DP-1357

662947

CALCULATION OF URANIUM INVENTORIES IN MIXER-SETTLERS DURING SOLVENT EXTRACTION WITH 7.5% TBP

M. C. THOMPSON

R. L. SHANKLE

E. I. du Pont de Nemours & Co.

Savannah River Laboratory

Aiken, S. C. 29801

PREPARED FOR THE U. S. ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(07-2)-1

Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

Price: Printed Copy $4.00; Microfiche $1.45

662947

DP-1357

UC-10

CALCULATION OF URANIUM INVENTORIES IN MIXER-SETTLERS DURING SOLVENT EXTRACTION WITH 7.5% TBP

M. C. THOMPSON

R. L. SHANKLE*

Approved by
J. A. Porter, Research Manager
Separations Chemistry Division

Publication Date: August 1974

E. I. du Pont de Nemours & Co.
Savannah River Laboratory
Aiken, S. C. 29801

PREPARED FOR THE U. S. ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(07-2)-1

*Present address: Department of Chemistry, University of Tennessee, Knoxville, Tennessee

ABSTRACT

The computer program TRANSIENTS was used to determine the total uranium inventory in each bank of mixer-settlers during solvent extraction processing of uranium fuels with 7.5% TBP in kerosene. The resulting data were used to derive general equations for calculating the total uranium inventory in the mixer-settler banks under various operating conditions. These equations can be used in conjunction with the enrichment of the fuel being processed to calculate the inventory of fissile ^{235}U in the banks and to establish nuclear safety controls.

CONTENTS

LIST OF TABLES AND FIGURES

INTRODUCTION

In the 3.5% TBP solvent extraction process for fully enriched uranium fuels at the Savannah River Plant (SRP), the allowed total uranium inventory for a mixer-settler bank is specified as a single value because the percent ^{235}U in the fuel is always quite high. The bank limit for nuclear safety purposes is stated in terms of ^{235}U, and operation within the limit is ensured by restricting

- Total uranium concentration of the feed to ≤6.0 grams per liter.
- Rate at which ^{235}U is fed to the mixer-settler, so that a quantity greater than the difference between the normal bank inventory and the inventory limit is not fed into the bank in less time than is necessary to correct ordinary operational problems.

In determining this feed rate limit, normal bank inventory was very conservatively taken as the maximum that could result when all operating conditions are at the most adverse limits that are within operating standards. For the 1A and 1D banks, these most adverse conditions are minimum extractant flow, maximum scrub flow, and minimum nitric acid in the scrub streams.

A new solvent extraction flowsheet has been developed using 7.5% TBP for processing both SRP uranium fuels and off-site uranium fuels of various enrichments. Uranium enrichment of the off-site fuels varies from ∿2 to >90%; to obtain the required higher feed rates and processing capacity for fuels of lower enrichment, solvent extraction with 7.5% TBP is necessary. Because of the low ^{235}U enrichment, the uranium concentration in the feed may considerably exceed the limit of 6 grams of total uranium per liter without exceeding 5.6 grams of ^{235}U per liter, which has been the maximum allowed at SRP for ^{235}U enrichments ≤95%.*

To facilitate the safe processing of higher uranium concentrations with 7.5% TBP, more specific calculation of total uranium inventory in the mixer-settler banks is needed for various concentrations of uranium in the feed under the operating conditions of interest. To assume the maximum possible inventory (most adverse operating limits), as in processing with 3.5% TBP, is too highly restrictive with 7.5% TBP, because this would reduce processing capacity below that of the present flowsheet. Equations were therefore derived to calculate the actual total uranium inventory

* This limit was set at approximately one-half of the minimum critical concentration of a geometrically unrestricted solution.

in each bank of mixer-settlers as a function of operating conditions. After the total uranium inventory is calculated, the ^{235}U inventory can be calculated from the known ^{235}U enrichment of the feed.

7.5% TBP SOLVENT EXTRACTION FLOWSHEET

The new 7.5% TBP solvent extraction flowsheet consists of two cycles to recover and purify uranium (Figures 1 and 2). In the first cycle with three mixer-settlers, uranium and neptunium (or plutonium if recovery is desired) are coextracted into the organic phase in the first mixer-settler (1A) and partitioned in the second mixer-settler (1B); uranium is stripped in the third mixer-settler (1C). The second cycle further purifies uranium with extraction in one mixer-settler (1D) and stripping in another (1E). In both cycles, 7.5 volume % TBP in kerosene is used as the extractant with various concentrations of nitric acid for scrubbing and stripping.

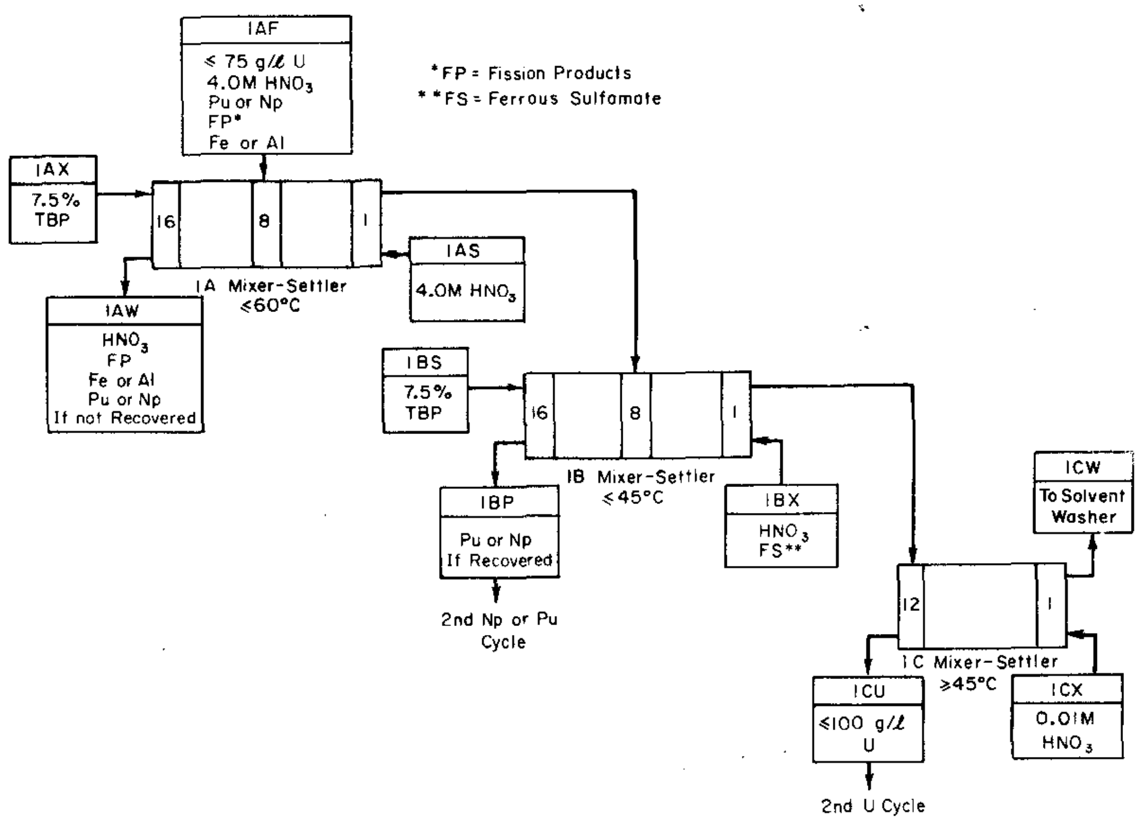

FIGURE 1 First Solvent Extraction Cycle

In both cycles, the flow of extractant is increased as the uranium concentration in the feed increases up to 75 grams per liter so that uranium does not reflux at any point to a concentration higher than that of the feed. The nominal nitric acid concentration of the feed and scrub streams to the 1A mixer-settler is 4.0M. Aluminum nitrate can be substituted for nitric acid on the basis of equal molarity of total nitrate, provided that sufficient acidity is maintained to prevent hydrolysis.

Molybdenum, iron, boric acid, nickel, manganese, and chromium in the feed do not interfere with uranium recovery. The concentration of nitric acid needed in the strip stream (1BX) to maintain uranium in the organic phase in the 1B mixer-settler is variable and is a function of the relative flow ratios of the feed, scrub, and strip streams. Ferrous sulfamate is added to the strip stream to aid in partitioning plutonium or neptunium from uranium. The nitric acid concentration in the scrub stream of the 1D mixer-settler is variable depending on the uranium concentration in the feed.

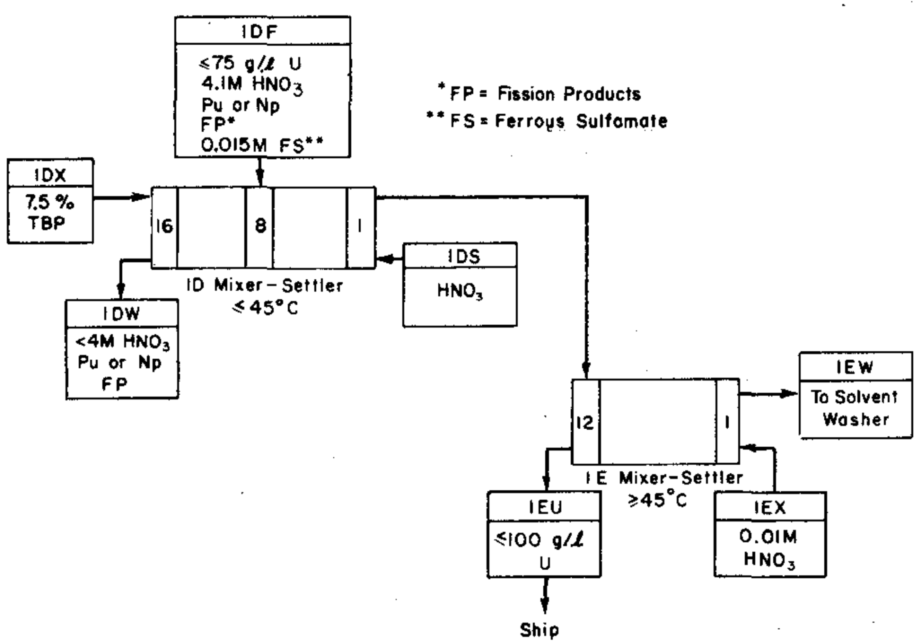

FIGURE 2 Second Uranium Solvent Extraction Cycle

CALCULATIONS FOR A, B, C, D, AND E BANKS

The effects of flow rates and feed concentrations on the uranium inventory were calculated for each mixer-settler bank. Ranges of operating parameters studied are given in Table 1; actual values studied and inventories calculated are given in Tables 2 through 5.

Uranium concentrations in mixer-settler stages were calculated using the TRANSIENTS solvent extraction program.[1] TRANSIENTS was modified to use the equations given in Table 6, which were derived from experimental distribution data. The total uranium inventory for the A, B, and D banks was calculated by Equation 1.

$$\text{Total U Inventory} = \sum_{i=1}^{16} \text{aqueous } U_i \times 23.97 \text{ liters/stage} + \sum_{i=1}^{16} \text{organic } U_i \times 47.95 \text{ liters/stage} \qquad (1)$$

The volume factors were based on weir heights in these banks being one-third of the total bank height, which corresponds to volumes for the aqueous and organic phases of 23.97 and 47.95 liters, respectively.[2]

Equation 2 was used to calculate the total uranium inventory for the C and E banks.

$$\text{Total U Inventory} = \sum_{i=1}^{12} \text{aqueous } U_i \times 94.6 \text{ liters/stage} + \sum_{i=1}^{12} \text{organic } U \times 189.3 \text{ liters/stage} \qquad (2)$$

The volume factors were derived similarly to those for A, B, and D banks.[2]

The data were examined graphically to give a general idea as to the type of equation to which they should be fitted, and in doing so, specific functional relationships were discovered. The total inventory values for the different conditions were then treated using these relationships and a linear least squares program written by Knight.[3] The best fits from the least squares analyses are:

A Bank

$$\ln U\ Inventory = 1.0452(\ln 1AF\ U) - 0.0037621(1AF\ HNO_3)^2(\ln 1AF\ HNO_3) + 0.0064749(1AS\ HNO_3) - 1.0985(\ln 1AX\ flow)^{*} - 4.2664(\ln 1AS/1AX) - 75.137(1AS/1AX)^2(\ln 1AS/1AX) \quad (3)$$

B Bank

$$\ln U\ Inventory = 5.3351 + 1.2287(\ln 1AU\ U) + 0.14962(\ln 1BX/1AU) - 0.71459(\ln 1BS/1BX) - 0.23303(1BX\ HNO_3) + 3.501(1AU\ HNO_3)^{**} \quad (4)$$

C and E Banks

$$\ln U\ Inventory = 6.1676 + 0.57(\ln U\ product\ stream\ flow/strip\ flow) + 0.19691(\ln U\ product\ stream\ flow/strip\ flow)^2 + 0.55566(\ln U\ product\ stream\ HNO_3) + 0.09831(\ln U\ product\ stream\ HNO_3)^2 + 1.0051(\ln feed\ U) \quad (5)$$

D Bank

$$\ln U\ Inventory = 1.0836(\ln 1DF\ U) - 0.010740(1DF\ HNO_3)^2(\ln 1DF\ HNO_3) - 0.42182(1DS\ HNO_3) - 1.0191(\ln 1DX\ flow)^{*} - 4.1848(\ln 1DS/1DX) - 93.093(1DS/1DX)^2(\ln 1DS/1DX) \quad (6)$$

The computer fits of Equations 3 through 6 are given in Tables 7 through 10.

---

* 1AU HNO_3, which is the HNO_3 in equilibrium with 1AS HNO_3 at a specific U concentration, may be obtained for minimum, nominal, and maximum HNO_3 concentrations in 1AS from Figure 3.

** 1AX and 1DX flow is equivalent to 1AX/1AF or 1DX/1DF flow ratio multiplied by 100.

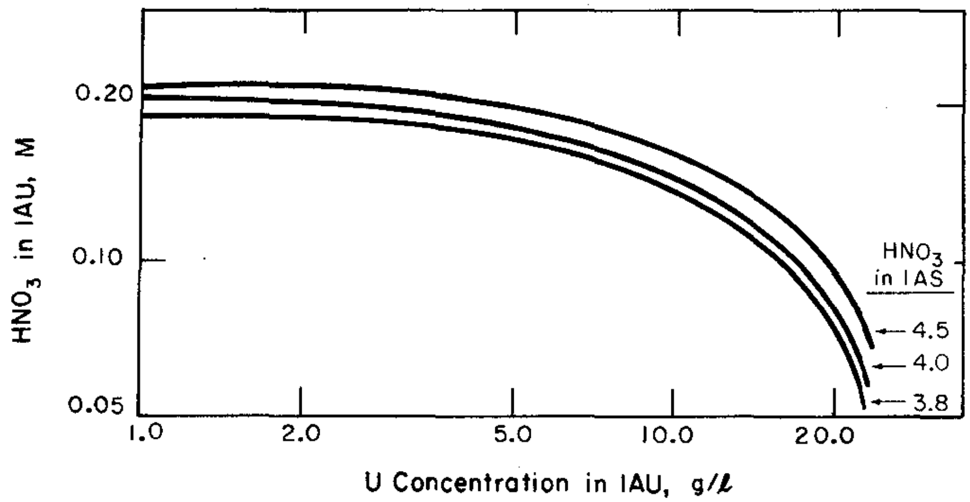

FIGURE 3 HNO_3 Concentration in 1AU as a Function of U Concentration in 1AU and HNO_3 Concentration in 1AS

EXPERIMENTAL VERIFICATION OF CALCULATED VALUES

Four miniature mixer-settler tests (Tables 11, 12, 13, and 14) were made to examine the fit between calculated and experimental stage profiles and inventories. The test conditions are representative of processing low enriched fuels. Miniature mixer-settler tests at uranium concentrations representative of enriched uranium processing were not made because the errors shown by least squares derivation of the equations were similar at all uranium concentrations. For D, and C or E banks, the inventory predicted from the respective equations can be correlated with the experimental inventories. The predicted values are slightly high in both cases. For the A and B banks, an insufficient number of stages were analyzed to allow full correlation with predicted inventories. However, the similarities of the calculated errors for A and B bank inventories to those for the D, and C or E banks indicate similar correlation of experimental and predicted inventories. The error analysis data in Table 15 also indicate that uranium inventories calculated from the inventory equations will be slightly high, and will thus be conservative for nuclear safety considerations.

REFERENCES

1. J. T. Lowe. "Calculation of the Transient Behavior of Solvent Extraction Processes." *I & EC Proc. Des. and Dev. 7*, 362-366 (1968).

2. A. A. Kishbaugh. *Mixer-Settler Development. Semiworks Tests of a "Jumbo" Pump-Mix Mixer-Settler.* USAEC Report DP-289, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, S. C. (1958).

3. F. D. Knight. *Generalized Linear Regression Analysis.* USAEC Report DP-1128, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, S. C. (1968).

TABLE 1

Ranges of Solvent Extraction Operating Parameters

A Bank			
1AS/1AX flow ratio	0.115	to	0.17
1AX/1AF flow ratio	1.20	to	3.50
1AS HNO_3, M	3.8	to	4.5
1AF HNO_3, M	3.8	to	5.6
1AF U, g/ℓ	1.0	to	49.5
B Bank			
1BS/1BX flow ratio	2.0	to	4.0
1BX/1BF[a] flow ratio	0.2	to	1.0
1BF[a] HNO_3, M	0.10	to	0.23
1BF[a] U, g/ℓ	0.40	to	16.0
1BX HNO_3, M	1.20	to	2.0
C and E Banks			
Feed HNO_3, M	0.03	to	0.09
Feed U, g/ℓ	1.3	to	10.3
Strip HNO_3, M	0.01	to	0.04
Feed flow/strip flow	1.0	to	10.0
D Bank			
1DS/1DX flow ratio	0.10	to	0.15
1DX/1DF flow ratio	1.70	to	4.00
1DS HNO_3, M	0.8	to	1.5
1DF HNO_3, M	3.9	to	4.3
1DF U, g/ℓ	2.0	to	35.0

a. 1BF = 1AU

TABLE 2

A-Bank Operating Parameters

1AS		1AF			1AX	U
Relative Flow	HNO_3, M	Relative Flow	HNO_3, M	U, g/ℓ	Relative Flow	Inventory, g/bank
20.4	3.8	100	3.8	1.0	120	433
18.0	3.8	100	3.8	1.0	120	430
13.8	3.8	100	3.8	1.0	120	426
20.4	3.8	100	3.8	6.1	120	2778
18.0	3.8	100	3.8	6.1	120	2758
13.4	3.8	100	3.8	6.1	120	2718
20.4	3.8	100	3.8	11.0	120	5439
18.0	3.8	100	3.8	11.0	120	5378
13.8	3.8	100	3.8	11.0	120	5377
20.4	3.8	100	4.0	1.0	120	431
18.0	3.8	100	4.0	1.0	120	428
13.8	3.8	100	4.0	1.0	120	424
20.4	3.8	100	4.0	6.1	120	2756
18.0	3.8	100	4.0	6.1	120	2744
13.8	3.8	100	4.0	6.1	120	2698
20.4	3.8	100	4.0	11.0	120	5391
13.8	3.8	100	4.0	11.0	120	5245
20.4	4.5	100	3.8	1.0	120	428
18.0	4.5	100	3.8	1.0	120	425
20.4	4.0	100	4.0	1.0	120	429
18.0	4.0	100	4.0	1.0	120	427
13.8	4.0	100	4.0	1.0	120	423
20.4	4.0	100	4.0	6.1	120	2750
18.0	4.0	100	4.0	6.1	120	2731
13.8	4.0	100	4.0	6.1	120	2698
20.4	4.0	100	4.0	11.0	120	5368
18.0	4.0	100	4.0	11.0	120	5304
13.8	4.0	100	4.0	11.0	120	5062
28.75	3.8	100	3.8	1.0	250	189.0
37.50	3.8	100	3.8	1.0	250	189.8
42.50	3.8	100	3.8	1.0	250	190.2
28.75	3.8	100	3.8	6.1	250	1260
37.50	3.8	100	3.8	6.1	250	1273
42.50	3.8	100	3.8	6.1	250	1280
28.75	3.8	100	3.8	11.0	250	2285
37.50	3.8	100	3.8	11.0	250	2308
42.50	3.8	100	3.8	11.0	250	2323
42.50	3.8	100	3.8	34.5	250	9171
28.75	3.8	100	4.0	1.0	250	188.5
37.50	3.8	100	4.0	1.0	250	189.4

TABLE 2 (Continued)

1AS		1AF			1AX	U
Relative Flow	HNO_3, M	Relative Flow	HNO_3, M	U, g/ℓ	Relative Flow	Inventory, g/bank
42.50	3.8	100	4.0	1.0	250	189.8
28.75	3.8	100	4.0	6.1	250	1255
37.50	3.8	100	4.0	6.1	250	1266
42.50	3.8	100	4.0	6.1	250	1274
28.75	3.8	100	4.0	11.0	250	2279
37.50	3.8	100	4.0	11.0	250	2299
42.50	3.8	100	4.0	11.0	250	2311
28.75	4.0	100	3.8	1.0	250	188.9
37.50	4.0	100	3.8	1.0	250	189.4
42.50	4.0	100	3.8	1.0	250	189.9
28.75	4.0	100	3.8	6.1	250	1257
37.50	4.0	100	3.8	6.1	250	1266
42.50	4.0	100	3.8	6.1	250	1274
28.75	4.0	100	3.8	11.0	250	2281
37.50	4.0	100	3.8	11.0	250	2298
42.50	4.0	100	3.8	11.0	250	2312
28.75	4.0	100	4.0	1.0	250	188.4
37.50	4.0	100	4.0	1.0	250	189.3
42.50	4.0	100	4.0	1.0	250	189.4
37.50	4.0	100	4.0	6.1	250	1262
42.50	4.0	100	4.0	6.1	250	1268
42.50	4.0	100	4.0	11.0	250	2304
59.50	3.8	100	3.8	6.1	350	913.8
59.50	3.8	100	3.8	11.0	350	1648
59.50	3.8	100	3.8	34.5	350	5674
59.50	3.8	100	4.0	11.0	350	1641
59.50	4.0	100	3.8	11.0	350	1642
59.50	4.0	100	4.0	11.0	350	1636
59.50	4.5	100	4.0	11.0	350	1620

TABLE 3

B-Bank Operating Parameters

1BX Relative Flow	1BX HNO_3, M	1BF Relative Flow	1BF HNO_3, M	1BF U, g/ℓ	1BS Relative Flow	U Inventory, g/bank
20	1.65	100	0.104	16	40	9345
20	1.50	100	0.104	16	60	7332
20	1.40	100	0.104	16	80	6182
50	1.65	100	0.104	16	100	6285
50	1.35	100	0.104	16	150	4845
50	1.20	100	0.104	16	200	3978
100	1.75	100	0.104	16	200	3756
100	1.30	100	0.104	16	300	3047
100	1.00	100	0.104	16	400	2867
20	1.65	100	0.110	16	40	9296
20	1.50	100	0.110	16	60	7305
20	1.40	100	0.110	16	80	6163
50	1.65	100	0.110	16	100	6270
50	1.35	100	0.110	16	150	4835
50	1.20	100	0.110	16	200	3970
100	1.75	100	0.110	16	200	3753
100	1.30	100	0.110	16	300	3043
100	1.00	100	0.110	16	400	2861
20	1.65	100	0.125	16	40	9184
20	1.50	100	0.125	16	60	7243
20	1.40	100	0.125	16	80	6116
50	1.65	100	0.125	16	100	6238
50	1.35	100	0.125	16	150	4811
50	1.20	100	0.125	16	200	3949
100	1.75	100	0.125	16	200	3745
100	1.30	100	0.125	16	300	3034
100	1.00	100	0.125	16	400	2846
20	2.00	100	0.104	16	40	7949
20	2.00	100	0.104	16	60	6116
20	2.00	100	0.104	16	80	5084
50	2.00	100	0.104	16	100	5342
50	2.00	100	0.104	16	150	3735
50	2.00	100	0.104	16	200	2937
100	2.00	100	0.104	16	200	3417
100	2.00	100	0.104	16	300	2296
100	2.00	100	0.104	16	400	1757
20	1.65	100	0.181	2.35	40	966.4
20	1.50	100	0.181	2.35	60	850.1
20	1.40	100	0.181	2.35	80	760.5
50	1.65	100	0.181	2.35	100	742.8

TABLE 3 (Continued)

1BX		1BF			1BS	U
Relative Flow	HNO_3, M	Relative Flow	HNO_3, M	U, g/ℓ	Relative Flow	Inventory, g/bank
50	1.35	100	0.181	2.35	150	618.8
50	1.20	100	0.181	2.35	200	520.7
100	1.75	100	0.181	2.35	200	491.8
100	1.30	100	0.181	2.35	300	386.2
100	1.00	100	0.181	2.35	400	328.4
20	2.00	100	0.181	2.35	40	900.5
20	2.00	100	0.181	2.35	60	766.4
20	2.00	100	0.181	2.35	80	669.3
50	2.00	100	0.181	2.35	100	675.0
50	2.00	100	0.181	2.35	150	510.4
50	2.00	100	0.181	2.35	200	408.6
100	2.00	100	0.181	2.35	200	457.9
100	2.00	100	0.181	2.35	300	309.5
100	2.00	100	0.181	2.35	400	230.5
20	1.65	100	0.200	0.40	40	126.9
20	1.50	100	0.200	0.40	60	108.2
20	1.40	100	0.200	0.40	80	94.1
50	1.65	100	0.200	0.40	100	84.2
50	1.35	100	0.200	0.40	150	65.2
50	1.20	100	0.200	0.40	200	53.2
100	1.75	100	0.200	0.40	200	52.8
100	1.30	100	0.200	0.40	300	38.9
100	1.00	100	0.200	0.40	400	31.3
20	2.00	100	0.200	0.40	40	123.5
20	2.00	100	0.200	0.40	60	104.7
20	2.00	100	0.200	0.40	80	91.1
50	2.00	100	0.200	0.40	100	82.6
50	2.00	100	0.200	0.40	150	63.8
50	2.00	100	0.200	0.40	200	52.2
100	2.00	100	0.200	0.40	200	52.6
100	2.00	100	0.200	0.40	300	38.7
100	2.00	100	0.200	0.40	400	30.9

TABLE 4

C- and E-Bank Operating Parameters

1EX		1EF			1EU	U
Relative Flow	HNO_3, M	Relative Flow	HNO_3, M	U, g/ℓ	HNO_3, M	Inventory, g/bank
100	0.01	100	0.03	6.3	0.04	1396
100	0.04	100	0.03	6.3	0.07	1396
100	0.04	100	0.06	6.3	0.10	1415
100	0.04	100	0.09	6.3	0.13	1437
20	0.01	100	0.03	6.3	0.16	5999
20	0.04	100	0.03	6.3	0.19	6312
20	0.01	100	0.06	6.3	0.19	7356
20	0.01	100	0.09	6.3	0.46	8555
100	0.04	100	0.03	1.3	0.07	288.1
100	0.01	100	0.06	1.3	0.07	288.1
100	0.01	100	0.09	1.3	0.10	292.0
20	0.04	100	0.03	1.3	0.19	1284
20	0.04	100	0.09	1.3	0.49	1897
20	0.04	100	0.06	10.3	0.22	12440
20	0.04	100	0.09	10.3	0.49	14140
100	0.01	100	0.09	10.3	0.10	2317
10	0.01	100	0.03	1.3	0.31	3919
20	0.025	100	0.03	6.3	0.175	6146
40	0.04	100	0.03	6.3	0.115	2886

TABLE 5

D-Bank Operating Parameters

1DS Relative Flow	1DS HNO3, M	1DF Relative Flow	1DF HNO3, M	1DF U, g/ℓ	1DX Relative Flow	U Inventory, g/bank
25.5	0.8	100	3.9	2.0	170	1020
17.0	0.8	100	3.9	6.1	170	2714
21.25	0.8	100	3.9	6.1	170	2958
25.5	0.8	100	3.9	6.1	170	3201
25.5	0.8	100	4.1	2.0	170	1001
25.5	0.8	100	4.1	6.1	170	3140
25.5	0.8	100	4.3	2.0	170	981.4
17.0	0.8	100	4.3	6.1	170	2562
25.5	0.8	100	4.3	6.1	170	3079
25.5	1.0	100	3.9	2.0	170	873.7
17.0	1.0	100	3.9	6.1	170	2420
21.25	1.0	100	3.9	6.1	170	2569
25.5	1.0	100	3.9	6.1	170	2714
25.5	1.0	100	4.1	2.0	170	860.9
25.5	1.0	100	4.1	6.1	170	2664
25.5	1.0	100	4.3	2.0	170	848.1
17.0	1.0	100	4.3	6.1	170	2308
25.5	1.0	100	4.3	6.1	170	2632
25.5	1.5	100	3.9	2.0	170	725.0
17.0	1.5	100	3.9	6.1	170	2094
21.25	1.5	100	3.9	6.1	170	2171
25.5	1.5	100	3.9	6.1	170	2240
25.5	1.5	100	4.1	2.0	170	718.0
25.5	1.5	100	4.1	6.1	170	2219
25.5	1.5	100	4.3	2.0	170	711.1
17.0	1.5	100	4.3	6.1	170	2034
25.5	1.5	100	4.3	6.1	170	2197
30	0.8	100	3.9	2.0	200	860.6
20	0.8	100	3.9	6.1	200	2289
25	0.8	100	3.9	6.1	200	2494
30	0.8	100	3.9	6.1	200	2695
30	0.8	100	4.1	2.0	200	844.6
30	0.8	100	4.1	6.1	200	2647
30	0.8	100	4.3	2.0	200	828.7
20	0.8	100	4.3	6.1	200	2163
30	0.8	100	4.3	6.1	200	2598
30	1.0	100	3.9	2.0	200	735.7
20	1.0	100	3.9	6.1	200	2042
25	1.0	100	3.9	6.1	200	2152
30	1.0	100	3.9	6.1	200	2291
30	1.0	100	4.1	2.0	200	725.4

TABLE 5 (Continued)

1DS		1DF			1DX	U
Relative Flow	HNO_3, M	Relative Flow	HNO_3, M	U, g/ℓ	Relative Flow	Inventory, g/bank
30	1.0	100	4.1	6.1	200	2259
30	1.0	100	4.3	2.0	200	715.2
20	1.0	100	4.3	6.1	200	1790
30	1.0	100	4.3	6.1	200	2228
30	1.5	100	3.9	2.0	200	658.4
20	1.5	100	3.9	6.1	200	1770
25	1.5	100	3.9	6.1	200	1835
30	1.5	100	3.9	6.1	200	1894
30	1.5	100	4.1	2.0	200	604.6
30	1.5	100	4.1	6.1	200	1877
30	1.5	100	4.3	2.0	200	599.1
20	1.5	100	4.3	6.1	200	1721
30	1.5	100	4.3	6.1	200	1859
60	0.8	100	3.9	2.0	400	379.5
40	0.8	100	3.9	6.1	400	1169
50	0.8	100	3.9	6.1	400	1284
60	0.8	100	3.9	6.1	400	1384
60	0.8	100	4.1	2.0	400	374.8
60	0.8	100	4.1	6.1	400	1364
60	0.8	100	4.3	2.0	400	370.5
40	0.8	100	4.3	6.1	400	1118
60	0.8	100	4.3	6.1	400	1344
60	1.0	100	3.9	2.0	400	329.7
40	1.0	100	3.9	6.1	400	1040
50	1.0	100	3.9	6.1	400	1111
60	1.0	100	3.9	6.1	400	1170
60	1.0	100	4.1	2.0	400	326.7
60	1.0	100	4.1	6.1	400	1157
60	1.0	100	4.3	2.0	400	324.0
40	1.0	100	4.3	6.1	400	1002
60	1.0	100	4.3	6.1	400	1144
60	1.5	100	3.9	2.0	400	281.1
40	1.5	100	3.9	6.1	400	896.1
50	1.5	100	3.9	6.1	400	930.7
60	1.5	100	3.9	6.1	400	957.0
60	1.5	100	4.1	2.0	400	279.9
60	1.5	100	4.1	6.1	400	950.7
60	1.5	100	4.3	2.0	400	278.7
40	1.5	100	4.3	6.1	400	872.4
60	1.5	100	4.3	6.1	400	945.1
60	1.0	100	3.9	35.0	400	9329

TABLE 6

Distribution Equations Used in Computing Bank Profiles[a]

For Nitric Acid - A, B, and D Banks

$$D_a^o = 0.0571 - 0.0236(H_a) + 0.00607(H_a)^2 - 0.00203(U_o) + 0.0000841(U_o)^2 - 0.00000182(U_o)^3$$

For Nitric Acid - C and E Banks

$$D_a^o = 0.027792 - 0.038423(H_a)^2 - 0.00060016(H_a)(U_o) - 0.0000072613(U_o)^2$$

For Uranium - A, B, and D Banks

$$D_a^o = \exp\{-0.304 + 1.53\ \ln(H_a) - 0.291[\ln(H_a)]^2 - 0.226\ \ln(U_o) + 0.326[\ln(U_o)]^2 - 0.129[\ln(U_o)]^3\}$$

For Uranium - C and E Banks

$$D_a^o = \{-0.7938 + 1.2781(H_a) + [0.22121 - 0.20802(H_a)][\ln(32.576 - U_o)] + [0.016304 - 0.031652(H_a)(U_o)]\}\{\exp -[0.5773 + 0.00351(U_o)]\}$$

---

a. D_a^o = distribution coefficient

H_a = HNO_3 concentration in aqueous phase, M

U_o = U concentration in organic phase, g/ℓ

TABLE 7

Least Squares Analysis of A-Bank Data[a]

Term	Regression Coefficient	Standard Error of Regression Coefficient	Computed T Value	Mean	Standard Deviation	Correlation F(X) vs H(Y)
B_1	0.10452D 01	0.57595D-02	181.48	0.14523D 01	0.10878D 01	0.87957
B_2	-0.37621D-02	0.41705D-02	-0.90	0.20750D 02	0.14621D 01	0.98504
B_3	0.64749D-02	0.38205D-01	0.17	0.39058D 01	0.15986D 00	0.98574
B_4	-0.10985D 01	0.15676D-01	-70.08	0.52578D 01	0.40362D 00	0.98250
B_5	-0.42664D 01	0.72576D-01	-58.79	-0.19159D 01	0.16211D 00	-0.98316
B_6	-0.75137D 02	0.14453D 01	-51.99	-0.42514D-01	0.93507D-02	-0.96708
H(Y)				0.70577D 01	0.11362D 01	
				Multiple correlation		0.99912
				Standard error of estimate		0.49576D-01

Analysis of Variance for the Regression

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to regression	6	0.87632D 02	0.14605D 02	0.59424D 04
Deviation from regression	63	0.15484D 00	0.24578D-02	
Total	69	0.87787D 02		

a. $\ln Y = B_1(\ln X_1) + B_2(X_2)^2(\ln X_2) + B_3(X_3) + B_4(\ln X_4) + B_5(\ln X_5)^2 - B_6(X_5)^2(\ln X_5)$

where

Y = uranium inventory, g

X_1 = 1AF U, g/ℓ

X_2 = 1AF HNO_3, M

X_3 = 1AS HNO_3, M

X_4 = 1AX flow = 1AX/1AF × 100

X_5 = 1AS/1AX flow ratio

TABLE 8

Least Squares Analysis of B-Bank Data[a]

Term	Regression Coefficient	Standard Error of Regression Coefficient	Computed T Value	Mean	Standard Deviation	Correlation F(X) vs H(Y)
B_1	0.53351D 01	0.17399D 00	30.66			
B_2	0.12287D 01	0.21847D-01	56.24	0.13708D 01	0.15460D 01	0.97309
B_3	0.14962D 00	0.38761D-01	3.86	-0.76753D 00	0.66378D 00	-0.19981
B_4	-0.71459D 00	0.36671D-01	-19.49	0.29182D 00	0.72290D 00	-0.22152
B_5	-0.23303D 00	0.32316D-01	-7.21	0.16389D 01	0.33486D 00	-0.16654
B_6	0.35010D 01	0.81600D 00	4.29	0.15062D 00	0.41177D-01	-0.92447
H(Y)				0.68415D 01	0.18261D 01	
				Multiple correlation		0.99907
				Standard error of estimate		0.81632D-01

Analysis of Variance for the Regression

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to regression	5	0.23633D 03	0.47266D 02	0.70930D 04
Deviation from regression	66	0.43981D 00	0.66637D-02	
Total	71	0.23677D 03		

a. $\ln Y = B_1 + B_2(\ln X_1) + B_3(\ln X_2) + B_4(\ln X_3) + B_5(X_4) + B_6(X_5)$

where

Y = uranium inventory, g

X_1 = 1AU U, g/ℓ

X_2 = 1BX/1AU flow ratio

X_3 = 1BS/1BX flow ratio

X_4 = 1BX HNO_3, M

X_5 = 1AU HNO_3, M (see Figure 3 for 1AU HNO_3)

TABLE 9

Least Squares Analysis of C- and E-Bank Data[a]

Term	Regression Coefficient	Standard Error of Regression Coefficient	Computed T Value	Mean	Standard Deviation	Correlation F(X) vs H(Y)
B_1	0.61676D 01	0.96892D-01	63.65			
B_2	0.57000D 00	0.73147D-01	7.79	0.93178D 00	0.84846D 00	0.74587
B_3	0.19691D 00	0.36900D-01	5.34	0.15502D 01	0.15553D 01	0.67450
B_4	0.55566D 00	0.85930D-01	6.47	-0.18818D 01	0.70699D 00	0.66182
B_5	0.98341D-01	0.23778D-01	4.14	0.40146D 01	0.26462D 01	-0.66699
B_6	0.10051D 01	0.16635D-01	60.42	0.14198D 01	0.82682D 00	0.67573
H(Y)				0.77801D 01	0.12170D 01	
				Multiple correlation		0.99930
				Standard error of estimate		0.53704D-01

Analysis of Variance for the Regression

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to regression	5	0.26621D 02	0.53242D 01	0.18460D 04
Deviation from regression	13	0.37493D-01	0.28841D-02	
Total	18	0.26658D 02		

a. $\ln Y = B_1 + B_2(\ln X_1) + B_3(\ln X_1)^2 + B_4(\ln X_2)^2 + B_5(\ln X_2)^2 + B_6(\ln X_3)$

where

Y = uranium inventory, g

X_1 = U product stream flow/strip flow ratio

X_2 = U product stream HNO_3, M

X_3 = feed U concentration, g/ℓ

TABLE 10

Least Squares Analysis of D-Bank Data[a]

Term	Regression Coefficient	Standard Error of Regression Coefficient	Computed T Value	Mean	Standard Deviation	Correlation F(X) vs H(Y)
B_1	0.10836D 01	0.12910D-01	83.93	0.14624D 01	0.57540D 00	0.95587
B_2	-0.10740D 01	0.24913D-02	-4.31	0.23427D 02	0.27565D 01	0.98713
B_3	-0.42182D 00	0.22923D-01	-18.40	0.10988D 01	0.29460D 00	0.95696
B_4	-0.10191D 01	0.18036D-01	-56.51	0.54815D 01	0.37539D 00	0.98971
B_5	-0.41848D 01	0.45462D-01	-92.05	-0.20061D 01	0.16792D 00	-0.99398
B_6	-0.93093D 02	0.10868D 01	-85.66	-0.37251D-01	0.82181D-02	-0.96640
H(Y)				0.71463D 01	0.70439D 00	
					Multiple correlation	0.99650
					Standard error of estimate	0.60775D-01

Analysis of Variance for the Regression

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to regression	6	0.39908D 02	0.66514D 01	0.18008D 04
Deviation from regression	76	0.28072D 00	0.36936D-02	
Total	82	0.40189D 02		

a. $\ln Y = B_1(\ln X_1) + B_2(X_2)^2(\ln X_2) + B_3(X_3) + B_4(\ln X_4) + B_5(\ln X_5) + B_6(X_5)^2(\ln X_5)$

where

Y = uranium inventory, g

X_1 = 1DF U, g/ℓ

X_2 = 1DF HNO_3, M

X_3 = 1DS HNO_3, M

X_4 = 1DX flow = 1DX/1DF × 100

X_5 = 1DS/1DX flow ratio

TABLE 11

Test of 1A Bank

Stream	Relative Flow	HNO_3, M	U, g/ℓ
1AS	34	4.13	0.0
1AF	100	3.78	25.17
1AX	200	0.0	0.0

Efficiency = 70%

Stage	Experimental U, g/ℓ		Calculated U, g/ℓ	
	Aqueous	Organic	Aqueous	Organic
1	NA[a]	12.1	NU[b]	12.6
2	NA	NA	NU	NU
3	NA	NA	NU	NU
4	7.78	12.1	6.15	13.6
5	NA	NA	NU	NU
6	7.75	13.6	6.43	13.7
7	NA	NA	NU	NU
8	5.68	9.73	6.50	8.54
9	NA	NA	NU	NU
10	0.37	1.21	1.32	1.98
11	NA	NA	NU	NU
12	0.10	0.24	0.59	0.40
13	NA	NA	NU	NU
14	NA	NA	NU	NU
15	NA	NA	NU	NU
16	0.02	NA	0.01	NU
Total	21.70	48.98	20.41	50.83

Experimental U inventory	2860 grams/bank
Calculated U Inventory	2927 grams/bank
Calculation	2.0% high

a. NA - not analyzed.

b. NU - not used in calculating the uranium inventory.

TABLE 12

Test of 1B Bank

Stream	Relative Flow	HNO_3, M	U, g/ℓ
1BX	50	1.78	0.0
1BF	200	0.04	12.625
1BS	100	0.0	0.0

Efficiency = 70%

Stage	Experimental U, g/ℓ Aqueous	Experimental U, g/ℓ Organic	Calculated U, g/ℓ Aqueous	Calculated U, g/ℓ Organic
1	NA[a]	8.50	NU[b]	8.42
2	5.504	9.680	6.570	9.157
3	NA	NA	NU	NU
4	5.730	9.560	8.203	9.695
5	NA	NA	NU	NU
6	5.428	9.499	8.617	9.833
7	NA	NA	NU	NU
8	4.629	10.615	8.568	9.858
9	NA	NA	NU	NU
10	NA	NA	NU	NU
11	NA	NA	NU	NU
12	NA	NA	NU	NU
13	NA	NA	NU	NU
14	0.014	0.432	0.144	0.190
15	NA	NA	NU	NU
16	NA	NA	NU	NU
Total	21.305	48.286	32.102	47.153

Experimental U inventory	2826 grams/bank
Calculated U inventory	3030 grams/bank
Calculation	7.2% high

a. NA - not analyzed

b. NU - not used in calculating the uranium inventory

TABLE 13

Test of 1E Bank

Stream	Relative Flow	HNO_3, M	U, g/ℓ
1EX	100	0.04	0.0
1EF	300	0.037	7.12

Efficiency = 70%

Stage	Experimental U, g/ℓ		Calculated U, g/ℓ	
	Aqueous	Organic	Aqueous	Organic
1	<0.005	<0.001	<0.001	<0.001
2	NA[a]	NA	NU[b]	NU
3	NA	NA	NU	NU
4	NA	NA	NU	NU
5	NA	NA	NU	NU
6	NA	NA	NU	NU
7	0.005	0.053	0.098	0.011
8	0.005	0.018	0.299	0.033
9	0.065	0.180	0.916	0.100
10	2.020	0.105	2.800	0.305
11	11.570	0.731	8.426	0.934
12	21.500	NA	21.360	NU
Total	35.165	1.087	33.899	1.383

Total experimental U inventory	3532 grams/bank
Total calculated U inventory	3467 grams/bank
Calculation	1.9% low
Prediction from Equation (5)	3876 grams/bank 9.7% high

a. NA - not analyzed

b. NU - not used in calculating the uranium inventory

TABLE 14

Test of 1D Bank

Stream	Relative Flow	HNO_3, M	U, g/ℓ
1DS	42	1.2	0.0
1DF	100	4.06	21.34
1DX	300	0.0	0.0

Efficiency = 70%

Stage	Experimental U, g/ℓ		Calculated U, g/ℓ	
	Aqueous	Organic	Aqueous	Organic
1	7.52	5.96	5.67	7.09
2	8.99	7.38	8.55	7.89
3	8.76	7.98	10.00	8.29
4	9.18	8.90	10.56	8.50
5	8.01	8.08	10.33	8.58
6	7.03	8.08	9.11	8.55
7	5.28	8.16	7.02	8.38
8	4.04	8.52	8.27	8.09
9	2.32	8.23	3.61	3.91
10	0.38	2.04	1.57	1.71
11	NA	NA	NU[b]	NU
12	NA	NA	NU	NU
13	NA	NA	NU	NU
14	NA	NA	NU	NU
15	NA	NA	NU	NU
16	NA	NA	NU	NU
Total	61.51	73.33	74.69	70.99

Total experimental U inventory	4991 grams/bank
Total calculated U inventory	5194 grams/bank
Calculation	4.1% high
Prediction from Equation (6)	5234 grams/bank 5.0% high

a. NA - not analyzed

b. NU - not used in calculating the uranium inventory

TABLE 15

Errors for Calculated Uranium Inventories

Bank	ln U Inventory: Calculated[a]	ln U Inventory: Summation[b]	ln U Inventory: % Difference	Multiple Correlation	Standard Error
A	8.9953	9.1238	12.1	0.99912	0.049576
B	7.0480	6.8736	19.1	0.99907	0.081632
C and E	8.7933	8.9033	11.6	0.99930	0.053704
D	5.9136	5.7982	12.2	0.99650	0.060775

a. Calculated by Equations 3 through 6

b. Summation of calculated stage inventories

EQN: 1s