Chemistry - Separation Processes
for Plutonium and Uranium

AEC Research and Development Report

EQUILIBRIUM DISTRIBUTION DATA
FOR PUREX AND
SIMILAR EXTRACTION PROCESSES

by

T. H. Siddall, III, S. G. Parker,
and W. E. Prout

Separations Chemistry Division
July 1957

E. I. du Pont de Nemours & Co.
Explosives Department - Atomic Energy Division
Technical Division - Savannah River Laboratory

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ABSTRACT

Data are presented for the equilibrium distribution of uranium, thorium, and nitric acid between solutions of tri-n-butyl phosphate in kerosene and the various aqueous solutions encountered in the separation of plutonium and uranium and in processes for the recovery of U-235 from spent reactor fuel.

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In this report, the terms "extraction coefficient" and "distribution coefficient" are used interchangeably.

An acid-deficient solution is one which would become stoichiometrically neutral upon addition of nitric acid equivalent to the deficiency (e.g., an acid-deficient solution designated as "-" 0.2M HNO_3 would become stoichiometrically neutral upon addition of 0.2 mol of HNO_3 per liter).

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* Minor component, concentration too small to affect its own or other distribution behavior.

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* Minor component, concentration too low to affect its own or other distribution behavior.

EQUILIBRIUM DISTRIBUTION DATA FOR PUREX AND SIMILAR EXTRACTION PROCESSES

INTRODUCTION

Solutions of tri-n-butyl phosphate (TBP) in hydrocarbon diluents are widely applicable as solvents for the separation of uranium, thorium, and plutonium from each other and from other chemical elements. These solvents are used for countercurrent extraction of aqueous solutions of a wide range of compositions and at various temperatures. Although the literature contains distribution data for many such processes, such data were not sufficiently complete, especially with respect to the effect of temperature, for certain separations problems studied in this Laboratory.

SUMMARY

The distribution of uranium and nitric acid between aqueous solutions and solutions of tri-n-butyl phosphate (TBP) in "Ultrasene" was determined over a range of conditions applicable to the Purex process. The distribution of thorium was measured between aqueous solutions of nitric acid and 30 volume per cent of TBP in "Ultrasene" at low concentrations of thorium.

Similar data were obtained which apply to processes for the recovery of U-235 from irradiated alloys of U-235 and aluminum.

Empirical equations were derived for the density of a number of solutions in terms of the molar density coefficients of the various solutes.

The range of conditions which were studied is summarized in the titles of the tables and figures.

DISCUSSION

"Ultrasene" was used as the diluent for the tri-n-butyl phosphate (TBP) for all of the distribution studies. "Ultrasene" is a high boiling kerosene produced by the Atlantic Refining Company. This kerosene is a mixture of normal, branched, and cycloparaffins with a very low content of unsaturated and aromatic compounds.

Solutions of TBP in "Ultrasene" were prepared by dilution to volume of weighed amounts of anhydrous TBP. For example, the solutions of 30 volume per cent of TBP were 1.10M TBP when anhydrous. The TBP was exhaustively washed with solutions of dichromate, caustic solutions, and distilled water before removing water by heating gently under vacuum.

The data are presented in tables and except in a few cases, also in graphs. The graphs were obtained by drawing smooth curves through the experimental points. Concentrations are expressed as mols of solute per liter of solution as analyzed at room temperature (23 to 25°C).

The following symbols are used:

U_A mols of uranium per liter of aqueous phase at equilibrium
 U_O mols of uranium per liter of organic phase at equilibrium
 H_A mols of nitric acid per liter of aqueous phase at equilibrium
 H_O mols of uranium per liter of organic phase at equilibrium
 $E_{O/A}$ equilibrium ratio of the concentration of a given solute in the organic phase to its concentration in the aqueous phase

An effort was made to establish limits of precision for the data in terms of average deviation (50 per cent confidence limits). As a rule precision was estimated as based on scattered duplicate analyses, material balance calculations, and routine performance of the method of analysis and was not estimated by rigorous statistics.

EQUILIBRIUM DIAGRAM: URANYL NITRATE - NITRIC ACID - 30 PER CENT TBP; 70°C (Table I, Figure 1)

These data are applicable to flowsheet calculations in a range of acidity from 0.0 to 3.8 mols of nitric acid per liter of aqueous phase.

Uranium was determined by the standard thiocyanate method. Acidity was determined potentiometrically. Fluoride was added to prevent interference by uranium. The uranium analyses agreed within three per cent, and acid analyses within one to ten per cent, depending on the ratio of acid to uranium.

Figure 1 is an equilibrium diagram constructed from smoothed curves of the raw data which are given in Table I. The solid curves show U_O plotted against U_A at constant concentrations of acid in the aqueous phase. The dotted curves show U_O against U_A at constant concentrations of acid in the organic phase. These curves are believed to be reliable except at aqueous acidities greater than 3.0 molar and aqueous uranium concentrations greater than 0.3 molar. Above these limits there is a tendency for the extraction of uranium to go through a maximum as a function of acidity. It is difficult to say, for example, that the curve at 3.0M acidity does not cross the curve at 3.8M acidity. Differences approach experimental error.

DISTRIBUTION OF URANIUM AND NITRIC ACID IN THE SYSTEM: URANYL NITRATE - NITRIC ACID - 50 PER CENT TBP; 50°C, 70°C (Table II)

Limited data for the distribution of uranium between aqueous solutions of nitric acid and 50 per cent TBP were obtained to supplement existing information. The increased concentration of TBP would

permit increased loading of uranium into the organic phase at the price of increased density and viscosity in the organic phase. The data are given in Table II.

The densities of all organic phases were measured at 25°C and fitted by the method of least squares to the equation,

$$\text{Density} = 0.877 + 0.313U_0 + 0.028H_0$$

The molar density coefficients for uranium and acid in 50 per cent TBP are nearly the same as those in 30 per cent TBP (0.322 and 0.025, respectively)⁽¹⁾.

DISTRIBUTION OF THORIUM IN THE SYSTEM: THORIUM NITRATE (LOW CONCENTRATION) - NITRIC ACID - SULFURIC ACID - 30 PER CENT TBP; 30°C, 50°C (Table III, Figure 2)

The data are useful for calculating the behavior of UX₁(Th-234) in the second plutonium cycle of the Purex process. Although Th-232 was used in obtaining the data, the concentrations of thorium are low enough that the behavior of UX₁ should be very closely approximated.

Thorium was analyzed colorimetrically by the Thorin method. The concentrations of sulfuric acid are expressed as mols per liter and refer to the initial aqueous phase. The concentrations of sulfuric acid were not measured at equilibrium.

DISTRIBUTION OF NITRIC ACID IN THE SYSTEM: NITRIC ACID - ALUMINUM NITRATE - 2.5 PER CENT TBP; 30°C (Table IV, Figure 3)

Aluminum nitrate increases the extraction of nitric acid from aqueous solutions by TBP.

Nitric acid in the organic phase was determined by direct titration with phenolphthalein indicator. Acidity in the aqueous phase was calculated from the composition of starting solutions and material balance. Poor technique contributed to scattering of data for the curve with 1.27M aluminum nitrate but was corrected for the curve with 0.83M aluminum nitrate.

DISTRIBUTION OF URANIUM IN THE SYSTEM: URANYL NITRATE - NITRIC ACID - ALUMINUM NITRATE - 5 PER CENT TBP; 30°C, 60°C (Tables V and VI)

The data given in this section may be used to calculate flowsheets which concentrate uranium. Such flowsheets might allow operation without evaporation between cycles of solvent extraction in a scheme to process alloys of uranium with aluminum.

The stock solution of aluminum nitrate for these experiments was standardized both by gravimetric analysis and by density. Uranium was analyzed by the thiocyanate method with a reliability of one to

three per cent. An equation to express the density of the organic phase at 25°C was obtained by the method of least squares.

$$\text{Density} = 0.786 + 0.32U_0$$

THE DISTRIBUTION OF URANIUM AND NITRIC ACID IN VARIOUS SYSTEMS
(Tables VII, VIII, and IX, Figures 4, 5, and 6)

The data in this section are for very low concentrations of uranium. In this range, the distribution coefficient for uranium does not change with change in concentration.

Concentrations of nitric acid were determined by titration to the phenolphthalein end point and are reliable to about one per cent except at low concentrations where the errors are larger.

Uranium was mostly determined by the thiocyanate method. In the systems containing no aluminum, the precision was one to three per cent. For the systems which contain aluminum nitrate, the data are considered to be sufficiently reliable only for preliminary calculations. The viscosity of some of the aluminum solutions prevented accurate pipetting. Also, at very low concentrations of uranium, uranium was determined by fluorimetric analysis with relatively low precision.

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BIBLIOGRAPHY

1. Coddington, J. W., Haas, W. O., and Heumann, F. K. Knolls Atomic Power Laboratory KAPL-602, November 26, 1951 (Classified).

TABLE I

URANYL NITRATE - NITRIC ACID - 30 PER CENT TBP; 70°C
(See Figure 1)

H_A	H_O	U_A	U_O
1.0	0.08	0.515	0.421
0.9	0.08	0.354	0.365
0.8	0.10	0.182	0.275
0.8	0.09	0.128	0.220
0.6	--	0.464	0.368
0.5	--	0.222	0.263
0.3	--	0.465	0.346
0.3	--	0.390	0.315
0.3	--	0.233	0.207
0.3	--	0.185	0.167
0	0	0.526	0.357
0	0	0.387	0.271
0	0	0.285	0.194
0	0	0.226	0.136
0	0	0.187	0.101
0	0	0.122	0.0401
0	0	0.088	0.0193
0	0	0.059	0.0067
1.08	0.04	0.74	0.458
1.05	0.05	0.52	0.421
1.06	0.068	0.316	0.359
1.07	0.074	0.240	0.334
1.08	0.10	0.149	0.242
1.09	0.13	0.081	0.180
1.09	0.15	0.022	0.070
2.03	0.02	0.84	0.491
2.01	0.03	0.62	0.451
2.04	0.06	0.411	0.440
1.97	0.08	0.302	0.400
1.96	0.19	0.220	0.369
1.94	0.21	0.133	0.325
1.89	0.23	0.086	0.266
1.97	0.25	0.042	0.192
1.89	0.30	0.016	0.097

(Continued on next page)

TABLE I (Continued)

H_A	H_O	U_A	U_O
3.03	0.13	0.93	0.458
3.00	0.16	0.344	0.409
2.83	0.16	0.341	0.425
2.86	0.17	0.240	0.404
3.00	0.23	0.142	0.330
2.94	0.24	0.132	0.325
2.99	0.29	0.091	0.293
3.02	0.40	0.042	0.211
3.00	0.52	0.012	0.110
3.63	0.17	0.84	0.474
3.59	0.21	0.462	0.447
3.90	0.22	0.345	0.422
3.87	0.25	0.238	0.393
3.60	0.31	0.135	0.368
3.81	0.35	0.087	0.303
3.94	0.43	0.042	0.232
3.70	0.70	0.011	0.107

TABLE II

URANYL NITRATE - NITRIC ACID - 50 PER CENT TBP; 50°C, 70°C
(Data not plotted)

Temp.	H _A	H _O	U _A	U _O	Density of Organic Phase at 25°C
50°C	4.2	0.9	0.0136	0.292	0.992
	3.8	1.0	0.0069	0.191	0.960
	3.6	0.2	0.416	0.73	1.112
	3.6	0.2	0.284	0.71	1.104
	3.4	0.3	0.147	0.64	1.085
	3.3	0.4	0.093	0.582	1.068
	3.0	0.2	0.410	0.73	1.112
	3.0	0.2	0.242	0.70	1.103
	2.6	0.2	0.087	0.558	1.060
	2.3	0.3	0.0513	0.460	1.031
	1.8	0.4	0.0281	0.318	0.987
	1.3	0.4	6.0181	0.195	0.946
	0.9	0.2	0.0136	0.099	0.913
70°C	0	0	0.0660	0.0207	0.881
	0	0	0.0118	0.077	0.905
	0	0	0.0201	0.235	0.954

TABLE III

THORIUM NITRATE (LOW CONCENTRATION) - NITRIC ACID - SULFURIC ACID -
 30 PER CENT TBP; 30°C, 50°C
 (See Figure 2)

Temp.	H _A	SO ₄	Th _A	Th _O	E _{O/A} (Th)
30°C	0.24	None	0.0052	0.000180	0.034
	0.52	None	0.00239	0.000409	0.171
	0.59	None	0.0064	0.00130	0.203
	1.11	None	0.00402	0.00314	0.78
	1.94	None	0.00105	0.00186	1.77
	2.62	None	0.00184	0.00454	2.45
	3.69	None	0.00139	0.00481	3.52
	5.44	None	0.00114	0.0051	4.47
50°C	0.54	None	0.00285	0.000362	0.127
	0.62	None	0.0068	0.00115	0.168
	1.03	None	0.00180	0.00093	0.52
	1.15	None	0.00444	0.0059	0.66
	1.52	None	0.00158	0.00161	1.02
	2.07	None	0.00153	0.00242	1.58
	3.12	None	0.00181	0.00451	2.49
	3.70	None	0.00175	0.00456	2.61
	4.11	None	0.00165	0.00464	2.81
	5.19	None	0.00160	0.00468	2.93
	5.44	None	0.00163	0.00467	2.87
	6.25	None	0.00164	0.00462	2.82
50°C	0.55	0.011	0.00466	0.000185	0.0397
	1.03	0.011	0.00270	0.00075	0.279
	1.51	0.011	0.00204	0.00146	0.72
	2.05	0.011	0.00182	0.00228	1.25
	3.11	0.011	0.00201	0.00432	2.15
	4.13	0.011	0.00177	0.00453	2.56
	5.21	0.011	0.00170	0.00457	2.69
	6.24	0.011	0.00171	0.00455	2.66
50°C	0.63	0.049	0.0064	0.00012	0.019
	1.13	0.049	0.00435	0.000434	0.099
	1.62	0.049	0.00315	0.00110	0.349
	2.15	0.049	0.00257	0.00192	0.75
	3.23	0.049	0.00243	0.00391	1.61
	4.20	0.049	0.00207	0.00423	2.04
	5.32	0.049	0.00188	0.00438	2.33
	6.41	0.049	0.00191	0.00431	2.26
50°C	2.30	0.097	0.00337	0.00153	0.454
	3.28	0.097	0.00303	0.00334	1.10
	4.33	0.097	0.00245	0.00387	1.58
	5.37	0.097	0.00223	0.00406	1.82
	6.50	0.097	0.00216	0.00409	1.89

TABLE IV

NITRIC ACID - ALUMINUM NITRATE - 2.5 PER CENT TBP; 30°C
(See Figure 3)

$\text{Al}(\text{NO}_3)_3$	H_A	H_O
1.27	-0.13*	0.002
1.27	0.148	0.031
1.27	0.436	0.053
1.27	0.739	0.061
1.27	1.34	0.081
1.27	2.25	0.102
1.27	3.73	0.111
1.27	4.73	0.109
0.85	0.218	0.0105
0.85	0.581	0.0273
0.85	1.37	0.057
0.85	2.36	0.077
0.85	3.94	0.089
0.85	4.89	0.093
0.85	6.15	0.094
0.85	7.10	0.093

* Minus sign signifies acid deficiency

TABLE V

URANYL NITRATE - NITRIC ACID - ALUMINUM NITRATE - 5 PER CENT TBP; 30°C
(Data not plotted)

$\text{Al}(\text{NO}_3)_3$	H_A	U_A	U_O	
2.02	-0.21*	7.7×10^{-4}	0.076	
2.02	-0.21	7.0×10^{-5}	0.051	
2.02	-0.21	$3 \times 10^{-5**}$	0.0380	
2.02	-0.21	$2 \times 10^{-5**}$	0.0250	
1.69	-0.18	8.2×10^{-3}	0.082	
1.69	-0.18	1.93×10^{-4}	0.0430	
1.27	-0.13	0.0235	0.073	
1.27	-0.13	9.7×10^{-3}	0.065	
1.27	-0.13	4.64×10^{-3}	0.055	
1.27	-0.13	1.88×10^{-3}	0.0304	
1.06	-0.11	0.0354	0.068	
1.06	-0.11	0.0120	0.053	
1.06	-0.11	5.6×10^{-3}	0.0413	
1.06	-0.11	3.25×10^{-3}	0.0336	
				Density of Organic Phase at 25°C
None	None	0.63	0.065	0.807
None	None	0.380	0.0400	0.798
None	None	0.266	0.0230	0.794
None	None	0.148	6.8×10^{-3}	0.788
				H_O
1.99	-0.13	6.3×10^{-4}	0.067	2×10^{-3}
1.99	+0.17	5.0×10^{-4}	0.068	0.015
1.99	+0.46	2.02×10^{-3}	0.066	0.036
1.99	+0.75	4.66×10^{-3}	0.063	0.045
1.25	-0.077	3.83×10^{-3}	0.050	--
1.25	+0.20	2.59×10^{-3}	0.050	0.013
1.25	+0.46	3.58×10^{-3}	0.050	0.034
1.25	+0.75	4.46×10^{-3}	0.049	0.048

* Minus sign signifies acid deficiency

** Analyzed by fluorophotometer

TABLE VI

URANYL NITRATE - NITRIC ACID - ALUMINUM NITRATE -
5 PER CENT TBP; 60°C

(Data not plotted)

$\text{Al}(\text{NO}_3)_3$	H_A	U_A	U_O
2.02	-0.21*	2.29×10^{-3}	0.076
1.69	-0.18	0.0146	0.078
1.69	-0.18	6.6×10^{-4}	0.0422
1.27	-0.13	0.0339	0.068
1.27	-0.13	0.0180	0.061
1.27	-0.13	0.0106	0.053
1.27	-0.13	4.71×10^{-3}	0.0331
1.06	-0.11	0.050	0.060
1.06	-0.11	0.0223	0.050
1.06	-0.11	0.0118	0.0397
1.06	-0.11	7.7×10^{-3}	0.0325
None	None	0.79	0.068
None	None	0.73	0.064
None	None	0.56	0.0458
None	None	0.356	0.0242
None	None	0.261	0.0130
None	None	0.153	3.57×10^{-3}

* Minus sign signifies acid deficiency

TABLE VII

URANYL NITRATE - ALUMINUM NITRATE - TBP (1.5, 2.5, 5 PER CENT);
 25, 30, 45.9, 70°C
 (Data not plotted)

TBP Volume %	Temp. (°C)	Al(NO ₃) ₃ M/L	U(Aqueous) M/L	U(Organic) M/L	E _{O/A} (U)
1.5	25	0.7	0.0114	0.0035	0.31
1.5	25	1.0	0.0077	0.0102	1.4
1.5	25	1.3	0.0028	0.0110	3.9
1.5	25	1.7	0.00080	0.0131	16
1.5	25	2.0	0.00050	0.0128	26
1.5	30	0.98	0.00047	0.00060	1.26
1.5	30	0.98	0.00075	0.00094	1.25
1.5	30	0.98	0.00191	0.00219	1.15
1.5	30	0.98	0.00269	0.00292	1.09
1.5	30	0.98	0.0061	0.0055	0.89
1.5	30	0.98	0.0097	0.0073	0.75
1.5	30	1.23	0.00034	0.00162	4.7
1.5	30	1.23	0.00044	0.00200	4.6
1.5	30	1.23	0.0061	0.00261	4.3
1.5	30	1.23	0.00094	0.00375	3.98
1.5	30	1.23	0.00210	0.0063	3.01
1.5	30	1.23	0.00391	0.0090	2.31
1.5	30	1.23	0.0054	0.0102	1.90
1.5	30	1.47	0.00017	0.00274	16
1.5	30	1.47	0.00029	0.0041	14
1.5	30	1.47	0.00077	0.0076	9.9
1.5	30	1.47	0.00220	0.0124	5.6
1.5	30	1.72	0.00024	0.0082	35
1.5	30	1.72	0.00104	0.0147	14.2
1.5	30	1.72	0.00278	0.0188	6.8
1.5	45.9	1.0	0.00297	0.00239	0.80
1.5	45.9	1.0	0.00387	0.00314	0.81
1.5	45.9	1.0	0.0058	0.00430	0.74
1.5	45.9	1.43	0.00260	0.0101	3.9
1.5	45.9	1.43	0.00038	0.0033	8.6
1.5	45.9	1.43	0.00067	0.0047	7.1
1.5	45.9	1.43	0.00147	0.0075	5.1
1.5	45.9	1.43	0.00178	0.0084	4.7
1.5	70	0.7	0.0132	0.0015	0.07
1.5	70	1.0	0.0089	0.0044	0.44
1.5	70	1.3	0.0063	0.077	1.10
1.5	70	1.7	0.0024	0.0112	4.7
1.5	70	2.0	0.0008	0.0128	16

TABLE VII (Continued)

TBP Volume %	Temp. (°C)	Al(NO ₃) ₃ M/L	U(Aqueous) M/L	U(Organic) M/L	E _{O/A} (U)
2.5	25	0.4	0.0122	0.0019	0.16
2.5	25	0.6	0.0089	0.0047	0.53
2.5	25	0.8	0.0055	0.0081	1.47
2.5	25	1.0	0.0038	0.0099	2.6
2.5	25	1.5	0.00080	0.0128	16
2.5	25	2.0	0.00040	0.0132	33
2.5	70	0.4	0.0138	0.0084	0.042
2.5	70	0.6	0.9119	0.0022	0.19
2.5	70	0.8	0.0114	0.0042	0.52
2.5	70	1.0	0.0055	0.0071	1.29
2.5	70	1.5	0.0017	0.0119	7
2.5	70	2.0	0.0005	0.0131	26
5.0	25	0.11	0.0065	0.00042	0.065
5.0	25	0.21	0.0061	0.00093	0.152
5.0	25	0.31	0.0052	0.0021	0.40
5.0	25	0.40	0.0142	0.0090	0.64
5.0	25	0.40	0.0088	0.0057	0.65
5.0	25	0.40	0.0029	0.0025	0.87
5.0	25	0.7	0.0016	0.0065	4.1
5.0	25	1.0	0.00024	0.0049	20
5.0	25	1.0*	0.00032	0.0070	22
5.0	25	1.5	2.1×10^{-5}	0.0072	350
5.0	25	1.5*	9×10^{-5}	0.0074	80
5.0	25	2.0*	7×10^{-6}	0.0070	1000
5.0	25	2.1	4×10^{-6}	0.0067	1600
5.0	70	0.11	0.0071	0.00010	0.014
5.0	70	0.31	0.0065	0.0060	0.093
5.0	70	0.4	0.019	0.0045	0.238
5.0	70	0.7	0.0024	0.0040	1.67
5.0	70	1.0	0.00126	0.0058	4.6
5.0	70	1.5	2.7×10^{-5}	0.0071	260
5.0	70	2.1	5×10^{-6}	0.0069	1500

* 0.9M HNO₃ added to aqueous phase

TABLE VIII

URANYL NITRATE (LOW CONCENTRATION) - NITRIC ACID - TBP
 (2.5, 5, 7.5, 10 PER CENT); 1-2, 25, 45.9, 70°C
 (See Figures 4 and 5)

TBP Volume %	Temp. (°C)	HNO ₃ (Aqueous) (H _A) M/L	U (Aqueous) (U _A) M/L	U (Organic) (U _O) M/L	E _{O/A} (U)
2.5	1.7	3.21	0.00290	0.0073	2.51
2.5	1.4	3.99	0.00239	0.0078	3.25
2.5	1.3	4.81	0.00223	0.0080	3.57
2.5	25.0	0.93	0.00580	0.00087	0.151
2.5	25.0	1.23	0.00458	0.00112	0.245
2.5	25.0	1.53	0.00354	0.00133	0.375
2.5	25.0	2.33	0.00300	0.00239	0.80
2.5	25.3	3.15	0.00321	0.00349	1.09*
2.5	25.3	3.91	0.00278	0.00373	1.38*
2.5	25.3	4.72	0.00264	0.00377	1.45*
5.0	25.0	0.60	0.00458	0.00112	0.245
5.0	25.0	0.92	0.00401	0.00206	0.513
5.0	25.0	1.23	0.00379	0.00320	0.84
5.0	25.0	1.53	0.00289	0.00365	1.26
5.0	25.2	2.18	0.00325	0.00693	2.14*
5.0	25.2	2.81	0.00256	0.00759	2.97*
5.0	25.2	4.69	0.00193	0.0083	4.14*
5.0	25.2	6.28	0.00214	0.0080	3.77*
5.0	45.9	0.60	0.00608	0.00082	0.135
5.0	45.9	0.90	0.00437	0.00110	0.252
5.0	45.9	1.16	0.00317	0.00140	0.442
5.0	45.9	1.46	0.00275	0.00186	0.667
5.0	45.9	2.13	0.00297	0.00361	1.21
5.0	45.9	2.71	0.00236	0.00381	1.61
5.0	45.9	4.69	0.00327	0.00691	2.09
5.0	45.9	6.28	0.00370	0.00648	1.73
5.0	25.0	3.48	0.00285	0.0099	3.46
5.0	45.9	3.48	0.00263	0.00505	1.92
5.0	70.0	3.48	0.00256	0.00254	0.99

* Corrected to 25.0°C

TABLE VIII (Continued)

TBP Volume %	Temp. (°C)	HNO ₃ (Aqueous) (H _A) M/L	U (Aqueous) (U _A) M/L	U (Organic) (U _O) M/L	E _{O/A} (U)
7.5	25.1	0.60	0.00401	0.00206	0.515*
7.5	25.1	0.91	0.00337	0.00341	1.01*
7.5	25.1	1.25	0.00382	0.00636	1.67*
7.5	25.1	1.56	0.00300	0.0072	2.39*
7.5	25.1	2.33	0.00194	0.0082	4.25*
7.5	25.1	3.10	0.00144	0.0087	6.04*
7.5	25.1	3.86	0.00120	0.0090	7.4*
7.5	25.1	4.65	0.00112	0.0091	8.0*
7.5	45.9	0.52	0.0234	0.00544	0.232
7.5	45.9	0.78	0.0169	0.0071	0.422
7.5	45.9	1.03	0.0090	0.00619	0.69
7.5	45.9	1.53	0.00674	0.0086	1.28
7.5	45.9	2.02	0.00353	0.00682	1.93
7.5	45.9	2.78	0.00130	0.00386	2.97
7.5	45.9	3.42	0.00113	0.00398	3.52
7.5	45.9	4.44	0.00105	0.00397	3.78
10.0	25.0	3.48	0.00118	0.0115	9.78
10.0	45.9	3.48	0.00200	0.0107	5.36
10.0	70.0	3.48	0.00398	0.01165	2.76
10.0	25.0	1.00	0.00262	0.00505	1.93
10.0	45.9	1.02	0.00280	0.00333	1.19
10.0	70.0	1.03	0.00288	0.00197	0.684
10.0	45.9	0.55	0.00320	0.00140	0.436
10.0	45.9	0.89	0.00352	0.00333	0.946
10.0	45.9	2.48	0.00336	0.0136	4.02
10.0	45.9	4.66	0.00261	0.0151	5.72

* Corrected to 25.0°C

TABLE IX

NITRIC ACID - TBP (2.5, 5, 7.5, 10 PER CENT); 25°C, 45.9°C
(See Figure 6)

TBP Volume %	Temperature (°C)	HNO ₃ (Aqueous) (H _A) M/L	HNO ₃ (Organic) (H _O) M/L
2.5	25	0.94	0.0090
2.5	25	1.11	0.0117
2.5	25	1.56	0.0214
2.5	25	2.19	0.0369
2.5	25	2.98	0.0545
2.5	25	3.40	0.0637
2.5	25	4.74	0.084
2.5	25	6.39	0.090
2.5	45.9	1.08	0.0108
2.5	45.9	1.33	0.0159
2.5	45.9	1.61	0.0218
2.5	45.9	2.12	0.0341
2.5	45.9	2.67	0.0501
2.5	45.9	3.18	0.0605
2.5	45.9	4.05	0.073
2.5	45.9	5.67	0.085
5.0	25	0.485	0.0060
5.0	25	0.666	0.0103
5.0	25	0.96	0.0196
5.0	25	1.86	0.0593
5.0	25	2.88	0.105
5.0	25	3.35	0.123
5.0	25	3.84	0.137
5.0	25	4.80	0.158
5.0	25	6.08	0.173
5.0	45.9	0.645	0.0093
5.0	45.9	0.96	0.0181
5.0	45.9	1.29	0.0318
5.0	45.9	1.95	0.0603
5.0	45.9	2.49	0.089
5.0	45.9	3.13	0.116
5.0	45.9	4.73	0.159
5.0	45.9	6.33	0.175

TABLE IX (Continued)

TBP Volume %	Temperature (°C)	HNO ₃ (Aqueous) (H _A) M/L	HNO ₃ (Organic) (H _O) M/L
7.5	25	0.262	0.0036
7.5	25	0.510	0.0113
7.5	25	0.75	0.0226
7.5	25	1.23	0.0516
7.5	25	1.57	0.071
7.5	25	1.87	0.092
7.5	25	2.50	0.133
7.5	45.9	0.509	0.0097
7.5	45.9	0.77	0.0209
7.5	45.9	0.95	0.0293
7.5	45.9	1.29	0.0516
7.5	45.9	2.55	0.139
7.5	45.9	3.39	0.164
7.5	45.9	4.49	0.236
10.0	25	0.392	0.0116
10.0	25	0.630	0.0248
10.0	25	0.771	0.0357
10.0	25	1.057	0.0586
10.0	25	1.80	0.124
10.0	25	2.68	0.202
10.0	25	3.32	0.246
10.0	25	4.54	0.315
10.0	45.9	0.398	0.0101
10.0	45.9	0.638	0.0216
10.0	45.9	0.793	0.0305
10.0	45.9	1.10	0.0563
10.0	45.9	1.84	0.124
10.0	45.9	2.73	0.201
10.0	45.9	3.01	0.224
10.0	45.9	4.60	0.308

FIGURE 1

EQUILIBRIUM DIAGRAM: URANYL NITRATE-NITRIC ACID-30% TBP; 70°C
(DERIVED FROM DATA IN TABLE I)

FIGURE 2

THORIUM NITRATE (LOW CONCENTRATION)
-NITRIC ACID-SULFURIC ACID-30 % TBP; 30°C, 50°C

(SEE TABLE III)

FIGURE 3

NITRIC ACID - ALUMINUM NITRATE - 2.5 % TBP; 30°C
 (SEE TABLE IV)

FIGURE 4

URANYL NITRATE (LOW CONCENTRATION) - NITRIC ACID - TBP (2.5, 5, 7.5%); 25°C
(SEE TABLE VIII)

FIGURE 5

URANYL NITRATE (LOW CONCENTRATION) - NITRIC ACID - TBP (5, 7.5, 10 %); 45.9°C
(SEE TABLE VIII)

FIGURE 6