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Distributions of 14 Elements on 60 Selected Absorbers from Two Simulant Solutions (Acid-Dissolved Sludge and Alkaline Supernate) for Hanford HLW Tank 102-SY

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TRADEMARKS

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Distributions of 14 Elements on 60 Selected Absorbers from Two Simulant Solutions (Acid-Dissolved Sludge and Alkaline Supernate) for Hanford HLW Tank 102-SY

by

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ABSTRACT

Sixty commercially available or experimental absorber materials were evaluated for partitioning high-level radioactive waste. These absorbers included cation and anion exchange resins, inorganic exchangers, composite absorbers, and a series of liquid extractants sorbed on porous support-beads. The distributions of 14 elements onto each absorber were measured from simulated solutions that represent acid-dissolved sludge and alkaline supernate solutions from Hanford high-level waste (HLW) Tank 102-SY. The selected elements, which represent fission products (Ce, Cs, Sr, Tc, and Y); actinides (U, Pu, and Am); and matrix elements (Cr, Co, Fe, Mn, Zn, and Zr), were traced by radionuclides and assayed by gamma spectrometry. Distribution coefficients for each of the 1680 element/absorber/solution combinations were measured for dynamic contact periods of 30 min, 2 h, and 6 h to provide sorption kinetics information for the specified elements from these complex media. More than 5000 measured distribution coefficients are tabulated.

EXECUTIVE SUMMARY

Reliable partitioning agents and technologies are needed to remediate the large quantities of hazardous waste stored in underground tanks at the Hanford Reservation in Washington State. To address this need, we have measured the distribution of 14 elements on 60 different absorbers, from simulants that represent acid-dissolved sludge and alkaline supernate solutions from Hanford high-level waste (HLW) Tank 102-SY.

This screening study, which is intended to identify the most promising absorbers and extractants, included mainly absorbers that either are commercially available or appear that they could be produced in commercial quantities at an acceptable cost, 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.

In many cases, the observed behavior of the absorber/element combination was significantly different from what had been expected, based on published measurements from relatively clean solutions, which demonstrates the value of using realistic simulants for such measurements. In some cases, we found inexpensive commercial materials outperform specialty products whose costs are orders of magnitude higher.

Table I summarizes how well each of the 14 elements is sorbed, from both acidic and basic solutions, by showing the number of absorbers identified as effective in each of the six distribution coefficient (Kd) categories.

Table I. Number of Identified Absorbers in Various Kd Categories, for Each of 14 Elements, from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Element	Kd >1000	Kd 300-1000	Kd 100-300	Kd 20-100	Kd 10-20	Kd 5-10
Acidic 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	11	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
Alkaline 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

Cerium, cesium, technetium, zirconium, uranium, and plutonium are elements for which good-to-excellent sorption has been demonstrated from acid-dissolved sludge simulant. Elements that show low sorption from acidic solution are strontium, yttrium, chromium, cobalt, iron, manganese, zinc, and americium.

Cerium, cesium, technetium, yttrium, zinc, uranium, and americium are elements for which good-to-excellent sorption has been demonstrated from alkaline supernate solution. Elements that show poor-to-marginal sorption from alkaline solution are strontium, chromium, cobalt, iron, manganese, zirconium, and plutonium.

Those absorbers identified as acceptable on the basis of these initial tests should be tested with other simulated tank compositions and with actual waste. In the case of elements for which no acceptable absorber has been identified, the effort to identify—or develop—satisfactory partitioning agents should be accelerated.

Our experimental results indicate that many existing partitioning agents are suitable for HLW tank remediation. If reliable partitioning agents can be identified, Hanford HLW tank processing might begin and be completed sooner, and at a lower cost, than would otherwise be possible. We therefore feel that the findings of our study could have a major beneficial impact on decommissioning and environmental remediation efforts at Hanford and elsewhere within the US Department of Energy (DOE) complex.

I. INTRODUCTION

The Hanford Reservation in Washington State incorporates 177 underground storage tanks that contain more than 165 million Curies of radioactivity in more than 65 million gallons of waste. Many different processes have been used at Hanford for the past fifty years, during which these wastes have accumulated from nuclear materials processing for national defense requirements. As a result, many different reagents and waste streams were neutralized and combined in underground tanks, often with insufficient concern about the compatibility of the components being stored. The resulting wastes are an extremely complicated and sometimes unstable mixture of sludges, saltcakes, slurries, and supernates. Adding significantly to the stored waste problem is the fact that 67 tanks are known, or are suspected, to have leaked.

The U S Department of Energy (DOE) is committed to the environmental remediation of hazardous wastes stored at the Hanford Site. Los Alamos National Laboratory has been directed by DOE 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 the TWRS mission is identifying suitable partitioning agents and technologies to accomplish this challenging goal.

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 plutonium[1] and neptunium[2] from a wide variety of impure nuclear materials. Cation exchangers also have been used in the nuclear industry,[3] but generally are considered to be less selective than anion exchange resins.

Although most of the tested absorbers are cation exchangers, we included some anion exchange resins and a series of liquid ion exchangers (sorbed on porous carbon beads) to obtain more comprehensive data, as well as to supply convenient reference points to other studies. We also included some experimental absorbers to provide guidance for future research activities.

Some of the recently developed specialty products included in our study are reported to offer high selectivity for specific ions; however, few of these absorbers have been evaluated with media approaching the complexity of Hanford high-level waste (HLW) solutions. Nor have any other investigators, to our knowledge, measured the distribution of as many elements (14) onto so many different absorber materials (60).

Our objective was to evaluate a large number of potentially useful absorber materials, including many not previously studied, from realistic simulants of acid-dissolved sludge and alkaline supernate solutions from the Hanford HLW Tank 102-SY. We recognize that no simulant will exactly represent the contents of any HLW tank. Nevertheless, we have used the best information available in our effort to prepare realistic simulants. The most promising absorbers eventually must be tested with actual waste; however, because actual waste samples are expensive and difficult to obtain, we suggest that the preliminary screening of promising candidate absorbers precede tests with actual waste.

Although we include comments and observations about our experimental data, we intentionally do not recommend which absorbers should be used. Our purpose is to identify options from which reliable flowsheets can be developed. The preferred partitioning options will depend heavily on the particular objectives of the flowsheet. Although our study initially was intended to support the Los Alamos flowsheet development program for Hanford Tank 102-SY,[4] many of our experimental findings are applicable to other flowsheet proposals, such as the so-called "Clean Option."[5] Decisions about whether the targeted elements should be recovered individually, or grouped for subsequent disposal, are properly left to the flowsheet designers. Whichever flowsheet is adopted, however, we expect that our experimental data could allow 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 two 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 solution in Tank 102-SY. All our assumptions about tank contents were checked against composition data obtained by reconstruction, based on 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 operations, based on PNL sludge-washing studies,[8] were subtracted from our best estimate of the initial sludge composition and added to our best estimate of the supernate composition. We then dissolved, in a minimum quantity of nitric acid, those components assumed to remain in the sludge. The simulated acid-dissolved sludge was filtered to remove insoluble residue.

The target compositions, actual compositions, and detailed procedure used to prepare the simulated acid-dissolved sludge for Hanford HLW Tank 102-SY are presented in Appendix A. The target compositions, actual compositions, and detailed procedure used to prepare the simulated alkaline supernate solution for Hanford HLW Tank 102-SY are presented in Appendix B.

We recognize that these simulant solutions (and the actual waste solutions) could be modified and manipulated in various ways to optimize the performance of specific absorbers or extractants. However, each modification of the waste solution would increase the complexity of the process and the quantity of secondary waste, an increase we seek to avoid.

We intentionally avoided modifying the simulant solutions in any way that could bias our study in favor of specific partitioning agents. Instead, we chose to evaluate all the selected partitioning agents on an equal basis with "as-is" simulants. If adequate partitioning technology for "as-is" waste solution cannot be identified, the feed solution can always be modified as required for specific portions of any selected flowsheet; however, in the interests of process simplification and waste minimization, such modifications should be applied only when they are essential.

B. Radiotracers

Because gamma spectrometry was selected as the technique for measuring the distribution of the selected elements, suitable radiotracers were obtained and added to the simulant solutions. The selected tracers and the gamma energies measured are listed in Table II.B. The actinides were isolated and purified in the Los Alamos Plutonium Facility. Chromium-51, ^{141}Ce, and ^{60}Co were purchased from DuPont New England Nuclear Products, Boston, MA. All other radioisotopes were obtained from the Nuclear Chemistry and Analysis Group, INC-13, Los Alamos National Laboratory.

To minimize the possibility of interference among gamma rays with similar energies, we divided the 14 radiotracers into two easily resolved groups. Each group of tracers was added to a separate portion of each simulant solution. Each of the four resulting solutions was evaluated with each of the 60 absorbers for dynamic contact periods of 30 min, 2 h, and 6 h.

C. Absorbers

The 60 absorbers evaluated in this study are listed in Table II.C. 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.

D. Solution/Absorber Contacts

In most cases, a 250-mg portion of each air-dried absorber was contacted with a measured 6- or 8-ml volume of each solution in a specially modified 20-ml disposable hypodermic syringe. We modified these syringes by inserting cylindrical plugs cut from 1/4"-thick porous Kynar (obtained from Porex Technologies, Fairburn, Georgia) into the tapered tips as filters, which permitted liquid, but not most solid absorber materials, to pass through. A 250-mg portion of each dried absorber was added beforehand to an appropriately labeled syringe.

To begin a set of experiments, we pipetted into a plastic beaker a measured volume of the selected solution, which then was drawn into a syringe through the Kynar filter. After sealing the tip of each syringe with a solid Luer cap, we mixed a set of six syringes, prepared as described, on a 48-rpm tube rotator for dynamic contact periods of 30 min, 2 h, and 6 h. At the end of each contact period, approximately 25% of the total solution volume was expelled through the filtered tip of the syringe into a tared counting vial. The weight of the dispensed solution was determined and recorded for later use in the calculation of distribution coefficient (Kd) values.

Table II.B. Radionuclides Used in this Study

Nuclide	Gamma energy, MeV	Branching, %
^{241}Am	.0595	35.9
^{239}Pu	.1293	6.2×10^{-3}
$^{238}Pu^{a}$	.153	1.0×10^{-3}
^{141}Ce	.145	48
^{95m}Tc	.204	100
^{237}U	.208	23.3
^{51}Cr	.320	10
^{88}Zr	.394	97
^{85}Sr	.514	100
^{137}Cs	.662	85
^{54}Mn	.835	100
^{88}Y	.898	92
^{59}Fe	1.099	56
^{65}Zn	1.115	51
^{60}Co	1.173	100

[a] ^{238}Pu was used as the tracer in all alkaline solutions and in a few of the acidic solutions. When ^{238}Pu was used, the plutonium concentration was 60 mg/L, whereas in the acidic solutions that contained ^{239}Pu, the plutonium concentration was 3 g/L.

These filtered syringes were unsuitable for the Sandia National Laboratories (SNL) crystalline silico-titanate (CST) absorbers because the particle size of the CSTs was much smaller than the pores in the Kynar filters. For these very finely divided materials, we contacted each absorber/solution combination in a 20-ml centrifuge tube, rather than a syringe. At the end of each contact period, the tubes were centrifuged at high speed for 10 min, after which 1.6 ml of solution was transferred into a smaller centrifuge tube, which also was centrifuged at high speed for 10 min.

Finally, approximately 1.5 ml of solution was transferred from the second centrifuge tube into a 10-ml hypodermic syringe having a 0.45-micron filter attached to the Luer-lock tip. The twice-centrifuged solution was expelled through this submicron filter into a tared counting vial, after which the solution weight was determined and recorded, as was done with the other solutions.

The unusually large variation in Kd values obtained with the CST absorbers indicates that, in spite of our efforts to exclude them, submicron particles sometimes contaminated the solution taken for gamma spectrometric assay. This was a particular problem for cesium, which is very strongly sorbed on CSTs. Even a few particles on which cesium activity is strongly sorbed could introduce a significant amount of activity into a solution that otherwise would be essentially free

Table II.C. Absorbers Used in this Study

COMMERCIALLY AVAILABLE ABSORBERS	Amberlyst™ 15 cation exchange resin (sulfonic acid)
	Amberlyst™ XN-1010 cation exchange resin (sulfonic acid)
	Duolite™ C-467 cation exchange resin (phosphonic acid)
	Diphonix™ cation exchange 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 exchange resin
	Ionac™ SR-3 anion exchange resin
	Purolite™ A-520-E $(Et)_3N$ anion exchange resin
	Ionac™ SR-6 anion exchange resin
EXPERIMENTAL ABSORBERS	Sybron™ $(Et)_3N$ anion exchange resin
	Sybron™ $(Pr)_3N$ anion exchange resin
	JSK-2 anion exchange resin
	JSK-3 anion exchange resin
	JSK-4 anion exchange resin
	Crypt-DER polymer resin
	PK-01-244 phosphinic acid resin
	Savannah River formaldehyde/resorcinol resin
COMPOSITE ABSORBERS	TiO-PAN titanium dioxide
Czech Republic	NiFC-PAN nickel ferrocyanide
(polyacrylonitrile matrix)	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 molybdophosphate
Poland	Titanium hexacyanoferrate
(phenolsulfonic-formaldehyde matrix)	Cobalt hexacyanoferrate

Table II.C. (Continued)

LANL-PREPARED COMPOSITE ABSORBERS	Zirconium phosphate Titanium phosphate Titanium dioxide Zirconium dioxide Niobium pentoxide
LANL-PREPARED EXTRACTANT BEADS	LIX™-1010 (di-2-ethylhexylphosphoric acid) LIX™-54 (a beta diketone) LIX™-84 (a ketoxime) LIX™-26 (8-hydroxyquinoline) Cyanex™ 923 (trialkylphosphine oxide) Cyanex™ 272 (trimethylpentylphosphoric acid) DHDECMP DHDECMP-diisopropylbenzene CMPO-diisopropylbenzene Aliquat™ 336 Czech cobalt dicarbollide INC-synthesized cobalt dicarbollide
SANDIA NATIONAL LABORATORIES ABSORBERS	SNL/CST35 crystalline silico-titanate SNL/CST48 crystalline silico-titanate SNL/CST68 crystalline silico-titanate SNL/CST69 crystalline silico-titanate SNL/CST84 crystalline silico-titanate SNL/CST111 crystalline silico-titanate SNL/HTO amorphous hydrous TiO_2

of cesium. However, in all such cases the error would cause us to understate the actual Kds for removing cesium from solution. Our reported Kds for the CST materials may therefore be considered as minimum values.

E. Calculation of Kd Values

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

Distribution coefficients (Kd) were calculated for each element as

$$Kd = \frac{\text{(pre-contact activity)}-\text{(post-contact activity)}}{\text{post-contact activity}} \quad \frac{\text{ml solution}}{\text{g absorber}}$$

We recognize that uncertainties become larger for very small distribution coefficients, when the numerator represents a small difference between two large numbers, as well as for very large distribution coefficients, when the denominator becomes very small. However, the objective of this screening study was to identify absorbers that sorb specific elements very well or poorly. If it is important to determine very large Kd values with high accuracy, such data can be obtained during follow-up studies, which would be limited to the most promising absorbers identified in this study.

F. Corrections

Because the weight of the post-contact assay solutions usually differed slightly from that of the pre-contact standard solution, each post-contact solution was first normalized to the same weight basis as the standard. Appropriate corrections also were made in the Kd calculations 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.

The activity of each radionuclide in the post-contact solution was compared with the activity of that same nuclide in the pre-contact standard. Because most absorbers were initially added in air-dried form, they sometimes preferentially absorbed the aqueous solvent, which had the effect of increasing the concentration of the solutes in the smaller solution volume. At times, this resulted in the activity of certain radionuclides being higher in the post-contact solution than in the pre-contact solution. Whenever the post-contact/pre-contact solution activity ratio of a radionuclide exceeded unity, we assigned a value of 1.000 to the ratio having the highest value, and then normalized all other radionuclides in that same portion of solution accordingly.

Corrections also were made for short-lived radionuclides, such as 6.8-day ^{237}U, whose decay during the typical gamma assay period was significant. All Kd calculations and corrections were done using an EXCEL™ spreadsheet.

G. Other Sources of Error

Each combination of element/absorber/solution/contact-time was measured only once. The absence of duplicates is partially 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 can indicate 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. The uncertainty for these worst cases appears to be within a factor of two to three. We estimate the uncertainty associated with the best Kd values to be 10-20 relative percent.

At times, Kd values are highest for the 30-min contact and decrease thereafter. Several scenarios could explain these decreasing Kd values. (1) The element in question might sorb rapidly and then be displaced by another slower-sorbing species. (2) Some of the strong complexing anions in the simulants could be participating in slow competitive reactions with the cations

being measured. (3) The absorber could be representatively or selectively dissolving, thereby releasing previously sorbed cations. (Slow dissolution of an amorphous phase within the crystalline silico-titanates was suggested by Sandia National Laboratories (SNL) personnel to explain decreasing Kd values of initially sorbed non-cesium cations.) And finally, (4) the decreasing Kd values could be solely due to experimental error.

Finally, the difficulty in accurately correcting for the complex background under the low-energy (59.5-keV) gamma peak of ^{241}Am resulted in this nuclide having larger-than-normal uncertainties associated with its Kd values.

H. Data Transfer and Processing

To minimize the need for transcribing large amounts of data, and the human errors that can be introduced during such operations, we automated the data transfer and calculation process. The area of each gamma peak of interest was determined from the raw data in the multichannel analyzer memory, using *Gamanal*,[9] which 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 nuclides. All interferences are resolved by a least-squares solution of the matrix of equations for the gamma intensities.

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

III. RESULTS AND DISCUSSION

A. Individual Elements

Tables III.A.3 through III.A.16 list the most promising absorbers for each element, ranked in order of their Kd values, from acid-dissolved sludge and from alkaline supernate simulant solutions. Partitioning agents that sorb the specified element poorly are generally omitted from these tables. However, those absorbers that have been designated as the baseline technologies for TWRS are always included, even when they perform poorly.

1. Cerium. Aside from the JSK experimental anion exchange resins, Reillex™ HPQ provides the highest sorption of cerium from acidic solution, within 2 h. From basic solution, Cyanex™ 923, a low-cost commercial extractant, outperforms specialty products costing orders of magnitude more.

Table III.A.1. Cerium Distribution Data

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	JSK-1 resin	28	29	27
	JSK-2 resin	27	26	24
	JSK-3 resin	23	23	22
	Reillex™ HPQ resin	14	13	13
	Purolite™ A-520-E resin	7.8	14	21
	Ionac™ SR-3 resin	6.6	13	21
	Crypt-DER resin	3.0	2.9	2.8
	Duolite™ C-467 resin	2.4	1.5	2.2
	Amberlyst™ 15 resin	2.0	1.7	1.8
Alkaline Supernate	Cyanex™ 923	744	988	1596
	TRU-Spec™ resin	547	594	644
	SNL/HTO	265	320	512
	CMPO-DIPB	78	370	499
	Amberlyst™ 15 resin	42	77	132
	LIX™-26	32	40	42
	DHDECMP	26	45	51
	Czech MgO-PAN	26	59	222
	Czech MnO-PAN	24	25	26
	Diphonix™ resin	22	23	22
	Bone char	19	33	53
	DHDECMP-DIPB	18	28	28
	SNL/CST111	17	32	57
	SRS resorcinol resin	14	26	42
	Amberlyst™ XN-1010 resin	13	38	114
	Czech AMP-PAN	12	22	28
	SNL/CST68	8.6	16	38
	SNL/CST48	6.4	8.6	17
	Duolite™ C-467 resin	6.3	4.3	3.6
	Czech Ba(Ca)SO_4-PAN	5.4	6.1	8.6
	Purolite™ A-520-E resin	4.8	5.3	6.1
	Czech NaY-PAN	4.6	4.0	3.3

2. Cesium. SNL crystalline silico-titanates outperform all other absorbers from both acidic and basic solution. Czech AMP-PAN composite also performs very well from both acidic and basic solution. Czech NiFC-PAN composite sorbs cesium highly from basic solution, but only moderately from acidic solution. The fact that many of these absorbers sorb cesium strongly from both acidic and basic solution suggests that elution may be difficult.

Table III.A.2. Cesium Distribution Data

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	SNL/CST35	4485	1011	3416
	SNL/CST111	3420	5021	5305
	SNL/CST69	2884	2279	3252
	SNL/CST84	1849	8096	11840
	Czech AMP-PAN	1626	4073	5504
	SNL/CST48	794	758	1180
	SNL/CST68	688	2307	1049
	Czech M315-PAN	50	64	61
	Czech NiFC-PAN	45	49	49
	Duracil™ 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 resin	0.5	1.1	1.3
Alkaline Supernate	SNL/CST35	13158	12421	4195
	SNL/CST69	8879	10844	20880
	SNL/CST84	5484	3953	3098
	SNL/CST111	4938	2713	1864
	SNL/CST68	4072	2453	722
	SNL/CST48	3951	2820	1031
	Czech NiFC-PAN	3533	11954	5998
	Czech AMP-PAN	2133	4636	8275
	Czech 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 resin	1.3	1.2	1.3

3. Strontium. Although Sr-Spec™ resin sorbs strontium better than the other absorbers from both acidic and basic solution, in neither case is the sorption very high. From basic solution, Amberlyst™ 15 cation exchange resin, whose cost is hundreds of times less than that of Sr-Spec™ resin, performs nearly as well. The poor-to-marginal performance of all the studied absorbers for strontium indicates that better partitioning agents are needed to remove this important fission product.

4. Technetium. Reillex™ HPQ resin offers the highest Kd for technetium from acidic solution and an even higher Kd from basic solution. Although Reillex™ HPQ resin provides Kd values of at least 250 from basic solution, two experimental resins and two commercial extractants outperform it. Aliquat™ 336 is especially interesting because it is nearly selective for sorbing technetium from basic solution, but not from acid, which indicates that acid should be an effective stripping agent.

Table III.A.3. Strontium Distribution Data

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	Sr-Spec™ resin	3.0	3.1	2.9
	Diphonix™ resin	2.0	1.7	1.3
	Ionsiv™ TIE-96	1.9	1.0	1.5
	Czech Ba(Ca)SO_4-PAN	1.5	1.7	1.5
	Czech MgO-PAN	1.4	1.6	2.0
Alkaline Supernate	Sr-Spec™ resin	18	18	17
	Amberlyst™ 15	12	13	13
	Czech Ba(Ca)SO_4-PAN	7.3	8.1	12
	Amberlyst™ XN-1010	5.9	7.8	8.3
	Czech NaTiO-PAN	4.9	5.3	5.0
	SRS resorcinol resin	4.9	2.6	1.5
	SNL/CST111	4.2	4.2	3.5
	SNL/CST69	3.4	2.9	6.6
	Czech MgO-PAN	3.0	4.8	7.4
	SNL/CST84	2.2	2.0	4.4
	SNL/CST35	1.6	1.3	3.3
	SNL/HTO	1.5	1.4	3.6

Table III.A.4. Technetium Distribution Data

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	Reillex™ HPQ resin	76	90	93
	Ionac™ SR-3 resin	32	44	43
	Purolite™ A-520-E resin	32	57	77
	Sybron™ $(Et)_3N$ resin	31	51	53
	LANL TiO_2	19	40	57
	LANL ZrO_2	17	41	60
	Duolite™ C-467 resin	12	12	13
	Sybron™ $(Pr)_3N$ resin	11	26	45
	Tannin	10	39	136
	LANL Nb_2O_5	6.9	17	31
	Duolite™ CS-100 resin	4.8	6.3	6.4
	Ionac™ SR-6 resin	2.1	4.6	8.4
	SRS resorcinol resin	2.1	4.6	11
Alkaline Supernate	Sybron™ $(Pr)_3N$ resin	401	777	992
	Cyanex™ 923	300	551	582
	Aliquat™ 336	295	443	572
	Sybron™ $(Et)_3N$ resin	264	405	440
	Reillex™ HPQ resin	250	280	274
	Purolite™ A-520-E resin	205	320	380
	Ionac™ SR-6 resin	151	394	618
	Ionac™ SR-3 resin	121	123	125
	TRU-Spec™ resin	90	78	74
	LANL TiO_2	54	185	290
	LIX™-26	54	112	190
	Sr-Spec™ resin	45	42	39
	DHDECMP	43	112	222
	CMPO-DIPB	41	111	196
	Duolite™ C-467 resin	40	42	44
	LANL ZrO_2	35	148	258
	LANL Nb_2O_5	28	134	271
	Crypt-DER resin	25	25	25

5. Yttrium. None of the absorbers sorbs yttrium well from acidic solution. From basic solution, however, Cyanex™ 923, a low-cost commercial extractant, sorbs yttrium at least tenfold better than much-costlier alternatives.

Table III.A.5. Yttrium Distribution Data

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	Amberlyst™ 15 resin	2.3	1.7	2.1
	Duolite™ C-467 resin	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 resin	1.5	1.7	1.4
	Ionsiv™ TIE-96	1.5	0.9	1.2
	Amberlyst™ XN-1010 resin	1.4	1.4	1.5
	Purolite™ A-520-E resin	1.4	1.1	1.1
	Reillex™ HPQ resin	1.2	0.5	0.8
	Tannin	1.2	1.2	0.7
Alkaline Supernate	Cyanex™ 923	1078	2014	2981
	TRU-Spec™ resin	98	94	92
	SNL/HTO	53	59	52
	Diphonix™ resin	28	31	31
	Amberlyst™ 15 resin	27	45	66
	Czech MgO-PAN	26	59	258
	CMPO-DIPB	15	45	89
	Czech AMP-PAN	15	27	34
	SRS resorcinol resin	12	21	36
	Bone char	11	18	26
	Amberlyst™ XN-101 resin	11	26	64

6. Chromium. None of the tested absorbers removes chromium adequately from acidic solution. Although four absorbers offer double-digit Kd values for 6-h contacts from basic solution, these Kds are significantly lower for shorter contact periods. The poor-to-marginal performance of all the studied absorbers for chromium indicates that better partitioning agents are needed to remove this important matrix element.

Table III.A.6. Chromium Distribution Data

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	Czech MgO-PAN	1.5	1.4	1.6
	LANL $Zr_3(PO_4)_4$	1.4	1.1	1.3
	Ionsiv™ TIE-96	1.4	0.8	1.1
	LANL $Ti_3(PO_4)_4$	1.2	1.1	0.8
	Czech $Ba(Ca)SO_4$-PAN	1.1	0.9	0.9
	Duolite™ C-467 resin	1.1	0.4	1.0
	Diphonix™ resin	1.1	0.6	0.8
	SNL/CST111	1.0	1.0	1.2
	Amberlyst™ 15 resin	1.0	0.7	0.9
Alkaline Supernate	SNL/HTO	5.9	7.8	21
	Amberlyst™ 15 resin	4.2	7.9	14
	Czech MgO-PAN	4.0	5.9	36
	LANL TiO_2	4.0	4.4	5.4
	Czech MnO-PAN	3.0	4.3	4.8
	SNL/CST69	2.8	3.8	14
	Czech NaY-PAN	2.3	4.1	4.8
	SNL/CST111	2.1	1.9	1.7
	SNL/CST68	1.7	2.4	6.6
	SNL/CST84	1.4	1.7	8.8
	Sr-Spec™ resin	1.3	1.6	2.0
	SNL/CST48	1.3	1.7	6.0
	TRU-Spec™ resin	1.3	1.9	2.5
	SNL/CST35	1.1	1.9	9.6
	Duolite™ CS-100 resin	1.0	2.3	3.5

7. Cobalt. Only tannin sorbs cobalt with a double-digit Kd value from acidic solution, and that requires a 6-h contact period. Although four partitioning agents sorb cobalt from basic solution with double-digit Kd values, only Czech MgO-PAN offers a Kd higher than 15, and this requires a 6-h contact. More effective absorbers are needed for both media if ^{60}Co, an important activation product, is to be removed.

Table III.A.7. Cobalt Distribution Data

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	Diphonix™ resin	1.4	1.7	2.1
	Czech MgO-PAN	1.3	1.4	1.4
	Duolite™ C-467 resin	1.3	0.4	0.8
	Czech M315-PAN	1.3	1.0	1.1
	LANL $Zr_3(PO_4)_4$	1.3	1.3	1.1
	Tannin	1.3	3.5	13
	Amberlyst™ XN-1010 resin	1.3	0.9	1.2
	Ionsiv™ TIE-96	1.2	0.7	0.8
Alkaline Supernate	Duolite™ C-467 resin	14	13	12
	SRS resorcinol resin	12	15	7.7
	Czech MgO-PAN	9.4	15	33
	Czech NiFC-PAN	8.9	10	11
	Czech NaTiO-PAN	6.2	7.9	9.5
	SNL/CST68	5.3	5.4	2.3
	SNL/CST48	4.5	4.6	2.0
	Bone char	4.4	5.5	6.9
	Amberlyst™ XN-1010 resin	4.0	3.5	3.4
	Amberlyst™ 15 resin	3.6	3.5	3.1
	Crypt-DER resin	2.1	2.1	2.1

8. Iron. Iron is poorly sorbed by all absorbers from both acidic and basic media. This is fortunate because iron is present at high concentration in many waste solutions. Interference by iron in the sorption of other elements may therefore be much less than had been expected. When iron is present at high concentration, however, significant amounts may load even on the absorbers with low Kd values.

Table III.A.8. Iron Distribution Data

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	Czech NaY-PAN	2.2	1.6	1.5
	LIX™-84	1.0	0.5	0.8
	Duolite™ CS-100 resin	0.8	0.8	1.4
	SNL/CST35	0.8	0.5	0.8
	Czech M315-PAN	0.8	0.5	0.5
	Duolite™ C-467	0.8	0.2	0.4
	TRU-Spec™ resin	0.8	0.8	0.8
	SNL/CST68	0.7	0.7	0.9
	LIX™-54	0.7	0.3	0.4
	SNL/CST48	0.7	1.0	1.0
	Ionsiv™ TIE-96	0.7	0.4	0.8
	Czech MgO-PAN	0.7	0.8	1.0
	Czech MnO-PAN	0.7	1.2	1.0
	CMPO-DIPB	0.6	0.6	0.5
	Amberlyst™ 15 resin	0.5	1.2	0.8
Alkaline Supernate	Czech MnO-PAN	3.1	4.5	5.8
	LIX™-54	2.8	3.4	4.7
	SNL/CST69	2.2	2.0	2.2
	SNL/HTO	2.2	3.1	3.9
	Diphonix™ resin	2.1	2.7	3.1
	Duolite™ CS-100 resin	1.8	2.6	3.2
	Czech NiFC-PAN	1.4	1.7	2.3
	Czech TiO-PAN	1.4	3.8	5.2
	Amberlyst™ 15 resin	1.2	3.4	5.8
	TRU-Spec™ resin	0.8	1.4	2.5
	Reillex™ HPQ	0.7	0.8	1.2
	SNL/CST111	0.6	1.6	1.9
	SNL/CST84	0.6	1.2	1.4
	Sr-Spec™ resin	0.3	0.8	1.5

9. Manganese. Manganese is moderately sorbed by Duolite™ C-467 resin and Czech NaTiO-PAN from basic solution, but by no absorbers from acidic solution. As in the case of iron, this indicates that the interference from manganese may be less than expected.

Table III.A.9. Manganese Distribution Data

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	Diphonix™ resin	1.8	3.2	3.8
	Duolite™ C-467 resin	1.3	1.3	1.4
	Amberlyst™ XN-1010 resin	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 resin	0.8	0.7	0.4
	Czech NaTiO-PAN	0.4	0.4	0.4
Alkaline Supernate	Duolite™ C-467 resin	15	17	17
	Czech NaTiO-PAN	6.0	7.3	7.6
	SRS resorcinol resin	5.9	4.7	2.2
	Amberlyst™ 15 resin	5.2	4.7	4.5
	LIX™-1010	4.9	5.7	5.3
	Amberlyst™ XN-1010 resin	4.3	4.9	5.0
	LIX™-54	2.4	2.1	2.6
	SNL/CST48	2.0	1.7	1.2
	SNL/CST68	1.9	1.9	1.6
	Bone char	1.8	2.5	2.9
	Czech MnO-PAN	1.8	1.9	2.2
	CMPO-DIPB	1.6	1.6	2.1
	Tannin	1.3	0.4	0.5

10. Zinc. None of the absorbers removes significant amounts of zinc from acidic solution; however, many absorbers offer moderate-to-high Kd values from basic solution.

Table III.A.10. Zinc Distribution Data

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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™ resin	1.2	2.1	2.1
	Duolite™ C-467 resin	0.9	0.7	0.8
	PK-01-244 resin	0.8	0.4	0.4
	SNL/CST111	0.8	0.6	0.6
	Crypt-DER resin	0.7	0.5	0.3
Alkaline Supernate	Czech NiFC-PAN	61	94	90
	SNL/CST68	33	44	43
	Duolite™ C-467 resin	24	46	89
	SNL/CST48	23	32	34
	Czech 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 resin	3.2	3.4	3.6

11. Zirconium. Many absorbers offer moderate-to-high sorption of zirconium from acidic solution. A particularly interesting material is Czech TiO-PAN composite, which is highly selective for zirconium among the 14 elements studied. Only Czech MgO-PAN offers a double-digit Kd value for zirconium from basic solution. However, because the 6-h value for MnO-PAN is significantly higher than the values obtained for shorter contact times, this high value is suspect. The erratic Kd values for SNL/CST69 are attributed to incomplete exclusion of submicron absorber particles from the assay solution, and for SNL/CST84 to dissolution of an amorphous phase that sorbs zirconium.

12. Uranium. Many absorbers offer useful Kd values for uranium from acidic solution. Note that all 60 absorbers were evaluated from acid-dissolved sludge that contained 3 g ^{239}Pu/L. A few selected absorbers also were evaluated from a similar solution that contained ^{238}Pu, but at a 50-fold lower concentration, to determine how the lower plutonium concentration affected actinide Kd values. From basic solution, Cyanex™ 923 outperforms other much-costlier partitioning agents.

Table III.A.11. Zirconium Distribution Data

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	Czech NaY-PAN	107	191	196
	SNL/CST69	91	14	116
	Duracil™ 230	75	220	205
	SNL/CST84	70	87	19
	Czech TiO-PAN	51	323	899
	Ionsiv™ TIE-96 (mod.)	35	88	115
	SNL/CST68	31	119	103
	Ionsiv™ TIE-96	28	64	85
	Czech M315-PAN	27	67	96
	SNL/CST48	15	49	51
	SNL/CST111	11	14	18
	Duolite™ CS-100 resin	9.2	16	22
	SNL/CST35	8.2	26	76
	Cyanex™ 272	8.0	32	199
Alkaline Supernate	Amberlyst™ 15 resin	2.8	4.6	8.4
	Czech MgO-PAN	1.7	2.9	28
	SNL/HTO	1.7	2.7	6.4
	SNL/CST69	1.7	2.5	5.5
	Czech MnO-PAN	1.7	2.2	2.3
	Sr-Spec™ resin	1.6	1.8	2.1
	Czech TiO-PAN	1.5	2.0	3.2
	TRU-Spec™ resin	1.4	1.9	2.6
	Duolite™ CS-100 resin	1.1	2.1	3.1

Table III.A.12. Uranium Distribution Data

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge (3 g Pu/L)	TRU-Spec™ resin	25	26	27
	JSK-2 resin	19	19	19
	JSK-3 resin	18	18	17
	Reillex™ HPQ resin	16	19	18
	JSK-1 resin	14	13	12
	Sybron™ $(Et)_3N$ resin	13	22	22
	Ionac™ SR-3 resin	12	21	37
	Purolite™ A-520-E resin	9.9	24	35
	Sr-Spec™ resin	4.9	5.1	5.7
	Duolite™ C-467 resin	3.8	5.0	6.0
	Amberlyst™ 15 resin	3.1	6.4	7.2
	DHDECMP-DIPB	1.2	2.3	2.7
	Diphonix™ resin	0.4	1.5	2.8
	CMPO-DIPB	0.4	0.8	1.4
(60 mg Pu/L)	Reillex™ HPQ resin	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 resin	10	22	39
	Cyanex™ 923	2.7	6.5	14
Alkaline Supernate	Cyanex™ 923	122	233	356
	Diphonix™ resin	96	153	214
	TRU-Spec™ resin	70	107	164
	Czech TiO-PAN	67	115	185
	SNL/HTO	52	69	90
	CMPO-DIPB	49	183	291
	SNL/CST35	25	45	54
	Cyanex™ 272	23	41	58
	SNL/CST68	23	38	45
	DHDECMP	22	31	32
	Duolite™ C-467 resin	19	38	63
	Amberlyst™ 15 resin	15	30	58
	Duolite™ CS-100 resin	12	19	25
	Reillex™ HPQ resin	8.4	8.9	8.9
	SRS resorcinol resin	7.5	13	22
	Bone char	6.1	9.6	13
	Sr-Spec™ resin	4.8	4.9	5.2

13. Plutonium. Aside from the outstanding performance of the experimental JSK anion exchange resins, and Sybron™ $(Et)_3N$ resin for a 6-h contact period, Reillex™ HPQ sorbs plutonium from acidic 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 basic solution may not be a serious problem because the solubility of plutonium in this medium is expected to be quite low.

Table III.A.13. Plutonium Distribution Data

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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 resin	78	274	485
	TRU-Spec™ resin	57	58	60
	Sybron™ $(Et)_3N$ resin	24	114	839
	Ionac™ SR-3 resin	21	64	207
	Sr-Spec™ resin	14	14	14
	Purolite™ A-520-E resin	13	51	415
	DHDECMP	4.4	8.2	15
	Duolite™ CS-100 resin	4.0	6.7	10
	Cyanex™ 923	3.0	7.6	21
	CMPO-DIPB	0.4	0.4	0.7
(60 mg Pu/L)	JSK-3 resin	870	1650	2185
	JSK-2 resin	329	337	261
	JSK-1 resin	178	249	254
	Reillex™ HPQ resin	132	184	205
	Purolite™ A-520-E resin	45	186	260
	Cyanex™ 923	21	100	199
Alkaline Supernate	Czech MnO-PAN	2.8	3.3	3.8
	Duolite™ CS-100 resin	2.7	3.4	4.4
	Amberlyst™ 15 resin	2.3	4.9	8.5
	LIX™-54	2.2	2.8	3.0
	Cyanex™ 923	1.4	1.9	2.0
	TRU-Spec™ resin	1.2	2.0	2.8
	Diphonix™ resin	1.0	1.2	1.0
	CMPO-DIPB	0.8	0.5	1.0
	Reillex™ HPQ resin	0.7	0.9	0.7
	DHDECMP-DIPB	0.7	0.6	0.4

14. Americium. Americium is sorbed by the JSK experimental anion exchange resins and by Reillex™ HPQ resin from acidic solution, but at lower levels than we would like. From basic solution, many absorbers offer high Kd values for americium. Cyanex™ 923 sorbs americium better than any other partitioning agent studied, including specialty products costing orders of magnitude more.

B. Individual Absorbers

Tables III.B.1.a. through III.B.7.g. present distribution coefficients for each of the 14 elements onto each of the 60 absorbers, from simulated acid-dissolved sludge and alkaline supernate solutions of Hanford PFP Tank 102-SY. These tables may be used to predict the selectivity of specific absorbers being considered.

Table III.A.14. Americium Distribution Data

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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 resin	3.9	2.4	2.4
	TRU-Spec™ resin	0.3	<0.1	<0.1
	Diphonix™ resin	<0.1	0.3	0.4
(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 resin	4.6	3.6	3.8
Alkaline Supernate	Cyanex™ 923	538	751	802
	TRU-Spec™ resin	495	598	671
	SNL/HTO	229	264	168
	CMPO-DIPB	49	355	472
	LIX™-54	34	32	30
	Amberlyst™ 15 resin	33	68	93
	Czech MnO-PAN	32	30	26
	Diphonix™ resin	28	25	22
	SNL/CST111	25	52	107
	DHDECMP	25	34	35
	Czech AMP-PAN	24	50	86
	LIX™-26	23	33	30
	Bone char	16	35	62
	Amberlyst™ XN-1010 resin	10	27	66
	LIX™-1010	10	27	64

1. Commercially Available Absorbers. Seventeen commercially available absorbers 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 III.B.1.a. shows that surprisingly few elements sorb on this cation exchange resin from acidic solution, and that lanthanides and trivalent actinides sorb reasonably well from alkaline solution. Amberlyst™ 15 is outperformed by only one other absorber for removing strontium from basic solution.

Table III.B.1.a. Distribution of 14 Elements onto Amberlyst™ 15 Cation Exchange Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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. Amberlyst XN-1010 is stated by the manufacturer to have a particularly high surface area and to be suitable for non-aqueous applications. Air-drying the as-received resin before use resulted in a weight loss of 4.4%.

Table III.B.1.b. shows that the behavior of Amberlyst™ XN-1010 is similar to that of Amberlyst™ 15, although the Kd values generally are lower.

Table III.B.1.b. Distribution of 14 Elements onto Amberlyst XN-1010 Cation Exchange Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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 III.B.1.c. shows moderate sorption of technetium and zirconium from acidic solution. From basic solution, technetium, zinc, and uranium sorb reasonably well, whereas cobalt, manganese, americium, and lanthanides sorb moderately.

Table III.B.1.c. Distribution of 14 Elements onto Duolite™ C-467 Cation Exchange Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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 acidic solution, whereas uranium, lanthanides, and americium sorb from basic solution.

Table III.B.1.d. Distribution of 14 Elements onto Diphonix™ Cation Exchange Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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 moderately from acidic solution. From basic solution, cesium is sorbed well and uranium is sorbed moderately.

Table III.B.1.e. Distribution of 14 Elements onto Ionsiv™ TIE-96 Absorber from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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 Kds of lanthanides, uranium, and americium from basic solution approximately doubled.

Table III.B.1.f. Distribution of 14 Elements onto Ionsiv™ TIE-96 (Modified) Absorber from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

g. Duolite™ CS-100 Resin. Duolite™ CS-100 is a phenolic resin 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 sorbs zirconium, plutonium, and technetium (but not cesium) from acidic solution. Only uranium is sorbed to a useful extent from basic solution.

Table III.B.1.g. Distribution of 14 Elements onto Duolite™ CS-100 Cation Exchange Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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 acidic solution, although the sorption kinetics are slow. Only uranium is sorbed with a Kd higher than 5 from basic solution, and again the sorption kinetics appear slow.

Table III.B.1.h. Distribution of 14 Elements onto Tannin Absorber from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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

The low Kd of 3 for strontium from acid is nearly matched by that for technetium, and is exceeded by Kds for uranium and plutonium. Technetium, strontium, and uranium sorb from basic solution. Some solution discoloration, observed in basic solution, indicated that Sr-Spec™ might be somewhat unstable in this medium.

Table III.B.1.i. Distribution of 14 Elements onto Sr-Spec™ Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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.

Plutonium and uranium sorb reasonably well from acid, while technetium and zirconium sorb weakly. Lanthanides, americium, uranium, and technetium sorb well from basic solution.

Table III.B.1.j. Distribution of 14 Elements onto TRU-Spec™ Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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

None of the 14 elements sorbs significantly from acidic solution, but cesium sorbs from basic solution.

Table III.B.1.k. Distribution of 14 Elements onto Durasil™ 190 Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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

Zirconium and cesium sorb from acidic solution. Cesium sorbs selectively from basic solution.

Table III.B.1.l. Distribution of 14 Elements onto Durasil™ 230 Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

m. Bone Char Absorber. Bone char, formed by calcining cattle bones in the absence of air, was obtained from Stauffer Chemical Company, Westport, CT. Bone char is predominantly calcium phosphate.

None of the 14 elements sorbs at useful levels from acidic solution, but lanthanides, americium, technetium, cobalt, and zinc sorb from basic solution.

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 ml, was 0.352 g.

Table III.B.1.m. Distribution of 14 Elements onto Bone Char Absorber from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

Technetium sorbs well from both acidic and basic solutions. Plutonium sorbs well, while uranium and cerium sorb moderately from acidic solution. Uranium sorbs somewhat less from basic solution.

Table III.B.1.n. Distribution of 14 Elements onto Reillex™ HPQ Anion Exchange Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	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
	U[a]	20	23	23
	Pu	78	274	485
	Pu[a]	131	184	205
	Am	3.9	2.4	2.4
	Am[a]	4.6	3.6	3.8
Alkaline 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

[a] These solutions contained 60 mg Pu/L; all others contained 3 g Pu/L.

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 ml, was 0.359 g.

Plutonium, technetium, uranium, and cerium sorb from acidic solution. We note that the sorptions of yttrium and americium from acid are significantly less than the sorption of cerium, which may provide an exploitable cerium-selective partitioning system. Technetium is well sorbed and cerium is weakly sorbed from basic solution.

Table III.B.1.o. Distribution of 14 Elements onto Ionac™ SR-3 Anion Exchange Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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 ml, was 0.351 g.

Plutonium, technetium, uranium, and cerium sorb from acidic solution. Technetium sorbs well, whereas cerium and uranium sorb slightly from basic solution.

Table III.B.1.p. Distribution of 14 Elements onto Purolite™ A-520-E Anion Exchange Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	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
	U[a]	9.9	22	39
	Pu	13	51	415
	Pu[a]	45	186	260
	Am	2.9	4.2	3.2
	Am[a]	2.7	4.2	3.7
Alkaline 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

[a] These solutions contained 60 mg Pu/L; all others contained 3 g Pu/L.

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 ml, was 0.462 g. Ionac™ SR-6 resin has been reported[10] to offer greatly increased selectivity for nitrate ion from groundwater.

This resin is quite selective for technetium, which sorbs moderately from acidic solution, but sorbs strongly from basic solution.

Table III.B.1.q. Distribution of 14 Elements onto Ionac™ SR-6 Anion Exchange Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

2. Experimental Absorbers. Eight experimental absorbers were included in our study.

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 ml, was 0.365 g. This resin was shown in a previous study[11] to significantly increase the sorption of Pu(IV) from dilute nitric acid.

The behavior of this experimental resin is similar to that of Purolite A-520-E resin (its commercial equivalent), except for the lower sorption of cerium from alkaline solution.

Table III.B.2.a. Distribution of 14 Elements onto Sybron $(Et)_3N$ Anion Exchange Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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 ml, was 0.406 g.

Only technetium and uranium are significantly sorbed from acidic solution, whereas cerium is weakly sorbed. Technetium is well sorbed, and uranium is weakly sorbed, from basic solution.

Table III.B.2.b. Distribution of 14 Elements onto Sybron $(Pr)_3N$ Anion Exchange Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

The three following JSK experimental resins are custom-synthesized anion exchangers whose composition cannot be disclosed until our 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 product.

c. JSK-1 Anion Exchange Resin. From acidic solution, plutonium is strongly sorbed, whereas cerium, technetium, and uranium sorb at lower, but useful levels. Zirconium and yttrium sorption from acid are low. Only technetium sorbs well from basic solution; zinc, uranium, and americium sorb slightly from basic solution.

Table III.B.2.c. Distribution of 14 Elements onto JSK-1 Experimental Anion Exchange Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	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
	U[a]	13	12	11
	Pu	83	143	196
	Pu[a]	178	249	254
	Am	7.4	6.5	5.9
	Am[a]	8.3	7.0	6.6
Alkaline 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

[a] These solutions contained 60 mg Pu/L; all others contained 3 g Pu/L.

d. JSK-2 Anion Exchange Resin. Plutonium sorbs well from acidic solution, while cerium, technetium, uranium, and americium sorb at lower levels. Only technetium sorbs at a useful level from basic solution.

Table III.B.2.d. Distribution of 14 Elements onto JSK-2 Experimental Anion Exchange Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	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
	U[a]	20	17	17
	Pu	142	278	422
	Pu[a]	329	337	261
	Am	8.4	7.9	7.6
	Am[a]	9.4	7.7	7.2
Alkaline Supernate	Ce	0.6	—	1.2
	Cs	0.1	—	0.3
	Sr	0.2	—	0.5
	Tc	50	—	51
	Y	<0.1	—	0.5
	Cr	<0.1	—	0.6
	Co	0.1	—	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	—	0.5
	U	1.3	1.2	1.2
	Pu	0.2	0.3	0.1
	Am	1.8	1.2	1.1

[a] These solutions contained 60 mg Pu/L; all others contained 3 g Pu/L.

e. JSK-3 Anion Exchange Resin. The sorption of plutonium is significantly greater than on any other absorber from acidic solution, whereas the sorption of other elements from acidic and basic solution is similar to that of JSK-2 resin. The exceptionally high sorption of plutonium from acid exceeds that of the next best absorber, Reillex™ HPQ resin, by an order of magnitude.

Table III.B.2.e. Distribution of 14 Elements onto JSK-3 Experimental Anion Exchange Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	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
	U[a]	18	17	17
	Pu	1053	1035	1173
	Pu[a]	870	1650	2185
	Am	6.2	5.3	5.0
	Am[a]	7.9	6.3	6.0
Alkaline 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

[a] These solutions contained 60 mg Pu/L; all others contained 3 g Pu/L.

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 functionality contained in the polymer selectively sorbs certain metal ions [e.g., Hg(II) and Cd(II)] from solutions of pH > 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.

Plutonium, technetium, and uranium sorb at useful levels from acidic solution, while cerium and zirconium are weakly sorbed. Only technetium offers useful Kds from basic solution.

Table III.B.2.f. Distribution of 14 Elements onto Crypt-DER Polymer Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

g. PK-01-244 Phosphinic Acid Resin. This PK-01-244 phosphinic acid cation exchanger, prepared by Prof. Spiro Alexandratos at the University of Tennessee, was stated to contain 45% water. We followed the accompanying directions to avoid drying this resin and took 455-mg portions that should have contained 250 mg of the dry resin.

Only cesium and technetium exhibit a Kd consistently higher than 1 from either acidic or basic solution.

Table III.B.2.g. Distribution of 14 Elements onto PK-01-244 Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

h. SRS Formaldehyde/Resorcinol Resin. Jane Bibler of Savannah River Site (SRS), who provided this formaldehyde/resorcinol resin, recommended that we convert it from the as-received potassium form to a sodium form. This was done by passing ten volumes of 10% NaOH solution through a column of potassium-form resin, followed by 15 column volumes of water, after which the resin was air-dried. The air-dried weight, per water-wet ml, was 0.254 g.

Chromium, technetium, and cesium sorb somewhat from acidic solution. Cesium sorbs well from basic solution, but is accompanied by significant levels of many other elements.

Table III.B.2.h. Distribution of 14 Elements onto SRS Formaldehyde/Resorcinol Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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.[12]

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

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 ml, was 0.231 g.

Zirconium is strongly sorbed from acidic solution, albiet with slow kinetics; only plutonium offers even weak competition. Uranium is strongly sorbed from basic solution, while several other elements are slightly sorbed.

Table III.B.3.a. Distribution of 14 Elements onto TiO-PAN Composite Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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 ml, was 0.231 g.

This absorber appears to be selective for cesium from acidic solution. From basic solution, cesium sorbed strongly, zinc is well sorbed, cobalt is moderately sorbed, and uranium and iron are slightly sorbed.

Table III.B.3.b. Distribution of 14 Elements onto NiFC-PAN Composite Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline Supernate	Ce	0.3	0.3	0.2
	Cs	3533	11954	5998
	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

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 ml, was 0.226 g.

Zirconium and several other elements are slightly sorbed from acidic solution. Because this absorber was unstable in basic solution, distributions in basic solution could not be measured. The observed resin swelling and solution discoloration indicated some instability, even in acidic solution.

Table III.B.3.c. Distribution of 14 Elements onto MgO-PAN Composite Resin from Acid-Dissolved Sludge Simulant for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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

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 ml, was 0.210 g.

Zirconium, plutonium, and a few other elements sorb somewhat from acidic solution. Cerium and americium show a more than tenfold higher sorption from basic solution than yttrium. Uranium, chromium, and iron are moderately sorbed from basic solution.

Table III.B.3.d. Distribution of 14 Elements onto MnO-PAN Composite Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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 ml, was 0.305 g.

This absorber appears to be selective for zirconium and plutonium from acidic solution. Cesium, chromium, cerium, and americium sorb weakly-to-moderately from basic solution.

Table III.B.3.e. Distribution of 14 Elements onto NaY-PAN Composite Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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 ml, was 0.222 g.

This absorber shows good selectivity for cesium and zirconium from acidic solution, and for cesium from basic solution.

Table III.B.3.f. Distribution of 14 Elements onto M315-PAN Composite Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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 ml, was 0.324 g.

Zirconium is moderately sorbed and cesium is weakly sorbed from acidic solution. Zinc is well sorbed from basic solution, whereas many other elements are moderately or weakly sorbed.

Table III.B.3.g. Distribution of 14 Elements onto NaTiO-PAN Composite Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

h. $Ba(Ca)SO_4$-PAN Barium/Calcium Sulfate Composite. The barium/calcium sulfate content of the dry $Ba(Ca)SO_4$-PAN composite was 85%. The air-dried weight of this composite, per water-wet ml, was 0.198 g.

Several elements are weakly sorbed from acidic solution, but none at useful levels. Strontium and cerium are moderately sorbed from basic solution.

Table III.B.3.h. Distribution of 14 Elements onto $Ba(Ca)SO_4$-PAN Composite Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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 ml, was 0.235 g.

Cesium is strongly and selectively sorbed from acidic solution. Cesium also is strongly sorbed from basic solution, but is accompanied by lanthanides and americium.

Table III.B.3.i. Distribution of 14 Elements onto AMP-PAN Composite Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	Ce	0.4	0.2	0.4
	Cs	1626	4072	5504
	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
Alkaline Supernate	Ce	12	22	28
	Cs	2133	4636	8275
	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

4. Phenolsulfonic-Formaldehyde 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 composite resins, the inorganic exchanger is dispersed in a matrix of phenolsulfonic-formaldehyde.[13]

a. Titanium Hexacyanoferrate Composite. The titanium hexacyanoferrate content of this composite was approximately 17%.

Cesium is weakly sorbed from acidic solution. Cesium is more strongly sorbed from basic solution, although the sorption kinetics appear slow. Several other elements are moderately or weakly sorbed from basic solution.

Table III.B.4.a. Distribution of 14 Elements onto Titanium Hexacyanoferrate Composite Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

b. Cobalt Hexacyanoferrate Composite. The cobalt hexacyanoferrate content of this composite was approximately 20%.

Cesium is moderately sorbed, and several other elements are weakly sorbed from acidic solution, although the sorption kinetics are slow. Cesium is more strongly sorbed from basic solution, again with slow sorption kinetics. Several other elements are moderately or weakly sorbed from basic solution.

Table III.B.4.b. Distribution of 14 Elements onto Cobalt Hexacyanoferrate Composite Resin from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

5. LANL-Prepared Composites. Metal phosphate composites were prepared 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. and 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.

a. Zirconium Phosphate. An 8.75-g portion of solid $ZrCl_4$ was dissolved (with quite a vigorous reaction) in 50 ml of 1.5 M HCl. This solution was added to 50 ml of wet Duolite™ C-467 resin and mixed on an extraction wheel for 2 h. The zirconium-loaded resin then was transferred to a column, washed with an excess of 0.5 M HCl, rinsed well with water, and air-dried.

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

None of the 14 elements studied sorbs at useful levels from acidic or basic solution.

Table III.B.5.a. Distribution of 14 Elements onto Zirconium Phosphate Composite from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

b. Titanium Phosphate. A 7.10-g portion of liquid $TiCl_4$ was mixed (with quite a vigorous reaction) in 50 ml of 1.5 M HCl. This solution was added to 50 ml of wet resin and mixed on an extraction wheel for 2 h. The titanium-loaded resin then was transferred to a column, washed with an excess of 0.5 M HCl, rinsed well with water, and air-dried.

After stepwise heating to 600°C, the weight of an initial 5.610 g 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%). This 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 this study.

None of the 14 elements sorbs at useful levels from acidic or basic solution.

Table III.B.5.b. Distribution of 14 Elements onto Titanium Phosphate Composite from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

Metal oxide composites were prepared by sorbing a dilution of the appropriate metal alkoxide into the pores of Ambersorb™ 563 porous carbon beads and allowing the volatile diluent to evaporate. The loaded Ambersorb™ beads then were heated in dilute acid to hydrolyze the metal alkoxide to the corresponding metal oxide,[14] after which the beads were air-dried to constant weight.

c. Titanium Dioxide. A 30-ml portion of titanium butoxide was diluted with 60 ml of cyclohexane. Then 79.1 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas, Philadelphia, PA, was added to absorb the liquid. After the volatile solvent evaporated, the beads were heated 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 Ambersorb™ beads). Assuming the TiO_2 was anhydrous, which it is not, this would represent 2.4 mmoles of Ti per initial g of Ambersorb™ beads.

Technetium and zirconium sorb from acidic solution, although the sorption kinetics are slow. Technetium is more strongly sorbed and uranium is moderately sorbed from basic solution.

Table III.B.5.c. Distribution of 14 Elements onto Titanium Dioxide Composite from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

d. Zirconium Dioxide. A 30-ml portion of zirconium butoxide.butanol was diluted with 60 ml of cyclohexane. Then 80.4 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas, Philadelphia, PA, was added to absorb the liquid. After the volatile solvent evaporated, the beads were heated in 0.1 M nitric acid for 2 h. The loaded beads were washed with an excess of water and then air-dried to yield 91.33 g (123.2 % of the added Ambersorb™ beads). Assuming the ZrO_2 was anhydrous, which it is not, this would represent 1.1 mmoles of Zr per initial g of Ambersorb™ beads.

Technetium is well sorbed and zirconium is weakly sorbed from acidic solution, both with slow sorption kinetics. Technetium is more strongly and selectively sorbed from basic solution, again with slow sorption kinetics.

Table III.B.5.d. Distribution of 14 Elements onto Zirconium Dioxide Composite from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

e. Niobium Pentoxide. A 50-ml portion of niobium ethoxide was diluted with 100 ml of cyclohexane. Then 113.9 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas, Philadelphia, PA, was added to absorb the liquid. After the volatile solvent evaporated, the beads were heated in 0.1 M nitric acid for 2 h. The loaded beads were washed with an excess of water and air-dried to yield 140.30 g (123.2 % of the added Ambersorb™ beads). Assuming the Nb_2O_5 was anhydrous, which it is not, this would represent 1.7 mmoles of Nb per initial g of Ambersorb™ beads.

Technetium and zirconium sorb moderately from acidic solution. Technetium is more strongly sorbed from basic solution, although with slow sorption kinetics. Several other elements sorb moderately or weakly from basic solution.

Table III.B.5.e. Distribution of 14 Elements onto Niobium Pentoxide Composite from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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

a. LIX™-1010. Ten ml of LIX™-1010 (di-2-ethylhexylphosphoric acid) was diluted with 20 ml of cyclohexane, after which 25.76 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, was added to absorb the liquid. The cyclohexane evaporated to yield 34.7 g of the loaded Ambersorb™ beads.

Zirconium is moderately sorbed and technetium is weakly sorbed from acidic solution, both with slow sorption kinetics. From basic solution, americium sorption is significantly greater than lanthanides sorption, which demonstrates a potential for an efficient trivalent actinide/lanthanide group separation. Uranium, zinc, and manganese are moderately sorbed from basic solution.

Table III.B.6.a. Distribution of 14 Elements into LIX™-1010 from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

b. LIX™-54. Ten ml of LIX™-54 (a beta diketone) was diluted with 20 ml of cyclohexane, after which 26.80 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, was added to absorb the liquid. The cyclohexane evaporated to yield 34.6 g of the loaded Ambersorb™ beads.

Zirconium is weakly sorbed from acidic solution. From basic solution, the sorption of americium is significantly greater than that of lanthanides, which demonstrates a potential for an efficient trivalent actinide/lanthanide group separation. Uranium, iron, manganese, plutonium, and technetium are weakly to moderately sorbed from basic solution.

Table III.B.6.b. Distribution of 14 Elements into LIX™-54 from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

c. LIX™-84. Ten ml of LIX™-84 (a ketoxime) was diluted with 20 ml of cyclohexane, after which 26.13 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, was added to absorb the liquid. The cyclohexane evaporated to yield 34.8 g of the loaded Ambersorb™ beads.

None of the 14 elements was significantly sorbed from acidic or basic solution.

Table III.B.6.c. Distribution of 14 Elements into LIX™-84 from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

d. LIX™-26. Ten ml of LIX™-26 (8-hydroxyquinoline) was diluted with 20 ml of cyclohexane, after which 26.90 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, was added to absorb the liquid. The cyclohexane evaporated to yield 37.1 g of the loaded Ambersorb™ beads.

Plutonium is moderately sorbed, whereas uranium and technetium are weakly sorbed from acidic solution. Technetium, cerium, americium, and uranium sorb at useful levels from basic solution.

Table III.B.6.d. Distribution of 14 Elements into LIX™-26 from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

e. CYANEX™ 923. Ten ml of Cyanex™ 923 (trialkylphosphine oxide) was diluted with 20 ml of cyclohexane, after which 26.83 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, was added to absorb the liquid. The cyclohexane evaporated to yield 36.8 g of the loaded Ambersorb™ beads.

From acidic solution, plutonium, zirconium, uranium, and technetium sorb moderately with slow sorption kinetics. Technetium, lanthanides, americium, and uranium sorb strongly from basic solution. This extractant demonstrates an outstanding ability to recover many targeted elements from alkaline supernate solution.

Table III.B.6.e. Distribution of 14 Elements into CYANEX™ 923 from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	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
	U[a]	2.7	6.5	14
	Pu	3.0	7.6	21
	Pu[a]	21	100	199
	Am	0.3	0.3	0.3
	Am[a]	0.4	0.4	0.4
Alkaline 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

[a] These solutions contained 60 mg Pu/L; all others contained 3 g Pu/L.

f. CYANEX™ 272. Ten ml of Cyanex™ 272 (trimethylpentylphosphoric acid) was diluted with 20 ml of cyclohexane, after which 26.49 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, was added to absorb the liquid. The cyclohexane evaporated to yield 37.1 g of the loaded Ambersorb™ beads.

Zirconium is strongly and selectively sorbed from acidic solution, although the sorption kinetics are slow. Uranium is selectively sorbed at a useful level from basic solution.

Table III.B.6.f. Distribution of 14 Elements into CYANEX™ 272 from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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

Plutonium is moderately sorbed, whereas uranium and technetium are weakly sorbed from acidic solution. From basic solution, technetium, cerium, americium, and uranium are well sorbed, whereas yttrium is weakly sorbed.

Table III.B.6.g. Distribution of 14 Elements into DHDECMP from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

h. DHDECMP-DIPB. Ten ml of DHDECMP was diluted with 10 ml of DIPB (diisopropylbenzene) and 30 ml of cyclohexane, after which 48.45 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, was added to absorb the liquid. The cyclohexane evaporated to yield 65.3 g of the loaded Ambersorb™ beads.

Plutonium is moderately sorbed from acidic solution. From basic solution, technetium, cerium, americium, and uranium are sorbed at useful levels, whereas yttrium is weakly sorbed.

Table III.B.6.h. Distribution of 14 Elements into DHDECMP-DIPB from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

i. CMPO-DIPB. Ten ml of CMPO (octylphenyl-N,N-diisobutylcarbamoyl-methylphosphine oxide), obtained from M&T Chemicals, Inc., Rahway, NJ, was diluted with 10 ml of DIPB (diisopropylbenzene) and 30 ml of cyclohexane, after which 46.83 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, was added to absorb the liquid. The cyclohexane evaporated to yield 64.1 g of the loaded Ambersorb™ beads.

None of the 14 elements sorbed at useful levels from acidic solution. Technetium, cerium, americium, uranium, and yttrium are well sorbed from basic solution, although the sorption kinetics are slow.

Table III.B.6.i. Distribution of 14 Elements into CMPO-DIPB from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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

Plutonium is moderately sorbed from acidic solution. In basic solution, technetium is strongly sorbed with high selectivity and only uranium is cosorbed to a significant extent. This extractant demonstrates an outstanding ability to selectively recover technetium from alkaline supernate solution.

Table III.B.6.j. Distribution of 14 Elements into Aliquat™ 336 from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

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

Technetium sorbs moderately, with slow sorption kinetics, from acidic and basic solution.

Table III.B.6.k. Distribution of 14 Elements into Czech Cobalt Dicarbollide from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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

l. INC-Synthesized Cobalt Dicarbollide. A 98.1-mg portion of cobalt dicarbollide prepared by the LANL Isotope and Nuclear Chemistry (INC) Division was dissolved in 1.816 g of nitrobenzene and 1 ml of ethanol. Then 2.270 g of Ambersorb™ 563 porous carbon beads, obtained from Rohm & Haas Co., Philadelphia, PA, was added to absorb the liquid. The ethanol evaporated to yield 3.64 g of the loaded, dry-appearing Ambersorb™ beads.

Moderate sorption of technetium and low sorption of cesium occur from acidic and basic solution, also with slow sorption kinetics.

Table III.B.6.l. Distribution of 14 Elements into INC-Synthesized Cobalt Dicarbollide from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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. SNL Absorbers. The materials designated as SNL/CST are a new class of inorganic ion-exchangers called crystalline silico-titanates (CSTs). These materials, jointly invented by SNL and Texas A&M University (a patent application has been filed), show significant potential for removal of cesium from defense wastes that are > 5 M Na^+ and > 1 M OH^-. The numerical values in the absorber designations represent different synthesis procedures. CST materials are very fine powders composed of cuboidal crystals with particle sizes of several hundred Angstroms.

Screening studies on these materials at SNL have indicated the selectivity for cesium removal is SNL/CST35 < SNL/CST48 < SNL/CST68 < SNL/CST69 < SNL/CST84 < SNL/CST111. SNL/CST84 and SNL/CST111 are markedly different from the other absorbers in terms of their synthesis; they contain a dopant, with the dopant/CST ratio highest for SNL/CST111. SNL investigations have demonstrated that the presence of the dopant significantly increases the value of the distribution coefficient, as well as the structural stability of the CST material in highly alkaline solutions.

As discussed in Section II.D., the unusually large variation in Kd values obtained with CST absorbers indicates that submicron CST particles sometimes contaminated the solution taken for gamma spectrometric assay. The inadvertent introduction of particles into the assay solution would, however, always cause us to understate the actual Kds for removing cesium from solution. Our reported Kd values for cesium sorption from the CST materials may therefore be considered as minimum values.

In a few other cases, the Kd values for non-cesium elements decrease with increasing contact time. SNL personnel suggested that this could be caused by a small amount of an amorphous phase in the crystalline material, which appears to preferentially sorb certain non-cesium elements. However, because the amorphous phase slowly dissolves, some of the initially sorbed element is released, causing the apparent Kd value to decrease with increased contact time.

a. SNL/CST35 Crystalline Silico-Titanate. Cesium is very strongly and quite selectively sorbed from acidic solution; only zirconium cosorbs to a significant extent. Cesium is sorbed even more strongly from basic solution, and uranium also is sorbed at useful levels from this medium.

Table III.B.7.a. Distribution of 14 Elements onto SNL/CST35 from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline Supernate	Ce	2.9	2.1	6.7
	Cs	13158	12421	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

b. SNL/CST48 Crystalline Silico-Titanate. Cesium is very strongly and selectively sorbed from acidic solution; only zirconium cosorbs to a significant extent. Cesium sorbs even more strongly from basic solution, although the selectivity is not as high.

Table III.B.7.b. Distribution of 14 Elements onto SNL/CST48 from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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/CST68 Crystalline Silico-Titanate. Cesium is very strongly and selectively sorbed from acidic solution; only zirconium is cosorbed to a significant extent. Cesium is sorbed even more strongly from basic solution, although the selectivity is not as high. The decreasing Kd values for cesium may be real, or they may reflect incomplete filtration of the submicron absorber particles from the assay solutions.

Table III.B.7.c. Distribution of 14 Elements onto SNL/CST68 from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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
Alkaline 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/CST69 Crystalline Silico-Titanate. Cesium is very strongly and selectively sorbed from acidic solution; only zirconium cosorbs to a significant extent. Cesium is sorbed even more strongly from basic solution, although the selectivity is not as high.

Table III.B.7.d. Distribution of 14 Elements onto SNL/CST69 from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
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	14[a]	115
	U	0.7	1.1	1.2
	Pu	3.4	3.8	4.5
	Am	0.6	0.3	0.3
Alkaline Supernate	Ce	4.0	4.2	14
	Cs	8879	10844	20880
	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

[a] This Kd value obviously is in error and should be ignored.

e. SNL/CST84 Crystalline Silico-Titanate. Cesium is very strongly and selectively sorbed from acidic solution; only zirconium cosorbs to a significant extent. The decreasing Kd values for zirconium from acidic solution (while cesium Kd values increase) may reflect the slow dissolution of an amorphous phase that preferentially sorbs zirconium. Cesium is sorbed well from basic solution, although the selectivity is not as high.

Table III.B.7.e. Distribution of 14 Elements onto SNL/CST84 from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	Ce	0.4	0.1	0.5
	Cs	1849	8096	11840
	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
Alkaline 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/CST111 Crystalline Silico-Titanate. Cesium is very strongly and selectively sorbed from acidic solution; only zirconium cosorbs to a significant extent. Cesium is sorbed well from basic solution, although the selectivity is not as high. The decreasing Kd values for cesium from basic solution may be real, or they may reflect incomplete filtration of the submicron absorber particles from the assay solutions.

Table III.B.7.f. Distribution of 14 Elements onto SNL/CST111 from Two Simulant Solutions for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	Ce	1.0	0.9	1.0
	Cs	3420	5021	5305
	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
Alkaline 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

g. SNL/HTO Amorphous Hydrous TiO_2. As expected, the behavior of this hydrous titanium oxide is very different from that of the crystalline silico-titanates. Cerium, americium, uranium and yttrium sorb well, whereas chromium, zinc, cesium, and zirconium sorb moderately from basic solution.

Table III.B.7.g. Distribution of 14 Elements onto SNL/HTO from Simulated Alkaline Supernate Solution for Hanford HLW Tank 102-SY

Medium	Absorber	30-min Kd	2-h Kd	6-h Kd
Acid-Dissolved Sludge	At the recommendation of SNL personnel, SNL/HTO was not tested in acid.			
Alkaline 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

IV. ELUTION CONSIDERATIONS

The purpose of this study was to screen a large number of candidate absorbers and identify those that show promise for specific elements. Although elution was not a part of our study, we recognize that elution of the sorbed species from the selected absorbers is essential if the absorbers are to be reused in a process. We therefore plan to investigate the elution characteristics of selected absorbers in the next phase of this study.

We can, however, offer some general comments about elution. Elution often can be achieved by (1) acidity changes, (2) oxidation state changes, (3) complexation, or (4) displacement. Because our present study reports distribution data from both acidic and basic simulant solutions, it often indicates whether acidity changes might elute a given species. In cases in which a specific oxidation state is strongly sorbed on an absorber, another oxidation state of that same element may not be sorbed, and conversion to this other oxidation state may achieve elution. In still other cases, the sorbed species may be capable of forming a strong complex with certain complexants, which can be used as eluting agents. Finally, sorbed species can sometimes be displaced by loading the absorber to capacity with another ion that is more strongly sorbed.

Because elution operations usually generate additional waste, we plan to emphasize waste minimization in the elution options we evaluate in the next phase of this study. One option worth considering is that of not eluting the sorbed species from the absorber. For example, this option is attractive in the case of the absorbers developed by SNL and Texas A&M because cesium appears to be irreversibly sorbed with very high Kd values on silico-titanates. Moreover, the silico-titanates provide an inorganic matrix that can be pressed into dense pellets suitable for long-term storage. In this case, elution may be unwise and unnecessary.

Ammonium molybdophosphate (AMP) offers cesium Kd values from acidic and basic solution nearly as high as those on silico-titanates. Moreover, cesium can be eluted from AMP with 5 M ammonium chloride.[15] A very attractive possibility is eluting cesium with ammonium chloride, distilling and collecting the water, followed by sublimation of ammonium chloride at 355°C, but not cesium chloride, whose sublimation temperature is 1290°C. The water and ammonium chloride could then be combined and recycled to elute the next batch of cesium, which could provide highly concentrated cesium, while generating zero secondary waste in the elution step. This is an example of innovative chemistry that can minimize secondary-waste generation.

V. FUTURE STUDIES

Our screening study has met its objective of identifying specific absorbers that seem capable of partitioning targeted elements from Hanford HLW Tank 102-SY. The best absorbers from this study and perhaps a few promising new materials should be evaluated with simulant compositions that represent other Hanford tanks, especially those on the safety watch-list. The 14 elements whose distributions have been measured should be reviewed to determine if any should be deleted or if additional elements should be incorporated in future measurements. Finally, radioactive tracers, which provide a rapid, reliable, and inexpensive way to obtain large amounts of distribution data, should be used in future studies.

The effect of ionizing radiation is an important factor to consider when selecting materials to be used in processing radioactive waste solutions. 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,[16] before any large-scale recovery flowsheet is selected.

VI. CONCLUSIONS

1. Our screening study of many absorbers from realistic simulants has met our initial objective of identifying numerous promising absorbers. Many of the separations required for the remediation of Hanford HLW Tank 102-SY can be achieved using available absorbers and existing, proven technology.
2. Radioactive tracers, as used in our study, provide a reliable and cost-effective way to rapidly obtain large amounts of distribution data. Follow-on studies should measure the distribution of key elements from other Hanford waste tank compositions onto the most promising absorbers identified by this study.
3. The performance of the 60 absorbers tested with these complex, high-salt media is often much different from published results for similar absorbers tested in relatively clean systems.
4. Elements for which good-to-excellent sorption has been demonstrated from simulated acid-dissolved sludge are cerium, cesium, technetium, zirconium, uranium, and plutonium. Elements that show low sorption from acidic solution are strontium, yttrium, chromium, cobalt, iron, manganese, zinc, and americium.
5. Elements for which good-to-excellent sorption has been demonstrated from alkaline supernate simulant solution are cerium, cesium, technetium, yttrium, zinc, uranium, and americium. Elements that show lower-than-desirable sorption from alkaline solution are strontium, chromium, cobalt, iron, manganese, zirconium, and plutonium.
6. Low-cost partitioning agents, such as Aliquat™ 336, Cyanex™ 923, and Reillex™ HPQ, often outperform other materials whose cost is hundreds of times higher.
7. Certain extractants, such as LIX-1010 and LIX-54, exhibit a large preference for americium over cerium and yttrium from basic solution, which indicates that a lanthanide/trivalent actinide group separation should be readily attainable. Elimination of lanthanides from the trivalent actinide fraction has been estimated to reduce the required number of glass logs by 5000,[5] which could save approximately $5 billion.
8. Experimental anion exchange resins under development by LANL, referred to as JSK resins in this report, offer major advantages over the best previously known resins for removing plutonium from HLW media. An increased priority should be assigned to the development and commercial production of these resins.
9. Even the best partitioning agents for strontium provide only low-to-moderate Kd values, which may be inadequate for reliable separations under process conditions. Near-term efforts should focus on identifying or developing improved absorbers for strontium.
10. Iron, manganese, and chromium show low Kd values on most of the 60 absorbers evaluated. Because these elements are present at significant concentrations in many Hanford waste tanks, however, even low Kds could result in sufficiently high loadings of some absorbers to

decrease their capacity for other elements. All Kds that we measured and report reflect realistic competition from these major matrix elements and therefore reflect what might be obtained with actual waste solution.

11. Measured Kd values for cobalt are low on all 60 absorbers from acidic solution and are only marginal from alkaline solution. If cobalt is to be removed from HLW solutions, other absorbers or extractants must be identified or developed.
12. Although elution was not a part of our study, the fact that we measured distributions from both acidic and basic solutions often indicates whether a change in acidity might elute a given element from a specific absorber.
13. SNL silico-titanate materials show outstanding sorption of cesium from acidic and basic simulant solutions. Because the sorption of cesium appears to be irreversible on silico-titanates, this matrix should be considered as a final waste form. Although there is concern that the high titanium content of these absorbers can easily exceed the assigned 1% limit for titanium in glass logs, the actual tolerance for titanium in glass (currently being measured) may be higher. Other waste forms, such as mineral analogues or different glass compositions, also may be compatible with silico-titanate absorbers. The excellent resistance of silico-titanates to loss of cesium by leaching may even allow this absorber to be safely incorporated in grout.

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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. Yarbro, W. A. Punjak, S. B. Schreiber, S. L. Dunn, G. D. Jarvinen, S. F. Marsh, S. F. Agnew, E. Birnbaum, and K. W. Thomas, "Status of Tank 102-SY Remediation Flowsheet Development at LANL," Los Alamos National Laboratory report LA-UR-93-1725 (April 1993).

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 TWRSPP-92-011 (June 9, 1992 draft).

9. R. Gunnink and J. B. Niday, "Computerized Quantitative Analysis by Gamma-Ray Spectrometry. Vol. 1. Description of the Gamanal Program," Lawrence Livermore Laboratory report UCRL-51061, Vol. 1 (March 1972).

10. F. X. McGarvey and R. Gonzales, "Ion Exchange Studies on Strongly Basic Anion Exchange Resins Prepared with Tertiary Amines of Varying Molecular W' ight," in *Ion Exchange Advances, Proceedings of IEX '92*, M. J. Slater, Ed. (Elsevier Science Publishing Ltd., Essex, England, 1992), pp. 97-103.

11. 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.

12. 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.

13. 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).

14. 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.

15. F. Sebesta and V. Stefula, "Composite Ion Exchanger with Ammonium Molybdophosphate and its Properties," *J. Radioanalyt. Nucl. Chem.*, Articles, **140**(1), 15-21 (1990).

16. S. F. Marsh and K. K. S. Pillay, "Effects of Ionizing Radiation on Modern Ion Exchange Materials," Los Alamos National Laboratory report LA-12655 (October 1993).

APPENDIX A

Preparation of Acid-Dissolved Sludge Simulant

The composition for Hanford Tank 102-SY sludge was provided by Westinghouse Hanford Company (WHC) personnel in letter 7K321-92-RAK-02. However, aside from the 0.6 M phosphate value in the single tank sample cited by WHC, no other 102-SY sample contained more than 0.11 M phosphate, and the phosphate level of most samples was near 0.05 M. For these reasons, we adjusted the initial phosphate level from the WHC-recommended value of 0.6 M to 0.1 M.

We further adjusted the sludge composition to reflect partial dissolution during the planned mixing of HLW Tank 102-SY supernate and solids during retrieval operations.

Lumetta and Swanson[8] estimated that dilute caustic washing would remove 69% of the initial Al, 17% of the initial Cr, and 10% of the initial Pb. Lumetta also agreed with our decision to change the initial phosphate level to 0.1 M and estimated that washing the sludge with dilute caustic solution would leach out 90% of the phosphate, 90% of the chloride, 90% of the sulfate, and 75% of the fluoride.

Using these figures as guidelines, we recalculated the composition of Tank 102-SY sludge, as it would exist after washing with the alkaline supernate solution. We then prepared the recalculated simulant composition in a minimum concentration of nitric acid to represent caustic-washed, acid-dissolved sludge. Lumetta agreed that this would represent the most realistic simulant of the feed for a partitioning process.

Table A. Composition of Acid-Dissolved Sludge Simulant

Component	Initial Conc., M	Factor	Adjusted Conc., M
Al	1.65	0.31	0.51
Ca	0.16	1.0	0.16
Cr	0.48	0.83	0.40
Cu	0.02	1.0	0.02
Fe	0.45	1.0	0.45
K	0.08	0.10	0.008
Mg	0.07	1.0	0.07
Mn	0.165	1.0	0.165
Na	6.0	0.10	0.60
Ni	0.01	1.0	0.01
Pb	0.016	0.90	0.014
Se	0.03	1.0	0.03
Si	0.08	1.0	0.08
Sr	0.001	1.0	0.001
Th	0.03	1.0	0.03
U	0.03	1.0	0.03
Cl	0.15	0.10	0.015
F	0.30	0.25	0.075
PO_4	0.10	0.10	0.01
SO_4	0.10	0.10	0.01

To the composition shown in Table A, plutonium was added as ^{239}Pu to obtain 3 g Pu/L; in a few cases ^{238}Pu was added, instead, to obtain 60 mg Pu/L.

We assumed that all hydroxide would be neutralized and that all carbonate would decompose when the sludge is dissolved in acid.

PROCEDURE

The following components were combined:

Component	**Compound taken**	**Moles**	**Grams**
Ca	$Ca(NO_3)_2 \cdot 4H_2O$	0.16	37.8
Cr	$Cr(NO_3)_3 \cdot 9H_2O$	0.40	160
Cu	$Cu(NO_3)_2 \cdot 2.5H_2O$	0.02	4.65
Fe	$Fe(NO_3)_3 \cdot 9H_2O$	0.45	181.8
K	KNO_3	0.008	0.81
Mg	$Mg(NO_3)_2 \cdot 6H_2O$	0.07	17.9
Mn	$Mn(NO_3)_2$	0.165	57 ml 51% solution
Na	$NaNO_3$	0.44	37.4
Ni	$Ni(NO_3)_2 \cdot 6H_2O$	0.01	2.91
Pb	$Pb(NO_3)_2$	0.014	4.63
Sr	$Sr(NO_3)_2$	0.001	0.21

Then 0.51 mole of aluminum was added as 230 ml of 2.2 M $Al(NO_3)_3$ solution, swirled to mix, and allowed to sit overnight. The liquid portion, about 1/3 of the total, was decanted into a separate container. Then 100 ml of 0.5 M nitric acid was added to the solids and the mixture was warmed in a hot-water bath. Most of the solids dissolved. The remaining solids dissolved in another 100-ml portion of 0.5 M nitric acid.

Thorium was added to the solution:

Th	$Th(NO_3)_4 \cdot 5H_2O$	0.03	17.1

An appropriate portion of UO_2 was dissolved in 40 ml of water and 4 ml of concentrated nitric acid, and was added to the solution.

U	UO_2	0.03	8.1

The other anions were added as portions of the appropriate acid to 40 ml of water, which then was added to the stirred solution.

Cl	HCl	0.015	1.3 ml conc. acid
PO_4	H_3PO_4	0.01	0.7 ml conc. acid
SO_4	H_2SO_4	0.01	0.6 ml conc. acid

Sodium silicate was dissolved in 50 ml of warm water.

Si	$Na_2SiO_3 \cdot 9H_2O$	0.08	22.7

To this silicate solution, 2.6 ml (0.075 mole) of concentrated HF was added.

The silicate-fluoride solution was mixed well and added, with stirring, to the total solution. A precipitate formed immediately, but seemed to disperse as the solution was stirred and warmed in a hot-water bath.

Another 50 ml of 0.5 M nitric acid was added and stirred while the solution was being warmed.

Finally, 0.03 mole of selenium was added as 3.87 grams of H_2SeO_3, which was dissolved directly in the simulant solution. After cooling to room temperature, sufficient 0.5 M nitric acid was added to bring the solution volume to 1.00 liter.

Silica, which precipitated as expected, was removed by filtration after the simulant preparation was complete. We therefore recommend that future efforts to prepare acid-dissolved sludge simulants omit the silicate component, as it only creates a messy precipitate that must be removed.

APPENDIX B

Preparation of Simulated Alkaline Supernate Solution

The composition data for the supernate solution of Hanford Tank 102-SY was provided by Stephen Agnew of Group INC-14 at LANL, who based the composition on tank records and analytical results.[7] The supernate composition was adjusted to what would be expected after the tank contents were thoroughly mixed, that is, after thorough washing of the sludge with the alkaline supernate solution. This is appropriate because we took credit for what would be dissolved during sludge washing when we estimated the composition of the caustic-washed, acid-dissolved sludge simulant.

The highest concentration was used whenever there was a range of uncertainty for a given component, which resulted in an insoluble fraction that was removed by filtration. The fact that some portion of the metal ions remained undissolved even after we stirred the mixture continuously for 40 h assured us that the solution was saturated, as the actual supernate solution would be after sludge washing.

All components calculated to be present at a concentration of 0.01 M or higher are included in this simulated supernate solution.

We recognize that our best composition estimate does not provide an ionic balance. Our supernate solution therefore has significantly less sodium, more nitrate, and somewhat more chloride than the targeted amounts.

Table B. Composition of Simulated Alkaline Supernate Solution

Component	Target Conc., M	Actual Conc., M
Al	0.42	0.42
Ca	0.23	0.023
Cr(III)	0.074	0.074
Cr(VI)	0.0072	0.072
Fe	0.097	0.097
K	0.078	0.078
Mg	0.011	0.011
Mn	0.038	0.038
Na	2.34	**1.39**
Si	0.019	0.019
Cl^-	0.024	**0.046**
F^-	0.107	0.107
NO_3^-	0.867	**1.87**
NO_2^-	0.193	0.193
PO_4^{3-}	0.12	0.12
SO_4^{2-}	0.023	0.023
CO_3^{2-}	0.11	0.11
OH^-	0.54	0.54
Density	1.27	1.21

To the composition shown in Table B, $^{238}Pu(CO_3)_2$ was added to obtain 60 mg Pu/L.

PROCEDURE

The following components were combined:

Component	Compound taken	Moles	Grams
Ca	$CaCl_2$	0.023	2.55
Cr	$Cr(NO_3)_3 \cdot 9H_2O$	0.074	29.6
Cr(VI)	$K_2Cr_2O_7$	0.0072	2.12
Fe	$Fe(NO_3)_3 \cdot 9H_2O$	0.097	39.2
K	KOH	0.078	4.37
Mg	$Mg(NO_3)_2 \cdot 6H_2O$	0.011	2.81
Mn	$Mn(NO_3)_2$	0.038	13.3 g 51% solution

$Al(NO_3)_3$ was added as 190 ml of 2.2 M solution and mixed by swirling.

Al	$Al(NO_3)_3$ solution	0.42	190 ml

NaOH was added as 50% solution.

Na	NaOH soln.	0.538	43 g of 50% solution.

Most other anions then were added as the appropriate sodium salts.

Cl	(added above as $CaCl_2$)		
F	$NaHF_2$	0.107	3.32
PO_4	$Na_2HPO_4 \cdot 7H_2O$	0.061	16.4
NO_3	(added above as many salts)		
NO_2	$NaNO_2$	0.193	16.5
SO_4	Na_2SO_4	0.023	3.27
CO_3	$Na_2CO_3 \cdot H_2O$	0.111	13.8

Finally, sodium silicate was added.

Si	$Na_2SiO_3 \cdot 9H_2O$	0.08	22.7

The solution was diluted with water to nearly 1 liter and stirred continuously on a magnetic mixer for 40 h. Because a large amount of solids remained undissolved, the solution was centrifuged to separate most of the solids and then filtered. The settled undissolved solids occupied approximately 25 cc. After filtration, the solution was diluted to 1.00 liter with water.

The density of 1.21 for the filtered solution was somewhat lower than the density of 1.27 calculated by Stephen Agnew, which we attribute to the undissolved (and removed) solids.

DATE
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5/19/94

END