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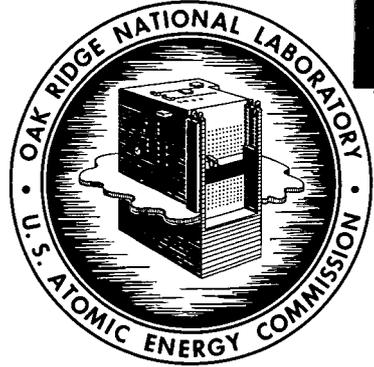
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EFFICIENCY AND FLOW CAPACITY OF
PULSED COLUMNS USED FOR THE
SEPARATION OF URANIUM FROM THORIUM
BY SOLVENT EXTRACTION WITH
DI-sec-BUTYLPHENYLPHOSPHONATE

A. D. Ryon
R. S. Lowrie

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CHEMICAL TECHNOLOGY DIVISION

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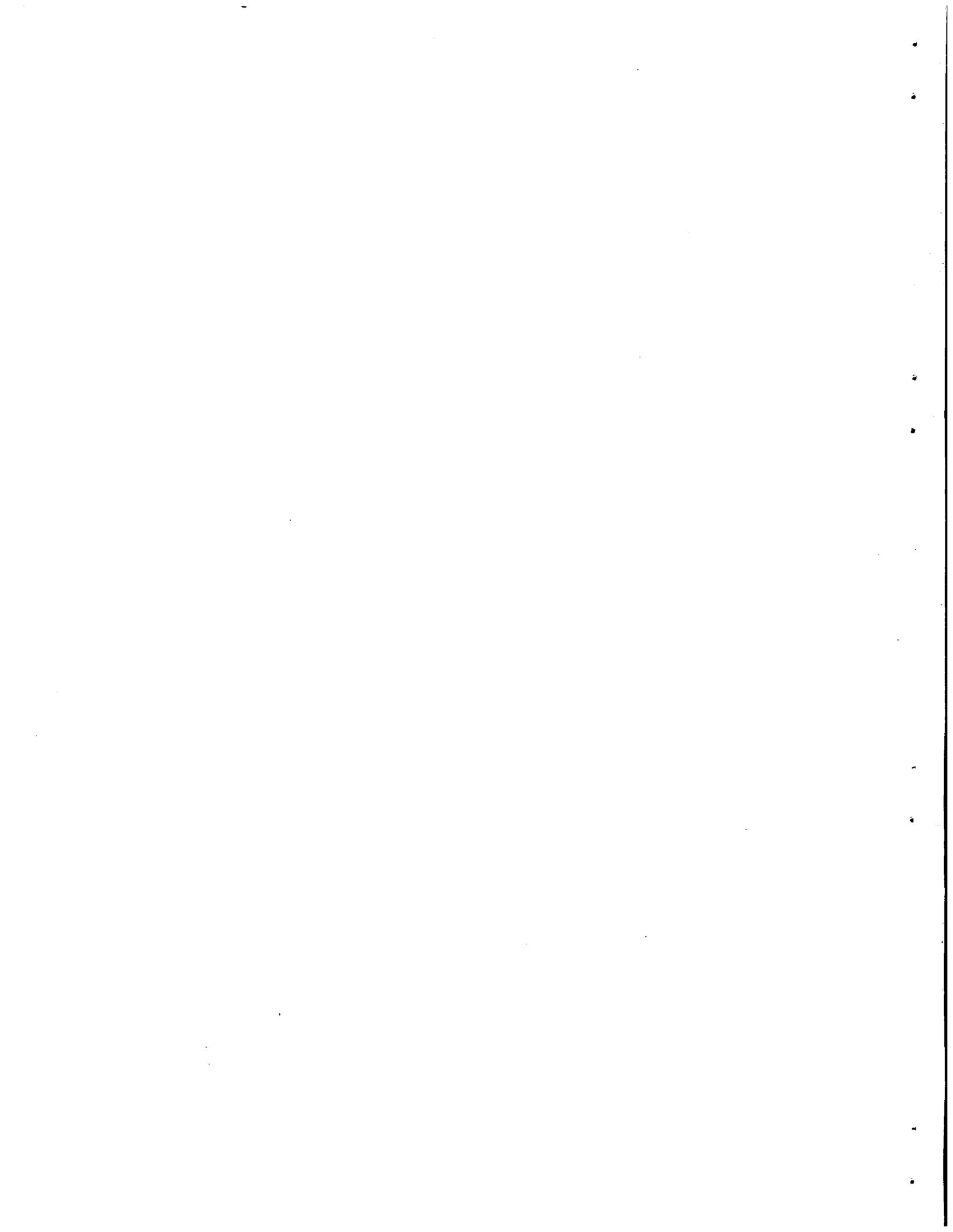
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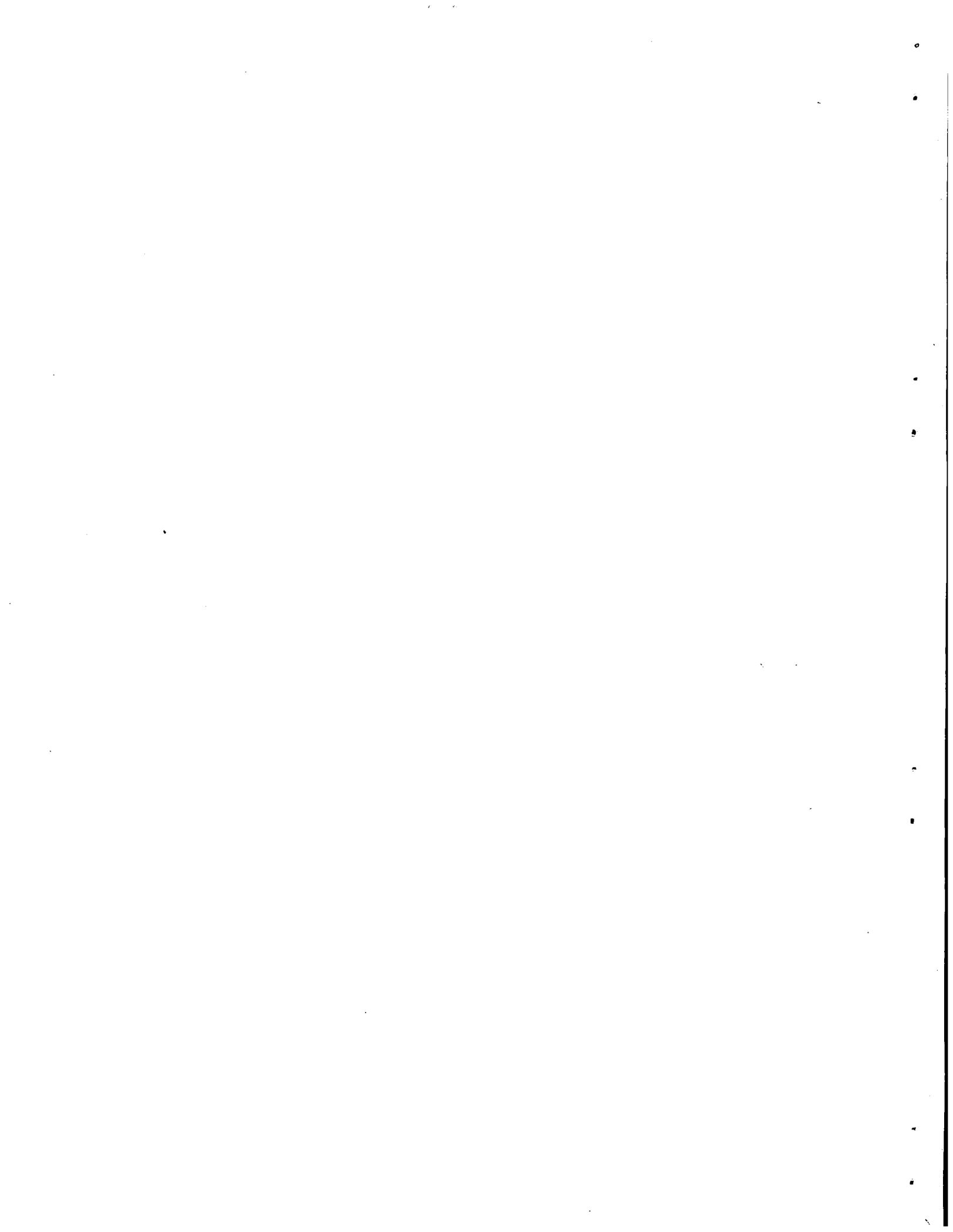


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A. D. Ryon R. S. Lowrie

ABSTRACT

Engineering studies were made to evaluate flow capacity and efficiency of sieve-plate pulsed columns, using the di-sec-butylphenylphosphonate solvent extraction process for separating uranium from thorium. The process was demonstrated to be capable of providing ^{233}U feed solution for the sol-gel process in the Kilorod program.

Process throughput was limited by the stripping column flow capacity. Operating the stripping column at a pulse frequency of 70 cpm gave a flow rate of $380 \text{ gal hr}^{-1} \text{ ft}^{-2}$, compared with $700 \text{ gal hr}^{-1} \text{ ft}^{-2}$ at the same pulse frequency for the compound extraction scrub column. HETS values at this pulse frequency were 4.2 ft for uranium stripping, 2.1 for uranium extraction and 4.1 for thorium scrubbing.

Decontamination factors (uranium from thorium) were consistently better than 10,000, and the nitrate-to-uranium ratio in the stripping-column product was less than 2.3.

Procedures for determining column flow capacity and efficiency are also described.

1. INTRODUCTION

This report summarizes the engineering studies made to evaluate the performance of sieve-plate pulsed columns, using the di-sec-butylphenylphosphonate (DSBPP) solvent extraction process for separating uranium from thorium. The use of DSBPP solvent was novel in the ORNL pilot plants, and this study was undertaken to provide the necessary flow capacity and efficiency data to design the pulsed columns for the solvent extraction

facility for purifying ^{233}U to be used as feed for the sol-gel process in the Kilorod program.^{1,2} Purification is required in order to remove daughters of ^{232}U , metal ions such as iron and nickel, etc., and nitric acid. Most of the results have been published in the series of monthly reports issued by the Unit Operations Section of the Chemical Technology Division.^{3,4}

Solvent extraction processes based on tri-n-butylphosphate (TBP) have been used for many years to separate uranium from thorium. However, recent studies showed that the separation factor (uranium from thorium) for DSBPP is about 10 times higher than that obtained with TBP under comparable conditions. In addition, its radiation stability, chemical stability, and ability to separate uranium from fission products are all better than those for TBP.^{5,6} For these reasons, the DSBPP process flowsheet was developed.^{7,8}

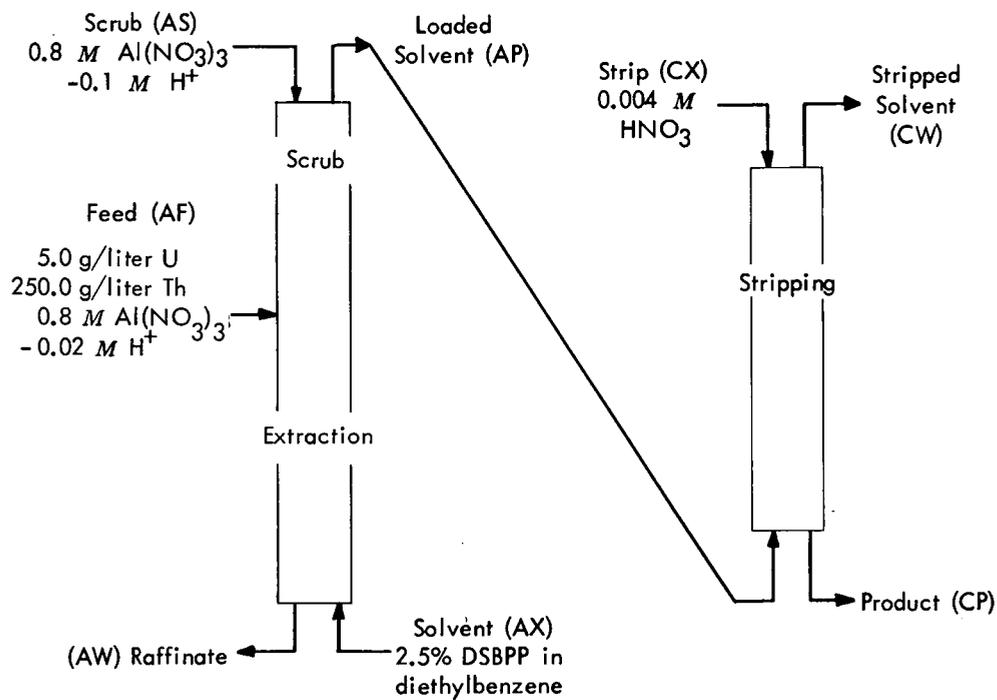
Acknowledgements

The authors wish to acknowledge the work done by F. G. Kilpatrick, K. Ladd, and C. H. Tipton. Analytical services were performed by the Analytical Chemistry Division under the direction of M. T. Kelly.

2. DI-sec-BUTYLPHENYLPHOSPHONATE PROCESS

The DSBPP process flowsheets are shown in Fig. 2.1. The solvent consists of 2.5% (by volume) of DSBPP reagent in an aromatic diluent, diethylbenzene. Uranium is extracted from a feed solution consisting of uranyl and thorium nitrates, "salted" with aluminum nitrate. The loaded solvent is then scrubbed with aluminum nitrate solution to remove the impurities. Both the feed and scrub solutions were slightly deficient

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Flow Ratios

Flowsheet	Feed	Scrub	Solvent	Strip
DSBPP-1	100	50	250	50
DSBPP-2	100	40	200	50

Fig. 2.1 Flowsheets for Di-sec-Butylphenylphosphonate Process.

in nitrate (acid deficient). Uranium is stripped from the scrubbed solvent with very dilute nitric acid.

The DSBPP reagent was purchased from Victor Chemical Works, Division of Stauffer Chemical Corporation, Chicago, Illinois, and performed equally as well as specially synthesized and purified batches.⁹ The diethylbenzene diluent was obtained from the Dow Chemical Corporation, Midland, Michigan. The physical and chemical properties of process streams typical for flow-sheet 1 are shown in Table 2.1. Properties of process streams for flowsheet 2, with the exception of a slightly higher uranium concentration in the loaded solvent (2.5 g/liter instead of 2) are identical. Interfacial tension and primary batch break times¹⁰ were determined for solvent-aqueous pairs present at steady state in the top and bottom sections of both the extraction-scrub and the stripping column (Table 2.2). The interfacial tension of liquid pairs ranged from 24.5 to 27.5 dynes/cm at 25°C. With one exception, the batch break-tests gave primary break times sufficiently low to indicate that no difficulties with emulsion formation would be encountered. The rather slow primary break time, 340 sec, obtained with an aqueous-continuous dispersion (A/O of 1/1) of stripped solvent and fresh strip solution would indicate a somewhat lower flow capacity than for the other conditions.

3. EQUIPMENT FOR THE ENGINEERING TEST

The pulsed columns used were built by stacking standard column sections to the desired height. Each section consisted of a combination sample flange and plate-support rod on which the sieve plates and spacers were placed (all parts made of stainless steel), a 2-ft section of 2-in.-

Table 2.1. Properties of Test Solutions

		U (g/liter)	Th (g/liter)	Al (g/liter)	H ⁺ (M)	NO ₃ (g/liter)	Viscosity ^a (centipoise)	Density ^a (g/cc)
Feed	AF	5.03	262	24.2	-0.024	429	7.14	1.561
Scrub	AS	-	-	23.2	-0.13	148	1.69	1.130
Solvent	AX	-	-	-	-	-	0.87	0.865
Loaded Solvent	AP	2.06	0.002	-	< 0.005	-	0.89	0.868
Raffinate	AW	< 0.0001	178	-	-0.052	-	4.20	1.422
Strip	CX	-	-	-	0.004	-	0.92	0.998
Stripped Solvent	CW	0.001	< 0.002	-	< 0.005	-	0.89	0.867
Product	CP	9.9	0.015	-	< 0.01	4.68	0.94	1.009

Physical Properties of Organic Reagents

	Density ^a (g/cc)	Viscosity ^a (centipoise)
DSBPP	1.029	9.37
Diethylbenzene	0.861	0.86

Flash point of solvent, 65°C (Cleveland open-cup method)

^a Measured at 25°C

Table 2.2. Batch Phase-Separation Tests in 300-ml Beaker

Liquid Pair		Separation Time (sec)			
		Aqueous Continuous		Organic Continuous	
Aqueous	Organic	A/O = 4/1	A/O = 1/1	A/O = 1/1	A/O = 1/4
(AS)	(AP)	70	65	45	20
(AW)	(AX)	90	115	65	45
(CX)	(CW)	165	340	35	30
(CP)	(AP)	40	40	35	45

diam precisely bored glass pipe, and the necessary flanges and polyethylene gaskets, shown in Fig. 3.1. The sieve plates used in both columns had 0.125-in.-diam holes, 23% free area, and were spaced 2 in. apart, center to center. The extraction-scrub column (Fig. 3.2) was 24 ft high, utilizing the top 8 ft as a scrub section for flowsheet 1, and the top 12 ft for flowsheet 2. Stripping tests were made in a 12-ft column (Fig. 3.3). Both columns were operated with the aqueous phase continuous and a 1-in. pulse amplitude (sine wave).

Aqueous- and solvent-phase samplers were installed in each flange (Fig. 3.4). The samplers were 1/4-in.-diam tubing, with 0.03-in.-diam holes drilled in a concave section positioned to face the stream to be sampled. The sampler for the aqueous phase was made of stainless steel since it was to be preferentially wetted by water and to discriminate against the solvent phase, thus permitting a steady-state sample of the aqueous phase to be obtained. The solvent-phase sampler, made of polyethylene, which is preferentially wetted by the solvent, discriminated against the aqueous phase when the steady-state solvent samples were taken. These samplers worked best when the phase ratio (A/O) ranged from 4/1 to 1/4 and the flow through them was less than 5 ml/min.

4. COLUMN FLOW CAPACITY

The flow capacity of each sieve-plate pulsed column was determined at each pulse frequency by a series of 30-min runs in which the holdup of solvent was measured as a function of flow rate. The flow rates were increased incrementally until visual flooding occurred. The column was then operated for an hour at the first flow-rate increment below visual

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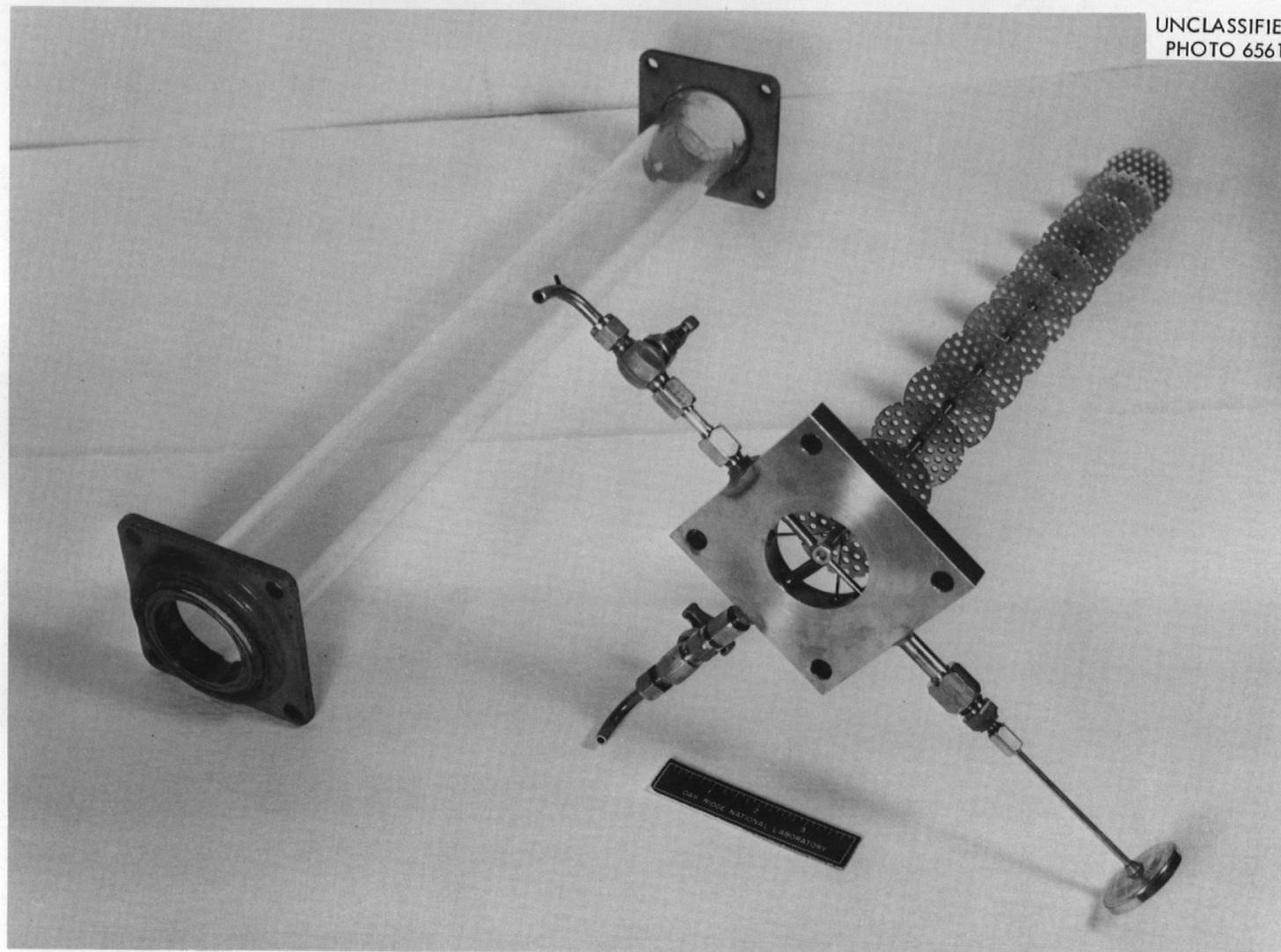


Fig. 3.1 Standard Column Section.

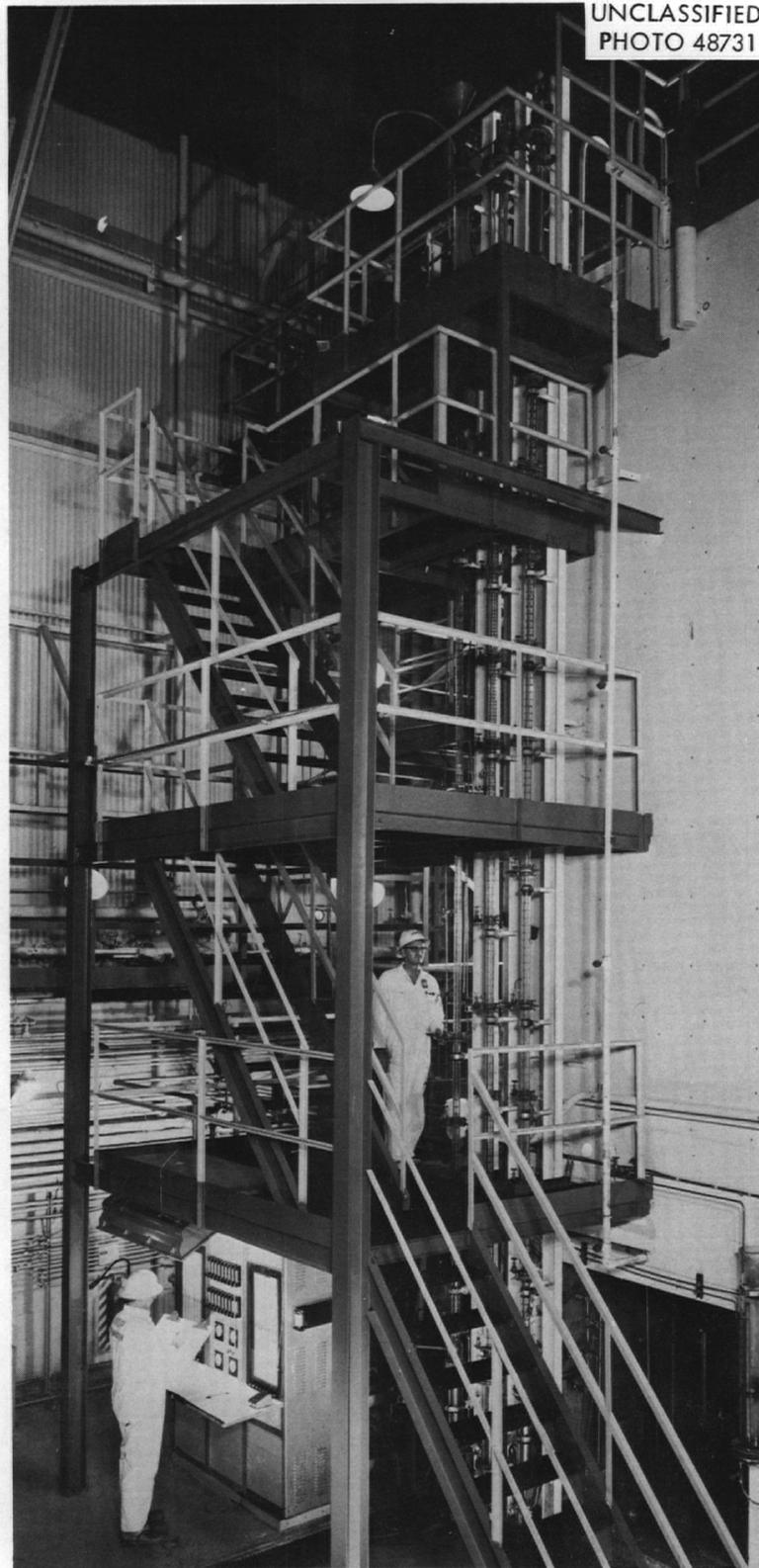


Fig. 3.2 General View of Extraction-Scrub Columns.

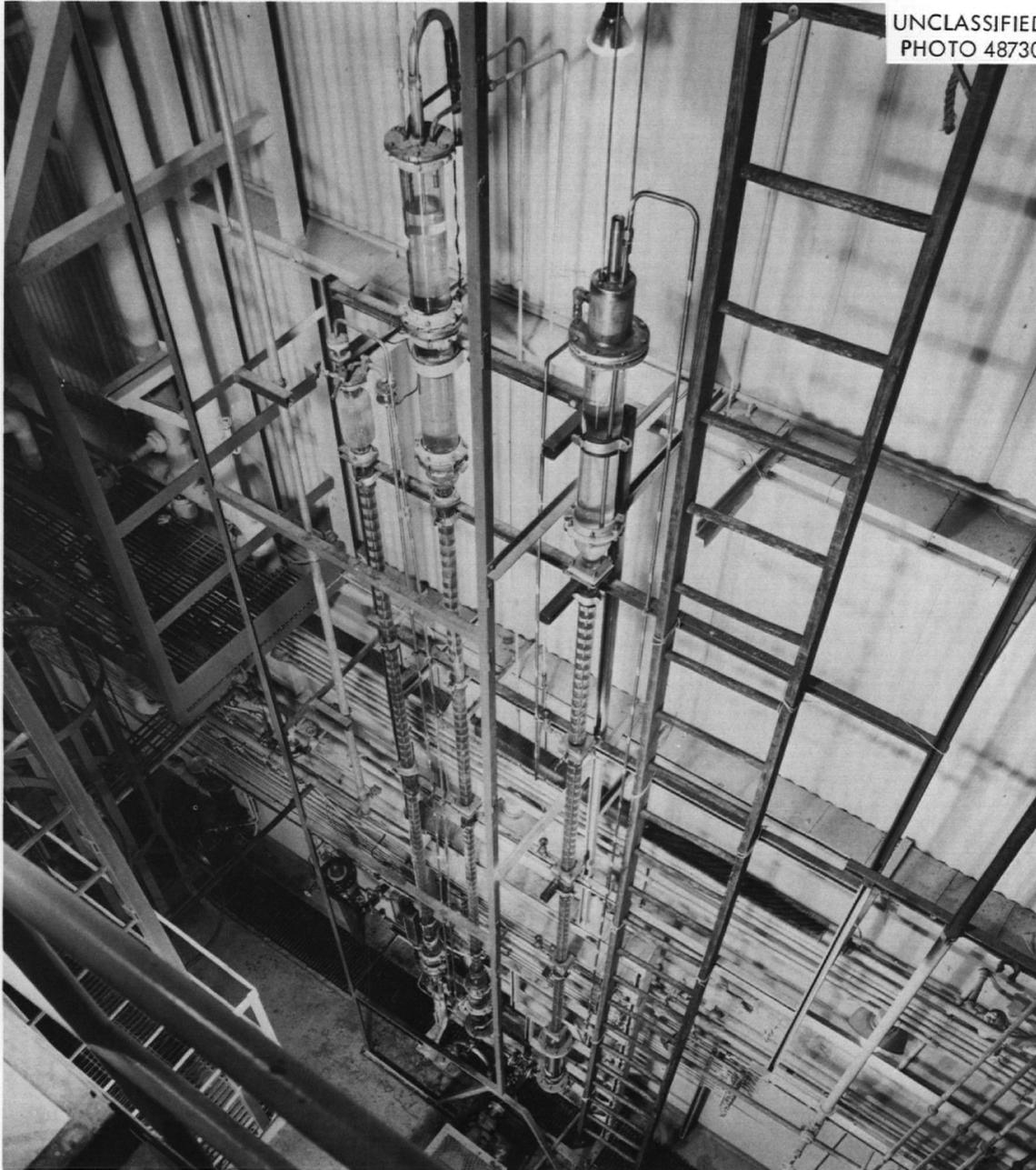
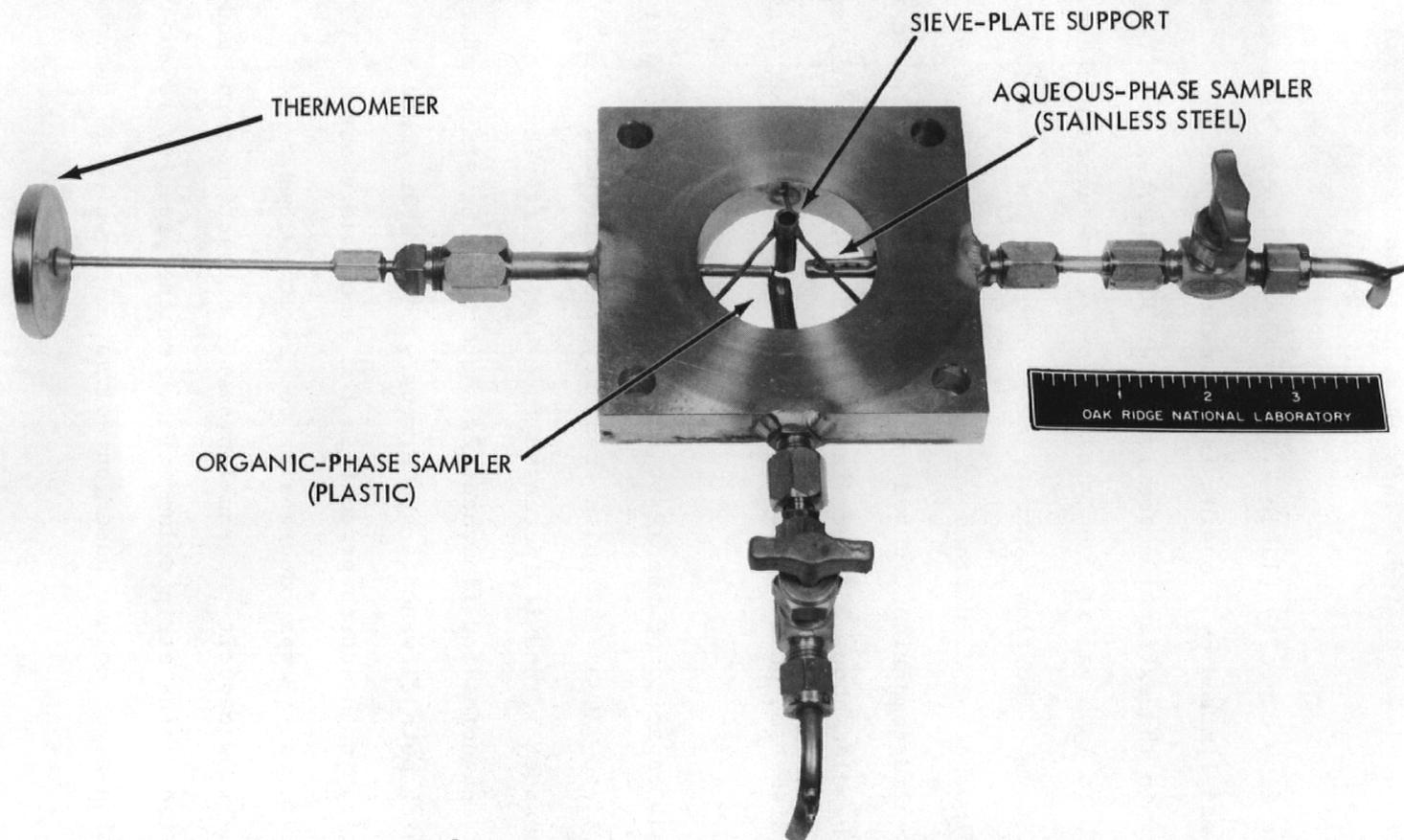


Fig. 3.3 View of Stripping Columns.

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THERMOMETER

SIEVE-PLATE SUPPORT

AQUEOUS-PHASE SAMPLER
(STAINLESS STEEL)

ORGANIC-PHASE SAMPLER
(PLASTIC)

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Fig. 3.4 Details of Sampler Flange.

flooding to confirm the holdup obtained after 30 min of operation. If the two values did not agree within $\pm 10\%$, the second flow-rate increment below flooding was tested. This procedure was repeated until the two values agreed.

The flow capacity (Table 4.1) for the 24-ft compound extraction-scrub column was limited by flooding in the extraction section. The total flow capacity in the extraction section under flowsheet-1 conditions increased from 490 to 1340 gal ft⁻² hr⁻¹ as the pulse frequency was decreased from 70 to 35 cpm. The flow capacity at 50 cpm for the same column operated under flowsheet-2 conditions was about 10% higher (990 vs 910 gal ft⁻² hr⁻¹). A more valid comparison, based on the feed flow rate, showed that the column handled about 25% more feed under flowsheet-2 conditions. Holdup of the dispersed phase (solvent) at about 90% of flooding ranged from 23 to 33%.

Flow capacity of the 12-ft stripping column increased from 380 gal ft⁻² hr⁻¹ to 730 as the pulse frequency was decreased from 70 cpm to 35 for flowsheet 1, and it increased from 400 gal ft⁻² hr⁻¹ to 860 at the same pulse frequencies for flowsheet 2. Note that the strip reagent capacity, upon which both flowsheets are directly comparable since the uranium concentration in the strip product is the same, was about 40% greater for flowsheet 2 at 35 cpm, decreasing to 12% at 70 cpm.

The flow capacity of equal-diameter extraction-scrub and strip columns is limited by the strip column, in which the capacity is about 70% of the extraction-scrub column based on solvent flow which is common to both columns.

Table 4.1. Flow Capacity for Sieve-Plate Pulsed Columns

Pulse Frequency (cpm)	Compound Extraction Scrub Column		Stripping Column	
	Flow Capacity (gal ft ⁻² hr ⁻¹)	Dispersed-Phase Holdup at 90% Flooding (%)	Flow Capacity (gal ft ⁻² hr ⁻¹)	Dispersed-Phase Holdup at 90% Flooding (%)
Flowsheet 1				
35	1340	33	730	31
50	910	23	490	23
70	700	25	380	25
90	490	29	-	-
Flowsheet 2				
35	-	-	860	33
50	990	28	530	24
70	-	-	400	25

5. COLUMN-EFFICIENCY VALUES

The data for the column-efficiency studies were obtained by operating the sieve column at each pulse frequency for several hours under steady-state conditions, during which period three sets of samples (consisting of feed and end streams plus aqueous- and solvent-profile samples) were taken at hourly intervals. The analytical data for these samples, together with the flow rates, are used to calculate HETS and HTU values. The HETS values are calculated by using a McCabe-Thiele diagram constructed for each test from equilibrium data, and an operating line calculated according to Eq. (1), which relates

$$y_n = \frac{A}{O} (x_{n+1} - x_w) + y_o, \quad (1)$$

the compositions of the aqueous (x_{n+1}) and organic (y_n) streams as they pass each other in the column as a function of aqueous-to-organic flow ratio (A/O) and composition of the respective streams at the dilute end of the column (x_w and y_o). The number of theoretical stages necessary to obtain the raffinate value were then stepped off by using the metal concentration measured at the particular sample point of interest as the feed point, as shown in Fig. 6.1 for the uranium extraction case. The HETS value was then obtained by dividing the length of the column between sample points by the number of theoretical stages necessary to reach the lower metal concentration.

The HTU values for uranium extraction were calculated with the Colburn¹¹ equation [Eq. (2)] to obtain the number of transfer units (N_t), and dividing this value into the incremental column length to obtain HTU values

$$N_t = \frac{1}{1 - \frac{A}{mO}} \ln \left[\left(\frac{x_1 - \frac{y_2}{m}}{x_2 - \frac{y_2}{m}} \right) \left(1 - \frac{A}{mO} \right) + \frac{A}{mO} \right], \quad (2)$$

where

N_t = number of transfer units,

A/O = phase ratio, aqueous/organic,

m = extraction coefficient at equilibrium,

x_1 = metal concentration (g/liter) in aqueous feed,

x_2 = metal concentration (g/liter) in aqueous raffinate,

y_2 = metal concentration (g/liter) in organic feed.

Two arbitrary rules were used for all HETS and HTU calculations.

First, calculations were based on the analysis of the phase from which the metal ions under consideration transferred, that is, aqueous phase for extraction, solvent phase for scrubbing and stripping. Second, the continuous-phase-profile samples were used in calculating incremental values since the differential samplers operated so that these samples were most representative of conditions in the column. This, in turn, required calculating by material balance the solvent-profile concentration for aqueous-continuous operation of the stripping column to satisfy the first condition.

5.1 Uranium Extraction

Uranium extraction efficiencies were determined for aqueous-continuous operation of the compound extraction-scrub column. Overall HETS values (Table 5.1) increased from 2.1 to 4.0 ft as the pulse frequency was decreased from 70 cpm to 50 for flowsheet 1. The HTU values increased from 0.62 to 0.98 ft for the same changes in pulse frequency. Changing the phase ratio

Table 5.1. Summary of Column-Efficiency Data for
DSBPP Flowsheets Operated at About
80% of Flooding

Experiment No.	Flowsheet No.	Uranium					Thorium	
		Extraction			Stripping		Scrubbing	
		Pulse Freq. (cpm)	HETS (ft)	HTU (ft)	Pulse Freq. (cpm)	HETS (ft)	Pulse Freq. (cpm)	HETS (ft)
26-230	1	50	4.0	0.98	35	12.0	50	4.6
26-222	1	70	2.1	0.62	50	6.7	70	4.1
27-320	1	-	-	-	70	4.2	-	-
27-301	2	50	4.1	1.14	35	12.0	50	6.2
30-370	2	-	-	-	-	-	50	13.0 ^a

^aColumn operated with the solvent phase continuous

slightly (flowsheet 2) gave a 4.1-ft HETS and a 1.14-ft HTU value for a pulse frequency of 50 cpm. Experimental conditions, column profile samples, and calculated incremental HETS and HTU values are shown in Tables 6.1, 6.2, and 6.3. Figure 6.1 is a typical McCabe-Thiele diagram showing the equilibrium line as well as theoretical stages.

In all cases, the profile samples were either on or very close to the operating line, indicating that no significant extraction occurred during sampling and, further, that no significant backmixing occurred in the extraction section of the column.

5.2 Uranium Stripping

Uranium stripping efficiencies were determined in a sieve-plate column operated with the aqueous phase continuous. The overall HETS values (Table 5.1) increased from 4.2 ft to 12.0 as the pulse frequency was decreased from 70 cpm to 35. Changing the phase ratio (A/O) from 1/5 to 1/4 did not affect the HETS value of 12 ft obtained at a pulse frequency of 35 cpm. Most profile samples fell on or quite near the operating line, indicating that little backmixing had occurred (Fig. 6.2). Experimental conditions, analyses of column-profile samples, and calculated incremental HETS values are shown in Tables 6.4, 6.5, and 6.6.

The aqueous-uranium-product stream from the stripping column was passed through a static diluent (diethylbenzene) wash column (7 ft, packed with 1/4-in.-diam stainless steel Raschig rings), where the entrained solvent was scrubbed out. About half the DSBPP reagent (based on the phosphorous content of washed and unwashed product) was removed (Table 5.2). The scrubbed product was then evaporated to about 1/10 its original volume and used as feed for the sol-gel process.

Table 5.2. The Effect of Diluent Wash
on Reagent Concentration in
the Aqueous Product

Run No.	Total Phosphorous (ppm)	
	CP	CPW
26-230	3.0	3.0
26-220	4.3	1.0
27-320	1.4	0.6
27-301	5.6	2.4

The specifications of uranium of the sol-gel process required that the thorium content in the aqueous product stream be less than 0.2 g/liter. Actual thorium content ranged from 0.01 to 0.035 g/liter (Table 6.4), well below the specified level. An NO_3 /uranium mole ratio of less than 2.3 was also specified. Actual NO_3 /uranium ratios ranged from 2.01 to 2.2 (Table 6.4). The excess nitrate was primarily due to the 0.004 M HNO_3 strip reagent and aluminum nitrate scrub that was entrained in the loaded solvent, although "grab" samples of AP contained less than 0.01% aqueous phase.

5.3 Thorium Scrubbing

Thorium scrubbing efficiencies were determined for the aqueous operation of the compound extraction scrub section, utilizing either an 8- or a 12-ft scrub section, and for the solvent-continuous operation of a 12-ft column. Overall HETS values (Table 5.1) for thorium scrubbing in the compound column utilizing the 8-ft scrub section (A/O of 1/5), increased slightly, from 4.1 ft to 4.6 as the pulse frequency was decreased from 70 cpm to 50. Operating the compound column with a 12-ft scrub section (A/O of 1/5.7) resulted in a 6.2-ft HETS value at a pulse frequency of 50 cpm. Operating the 12-ft single column with the solvent phase continuous (A/O of 1/5) resulted in a 13-ft HETS value at a pulse frequency of 50 cpm. Most of the scrub solution flowed down the walls of the column as a film instead of dispersing in the solvent, thus reducing the surface area available for mass transfer and decreasing the scrubbing efficiency. The experimental conditions, analyses of profile samples, and calculated HETS values are shown in Tables 6.7 and 6.8, Figure 6.3 is a typical McCabe-Thiele diagram for thorium scrubbing.

6. APPENDIX

Table 6.1. Experimental Conditions and End-Stream Analyses of Extraction-Scrub Column

Run No.	26-230	26-222	27-301
Flowsheet	1	1	2
Pulse frequency, cpm	50	70	50
Flow rate, gal ft ⁻² hr ⁻¹			
Feed (AF)	195	141	269
Scrub (AS)	101	66	97
Solvent (AX)	478	343	548
Uranium conc., g/liter			
Feed (AF)	4.96	5.03	4.91
Raffinate (AW)	< 0.0001	< 0.0001	< 0.0001
Loaded solvent (AP)	2.15	2.02	2.49
Thorium conc., g/liter			
Feed (AF)	259	262	258
Raffinate (AW)	183	176	192
Loaded solvent (AP)	0.009	< 0.002	0.004

Table 6.2. Analyses of Profile Samples:
Uranium Extraction

Location of Sample Points (ft from top)	Aqueous		Solvent		
	U	Th	U	Th	Th ^b
	(g/liter)	(g/liter)	(g/liter)	(g/liter)	(g/liter)
Run 26-230					
2	1.24	0.75	2.77	0.063	0.14
4	1.27	2.5 ⁴	2.62	0.30	0.55
6	1.17	11.5	2.69	1.36	2.10
8	2.32 ^a	166 ^a	2.17 ^a	4.61 ^a	-
10	0.71	187	0.435	5.66	-
12	0.055	190	0.063	5.74	-
14	0.007	188	0.006	5.74	-
16	0.001	190	0.0008	5.90	-
18	0.0004	189	0.0002	5.66	-
20	<0.0001	189	0.0001	5.78	-
22	<0.0001	189	<0.0001	5.74	-
24	<0.0001	189	<0.0001	3.95	-
Run 26-222					
2	1.44	3.12	2.39	0.01	0.1
4	1.15	3.2 ⁴	2.51	0.11	0.63
6	0.99	18.5	2.39	0.85	3.59
8	1.94 ^a	205 ^a	1.86 ^a	4.34 ^a	-
10	0.101	186	0.56	4.50	-
12	0.005	184	0.039	5.54	-
14	0.003	189	0.005	5.14	-
16	0.001	212	0.003	5.46	-
18	0.0007	190	0.002	5.44	-
20	0.0005	188	0.002	4.91	-
22	0.0003	187	0.003	5.43	-
24	0.0001	185	0.0005	3.67	-
Run 27-301					
2	2.01	0.15	2.75	0.009	0.031
4	2.04	0.5 ⁴	2.87	0.027	0.100
6	1.93	1.65	2.97	0.119	0.296
8	1.89	5.76	2.92	0.883	1.024
10	1.46	22.5	2.82	0.970	3.987
12	2.55 ^a	193 ^a	2.21 ^a	5.42 ^a	-
14	0.595	211	0.422	6.25	-
16	0.097	210	0.054	6.40	-
18	0.015	210	0.009	6.38	-
20	0.003	215	0.002	6.45	-
22	0.002	213	0.0005	6.33	-
24	0.001	204	0.0004	4.33	-

^a Feed point

^b Calculated by material balance

Table 6.3. Calculated HETS and HTU Values:
Uranium Extraction

Location of Column Section (ft from feed point)	Run 26-230		Run 26-222		Run 27-301	
	HETS (ft)	HTU (ft)	HETS (ft)	HTU (ft)	HETS (ft)	HTU (ft)
FP-2	2.5	1.3	2.0	0.58	2.5	1.17
FP-4	3.7	0.97	2.1	0.62	4.2	1.13
FP-6	3.2	0.97	-	-	3.4	1.11
FP-8	4.0	0.99	-	-	4.1	1.14
2-4	2.1	0.78	2.1	0.67	2.4	1.11
4-6	2.3	0.96	-	-	2.4	1.07
6-8	2.3	1.05	-	-	2.5	1.24

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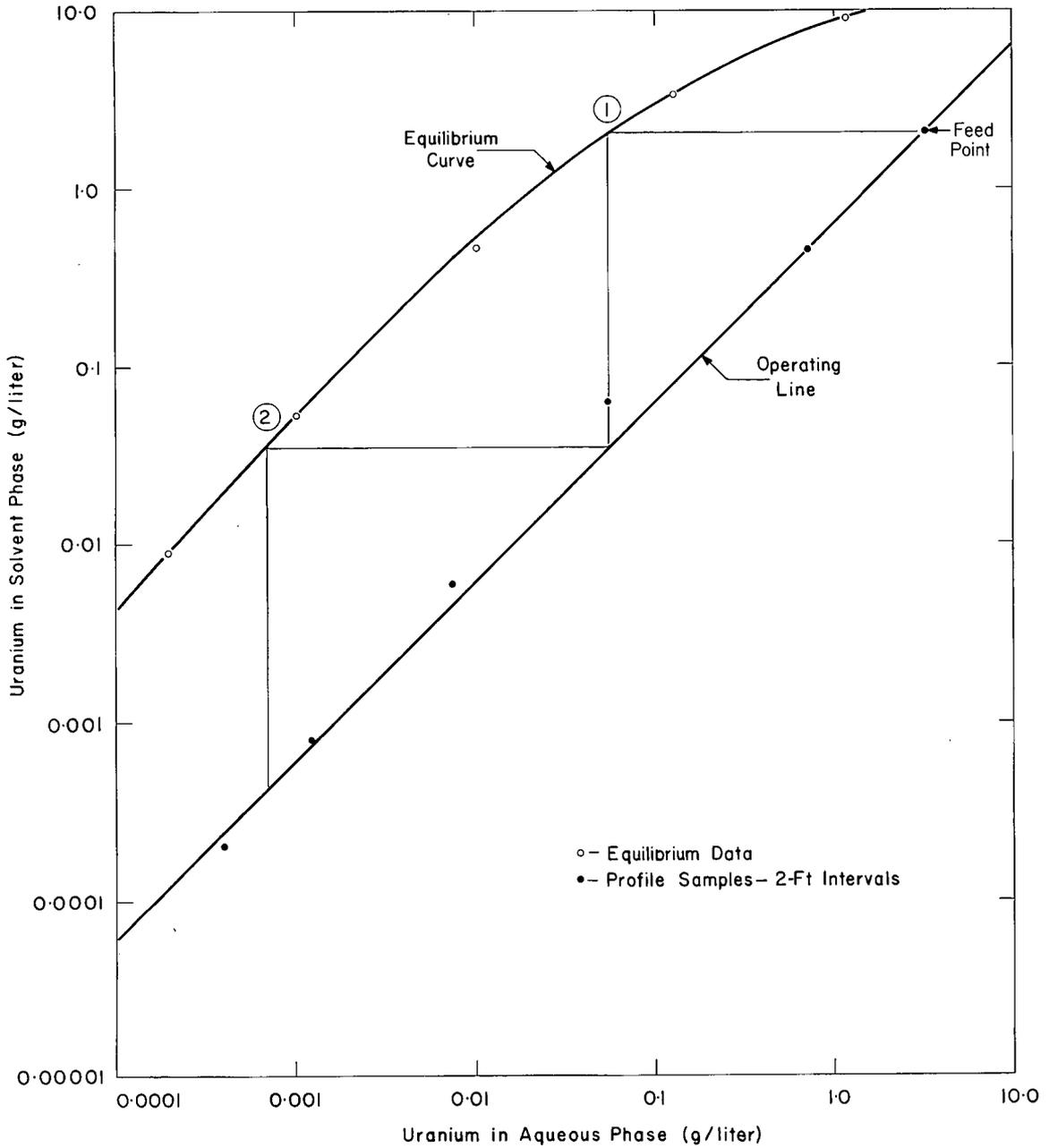


Fig. 6.1 Typical McCabe-Thiele Diagram for Uranium Extraction, Experiment 26-230.

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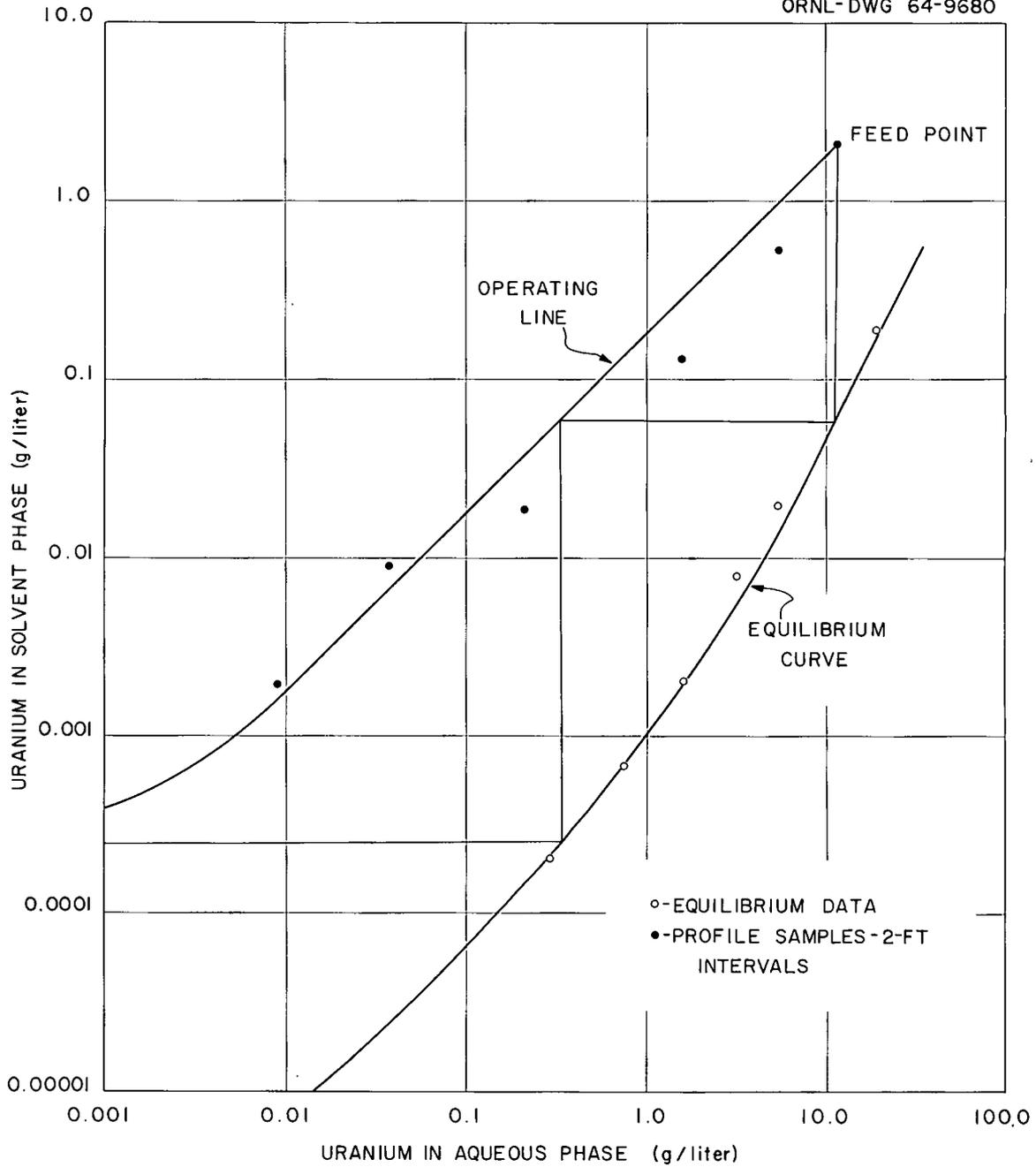


Fig. 6.2 Typical McCabe-Thiele Diagram for Uranium Stripping, Experiment 27-320.

Table 6.4. Experimental Conditions and End-Stream Analyses
for Uranium Strip Column

Run No.	26-230	26-222	27-320	27-301
Flowsheet	1	1	1	2
Pulse frequency, cpm	35	50	70	35
Flow rate, gal ft ⁻² hr ⁻¹				
Loaded solvent (AP)	478	343	257	548
Strip reagent (CX)	95	62	50	131
Loaded Solvent (AP)				
U, g/liter	2.15	2.02	2.04	2.49
Th, g/liter	0.009	< 0.002	0.003	0.004
Stripped solvent (CW)				
U, g/liter	0.060	0.012	< 0.0001	0.055
Th, g/liter	< 0.002	< 0.002	< 0.002	< 0.002
Product (CP)				
U, g/liter	9.98	10.5	10.3	10.1
Th, g/liter	0.035	0.011	0.015	0.025
NO ₃ , g/liter	5.71	5.51	5.53	5.83
NO ₃ /U, mole ratio	2.20	2.01	2.06	2.22

Table 6.5. Analyses of Profile Samples
Uranium Stripping

Location of Sample Point (ft from bottom)	Aqueous		Solvent		
	U (g/liter)	Th (g/liter)	U (g/liter)	U ^a (g/liter)	Th (g/liter)
Run 26-320					
2	6.97	0.013	1.09	1.45	<0.002
4	3.30	0.006	-	0.713	<0.002
6	1.70	0.003	0.358	0.396	<0.002
8	0.801	0.002	0.151	0.218	<0.002
10	0.288	<0.002	0.088	0.105	<0.002
Run 26-222					
2	7.27	0.006	1.01	1.34	0.002
4	3.25	0.002	0.482	0.607	<0.002
6	1.43	0.002	0.239	0.234	<0.002
8	0.548	<0.002	0.101	0.117	<0.002
10	0.193	<0.002	0.047	0.067	<0.002
Run 27-320					
2	5.56	0.006	0.543	1.03	<0.002
4	1.33	0.002	0.125	0.247	<0.002
6	0.213	<0.002	0.017	0.040	<0.002
8	0.038	<0.002	0.009	0.007	<0.002
10	0.009	<0.002	0.002	0.002	<0.002
Run 27-301					
2	6.49	<0.002	1.41	1.60	0.006
4	3.66	<0.002	0.780	0.93	0.003
6	1.88	<0.002	0.491	0.504	0.002
8	0.870	0.002	0.256	0.263	0.002
10	0.334	0.002	0.109	0.135	<0.002

^a Calculated by material balance from aqueous samples

Table 6.6. Calculated HETS Values:
Uranium Stripping

Location of Column Section (ft from bottom)	HETS (ft)			
	Experiment No.			
	26-230	26-222	27-320	27-301
0-2	6.2	5.7	3.9	5.6
0-4	5.5	5.6	4.4	6.3
0-6	7.2	6.7	4.1	7.4
0-8	8.8	8.2	4.2	8.7
0-10	10.3	6.7	-	10.3
0-12	12.0	6.7	-	12.0
2-4	3.9	3.6	2.6	4.8
4-6	4.5	3.6	2.4	4.4
6-8	3.9	3.4	2.4	4.2
8-10	3.9	2.7	-	4.0
10-12	10.5	3.5	-	3.6

Table 6.7. Steady-State Conditions for Thorium Scrubbing with the Solvent Phase Continuous (Run 30-470)

	Flow Rate (gal ft ⁻² hr ⁻¹)	Concentration	
		U (g/liter)	Th (g/liter)
Loaded solvent	343	3.30	1.680
Scrubbed solvent	343	2.53	0.155
Scrub reagent	70	0.0	0.0
Scrub effluent	70	3.76	8.50

Analyses of Profile Samples

Location of Sample Point (ft from bottom)	Solvent	
	U (g/liter)	Th (g/liter)
2	3.30	0.835
4	3.30	0.783
6	3.14	0.585
8	2.92	0.222
10	2.60	0.157

Table 6.8. Calculated HETS Values for Thorium Scrubbing

Location of Column Section (ft above feed point)	HETS (ft)			
	Experiment No.			
	26-230	26-222	27-301	30-470
0-2	3.6	11.1	7.4	4.0
0-4	4.5	4.7	4.9	7.4
0-6	6.5	6.1	6.3	9.1
0-8	4.6	4.1	8.0	9.2
0-10	-	-	7.1	11.0
0-12	-	-	6.2	13.0
2-4	3.4	2.3	2.7	33.3
4-6	2.2	2.4	2.8	8.0
6-8	2.2	2.0	2.4	3.1
8-10	-	-	2.8	6.7

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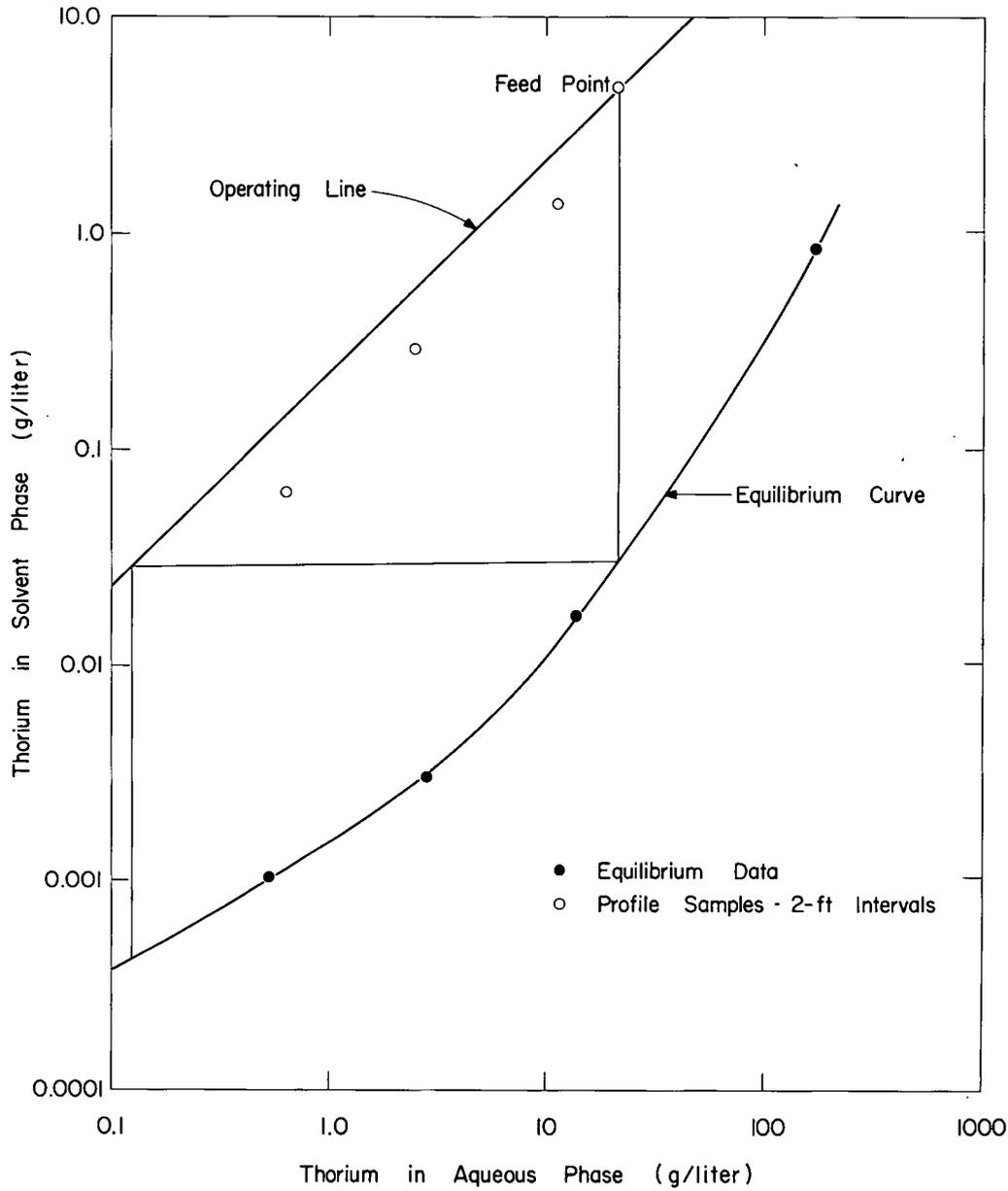


Fig. 6.3 Typical McCabe-Thiele Diagram for Thorium Scrubbing, Experiment 26-230.

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