Chemical Separations Processes
for Plutonium and Uranium

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**DISTRIBUTION OF SELECTED
LANTHANIDES AND ACTINIDES BETWEEN
30% TBP IN n-PARAFFIN AND VARIOUS
METAL NITRATE SOLUTIONS**

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ABSTRACT

The distributions were measured for nitric acid, americium, curium, cerium, neodymium, samarium, europium, manganese, and mercury between 30 volume percent tributyl phosphate in n-paraffin and aqueous solutions containing nitric acid, aluminum nitrate, lithium nitrate, and/or sodium nitrate. Equations for the distributions were derived from the data and used in designing solvent extraction flowsheets for recovery and decontamination of americium and curium from irradiated plutonium-aluminum alloy. Also investigated was the effect of diethylenetriaminepentaacetic acid on the distribution of the actinides and lanthanides in the same systems. The actinides (Am and Cm) are more strongly complexed than the light lanthanides (La, Ce, Pr, and Nd) by diethylenetriaminepentaacetic acid. By controlling the solution pH in the range of 1 to 3, separation of actinides from lanthanides by factors of 10 to 100 may be obtained by extraction with 30% TBP.

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INTRODUCTION

The chemistry of the transplutonium actinides has been studied extensively in recent years because large-scale production of americium, curium, and californium has begun. The transplutonium actinides and the lanthanides have the 3+ state as the most stable valence in solution and have similar chemical reactivity and solvent extractability. Thus, like lanthanide fission products, these actinides are not extracted by tributyl phosphate (TBP) during Purex solvent extraction processing of irradiated uranium, but remain in the aqueous waste.¹ Their extractability into TBP may be increased by adding inextractable metal nitrates¹⁻⁷ or by increasing the nitric acid concentration to >10M.⁷⁻¹¹ Extraction of nitric acid and trivalent lanthanides and actinides⁷ by TBP is shown in the following equations:

where the subscripts aq and org refer to the aqueous and organic phases, respectively. Thus, an increase in nitrate ion concentration shifts the equilibrium toward higher concentrations in the organic phase (greater extractability). Inextractable metal nitrates $[\text{Al}(\text{NO}_3)_3, \text{NaNO}_3]$ produce a larger increase in organic phase concentration of trivalent metals than does HNO_3 because HNO_3 can be extracted (Equation 1) and can compete with the trivalent metals for TBP.

The distributions of nitric acid, cerium, neodymium, samarium, europium, americium, and curium between 30% TBP and the inextractable sodium, lithium, and aluminum nitrates were determined to assist in designing solvent extraction flowsheets to recover and decontaminate trivalent lanthanides and actinides from fission products and from other major contaminants, such as iron and aluminum. Separation of individual actinides and lanthanides by cation exchange chromatography has been demonstrated.¹² The data were also used to determine the feasibility of solvent extraction separation of lanthanides from actinides.⁶

EXPERIMENTAL

Equilibrations

A series of equilibration studies were made, in which a solution of 8M LiNO_3 containing the desired actinides and lanthanides was equilibrated with 30% TBP containing a known quantity of HNO_3 to give a stock organic solution containing the desired metals at a predetermined acid concentration.

All equilibrations were made at 23°C by mixing 3 ml of the stock organic solution with 3 ml of aqueous metal nitrate solution for 2 minutes with a vortex mixer and centrifuging to separate the phases. The organic phase was analyzed for acid, actinides, and lanthanides. Equilibrations and analyses were done in duplicate.

Analyses

Acid was analyzed by titration of an aliquot with 0.05M sodium hydroxide to the phenolphthalein end point. ^{244}Cm was determined by alpha counting a 25-microliter aliquot evaporated on a stainless steel planchet. ^{241}Am was determined by alpha counting and alpha pulse height analysis of a 25-microliter aliquot evaporated on a stainless steel planchet. The gamma activities of a 1-milliliter aliquot of ^{144}Ce , ^{154}Eu , ^{54}Mn , and ^{203}Hg were counted with a $\text{Ge}(\text{Li})$ detector and 4096 channel analyzer. Natural Nd and Sm were determined by atomic absorption analyses of the solution obtained by stripping the organic phase with 0.01M HNO_3 . The aqueous concentrations of the distributing elements were obtained by difference between the concentration in the organic phase before and after equilibration.

Chemicals

Reagent-grade NaNO_3 , LiNO_3 , $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$, DTPA, HNO_3 , $\text{Hg}(\text{NO}_3)_2$, and TBP were used to prepare the solutions. The 30% TBP was prepared by dilution with n-paraffin diluent obtained from the Savannah River Plant. The diluent is predominantly 13- and 14-carbon n-paraffins with an average molecular weight of 191. The diluted TBP was washed, successively, with 2.5% Na_2CO_3 , 0.1M HNO_3 , 2.5% Na_2CO_3 , and then three to five times with distilled water to remove excess Na_2CO_3 . The washed TBP was adjusted to the desired acid concentration by equilibration with HNO_3 . NaNO_3 , LiNO_3 , and $\text{Al}(\text{NO}_3)_3$ solutions were prepared by weighing the appropriate quantity of metal nitrate, dissolving in distilled water, adding the desired amount of concentrated HNO_3 , and diluting to volume.

Preparation of Stock Solutions

The stock curium solution contained 7.38×10^9 dis/(min ml) ^{244}Cm , 1.15×10^9 dis/(min ml) ^{144}Ce , and 6.66×10^8 dis/(min ml) ^{154}Eu . The stock solution was added to 7.5-8.0M LiNO_3 (200 λ per 25 ml) before equilibration with organic solution. The stock ^{241}Am solution contained 3×10^9 dis/(min ml) of alpha activity, of which 59% was ^{241}Am and 41% was ^{244}Cm . This ^{241}Am solution was added to 7.5-8.0M LiNO_3 (250 λ per 25 ml) or to the stock Nd-Sm solution [7.9M LiNO_3 , 0.18M $\text{Nd}(\text{NO}_3)_3$, and 0.023M $\text{Sm}(\text{NO}_3)_3$].

In the distributions involving mercury, macroconcentrations of mercuric ions were used to avoid possible tracer effects. A solution of saturated mercuric nitrate was made and analyzed to be 2.08M. Before equilibration with organic solution, 250 microliters of the 2M $\text{Hg}(\text{NO}_3)_2$ solution and 250 microliters of a solution containing 1×10^9 dis/(min ml) of $^{203}\text{Hg}(\text{NO}_3)_2$ were added to 25 milliliters of 7.5-8M LiNO_3 . Two milliliters of a ^{54}Mn solution containing 3×10^6 dis/(min ml) was added to 7.5-8M LiNO_3 to prepare the organic solution.

DISTRIBUTION OF HNO_3 , Am, Cm, Ce, Nd, Sm, AND Eu

The distributions of HNO_3 , Am, Cm, Ce, Nd, Sm, and Eu between 30% TBP and aqueous solutions of $\text{Al}(\text{NO}_3)_3$, LiNO_3 , NaNO_3 , and their mixtures as a function of HNO_3 and metal nitrate concentrations are shown in Figures 1-6 and Tables 1-9. HNO_3 concentration in the organic and aqueous phases with no metal nitrate salt and with varying concentrations of the different metal salts is illustrated in Figure 1. The effect of adding nitrate salts is largest at low HNO_3 concentration where the total nitrate activity comes from the metal nitrate. As the HNO_3 concentration becomes significant, the differences become smaller because the TBP becomes saturated with HNO_3 .

The effect depends on the metal ion in the inextractable nitrate as well as total nitrate concentration; the salting order is $\text{Li} > \text{Al} \gg \text{Na}$ (Figure 2). This salting order is related to the hydration of the respective cations and the effect of hydration on the activity of water and nitrate ion in the system. Diamond and coworkers¹³ found that at very high HClO_4 concentrations ($\geq 11.6\text{M}$) no water was extracted into TBP along with the proton. This was interpreted as a greatly reduced water activity in the aqueous phase, allowing TBP to compete more favorably as a solvate for the bare proton.

Similarly, Li is more highly hydrated than Na and reduces water activity more than Na, resulting in better solvation of the rare earths and actinides by TBP. On the basis of size of the hydrated ion and known hydration number, Al would be expected to be a better salting agent than Li. However, Al with its higher charge density is more likely to associate with nitrate ions and reduce the free nitrate activity. Li is observed to be a slightly better salting agent than Al, presumably for this reason. A similar salting order was observed by Orth et al.⁶

Figures 3 and 4 show the distribution of Cm in various metal nitrate solutions as a function of HNO₃ in the organic and aqueous phases. Figure 5 shows Cm distribution as a function of HNO₃ in the organic phase for mixtures of the metal nitrate salts. The mixture of Al(NO₃)₃-LiNO₃ is the best salting mixture on a total nitrate basis. The different slope for Al(NO₃)₃-LiNO₃ is possibly due to the difference in total nitrate concentration; however, it is more probable that experimental error and lack of additional data at lower HNO₃ concentrations cause the deviation. In single metal nitrate solutions, the slope of the curve changed only slightly with change in concentration (NaNO₃ in Figure 3).

Figure 6 shows the distribution of several lanthanides, Am, Cm, and HNO₃ as a function of HNO₃ in the organic phase. HNO₃ becomes the most extractable species as its concentration in the organic increases. Above 0.4M HNO₃ in the organic phase, Ce is being forced out of the organic phase by HNO₃(backsalted), and its distribution falls sharply. For the other nuclides, distribution decreases sharply at acid concentrations above 0.5M, because less free TBP is available to extract them. The optimum point for separation of lanthanides and actinides would be at an acid concentration where the distribution of Ce and the lower lanthanides has decreased sharply, but below the acid concentration where the distribution of Am and Cm decreases sharply this narrow range of acidities might require closer control of feed acidity than is practical in plant operation.

The data for Nd and Sm (Table 9) were obtained using macro-quantities of the rare earths (0.02M), and therefore are not strictly comparable since concentration effects were not investigated.

In general, the logarithm of the distribution coefficient is a linear function of the acid concentration in the organic phase and of the total nitrate in the aqueous phase. Equations 3 through 7 gave the best fit to the distribution data in Tables 1 through 8. A linear least squares computer program was used to determine the fit.¹⁴

HNO₃

$$D_a^O = \exp\{-1.08 - 3.63[H_O^+] + 0.823[Li^+] + 2.54[Al^{3+}] + 0.530[Na^+]\} \quad (3)$$

Curium

$$D_a^O = \exp\{-2.56 - 5.12[H_O^+] + 1.31[Li^+] + 3.98[Al^{3+}] + 0.829[Na^+]\} \quad (4)$$

Americium

$$D_a^O = \exp\{-1.90 - 5.93[H_O^+] + 1.35[Li^+] + 3.86[Al^{3+}] + 0.747[Na^+]\} \quad (5)$$

Cerium (III)

$$D_a^O = \exp\{-2.29 - 4.88[H_O^+] + 1.11[Li^+] + 3.21[Al^{3+}] + 0.682[Na^+]\} \quad (6)$$

Europium

$$D_a^O = \exp\{-2.41 - 5.43[H_O^+] + 1.51[Li^+] + 4.46[Al^{3+}] + 0.923[Na^+]\} \quad (7)$$

where

D_a^O = distribution coefficient

$[H_O^+]$ = HNO₃ molarity in the organic phase

$[Li^+]$ = Li molarity in the aqueous phase

$[Na^+]$ = Na molarity in the aqueous phase

$[Al^{3+}]$ = Al molarity in the aqueous phase

Equations 3 through 7 were used in the steady-state computer program developed by Eubanks and Lowe¹⁵ to define the conditions for recovery of Am and Cm from solutions of irradiated Pu-Al alloy using 30% TBP.

EFFECT OF DTPA ON DISTRIBUTION OF Am, Cm, Ce, Nd, Sm, AND Eu

Tables 10, 11, and 12 show the effect of DTPA on distribution of Am, Cm, and several rare earths. DTPA is a strong complexing agent in solutions of $\text{pH} > 1$. The stabilities of the DTPA complexes of Am and Cm are greater than the stabilities of the DTPA complexes of La, Ce, Pr, and Nd.¹² Therefore, by controlling the pH, the light lanthanides can be extracted from aqueous solutions with TBP while Am and Cm remain in the aqueous phase as DTPA complexes. Large separation factors can be obtained for Ce and Cm (Figure 7). The pH must not be too high or the Ce distribution coefficient will be too low to allow Ce to be extracted into TBP. If the pH is too low, the distribution coefficient for Cm is high enough to allow some Cm to be extracted along with the Ce. With 3.01M LiNO_3 , the pH would have to be maintained between 1.4 and 2.0. The data also show that 0.05M DTPA is necessary to observe significant improvement in separation factors. Al salting cannot be used because Al forms complexes with DTPA.

DISTRIBUTION OF Mn AND Hg

Two impurities, Hg and Mn, were added during dissolution and head end treatment of the irradiated Pu-Al alloy used for actinide production. Hg^{2+} is added as a catalyst in the HNO_3 dissolution of Al in the target. The data in Table 13 show that if the salting is high and the acid concentration is low, most of the Hg will be extracted along with the actinides. Mn is added in permanganate head end treatment. The data in Table 14 show that Mn will be rejected to the aqueous waste stream.

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TABLE 1

Distribution of Cm, Ce, and Eu Between 30% TBP
and Aqueous $\text{Al}(\text{NO}_3)_3$ Solutions

$\text{Al}(\text{NO}_3)_3$, M	HNO_3 , M		D_a^0		
	Aqueous	Organic	Cm	Ce	Eu
1.08	0.049	0.032	-	1.66	4.69
1.08	0.0968	0.172	-	2.14	3.85
1.08	0.0968	0.172	-	1.97	3.76
1.08	0.162	0.247	-	1.12	2.57
1.08	0.227	0.314	-	0.878	2.03
1.53	0.310	0.635	1.92	0.826	2.96
1.55	0.370	0.700	1.41	0.609	2.65
1.53	0.450	0.710	1.07	0.472	2.46
1.63	0.008	0.062	4.14	18.5	74.3
1.63	0.036	0.222	4.07	15.7	45.4
1.63	0.059	0.339	3.14	7.21	22.4
1.63	0.117	0.413	2.41	4.44	14.9
1.97	0.20	0.740	5.82	1.98	5.36
1.97	0.28	0.790	3.25	1.10	4.26
1.97	0.34	0.825	2.18	0.756	-
2.17	-	0.112	189	126	1250
2.17	0.001	0.267	-	67.4	907
2.17	0.027	0.381	-	51.0	490
2.17	0.060	0.480	74.3	17.7	89.4

TABLE 2
Distribution of Cm, Ce, and Eu Between 30% TBP
and Aqueous LiNO_3 Solutions

LiNO_3 , M	HNO_3 , M		D_a^0		
	Aqueous	Organic	Cm	Ce	Eu
1.55	0.123	0.110	0.214	0.244	0.362
1.55	0.170	0.140	0.212	0.264	0.350
1.55	0.259	0.188	0.175	0.232	0.315
1.55	0.335	0.214	0.151	0.200	0.288
1.55	0.705	0.340	0.116	0.094	0.174
2.4	0.099	0.134	0.858	0.872	1.42
2.4	0.140	0.170	0.782	0.770	1.10
2.4	0.217	0.230	0.593	0.604	0.995
2.4	0.241	0.273	0.464	0.488	0.927
2.4	0.627	0.418	0.260	0.188	0.430
3.1	0.062	0.142	2.44	1.95	3.66
3.1	0.070	0.145	2.51	-	3.44
3.1	0.102	0.190	2.11	2.08	-
3.1	0.172	0.257	1.40	1.22	2.54
3.1	0.258	0.308	1.04	0.989	1.91
3.1	0.555	0.472	0.460	0.228	0.628
6.05	-	0.700	5.44	1.82	10.1
6.05	-	0.750	3.29	1.09	7.6
6.05	0.324	0.770	2.82	0.835	6.8

TABLE 3

Distribution of Am, Nd, and Sm Between 30% TBP
and Aqueous LiNO_3 Solutions

LiNO_3 , M	HNO_3 , M		D_a^0		
	Aqueous	Organic	Am	Nd	Sm
1.55	0.100	0.095	0.277	0.304	0.399
1.55	0.250	0.183	0.247	0.307	0.357
1.55	0.353	0.220	0.199	0.275	0.298
1.55	0.420	0.270	0.208	0.248	0.294
2.4	0.077	0.118	1.06	1.21	1.64
2.4	0.203	0.230	0.848	0.902	1.27
2.4	0.288	0.285	0.593	0.751	0.836
2.4	0.352	0.338	0.531	0.573	0.764
3.1	0.052	0.125	3.40	3.54	6.62
3.1	0.152	0.263	1.84	2.41	2.69
3.1	0.235	0.320	1.28	1.62	1.92
3.1	0.297	0.375	1.04	1.38	1.56

TABLE 4

Distribution of Cm, Ce, and Eu Between 30% TBP
and Aqueous NaNO_3 Solutions

NaNO_3 , M	HNO_3 , M		D_a^0		
	Aqueous	Organic	Cm	Ce	Eu
3.1	0.101	0.111	0.416	0.360	0.719
3.1	0.150	0.146	0.368	0.319	0.454
3.1	0.319	0.233	0.244	0.176	0.343
3.1	0.625	0.353	0.148	0.130	0.279
4.3	0.049	0.115	1.65	0.942	3.04
4.3	0.093	0.156	1.27	0.982	2.46
4.3	0.142	0.226	0.894	0.708	1.54
4.3	0.233	0.271	0.616	0.427	0.904
4.3	0.500	0.430	0.282	0.192	0.525
5.6	0.014	0.091	7.82	-	15.3
5.6	0.045	0.145	5.16	3.53	5.64
5.6	0.081	0.230	3.24	2.54	3.67
5.6	0.155	0.290	1.67	1.02	2.37
5.6	0.383	0.488	0.562	0.312	1.14

TABLE 5
Distribution of Am Between 30% TBP
and Aqueous NaNO₃ Solutions

NaNO ₃ , M	HNO ₃ , M		D _a ^o Am
	Aqueous	Organic	
3.1	0.182	0.165	0.398
3.1	0.262	0.255	0.322
3.1	0.302	0.270	0.310
4.3	0.154	0.145	1.26
4.3	0.184	0.300	-
4.3	0.220	0.304	0.804
5.6	0.072	0.168	3.28
5.6	0.110	0.315	1.56
5.6	0.140	0.325	

TABLE 6
Distribution of Nd and Sm Between 30% TBP
and Aqueous NaNO₃ Solutions

NaNO ₃ , M	HNO ₃ , M		D _a ^o	
	Aqueous	Organic	Nd	Sm
3.1	0.157	0.162	0.810	1.11
3.1	0.204	0.195	0.516	-
3.1	0.232	0.210	0.90	0.700
3.1	0.294	0.243	0.386	0.528
3.1	0.400	0.288	0.369	0.554
4.3	0.109	0.163	2.81	4.44
4.3	0.126	0.225	1.75	-
4.3	0.188	0.255	1.36	2.70
4.3	0.204	0.285	1.24	1.62
4.3	0.304	0.335	1.04	1.49
5.6	0.075	0.138	8.34	12.6
5.6	0.162	0.230	6.14	-
5.6	0.166	0.258	4.31	11.4
5.6	0.130	0.300	3.30	6.66
5.6	0.202	0.378	-	5.90

TABLE 7

Distribution of Cm, Ce, and Eu Between 30% TBP and Aqueous
 $\text{Al}(\text{NO}_3)_3$, LiNO_3 , and NaNO_3 Solutions

$\text{Al}(\text{NO}_3)_3$, M	LiNO_3 , M	NaNO_3 , M	HNO_3 , M		D_a^0		
			Aqueous	Organic	Cm	Ce	Eu
0.73	3.15	0	0.047	0.378	-	5.82	11.3
0.73	3.15	0	0.140	0.535	6.14	5.04	-
0.73	3.15	0	0.305	0.620	3.65	1.88	-
0.73	3.15	0	0.350	0.700	2.52	1.08	3.74
1.05	0	3.23	0.064	0.365	14.0	6.34	-
1.05	0	3.23	0.157	0.528	4.54	2.79	-
1.05	0	3.23	0.300	0.635	1.86	0.858	3.90
1.05	0	3.23	0.375	0.685	1.44	0.646	2.88
0	3.09	2.99	0.072	0.353	11.7	6.19	-
0	3.09	2.99	0.155	0.520	4.54	2.10	12.0
0	3.09	2.99	0.305	0.620	1.88	1.08	5.43
0	3.09	2.99	0.375	0.675	1.42	0.805	3.69
0.75	2.07	1.93	0.025	0.400	-	5.85	21.6
0.75	2.07	1.93	0.135	0.540	9.68	4.00	-
0.75	2.07	1.93	0.235	0.690	3.36	2.04	15.3
0.75	2.07	1.93	0.300	0.750	1.52	1.02	5.30

TABLE 8
Distribution of Am and Cm Between 30% TBP and Aqueous
Al(NO₃)₃, LiNO₃, and NaNO₃ Solutions

Al(NO ₃) ₃ , M	LiNO ₃ , M	NaNO ₃ , M	HNO ₃ , M		D _a ^o	
			Aqueous	Organic	Am	Cm
0.73	3.15	0	0.055	0.355	21.0	-
0.73	3.15	0	0.135	0.565	7.57	-
0.73	3.15	0	0.285	0.710	3.05	2.98
0.73	3.15	0	0.345	0.745	2.26	2.59
1.05	0	3.23	0.050	0.360	10.1	-
1.05	0	3.23	0.145	0.555	4.07	-
1.05	0	3.23	0.320	0.675	1.69	2.14
1.05	0	3.23	0.375	0.715	1.21	1.32
0	3.09	2.99	0.040	0.370	8.49	-
0	3.09	2.99	0.160	0.540	4.14	-
0	3.09	2.99	0.345	0.650	1.76	1.98
0	3.09	2.99	0.431	0.659	1.38	1.51
0.75	2.07	1.93	0.025	0.385	24.8	-
0.75	2.07	1.93	0.125	0.575	6.55	-
0.75	2.07	1.93	0.280	0.685	2.66	3.12
0.75	2.07	1.93	0.372	0.718	1.94	2.20

TABLE 9

Distribution of Nd and Sm Between 30% TBP and Aqueous
 $\text{Al}(\text{NO}_3)_3$, LiNO_3 , and NaNO_3 Solutions

$\text{Al}(\text{NO}_3)_3$, M	LiNO_3 , M	NaNO_3 , M	HNO_3 , M		D_a^0	
			Aqueous	Organic	Nd	Sm
0.73	3.15	0	0.198	0.716	4.42	5.81
0.73	3.15	0	0.312	0.767	2.34	5.89
0.73	3.15	0	0.343	0.816	2.12	4.96
1.05	0	3.23	0.242	0.682	2.12	5.57
1.05	0	3.23	0.370	0.719	1.24	4.68
1.05	0	3.23	0.393	0.776	1.04	3.97
0	3.09	2.99	0.248	0.666	1.78	5.34
0	3.09	2.99	0.360	0.719	1.36	3.51
0	3.09	2.99	0.402	0.757	1.03	-
0.75	2.07	1.93	0.216	0.698	1.93	6.67
0.75	2.07	1.93	0.322	0.757	1.80	5.43
0.75	2.07	1.93	0.354	0.805	1.40	4.80

TABLE 10

Effect of 0.05M DTPA on the Distribution of Am, Cm, Ce, Eu, Nd,
 and Sm Between 30% TBP and 3.01M LiNO_3 Solutions

HNO_3 , M		D_a^0					
Aqueous	Organic	Am	Cm	Ce	Eu	Nd	Sm
0.012	0.023	-	9.3×10^{-3}	0.956	5.0×10^{-2}	-	-
0.045	0.052	0.195	0.138	-	-	1.74	0.724
0.070	0.075	-	0.860	4.13	2.45	-	-
0.118	0.100	-	2.04	-	2.42	-	-
0.145	0.130	1.48	-	-	-	4.92	5.23
0.153	0.170	1.68	2.13	-	-	2.14	3.36
0.220	0.190	-	1.89	2.15	5.34	-	-
0.245	0.235	-	1.62	1.37	2.88	-	-

TABLE 11
Effect of DTPA on the Distribution of Cm, Ce, and Eu
Between 30% TBP and Aqueous NaNO₃ Solutions

NaNO ₃ , M	DTPA, M	HNO ₃ , M		D_a^0		
		Aqueous	Organic	Cm	Ce	Eu
3.14	0.05	0.0066	0.015	2.5×10^{-3}	0.229	8.6×10^{-3}
3.14	0.05	0.044	0.040	6.78×10^{-2}	-	-
3.14	0.05	0.074	0.058	0.360	0.822	0.823
3.14	0.05	0.129	0.075	0.518	-	0.697
3.14	0.05	0.242	0.155	0.422	0.487	0.846
3.14	0.05	0.284	0.182	0.392	0.362	0.680
4.90	0.001	0.030	0.080	0.292	-	-
4.90	0.001	0.088	0.133	0.196	-	-
4.90	0.005	0.038	0.073	3.08	-	-
4.90	0.005	0.092	0.128	2.08	-	-
4.90	0.01	0.050	0.060	2.76	-	-
4.90	0.01	0.105	0.115	2.22	-	-
6.49	0.05	0.0024	0.025	4.63×10^{-3}	2.40	0.158
6.49	0.05	0.037	0.052	0.280	-	-
6.49	0.05	0.057	0.080	4.76	5.32	6.37
6.49	0.05	0.102	0.108	6.04	3.17	5.68
6.49	0.05	0.187	0.215	5.17	2.85	-
6.49	0.05	0.212	0.260	3.02	1.72	5.92

TABLE 12

Effect of 0.05M DTPA on the Distribution of Nd and Sm
Between 30% TBP and Aqueous NaNO_3 Solutions

NaNO_3 , M	HNO_3 , M Organic	D_a^0	
		Nd	Sm
3.14	0.058	0.790	0.836
3.14	0.145	0.933	1.65
3.14	0.320	0.280	0.358
3.14	0.340	0.240	0.350
3.14	0.390	0.269	0.341
4.90	0.038	2.49	4.14
4.90	0.150	3.19	5.29
4.90	0.325	0.502	0.866
4.90	0.380	3.56	-
4.90	0.390	0.490	0.759
4.90	0.405	0.516	0.841
6.49	0.01	7.19	11.3
6.49	0.12	7.50	-
6.49	0.24	1.74	3.08
6.49	0.355	1.12	2.57
6.49	0.405	0.894	1.89
6.49	0.440	0.858	1.87

TABLE 13

Distribution of Hg^{2+} Between 30% TBP
and Various Aqueous $\text{Al}(\text{NO}_3)_3$, LiNO_3 ,
and NaNO_3 Solutions

$\text{Al}(\text{NO}_3)_3$, M	LiNO_3 , M	NaNO_3 , M	HNO_3 , M Organic	D_a^0 Hg^{2+}
0	6	0	0.142	8.52
0	6	0	0.631	0.621
0	8	0	0.150	19.5
0	8	0	0.710	0.696
0	0	4.3	0.152	0.228
0	0	4.3	0.421	0.440
0	0	5.6	0.123	0.357
0	0	5.6	0.526	0.515
1.53	0	0	0.208	1.01
1.53	0	0	0.605	0.738
1.97	0	0	0.289	1.97
1.97	0	0	0.736	0.715
0.73	3.15	0	0.152	3.91
0.73	3.15	0	0.605	0.605
1.05	0	3.23	0.145	0.727
1.05	0	3.23	0.552	0.443

TABLE 14

Distribution of Mn Between 30% TBP and 7.6M
 LiNO_3 or $\text{Al}(\text{NO}_3)_3$ Solutions

Metal Nitrate	HNO_3 , M Organic	D_a^0 Mn
Li	0.33	0.119
Li	0.78	0.094
Li	0.82	0.078
Al	0.48	0.113
Al	0.81	0.064

FIGURE 1 Distribution of HNO₃ in 30% TBP in n-Paraffin as a Function of Aqueous Metal Nitrate Solutions

FIGURE 2 Distribution of Cm Between 30% TBP in n-Paraffin and Aqueous Metal Nitrate Solutions as a Function of Total Nitrate at Constant HNO₃ in the Organic Phase (0.3M)

FIGURE 3 Distribution of Cm Between 30% TBP in n-Paraffin and Various Aqueous Metal Nitrate Solutions as a Function of HNO_3 in the Organic Phase

FIGURE 4 Distribution of Cm Between 30% TBP in n-Paraffin and Various Aqueous Metal Nitrate Solutions as a Function of HNO_3 in the Aqueous Phase

FIGURE 5 Distribution of Cm Between Mixtures of Aqueous Metal Nitrate Solutions and 30% TBP in n-Paraffin as a Function of HNO_3 in the Organic Phase

FIGURE 6 Distribution of HNO₃, Am, Cm, Ce, Nd, Sm, and Eu Between 30% TBP in n-Paraffin and 3.1M LiNO₃ Solution as a Function of HNO₃ in the Organic Phase

FIGURE 7 Separation Factor Between Ce and Cm as a Function of pH in Aqueous Metal Nitrate Solutions Containing 0.05M DTPA