25	26
	Cs	0.5	0.8	1.1
	Sr	<0.1	<0.1	<0.1
	Tc	1.1	1.4	1.4
	Y	2.0	2.1	1.8
	Cr	3.0	4.3	4.8
	Co	<0.1	0.6	0.9
	Fe	3.1	4.5	5.8
	Mn	1.8	1.9	2.2
	Zn	<0.1	0.1	0.2
	Zr	1.7	2.2	2.3
	U	11	13	13
	Pu	2.8	3.3	3.8
	Am	32	30	26
Alkaline Supernate ^a	Ce	5.4	1007	>1500
	Cs	0.4	0.6	0.8
	Sr	27	>8K	>8K
	Tc	1.0	2.1	2.0
	Y	17	151	229
	Cr	<0.1	0.3	0.3
	Co	0.8	1.6	1.7
	Fe	107	244	>1000
	Mn	25	76	>1000
	Zn	1519	3806	>10K
	Zr	270	925	1543
	U	12	14	15
	Am	21	65	>1000

^a After the absorber/solution contacts for 2 h and 6 h, the alkaline supernate solutions for cerium, technetium, yttrium, chromium, iron, and zirconium were passed through a 0.45- μ m filter to remove visible particles. The same was done for cesium, strontium, cobalt, manganese, zinc, uranium, and americium after the 6-h contact.

e. NaY-PAN Synthetic Zeolite Composite. The synthetic zeolite content of the dry NaY-PAN composite was 94%. The air-dried weight of this composite, per water-wet milliliter, was 0.305 g.

NaY-PAN appears to be selective for sorbing zirconium and plutonium from acid-dissolved sludge

solution. Only cesium offers double-digit Kd values for sorption from acidified supernate solution. For sorption from alkaline supernate solution, zirconium, yttrium, manganese, strontium, americium, and iron offer double-digit Kd values.

Table 48. NaY-PAN Composite: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.9	1.1	0.9
	Cs	0.9	1.0	0.7
	Sr	0.7	0.9	0.9
	Tc	1.0	0.9	0.9
	Y	0.9	1.0	0.9
	Cr	0.9	1.0	0.9
	Co	0.8	0.9	0.9
	Fe	2.2	1.6	1.5
	Mn	0.4	0.1	0.1
	Zn	0.2	0.2	0.1
	Zr	107	191	198
	U	0.3	0.1	0.3
	Pu	12	15	15
	Am	<0.1	<0.1	<0.1
Acidified Supernate	Ce	4.6	4.0	3.3
	Cs	11	10	10
	Sr	0.6	1.0	0.9
	Tc	0.1	0.5	0.3
	Y	1.5	1.6	1.4
	Cr	2.3	4.1	4.8
	Co	0.7	0.4	0.4
	Fe	0.2	0.5	0.9
	Mn	0.8	0.7	0.7
	Zn	1.5	1.3	1.2
	Zr	0.2	0.8	0.8
	U	0.9	0.8	0.9
	Pu	<0.1	<0.1	<0.1
	Am	3.7	3.5	3.3
Alkaline Supernate	Ce	1.1	1.9	3.1
	Cs	8.0	7.8	7.5
	Sr	12	15	20
	Tc	0.2	0.1	0.1
	Y	10	23	40
	Cr	<0.1	<0.1	<0.1
	Co	0.3	0.2	0.2
	Fe	5.2	7.6	11
	Mn	6.9	14	28
	Zn	2.0	2.7	3.4
	Zr	19	34	50
	U	1.7	2.3	2.4
	Am	1.3	12	35

f. M315-PAN Synthetic Mordenite Composite. The synthetic mordenite content of the dry M315-PAN composite was 93%. The air-dried weight of this composite, per water-wet milliliter, was 0.222 g.

M315-PAN shows good selectivity for sorbing cesium and zirconium from acid-dissolved sludge solution and for sorbing cesium from acidified supernate solution. It sorbs cesium, strontium, zirconium, cerium, and yttrium from alkaline supernate solution.

Table 49. M315-PAN Composite: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.9	1.0	0.8
	Cs	50	64	61
	Sr	0.8	1.0	0.9
	Tc	0.7	0.7	0.8
	Y	1.0	1.0	0.8
	Cr	0.8	1.0	0.7
	Co	1.3	1.0	1.1
	Fe	0.8	0.5	0.5
	Mn	0.3	0.2	0.2
	Zn	0.3	0.4	0.3
	Zr	27	67	96
	U	0.4	0.6	0.4
	Pu	1.1	1.0	1.2
	Am	<0.1	<0.1	<0.1
Acidified Supernate	Ce	0.5	0.2	0.4
	Cs	191	227	231
	Sr	1.1	1.2	1.4
	Tc	0.3	0.6	0.6
	Y	0.6	0.6	0.7
	Cr	0.6	0.7	1.0
	Co	0.1	<0.1	<0.1
	Fe	0.5	0.7	0.7
	Mn	0.6	0.6	0.6
	Zn	0.5	0.2	0.4
	Zr	<0.1	0.3	0.5
	U	1.2	0.7	0.9
	Pu	<0.1	<0.1	<0.1
	Am	0.8	0.6	0.7
Alkaline Supernate	Ce	5.3	13	53
	Cs	161	177	177
	Sr	22	165	432
	Tc	0.4	0.4	0.3
	Y	11	31	67
	Cr	<0.1	<0.1	<0.1
	Co	0.2	0.1	<0.1
	Fe	1.7	2.8	3.6
	Mn	2.9	4.8	6.1
	Zn	0.7	1.2	1.5
	Zr	12	18	21
	U	<0.1	0.6	0.6
	Am	<0.1	4.8	8.6

g. NaTiO-PAN Sodium Titanate Composite. The sodium titanate content of the dry NaTiO-PAN composite was 92%. The air-dried weight of this composite, per water-wet milliliter, was 0.324 g.

NaTiO-PAN sorbs zirconium moderately from acid-dissolved sludge solution. Only zinc and cesium sorb

with double-digit Kd values from acidified supernate solution. This composite sorbs iron, zinc, zirconium, uranium, manganese, and strontium with at least triple-digit Kd values, whereas it sorbs americium, cerium, and yttrium at lower values.

Table 50. NaTiO-PAN Composite: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.9	0.5	0.8
	Cs	2.2	1.6	1.9
	Sr	0.5	0.6	0.7
	Tc	0.9	0.6	1.1
	Y	1.2	0.7	0.9
	Cr	0.7	0.4	0.7
	Co	0.9	0.6	0.7
	Fe	0.7	0.3	0.4
	Mn	0.4	0.4	0.4
	Zn	0.4	0.4	0.4
	Zr	3.5	5.4	13
	U	0.2	0.7	0.7
	Pu	0.9	0.8	1.0
	Am	<0.1	<0.1	<0.1
Acidified Supernate	Ce	3.7	5.2	6.6
	Cs	11	12	12
	Sr	4.9	5.3	5.0
	Tc	0.7	0.4	0.5
	Y	3.1	3.5	4.3
	Cr	0.8	0.7	1.0
	Co	6.2	7.9	9.5
	Fe	0.5	0.6	1.0
	Mn	6.0	7.3	7.6
	Zn	21	45	71
	Zr	<0.1	<0.1	0.2
	U	4.5	6.8	8.2
	Pu	<0.1	<0.1	0.1
	Am	4.6	6.0	6.9
Alkaline Supernate	Ce	2.5	6.1	14
	Cs	1.9	1.6	1.5
	Sr	314	410	296
	Tc	0.6	0.3	0.4
	Y	17	40	68
	Cr	<0.1	<0.1	0.1
	Co	0.2	<0.1	<0.1
	Fe	537	1350	1703
	Mn	142	319	616
	Zn	115	540	1117
	Zr	189	526	833
	U	48	183	403
	Am	1.4	18	55

h. Ba(Ca)SO₄-PAN Barium/Calcium Sulfate Composite. The barium/calcium sulfate content of the dry Ba(Ca)SO₄-PAN composite was 85%. The air-dried weight of this composite, per water-wet milliliter, was 0.198 g.

Ba(Ca)SO₄-PAN sorbs no elements at useful levels from acid-dissolved sludge solution. It sorbs strontium and cerium somewhat from acidified supernate solution and sorbs many elements with at least double-digit Kd values from alkaline supernate solution.

Table 51. Ba(Ca)SO₄-PAN Composite: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.4	0.4	0.3
	Cs	1.1	1.6	1.1
	Sr	1.5	1.7	1.5
	Tc	1.0	1.1	1.0
	Y	0.8	0.7	0.9
	Cr	1.1	0.9	0.9
	Co	1.0	0.9	0.8
	Fe	<0.1	0.2	0.2
	Mn	0.3	0.1	0.1
	Zn	0.2	0.2	0.2
	Zr	1.0	2.0	1.9
	U	0.4	0.5	0.4
	Pu	0.9	0.9	0.7
	Am	0.1	<0.1	0.1
Acidified Supernate	Ce	5.4	6.1	8.6
	Cs	0.3	0.1	0.2
	Sr	7.3	8.0	12
	Tc	0.6	1.0	1.2
	Y	0.8	0.3	0.3
	Cr	<0.1	<0.1	0.2
	Co	0.4	0.3	0.2
	Fe	0.5	0.7	0.9
	Mn	<0.1	0.1	<0.1
	Zn	0.4	0.1	0.2
	Zr	0.7	0.7	0.8
	U	1.2	1.7	2.2
	Pu	0.8	0.5	1.0
	Am	0.8	0.6	1.3
Alkaline Supernate	Ce	5.3	12	24
	Cs	<0.1	<0.1	<0.1
	Sr	76	116	146
	Tc	0.3	0.9	1.1
	Y	16	34	61
	Cr	1.7	2.2	2.6
	Co	0.3	0.5	0.5
	Fe	12	19	25
	Mn	17	58	104
	Zn	1.5	0.8	1.0
	Zr	161	327	482
	U	15	22	37
	Am	14	71	171

i. AMP-PAN Ammonium Molybdophosphate Composite. The ammonium molybdophosphate content of the dry composite was 81%. The air-dried weight of this composite, per water-wet milliliter, was 0.235 g.

AMP-PAN strongly and selectively sorbs cesium from acid-dissolved sludge solution. It also strongly

sorbs cesium from acidified supernate solution, but the cesium is accompanied by lanthanides and americium. It sorbs only zinc and iron with double-digit Kd values from alkaline supernate solution, which suggests that cesium sorbed from acidic solution could be eluted with basic solution.

Table 52. AMP-PAN Composite: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.4	0.2	0.4
	Cs	1626	4072	>5K
	Sr	0.5	0.7	0.9
	Tc	0.8	0.9	1.2
	Y	0.8	0.5	0.4
	Cr	1.0	0.9	1.0
	Co	0.8	0.8	0.8
	Fe	0.1	0.1	0.1
	Mn	0.2	0.1	0.4
	Zn	0.2	0.1	0.2
	Zr	1.4	2.9	4.7
	U	0.2	0.1	0.6
	Pu	0.3	0.4	1.0
	Am	<0.1	<0.1	<0.1
Acidified Supernate	Ce	12	22	28
	Cs	2133	4636	>8K
	Sr	<0.1	<0.1	<0.1
	Tc	0.8	1.2	1.4
	Y	15	27	34
	Cr	0.5	1.3	1.3
	Co	1.5	1.8	1.7
	Fe	0.5	1.1	1.0
	Mn	<0.1	0.1	<0.1
	Zn	0.5	0.4	0.5
	Zr	0.4	1.1	0.9
	U	1.6	2.1	2.5
	Pu	0.5	0.8	1.2
	Am	24	50	86
Alkaline Supernate	Ce	3.4	3.7	4.7
	Cs	0.7	0.4	0.6
	Sr	4.1	2.8	2.6
	Tc	1.4	1.5	1.9
	Y	5.1	5.1	5.2
	Cr	0.5	0.6	0.8
	Co	1.0	0.9	1.0
	Fe	16	17	15
	Mn	3.9	5.5	6.0
	Zn	34	37	29
	Zr	5.2	5.9	6.9
	U	<0.1	1.0	0.8
	Am	1.3	3.2	3.9

4. Phenolsulfonic-Formaldehyde (PSF) Composite Absorbers. These two composites were prepared and provided to us by Dr. Jerzy Narbutt, Head, 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. TiFC-PSF Titanium Hexacyanoferrate Composite. The titanium hexacyanoferrate content of the TiFC-PSF composite was approximately 17%.

TiFC-PSF sorbs cesium weakly from acid-dissolved sludge solution and more strongly from acidified supernate solution, although the sorption kinetics appear slow. It sorbs many elements well from alkaline supernate solution.

Table 53. TiFC-PSF Composite: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	<0.1	0.3	0.2
	Cs	1.8	2.7	4.7
	Sr	0.3	0.8	0.9
	Tc	0.3	0.4	0.6
	Y	0.2	0.3	0.4
	Cr	0.7	0.9	0.9
	Co	0.6	0.7	0.8
	Fe	0.4	0.3	0.3
	Mn	0.4	0.3	0.5
	Zn	0.4	0.2	0.5
	Zr	0.8	0.8	1.7
	U	<0.1	0.2	0.2
	Pu	0.4	0.1	0.3
	Am	0.2	0.2	0.1
Acidified Supernate	Ce	2.1	4.7	7.4
	Cs	17	80	255
	Sr	1.5	2.3	2.3
	Tc	0.6	0.7	0.6
	Y	2.0	4.3	5.8
	Cr	0.1	0.9	1.5
	Co	1.9	2.2	3.0
	Fe	<0.1	<0.1	<0.1
	Mn	1.2	2.3	2.0
	Zn	1.5	2.6	3.6
	Zr	<0.1	<0.1	<0.1
	U	1.2	2.7	5.6
	Pu	0.4	0.5	0.4
	Am	1.7	3.6	5.3
Alkaline Supernate	Ce	4.3	16	40
	Cs	59	102	102
	Sr	144	260	254
	Tc	<0.1	<0.1	<0.1
	Y	9.7	25	37
	Cr	<0.1	0.3	0.3
	Co	0.6	1.7	2.4
	Fe	62	159	257
	Mn	9.9	33	87
	Zn	30	211	335
	Zr	73	192	222
	U	25	93	135
	Am	4.9	21	53

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

CoFC-PSF sorbs only cesium at a useful level from acid-dissolved sludge solution. It sorbs cesium strongly

and quite selectively from acidified supernate solution. It strongly sorbs cesium and strontium from alkaline supernate solution, although several other elements also sorb well from this solution.

Table 54. CoFC-PSF Composite: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.6	1.2	1.0
	Cs	1.9	5.8	10
	Sr	0.9	1.7	1.5
	Tc	0.6	1.4	1.3
	Y	0.8	1.2	1.2
	Cr	0.8	2.0	1.4
	Co	0.8	1.5	1.3
	Fe	0.1	0.1	<0.1
	Mn	<0.1	0.3	0.5
	Zn	0.2	0.3	0.5
	Zr	1.1	1.6	1.9
	U	0.4	0.1	0.6
	Pu	0.2	0.3	0.6
	Am	<0.1	<0.1	0.1
Acidified Supernate	Ce	1.3	2.8	3.9
	Cs	39	263	880
	Sr	0.5	1.2	1.4
	Tc	0.6	0.4	0.6
	Y	1.7	3.5	4.0
	Cr	<0.1	0.5	0.7
	Co	1.8	3.4	5.7
	Fe	<0.1	<0.1	<0.1
	Mn	0.9	1.3	1.4
	Zn	1.5	4.1	8.9
	Zr	0.2	<0.1	<0.1
	U	1.2	2.6	4.0
	Pu	0.2	0.1	0.3
	Am	1.6	2.3	3.0
Alkaline Supernate	Ce	0.9	2.0	2.8
	Cs	1154	3793	3575
	Sr	84	293	1270
	Tc	<0.1	<0.1	<0.1
	Y	3.7	11	23
	Cr	0.3	0.2	0.3
	Co	1.5	2.8	4.0
	Fe	30	82	110
	Mn	2.3	5.0	6.5
	Zn	11	85	471
	Zr	13	46	129
	U	7.6	36	92
	Am	<0.1	0.8	1.1

5. Los Alamos-Prepared Composites. We prepared metal phosphate composites by loading the selected metal ion on Duolite™ C-467 phosphonate cation exchange resin, obtained from Rohm & Haas Co., Philadelphia, PA, and then heating the loaded resin stepwise in a tube furnace (in a stream of nitrogen) to a final temperature of 600°C. We first tested this technique by heating 1.002 g of unloaded, air-dried Duolite™ resin for 2 h at 400°C. We found that the

resin weight had decreased to 589 mg. After the same portion of resin was heated for an additional hour at 500°C and one more hour at 850°C, only 453 mg remained.

We prepared metal oxide composites by impregnating Amborsorb™ 563 porous carbon beads with the appropriate metal alkoxide, after which we hydrolyzed the alkoxide to the metal oxide within the pores of the support beads, using the procedure of Suzuki.¹⁵

a. LANL-ZrP Zirconium Phosphate. We dissolved an 8.75-g portion of solid ZrCl_4 (with quite a vigorous reaction) in 50 mL of 1.5 M HCl and added this solution to 50 mL of wet Duolite™ C-467 resin. We agitated this mixture on a 48-rpm tube rotator for 2 h and then transferred the zirconium-loaded resin to a column, washed it with an excess of 0.5 M HCl, rinsed it well with water, and air-dried it.

After stepwise heating to 600°C, the weight of an initial 3.126 g of zirconium-loaded, air-dried resin decreased to 1.177 g (37.7%). Stepwise heating of a sepa-

rate 7.714-g portion resulted in a weight of 3.772 g (48.9%). The difference in final weight indicates that larger portions are less efficiently decomposed to the metal phosphates. The two portions were combined for use in this study.

LANL-Zrp sorbs none of the 14 elements at useful levels from acid-dissolved sludge or acidified supernate solution, whereas it sorbs many elements well from alkaline supernate solution.

Table 55. LANL-ZrP Composite: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.9	0.4	0.6
	Cs	1.0	1.1	1.4
	Sr	1.0	1.0	1.2
	Tc	1.0	1.0	1.2
	Y	1.1	0.3	0.8
	Cr	1.4	1.1	1.3
	Co	1.3	1.3	1.1
	Fe	0.3	0.1	0.3
	Mn	<0.1	<0.1	0.2
	Zn	0.2	0.3	0.2
	Zr	2.0	2.4	3.3
	U	0.2	0.1	0.5
	Pu	0.5	0.3	0.6
	Am	<0.1	0.2	0.1
Acidified Supernate	Ce	0.2	0.8	0.8
	Cs	1.3	2.2	2.6
	Sr	<0.1	0.2	0.1
	Tc	0.7	1.0	0.6
	Y	1.0	1.2	1.0
	Cr	0.3	0.3	0.4
	Co	0.7	0.6	0.4
	Fe	<0.1	<0.1	<0.1
	Mn	0.3	0.6	0.5
	Zn	0.4	0.7	0.9
	Zr	0.7	0.2	0.2
	U	1.4	2.5	2.6
	Pu	<0.1	0.1	0.3
	Am	0.3	0.5	0.4

Table 55. LANL-ZrP Composite: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY (Cont.)

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Alkaline Supernate	Ce	6.4	37	114
	Cs	0.9	1.3	1.4
	Sr	34	108	343
	Tc	<0.1	<0.1	<0.1
	Y	6.7	20	39
	Cr	0.1	0.4	0.3
	Co	2.6	3.9	4.9
	Fe	26	162	195
	Mn	12	106	96
	Zn	8.8	30	104
	Zr	18	52	159
	U	5.3	14	20
	Am	9.4	102	75

b. LANL-TiP Titanium Phosphate. We mixed a 7.10-g portion of liquid TiCl_4 (with quite a vigorous reaction) in 50 mL of 1.5 M HCl and added the resulting solution to 50 mL of wet Duolite™ C-467 resin. We agitated this mixture on a 48-rpm tube rotator for 2 h and then transferred the titanium-loaded resin to a column, washed it with an excess of 0.5 M HCl, rinsed it well with water, and air-dried it.

After stepwise heating to 600°C, the weight of an initial 5.610-g portion of this titanium-loaded, air-dried resin decreased to 2.409 g (42.9%). Stepwise heating of

a separate 5.669-g portion resulted in a weight of 2.443 g (43.1%). The difference between the two final weights indicates that when the weights of the initial portions are reasonably constant, the decomposition to metal phosphates is fairly reproducible. The two portions were combined for use in this study.

LANL-TiP sorbs none of the 14 elements at useful levels from acid-dissolved sludge or acidified supernate solution. However, it sorbs nearly half of the elements studied at useful levels from alkaline supernate solution.

Table 56. LANL-TiP Composite: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.6	0.3	0.3
	Cs	2.0	2.4	4.0
	Sr	1.0	0.4	0.7
	Tc	1.6	0.7	0.9
	Y	1.0	0.5	0.4
	Cr	1.2	1.1	0.8
	Co	0.7	0.2	0.5
	Fe	0.1	0.1	0.1
	Mn	<0.1	<0.1	0.1
	Zn	0.2	0.2	0.2
	Zr	1.8	1.7	2.1
	U	0.4	0.3	0.3
	Pu	0.6	0.7	0.8
	Am	<0.1	<0.1	<0.1
Acidified Supernate	Ce	1.0	0.8	0.9
	Cs	2.1	2.6	3.5
	Sr	0.4	0.1	0.1
	Tc	1.1	0.7	0.7
	Y	1.2	0.9	0.8
	Cr	0.3	0.5	0.3
	Co	1.0	0.5	0.4
	Fe	<0.1	0.3	0.2
	Mn	0.3	0.1	0.5
	Zn	1.1	1.7	2.6
	Zr	<0.1	0.1	0.1
	U	2.5	3.6	3.8
	Pu	<0.1	0.5	0.2
	Am	1.1	1.0	0.9

Table 56. LANL-TiP Composite: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY (Cont.)

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Alkaline Supernate ^{a,b}	Ce	30	61	22
	Cs	0.7	1.1	1.4
	Sr	76	117	16
	Tc	<0.1	<0.1	<0.1
	Y	20	31	20
	Cr	<0.1	0.2	0.3
	Co	2.0	4.0	6.1
	Fe	75	53	>1000
	Mn	47	49	>1000
	Zn	173	118	>1000
	Zr	88	106	34
	U	80	51	79
	Am	40	44	908

^a After the absorber/solution contact period of 6 h, we passed the alkaline supernate solutions containing cesium, strontium, iron, manganese, zinc, uranium, and americium through a 0.45- μ m filter to remove visible particles.

^b The Kd value for sorbing strontium from alkaline supernate solution after 6 h is obviously in error and should be disregarded.

c. **LANL-TiO Titanium Dioxide.** We diluted a 30-mL portion of titanium butoxide with 60 mL of cyclohexane and added 79.1 g of Amborsorb™ 563 porous carbon beads, obtained from Rohm & Haas, Philadelphia, PA, to absorb the liquid. After the volatile solvent evaporated, we heated the beads in 0.1 M nitric acid for 2 h. The loaded beads were washed with an excess of water and air-dried to yield 94.3 g (119.3 % of the added Amborsorb™ beads). If the TiO₂ were

anhydrous, which it is not, this would represent 2.4 mmoles of titanium per initial gram of Amborsorb™ beads.

LANL-TiO sorbs technetium and zirconium from acid-dissolved sludge solution, although the sorption kinetics are slow. It sorbs technetium well and uranium moderately from acidified supernate solution. It sorbs strontium, zirconium, zinc, and iron well and several other elements moderately from alkaline supernate solution.

Table 57. LANL-TiO Composite: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.8	0.8	0.6
	Cs	0.8	0.4	0.3
	Sr	0.3	0.1	0.1
	Tc	19	40	57
	Y	0.8	0.8	0.6
	Cr	0.5	0.6	0.5
	Co	0.6	0.7	0.6
	Fe	<0.1	0.1	0.1
	Mn	0.3	0.1	0.1
	Zn	0.4	0.2	0.2
	Zr	4.4	10	28
	U	0.3	0.2	0.4
	Pu	1.1	1.6	2.1
	Am	0.2	0.2	0.2
Acidified Supernate	Ce	1.7	2.2	1.6
	Cs	0.1	<0.1	<0.1
	Sr	<0.1	0.1	0.1
	Tc	54	185	290
	Y	0.7	0.8	0.5
	Cr	0.4	1.1	1.7
	Co	0.4	0.7	0.4
	Fe	<0.1	0.5	1.0
	Mn	0.4	0.1	0.1
	Zn	<0.1	<0.1	0.2
	Zr	0.4	0.8	1.0
	U	3.8	9.1	19
	Pu	0.3	0.5	1.1
	Am	1.3	1.5	1.5
Alkaline Supernate	Ce	2.3	3.5	6.7
	Cs	0.4	0.5	0.4
	Sr	51	129	660
	Tc	2.2	1.8	1.8
	Y	6.9	18	56
	Cr	<0.1	0.2	0.1
	Co	6.4	12	18
	Fe	41	83	128
	Mn	4.3	7.3	13
	Zn	51	215	448
	Zr	35	205	570
	U	14	41	45
	Am	<0.1	0.7	5.0

d. LANL-ZrO Zirconium Dioxide. We diluted a 30-mL portion of zirconium butoxide-butanol with 60 mL of cyclohexane and added 80.4 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas, Philadelphia, PA, to absorb the liquid. After the volatile solvent evaporated, we heated the beads in 0.1 M nitric acid for 2 h. We then washed the loaded beads with an excess of water and air-dried them to yield 91.33 g (123.2% of the added Ambersorb™ beads). If the ZrO_2 were anhydrous, which it

is not, this would represent 1.1 mmoles of zirconium per initial gram of Ambersorb™ beads.

LANL-ZrO sorbs technetium from acid-dissolved sludge solution, although with slow sorption kinetics. It sorbs technetium strongly and selectively from acidified supernate solution, again with slow sorption kinetics. For sorption from alkaline supernate solution, zirconium and strontium offer triple-digit K_d values, whereas several other elements sorb at lower but still useful levels.

Table 58. LANL-ZrO Composite: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.7	0.8	0.8
	Cs	0.5	0.3	0.5
	Sr	0.9	0.2	0.3
	Tc	17	41	60
	Y	0.8	1.0	1.0
	Cr	1.0	0.7	0.6
	Co	0.8	0.5	0.5
	Fe	0.6	0.2	0.2
	Mn	<0.1	0.2	0.1
	Zn	0.2	0.2	0.2
	Zr	1.7	2.8	3.7
	U	0.1	<0.1	0.3
	Pu	0.6	0.7	0.8
	Am	0.4	0.2	0.3
Acidified Supernate	Ce	<0.1	0.2	0.6
	Cs	<0.1	<0.1	0.1
	Sr	1.0	0.6	0.6
	Tc	35	148	258
	Y	0.1	<0.1	<0.1
	Cr	0.4	0.6	1.2
	Co	0.4	0.6	0.5
	Fe	<0.1	0.6	0.4
	Mn	0.1	0.7	0.5
	Zn	0.3	0.3	0.3
	Zr	<0.1	0.7	0.9
	U	1.4	2.2	2.9
	Pu	0.1	0.4	0.6
	Am	<0.1	<0.1	<0.1
Alkaline Supernate	Ce	1.6	2.8	4.9
	Cs	<0.1	<0.1	<0.1
	Sr	60	164	526
	Tc	0.4	0.6	0.6
	Y	6.7	17	41
	Cr	<0.1	<0.1	<0.1
	Co	4.3	7.6	10
	Fe	35	71	92
	Mn	3.4	5.3	7.2
	Zn	19	37	53
	Zr	58	273	611
	U	9.7	17	27
	Am	<0.1	<0.1	0.5

e. LANL-NbO Niobium Pentoxide. We diluted a 50-mL portion of niobium ethoxide with 100 mL of cyclohexane and added 113.9 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas, Philadelphia, PA, to absorb the liquid. After the volatile solvent evaporated, we heated the beads in 0.1 M nitric acid for 2 h. We then washed the loaded beads with an excess of water and air-dried them to yield 140.30 g (123.2% of the added Ambersorb™ beads). If the Nb₂O₅ were anhydrous, which it is not, this

would represent 1.7 mmol of niobium per initial gram of Ambersorb™ beads.

LANL-NbO sorbs technetium and zirconium moderately from acid-dissolved sludge solution. It sorbs technetium more strongly from acidified supernate solution, although with slow sorption kinetics. It sorbs strontium well and many other elements moderately from alkaline supernate solution.

Table 59. LANL-NbO Composite: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.3	0.5	0.5
	Cs	0.5	0.9	0.7
	Sr	0.1	0.3	0.1
	Tc	6.9	17	31
	Y	0.8	0.3	0.5
	Cr	0.6	0.5	0.6
	Co	0.3	0.4	0.6
	Fe	0.5	0.3	0.4
	Mn	0.1	0.2	0.1
	Zn	0.3	0.3	0.3
	Zr	2.2	6.3	14
	U	<0.1	0.6	0.5
	Pu	1.5	2.4	3.4
	Am	0.2	0.1	0.1
Acidified Supernate	Ce	1.7	2.4	2.8
	Cs	4.5	5.6	6.8
	Sr	0.5	0.1	0.2
	Tc	28	134	271
	Y	0.9	0.8	0.8
	Cr	0.9	1.6	2.9
	Co	0.4	0.6	0.6
	Fe	<0.1	<0.1	0.2
	Mn	0.8	0.7	0.3
	Zn	1.3	0.8	0.7
	Zr	<0.1	0.2	0.6
	U	2.3	4.1	7.3
	Pu	0.5	0.2	0.2
	Am	1.1	1.7	2.9
Alkaline Supernate	Ce	3.1	5.0	6.8
	Cs	0.6	0.7	1.0
	Sr	31	63	129
	Tc	2.8	2.8	3.0
	Y	6.4	10	15
	Cr	<0.1	<0.1	0.2
	Co	5.7	15	22
	Fe	6.9	22	34
	Mn	<0.1	5.4	12
	Zn	5.5	12	15
	Zr	12	12	14
	U	7.2	11	7.5
	Am	<0.1	0.2	4.7

6. Liquid Extractants. We prepared and evaluated porous beads impregnated with 12 different liquid extractants.

a. LIXTM-1010. We diluted 10 mL of LIXTM-1010 (di-2-ethylhexylphosphoric acid), obtained from Henkel Corporation, Tucson, AZ, with 20 mL of cyclohexane and added 25.76 g of AmbersorbTM 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, to absorb the liquid. The cyclohexane evaporated to yield 34.7 g of the loaded AmbersorbTM beads.

LIXTM-1010 sorbs zirconium moderately from acid-dissolved sludge solution, but with slow sorption kinetics. It sorbs americium and uranium at useful levels from acidified sludge solution. Because the K_d values for americium sorption are much higher than those for cerium or yttrium, a trivalent actinide/lanthanide group separation from this solution may be achievable. Yttrium and strontium are sorbed with double-digit K_d values from alkaline supernate solution.

Table 60. LIXTM-1010: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	K _d Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.8	0.9	0.6
	Cs	<0.1	0.3	0.1
	Sr	<0.1	0.2	0.1
	Tc	1.8	2.7	4.0
	Y	1.1	0.5	0.4
	Cr	0.8	0.8	0.7
	Co	0.4	0.1	0.2
	Fe	0.4	0.3	0.5
	Mn	<0.1	0.2	0.1
	Zn	<0.1	0.4	0.2
	Zr	3.6	10	25
	U	0.1	<0.1	0.5
	Pu	0.8	0.7	0.9
	Am	0.1	0.1	0.1
Acidified Supernate	Ce	0.5	1.5	1.7
	Cs	<0.1	<0.1	0.2
	Sr	0.7	0.7	0.4
	Tc	1.0	1.7	3.0
	Y	1.0	1.2	1.3
	Cr	0.3	0.6	0.6
	Co	1.0	0.9	0.6
	Fe	<0.1	0.1	<0.1
	Mn	4.9	5.7	5.3
	Zn	3.6	4.0	4.0
	Zr	0.1	0.8	0.5
	U	4.3	7.1	15
	Pu	0.1	<0.1	0.1
	Am	10	27	64
Alkaline Supernate	Ce	3.0	5.0	5.0
	Cs	<0.1	<0.1	<0.1
	Sr	4.4	11	17
	Tc	0.2	0.3	0.4
	Y	4.4	13	33
	Cr	<0.1	0.2	0.3
	Co	<0.1	0.2	0.5
	Fe	2.9	6.0	7.8
	Mn	0.2	0.3	0.7
	Zn	<0.1	0.1	0.2
	Zr	0.7	1.7	3.0
	U	0.2	0.4	0.5
	Am	<0.1	<0.1	<0.1

b. LIXTM-54. We diluted 10 mL of LIXTM-54 (a beta diketone), obtained from Henkel Corporation, Tucson, AZ, with 20 mL of cyclohexane and added 26.80 g of AmbersorbTM 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, to absorb the liquid. The cyclohexane evaporated to yield 34.6 g of the loaded AmbersorbTM beads.

LIXTM-54 sorbs zirconium slightly from acid-dissolved sludge solution. From acidified supernate solution, the sorption of americium is significantly greater

than that of the lanthanides, suggesting that an efficient trivalent actinide/lanthanide group separation is possible. Uranium, iron, manganese, plutonium, and technetium are weakly to moderately sorbed from this solution.

From alkaline supernate solution, this extractant sorbs iron, strontium, yttrium, and manganese at useful levels. Because the K_d value for yttrium is significantly higher than that for cerium, this extractant might be useful for separating these two elements.

Table 61. LIXTM-54: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	K _d Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.7	0.8	0.8
	Cs	0.5	0.5	0.3
	Sr	0.5	0.3	0.2
	Tc	0.5	0.5	0.5
	Y	0.7	0.6	0.6
	Cr	0.8	1.0	0.8
	Co	0.9	0.4	0.5
	Fe	0.7	0.3	0.4
	Mn	0.3	0.2	0.2
	Zn	0.5	0.3	0.2
	Zr	1.4	1.7	3.4
	U	<0.1	0.1	0.1
	Pu	0.5	0.1	0.1
	Am	0.3	0.2	0.1
Acidified Supernate	Ce	<0.1	0.4	0.4
	Cs	<0.1	0.3	0.1
	Sr	0.8	0.3	0.6
	Tc	1.4	2.8	4.1
	Y	0.4	0.1	0.3
	Cr	0.5	0.3	0.7
	Co	0.5	1.0	0.9
	Fe	2.9	3.4	4.7
	Mn	2.4	2.1	2.6
	Zn	0.4	0.3	0.6
	Zr	0.1	0.3	0.4
	U	11	12	12
	Pu	2.2	2.8	3.0
	Am	34	32	30
Alkaline Supernate	Ce	2.3	2.5	2.9
	Cs	<0.1	<0.1	<0.1
	Sr	37	67	84
	Tc	<0.1	<0.1	0.2
	Y	9.3	24	56
	Cr	<0.1	<0.1	0.2
	Co	0.3	0.6	1.2
	Fe	41	72	135
	Mn	1.1	2.5	14
	Zn	1.8	1.5	1.1
	Zr	1.2	1.5	1.7
	U	<0.1	0.3	0.5
	Am	<0.1	<0.1	7.4

c. **LIXTM-84.** We diluted 10 mL of LIXTM-84 (a ketoxime), obtained from Henkel Corporation, Tucson, AZ, with 20 mL of cyclohexane and added 26.13 g of AmbersorbTM 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, to absorb the liquid. The cyclohexane evaporated to yield 34.8 g of the loaded AmbersorbTM beads.

LIXTM-84 sorbs none of the 14 elements significantly from acid-dissolved sludge or acidified supernate solutions. From alkaline supernate solution, it sorbs iron, yttrium, and strontium with double-digit Kd values.

Table 62. LIXTM-84: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.7	0.7	0.9
	Cs	0.4	0.1	0.4
	Sr	<0.1	0.3	0.1
	Tc	0.7	1.2	1.7
	Y	0.7	0.6	0.8
	Cr	0.4	0.7	0.8
	Co	0.6	1.0	0.7
	Fe	1.0	0.5	0.8
	Mn	0.9	0.3	0.5
	Zn	0.6	0.2	0.3
	Zr	0.8	1.4	1.8
	U	<0.1	0.3	0.5
	Pu	0.6	0.4	0.3
	Am	0.7	0.2	0.2
Acidified Supernate	Ce	0.9	0.4	0.5
	Cs	<0.1	0.4	0.2
	Sr	0.5	0.4	0.6
	Tc	0.2	0.7	0.7
	Y	0.2	0.4	0.4
	Cr	1.0	1.3	1.3
	Co	0.8	0.8	1.1
	Fe	0.3	0.6	0.5
	Mn	0.9	0.9	0.6
	Zn	0.6	0.4	0.2
	Zr	<0.1	<0.1	0.4
	U	0.8	0.8	0.7
	Pu	0.7	0.5	0.4
	Am	<0.1	<0.1	<0.1
Alkaline Supernate	Ce	1.4	4.9	4.9
	Cs	0.2	0.1	0.2
	Sr	4.5	10	11
	Tc	<0.1	0.2	<0.1
	Y	3.5	11	18
	Cr	0.2	0.2	0.1
	Co	0.6	1.0	1.6
	Fe	36	50	67
	Mn	3.3	3.0	4.6
	Zn	2.3	23.1	3.2
	Zr	1.3	1.8	2.0
	U	4.9	3.7	1.7
	Am	<0.1	<0.1	<0.1

d. **LIXTM-26.** We diluted 10 mL of LIXTM-26 (8-hydroxyquinoline) with 20 mL of cyclohexane and added 26.90 g of AmbersorbTM 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, to absorb the liquid. The cyclohexane evaporated to yield 37.1 g of the loaded AmbersorbTM beads.

LIXTM-26 sorbs plutonium moderately and uranium and technetium slightly from acid-dissolved sludge solu-

tion. It sorbs technetium, cerium, americium, and uranium at useful levels from alkaline supernate solution. Because the K_d value for cerium is significantly higher than that for yttrium, this extractant is a candidate for separating these two elements. From alkaline supernate solution, it sorbs only technetium with double-digit K_d values.

Table 63. LIXTM-26: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	K _d Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.4	0.5	0.4
	Cs	0.4	0.5	0.2
	Sr	0.7	0.4	0.5
	Tc	1.1	1.4	1.4
	Y	0.5	0.6	0.4
	Cr	0.5	0.6	0.5
	Co	0.4	0.4	0.5
	Fe	0.3	0.6	0.5
	Mn	<0.1	<0.1	<0.1
	Zn	0.5	0.4	0.3
	Zr	0.6	0.6	0.7
	U	2.0	2.7	3.4
	Pu	3.9	7.9	15
	Am	0.4	0.5	0.4
Acidified Supernate	Ce	32	40	42
	Cs	<0.1	<0.1	<0.1
	Sr	0.6	0.7	0.6
	Tc	54	112	190
	Y	4.1	4.7	4.9
	Cr	<0.1	0.2	0.3
	Co	1.3	1.1	1.1
	Fe	0.3	0.3	0.3
	Mn	<0.1	<0.1	0.1
	Zn	0.3	0.2	0.1
	Zr	0.8	0.9	0.7
	U	12	21	24
	Pu	0.2	0.1	0.2
	Am	24	33	30
Alkaline Supernate	Ce	2.5	2.7	3.6
	Cs	<0.1	<0.1	<0.1
	Sr	2.1	3.4	5.4
	Tc	21	23	22
	Y	2.6	3.6	4.2
	Cr	0.2	0.2	0.4
	Co	<0.1	<0.1	<0.1
	Fe	0.9	0.8	0.8
	Mn	0.8	0.3	0.3
	Zn	1.1	0.6	0.5
	Zr	0.4	0.7	0.8
	U	1.0	0.7	0.7
	Am	<0.1	<0.1	<0.1

e. **Cyanex™ 923.** We diluted 10 mL of Cyanex™ 923 (trialkylphosphine oxide), obtained from American Cyanamid Company, Wayne, NJ, with 20 mL of cyclohexane and added 26.83 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, to absorb the liquid. The cyclohexane evaporated to yield 36.8 g of the loaded Ambersorb™ beads.

Cyanex™ 923 sorbs plutonium, zirconium, and technetium somewhat from acid-dissolved sludge solu-

tion but with slow sorption kinetics. However, the plutonium Kd values are an order of magnitude higher when the plutonium concentration is 50-fold lower. This extractant sorbs technetium, lanthanides, americium, and uranium strongly from acidified supernate solution.

From alkaline supernate solution, Cyanex™ sorbs only technetium well.

Table 64. Cyanex™ 923: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge, 3 g Pu/L	Ce	0.5	0.2	0.5
	Cs	0.5	0.3	0.4
	Sr	0.8	0.5	0.5
	Tc	1.8	2.6	4.3
	Y	0.7	0.4	0.7
	Cr	0.8	0.6	0.9
	Co	0.5	0.2	0.3
	Fe	<0.1	0.4	0.6
	Mn	<0.1	<0.1	<0.1
	Zn	0.2	0.1	0.2
	Zr	2.0	3.1	7.6
	U	<0.1	1.0	1.9
	Pu	3.0	7.6	21
	Am	0.3	0.3	0.3
Acid-Dissolved Sludge, 60 mg Pu/L	U	2.7	6.5	14
	Pu	21	100	199
	Am	0.4	0.4	0.4
Acidified Supernate	Ce	744	987	1596
	Cs	0.8	0.5	0.4
	Sr	0.8	0.5	0.6
	Tc	300	551	582
	Y	1078	2014	2981
	Cr	<0.1	<0.1	0.3
	Co	0.6	0.7	0.7
	Fe	<0.1	<0.1	<0.1
	Mn	0.4	0.9	0.7
	Zn	2.9	4.4	4.3
	Zr	0.9	0.4	0.8
	U	122	233	356
	Pu	1.4	1.9	2.0
	Am	538	751	802
Alkaline Supernate	Ce	1.8	3.8	4.5
	Cs	<0.1	<0.1	<0.1
	Sr	1.6	2.6	3.8
	Tc	80	116	110
	Y	1.9	2.9	4.1
	Cr	<0.1	0.2	0.2
	Co	<0.1	0.3	0.1
	Fe	0.3	0.4	0.7
	Mn	0.2	0.4	0.7
	Zn	<0.1	0.3	0.2
	Zr	0.2	0.6	0.6
	U	<0.1	0.4	0.6
	Am	<0.1	<0.1	<0.1

f. Cyanex™ 272. We diluted 10 mL of Cyanex™ 272 (trimethylpentylphosphoric acid), obtained from American Cyanamid Company, Wayne, NJ, with 20 mL of cyclohexane and added 26.49 g of Amborsorb™ 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, to absorb the liquid. The cyclohexane evaporated to yield 37.1 g of the loaded Amborsorb™ beads.

Cyanex™ 272 sorbs zirconium strongly and selectively from acid-dissolved sludge solution, although the sorption kinetics are slow. It sorbs uranium selectively at a useful level from acidified supernate solution. However, it sorbs none of the 14 elements studied at even double-digit Kd values from alkaline supernate solution.

Table 65. Cyanex™ 272: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.4	0.2	0.5
	Cs	0.3	0.2	0.3
	Sr	0.5	0.2	0.4
	Tc	0.4	0.6	0.7
	Y	0.8	0.7	0.7
	Cr	0.5	0.6	0.8
	Co	0.5	0.4	0.4
	Fe	<0.1	0.3	0.3
	Mn	<0.1	<0.1	<0.1
	Zn	0.1	0.3	0.2
	Zr	8.0	32	199
	U	0.3	1.4	1.4
	Pu	0.9	1.3	2.8
	Am	<0.1	0.2	0.1
Acidified Supernate	Ce	0.1	0.5	0.2
	Cs	0.4	0.1	0.1
	Sr	0.9	0.6	0.9
	Tc	0.5	0.3	0.5
	Y	0.8	1.0	1.1
	Cr	<0.1	0.7	0.7
	Co	0.8	0.7	0.7
	Fe	0.5	0.6	0.6
	Mn	<0.1	<0.1	<0.1
	Zn	1.1	1.3	1.6
	Zr	0.5	0.7	0.6
	U	23	41	58
	Pu	0.2	0.1	0.3
	Am	1.2	1.1	1.3
Alkaline Supernate	Ce	0.5	2.9	3.6
	Cs	<0.1	<0.1	0.3
	Sr	4.0	6.3	8.5
	Tc	0.2	0.4	0.7
	Y	1.4	2.1	3.2
	Cr	<0.1	0.2	0.4
	Co	<0.1	<0.1	<0.1
	Fe	0.5	0.8	1.6
	Mn	<0.1	<0.1	0.2
	Zn	0.3	0.5	0.3
	Zr	0.4	0.6	1.2
	U	<0.1	0.2	0.5
	Am	<0.1	<0.1	<0.1

g. DHDECMP. We diluted 10 mL of DHDECMP (dihexyl-N,N-diethylcarbamoylmethylphosphonate), obtained from Occidental Chemical Corporation, Specialty Products Division, Niagara Falls, NY, with 20 mL of cyclohexane and added 27.99 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, to absorb the liquid. The cyclohexane evaporated to yield 39.5 g of the loaded Ambersorb™ beads.

DHDECMP sorbs only plutonium at a useful level from acid-dissolved sludge solution. It sorbs technetium, cerium, americium, and uranium well from acidified supernate solution. A significant separation factor favoring cerium over yttrium also appears in this solution. It sorbs technetium at useful levels from alkaline supernate solution.

Table 66. DHDECMP: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.2	0.3	0.4
	Cs	0.4	0.3	0.4
	Sr	0.3	0.4	0.4
	Tc	0.7	1.0	1.6
	Y	0.5	1.0	0.6
	Cr	0.8	0.8	0.7
	Co	0.5	0.4	0.2
	Fe	0.2	0.3	0.3
	Mn	<0.1	<0.1	<0.1
	Zn	0.2	0.3	0.2
	Zr	0.9	0.6	0.9
	U	1.3	2.2	3.2
	Pu	4.4	8.2	15
	Am	0.4	0.6	0.4
Acidified Supernate	Ce	26	45	51
	Cs	<0.1	<0.1	<0.1
	Sr	0.5	0.6	0.7
	Tc	43	112	222
	Y	3.4	5.1	5.8
	Cr	0.3	0.2	0.6
	Co	0.8	0.9	1.1
	Fe	<0.1	<0.1	<0.1
	Mn	0.6	0.5	0.4
	Zn	0.7	0.4	0.5
	Zr	<0.1	0.5	0.8
	U	22	31	33
	Pu	0.4	0.3	0.4
	Am	25	34	35
Alkaline Supernate	Ce	3.7	5.2	4.7
	Cs	<0.1	<0.1	<0.1
	Sr	1.6	3.4	5.3
	Tc	21	23	21
	Y	2.5	3.9	4.2
	Cr	0.2	0.2	0.3
	Co	0.1	<0.1	<0.1
	Fe	0.5	0.6	0.6
	Mn	<0.1	0.2	0.1
	Zn	0.3	0.3	0.2
	Zr	0.7	0.8	1.1
	U	0.3	0.4	0.5
	Am	<0.1	<0.1	<0.1

h. DHDECMP-DIPB. We diluted 10 mL of DHDECMP, obtained from Occidental Chemical Corporation, Specialty Products Division, Niagara Falls, NY, with 10 mL of DIPB (diisopropylbenzene) and 30 ml of cyclohexane and added 48.45 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas Co.,

Philadelphia, PA, to absorb the liquid. The cyclohexane evaporated to yield 65.3 g of the loaded Ambersorb™ beads.

As expected, the sorption patterns are similar to, but somewhat lower than, those observed with undiluted DHDECMP.

Table 67. DHDECMP-DIPB: Distribution of 14 Elements from Three Simulant Solutions for Hanford HLW 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	<0.1	0.4	0.6
	Cs	0.1	<0.1	0.2
	Sr	0.2	0.1	0.4
	Tc	0.6	1.1	1.5
	Y	0.3	0.4	0.6
	Cr	0.5	0.7	0.9
	Co	0.1	0.4	0.5
	Fe	0.3	0.5	0.3
	Mn	<0.1	<0.1	<0.1
	Zn	0.3	0.5	0.2
	Zr	0.4	0.8	1.0
	U	1.2	2.3	2.7
	Pu	2.9	5.5	10
	Am	0.4	0.6	0.3
Acidified Supernate	Ce	18	28	28
	Cs	0.1	<0.1	0.2
	Sr	0.5	0.7	0.4
	Tc	27	49	62
	Y	2.9	3.3	3.1
	Cr	0.6	0.5	0.5
	Co	0.6	0.9	0.6
	Fe	0.1	0.3	0.4
	Mn	<0.1	0.3	0.2
	Zn	0.2	0.3	0.1
	Zr	0.4	0.5	0.5
	U	9.3	16	18
	Pu	0.7	0.6	0.4
	Am	14	21	19
Alkaline Supernate	Ce	1.3	2.4	2.6
	Cs	<0.1	<0.1	<0.1
	Sr	2.3	4.0	5.9
	Tc	14	14	13
	Y	2.2	3.5	4.4
	Cr	0.2	0.3	0.4
	Co	<0.1	0.1	<0.1
	Fe	0.8	1.4	2.3
	Mn	<0.1	0.2	0.4
	Zn	0.5	0.7	0.8
	Zr	0.8	1.4	1.8
	U	0.1	0.5	0.8
	Am	<0.1	<0.1	<0.1

i. **CMPO-DIPB.** We diluted 10 mL of CMPO (octylphenyl-N,N-diisobutylcarbamoylmethylphosphine oxide), obtained from M&T Chemicals, Inc., Rahway, NJ, with 10 mL of DIPB (diisopropylbenzene) and 30 mL of cyclohexane and added 46.83 g of Amborsorb™ 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, to absorb the liquid. The cyclohexane evaporated to yield 64.1 g of the loaded Amborsorb™ beads.

CMPO-DIPB sorbs none of the 14 elements at useful levels from acid-dissolved sludge solution. It sorbs technetium, cerium, americium, uranium, and yttrium well from acidified supernate solution, although the sorption kinetics are slow. No elements offer even double-digit Kd values for sorption from alkaline supernate solution.

Table 68. CMPO-DIPB: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.3	0.3	0.6
	Cs	0.5	0.2	0.3
	Sr	0.5	0.4	0.3
	Tc	0.6	1.1	2.2
	Y	0.5	0.6	0.5
	Cr	0.7	0.8	0.9
	Co	0.2	0.1	0.1
	Fe	0.6	0.6	0.5
	Mn	<0.1	<0.1	<0.1
	Zn	0.4	0.3	0.3
	Zr	0.8	0.8	1.4
	U	0.4	0.8	1.4
	Pu	0.4	0.4	0.7
	Am	0.4	0.5	0.5
Acidified Supernate	Ce	78	370	499
	Cs	0.8	0.3	0.3
	Sr	<0.1	0.2	0.3
	Tc	41	111	196
	Y	15	45	89
	Cr	0.8	0.7	0.5
	Co	0.1	1.0	0.8
	Fe	<0.1	<0.1	0.2
	Mn	1.6	1.6	2.1
	Zn	1.0	0.4	0.5
	Zr	1.1	0.8	0.8
	U	49	183	291
	Pu	0.8	0.5	1.0
	Am	49	355	472
Alkaline Supernate	Ce	0.4	1.0	1.3
	Cs	0.2	<0.1	<0.1
	Sr	1.9	3.4	5.0
	Tc	4.5	6.8	7.6
	Y	1.5	3.0	4.8
	Cr	0.4	0.5	0.5
	Co	<0.1	0.1	0.2
	Fe	0.6	0.9	1.6
	Mn	<0.1	<0.1	0.2
	Zn	0.5	0.6	0.7
	Zr	0.7	1.2	1.8
	U	0.4	0.6	1.0
	Am	<0.1	<0.1	<0.1

j. Aliquat™ 336. We diluted 5.00 g of Aliquat™ 336 (tricaprylmethylammonium chloride), obtained from Aldrich Chemical Co., with 10 mL of hexane and added 17.32 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, to absorb the liquid. The cyclohexane evaporated to yield 26.2 g of the loaded Ambersorb™ beads.

Aliquat™ 336 sorbs plutonium moderately from acid-dissolved sludge solution and sorbs technetium strongly and selectively from both acidified supernate and alkaline supernate solutions. The low Kd value for technetium sorption from acid-dissolved sludge solution indicates that this element might be recovered easily by eluting with nitric acid.

Table 69. Aliquat™ 336: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.4	0.6	0.6
	Cs	0.3	0.3	0.2
	Sr	0.4	0.3	0.3
	Tc	0.7	0.8	1.0
	Y	0.3	0.3	0.2
	Cr	<0.1	<0.1	0.1
	Co	0.6	0.3	<0.1
	Fe	0.2	0.3	0.5
	Mn	<0.1	<0.1	<0.1
	Zn	0.3	0.1	0.1
	Zr	0.8	0.4	0.6
	U	0.5	1.1	1.7
	Pu	2.3	5.7	14
	Am	0.2	0.2	0.2
Acidified Supernate	Ce	1.0	1.6	2.0
	Cs	1.8	2.2	2.1
	Sr	0.3	0.2	0.3
	Tc	295	444	572
	Y	0.3	0.4	0.2
	Cr	0.1	0.1	0.1
	Co	0.2	0.1	<0.1
	Fe	0.2	0.3	0.3
	Mn	0.3	0.3	0.3
	Zn	<0.1	<0.1	<0.1
	Zr	<0.1	0.1	0.1
	U	3.2	5.5	7.9
	Pu	0.1	0.2	0.4
	Am	0.4	0.6	0.6
Alkaline Supernate	Ce	3.7	4.1	5.1
	Cs	<0.1	<0.1	<0.1
	Sr	6.8	7.1	8.1
	Tc	417	614	651
	Y	5.2	5.6	6.6
	Cr	0.2	0.4	0.7
	Co	<0.1	<0.1	0.2
	Fe	0.5	1.1	1.6
	Mn	0.4	0.6	1.1
	Zn	0.2	0.4	0.5
	Zr	0.8	1.0	1.6
	U	0.3	0.5	0.7
	Am	<0.1	<0.1	<0.1

k. Czech Cobalt Dicarbollide. We dissolved 93.6 mg of cobalt dicarbollide, prepared in the Czech Republic, in 2.323 g of nitrobenzene and 1 mL of ethanol, and added 2.628 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, to absorb the liquid. The ethanol evaporated to yield 4.48 g of the loaded, dry-appearing Ambersorb™ beads.

This extractant sorbs technetium slightly, with slow sorption kinetics, from acid-dissolved sludge and acidified supernate solution. It was not tested with alkaline supernate solution.

Table 70. Czech Cobalt Dicarbollide: Distribution of 14 Elements from Two Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.5	0.1	0.1
	Cs	<0.1	<0.1	0.3
	Sr	0.6	0.5	0.9
	Tc	0.9	2.9	7.0
	Y	0.4	0.4	0.5
	Cr	0.2	0.4	0.4
	Co	0.2	0.3	0.3
	Fe	<0.1	<0.1	<0.1
	Mn	0.2	0.7	0.6
	Zn	0.3	0.3	0.4
	Zr	0.5	0.7	0.8
	U	1.2	0.9	1.1
	Pu	<0.1	0.3	0.4
	Am	0.2	0.3	0.3
Acidified Supernate	Ce	0.7	1.4	1.2
	Cs	0.8	1.0	0.8
	Sr	<0.1	0.5	0.7
	Tc	0.6	3.8	13
	Y	<0.1	<0.1	<0.1
	Cr	0.5	0.9	1.1
	Co	0.4	0.8	0.7
	Fe	0.2	<0.1	0.2
	Mn	0.2	0.3	0.2
	Zn	0.5	0.3	0.2
	Zr	0.2	0.7	1.0
	U	0.9	0.9	0.8
	Pu	0.1	<0.1	<0.1
	Am	0.2	0.1	0.1

I. Los Alamos Cobalt Dicarbollide. We dissolved 98.1 mg of cobalt dicarbollide, prepared by the Inorganic and Structural Chemistry group (CST-3) at Los Alamos, in 1.816 g of nitrobenzene and 1 mL of ethanol. We then added 2.270 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, to absorb the

liquid. The ethanol evaporated to yield 3.64 g of the loaded, dry-appearing Ambersorb™ beads.

This extractant sorbs technetium slightly, with slow sorption kinetics, from acid-dissolved sludge and acidified supernate solution. It was not tested with alkaline supernate solution.

Table 71. Los Alamos Cobalt Dicarbollide: Distribution of 14 Elements from Two Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	<0.1	<0.1	<0.1
	Cs	1.5	1.8	1.2
	Sr	0.6	0.5	0.6
	Tc	1.6	3.4	7.7
	Y	0.6	0.2	0.2
	Cr	0.1	<0.1	0.1
	Co	0.2	0.5	0.2
	Fe	0.1	<0.1	<0.1
	Mn	<0.1	0.2	0.3
	Zn	0.2	0.3	0.3
	Zr	0.4	0.4	0.7
	U	0.7	0.7	0.5
	Pu	<0.1	<0.1	0.2
	Am	0.1	0.1	0.2
Acidified Supernate	Ce	0.9	0.8	0.6
	Cs	3.1	2.0	1.2
	Sr	0.6	0.5	0.2
	Tc	1.9	7.2	44
	Y	<0.1	<0.1	<0.1
	Cr	0.8	1.2	0.6
	Co	0.6	1.0	0.5
	Fe	0.2	0.5	0.4
	Mn	0.2	0.1	0.1
	Zn	<0.1	0.1	0.1
	Zr	1.1	0.9	0.8
	U	0.5	0.9	0.9
	Pu	0.3	0.1	0.2
	Am	<0.1	0.1	0.1

7. Sandia 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 and Texas A&M University (a patent application has been filed), 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 used in this study 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 the various CST materials we evaluated is proprietary, we can provide only general information. SNL/CST 35, 48, 69, and 84 are developmental compositions that were prepared in relatively small quantities. As the development effort progressed, however, a baseline composition was selected for larger-scale synthesis, characterization, and evaluation of properties. SNL/CST 111, 120, 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 preparation has been demonstrated at a pilot-plant scale. The CST synthesis procedures currently are being scaled up for commercial production by UOP Corporation, Des Plaines, IL, Sandia'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.

During earlier screening studies conducted at Sandia, the selectivities of these materials for removing cesium were determined. Using 100 ppm of cesium in a simulant of 5.7 M Na⁺ and 0.6 M OH⁻, the cesium selectivities were SNL/CST 35 = SNL/CST 120 < SNL/CST 48 < SNL/CST 68 < SNL/CST 69 < SNL/CST 84 < SNL/CST 149 < SNL/CST 111 < SNL/CST 141.

As discussed in section II.D, unusually large variations in K_d values obtained with CST absorbers may indicate that submicrometer-sized CST particles at times contaminated the solution taken for gamma spectrometric assay. Inadvertent introduction of particles into the assay solution would, however, always cause us to understate the actual K_d values for the sorption of cesium from solution. Our reported K_d values for cesium sorption on the CST materials, therefore, represent minimum values.

In a few cases, the K_d values for non-cesium elements decrease with increasing contact time. Sandia personnel who prepared the CSTs suggested that this could be caused by a small amount of an impurity that preferentially sorbs certain non-cesium elements. However, because the proposed impurity slowly dissolves out of the crystalline material, some of the initially sorbed non-cesium element would be released, causing the K_d value to decrease with increased contact time. Displacement by a more strongly sorbed, but kinetically slower, ionic species is another possibility.

a. SNL/CST 35 Crystalline Silico-Titanate. This absorber strongly and quite selectively sorbs cesium from acid-dissolved sludge solution; only zirconium is cosorbed to a significant extent. Cesium sorbs even more strongly from acidified supernate solution, although uranium also sorbs at useful levels from this solution.

SNL/CST 35 sorbs cesium well and strontium strongly from alkaline supernate solution, and many other elements are cosorbed at moderate to high levels. The fact that only cesium is strongly sorbed from acid-dissolved sludge solution indicates that most non-cesium elements sorbed from alkaline solution could subsequently be eluted with nitric acid, leaving cesium selectively sorbed.

Table 72. SNL/CST 35: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.6	0.7	0.7
	Cs	4485	1011	3416
	Sr	<0.1	<0.1	<0.1
	Tc	0.9	0.5	0.5
	Y	0.3	0.4	0.4
	Cr	0.4	0.4	0.4
	Co	0.6	0.7	0.5
	Fe	0.8	0.5	0.8
	Mn	<0.1	<0.1	0.1
	Zn	0.5	0.3	0.3
	Zr	8.3	26	76
	U	0.9	0.5	0.5
	Pu	2.4	2.6	2.4
	Am	<0.1	0.1	<0.1
Acidified Supernate	Ce	2.9	2.1	6.7
	Cs	>13K	>12K	4195
	Sr	1.6	1.3	3.3
	Tc	1.2	1.7	5.6
	Y	2.5	1.7	0.9
	Cr	1.1	1.9	9.6
	Co	0.7	0.2	0.2
	Fe	0.9	2.2	2.5
	Mn	0.5	0.1	0.1
	Zn	1.5	1.1	0.9
	Zr	0.5	1.1	3.6
	U	25	45	54
	Pu	0.8	1.5	1.5
	Am	1.3	1.1	0.7
Alkaline Supernate	Ce	153	>300	191
	Cs	165	277	385
	Sr	>4200	>4400	>4600
	Tc	0.6	0.2	0.2
	Y	8.9	17	37
	Cr	0.5	0.2	0.2
	Co	0.5	0.5	0.5
	Fe	55	113	181
	Mn	95	375	635
	Zn	6.9	9.0	10
	Zr	113	280	504
	U	31	56	72
	Am	63	123	138

b. SNL/CST 48 Crystalline Silico-Titanate. This absorber strongly sorbs cesium from acid-dissolved sludge solution; only zirconium is cosorbed to a significant extent. It sorbs cesium even more strongly from acidified supernate

solution, although uranium, zinc, cerium and americium are cosorbed with double-digit Kd values. SNL/CST 48 was not studied with alkaline supernate solution.

Table 73. SNL/CST 48: Distribution of 14 Elements from Two Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.6	0.4	0.6
	Cs	794	758	1180
	Sr	<0.1	<0.1	<0.1
	Tc	0.8	0.5	0.6
	Y	0.7	0.4	0.5
	Cr	0.3	0.3	0.3
	Co	0.9	0.4	0.6
	Fe	0.7	1.0	1.0
	Mn	<0.1	<0.1	<0.1
	Zn	0.3	0.2	0.2
	Zr	15	49	51
	U	1.5	1.1	1.2
	Pu	2.6	3.2	4.4
	Am	<0.1	0.2	0.1
Acidified Supernate	Ce	6.4	8.6	17
	Cs	3951	2820	1030
	Sr	1.8	1.2	1.2
	Tc	1.6	1.5	2.0
	Y	6.0	7.0	5.3
	Cr	1.3	1.7	6.0
	Co	4.5	4.6	2.0
	Fe	1.2	1.5	1.8
	Mn	2.0	1.7	1.2
	Zn	23	32	34
	Zr	0.7	0.8	0.8
	U	16	30	37
	Pu	<0.1	<0.1	0.1
	Am	9.4	13	15

c. *SNL/CST 68 Crystalline Silico-Titanate*. This absorber strongly sorbs cesium from acid-dissolved sludge solution; only zirconium is cosorbed at useful levels. It sorbs cesium even more strongly from acidified supernate solution, although uranium, zinc, cerium, and americium are cosorbed

with double-digit Kd values. The decreasing Kd values for cesium may be real, or they may reflect incomplete filtration of the submicrometer-sized absorber particles from the assay solutions. SNL/CST 68 was not studied with alkaline supernate solution.

Table 74. SNL/CST 68: Distribution of 14 Elements from Two Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.1	0.4	0.7
	Cs	688	2308	1049
	Sr	<0.1	<0.1	<0.1
	Tc	0.6	0.4	0.8
	Y	0.5	0.2	0.3
	Cr	0.1	0.4	0.4
	Co	0.5	0.3	0.5
	Fe	0.7	0.7	0.9
	Mn	<0.1	0.3	0.1
	Zn	0.2	0.4	0.3
	Zr	31	119	103
	U	1.1	1.2	1.0
	Pu	3.9	4.4	5.3
	Am	0.4	0.1	0.1
Acidified Supernate	Ce	8.6	16	38
	Cs	4072	2453	722
	Sr	1.7	1.6	1.3
	Tc	1.5	1.8	1.7
	Y	7.4	9.7	7.5
	Cr	1.7	2.4	6.6
	Co	5.3	5.4	2.3
	Fe	0.9	1.7	2.2
	Mn	1.9	1.9	1.6
	Zn	33	44	43
	Zr	1.0	1.2	0.9
	U	23	38	45
	Pu	0.6	0.5	0.3
	Am	15	20	20

d. *SNL/CST 69 Crystalline Silico-Titanate.* This absorber strongly sorbs cesium from acid-dissolved sludge solution; only zirconium is cosorbed at useful levels. It sorbs cesium even more strongly from acidified supernate solution, although uranium, chromium, cerium, and technetium are

cosorbed with double-digit Kd values. Sorption of cesium from alkaline supernate solution is much lower, whereas strontium, cerium, manganese, iron, zirconium, and americium are strongly sorbed from this solution.

Table 75. SNL/CST 69: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.5	0.6	0.7
	Cs	2884	2279	3252
	Sr	<0.1	<0.1	<0.1
	Tc	1.1	0.8	1.1
	Y	0.4	0.4	0.2
	Cr	0.6	0.7	0.6
	Co	0.4	0.4	0.4
	Fe	0.4	0.6	0.7
	Mn	<0.1	<0.1	<0.1
	Zn	0.4	0.4	0.4
	Zr	91	—	115
	U	0.7	1.1	1.2
	Pu	3.4	3.8	4.5
	Am	0.6	0.3	0.3
Acidified Supernate	Ce	4.0	4.2	14
	Cs	>8K	>10K	>20K
	Sr	3.4	2.9	6.6
	Tc	4.9	6.7	12
	Y	1.8	1.0	1.6
	Cr	2.8	3.8	14
	Co	<0.1	<0.1	<0.1
	Fe	2.2	2.0	2.2
	Mn	0.4	0.4	0.4
	Zn	2.0	2.9	3.7
	Zr	1.7	2.5	5.5
	U	21	33	43
	Pu	0.7	0.7	1.0
	Am	2.5	3.0	3.3
Alkaline Supernate	Ce	205	>290	298
	Cs	10	13	16
	Sr	3839	1332	1659
	Tc	0.4	<0.1	1.3
	Y	16	26	38
	Cr	<0.1	<0.1	1.2
	Co	0.6	0.4	1.0
	Fe	45	80	145
	Mn	50	101	167
	Zn	3.8	4.9	5.4
	Zr	32	87	141
	U	6.7	9.3	10
	Am	24	67	135

e. *SNL/CST 84 Crystalline Silico-Titanate*. This absorber strongly sorbs cesium from acid-dissolved sludge solution; only zirconium is cosorbed at useful levels. The fact that Kd values for zirconium sorption from acid-dissolved sludge solution decrease, while those for cesium increase, may reflect slow dissolution of an amorphous phase that preferentially sorbs zirconium.

This absorber sorbs cesium well from acidified supernate solution, although uranium and cerium are cosorbed with double-digit values. SNL/CST 84 was not studied with alkaline supernate solution.

Table 76. SNL/CST 84: Distribution of 14 Elements from Two Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	0.4	0.1	0.5
	Cs	1849	>8K	>11K
	Sr	<0.1	<0.1	<0.1
	Tc	0.8	0.4	0.7
	Y	<0.1	0.1	0.2
	Cr	0.4	0.6	0.6
	Co	0.6	0.3	0.4
	Fe	0.4	0.2	0.4
	Mn	<0.1	0.1	<0.1
	Zn	0.4	0.3	0.2
	Zr	70	87	19
	U	0.6	0.9	0.5
	Pu	2.0	1.8	1.9
	Am	0.1	<0.1	<0.1
Acidified Supernate	Ce	3.5	4.8	14
	Cs	5484	3953	3098
	Sr	2.2	2.0	4.4
	Tc	1.5	1.9	4.6
	Y	1.3	1.1	1.1
	Cr	1.4	1.7	8.8
	Co	0.3	0.2	0.1
	Fe	0.6	1.2	1.4
	Mn	0.9	0.6	0.5
	Zn	1.0	1.4	2.1
	Zr	0.9	1.1	3.0
	U	13	19	22
	Pu	0.1	0.3	0.2
	Am	2.9	4.1	5.8

f. SNL/CST 111 Crystalline Silico-Titanate. This absorber strongly sorbs cesium from acid-dissolved sludge solution; only zirconium is cosorbed to a significant extent. It sorbs cesium well from acidified supernate solution, although americium, cerium, and uranium are cosorbed at useful levels. The decreasing K_d values for cesium sorption from basic solution may be real or may reflect incomplete filtration of the submicrometer-sized absorber particles from the assay solutions.

SNL/CST 111 strongly sorbs cesium and strontium from alkaline supernate solution, whereas many other elements are cosorbed at moderate to high levels. The fact that only cesium is strongly sorbed from acid-dissolved sludge solution indicates that most non-cesium elements sorbed from alkaline solution could subsequently be eluted with nitric acid, leaving cesium selectively sorbed.

Table 77. SNL/CST 111: Distribution of 14 Elements from Three Simulant Solutions for Hanford Tank 102-SY

Solution	Element	K _d Value for Specified Time		
		30 min	2 h	6 h
Acid-Dissolved Sludge	Ce	1.0	0.9	1.0
	Cs	3420	>5K	>5K
	Sr	0.6	0.4	0.5
	Tc	0.6	0.7	0.7
	Y	0.3	0.3	0.3
	Cr	1.0	1.1	1.2
	Co	<0.1	<0.1	<0.1
	Fe	0.6	0.6	0.7
	Mn	0.1	0.3	0.1
	Zn	0.8	0.6	0.6
	Zr	11	14	18
	U	0.7	1.3	1.5
	Pu	3.1	3.5	3.8
	Am	0.2	0.3	0.3
Acidified Supernate	Ce	17	32	57
	Cs	4939	2713	1864
	Sr	4.2	4.2	3.5
	Tc	1.5	1.8	1.2
	Y	4.4	4.7	4.8
	Cr	2.1	1.9	1.7
	Co	1.0	0.8	0.4
	Fe	0.6	1.6	1.9
	Mn	1.2	1.6	1.5
	Zn	2.3	3.2	5.1
	Zr	0.9	1.0	0.6
	U	15	21	25
	Pu	0.2	0.8	0.4
	Am	25	52	107
Alkaline Supernate	Ce	139	>300	>300
	Cs	2323	2708	3076
	Sr	4660	>4500	>4600
	Tc	<0.1	0.2	<0.1
	Y	13	16	24
	Cr	<0.1	<0.1	<0.1
	Co	0.2	0.4	0.4
	Fe	36	60	93
	Mn	52	109	225
	Zn	2.6	3.2	3.7
	Zr	83	85	68
	U	16	30	43
	Am	47	92	53

g. *SNL/CST 120 Crystalline Silico-Titanate*. This absorber sorbs strontium more strongly than cesium from alkaline supernate solution, although cesium also is strongly sorbed. Many other elements are cosorbed at useful levels from this solution.

Although SNL/CST 120 was not studied with acid-dissolved sludge or acidified supernate solutions, the fact that only cesium is strongly sorbed on most CSTs from acid-dissolved sludge solution suggests that most non-cesium elements sorbed from alkaline supernate solution could subsequently be eluted with nitric acid, leaving cesium selectively sorbed.

Table 78. SNL/CST 120: Distribution of 14 Elements from Alkaline Supernate Simulant Solution for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Alkaline Supernate	Ce	106	230	150
	Cs	570	786	898
	Sr	>4400	>4500	>4600
	Tc	<0.1	0.1	<0.1
	Y	8.3	12	21
	Cr	<0.1	<0.1	<0.1
	Co	0.1	0.5	0.2
	Fe	52	104	166
	Mn	24	117	215
	Zn	7.6	7.0	9.4
	Zr	147	283	449
	U	73	77	101
	Am	15	43	71

h. SNL/CST 141 Crystalline Silico-Titanate. This absorber sorbs strontium more strongly than cesium from alkaline supernate solution, especially for longer contact times, although cesium also is strongly sorbed. Many other elements are cosorbed at useful levels.

Although SNL/CST 141 was not studied with acid-dissolved sludge or acidified supernate solutions, the fact that only cesium is strongly sorbed on most CSTs from acid-dissolved sludge solution suggests that most non-cesium elements sorbed from alkaline solution could subsequently be eluted with nitric acid, leaving cesium selectively sorbed.

Table 79. SNL/CST 141: Distribution of 14 Elements from Alkaline Supernate Simulant Solution for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Alkaline Supernate	Ce	177	199	296
	Cs	2521	2521	2312
	Sr	2755	>4300	>4400
	Tc	<0.1	0.2	<0.1
	Y	13	16	22
	Cr	0.1	0.2	0.3
	Co	0.5	0.1	0.4
	Fe	37	63	89
	Mn	102	178	275
	Zn	0.8	1.0	1.1
	Zr	64	62	53
	U	16	28	37
	Am	54	41	20

i. *SNL/CST 149 Crystalline Silico-Titanate.* This absorber sorbs strontium more strongly than cesium from alkaline supernate solution, especially for longer contact times, although cesium also is strongly sorbed. Many other elements are cosorbed at useful levels.

Although SNL/CST 149 was not studied with acid-dissolved sludge or acidified supernate solutions, the

fact that only cesium is strongly sorbed on most CSTs from acid-dissolved sludge solution suggests that most non-cesium elements sorbed from alkaline supernate solution could subsequently be eluted with nitric acid, leaving cesium selectively sorbed.

Table 80. SNL/CST 149: Distribution of 14 Elements from Alkaline Supernate Simulant Solution for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Alkaline Supernate	Ce	797	948	701
	Cs	1866	2402	3084
	Sr	>9K	>9K	>9K
	Tc	1.5	1.5	1.4
	Y	81	77	104
	Cr	0.6	0.6	0.7
	Co	0.6	0.6	0.6
	Fe	37	58	94
	Mn	69	134	235
	Zn	0.9	1.2	1.6
	Zr	94	104	95
	U	15	27	39
	Am	12	11	12

j. *SNL/HTO Amorphous Hydrous TiO₂*. As expected, the behavior of hydrous titanium oxide is very different from that of the crystalline silico-titanates. With this absorber, cerium, americium, uranium, yttrium, and zinc all sorb with double-digit Kd values from acidified supernate solution.

From alkaline supernate solution, the sorption of cesium is very weak, whereas many other elements are sorbed very strongly. SNL/HTO absorber was not studied with acid-dissolved sludge solution.

Table 81. SNL/HTO: Distribution of 14 Elements from Two Simulant Solutions for Hanford Tank 102-SY

Solution	Element	Kd Value for Specified Time		
		30 min	2 h	6 h
Acidified Supernate	Ce	265	320	511
	Cs	10	8.9	8.5
	Sr	1.5	1.4	3.6
	Tc	1.3	1.7	4.3
	Y	53	59	52
	Cr	5.9	7.8	21
	Co	0.9	0.7	0.4
	Fe	2.2	3.1	3.9
	Mn	1.2	0.3	0.4
	Zn	18	18	19
	Zr	1.7	2.7	6.3
	U	52	69	90
	Pu	1.5	1.8	2.4
	Am	229	264	168
Alkaline Supernate	Ce	184	>280	>290
	Cs	1.5	1.4	1.4
	Sr	>4000	>4100	>4200
	Tc	<0.1	<0.1	<0.1
	Y	37	68	93
	Cr	<0.1	0.3	0.3
	Co	0.8	0.8	1.0
	Fe	4235	>7K	>26K
	Mn	1969	4777	>9K
	Zn	4625	>11K	>25K
	Zr	1037	2220	4276
	U	2127	>9K	>17K
	Am	200	510	779

IV. ELUTION CONSIDERATIONS

The purpose of this study was to evaluate a large number of candidate absorbers and identify those that show promise for sorbing specific elements from HLW stored in Hanford Tank 102-SY. Although elution was not a part of the experimental procedure, we recognize that elution of the sorbed species from the absorbers is essential if the selected absorbers are to be reused in a process application. We plan to investigate the elution characteristics of selected absorbers in a later phase of this study.

We can, however, offer some general comments about elution. Elution often can be achieved by acidity changes, oxidation state changes, complexation, or displacement. Because the present study reports K_d values for sorption from three simulant solutions that range from acidic to basic, it often indicates whether acidity changes might facilitate the elution of a given species. For example, the fact that most Sandia CSTs strongly sorb both strontium and cesium from alkaline solution, but only cesium from acidic solution, suggests that the cosorbed strontium might elute with nitric acid, which would leave cesium selectively sorbed on the CST.

For those elements in which only one oxidation state strongly sorbs on an absorber, conversion to a different oxidation state may achieve elution. In other cases, the sorbed species may form a strong complex with specific complexants, which can be used as eluting agents. Finally, sorbed species sometimes can be displaced by loading the absorber to capacity with another, more strongly sorbed, ion.

Because elution operations usually generate additional waste, we plan to emphasize waste minimization in the elution options we evaluate in later studies. One option worth considering is that of not eluting the sorbed species from the absorber. This option is attractive in the case of the absorbers developed by Sandia and Texas A&M because cesium appears to be strongly and irreversibly sorbed on crystalline silico-titanates. Moreover, silico-titanates provide an inorganic matrix that could be pressed into dense pellets suitable for long-term storage. In this case, elution may be unwise and unnecessary.

V. FUTURE STUDIES

This screening study met its objective of identifying specific absorbers that appear capable of partitioning targeted elements from Hanford Tank 102-SY. The best absorbers and promising new materials are being evaluated with simulant compositions that represent other

Hanford tanks, especially those scheduled to be processed first. The 14 elements for which we acquired sorption data in this study will be reviewed to determine whether some should be deleted and others added in future measurements. We plan to continue using radioactive tracers, which provide a rapid, reliable, and inexpensive way to obtain large amounts of distribution data.

Because even the best simulant solutions cannot accurately represent the contents of any HLW storage tank, we look forward to obtaining and testing solutions from the Hanford waste tanks. Only by testing actual 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 contents of the Hanford tanks vary greatly and that 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 solutions.

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 present and future studies should be determined (if such information is not already available) before these absorbers are considered for use in large-scale recovery processes.

VI. CONCLUSIONS

Our screening study of many absorbers from realistic simulants 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 that specifies which unwanted elements are most likely to compete for absorber sites. Based on our study, it appears that many of the separations required for processing HLW from Hanford Tank 102-SY, and perhaps other underground storage tanks as well, can be achieved using available absorbers and existing, proven technology.

A. Experimental Procedure

Radioactive tracers, as used in our study, provide a fast, reliable, and cost-effective way to obtain large amounts of distribution data.

Follow-on studies should measure the distributions of key elements from other Hanford waste tank compositions onto the most promising absorbers identified by this study.

B. Individual Absorbers

1. The performance of the 63 absorbers tested with these complex, high-salt media is often much different from the performance reported for similar absorbers tested in relatively clean systems.
 2. None of the tested absorbers sorbs strontium well from acid-dissolved sludge or acidified supernate solutions.
 3. Low-cost partitioning agents such as AliquatTM 336, CyanexTM 923, and ReillexTM HPQ often outperform other materials whose cost is many times higher.
 4. Certain extractants, such as LIX-1010 and LIX-54, sorb americium much better than cerium and yttrium from acidified supernate solution. This large difference in sorption suggests that a lanthanide/trivalent actinide group separation may be attainable. An earlier study⁵ estimated that, if the lanthanide elements could be eliminated from the trivalent actinide fraction before vitrification, 5000 fewer vitrified HLW logs would be required, with a consequent saving of approximately \$5 billion.
 5. Experimental anion exchange resins under development at Los Alamos, referred to as JSK resins in this report, offer major advantages over the best previously known resins for removing plutonium from HLW media. Development of these resins should continue until a commercial version is produced.
 6. The silico-titanate absorbers from Sandia show outstanding sorption of cesium from all three simulant solutions. Because the sorption of cesium on silico-titanates appears to be irreversible, this material should be considered for interim storage of radioactive waste, incorporation into HLW glass, or as a final waste form.
2. Measured Kd values for sorption of cobalt and zinc from acid-dissolved sludge solution are low on all absorbers. If there is need to remove these elements from similar acidic waste solutions, other absorbers or extractants must be identified or developed.
 3. Iron, manganese, and chromium show low Kd values for sorption from acidic solutions on most of the absorbers evaluated. Because these elements are present at significant concentrations in many Hanford waste tanks, however, even low Kd values could result in sufficiently high loadings on some absorbers to decrease their capacity for sorbing other elements. All reported Kd values reflect realistic competition from these major matrix elements and, therefore, reflect values that might be obtained with actual waste solutions.
 4. Elements for which good to excellent sorption from simulated acid-dissolved sludge has been demonstrated are cerium, cesium, technetium, zirconium, uranium, and plutonium. Elements that show low sorption from this solution are strontium, yttrium, chromium, cobalt, iron, manganese, zinc, and americium.
 5. Elements for which good to excellent sorption from acidified supernate solution has been demonstrated are cerium, cesium, technetium, yttrium, zinc, uranium, and americium. Elements that show less than desirable sorption from acidified supernate solution are strontium, chromium, cobalt, iron, manganese, zirconium, and plutonium.
 6. Elements for which good to excellent sorption from alkaline supernate simulant solution has been demonstrated are cerium, cesium, strontium, yttrium, zinc, iron, manganese, zirconium, uranium, and americium. Elements that show low to moderate sorption from alkaline supernate solution are chromium and cobalt.

C. Individual Elements

1. Measured Kd values for strontium are low on all absorbers for sorption from dissolved sludge and acidified supernate solutions. Because ⁹⁰Sr is a major biological hazard, near-term efforts should focus on identifying or developing suitable absorbers for removing strontium from acidic HLW solutions.

D. Elution

Although elution was not a part of our study, by measuring Kd values from acidic, slightly acidic, and basic solutions, we often provide a basis for predicting whether a change in acidity might elute a given element from a specific absorber.

For example, most CSTs strongly sorb both cesium and strontium from alkaline supernate solution. The fact that only cesium is sorbed strongly from acid-dissolved sludge solution, however, indicates that the strontium sorbed from alkaline supernate solution could be eluted with nitric acid, leaving cesium selectively sorbed.

VII. ACKNOWLEDGMENTS

This study was supported by the Hanford Tank Waste Remediation System (TWRS) program of DOE/Richland Operations Office; the TWRS Technology Development Program Office (TDPO) of Westinghouse Hanford Company; and the Hanford Program Office, EM-36, of the Office of Environmental Restoration and Waste Management, U.S. Department of Energy.

Clifford Mills of the Nuclear Materials Process Technology group (NMT-2) at Los Alamos designed the tip-filter system that allowed disposable hypodermic syringes to be successfully used as container-dispensers during our many hundreds of dynamic contact experiments.

Frank McGarvey of Sybron Chemical Co. provided samples of macroporous anion exchange resins with trimethyl, triethyl, tripropyl, and tributyl amine functional groups.

Jane Bibler of Westinghouse Savannah River Company provided the sample of SRS resorcinol/formaldehyde resin (batch BSC-187).

Dennis Fennelly of UOP Molecular Sieves provided samples of Ionsiv™ TIE-96 for evaluation.

Elmer Klavetter and Norman Brown of Sandia National Laboratories provided samples of crystalline silico-titanate (SNL/CST) absorbers and hydrous titanium oxide (SNL/HTO) absorber.

Ferdinand Sebesta, Department of Nuclear Chemistry, Czech Technical University, Prague, Czech Republic, prepared and provided samples of nine polyacrylonitrile-matrix composite absorbers for our evaluation.

Jerzy Narbutt, Department of Radiochemistry, Institute of Nuclear Chemistry and Technology, Warsaw, Poland, prepared and provided samples of two phenolsulfonic-formaldehyde-matrix composite absorbers for our evaluation.

Stephen Yarbrow and Gordon Jarvinen of the Nuclear Materials Process Technology group (NMT-2) at Los Alamos provided valuable advice and suggestions during numerous technical discussions.

Stephen Agnew of the Spectroscopy and Biochemistry group (CST-14) at Los Alamos provided much detailed tank composition data, based on reconstruction from historical records and many useful technical suggestions.

Norman Brown of Sandia National Laboratories provided valuable advice and suggestions during numerous technical discussions and also peer-reviewed this manuscript.

We especially appreciate the assistance and cooperation of many members of the Separations and Radiochemistry Group, the Nuclear Chemistry and Analysis Group, and the Medical Radioisotopes and Reactor Applications Group at Los Alamos National Laboratory.

VIII. REFERENCES

1. J. L. Ryan and E. J. Wheelwright, "Recovery and Purification of Plutonium by Anion Exchange," *Ind. Eng. Chem.* **51**(1), 60-65 (1959).
2. W. L. Poe, A. W. Joyce, and R. I. Martens, "Np-237 and Pu-238 Separation at the Savannah River Plant," *I&EC Proc. Design Devel.* **3**(4), 314-322 (1964).
3. J. A. Kelly, "Ion Exchange Process for Separating Americium and Curium from Irradiated Plutonium," Savannah River Laboratory report DP-1308 (1972).
4. S. L. Yarbrow, W. A. Punjak, S. B. Schreiber, S. L. Dunn, G. D. Jarvinen, S. F. Marsh, N. G. Pope, S. F. Agnew, E. Birnbaum, and K. W. Thomas, and E. A. Ortic, "Tank 102-SY Remediation Project—Flowsheet and Conceptual Design," Los Alamos National Laboratory report LA-12701-MS (January 1994).
5. J. L. Straalsund, J. L. Swanson, E. G. Baker, J. J. Holmes, E. O. Jones, and W. L. Kuhn, "Clean Option: An Alternative Strategy for Hanford Tank Waste Remediation: Volume 1. Overview," Pacific Northwest Laboratory report PNL-8388, Vol. 1 (December 1992).
6. R. K. Scheele and M. K. Peterson, "Results of the Characterization of Samples of Waste from Double-Shell Tank 102-SY," Westinghouse Hanford Company internal letter report (January 1990).
7. S. F. Agnew, "Preliminary Estimation of SY-102 Based on Tank History," Los Alamos National Laboratory internal letter report INC-14:93-sfa1645 (May 18, 1993).
8. G. J. Lumetta and J. L. Swanson, "Pretreatment of Plutonium Plant (PFP) Sludge: Report for the Period October 1990-March 1992," Pacific Northwest Laboratory report TWRSP-92-011 Draft (June 9, 1992).

9. R. Gunnink and J. B. Niday, "Computerized Quantitative Analysis by Gamma-Ray Spectrometry. Vol. 1. Description of the Gamanal Program," Lawrence Livermore National Laboratory report UCRL-51061, Vol. 1 (March 1972).
10. T. M. Benjamin, Nuclear Chemistry and Analysis Group, Los Alamos National Laboratory, personal communication, April 1994.
11. F. X. McGarvey and R. Gonzales, "Ion Exchange Studies on Strongly Basic Anion Exchange Resins Prepared with Tertiary Amines of Varying Molecular Weight," in *Ion Exchange Advances, Proceedings of IEX '92*, M. J. Slater, Ed. (Elsevier Science Publishing Ltd., Essex, England, 1992), pp. 97-103.
12. S. F. Marsh, "The Effect of Triethyl, Trimethyl, Tripropyl, and Tributyl Amine Functional Groups in Strong-Base Anion Exchange Resin on the Sorption of Pu(IV) from Nitric Acid," in *Ion Exchange Processes: Advances and Applications*, A. Dyer, M. J. Hudson, and P. A. Williams, Eds. (Royal Society of Chemistry, Cambridge, England, 1993), pp. 81-89.
13. F. Sebesta, A. Motl, and J. John, "Composite Ion-Exchangers, Their Development and Use," in *Workshop of the Czech Technical University in Prague*, INIS-mf-13201 or CONF-9201108 (January 1992), pp. 25-26.
14. J. Narbutt, A. Bilewicz, and B. Bartos, "Composite Ion Exchangers for Radiocaesium Removal from Nuclear Reactor Wastes," in *Proc. Int. Symp. on Management of Low and Intermediate Level Radioactive Wastes*, CONF-880510, v-2 (Stockholm, May 16-20, 1988).
15. T. M. Suzuki, "Porous Spherical Resins Loaded with Hydrous Metal Oxides—Preparation and the Ion Exchange Properties," in *New Developments in Ion Exchange; Materials, Fundamentals, and Applications, Proc. Int. Conf. on Ion Exchange, ICIE '91*, M. Abe, Ed. (Elsevier, Amsterdam-Oxford-New York-Tokyo, 1992), pp. 181-186.