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A LITERATURE SURVEY OF DISTRIBUTION DATA FOR NITRIC ACID - WATER/TRIBUTYL PHOSPHATE SYSTEMS PART 1: URANIUM

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DISCLAIMER

A LITERATURE SURVEY OF DISTRIBUTION DATA FOR NITRIC ACID — WATER/TRIBUTYL PHOSPHATE SYSTEMS
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INTRODUCTION

Since the late 1940's, when it was discovered at Ames Laboratory that tri-n-butyl phosphate (TBP) would preferentially extract uranium and plutonium from nitric acid solutions,[1] extensive distribution measurements have been made for various materials between aqueous solutions and TBP (usually in an organic diluent). Some compilations have been made, such as Smith's compilation of plutonium distribution data with various extractants[2] and Petrich and Kolarik's compilation of data for uranium, plutonium, neptunium, and nitric acid in 30% TBP;[3] however, previous compilations have usually been specific for a particular species or TBP concentration. It has recently been recognized that an extensive compilation of distribution data for various materials between aqueous solutions and TBP at various concentrations is needed to adequately characterize the behavior of these species in nuclear fuel reprocessing.

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SUMMARY

As a part of SRL's response to RTA 1058-S, an extensive search was conducted of the open literature, some classified publications, and SRP/SRL documents. This search uncovered a large amount of existing information, in external and internal documents and publications, as well as previously unpublished distribution data in SRL laboratory notebooks. This work is the first of a series of documents that will provide a compilation of the information gathered in this search.

Since the behavior of uranium in the nitric acid/TBP system is of immediate interest, this memorandum presents information gathered on uranium distribution. Future documents will present compilations of distribution data of plutonium, neptunium, thorium, nitric acid and other species in the nitric acid/TBP system.

SUMMARY

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DISCUSSION

Correlations

Early in the history of the use of TBP as an extractant in nuclear fuel reprocessing, investigators began examining correlations for the distribution of uranium. Codding et al.,[4] used correlations to extrapolate from experimental results and devotes an appendix to a discussion of their technique. Building on this information, Wilburn[5] developed a correlation using thermodynamic considerations for the limited amount of information, available at that time, for temperatures above 25°C. During this same period, Granquist and Merrill[6] developed correlations for low (10 to 15%) TBP concentrations.

In 1970, Horner[7] developed a mathematical model of the nitric acid/TBP system which estimated distribution coefficients for uranium, plutonium, and nitric acid. This model was refined and evaluated by Jubin[8] who established that it gave adequate predictions for uranium over a wide range of uranium concentrations (up to 350 grams/liter), temperatures (20 to 70°C) and nitric acid concentrations (0.01 to 11.0M). Although the data he used for comparison was concentrated around a TBP concentration of 30%, the model also accounts for various TBP concentrations. Jubin's model is currently incorporated in two computer models developed at the Oak Ridge National Laboratory (ORNL) for the Purex system, MATEX and SEPHIS.

Russian investigators have published some correlations. Rozen and Kartasheva[9] developed correlations for the distribution of uranium between nitric acid and a 10 volume percent solution of TBP and kerosene at 22 and 60°C. They are:

at 22°C:

$$D_u = 30.8 - 87.6\ X_{ef} + 126.7\ X^2_{ef} \qquad (1)$$

and at 60°C

$$D_u = 10.6 - 28.8\ X_{ef} + 41.6\ X^2_{ef} \qquad (2)$$

where:

$$X_{ef} = [U]_{aq} + 0.15\ [H^+]$$

D_u = Distribution coefficient of uranium

$[U]_{aq}$ = Aqueous uranium concentration in moles/liter

$[H^+]$ = Aqueous acid concentration in moles/liter

They also detail adjustments to the model to account for a different diluent. This model appears accurate in range of experimental values it was compared to: uranium concentration = 5 to 100 g/L, aqueous phase, and HNO_3 concentration = 0.05 to 0.5M.

Vereschasin, et al.,[10] developed a more complicated model for the 30% TBP system that was found to be accurate to ±3.8%. This model covers 2 to 4M HNO_3, and 30 to 300 g/L uranium. A modification of this model will account for the effect of up to 100 g/L of plutonium. These models are given below:

$$D_u = A\,[U]_{aq}^{B} \tag{3}$$

where:

$$A = \frac{[H^+]}{0.0121 + 0.0091\,[H^+]}$$

$$B = \frac{\log[H^+]}{18.7\,\log\,[H^+] - 2.52}$$

$[U]_{aq}$ = Aqueous phase uranium concentration in grams/liter. Note that these units are different from units in Equations 1 and 2 above.

In the presence of Pu:

$$D_u = \frac{A[U]_{aq}^{B} - 5\,[Pu]_{aq}\,C^{0.626}}{[U]_{aq}} \tag{4}$$

where:

$$C = [H^+]/[U]_{aq}$$

$[Pu]_{aq}$ = Aqueous phase plutonium concentration in grams/liter

Vereshchagin and Renard[11] updated and modified the earlier model using experimental data to yield a more accurate correlation and expanded the nitric acid concentration range to 0.1 - 4.0M. Again, two models were given. The first model applies to uranium-nitric acid solutions. The concentration of uranium in the organic phase is given by:

$$\log [U]_o = \frac{\log [U]_{aq}}{0.445 \log [U]_{aq} + D} \quad (5)$$

where:

$[U]_{aq}$ = Aqueous phase concentration of uranium in grams/liter

$[U]_o$ = Organic phase concentration of uranium in grams/liter

$$D = \frac{[H^+]}{20[H^+] - 19.8}$$

The second model includes the interference from up to 100 g/L of Pu(IV):

$$\log[U]_o = \frac{\log [U]_{aq}}{(0.445 - 0.001\ E) \log [U]_{aq} + 0.026\ E + D} \quad (6)$$

where:

$$E = [H^+][Pu]_{aq}$$

$[Pu]_{aq}$ = Aqueous phase plutonium concentration in grams/liter

Thompson and Shankle[12] developed a correlation for the distribution of uranium between 7.5% TBP and nitric acid. Their correlation was broken up into two equations, one for high acid concentrations and one for low acid conditions. The high acid (>1M) model is:

$$\ln D_u = X \quad (7)$$

where:

$$X = -0.304 + 1.53 \ln[H^+] - 0.291(\ln[H^+])^2 - 0.226 \ln[U]_o + 0.326(\ln[U]_o)^2 - 0.129(\ln[U]_o)^3$$

While the low acid (<0.5M) model is:

$$\ln D_u = Y \ln Z \quad (8)$$

where:

$$Y = -(0.577 + 0.00351[U]_o)$$

$$Z = -0.794 + 1.28\ [H^+] + (0.221 - 0.208\ [H^+])(\ln(32.6 - [U]_o)) + 0.0163\ [H^+][U]_o$$

Kalina et al.,[13] have reported a model for the effect of temperature (T) on uranium extraction into 6.8% TBP from a 0.25M HNO_3 solution. This model is:

$$D_u = (3309/T) - 12.74 \quad (9)$$

Goldberg et al., have published a model for uranium distribution in 30% TBP at 25°C.[14] These equations are too extensive to detail here. They claim an average deviation of 5.8% for their model.

Swedish investigators (Svantesson et al.)[15] have developed an equation for the distribution of uranium with 50% TBP. This model is for trace concentrations of uranium and nitric acid concentrations of 0.2 to 7.4M:

$$D_u = \frac{9.75\ [H^+]^{1.11}}{1 + (6.866 \times 10^{-5})[H^+]^{4.95}} \quad (10)$$

An accuracy of 4% is claimed for this model.

The most interesting work in the correlation of uranium distribution in TBP is being conducted in West Germany. German researchers at Karlsruhe have collected an extensive amount of distribution data at 30% TBP and compiled this information in an obviously computer coded format.[3] Kolarik and Petrich recently published mathematical models for the distribution of both U(VI) and U(IV) in 30% TBP at various temperatures.[16] They claimed that these models had an error of no more than 25% and typically 5 to 15%. This compares to an accuracy of 50% claimed by Jubin for his model.[8] Kolarik and Petrich, however, only published the empirical equations; the equation coefficients were not included. Thus, there is no way to verify their claims or make use of their model.

Reference Material

Several documents were found during the literature search which, while they did not lend themselves to categorization as distribution data or contained so much information that it was unwieldy to present in this work, deserve mention. Perhaps in the future these references may prove useful to other investigators.

One document in this category is R. J. Smith's literature search on the solvent extraction of uranium.[17] His compilation gives the references available on that subject prior to 1957 from primarily American sources. This effort includes references on TBP as well several other extractants.

Siddall, et al.,[18] measured uranium distribution using several temperatures and TBP concentrations. This work also includes information on the salting-out effect of aluminum nitrate.

Thompson, et al.,[19] measured distribution data for uranyl nitrate between nitric acid and 7.5% TBP. Three temperatures (23, 45 and 60°C) were used with aqueous phase nitric acid concentrations as high as 4M.

Clagett[20] also made extensive measurements of the distribution of uranium from nitric acid waste solutions to dilute TBP solutions. The TBP concentrations used were 12.5% and 15%.

Two publications by J. W. Codding present much information on the extraction of uranium by TBP, but contain too much information for convienient inclusion here. The first work[21] presents primarily distribution data for uranium and nitric acid while the second publication[22] examines the salting-out effect of aluminum nitrate on uranium distribution.

The salting-out effect of Pu(III) and hydrazine nitrate has been measured by German investigators.[23] This work was conducted using 30% TBP in kerosene.

Lang and Nethaway[24] examined the effect of sulfate on uranium distribution in 30% TBP. Their data covers a concentration range from 0.15 to 480 g/L of uranium.

Recent work conducted at ORNL is presented by Knauer, et al.[25] This work details experimentally determined distribution coefficients for uranium, plutonium, and nitric acid in with 6 and 30% solutions of TBP in n-dodecane at 25°C. Concentration ranges that were covered were 0.1 to 4.5M in nitric acid, 0 to 10 g/L of plutonium of plutonium and 0 to 350 g/L of uranium.

Knauer and coworkers have also published recent measurements of uranium, thorium, and plutonium distribution between nitric acid and 30% TBP in n-dodecane.[26] The ranges measured were one and 15 g/L of plutonium, 0 to 100 g/L of uranium, 0 to 200 g/L of thorium, and 0.1 to 4.5M nitric acid. These measurements were made at 25 and 50°C.

Eschrich and coworkers[27] measured the distribution of uranyl nitrate and nitric acid between an aqueous solution and 100% TBP. These measurements were carried out at 24°C.

Perhaps the most extensive compilation of distribution data for the nitric acid - uranium - 30% TBP system has been collected by Petrich and Kolarik. Their first effort was published in 1977.[28] In 1981, they updated their compilation.[3] Their database contains nearly 1500 data points for U(VI) distribution at various temperatures acid concentrations, and concentrations of plutonium and neptunium. Some 124 data points for the distribution of U(IV) are also included. This collection, however, is too extensive to be reproduced in this document.

DISTRIBUTION DATA

Applicable distribution data found during the course of this search is presented in both graphical and tabular form in the Appendix. Commentary on the information has been minimized. A critical evaluation has not been performed on this information.

Some readers may be aware of distribution data for uranium in nitric acid/TBP that is not included in this document. If so, the author would appreciate this information.

FUTURE WORK

Future parts of this series will present distribution data for other species in the nitric acid - water/TBP system.

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APPENDIX

Figures and Tables

TABLE 1

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 29
TBP Concentration: 22.5%
Diluent: GSN Kerosene
Temperature: 25°C

Uranium Conc. (g/L)		HNO_3 Conc. (M)*
Aq.	Org.	Aq.
22.6	7.36	0
47.4	28.8	0
88.2	51.2	0
177.0	75.6	0
263.0	84.1	0
415.0	86.5	0
526.0	85.7	0
13.0	7.55	0.24
62.4	48.9	0.16
265.0	83.7	0.17
414.0	87.4	0.25
3.87	12.6	0.79
38.2	57.2	0.78
76.2	67.0	0.81
231.0	84.0	0.94
419.0	85.6	1.10
0.71	10.3	1.90
29.7	56.4	2.71
38.2	70.7	2.29
182.0	83.3	2.84
370.0	85.5	3.03
0.42	5.23	4.00
7.94	55.3	4.87
23.3	65.2	4.21
130.0	80.4	4.00
307.0	87.4	4.21

* At equilibrium

TABLE 2

Distribution of Uranyl Nitrate

Reference: 29
TBP Concentration: 22.5%
Diluent: GSN Kerosene
Temperature: 25, 40, and 70°C

Temp. °C	Uranium Conc. (g/L) Aq.	Org.
25	22.6	7.36
	47.4	28.8
	88.2	51.2
	177.0	75.6
	263.0	84.1
	415.0	86.5
	526.0	85.7
40	24.2	5.72
	91.6	50.2
	183.0	74.0
	263.0	81.9
	417.0	78.3
70	25.2	3.12
	96.6	41.9
	181.0	67.0
	262.0	76.2
	410.0	82.9

TABLE 3

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 29
TBP Concentration: 22.5%
Diluent: GSN Kerosene
Temperature: 25, 40, and 70°C

Temp. °C	Uranium Conc. (g/L)		HNO_3 Conc. (M)*
	Aq.	Org.	Aq.
25	3.17	12.6	0.79
	38.2	57.2	0.78
	76.2	67.0	0.81
	231.0	84.0	0.94
	419.0	85.6	1.10
40	4.07	12.9	0.79
	39.8	50.2	0.78
	263.0	82.0	1.00
	420.0	84.8	1.02
70	5.27	10.1	0.79
	46.1	44.1	0.98
	83.0	60.1	1.22
	234.0	77.5	1.13
	424.0	80.0	1.17

* At equilibrium

TABLE 4

Distribution of Uranyl Nitrate

Reference: 30
TBP Concentration: 20%
Diluent: Kerosene
Temperature: 16.5, 21, and 29.5°C

Temp. °C	Uranium Conc. (g/L) Aq.	Org.
16.5	16.9	5.6
	18.6	6.6
	24.6	11.2
	33.6	18.3
	35.0	19.6
	42.7	26.2
	43.8	26.4
	45.8	28.2
	53.1	33.9
	66.1	41.0
	69.4	43.3
21.0	52.7	31.5
	71.3	42.0
	80.0	49.2
	116.5	62.2
	127.0	63.0
	130.0	64.5
	131.8	63.5
	145.3	67.0
	150.4	68.8
	162.5	70.0
	175.5	70.5
	186.0	73.5
	192.5	74.0
	215.5	76.5
	223.5	76.5
	252.6	77.5
	301.0	78.8
	307.5	79.0
29.5	19.6	4.9
	24.4	7.8
	24.2	8.0
	27.1	9.8
	33.4	14.2
	38.6	17.6
	51.6	25.8
	51.4	26.3
	58.6	30.4
	71.6	38.4
	101.3	51.2

TABLE 5

Distribution of Uranyl Nitrate with 1M Nitric Acid

Reference: 30
TBP Concentration: 20%
Diluent: Kerosene
Temperature: 21°C

Uranium Conc. (g/L)	
Aq.	Org.
51.2	54.5
61.8	61.0
68.2	60.0
75.3	65.2
90.0	67.8
108.3	70.0
111.3	67.4
144.5	74.0
146.5	73.0
147.0	72.0
166.5	74.0
179.2	75.0
200.0	74.8
216.0	75.5
253.0	78.0

TABLE 6

Distribution Coefficients of Uranyl Nitrate with 1M Nitric Acid (At Equilibrium)

Reference: 31
TBP Concentration: (as noted)
Diluent: (as noted)
Temperature: (as noted)

Temp.	D_u					
	5% TBP		15% TBP		30% TBP	
°C	sst*	NDD**	sst	NDD	sst	NDD
10	1.03	0.864	4.39	4.11	8.53	7.92
20	0.715	0.600	3.43	3.18	7.25	6.89
30	0.511	0.422	2.69	2.44	6.76	5.78
40	0.373	0.311	2.09	1.98	5.18	4.90
50	0.283	0.236	1.72	1.58	4.41	4.18
60	0.218	0.183	1.37	1.25	3.82	3.58

* Shellsol-T

** N-dodecane

NOTE: Uranium concentration is <1.0 g/L.

TABLE 7

Distribution Coefficients of Uranyl Nitrate with Nitric Acid

Reference: 31
TBP Concentration: (as noted)
Diluent: n-dodecane
Temperature: 20°C

HNO_3* (at eq.)	D_u			
	2.5% TBP	5% TBP	15% TBP	30% TBP
0.1	0.0028	0.0113	0.096	0.335
0.25	0.013	0.052	0.411	1.27
0.5	0.042	0.163	1.18	3.25
1.0	0.180	0.600	3.18	6.89
4.0	1.61	4.36	13.6	21.4

* Aqueous concentration

NOTE: Uranium Concentration is <1.0 g/L.

TABLE 8

Distribution Coefficients of Uranyl Nitrate with Nitric Acid

Reference: 31
TBP Concentration: (as noted)
Diluent: n-dodecane
Temperature: 30°C

HNO_3 (at eq.)	D_u 2.5% TBP	5% TBP	15% TBP	30% TBP
0.1	0.0021	0.0080	0.067	0.241
0.25	0.0088	0.035	0.288	0.960
0.5	0.029	0.116	0.868	2.55
1.0	0.123	0.422	2.44	5.78
4.0	1.08	3.14	11.0	18.7

NOTE: Uranium Concentration is <1.0 g/L.

TABLE 9

Distribution Coefficients of Uranyl Nitrate with Nitric Acid

Reference: 31
TBP Concentration: (as noted)
Diluent: n-dodecane
Temperature: 40°C

HNO_3	D_u			
(at eq.)	2.5% TBP	5% TBP	15% TBP	30% TBP
0.1	0.0016	0.0061	0.051	0.183
0.25	0.0063	0.026	0.210	0.733
0.5	0.021	0.085	0.650	2.07
1.0	0.089	0.311	1.98	4.90
4.0	0.737	2.26	8.86	15.8

NOTE: Uranium Concentration is <1.0 g/L.

TABLE 10

Distribution Coefficients of Uranyl Nitrate with Nitric Acid

Reference: 31
TBP Concentration: (as noted)
Diluent: n-dodecane
Temperature: 50°C

HNO_3 (at eq.)	D_u 2.5% TBP	5% TBP	15% TBP	30% TBP
0.1	0.0013	0.0048	0.039	0.144
0.25	0.005	0.020	0.163	0.575
0.5	0.016	0.062	0.504	1.68
1.0	0.067	0.236	1.58	4.16
4.0	0.512	1.61	6.93	13.0

NOTE: Uranium Concentration is <1.0 g/L.

TABLE 11

Distribution Coefficients of Uranyl Nitrate with Nitric Acid

Reference: 31
TBP Concentration: (as noted)
Diluent: n-dodecane
Temperature: 60°C

HNO_3 (at eq.)	D_u 2.5% TBP	5% TBP	15% TBP	30% TBP
1.0	0.063	0.183	1.29	3.58
4.0	0.356	1.18	5.42	11.2

NOTE: Uranium Concentration is <1.0 g/L.

TABLE 12

Distribution of Uranous(IV) Nitrate with Nitric Acid

Reference: 32
TBP Concentration: 100%
Diluent: none
Temperature: 22°C

HNO_3 Conc.(M) Aq. (at eq.)	D_u
0.09	0.39
0.24	0.81
0.33	1.32
0.48	2.3
0.71	2.5
1.41	7.5
2.4	17.0
3.48	28.0
4.5	39.0
6.6	61.0
8.16	86.0
9.65	77.0
11.5	58.0
14.0	55.0

Note: Uranium concentration is <1.0 g/L.

TABLE 13

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 33
TBP Concentration: 4.5%
Diluent: Amsco 125-90W
Temperature: 22°C

HNO_3 Conc.	Uranium Conc. (g/L)	
M	aq.	org.
0.0	0.474	0.00000952
	1.42	0.0000160
	3.31	0.00150
	14.21	0.0157
	1.27	0.0000210
	6.31	0.00981
	30.2	0.914
0.02	1.27	0.00120
	2.55	0.00509
	6.31	0.0340
	30.2	1.08
0.04	1.42	0.00640
	3.31	0.0150
	14.21	0.257
	1.27	0.00431
	2.55	0.0113
	6.31	0.0507
	30.2	1.22
0.06	0.474	0.00250
	1.42	0.00981
	3.31	0.0236
	14.21	0.307
	1.27	0.00750
	2.55	0.0184
	6.31	0.0762
	30.2	1.37

TABLE 14

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 34
TBP Concentration: 20%
Diluent: Kerosene
Temperature: 20°C

HNO_3 Conc.	Uranium Conc. (g/L)	
M	aq.	org.
0.5	1.43	1.9
	2.62	3.8
	6.4	7.1
	14.5	16.0
	42.0	41.0
	80.8	57.0
	148.5	73.0
1.0	5.0	11.6
	9.8	25.9
	13.58	34.64
	22.68	40.0
	42.7	53.98
	50.6	56.0
	104.0	70.0
	133.0	73.5
	164.2	75.99
2.0	1.44	9.0
	4.7	28.0
	8.8	35.46
	13.3	46.41
	18.0	48.9
	39.3	63.07
	88.0	72.5
	135.5	75.0
	240	77.0

TABLE 14, Contd.

HNO_3 Conc.	Uranium Conc. (g/L)	
M	aq.	org.
4.0	3.91	36.2
	8.2	55.2
	17.66	63.05
	19.1	64.6
	46.4	72.0
	95.0	75.5
	214.0	81.0
	108.0	77.0
	173.6	78.2
6.0	3.8	41.5
	28.6	65.0
	72.3	73.4
	121.0	76.0
	156.0	76.8
	236.4	78.4
8.0	4.4	35.3
	31.1	62.7
	53.2	66.9
	99.3	75.9
	206.0	77.0

TABLE 15

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 34
TBP Concentration: 20%
Diluent: Kerosene
Temperature: 40°C

HNO_3 Conc.	Uranium Conc. (g/L)	
M	aq.	org.
0.5	12.03	11.95
	42.3	35.9
	94.3	61.4
	178.7	75.3
1.0	24.2	35.0
	50.3	52.0
	100.5	67.5
	180.4	76.7
2.0	11.7	36.2
	29.6	52.02
	38.9	58.45
	52.8	63.0
	101.2	71.5
	195.4	75.0
4.0	4.8	34.6
	29.5	60.14
	53.66	67.5
	97.15	72.9
	192.5	76.9
8.0	7.8	32.98
	28.7	50.0
	30.5	51.2
	46.1	59.5
	49.0	60.9
	60.0	64.0
	105.0	71.6
	122.5	72.0
	198.2	80.0

TABLE 16

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 34
TBP Concentration: 20%
Diluent: Kerosene
Temperature: 70°C

HNO_3 Conc.	Uranium Conc. (g/L)	
M	aq.	org.
0.05	20.0	12.7
	47.0	33.0
	97.5	58.0
	195.0	71.0
1.0	32.5	33.3
	60.0	47.0
	122.0	66.0
	210.0	75.5
	15.5	19.5
2.0	11.2	25.8
	15.5	32.0
	36.07	47.2
	45.2	52.0
	54.7	56.9
	112.8	70.2
	186.0	76.2
4.0	9.57	31.9
	9.66	31.7
	35.5	55.5
	66.0	64.9
	114.0	74.0
	200.4	77.2
8.0	13.6	24.9
	35.0	42.0
	70.5	54.1
	74.8	55.8
	111.3	65.4
	150.0	70.0
	211.1	75.3

TABLE 17

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 35
TBP Concentration: 20%
Diluent: n-dodecane
Temperature: 25°C

HNO_3 Conc.	Uranium Conc. (g/L)	
M	aq.	org.
0.02	1.14	0.059
	2.28	0.083
	4.45	0.25
	10.33	1.31
	19.28	5.09
	32.13	14.80
	73.07	34.98
3.0	0.08	1.06
	0.14	2.08
	0.26	4.81
	0.62	10.90
	1.62	21.20
	6.40	39.75
	45.93	66.40

TABLE 18

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 36
TBP Concentration: 20%
Diluent: odorless kerosene
Temperature: unknown

HNO_3 Conc.*	Uranium Conc. (g/L)	
M	aq.	org.
1.98	5.6	37.0
	20.5	57.5
	50	72
5.12	1.06	23.5
	20.7	65
	75.5	82
	240	83

* Aqueous acid concentration at equilibrium.

TABLE 19

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 36
TBP Concentration: 20%
Diluent: Turpolene
Temperature: unknown

HNO_3 Conc.*	Uranium Conc. (g/L)	
M	aq.	org.
0	9.9	1.0
	20	6.0
	44	24.5
	50	29
	66	41
	82	49
	102	55
	5	0
	15.2	2.8
	30	12
	30.2	13.4
	47	26
	59	38
	65.5	40
	92	49.5
	91	52
	137	66.5
	134	67
	192	76
	218	78
	230	80
1.0	2.7	10.7
	5.8	19.8
	10.8	29.8
	20.2	43.5
	35	50
	40.5	54
	52	63.5
	87	69
	105	75
	128	76
	224	78
	162	79
	192	80

TABLE 19, Contd.

HNO_3 Conc.	Uranium Conc. (g/L)	
M	aq.	org.
3.0	0.2	9
	0.73	11.8
	1.1	15.5
	1.5	21.0
	2.8	31.0
	3.3	36.5
	3.5	38.0
	4.7	38.0
	5	44.5
	7	46
	10.3	51.5
	14.2	56
	19.2	63
	25.5	67
	34	72
	41.6	72
	49	73
	72	79
5.0	0.62	18.6
	2.3	44.5
	5.6	56
	16	62.5
	35	74
	71	76
7.0	0.96	18.6
	5.8	41
	16.6	56.5
	39	65
	82	76
	130	76

* Aqueous acid concentration at equilibrium.

TABLE 20

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 36
TBP Concentration: 20%
Diluent: Dekalin
Temperature: unknown

HNO_3 Conc.*	Uranium Conc. (g/L)	
M	aq.	org.
0.41	8.65	15.24
	19.52	31.61
	49	48.8
	129	73
	208	78
3.28	1.3	25.5
	4.5	48
	36.6	71
	127.5	78.5
	226	86
4.8	0.03	0.55
	0.064	2.25
	0.128	4.62
	0.34	12.2
	0.855	23.6
	1.71	37.7
	3.16	47.3
	11.6	57.3

* Aqueous acid concentration at equilibrium.

TABLE 21

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 36
TBP Concentration: 20%
Diluent: Odorless kerosene
Temperature: unknown

HNO_3 Conc.*	Uranium Conc. (g/L)	
M	aq.	org.
5.07	0.15	4.66
	1.0	20.3
	3.54	43.6
	11.15	58.05
	29	68.5
	168	81
6.02	0.18	4.86
	1.14	21.4
	4.0	42.8
	13.2	60.5
	31.8	67.5
	171	79

* Aqueous acid concentration at equilibrium.

TABLE 22

Distribution of Uranyl Nitrate

Reference:	36
TBP Concentration:	20%
Diluent:	Turpolene
Temperature:	60°C

Uranium Conc. (g/L)	
aq.	org.
9.8	1.3
22	4.8
47	18
53	19
73	32
89	40
107	48

TABLE 23

Distribution of Uranyl Nitrate with 4.8 M Nitric Acid

Reference: 36
TBP Concentration: 20%
Diluent: Dekalin
Temperature: 0.5°C

Uranium Conc. (g/L)	
aq.	org.
0.37	25.8
1.232	50.25
6.84	70.4

TABLE 24

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 36
TBP Concentration: 20%
Diluent: Turpolene
Temperature: unknown

HNO_3 Conc.	Uranium Conc. (g/L)	
M	aq.	org.
5	0.6	18.5
	2.3	44
	5.6	56
	16	62
	35	74
	71	76
7	1.0	18.6
	5.8	41
	16.5	57
	39	65
	32	76
	130	76

TABLE 25

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 36
TBP Concentration: 35%
Diluent: Turpolene
Temperature: unknown

HNO_3 Conc.	Uranium Conc. (g/L)	
M	aq.	org.
0	4.6	0.8
	11.4	3.1
	19.1	8.8
	19.2	10.4
	26.0	18.3
	26.0	20.0
	26.5	21.0
	33.8	31.8
	34.8	31.5
	35.0	33.0
	37.0	34.2
	48.0	50.5
	49.0	52.7
	68.5	74.5
0.05	18.2	14.8
	24.4	23.9
	32.0	36.1
	45.0	52.1
0.1	11.6	10.0
	20.0	21.6
	32.6	41.0
0.5	11.4	32.0
	12.0	35.8
	15.0	39.8
	17.0	44.8
	21.5	50.5
	24.0	57.7
	31.5	65.7
	38.5	76.0

TABLE 26

Distribution of Uranyl Nitrate with 5.4 M Nitric Acid

Reference: 36
TBP Concentration: 33%
Diluent: Dekalin
Temperature: unknown

Uranium Conc. (g/L)	
aq.	org.
0.425	26.2
1.35	53.9
4.6	95.5
73.5	126
126	127

TABLE 27

Distribution of Uranyl Nitrate with 5.9 M Nitric Acid

Reference: 36
TBP Concentration: 33%
Diluent: Dekalin
Temperature: unknown

Uranium Conc. (g/L)	
aq.	org.
0.2	5.74
0.715	26.8
2.3	54.4
18.8	96
107	116
150	120

TABLE 28

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 37
TBP Concentration: 18%
Diluent: n-dodecane
Temperature: 40°C

HNO_3 Conc.*	Uranium Conc. (g/L)	
M	aq.	org.
3.18	189.4	68.0
3.11	65.7	61.3
3.24	30.7	54.3
3.14	17.6	48.2
3.14	12.4	42.9
3.11	8.29	37.0
3.11	3.84	26.1
3.10	1.18	11.9
3.04	0.363	4.19
3.05	0.198	2.47

* Aqueous acid concentration at equilibrium.

TABLE 29

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 38
TBP Concentration: (as noted)
Diluent: saturated hydrocarbons
Temperature: (as noted)

TBP Conc. (%)	HNO_3 Conc. (M)*		Uranium Conc. (g/L)		Temp. °C
	Aq.	Org.	Aq.	Org.	
2.57	2.0	0.05	2.21	1.00	20
	1.95	0.06	2.62	0.50	40
	1.97	0.05	2.26	0.21	80
30	2.40	0.24	10.0	80.92	20
	2.08	0.29	14.28	64.26	40
	2.25	0.21	26.18	73.78	80

* Aqueous acid concentration at equilibrium.

TABLE 30

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 39
TBP Concentration: 30%
Diluent: n-paraffin
Temperature: (as noted)

HNO_3 Conc. (M)*	Uranium Conc. (g/L)		
	Aq.	Org.	Temp. °C
0	2.95	11.0	21.3
0.49	2.98	10.73	22.8
0	3.84	12.97	22.8
0	2.44	8.85	22.8
0.49	3.09	11.14	22.8
0	3.14	10.85	24.3
0.48	3.11	11.02	24.3
0	3.11	11.05	24.3
0	1.44	5.09	25.8
0	2.27	7.92	25.8
0.48	3.18	10.97	25.8
0	3.27	10.88	27.3

* Aqueous acid concentration at equilibrium.

TABLE 31

Distribution Coefficients of Uranyl Nitrate with Nitric Acid

Reference: 40
TBP Concentration: 100%
Diluent: None
Temperature: 25°C

HNO_3 Conc. (M)*	D_u
0.09	2.09
0.18	4.46
0.38	8.70
0.60	14.58
1.02	25.34
1.56	37.46

* Aqueous acid concentration at equilibrium.

TABLE 32

Distribution of Uranyl Nitrate

Reference: 41
TBP Concentration: (as noted)
Diluent: n-Decane
Temperature: (as noted)

TBP Conc. (%)	Uranium Conc. (g/L) Aq.	Org.	Temp. °C
0.55	40.0	0.058	10
	91.4	0.042	25
	40.2	0.029	30
	92.3	0.025	40
	90.9	0.017	50
1.37	39.5	0.331	10
	40.7	0.214	25
	39.7	0.157	30
	39.7	0.145	40
	40.2	0.101	50
2.74	38.1	1.04	10
	40.0	0.676	25
	39.5	0.676	30
	39.3	0.531	40
	39.0	0.340	50
4.11	37.4	2.24	10
	40.0	1.69	25
	38.3	1.44	30
	38.8	0.961	40
	40.7	0.919	50
5.47	35.7	3.55	10
	36.7	2.40	25
	35.5	1.48	30
	37.1	1.68	40
	37.8	1.18	50

TABLE 33

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 42
TBP Concentration: 15%
Diluent: Shell Deodorized Spray Base/Deobase Mixture
Temperature: 25°C

HNO_3 Conc.	Uranium Conc. (g/L)	
M	aq.	org.
0	84.1	34.1
0.13	80.5	38.3
0.29	77.9	40.5
0.46	76.0	42.3
0	51.3	21.1
0.14	46.4	25.7
0.30	43.4	28.6
0.44	40.9	31.2
0	23.4	5.3
0.14	19.6	9.1
0.30	16.7	11.8
0.46	14.5	14.1
0	11.0	0.76
0.17	8.7	2.9
0.32	6.9	4.7
0.48	6.0	6.2
0	3.6	0.03
0	3.9	0.05
0.19	3.3	0.71
0.14	3.8	0.65
0	1.3	0.0007
0	1.3	0.0007
0.16	0.82	0.15
0.16	0.99	0.24
0	0.34	0.0002
0	0.39	0.00005
0.16	0.33	0.057
0.16	0.34	0.066
0	0.11	0.0002
0	0.12	0.00005
0.16	0.11	0.018
0.16	0.11	0.019
0.16	0.10	0.019

TABLE 34

Distribution of Uranyl Nitrate with Nitric Acid*

Reference: 43
TBP Concentration: (as noted)
Diluent: hexane
Temperature: 20°C

TBP Conc. (%)	Uranium Conc. (g/L)	
	Aq.	Org.
1	480	4.12
5	520	20.75
10	498	41.0
15	460	63.5
20	440	84.0
30	410.4	116.0
50	326.0	195.0
100	191.0	360.0

* Aqueous HNO_3 concentration was originally 0.16M.

TABLE 35

Distribution of Uranyl Nitrate with Nitric Acid*

Reference: 43
TBP Concentration: 20%
Diluent: hexane
Temperature: (as noted)

Temp. °C	Uranium Conc. g/L	
	Aq.	Org.
10	19.15	7.10
20	22.0	6.40
30	20.48	4.90
50	23.00	3.62

* Aqueous HNO_3 concentration was originally 0.05M.

TABLE 36

Distribution of Uranyl Nitrate with Nitric Acid*

Reference: 43
TBP Concentration: (as noted)
Diluent: hexane
Temperature: 20°C

TBP Conc. (%)	Uranium Conc. (g/L) Aq.	Org.
1	0.04	26.5
5	1.04	26.5
10	2.77	23.3
20	5.6	22.0
30	8.28	20.4

* Aqueous HNO_3 concentration was originally 0.01M.

TABLE 37

Distribution Coefficients of Uranyl Nitrate with Nitric Acid

Reference: 43
TBP Concentration: 15%
Diluent: hexane
Temperature: 20°C

HNO_3 Conc. (M) aq.	D_u
0.02	0.22
0.1	0.39
0.5	1.11
1.0	2.40
2.1	5.77
3.1	8.83
5.2	12.8
8.0	7.90

TABLE 38

Distribution of Uranyl Nitrate with Sodium Nitrate

Reference: 43
TBP Concentration: 20%
Diluent: hexane
Temperature: 20°C

$NaNO_3$ Conc. (M)	Uranium Conc. (g/L) aq.	org.
0.0	16.75	4.05
0.1	14.30	6.45
0.25	11.10	10.05
0.5	7.69	12.88
1.0	4.12	17.25
2.0	1.18	20.0
3.0	0.45	20.9
5.0	0.062	20.5

TABLE 39

Distribution of Uranyl Nitrate

Reference:	43
TBP Concentration:	20%
Diluent:	hexane
Temperature:	20°C

Uranium Conc. (g/L)	
Aq.	Org.
9.62	1.02
17.2	3.80
30.0	12.9
51.3	33.5
72.4	46.6
142.5	78.0
354.0	91.6
452.0	90.0

TABLE 40

Distribution of Uranyl Nitrate*

Reference: 44
TBP Concentration: 15%
Diluent: n-dodecane
Temperature: (as noted)

Temp. °C	Uranium Conc. (g/L) Aq.	Org.
25	7.8	3.4
30	7.3	3.1
35	8.0	2.7
40	8.1	2.5
45	8.3	2.3
50	8.6	2.2
55	8.6	1.9
60	9.1	1.9

* Initial aqueous HNO_3 concentration was 0.3M.

TABLE 41

Distribution of Uranyl Nitrate*

Reference: 44
TBP Concentration: 15%
Diluent: n-dodecane
Temperature: (as noted)

Temp. °C	Uranium Conc. (g/L) Aq.	Org.
25	1.2	9.8
30	1.9	9.8
35	2.0	9.5
40	2.2	9.1
45	2.4	8.9
50	2.5	8.8
55	2.8	8.6
60	3.1	8.4

* Initial aqueous HNO_3 concentration was 2.0M.

TABLE 42

Distribution of Uranyl Nitrate*

Reference: 44
TBP Concentration: 15%
Diluent: n-dodecane
Temperature: (as noted)

Temp. °C	Uranium Conc. (g/L) Aq.	Org.
25	1.1	11
	51	44
30	1.1	12
	52	45
35	1.4	12
	52	44
40	1.5	12
	54	43
45	1.6	11
	54	42
50	1.8	12
	55	42
55	2.0	11
	55	41
60	2.2	11
	58	41

* Initial aqueous HNO_3 concentration was 3.0M.

TABLE 43

Distribution of Uranyl Nitrate with Plutonium and Nitric Acid

Reference: 44
TBP Concentration: 15%
Diluent: n-dodecane
Temperature: (as noted)

Temp. (°C)	Aqueous Pu Conc. (g/L)	HNO_3 Conc. (M) aq.	Uranium Conc. (g/L) aq.	org.
23	4.1	2.5	24	42
40	3.6	2.5	29	38
60	3.0	2.5	33	34

TABLE 44

Distribution Coefficients of Uranyl Nitrate with 1.0M Nitric Acid

Reference: 45
TBP Concentration: (as noted)
Diluent: n-dodecane
Temperature: 20°C

TBP Conc. (Vol. %)	D_u
2.74	0.2801
1.37	0.067
0.27	0.00276

TABLE 45

Distribution Coefficients of Uranyl Nitrate with Nitric Acid

Reference: 46
TBP Concentration: (as noted)
Diluent: kerosene
Temperature: 20°C

Initial Aqueous HNO_3 Conc. (M)	D_U 19% TBP	39% TBP	58% TBP	93% TBP
0.03	0.024	0.075	0.131	0.206
0.95	5.65	8.87	12.4	13.2
3.08	20.0	27.8	33.1	35.5
4.90	31.0	53.3	67.6	30.6
5.95	33.2	63.1	79.4	97.4
7.12	32.0	69.2	87.2	103
9.18	21.8	58.1	87.1	121
11.07	12.8	45.0	71.1	129
12.96	8.65	30.2	64.5	136

TABLE 46

Distribution Coefficients of Uranyl Nitrate with Nitric Acid

Reference: 47
TBP Concentration: 4.8%
Diluent: kerosene
Temperature: unknown

HNO_3 Conc.(M)*	D_u
1.03	0.628
1.50	1.30
2.02	1.97
2.49	2.66
3.06	3.52
4.42	4.96
4.92	5.08
5.42	4.85
6.68	3.80
9.07	1.97
10.8	1.58
12.8	0.96

* Aqueous HNO_3 concentration at equilibrium

TABLE 47

Distribution Coefficients of Uranyl Nitrate with Nitric Acid

Reference: 47
TBP Concentration: 19%
Diluent: kerosene
Temperature: unknown

HNO_3 Conc.(M)*	D_u
0.137	0.227
0.32	0.832
0.60	2.07
1.05	5.30
1.62	9.73
2.50	17.7
3.50	25.6
4.58	32.0
5.09	34.2
5.52	35.0
5.56	33.6
6.01	32.4
7.06	28.4
7.57	24.0
8.07	22.8
8.73	17.5
9.37	15.2
10.8	10.1
11.9	8.19
12.9	7.19
13.8	6.95
14.4	7.27

* Aqueous acid concentration at equilibrium

TABLE 48

Distribution of Uranyl Nitrate

Reference: 48
TBP Concentration: 100%
Diluent: none
Temperature: 25°C

Uranium Conc. (g/L)	
aq.	org.
116.2	289.2
195.6	330.5
246.9	343.4
509.8	387.3

TABLE 49

Distribution of Uranyl Nitrate

Reference: 48
TBP Concentration: 65%
Diluent: Amsco 125-82
Temperature: 25°C

Uranium Conc. (g/L)	
aq.	org.
15.0	13.6
22.1	31.8
28.2	51.6
41.4	88.5
60.2	134.6
173.0	221.7
374.9	246.9
431.5	250.2
588.5	252.8

TABLE 50

Distribution of Uranyl Nitrate

Reference: 48
TBP Concentration: 30%
Diluent: Amsco 125-82
Temperature: 25°C

Uranium Conc. (g/L)	
aq.	org.
18.1	7.42
28.7	18.8
38.4	32.0
59.4	55.6
73.6	67.8
91.0	80.3
116.8	93.0
205.5	114.3
262.2	116.9
318.7	120.6
378.2	122.2
430.5	123.0
591.8	125.4

TABLE 51

Distribution of Uranyl Nitrate

Reference: 48
TBP Concentration: 15%
Diluent: Amsco 125-82
Temperature: 25°C

Uranium Conc. (g/L)	
aq.	org.
20.1	3.14
33.2	9.23
46.6	16.3
73.1	28.9
91.3	35.2
110.7	40.6
136.5	46.6
215.2	54.3
270.0	56.8
323.6	58.2
377.5	58.8
430.4	58.9
583.8	60.3

TABLE 52

Distribution of Uranyl Nitrate

Reference: 48
TBP Concentration: 10%
Diluent: Amsco 125-82
Temperature: 25°C

Uranium Conc. (g/L)	
aq.	org.
21.0	1.71
35.1	5.57
49.6	10.4
77.7	19.2
97.2	23.7
116.5	27.5
146.6	31.8
199.0	35.3
246.7	37.8
307.5	39.4
362.5	39.9
414.6	40.7
575.4	39.9

TABLE 53

Distribution of Uranyl Nitrate

Reference: 48
TBP Concentration: 5%
Diluent: Amsco 125-82
Temperature: 25°C

Uranium Conc. (g/L)	
aq.	org.
21.3	0.50
37.0	1.86
52.3	3.88
82.6	8.28
102.7	10.6
123.2	12.5
154.3	15.1
207.8	16.8
260.9	18.2
317.9	19.3
368.0	19.4
579.3	20.1

TABLE 54

Distribution Coefficients of Uranous Nitrate with 3.0M Nitric Acid

Reference: 49
TBP Concentration: 30%
Diluent: xylene
Temperature: (as noted)

Temp. (°C)	D_u
10	1.5
15	1.63
20	1.59
25	1.76
30	1.74
40	2.10

Note: Uranium concentration is <1.0 g/L.

TABLE 55

Distribution Coefficients of Uranyl Nitrate with 3.0M Nitric Acid

Reference: 49
TBP Concentration: 30%
Diluent: xylene
Temperature: (as noted)

Temp. (°C)	D_u
20	23.6
30	20.5
40	17.8
50	15.0
60	13.2

Note: Uranium concentration is <1.0 g/L.

TABLE 56

Distribution Coefficients of Uranyl Nitrate with Nitric Acid

Reference: 50
TBP Concentration: 100%
Diluent: none
Temperature: 22°C

Conc. of HNO_3 (M)*	Distribution Coefficient (D_u) for Initial Concentrations of Uranyl Nitrate in Aqueous Phase		
	15 mg/L	0.97 g/L	5.0 g/L
0.10	1.6	2.0	2.5
0.30	7.0	7.5	7
0.50	12.3	12	11.5
0.75	18	18	18
1.0	25	25	26
2.0	49	51	52
3.0	79	74	85
3.5	95	86	103
4.5	124	115	130
5.0	139	140	146
5.5	151	145	156
6.0	162	146	162
6.25	156	149	-
6.5	-	151	154
6.75	-	146	151
7.0	153	145	147
8.0	-	120	130
9.0	-	105	114
9.5	113	109	108
10.0	-	100	104
11.6	107	-	99
12.0	-	104	-
13.0	-	107	-
14.3	119	112	-
14.5	122	114	-

* Aqueous acid concentration at equilibrium.

TABLE 57

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 50
TBP Concentration: 100%
Diluent: none
Temperature: 22°C

Initial U Conc. (g/L)	Distribution Coefficient (D_u) HNO_3 Conc., M*	
	1M, D_u	8M, D_u
0.1	25	120
0.5	24	113
1.0	25	122
2.5	24	121
5.0	25	127
10.0	25	125
50.0	23	118
70.0	21	107
100.0	18.5	95
150.0	16	72
200	13	48
250	10	-
300	8	-
350	6	-
400	5	-
450	3.5	-

* Aqueous acid concentration at equilibrium.

TABLE 58

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 51
TBP Concentration: 30%
Diluent: dodecane
Temperature: 70°C

HNO_3 Conc.* (M)	Uranium Conc. (g/L) aq.	org.
0.28	111.9	78.5
0.88	252.3	109.5
2.12	223.7	104.7
2.19	238	104.7
0.67	54.7	57.1
2.32	159.5	104.7
1.32	35.7	45.2
2.36	88.1	90.4
3.27	249.9	92.8
3.54	90.4	85.7
4.18	192.8	100.0
1.0	59.5	66.6

* Aqueous acid concentration at equilibrium

TABLE 59

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 52
TBP Concentration: 22.5%
Diluent: GSN kerosene
Temperature: 25°C

HNO_3 Conc.* (M)	Uranium Conc. (g/L) aq.	org.
0	22.6	7.36
0	47.4	28.8
0	88.2	51.2
0	177	75.6
0	263	84.1
0	415	86.5
0	526	85.7
0.23	13.0	7.55
0.16	62.4	48.9
0.17	265	83.7
0.25	414	87.4
0.80	3.87	12.6
0.78	38.2	57.2
0.81	76.2	67.0
0.94	231	84
1.10	419	85.6
1.91	0.71	10.3
2.72	29.7	56.4
2.29	38.2	70.7
2.85	182	83.3
3.04	370	85.5
4.01	0.42	5.23
4.88	7.94	55.3
4.21	23.3	65.2
4.01	130	80.4
4.21	307	87.4
2.06	355	86.0
0.90	480	86.8
0.48	507	88.2

* Aqueous acid concentration at equilibrium

TABLE 60

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 52
TBP Concentration: 22.5%
Diluent: GSN kerosene
Temperature: (as noted)

Temp. (°C)	HNO_3 Conc.* (M)	Uranium Conc. (g/L) aq.	org.
40	0	24.2	5.72
	0	91.6	50.2
	0	183	74.0
	0	263	81.9
	0	417	78.3
	0.80	4.07	12.9
	0.78	39.8	50.2
	1.00	263	82.0
	1.02	420	84.8
	2.06	377	84.2
	1.00	481	86.8
	0.63	509	86.3
70	0	25.2	3.12
	0	96.6	41.9
	0	181	67.0
	0	262	76.2
	0	410	82.9
	0.80	5.27	10.1
	0.99	46.1	44.1
	1.22	83.0	60.1
	1.13	234	77.5
	1.18	424	80.0
	2.06	426	83.7
	0.83	496	86.6
	0.63	516	87.2

* Aqueous acid concentration at equilibrium

TABLE 61

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 53
TBP Concentration: 25%
Diluent: Gulfspray Naphtha
Temperature: 26°C

HNO_3 Conc.* (M)	Uranium Conc. (g/L) aq.	org.
0	0.232	0.015
	0.431	0.023
	1.18	0.039
	2.39	0.080
	4.51	0.244
	7.15	0.573
	8.60	0.88
	16.0	4.0
	32.6	18.1
	46.6	29.1
	60.1	41.0
	89.4	60.9
	122.3	73.2
	217.2	91.9
	314.8	96.7
	616.3	102.0
0.25	0.146	0.092
	0.280	0.196
	0.665	0.53
	2.67	2.10
	10.3	9.5
	25.3	25.4
	50.0	48.9
	121	78.0
	215	93.0
	308	97.4

TABLE 61, Contd.

HNO_3 Conc.* (M)	Uranium Conc. (g/L) aq.	org.
0.5	0.080	0.151
	0.164	0.301
	0.436	0.748
	0.904	1.51
	1.87	2.99
	7.2	13.1
	21.2	30.1
	45.3	54.3
	214.6	93.0
	314	97.5
	575	100.9
1.0	0.031	0.182
	0.065	0.411
	0.172	0.956
	0.363	2.02
	0.779	4.00
	3.8	16.0
	13.5	36.8
	36.6	61.1
	212	95.2
	315	98.1
	553	99.5
2.0	0.015	0.208
	0.031	0.445
	0.081	1.07
	0.169	2.21
	0.363	4.47
	1.8	18.1
	6.9	43.6
	211	95.1

TABLE 61, Contd.

HNO_3 Conc.* (M)	Uranium Conc. (g/L) aq.	org.
3.0	0.009	0.229
	0.018	0.455
	0.047	1.14
	0.234	4.53
	1.1	18.3
	4.4	45.4
	26.1	75.0
	214	95.4
	314	96.5
	430	97.9
6.0	0.005	0.233
	0.010	0.466
	0.026	1.16
	0.119	4.64
	0.74	18.8
	3.5	45.9
	25.0	77.2
	116	89.5
	216	93.3
	363	96.1

* Initial aqueous HNO_3 concentration

TABLE 62

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 54
TBP Concentration: 30%
Diluent: ultrasene
Temperature: 70°C

HNO_3 Conc.(M)*	Uranium Conc. (g/L)*	D_u
0	79	0.61
0	~40	0.60
0	2.8	0.15
0	0.032	0.015
0	0.0025	0.0011
1.1	93	0.83
1.1	68	1.6
0.98	15.8	2.6
0.99	1.8	8.3
3.1	101	1.1
3.0	96	2.3
2.8	18.9	9.45
3.0	2.1	10.7
4.9	96	1.1
4.7	72	2.9
4.7	13.6	6.2
5.2	2.2	10.0
5.2	0.22	22

* Aqueous concentration at equilibrium

TABLE 63

Distribution of Uranyl Nitrate with Nitric Acid and Plutonium

Reference: 55
TBP Concentration: 30%
Diluent: unknown
Temperature: 30°C

HNO_3 Conc.* (M) aq.	Pu(IV) Conc.* (g/L)	Uranium Conc. (g/L) aq.	org.
0.1	2.46	2.69	1.43
0.2	2.34	18.3	2.24
0.4	2.29	0.93	2.98
0.6	2.03	0.57	3.43
0.8	1.91	0.43	3.47
1.0	1.65	0.31	3.64
1.2	1.46	0.26	3.76

* Aqueous concentration at equilibrium

TABLE 64

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 56
TBP Concentration: 20%
Diluent: Shell Deodorized Spraybase
Temperature: (as noted)

Temp. (°C)	HNO_3 Conc.* (M)	Uranium Conc. (g/L) aq.	org.
25	2.3	6.96	36.4
	2.6	21.0	58.8
	2.63	2.88	24.6
	0.770	7.92	22.9
50	2.3	9.12	34.4
	2.57	23.8	53.9
	2.40	5.52	23.6
	0.816	13.1	21.0

* Aqueous acid concentration at equilibrium

TABLE 65

Distribution of Uranyl Nitrate with Nitric Acid and Plutonium

Reference: 57
TBP Concentration: 40%
Diluent: Amsco
Temperature: unknown

HNO_3 Conc.* (M) aq.	Pu(IV) Conc.* (g/L)	Uranium Conc. (g/L) aq.	org.
0.21	0.015	0.112	1.18
0.21	0.117	1.00	2.15
0.25	2.69	0.89	2.30
0.26	25.1	0.230	1.45
0.41	49.4	0.125	1.35
0.42	49.4	0.0195	0.138
0.41	48.8	0.0021	0.044

* Aqueous phase concentration at equilibrium

TABLE 66

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 58
TBP Concentration: 30%
Diluent: (as noted)
Temperature: 30°C

Diluent	HNO_3 Conc.* (M)	Uranium Conc. (g/L)	
		aq.	org.
Ultrasene	2.93	25.2	90.7
	2.94	27.8	93.1
	0.72	37.4	68.3
	0.20	49.0	56.6
	0	29.0	17.6
Shell n-paraffin	2.94	25.5	90.9
	2.94	28.8	93.1
	0.73	38.1	68.5
	0.17	51.2	55.9
	0	29.3	17.1

TABLE 67

Distribution of Uranyl Nitrate with Nitric Acid and Thorium

Reference: 59
TBP Concentration: 42.5%
Diluent: ultrasene
Temperature: 30°C

HNO_3 Conc.* (M)	Thorium Conc.* (M)	Uranium Conc. (g/L)	
		aq.	org.
0	0.6	0.57	3.97
	0.3	1.00	4.76
	0.1	4.83	1.28
	0.01	4.47	1.36
	0.001	5.28	1.29
0.5	0.6	0.68	7.45
	0.3	0.74	7.50
	0.1	1.14	12.7
	0.01	1.58	11.4
	0.001	0.71	2.59
1.0	0.6	1.43	16.1
	0.3	1.43	15.9
	0.1	1.43	14.3
	0.01	1.55	14.8
	0.001	1.57	13.6

* Aqueous phase concentration at equilibrium

TABLE 68

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 60
TBP Concentration: 42.5%
Diluent: ultrasene
Temperature: 50°C

HNO_3 Conc.* (M)	Uranium Conc. (g/L)	
	aq.	org.
0.104	1.03	0.31
0.205	0.76	0.63
0.441	0.87	2.30
0.715	1.13	5.81
0.894	1.32	9.04
1.11	1.08	9.81
1.36	0.94	10.2
0.059	1.42	0.12
0.153	1.04	0.49
0.332	0.76	1.25
2.35	1.19	21.9
3.25	0.93	22.6
4.42	0.79	22.8

* Aqueous phase concentration at equilibrium

TABLE 69

Distribution of Uranyl Nitrate with Thorium and Nitric Acid

Reference: 60
TBP Concentration: 30%
Diluent: ultrasene
Temperature: (as noted)

Temp. (°C)	Aqueous Th Conc. (M)	Uranium Conc. (g/L) aq.	org.
30	0.333	0.73	5.12
	0.203	0.85	4.87
	0.168	0.93	4.71
	0.130	0.46	1.98
	0.077	0.57	1.88
	0.0327	0.74	1.62
50	0.326	0.71	3.90
	0.204	1.00	2.50
	0.172	1.10	3.67
	0.132	0.55	1.55
	0.078	0.66	1.43
	0.0333	0.89	1.19

Note: Aqueous phase HNO_3 concentration at equilibrium is 0.27M

TABLE 70

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 61
TBP Concentration: 35%
Diluent: ultrasene
Temperature: (as noted)

Temp. (°C)	HNO_3 Conc.* (M)	Uranium Conc. (g/L) aq.	org.
40	2.88	6.62	62.4
	3.08	14.3	88.1
	3.25	28.6	107.1
	3.13	44.0	116.6
50	3.00	8.09	61.9
	2.90	16.4	84.0
	3.00	32.6	104.3
	2.97	52.1	114.2
60	2.85	9.28	60.5
	2.94	19.3	81.9
	3.06	35.2	100.0
	3.00	54.7	112.8

* Aqueous phase concentration at equilibrium

TABLE 71

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 61
TBP Concentration: 30%
Diluent: ultrasene
Temperature: (as noted)

Temp. (°C)	HNO_3 Conc.* (M)	Uranium Conc. (g/L) aq.	org.
40	2.42	10.2	58.1
	2.44	21.7	78.5
	2.56	39.7	93.8
	2.46	63.8	103.3
50	2.59	9.5	59.0
	3.24	22.1	79.5
	2.62	45.7	92.6
	2.62	85.68	104.7
	3.38	10.0	61.9
	3.38	22.1	80.0
	3.36	41.2	95.0
	3.34	65.5	102.6
60	2.52	11.7	56.6
	2.60	25.0	73.3
	2.64	44.5	87.3
	2.52	61.2	95.2

* Aqueous phase HNO_3 concentration at equilibrium

TABLE 72

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 61
TBP Concentration: 25%
Diluent: ultrasene
Temperature: 50°C

HNO_3 Conc.* (M)	Uranium Conc. (g/L)	
	aq.	org.
3.04	13.6	56.6
3.06	30.0	70.0
3.04	52.4	79.7
3.11	74.5	85.7
3.58	80.9	86.6
2.43	77.6	84.3

* Aqueous phase HNO_3 concentration at equilibrium

TABLE 73

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 61
TBP Concentration: 35%
Diluent: ultrasene
Temperature: (as noted)

Temp. (°C)	HNO_3 Conc.* (M)	Uranium Conc. (g/L) aq.	org.
40	3.61	26.9	106.1
	2.56	28.3	104.7
50	3.73	30.7	102.6
	2.62	32.8	98.8
60	2.93	34.0	103.3
	3.85	36.4	104.0

* Aqueous phase HNO_3 concentration at equilibrium

TABLE 74

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 61
TBP Concentration: (as noted)
Diluent: ultrasene
Temperature: 25°C

TBP Conc. (%)	HNO_3 Conc.* (M)	Uranium Conc. (g/L) aq.	org.
5	1.27	1.71	1.36
	0.99	1.69	0.93
	0.80	2.45	0.86
	0.59	3.21	0.57
	0.43	4.14	0.57
	0.21	6.28	0.31
7.5	0.17	12.8	1.36
	0.31	6.04	1.19
	0.51	2.36	0.83
	0.72	1.52	0.79
12.5	0.16	7.88	1.67
	0.32	3.88	1.74
	0.53	1.67	1.71
	0.74	0.74	1.36

* Aqueous phase acid concentration at equilibrium

TABLE 75

Distribution of Uranyl Nitrate with Nitric Acid

Reference: 61
TBP Concentration: 7.5%
Diluent: Ulrasene
Temperature: 70°C

HNO_3 Conc.* (M)	Uranium Conc. (g/L) aq.	org.
0.21	11.2	0.48
0.48	6.66	0.95
0.59	2.62	0.48
0.82	1.95	0.48

* Aqueous phase acid concentration at equilibrium

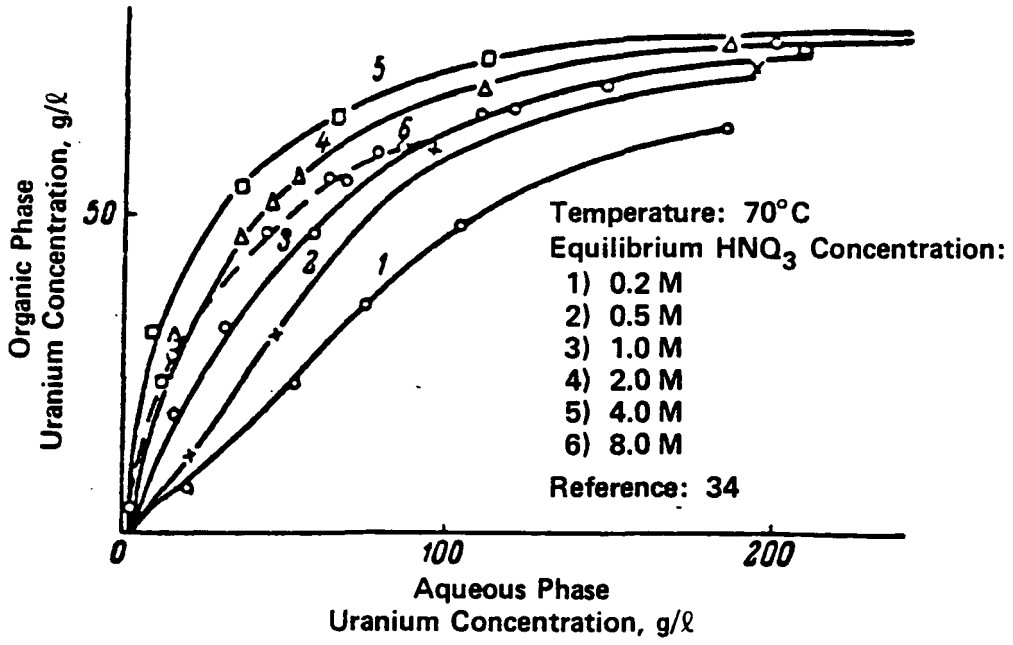

FIGURE 1. Distribution of Uranium with 20% TBP in Kerosene

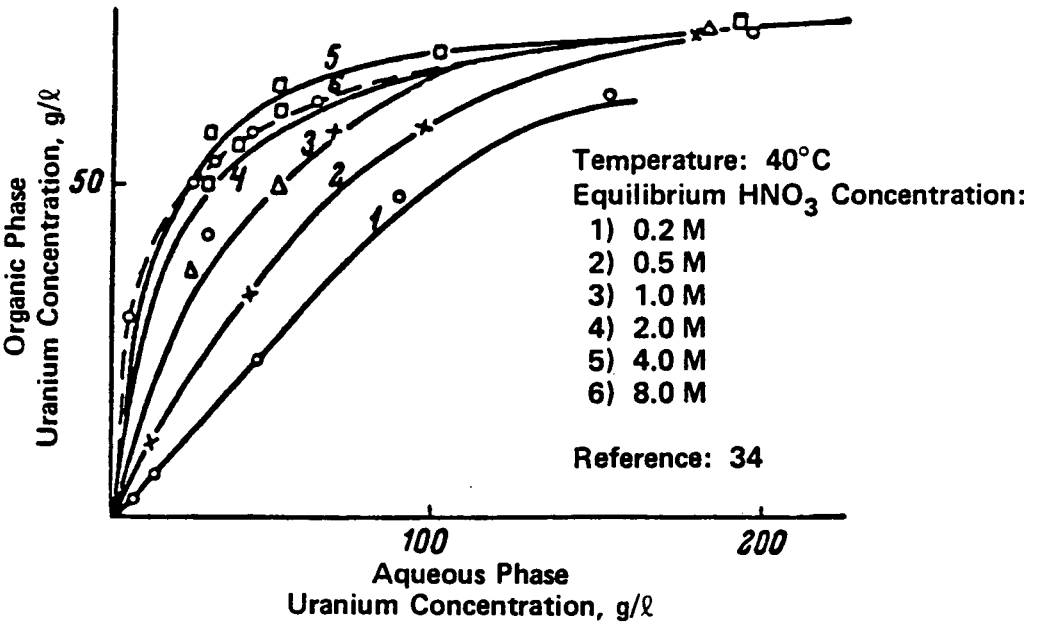

FIGURE 2. Distribution of Uranium with 20% TBP in Kerosene

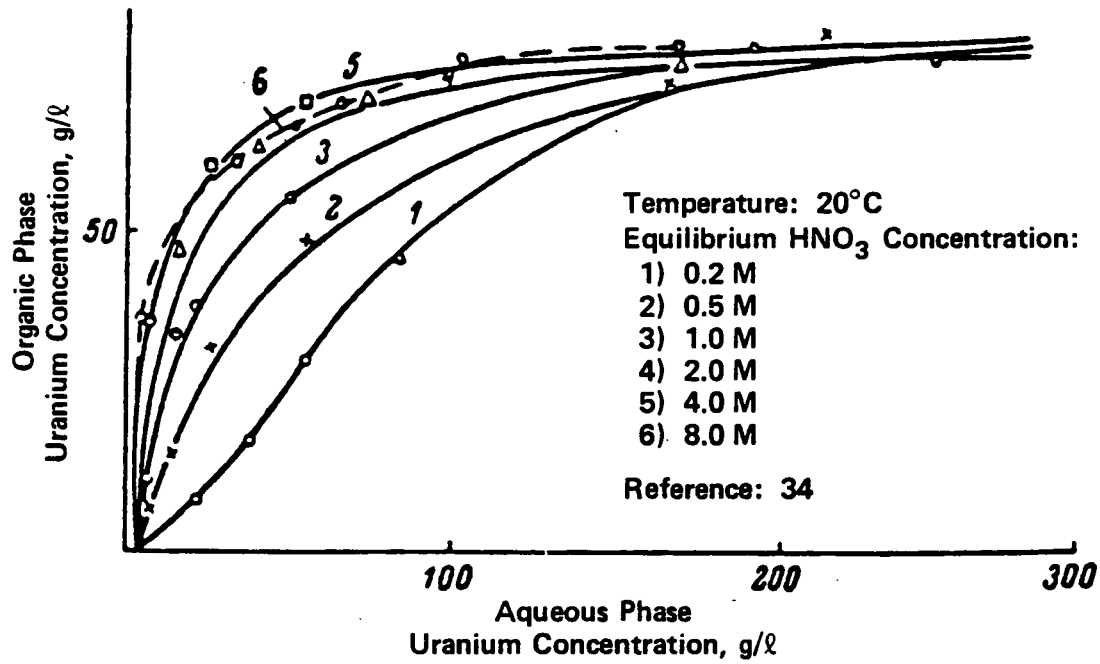

FIGURE 3. Distribution of Uranium with 20% TBP in Kerosene

Aqueous Phase Equilibrium Uranyl Nitrate Concentration

1) 10 g/ℓ
2) 20 g/ℓ
3) 50 g/ℓ
4) 100 g/ℓ

Reference: 34

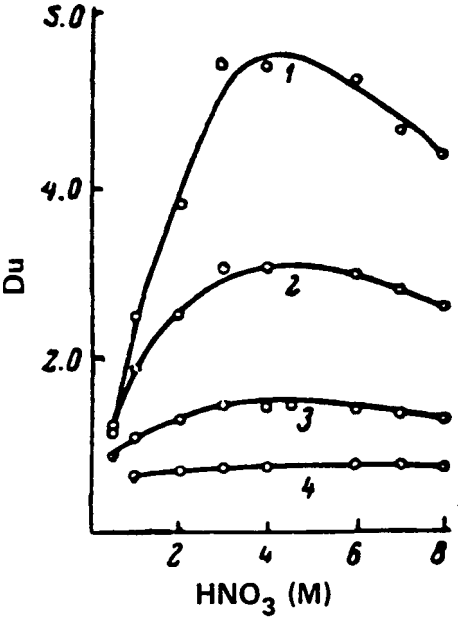

FIGURE 4. Effect of Acid Concentration on the Distribution Coefficient of Uranyl Nitrate

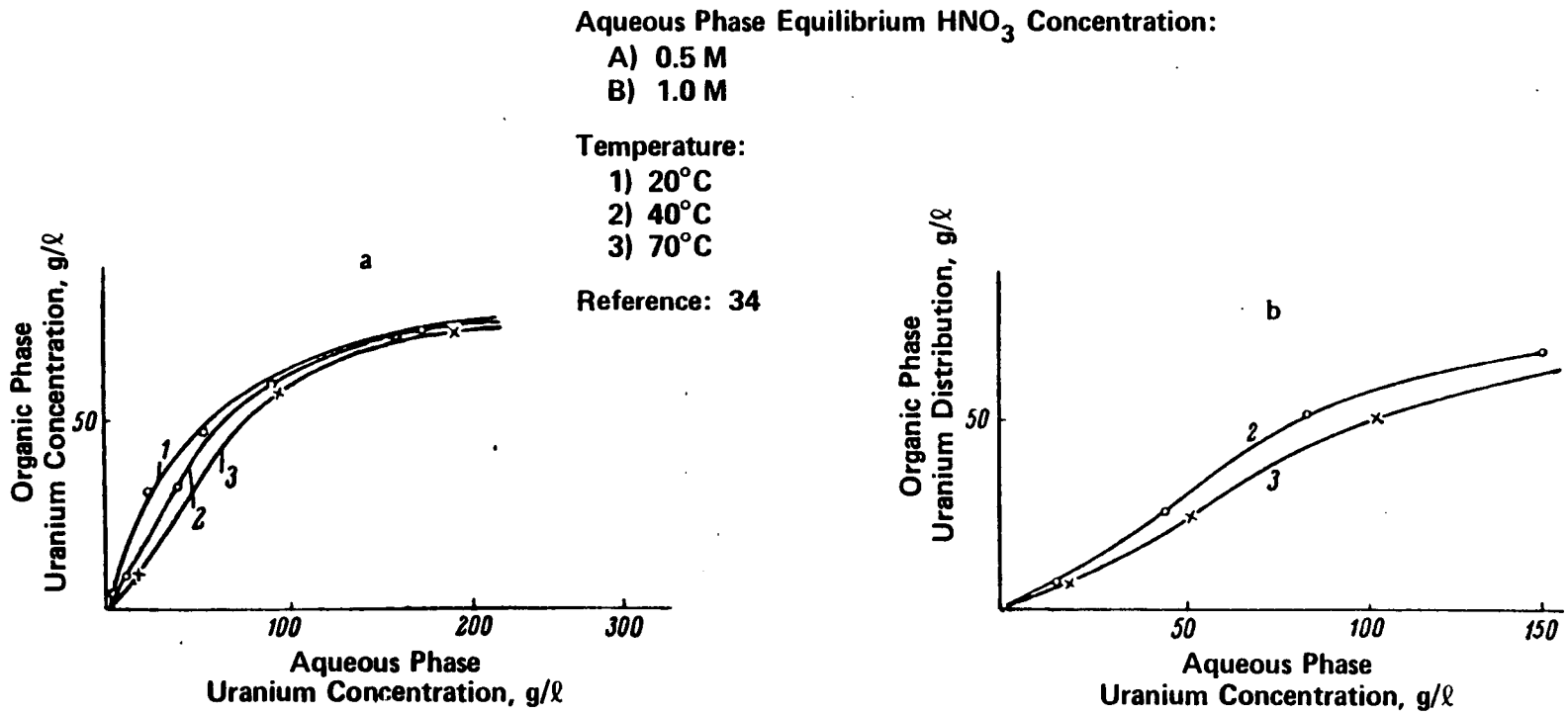

FIGURE 5. Distribution of Uranium with 20% TBP in Kerosene

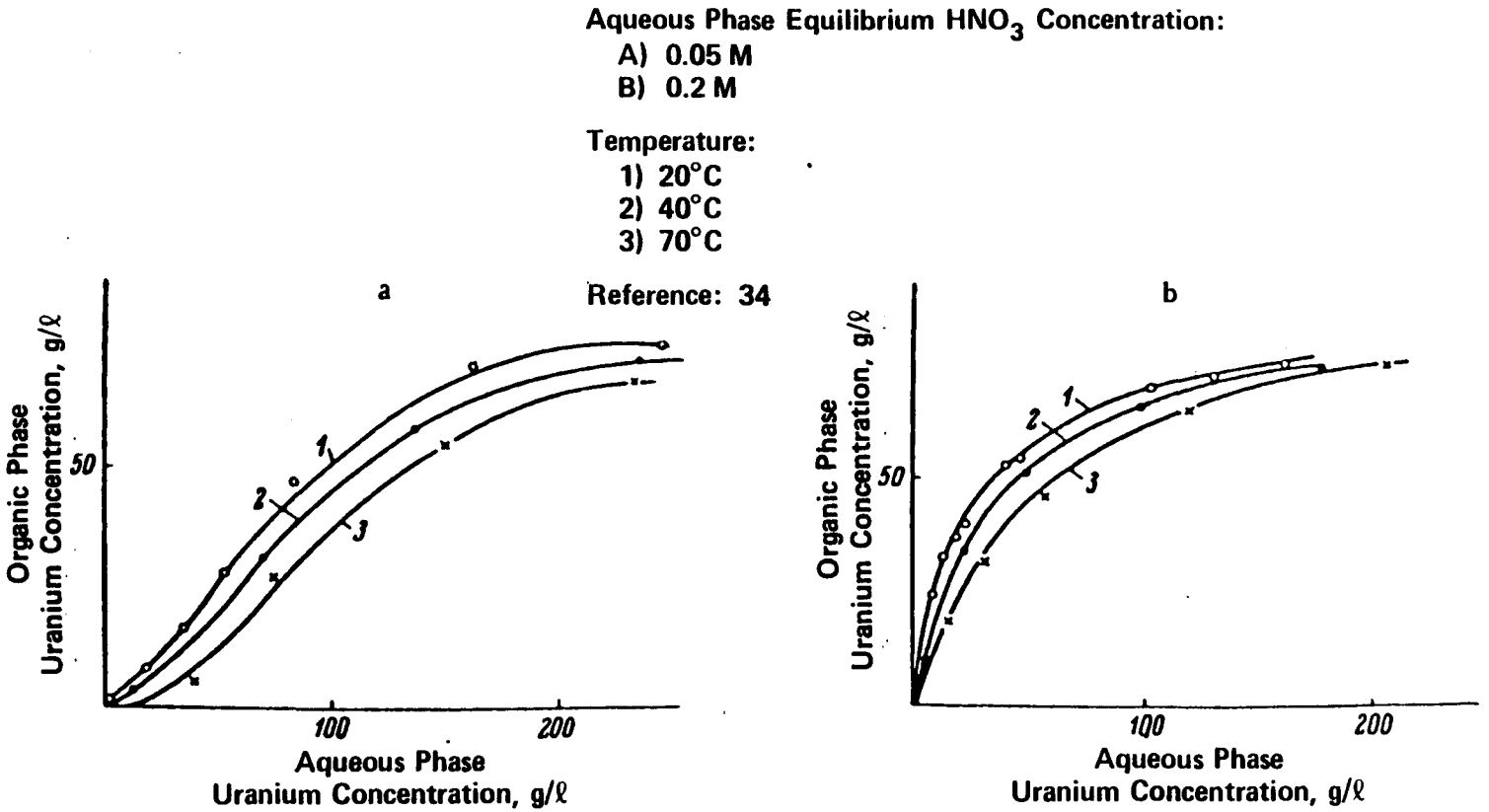

FIGURE 6. Distribution of Uranium with 20% TBP in Kerosene

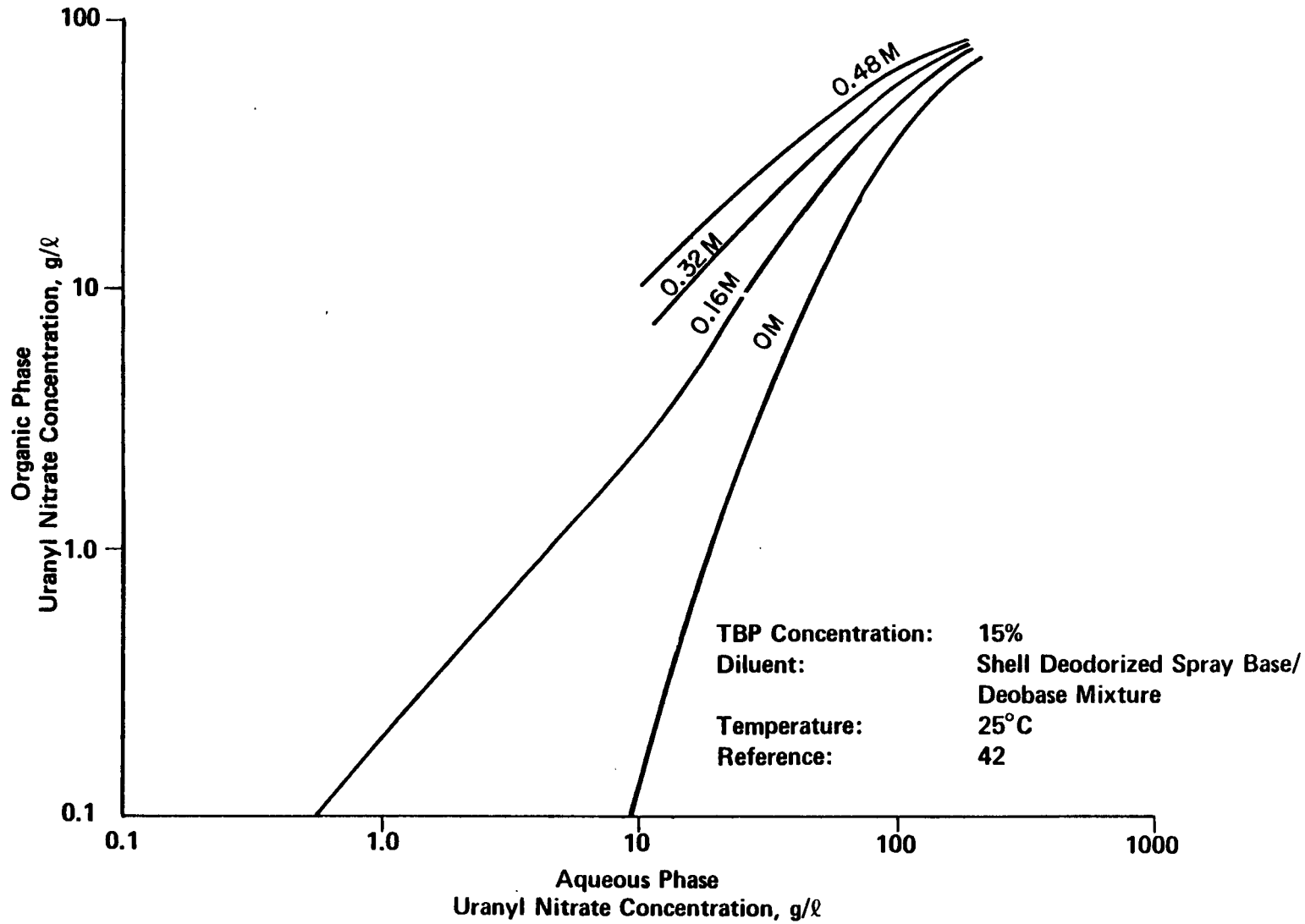

FIGURE 7. Uranium Equilibrium with Nitric Acid

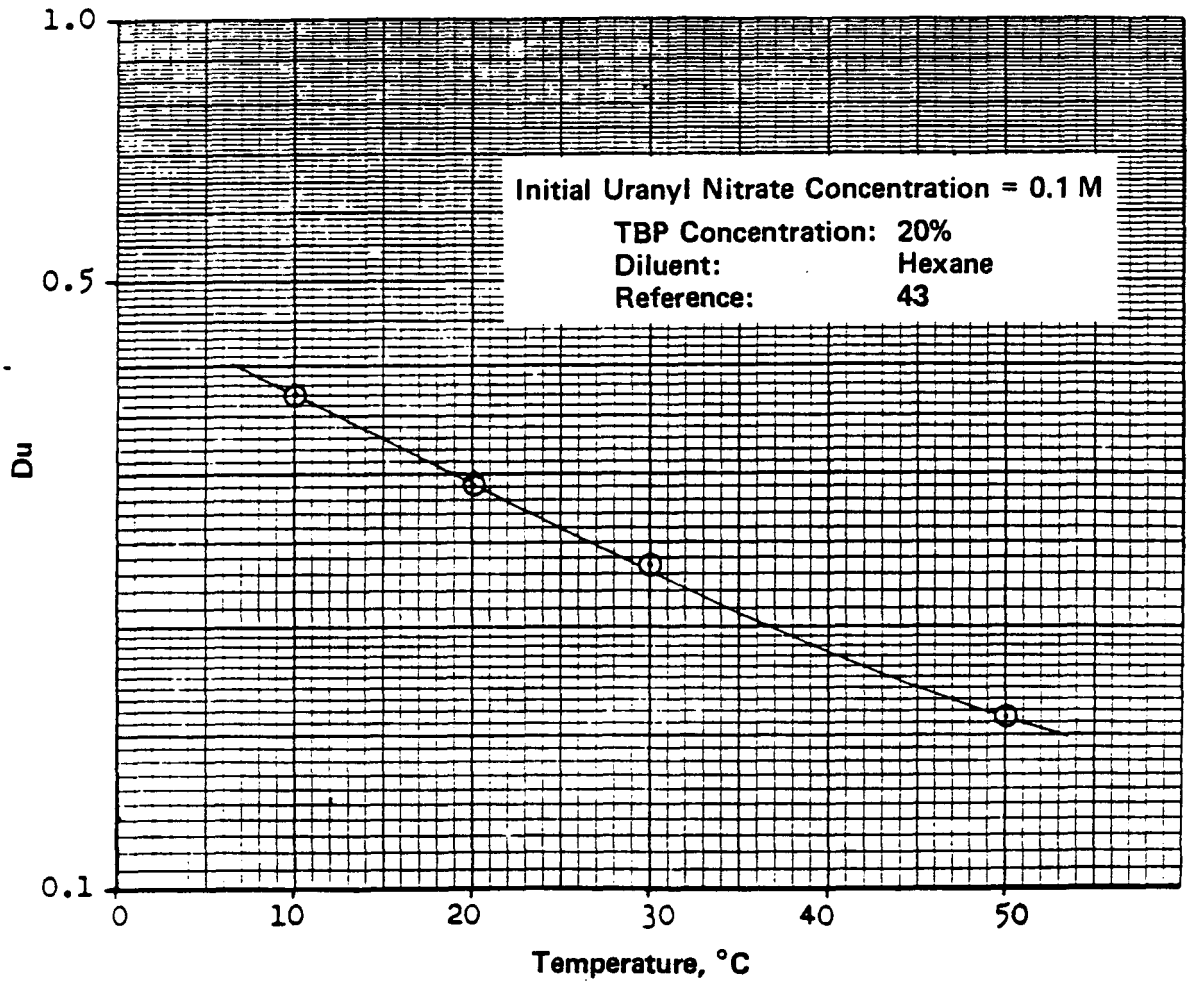

FIGURE 8. Effect of Temperature on Uranium Distribution Coefficients

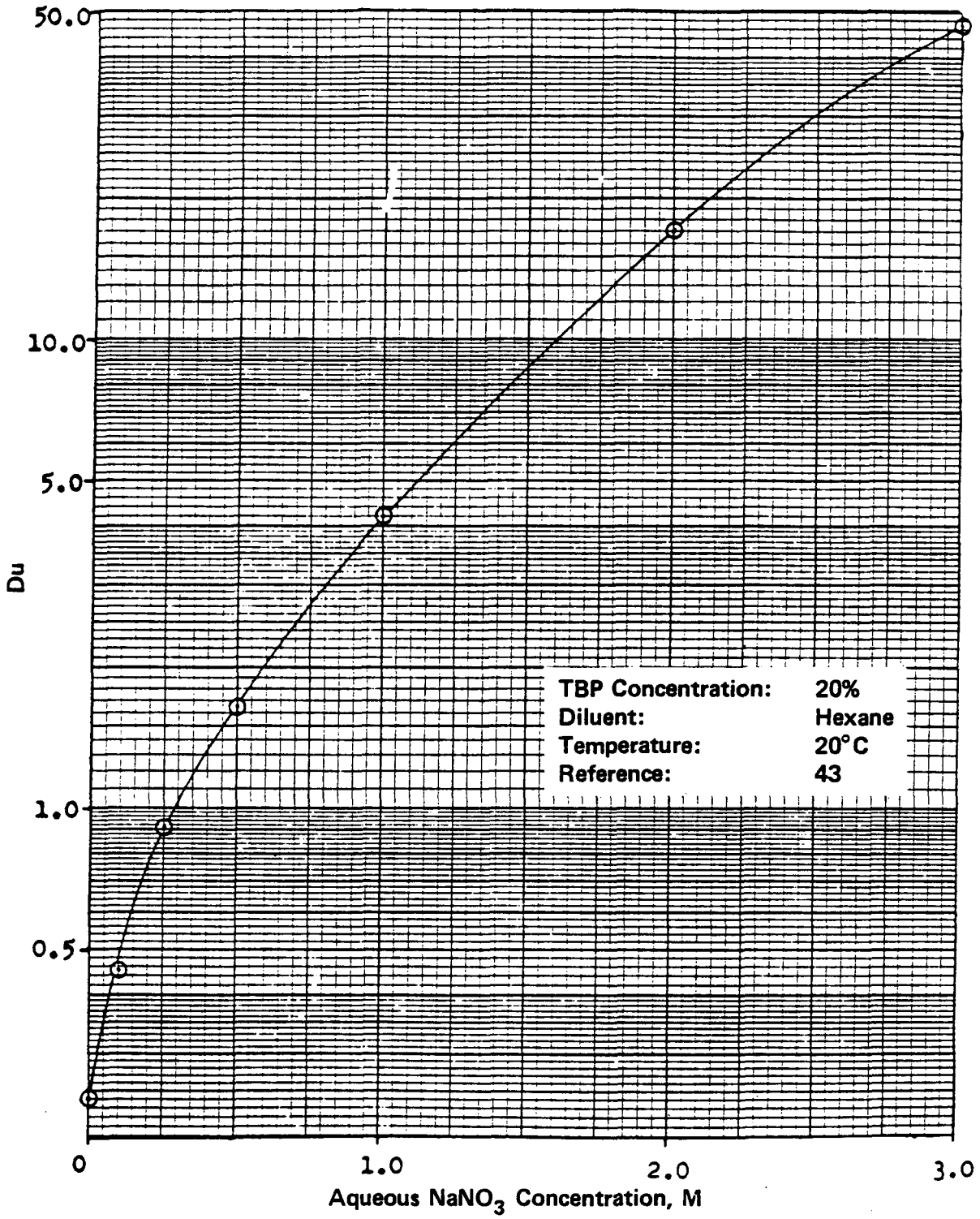

FIGURE 9. Effect of $NaNO_3$ Concentration on Uranium Distribution Coefficients

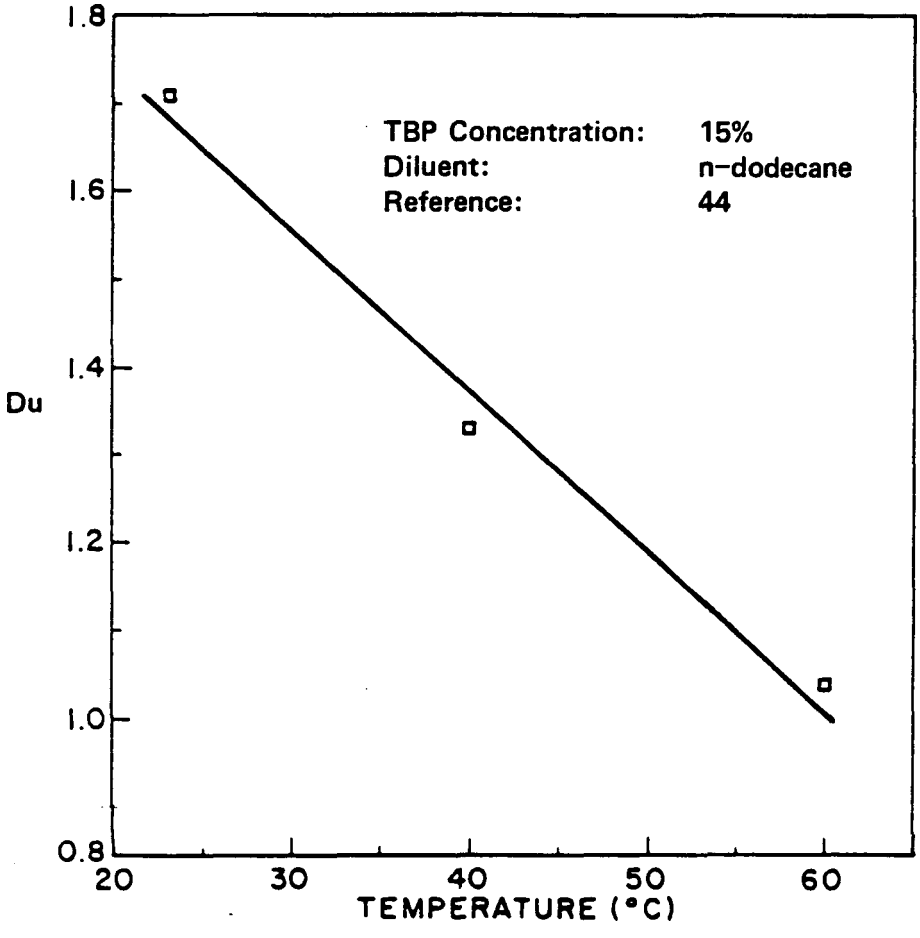

FIGURE 10. Effect of Temperature on the Distribution Coefficient of Uranium

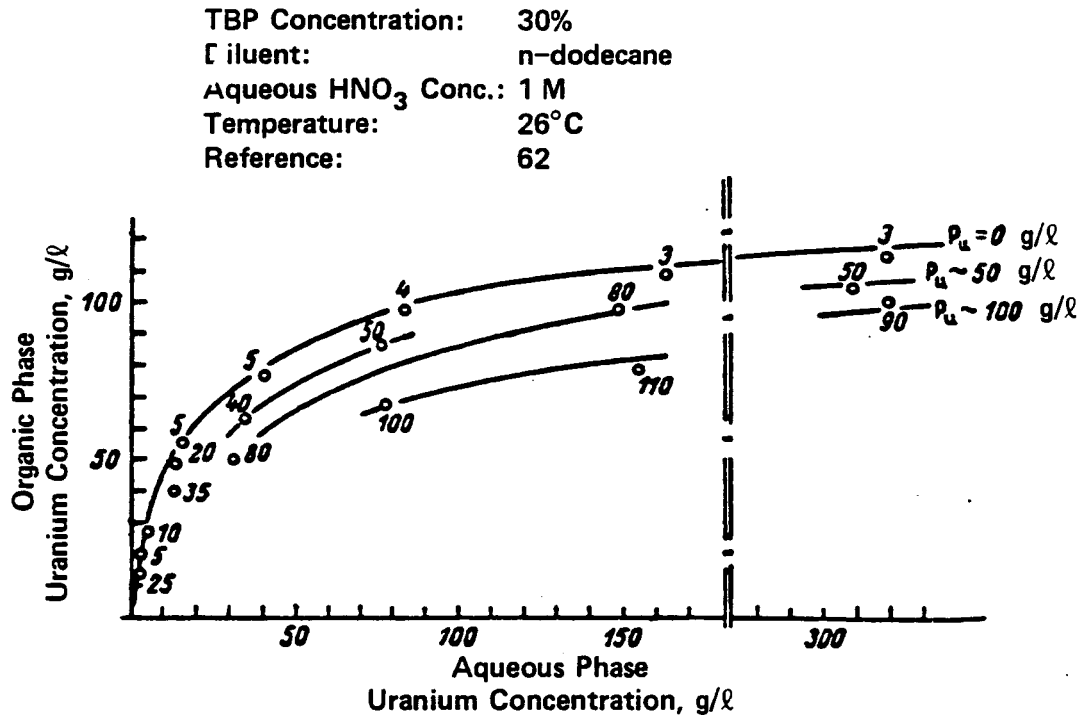

FIGURE 11. Effect of Pu on Uranium Distribution

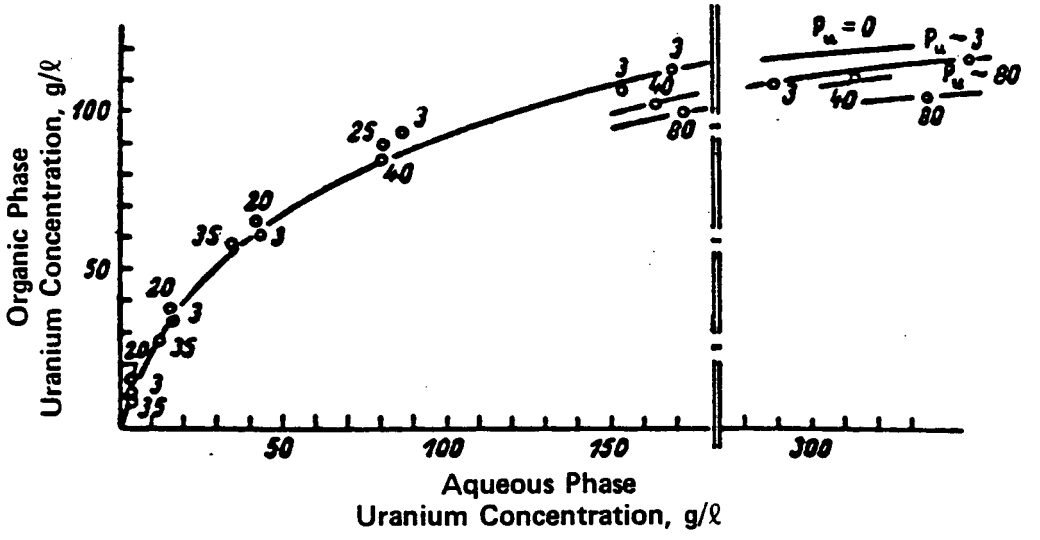

FIGURE 12. Effect of Pu on Uranium Distribution

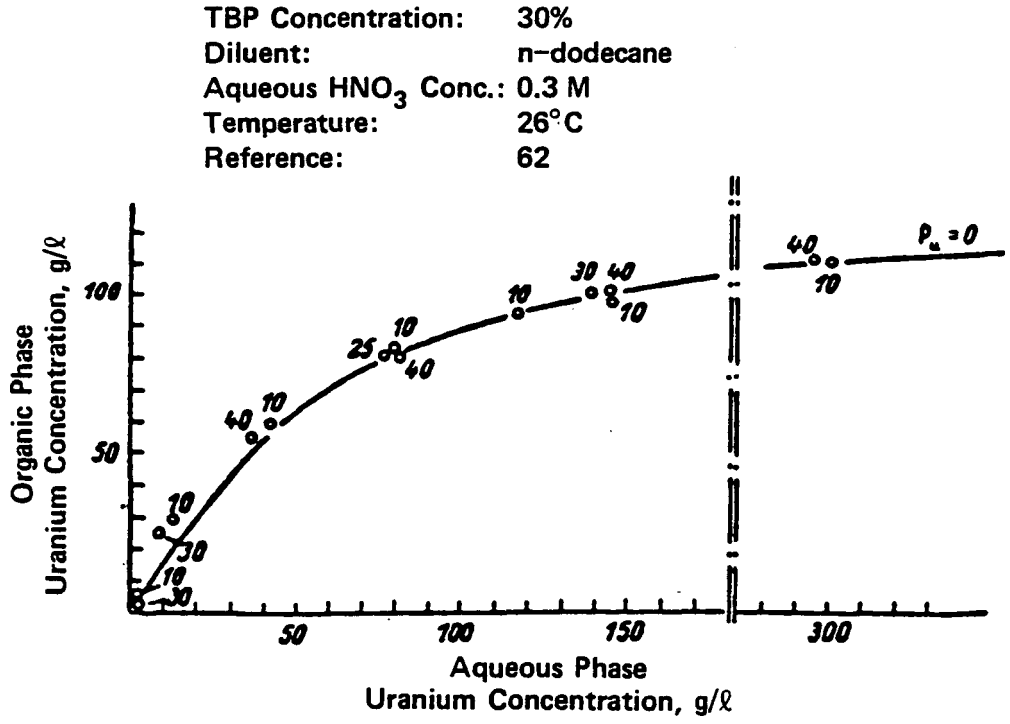

FIGURE 13. Effect of Pu on Uranium Distribution

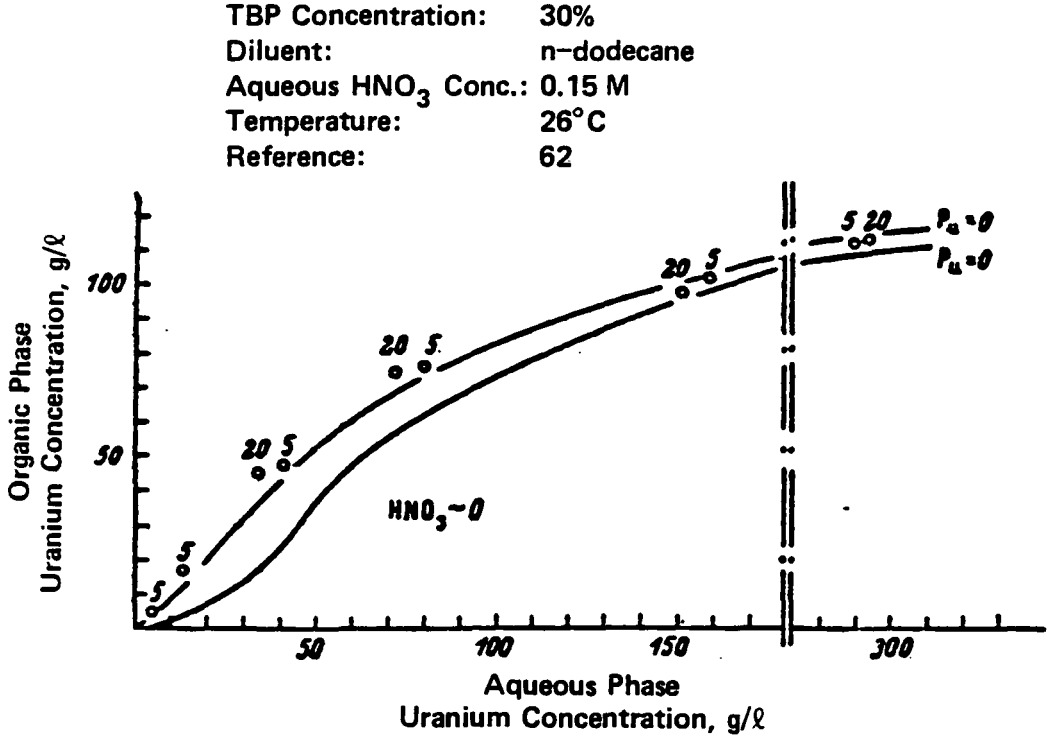

FIGURE 14. Effect of Pu on Uranium Distribution

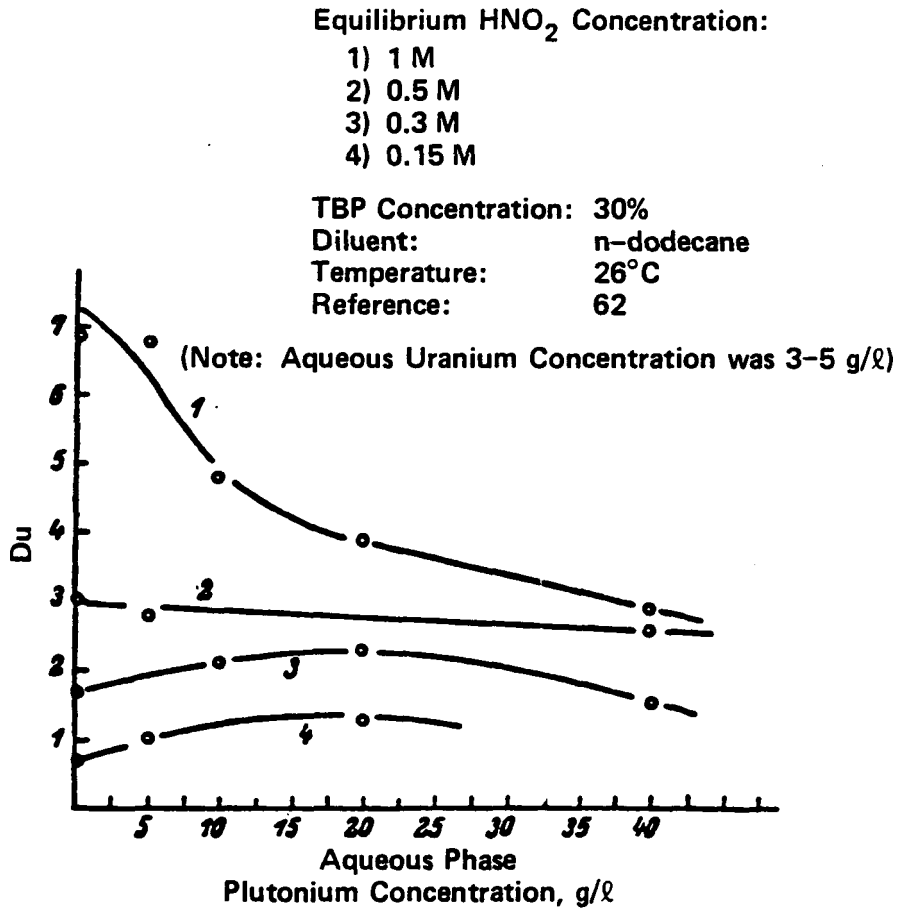

FIGURE 15. Influence of Plutonium and HNO_3 on Uranium Distribution

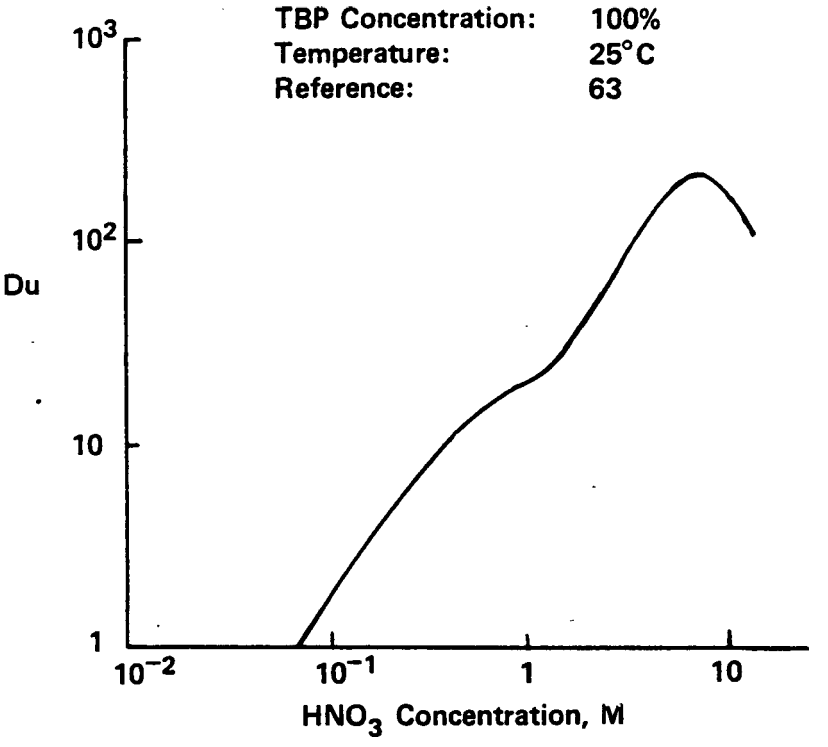

FIGURE 16. Effect of Acid Concentration on Uranium Distribution

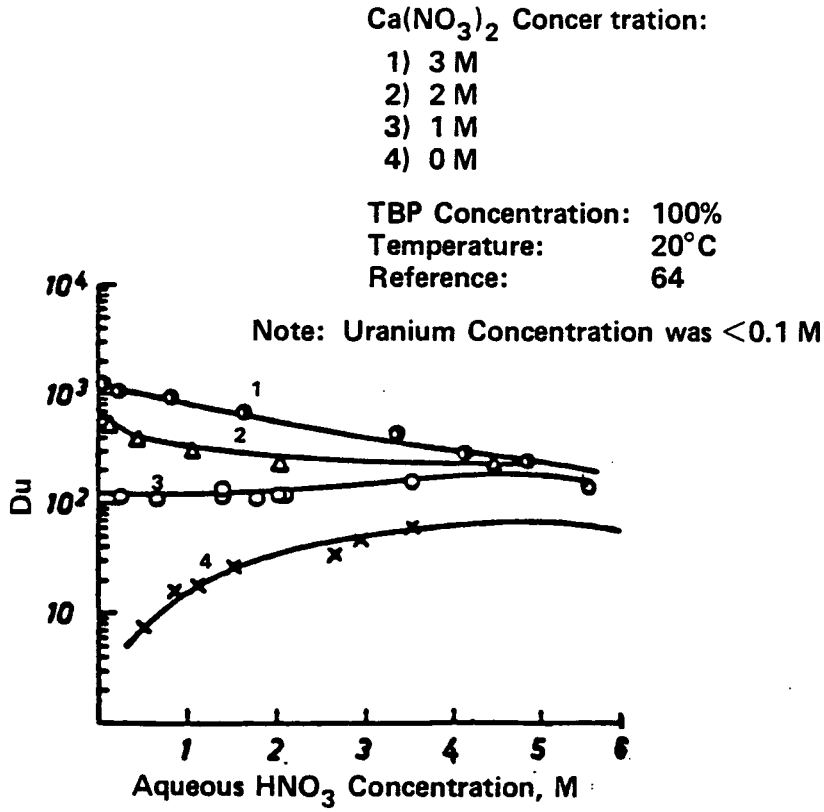

FIGURE 17. Effect of $Ca(NO_3)_2$ on Uranium Distribution

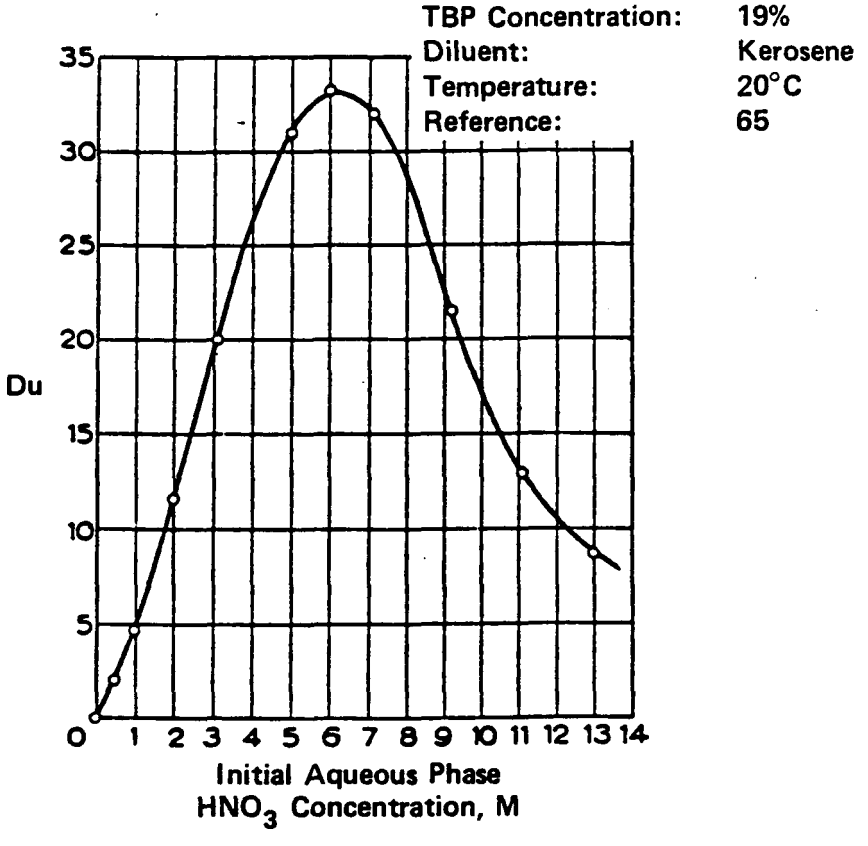

FIGURE 18. Effect of HNO_3 on Uranium Distribution

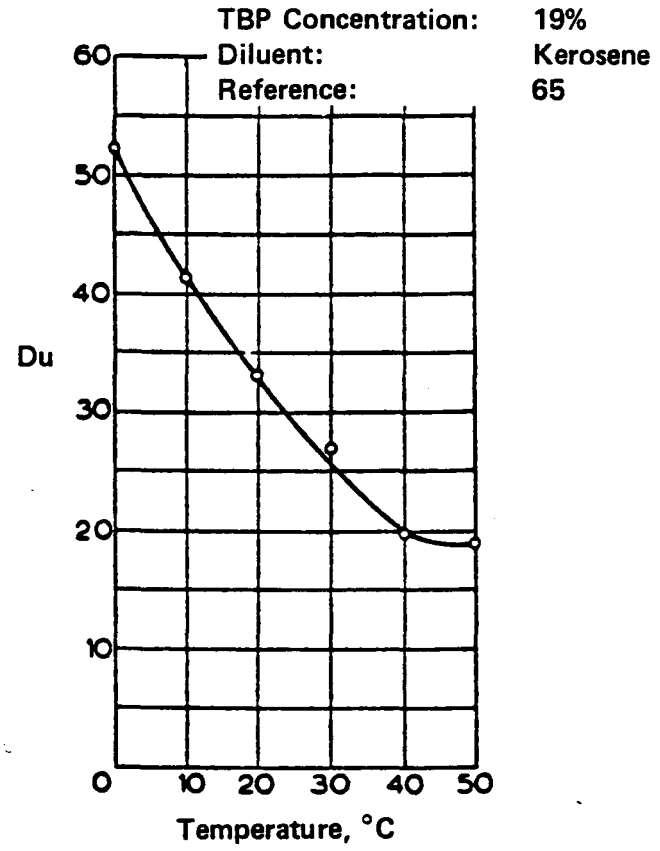

FIGURE 19. Effect of Temperature on the Distribution of 5 g/l Uranium from 6M HNO_3