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DEVELOPMENT OF THE EXCER PROCESS V: RECOVERY, PURIFICATION, AND IRON REDUCTION OF URANIUM USING A SULFATE ION EXCHANGE SYSTEM

R. R. Holcomb
I. R. Higgins

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ABSTRACT

A uranium sulfate process flowsheet for the production of UF_4 from sulfate ore leach liquors is presented. The uranium is sorbed on an anion-exchange resin from 0.2 M sulfate ore leach and eluted with 2 M H_2SO_4. Iron powder reduces UO_2SO_4 to $U(SO_4)_2$ which is then sorbed on anion-exchange resin to separate it from the iron, and eluted from the anion exchange resin with 2 M H_2SO_4. The resulting $U(SO_4)_2$ is sorbed on a cation-exchange resin from the H_2SO_4 solution and eluted from the resin with 5-6 M HCl. The UCl_4 thus produced may be treated with stoichiometric amounts of HF in order to precipitate $UF_4 \cdot 3/4H_2O$.

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1.0 INTRODUCTION

Ion exchange is presently used to recover and partially purify uranium from sulfuric acid-leached ores. However, its potential ability to give higher purification at lower cost has not been developed. This process may be improved by use of continuous contacting equipment, rather than fixed beds, and by substitution of cheaper chemicals. At the Oak Ridge National Laboratory several ion exchange flowsheets for the purification and conversion of uranium to uranium tetrafluoride have been developed.[1,2,3,4]

The purpose of this study was to combine previous developments and new proposals into a simpler and less costly method of converting unclarified sulfate ore leach to high-purity uranium tetrafluoride.

The continuous ion exchange steps were demonstrated on a 2-in.-dia Higgins solid-liquid contactor[5] developed at Oak Ridge National Laboratory. The runs were designed to demonstrate the over-all feasibility of the combined ion exchange steps. Further detailed work is required. Unsolved problems are: (1) optimization of the flow conditions and column dimensions for efficient performance; (2) minimization of oxidation of uranium(IV) to uranium(VI), and (3) definition of conditions which avoid hydrolysis of the uranium(IV) ion.

Acknowledgment is made to W. J. Neill, H. H. Carmichael, and J. E. Davidson for their technical and operational assistance in this study and to G. R. Wilson and W. R. Laing for analytical service.

2.0 FLOWSHEET

The flowsheet presented in Fig. 1 represents a combination of both old and new steps designed to provide a low-cost short route for converting uranium from a crude ore leach to highly purified green salt in one plant. Any uranium source may be used as feed, but location of the Excer plant at the ore mill is recommended because all waste streams containing acid and uranium may be recycled to the ore leach. Consequently, the sulfuric acid used in the ion exchange plant is used without cost since it will be reconstituted and used again in the leach step.

In the first column, (Fig. 1) the uranyl sulfate from a crude ore leach liquor is loaded on an anion exchange resin, is water washed and then eluted with 2 M sulfuric acid as partially purified uranyl sulfate. The uranium(VI) is then reduced to uranium(IV) with powdered iron.[6] Iron metal was chosen because of its low cost, high efficiency, and ease of separation from uranium(IV) in sulfate solutions by ion exchange. The solution is then diluted with water to an acid concentration of 0.5 M.

In a second column, the uranous sulfate is loaded on an anion exchange resin, is water washed, and then eluted with 2 M sulfuric acid as purified, iron-free uranous sulfate. Again the solution is diluted to an acid concentration of 0.5 M. To convert uranous sulfate to uranous chloride the

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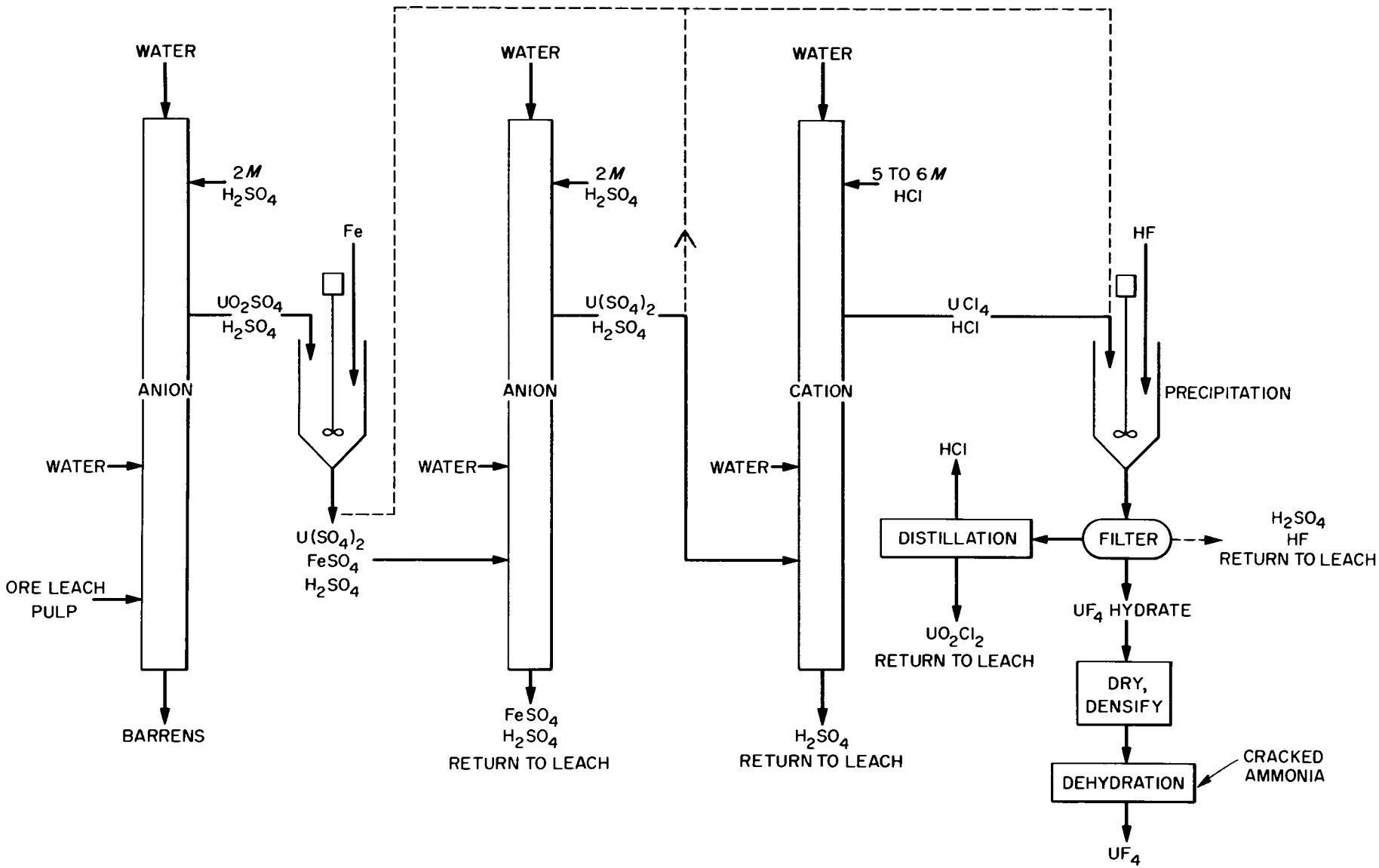

Fig. 1. Proposed ORE Leach – Sulfate-Iron Flowsheet.

uranous sulfate is loaded on a cation exchange resin in the third ion exchange column, is water washed and then eluted with 5-6 M hydrochloric acid as uranous chloride. Uranium tetrafluoride is precipitated from this uranous chloride solution by the addition of a stoichiometric amount of hydrofluoric acid. If precipitation of uranium tetrafluoride is made from the uranous sulfate product of the second column, excessive amounts of hydrofluoric acid are required to prevent sulfate contamination of the product.

The three step ion-exchange process, extraction, iron separation, and conversion from sulfate to chloride, thoroughly purifies uranium from all contaminants as shown in previous development work.[1,2,3,4] Efficiency is gained by using continuous countercurrent ion exchange equipment. The process steps are closely integrated and intermediate products do not have to be shipped to another plant for final purification.

3.0 EXPERIMENTAL

The three ion exchange steps presented in the flowsheet for the extraction and purification of uranium, separation of iron after reduction, and conversion from the sulfate to the chloride system were accomplished with the 2-in.-dia Higgins contactor shown in Fig. 2.

3.1 Ion Exchange Purification of Uranyl Sulfate

Uranium losses from this first step must be low since the barren waste from the ore leach is the most bulky and contains the greatest quantity of contaminants, and therefore, will not be recycled. Uranium losses were as low as 0.0009 grams per liter even with the simulated, abnormally high feeds of 10 to 20 grams of uranium per liter (Table 1). An approximate height of 6.5 feet was required for the loading conditions used. Figure 3 shows the loading of uranium on the column as a function of height for the conditions (run 10) specified on the graph. The profile type graphs are useful for showing the performance of several different lengths of column section under one set of feed and flow conditions. The objective is to achieve a resin loading or product concentration close to maximum possible on one end and a low uranium content on the other. Minimum section heights are chosen to achieve this near maximum resin loading or minimum chemical consumption.

The elution of uranium from anion exchange resin with sulfuric acid was not expected to be as efficient as with chloride or nitrate, in which 3 to 4 pounds of salt were consumed per pound of uranium.[7] From 5 to 9 pounds of sulfuric acid were required per pound of uranium and a product concentration of only 12 to 19 grams of uranium per liter was obtained. The height required for the above mentioned consumption of sulfuric acid was 8 ft (Fig. 4). From these data it may be noted that sulfuric acid elution of uranyl ion from ion exchange resin is practical. Even if the sulfuric acid were not recycled for leaching, its use at 1¢ per pound would cost 6 to 9¢ per pound of uranium produced as compared with 14¢ per pound of uranium using ammonium nitrate costing 3-1/2¢ per pound.[7]

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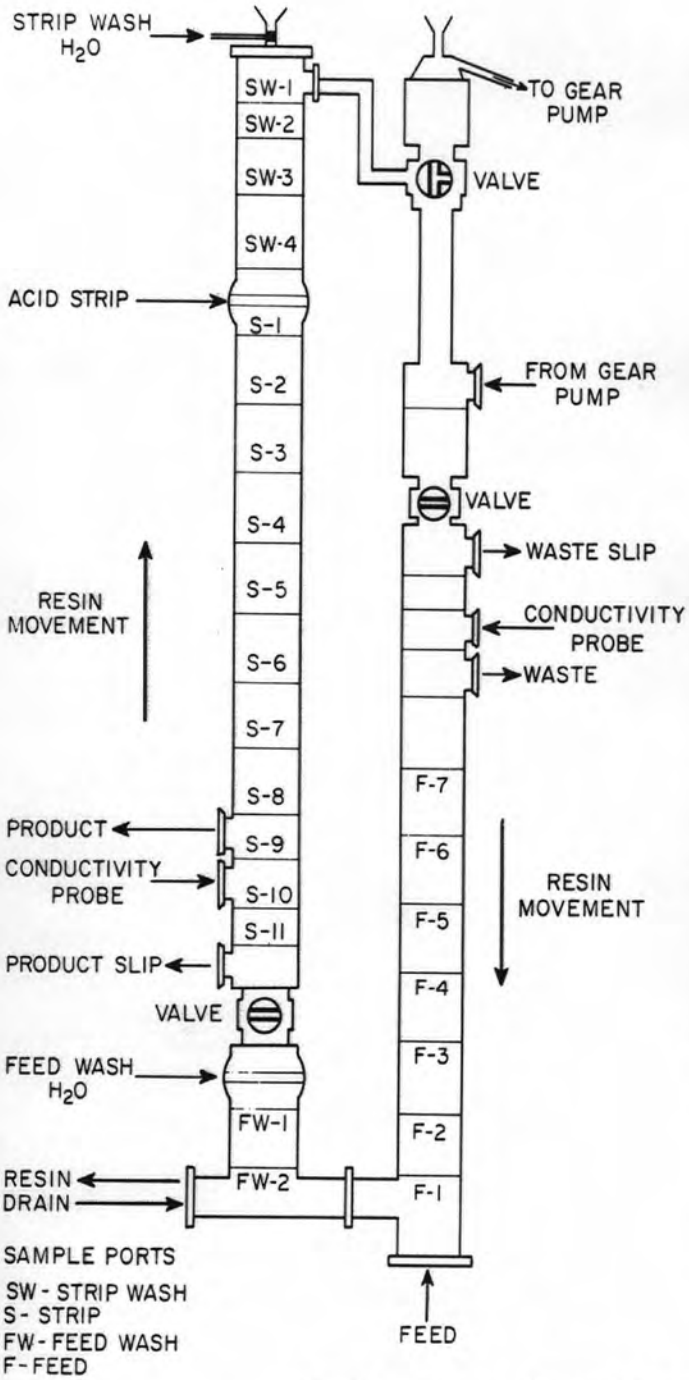

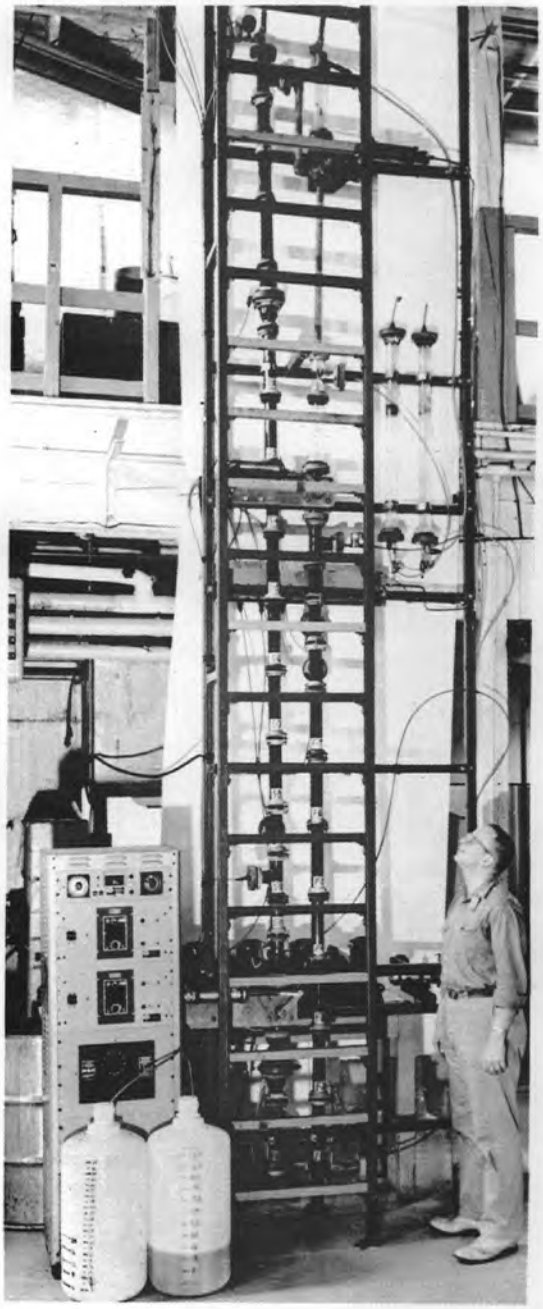

Fig. 2. Two-in.-dia Higgins Solid-Liquid Contactor.

Table 1. Average Conditions for Continuous Loading and Stripping of Uranyl Sulfate on Anion Resin from the Sulfate System

Conditions	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10
Feed Rate (ml/min)	262	260	267	298	146	181	167	107	105	118
Feed Conc. (g U per liter)	11.0	11.0	10.18	9.36	20.5	20.9	20.9	20.5	20.5	20.6
Strip Rate (ml/min)	146	147	148	159	173	180	128	84	90	72
Strip Conc. (N H_2SO_4)	2	2	2	2	2	4	4	4	2	4
Product Rate (ml/min)	184	146	188	231	236	259	216	133	129	111
Product Conc. (g U per liter)	13.8	13.8	16.3	12.2	12.1	14.8	14.8	13.6	18.6	19.9
Waste Rate (ml/min)	325	299	357	412	251	266	277	183	167	175
Waste Conc. (g U per liter)	0.011	0.011	0.009	0.014	0.009	0.011	0.011	0.002	0.0009	0.02
Feed Wash Rate (ml/min)	96	57	87	115	112	98	134	63	53	69
Strip Wash Rate (ml/min)	96	50	97	115	120	134	134	62	52	58
Slip Water Rate (ml/min)	66	60	53	39	58	46	39	17	17	15
Resin Rate (ml/min)	50	50	50	50	50	50	50	25	25	25
Length of Run (hr)	3	5-3	4-8	7	15	7	6	7	7	14
Results										
lb H_2SO_4 per lb U produced	5.63	7.15	4.73	5.53	5.94	9.17	7.82	9.10	3.68	6.38
Loading (g U per liter of resin)	57.6	57.2	54.4	55.8	59.9	75.6	69.8	87.7	86.1	97.2
U Production (lb U/hr/ft^2)	15.6	12.4	18.8	17.3	17.5	23.6	19.6	11.1	14.8	13.6
U Waste Loss (%)	0.124	0.115	0.120	0.207	0.075	0.077	0.087	0.017	0.007	0.014

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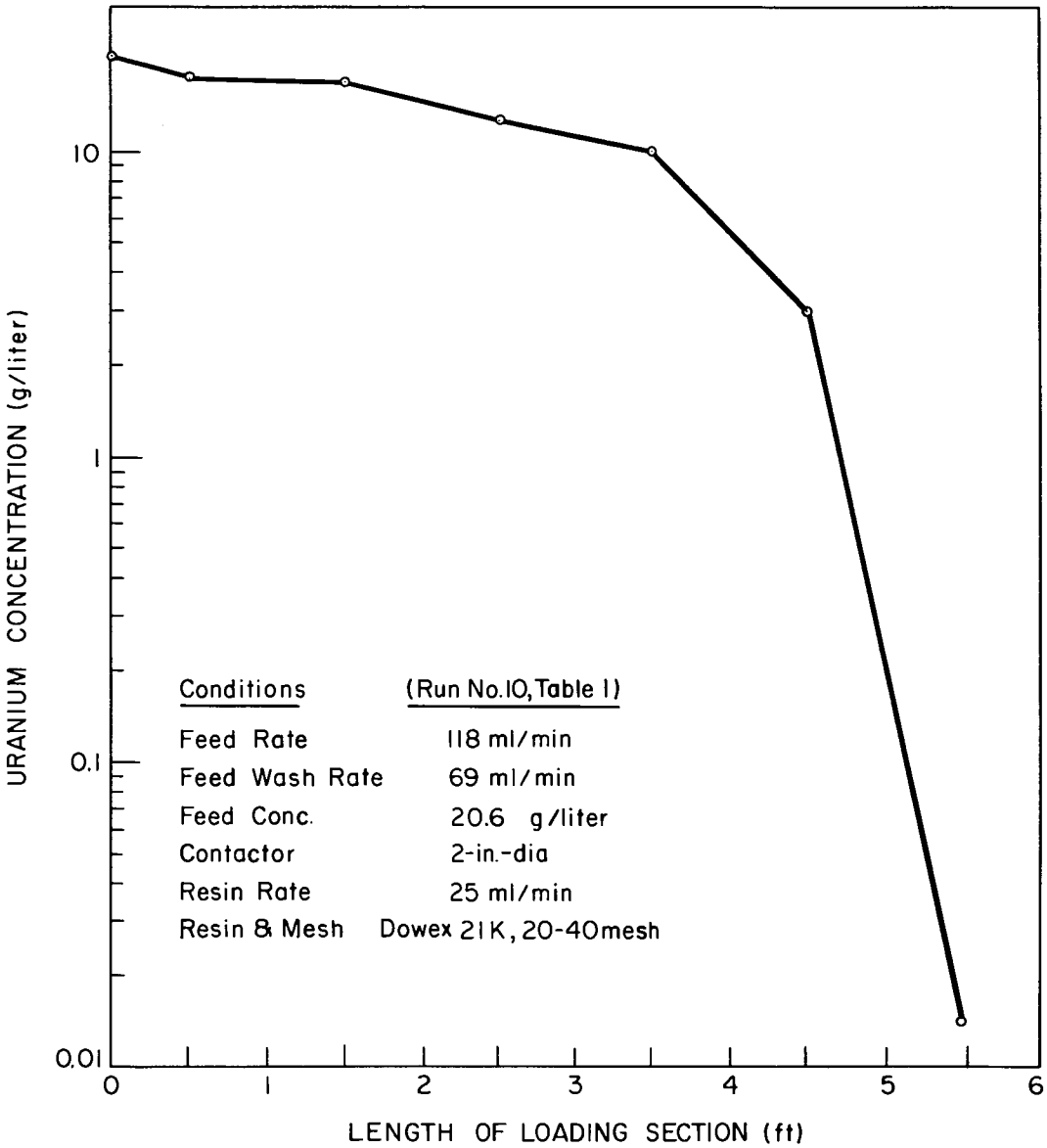

Fig. 3. Uranyl Sulfate Loading Profile on Anion Resin.

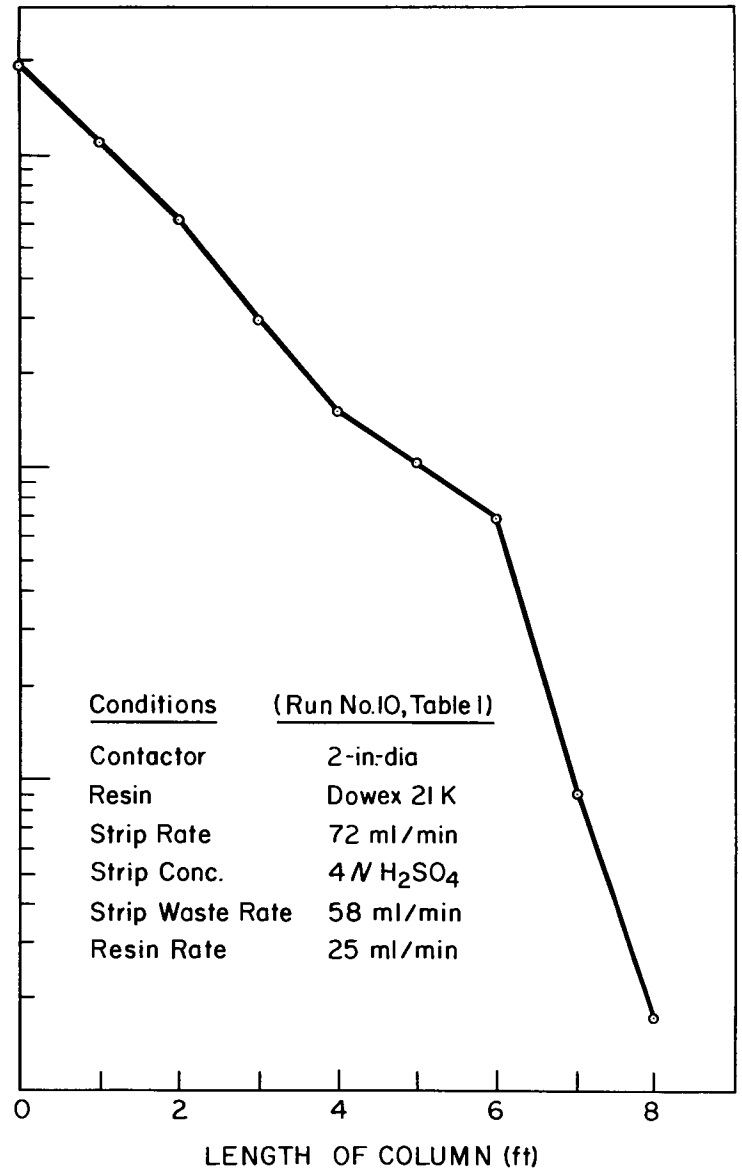

Fig. 4. Uranyl Sulfate Elution Profile from Anion Resin.

A series of 10 runs (Appendix I) was made to determine the conditions for this anion exchange step. The average conditions used and the average results obtained for each run were listed in Table 1.

3.2 Ion Exchange Separation of Iron(II) from Uranium(IV)

The uranyl sulfate from the anion exchange recovery and partial purification step was reduced with sponge iron to uranous sulfate. The separation of iron(II) and uranium(IV) made necessary by the presence of ferrous ion in the reduction product is readily accomplished in the sulfate system. Uranous sulfate has an affinity for anion exchange resins, similar to uranyl sulfate, while ferrous sulfate exhibits no affinity. Decontamination factors of from 438 to 1220 were demonstrated in a series of 8 runs (Appendix II). The average conditions along with the average results are shown in Table 2.

The product from the first anion exchange step in the flowsheet was 1 to 2 M in sulfuric acid and contained 16 to 20 grams of uranium per liter. Iron powder efficiently reduces uranyl ion to uranous and adds ferrous sulfate to the solution in equimolar quantities. The sulfuric acid concentration must be reduced to increase the distribution coefficient of uranium(IV) for the resin sufficiently to give practical loading. The sulfate was diluted to about 0.2 M and the resin was loaded to 40 to 50 grams of uranium per liter. Stripping with sulfuric acid was more efficient for uranous than for uranyl sulfate, but because the concentration of uranous sulfate was about 2/3 that of uranyl sulfate the sulfuric acid consumption was approximately the same, 6 to 9 pounds per pound of uranium. Waste losses could be reduced to 0.001 grams of uranium per liter, but no particular attempt was made to do so because this feed waste is destined to be used for its acid value to treat more fresh ore.

The runs (Appendix II) were made to determine the practicality of uranous sulfate loading and stripping, and the efficiency of separation of iron from uranous ion. Conditions for the separation of iron were favorable as indicated by decontamination factors of 438 to 1220. Oxidation of uranium(IV) to uranium(VI) during the separation of iron from uranium in the second column will not cause an increase in uranium loss in the waste stream since the distribution coefficients of uranium(IV) and uranium(VI) on anion resin are approximately the same. However, oxidation causes an increase in uranium recycle in the final precipitation step (see Section 3.3). The loading and stripping profiles and the height required for the conditions used (Table 2) may be noted in Figs. 5 and 6.

These runs proved that iron reduction is as satisfactory as electrolysis in producing uranium tetrafluoride by wet methods. At this point hydrofluoric acid may be added to precipitate $UF_4 \cdot 3/4H_2O$, but when precipitations are made from sulfate solutions, about 100-500 ppm of sulfate appear with the product. The sulfate may be reduced by using excessive amounts of hydrofluoric acid, but it is desirable to hold hydrofluoric acid consumption close to stoichiometric. Since the sulfate contamination problem did not exist in chloride solutions, uranous sulfate was converted to uranous chloride by cation exchange.

Table 2. Average Conditions for Continuous Loading and Stripping of Uranous Sulfate on Anion Resin from the Sulfate System

Conditions	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
Feed Rate (ml/min)	85	83	72	70	100	101	98	102
Feed Conc. (g U per liter)	25.6	19	19	11	11	11	10.8	10.8
Feed Conc. (g U per liter)	19.3	13	13	--	--	--	5.72	5.72
Strip Rate (ml/min)	111	81	75	62	48	51	48	50
Strip Conc. (N H_2SO_4)	2	4	2	4	4	4	4	4
Product Rate (ml/min)	150	150	126	122	102	108	94	87
Product Conc. (g U per liter)	13.3	14.0	9.92	8.57	10.5	10.2	9.68	11.2
Waste Rate (ml/min)	167	133	158	150	180	181	179	172
Waste Conc. (g U per liter)	0.111	1.88	1.67	0.004	0.018	0.067	0.004	0.004
Feed Wash Rate (ml/min)	83	76	82	76	75	78	82	83
Strip Wash Rate (ml/min)	62	58	61	63	63	62	55	52
Product Slip Rate (ml/min)	18	11	15	5	25	19	6.3	11.2
Resin Rate (ml/min)	25	25	25	25	25	25	25	25
Length of Run (hr)	3 - 7	8	8	6-1/2	8	15	7	14
Results								
lb H_2SO_4/lb U produced	5.45	7.56	5.88	11.6	8.78	0.07	10.3	10.0
Loading (g U per liter resin)	12.3	12.9	7.68	6.42	6.58	6.77	5.59	5.99
U Waste Loss (%)	0.851	15.9	19.3	0.078	0.294	1.09	0.0068	0.0062
Decontamination Factor	438	688	610	1220	665	836	---	505
U Production (lb U/hr/ft^2)	12.3	12.9	7.68	6.42	6.58	6.77	5.59	5.99

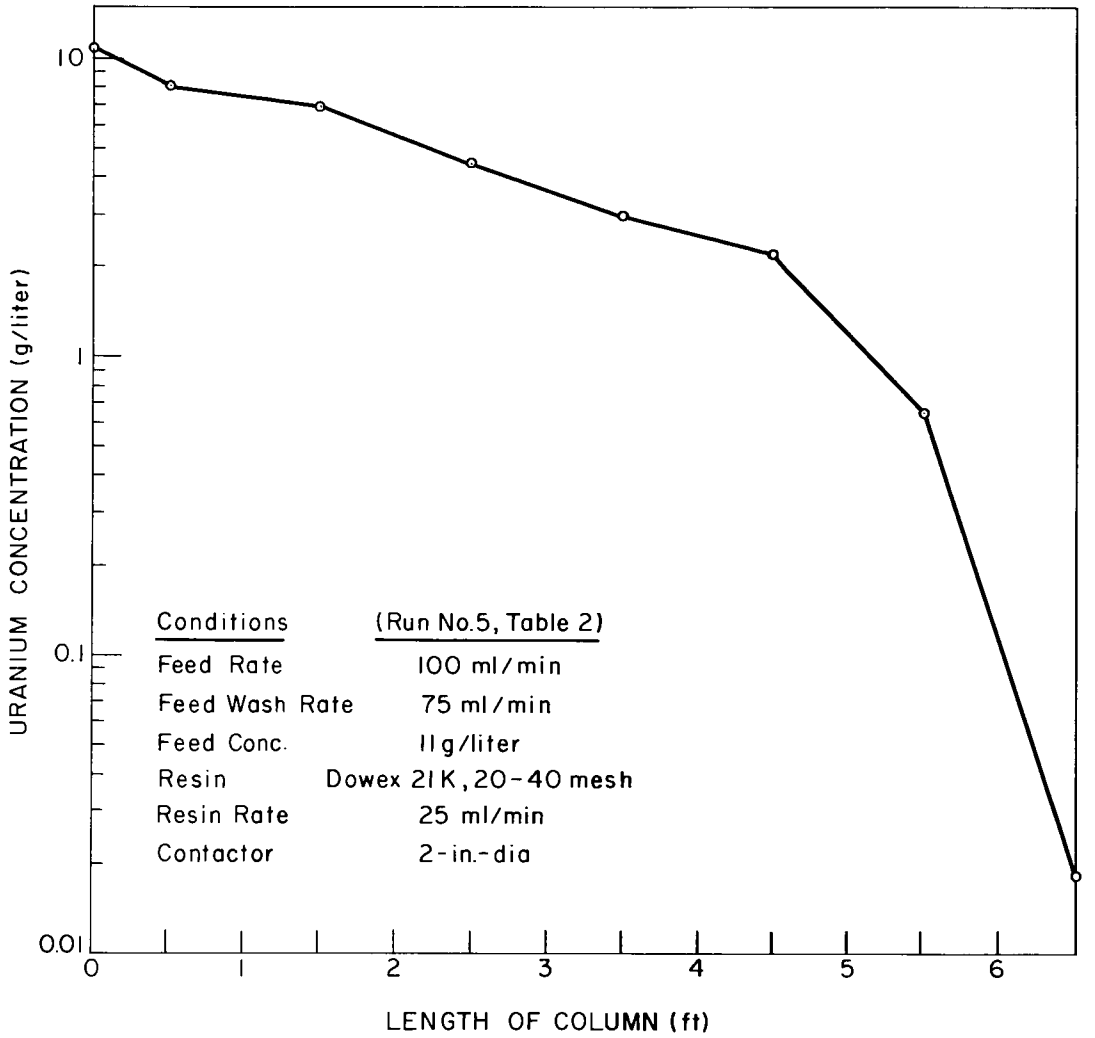

Fig. 5. Uranous Sulfate Loading Profile on Anion Resin.

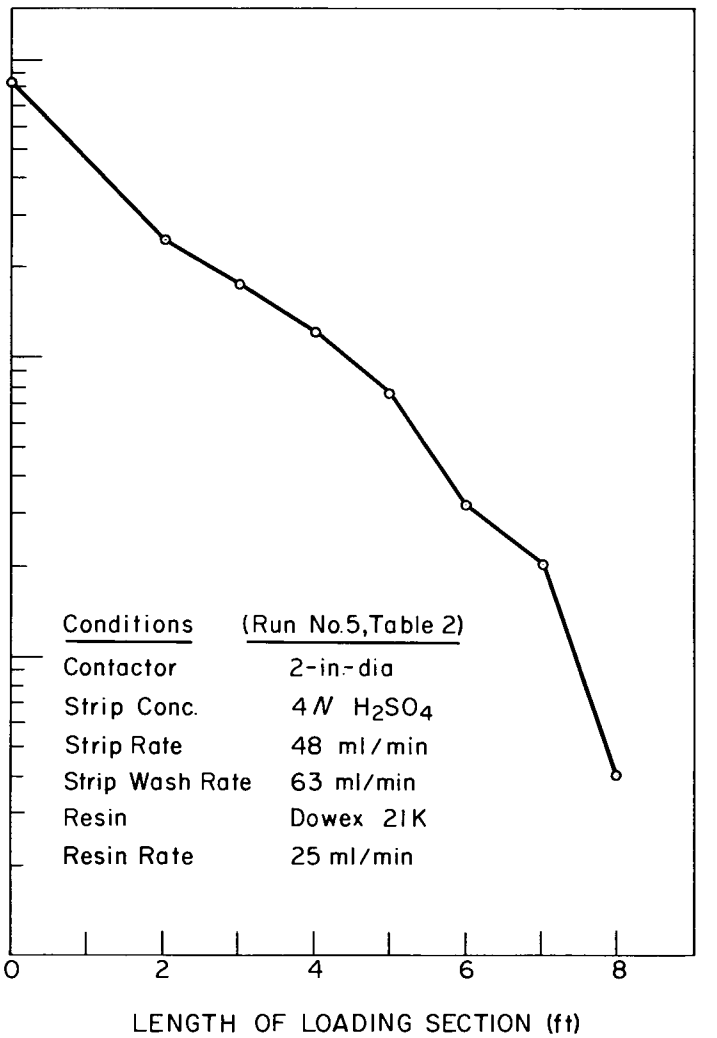

Fig. 6. Uranous Sulfate Elution Profile from Anion Resin.

3.3 Ion Exchange Conversion of Uranous Ion from Sulfate to Chloride

A better grade of UF_4 is produced by precipitation from chloride than from sulfate solutions. A series of 4 runs (Appendix III) were made to demonstrate the feasibility of converting $U(SO_4)_2$ to UCl_4 on a cation resin. The average conditions and results of the runs are presented in Table 3. The loading and stripping profiles and the heights required may be noted in Figs. 7 and 8.

The results from the cation conversion of uranous sulfate to uranous chloride were considered satisfactory for practical operation, but problems presented themselves which indicate the need of further development to produce optimum operation. A slight green coloration of the resin due to tailing (incomplete elution) was noted above the stripping section (see Fig. 2). Acid rather than water washes (see Fig. 1) are recommended to prevent hydrolysis of this uranium and consequently a loss in the capacity of the resin. In strong chloride, uranium oxidizes easily from the IV to the VI state. The development runs were made on one contactor whereas a production plant would use three contactors in sequence. Consequently, varying amounts of uranium were oxidized as the solutions were stored, waiting for the next cycle. This explains the 8-30% uranium (U-VI) loss (see Table 3) in the waste stream from the third column. It is estimated that this recycle stream of uranium(VI) would be less than 1% in a continuous plant. It was hoped that hydrochloric acid consumption would be sufficiently low that the waste from the cation column could be thrown in with the ore leach. Because of the consumption of hydrochloric acid, and its cost, a hydrochloric acid distillation recovery is recommended.

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Table 3. Average Conditions for Continuous Conversion of Uranous Sulfate to Uranous Chloride on Cation Resin

Conditions	Run 1	Run 2	Run 3	Run 4
Feed Rate (ml/min)	222	250	364	199
Feed Conc. (g U per liter)	3.87	3.23	3.29	13.7
Feed Conc. (g U per liter)	---	2.69	3.06	10.3
Strip Rate (ml/min)	39.5	41	96	74
Strip Conc. M HCl	9-10	9-10	6	6
Product Rate (ml/min)	66.5	58	124	94
Product Conc. (g U per liter)	7.68	7.33	6.60	19.3
Waste Rate (ml/min)	239	265	402	240
Waste Conc. (g U per liter)	0.882	1.04	0.289	0.99
Feed Wash Rate (ml/min)	24.7	35	32	32
Strip Wash Rate (ml/min)	38.5	39	39	33
Product Slip Rate (ml/min)	12.3	16	14	20
Waste Slip Rate (ml/min)	5.58	8.3	6.6	--
Resin Rate (ml/min)	12.5	12.5	25	25
Length of Run (hr)	23	7	12	15
Results				
lb HCl per lb U produced	26.8	33.4	25.68	8.93
Loading (g U per liter of resin)	68.7	64.6	47.9	109
Production (lb U per hr per ft^2)	3.14	2.61	5.03	11.2
% U Waste Loss (to be recycled)	24.5	34.1	9.70	8.71

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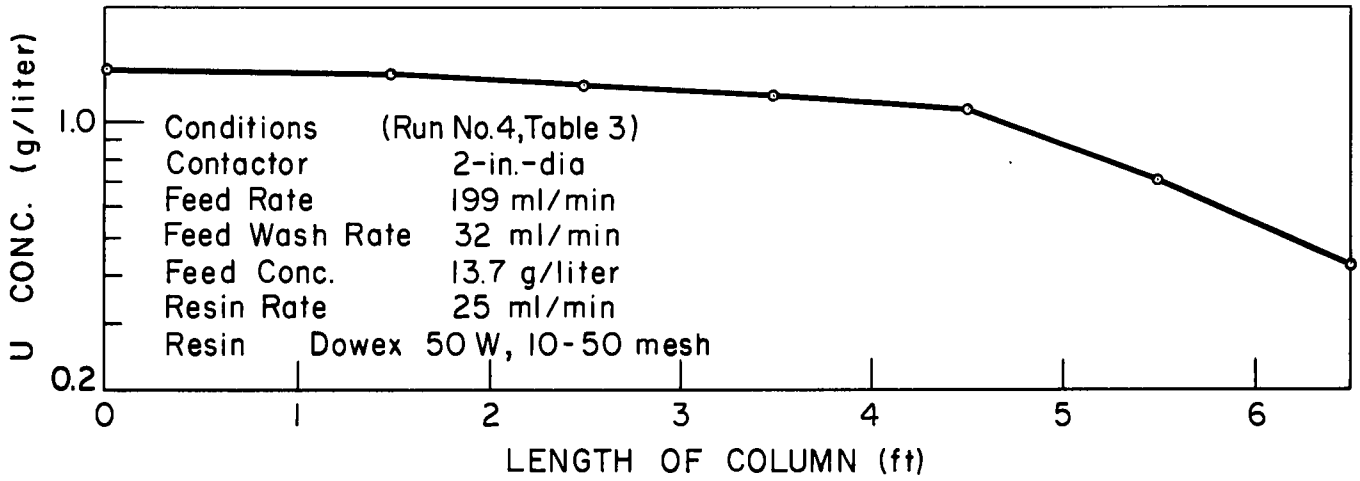

Fig. 7. Uranous Sulfate Loading Profile on Cation Resin.

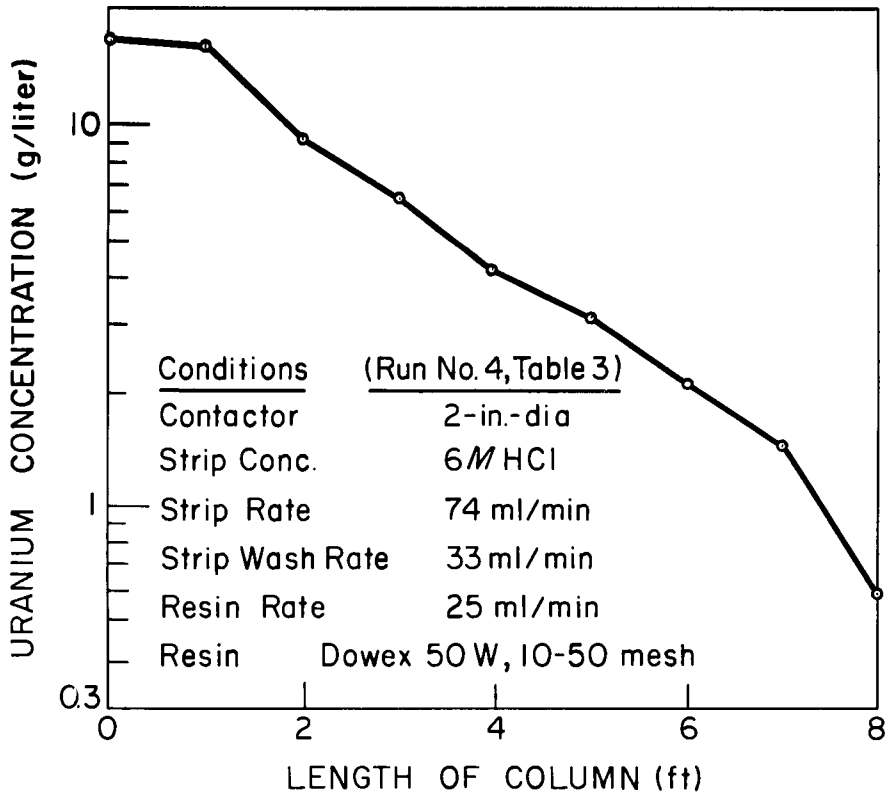

Fig. 8. Uranous Chloride Stripping Profile from Cation Resin.

4.0 APPENDIX I

ANION EXCHANGE PURIFICATION OF URANYL SULFATE

Table 1. Conditions for Continuous Loading and Stripping of Uranyl Sulfate: December 12-13 Run

Contactor: 2-in. dia
Loading section: 6.5 ft
Feed wash section: 2.0 ft
Strip section: 9.5 ft
Strip wash section: 2.0 ft
Feed: 11.0 g/liter UO_2SO_4--0.025 N H_2SO_4
Eluant: 2 N H_2SO_4
Resin: Dowex 21K, 20-40 mesh, ~50 liters
Resin flow rate: 50 ml/min

Run Time (hr)	Flow Rates (ml/min)							Product		Waste	
	Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	U (g/liter)	H+ (N)	U (g/liter)	H+ (N)
1	150	46.6	150	58	200	132	53	---	---	---	---
2	310	35.5	172	34.5	345	156	56	---	---	---	---
3	300	27.0	140	36.0	265	100	57	---	---	---	---
4	266	31.7	130	36.0	300	116	57	---	---	---	---
5	266	25.0	144	33.4	308	116	62	---	---	---	---
6	250	95	134	92	300	192	---	---	---	---	---
7	280	104	144	96	306	174	63	---	---	---	---
8	257	90	160	100	370	186	70	13.8	1.54	0.011	0.04

Table 2. Profile of Column After 8 Hr of Operation: December 12-13 Run

Sample Port	U (g/liter)	H+ (N)
Strip Wash - 1	0.050	0.28
2	0.065	0.31
3	0.078	0.40
Strip-1	0.751	1.86
2	2.81	1.89
3	4.48	1.89
4	5.93	1.88
5	7.97	1.85
6	9.38	1.84
7	10.9	1.83
8	13.7	1.82
9	16.3	1.79
10	15.0	0.87
11	1.64	0.12
Feed Wash -1	0.838	0.025
2	1.18	0.025
Feed-1	9.03	0.02
2	3.20	0.04
3	0.012	0.068
4	0.013	0.065
5	0.011	0.063
6	0.016	0.065

Table 3. Conditions for Continuous Loading and Stripping of Uranyl Sulfate: December 16-17 Run

Contactor: 2-in. dia
Loading section: 6.5 ft
Feed wash section: 2.0 ft
Strip section: 9.5 ft
Strip wash section: 2.0 ft
Feed: 11.0 g/liter UO_2SO_4--0.04 N H_2SO_4
Eluant: 2 N H_2SO_4
Resin: Dowex 21K, 20-40 mesh, ~50 liters
Resin flow rate: 50 ml/min

Run Time (hr)	Flow Rates (ml/min) Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	Product U (g/liter)	Product H+ (N)	Waste U (g/liter)	Waste H+ (N)
1	266	80	142	87	347	200	30	15.8	1.65	0.0104	0.073
2	266	83	134	97	320	166	48	15.1	1.50	0.0096	0.083
3	266	100	158	105	400	184	75	17.0	1.70	0.0084	0.093
4	283	95	157	95	375	192	63	17.2	1.65	0.0094	0.090
5	283	88	157	100	367	236	28	17.0	1.53	0.0100	0.090
6	266	93	155	100	367	197	47	17.7	1.86	0.0070	0.070
7	266	83	155	100	350	180	58	17.3	1.81	0.0060	0.093
8	283	92	166	100	384	203	67	16.5	1.70	0.0070	0.093
9	250	80	134	100	310	164	58	14.4	1.47	0.0090	0.090
10	266	85	134	97	360	186	58	15.7	1.34	0.0080	0.087
11	240	80	144	90	355	174	52	15.8	1.38	0.0090	0.092
12	266	83	143	92	345	168	56	16.0	1.46	0.0100	0.097

Table 4. Profile of Column After 11 Hr of Operation: December 16-17 Run

Sample Port	U (g/liter)	H+ (N)
Strip Wash - 1	0.040	0.29
2	0.049	0.33
3	0.064	0.41
Strip - 1	1.25	1.76
2	2.59	1.69
3	4.03	1.70
4	5.66	1.69
5	6.72	1.66
6	8.54	1.68
7	10.5	1.66
8	12.5	1.65
9	15.6	1.63
10	10.7	0.55
11	1.89	0.13
Feed Wash - 1	0.844	0.08
2	1.20	0.08
Feed - 1	5.16	0.08
2	1.60	0.09
3	0.051	0.11
4	0.015	0.11
5	0.014	0.10
6	0.012	0.09

Table 5. Conditions for Continuous Loading and Stripping of Uranyl Sulfate: December 19 Run

Contactor: 2-in. dia
Loading section: 6.5 ft
Feed wash section: 2.0 ft
Strip section: 9.5 ft
Strip wash section: 2.0 ft
Feed: 9.36 g/liter UO_2SO_4--0.05 N H_2SO_4
Eluant: 2 N H_2SO_4
Resin: Dowex 21K, 20-40 mesh, ~50 liters
Resin flow rate: 50 ml/min

Run Time (hr)	Flow Rates (ml/min) Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	Product U (g/liter)	Product H+ (N)	Waste U (g/liter)	Waste H+ (N)
1	315	90	133	102	400	240	30	7.02	0.65	0.013	0.10
2	300	106	160	115	416	260	20	13.3	1.35	0.016	0.10
3	350	125	173	120	430	250	18	13.4	1.43	0.018	0.10
4	284	117	168	114	400	220	40	12.5	1.44	0.016	0.09
5	250	118	168	114	417	200	58	11.9	1.18	0.011	0.08
6	284	130	150	120	425	221	55	14.0	1.50	0.014	0.09
7	300	117	162	118	400	225	53	13.2	1.47	0.011	0.09

Table 6. Profile of Column After 7 Hr of Continuous Operation: December 19 Run

Sample Port	U (g/liter)	H+ (N)
Strip Wash - 1	0.019	0.18
2	0.031	0.25
3	0.037	0.31
Strip -1	0.582	1.98
2	2.39	1.88
3	3.86	1.84
4	4.98	1.75
5	6.01	1.70
6	7.89	1.69
7	9.20	1.48
8	11.5	1.63
9	13.5	1.60
10	11.7	0.65
11	0.745	0.06
Feed Wash - 1	1.20	0.04
2	1.88	0.04
Feed - 1	8.33	0.06
2	5.29	0.07
3	0.264	0.08
4	0.015	0.08
5	0.014	0.08
6	0.012	0.10

Table 7. Conditions for Continuous Loading and Stripping of Uranyl Sulfate: December 26 Run

Contactor: 2-in. dia
Loading section: 6.5 ft
Feed wash section: 2.0 ft
Strip section: 9.5 ft
Strip wash section: 2.0 ft
Feed: 20.5 g/liter UO_2SO_4--0.01 N H_2SO_4
Eluant: 2 N H_2SO_4
Resin: Dowex 21K, 20-40 mesh, ~50 liters
Resin flow rate: 50 ml/min

Run Time (hr)	Flow Rates (ml/min) Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	Product U (g/liter)	Product H+ (N)	Waste U (g/liter)	Waste H+ (N)
1	170	124	170	117	262	287	--	10.4	1.28	0.010	0.074
2	143	126	188	128	276	237	71	12.2	1.72	0.009	0.086
3	117	115	174	117	254	220	53	10.2	1.45	0.008	0.090
4	166	125	186	134	275	244	53	10.3	1.52	0.007	0.089
5	150	110	179	117	260	224	53	11.6	1.58	0.005	0.086
6	170	118	178	125	266	260	63	12.3	1.44	0.005	0.104
7	166	110	158	117	264	216	67	13.0	1.44	0.005	0.086
8	150	120	164	117	240	216	50	12.1	1.40	0.006	0.088
9	134	109	170	109	222	250	49	10.7	1.48	0.008	0.108
10	134	100	168	117	235	200	51	15.0	1.52	0.007	0.094
11	134	109	175	122	250	250	67	15.8	1.52	0.006	0.086
12	134	109	175	122	235	250	67	13.1	1.36	0.012	0.094
13	134	100	168	122	250	235	58	10.3	1.22	0.020	0.097
14	134	100	175	122	235	216	58	12.3	1.43	0.015	0.094
15	150	100	168	122	235	235	58	11.8	1.48	0.016	0.094

Table 8. Profiles of Column After 7 and 14 Hr of Continuous Operation: December 26 Run

Sample Port	After 7 Hr U (g/liter)	After 7 Hr H+ (N)	After 14 Hr U (g/liter)	After 14 Hr H+ (N)
Strip Wash - 1	0.012	0.15	0.028	0.204
2	0.016	0.21	0.053	0.270
3	0.023	0.23	0.088	0.370
Strip - 1	0.591	2.02	0.926	1.86
2	1.69	1.91	2.60	1.91
3	2.89	1.82	4.11	1.84
4	4.08	1.80	5.03	1.82
5	5.33	1.78	6.61	1.79
6	4.22	1.80	7.35	1.76
7	9.26	1.78	8.76	1.77
8	11.0	1.75	9.58	1.78
9	13.0	1.71	12.4	1.68
10	3.21	0.20	6.23	0.52
11	1.63	0.072	0.684	0.099
Feed Wash - 1	1.85	0.068	1.64	0.136
2	2.67	0.100	2.70	0.155
Feed - 1	16.0	0.117	15.1	0.144
2	8.44	0.150	0.082	0.238
3	1.58	0.188	0.061	0.240
4	0.015	0.212	0.059	0.232
5	0.012	0.190	0.060	0.228
6	0.015	0.182	0.051	0.221

Table 9. Conditions for Continuous Loading and Stripping of Uranyl Sulfate: January 2 Run

Contactor: 2-in. dia
Loading section: 6.5 ft
Feed wash section: 2.0 ft
Strip section: 9.5 ft
Strip wash section: 2.0 ft
Feed: 20.9 g/liter UO_2SO_4--0.16 N H_2SO_4
Eluant: 4 N H_2SO_4
Resin: Dowex 21K, 20-40 mesh, ~50 liters
Resin flow rate: 50 ml/min

Run Time (hr)	Flow Rates (ml/min)							Product		Waste	
	Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	U (g/liter)	H+ (N)	U (g/liter)	H+ (N)
1	200	122	200	144	312	312	67	12.9	2.68	0.026	0.14
2	167	117	182	133	300	250	17	6.07	1.86	0.024	0.18
3	167	83	190	133	266	250	67	11.7	2.80	0.011	0.12
4	183	67	175	133	250	250	42	14.0	2.76	0.014	0.16
5	183	67	167	133	234	250	42	16.6	2.78	0.008	0.12
6	183	117	182	133	250	250	42	13.1	2.76	0.012	0.20
7	183	117	167	133	250	250	42	12.7	2.68	0.005	0.14

Table 10. Profile of Column After 6 Hr of Continuous Operation: January 2 Run

Sample Port	U (g/liter)	H+ (N)
Strip Wash - 1	0.002	0.13
2	0.003	0.16
3	0.003	0.21
Strip - 1	0.112	3.48
2	0.412	3.60
3	0.916	3.10
4	1.50	3.08
5	2.19	3.06
6	3.07	2.90
7	5.09	2.86
8	7.62	2.88
9	11.5	2.84
10	3.21	0.24
11	0.702	0.04
Feed Wash - 1	1.46	0.06
2	2.53	0.10
Feed - 1	17.9	0.16
2	15.6	0.17
3	11.4	0.18
4	6.39	0.21
5	0.780	0.25
6	0.015	0.25

Table 11. Conditions for Continuous Loading and Stripping of Uranyl Sulfate: January 3 Run

Contactor: 2-in. dia
Loading section: 6.5 ft
Feed wash section: 2.0 ft
Strip section: 9.5 ft
Strip wash section: 2.0 ft
Feed: 20.9 g/liter UO_2SO_4--0.16 N H_2SO_4
Eluant: 4 N H_2SO_4
Resin: Dowex 21K, 20-40 mesh, ~50 liters
Resin flow rate: 50 ml/min

Run Time (hr)	Flow Rates (ml/min)							Product		Waste	
	Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	U (g/liter)	H+ (N)	U (g/liter)	H+ (N)
1	167	130	127	125	266	233	32	15.7	2.60	0.004	0.13
2	167	136	108	140	266	216	43	19.7	2.44	0.003	0.13
3	167	134	134	134	300	216	42	17.7	2.56	0.012	0.13
4	167	134	134	134	300	216	42	16.9	2.54	0.007	0.12
5	167	134	134	134	266	200	33	18.5	2.60	0.010	0.16
6	167	134	134	134	266	216	42	16.9	2.62	0.013	0.18

Table 12. Profile of Column After 5 Hr of Continuous Operation: January 3 Run

Sample Port	U (g/liter)	H+ (N)
Strip Wash - 1	0.007	0.20
2	0.009	0.23
3	0.010	0.28
Strip - 1	0.477	3.35
2	1.32	3.20
3	2.50	3.13
4	4.45	3.08
5	5.47	3.00
6	7.32	2.95
7	9.88	2.95
8	12.2	2.98
9	15.7	2.88
10	6.40	0.49
11	1.16	0.11
Feed Wash - 1	1.52	0.09
2	3.37	0.13
Feed - 1	19.1	0.15
2	7.07	0.20
3	7.18	0.22
4	0.375	0.27
5	0.021	0.30
6	0.021	0.25

Table 13. Conditions for Continuous Loading and Stripping of Uranyl Sulfate: January 8 Run

Contactor: 2-in. dia
Loading section: 6.5 ft
Feed wash section: 2.0 ft
Strip section: 9.5 ft
Strip wash section: 2.0 ft
Feed: 20.5 g/liter UO_2SO_4--0.04 N H_2SO_4
Eluant: 4 N H_2SO_4
Resin: Dowex 21K, 20-40 mesh, ~50 liters
Resin flow rate: 25 ml/min

Run Time (hr)	Flow Rates (ml/min) Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	Product U (g/liter)	Product H+ (N)	Waste U (g/liter)	Waste H+ (N)
1	83	83	75	83	200	167	17	---	---	---	---
2	116	100	83	92	200	140	---	13.0	2.55	0.005	0.11
3	100	50	92	50	167	158	---	13.7	2.90	0.003	0.08
4	100	50	83	50	183	117	---	12.2	2.75	0.003	0.09
5	116	58	92	58	183	117	---	11.0	3.05	0.002	0.12
6	116	50	83	50	167	117	---	16.1	3.40	0.001	0.08
7	116	50	83	50	183	117	---	15.3	3.08	0.001	0.11

Table 14. Profile of Column After 6 Hr of Continuous Operation: January 8 Run

Sample Port	U (g/liter)	H+ (N)
Strip Wash - 1	0.012	0.19
2	0.002	0.20
3	0.002	0.31
Strip - 1	0.032	3.65
2	0.137	3.65
3	0.265	3.55
4	0.435	3.53
5	0.914	3.55
6	1.54	3.55
7	3.65	3.63
8	6.74	3.68
9	13.1	3.68
10	19.5	1.25
11	10.2	0.43
Feed Wash - 1	4.27	0.03
2	6.20	0.04
Feed - 1	19.9	0.04
2	16.9	0.05
3	11.4	0.07
4	7.29	0.10
5	0.615	0.144
6	0.004	0.136

Table 15. Conditions for Continuous Loading and Stripping of Uranyl Sulfate: January 14 Run

Contactor: 2-in. dia
Loading section: 6.5 ft
Feed wash section: 2.0 ft
Strip section: 9.5 ft
Strip wash section: 2.0 ft
Feed: 20.5 g/liter UO_2SO_4--0.04 N H_2SO_4
Eluant: 2 N H_2SO_4
Resin: Dowex 21K, 20-40 mesh, ~50 liters
Resin flow rate: 25 ml/min

Run Time (hr)	Flow Rates (ml/min)							Product		Waste	
	Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	U (g/liter)	H+ (N)	U (g/liter)	H+ (N)
1	100	50	83	58	167	134	---	17.4	1.41	0.0006	0.092
2	100	58	83	50	167	117	17	17.2	1.48	0.0006	0.120
3	116	50	92	58	167	134	17	17.5	1.52	0.0004	0.106
4	116	58	92	50	167	117	17	20.6	1.56	0.0006	0.107
5	100	58	100	50	167	134	17	20.4	1.40	0.0008	0.111
6	100	50	92	50	167	134	17	19.0	1.53	0.0015	0.128
7	100	50	92	50	167	134	17	18.1	1.40	0.0018	0.116

Table 16. Profile of Column After 6 Hr of Continuous Operation: January 14 Run

Sample Port	U (g/liter)	H+ (N)
Strip Wash - 1	0.019	0.266
2	0.011	0.294
3	0.010	0.312
Strip - 1	0.355	1.92
2	0.975	1.92
3	2.11	1.84
4	3.10	1.80
5	4.78	1.80
6	6.57	1.76
7	9.74	1.76
8	12.8	1.76
9	17.4	1.72
10	5.17	0.11
11	1.79	0.008
Feed Wash - 1	3.61	0.048
2	5.01	0.048
Feed - 1	19.4	0.053
2	10.7	0.082
3	0.775	0.15
4	0.036	0.16
5	0.003	0.16
6	0.004	0.15

Table 17. Conditions for Continuous Loading and Stripping of Uranyl Sulfate: January 17 Run

Contactor: 2-in. dia
Loading section: 6.5 ft
Feed wash section: 2.0 ft
Strip section: 9.5 ft
Strip wash section: 2.0 ft
Feed: 20.6 g/liter UO_2SO_4--0.026 N H_2SO_4
Eluant: 4 N H_2SO_4
Resin: Dowex 21K, 20-40 mesh, ~50 liters
Resin flow rate: 25 ml/min

Run Time (hr)	Flow Rates (ml/min) Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	Product U (g/liter)	Product H+ (N)	Waste U (g/liter)	Waste H+ (N)
1	116	58	83	50	166	134	8	27.2	2.88	0.002	0.10
2	100	58	67	58	166	134	8	20.6	2.30	0.004	0.10
3	114	64	72	57	170	115	13	20.6	2.28	0.002	0.10
4	120	80	80	70	200	100	18	20.6	2.43	0.001	0.10
5	100	58	67	58	166	106	10	17.6	2.25	0.001	0.09
6	116	67	75	58	166	100	13	16.9	2.50	0.001	0.09
7	116	67	75	58	182	100	13	17.0	2.65	0.001	0.08
8	116	75	75	58	182	100	13	15.8	2.60	0.002	0.09
9	116	75	75	57	170	116	18	18.5	2.73	0.004	0.08
10	116	75	67	58	182	108	17	19.0	2.68	0.006	0.08
11	116	75	67	58	170	108	21	22.8	2.93	0.002	0.08
12	100	67	67	58	182	116	17	19.6	2.80	0.002	0.08
13	116	67	67	58	166	108	25	22.0	2.70	0.001	0.08
14	116	75	67	58	182	108	17	20.0	2.38	0.001	0.08

Table 18. Profiles of Column After 6 and 13 Hr of Continuous Operation: January 17 Run

Sample Port	U(g/liter)	H+ (N)	U(g/liter)	H+ (N)
Strip wash - 1	0.002	0.176	0.010	0.222
2	0.001	0.220	0.0012	0.239
3	0.0009	0.249	0.0009	0.291
Strip - 1	0.021	3.45	0.017	3.55
2	0.103	3.28	0.088	3.53
3	0.325	3.20	0.682	3.35
4	0.680	3.18	1.05	3.28
5	1.31	3.15	1.50	3.30
6	2.45	3.13	2.87	3.33
7	4.15	3.18	6.20	3.38
8	7.84	3.18	11.2	3.25
9	13.9	3.13	19.4	3.28
10	18.8	1.10	12.2	0.63
11	9.82	0.43	7.56	0.20
Feed wash - 1	2.35	0.011	3.13	0.004
2	3.55	0.025	4.95	0.015
Feed - 1	19.6	0.028	17.4	0.065
2	14.9	0.036	16.9	0.052
3	13.9	0.055	12.3	0.058
4	4.36	0.084	9.88	0.064
5	0.039	0.106	2.95	0.088
6	0.006	0.104	0.014	0.096

5.0 APPENDIX II

ANION EXCHANGE SEPARATION OF IRON FROM URANIUM

Table 1. Conditions for Continuous Loading and Stripping of Uranous Sulfate: January 22-23 Run

Contactor: 2-in. dia.
Loading section: 6.5 ft
Feed wash section: 2.0 ft
Strip section: 9.5 ft
Strip wash section: 2.0 ft
Feed: 25.6 g/liter $U(SO_4)_2$ --0.12 N H_2SO_4--5.06 g/liter Fe
Eluant: 2 N H_2SO_4
Resin: Dowex 21K, 20-40 mesh, ~50 liters
Resin flow rate: 25 ml/min

Run	Flow Rates (ml/min)							Product			Waste		
Time (hr)	Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	U, (g/liter)	H^+ (N)	Fe (g/liter)	U, (g/liter)	H^+ (N)	Fe (g/liter)
1	100	83	83	50	167	150	6	-	-	-	-	-	-
2	83	83	117	67	167	150	8	-	-	-	-	-	-
3	83	100	117	67	200	167	8	-	-	-	-	-	-
4	83	83	117	67	167	167	-	-	-	-	-	-	-
5	83	83	100	58	167	133	23	-	-	-	-	-	-
6	83	83	117	58	167	150	25	-	-	-	-	-	-
7	83	83	117	58	167	150	25	-	-	-	-	-	-
8	83	83	117	67	167	150	17	-	-	-	-	-	-
9	83	83	117	58	167	150	23	-	-	-	-	-	-
10	83	67	109	67	167	133	23	13.3	1.54	0.006	0.111	0.07	2.99

Table 2. Conditions for Continuous Loading and Stripping of Uranous Sulfate: January 29 Run

Contactor: 2-in dia.
Loading section: 6.5 ft
Feed wash section: 2.0 ft
Strip section: 9.5 ft
Strip wash section: 2.0 ft
Feed: 19.0 g/liter $U(SO_4)_2$ --0.28 N H_2SO_4 -5.36 g/liter Fe
Eluant: 4 N H_2SO_4
Resin: Dowex 21K, 20-40 mesh, ~50 liters
Resin flow rate: 25 ml/min

Run	Flow Rates (ml/min)							Product			Waste		
Time (hr)	Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	U (g/liter)	H^+ (N)	Fe (g/liter)	U (g/liter)	H^+ (N)	Fe (g/liter)
1	83	58	100	50	133	133	3	22.6	-	-	0.036	-	-
2	83	67	83	58	150	133	8	15.8	-	-	1.50	-	-
3	83	67	75	58	150	133	8	16.3	-	-	2.42	-	-
4	83	67	67	58	150	133	10	9.92	-	-	2.46	-	-
5	83	67	75	58	150	133	12	11.2	-	-	1.88	-	-
6	83	100	83	58	150	133	17	10.6	-	-	1.21	-	-
7	83	92	83	58	150	133	13	11.0	-	-	1.90	-	-
8	83	92	83	58	150	133	15	14.6	2.55	0.006	1.82	0.23	2.74

Table 3. Profile of Column After 7 Hr of Continuous Operation: January 29 Run

Sample Port	U (g/liter)
Strip Wash -1	0.005
2	0.002
3	0.0017
Strip - 1	0.020
2	0.081
3	0.136
4	0.273
5	0.479
6	0.926
7	1.48
8	2.85
9	9.68
10	18.9
11	6.94
Feed Wash - 1	1.14
2	1.59
Feed -1	12.7
2	12.7
3	11.4
4	11.7
5	9.52
6	5.96

Table 4. Conditions for Continuous Loading and Stripping of Uranous Sulfate: January 31 Run

Contactor: 2-in. dia
Loading section: 6.5 ft
Feed wash section: 2.0 ft
Strip section: 9.5 ft
Strip wash section: 2.0 ft
Feed: 19 g/liter U $(SO_4)_2$ --0.28 N H_2SO_4--5.36 g/liter Fe
Eluant: 2 N H_2SO_4
Resin: Dowex 21K, 20-40 mesh, ~50 liters
Resin flow rate: 25 mil/min

Run Time (hr)	Flow Rates (ml/min) Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	Product U (g/liter)	Product H^+ (N)	Product Fe (g/liter)	Waste U (g/liter)	Waste H^+ (N)	Waste Fe (g/liter)
1	89	89	78	56	178	134	2	6.84	-	-	3.26	-	-
2	83	83	67	67	166	142	7	8.16	-	-	1.50	-	-
3	67	92	75	58	150	134	5	9.46	-	-	1.69	-	-
4	67	83	75	67	166	116	25	11.2	-	-	0.29	-	-
5	67	75	75	58	150	116	18	10.8	-	-	1.08	-	-
6	67	75	75	58	150	116	21	11.5	-	-	0.993	-	-
7	67	83	83	67	150	134	21	10.6	-	0.005	2.33	-	-
8	67	75	75	58	150	116	21	10.8	-	0.005	2.23	-	2.85

Table 5. Profile of Column After 7 Hr of Continuous Operation: January 31 Run

Sample Port	U (g/liter)
Strip Wash -1	0.0085
2	0.0062
3	0.0078
Strip- 1	0.105
2	0.405
3	0.785
4	1.08
5	1.30
6	1.53
7	2.11
8	2.86
9	5.68
10	1.37
11	0.494
Feed Wash- 1	1.20
2	1.75
Feed- 1	12.5
2	10.1
3	11.4
4	10.6
5	9.74
6	6.74

Table 6. Conditions for Continuous Loading and Stripping of Uranous Sulfate: February 6 Run

Contactor: 2-in. dia.
Loading section: 6.5 ft
Feed wash section: 2.0 ft
Strip section: 9.5 ft
Strip wash section: 2.0 ft
Feed: 11.0 g/liter U $(SO_4)_2$--0.16 N H_2SO_4--3.12 g/liter Fe
Eluant: 4 N H_2SO_4
Resin: Dowex 21K, 20-40 mesh, ~ 50 liters
Resin Flow Rate: 25 ml/min

Run	Flow Rates (ml/min)							Product			Waste		
Time (hr)	Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	U (g/liter)	H^+ (N)	Fe (g/liter)	U (g/liter)	H^+ (N)	Fe (g/liter)
1	67	75	75	58	150	134	5	-	-	-	-	-	-
2-1/2	67	72	67	61	152	134	-	-	-	-	-	-	-
3-1/2	67	83	58	67	150	116	-	-	-	-	-	-	-
4-1/2	67	75	58	67	150	116	-	-	-	-	-	-	-
5-1/2	83	75	58	58	150	116	-	8.57	1.90	0.002	0.004	0.12	1.37
6-1/2	67	75	58	67	150	116	-	-	-	-	-	-	-

Table 7. Profile of Column After 5-1/2 Hr of Continuous Operation: February 6 Run

Sample Port	U (g/liter)
Strip Wash -1	0.0022
2	0.0016
3	0.0009
Strip -1	0.017
2	0.074
3	0.116
4	0.224
5	0.335
6	0.598
7	1.23
8	2.63
9	6.80
10	10.0
11	0.952
Feed Wash - 1	1.28
2	1.63
Feed - 1	7.02
2	2.79
3	2.18
4	1.09
5	0.208
6	0.022

Table 8. Conditions for Continuous Loading and Stripping of Uranous Sulfate: February 10 Run

Contactor: 2-in. dia
Loading section: 6.5 ft
Feed wash section: 2.0 ft
Strip section: 9.5 ft
Strip wash section: 2.0 ft
Feed: 11.0 g/liter U $(SO_4)_2$--0.16 N H_2SO_4--3.12 g/liter Fe
Eluant: 4 N H_2SO_4
Resin: Dowex 21K, 20-40 mesh, ~ 50 liters
Resin flow rate: 25 ml/min

Run	Flow Rates (ml/min)							Product			Waste		
Time (hr)	Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	U (g/liter)	H^+ (N)	Fe (g/liter)	U (g/liter)	H^+ (N)	Fe (g/liter)
1	100	83	33	67	183	100	17	9.37	1.25	-	0.006	0.16	-
2	100	67	50	58	175	100	17	9.22	1.33	-	0.010	0.13	-
3	100	75	50	58	175	100	50	13.4	1.93	-	0.015	0.11	-
5	100	75	50	63	175	108	17	9.02	1.55	-	0.025	0.10	-
6	100	75	50	58	183	100	-	12.6	1.75	-	0.026	0.07	-
7	100	75	50	67	183	108	-	9.38	1.54	0.004	0.028	0.07	1.82
8	100	75	50	67	183	100	-	-	-	-	-	-	-

Table 9. Profile of Column After 7 Hr of Continuous Operation - February 10 Run

Sample Port	U (g/liter)	H^+ (N)
Strip Wash -1	0.003	0.24
2	-	-
3	0.001	0.29
Strip -1	0.048	2.80
2	0.203	2.90
3	0.325	2.80
4	0.761	2.10
5	1.20	2.20
6	1.73	2.25
7	2.46	2.25
8	4.27	2.19
9	8.46	2.15
10	11.5	0.58
11	-	-
Feed wash- 1	-	-
2	-	-
Feed- 1	8.04	0.15
2	6.81	0.16
3	4.40	0.16
4	2.87	0.14
5	2.21	0.15
6	0.650	0.13

Table 10. Conditions for Continuous Loading and Stripping of Uranous Sulfate: February 12 Run

Contactor: 2-in.-dia
Loading section 6.5 ft
Feed wash section 2.0 ft
Strip section: 9.5 ft
Strip wash section: 2.0 ft
Feed: 11.0 g/liter U $(SO_4)_2$--0.16 N H_2SO_4--3.12 g/liter Fe
Eluant: 4 N H_2SO_4
Resin: Dowex 21K, 20-40 mesh, ~ 50 liters
Resin flow rate: 25 ml/min

Run Time (hr)	Flow Rates (ml/min) Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	Product U (g/liter)	Product H^+ (N)	Product Fe (g/liter)	Waste U (g/liter)	Waste H^+ (N)	Waste Fe (g/liter)
1	100	83	58	67	200	124	17	8.04	-	-	0.051	-	-
2	116	75	50	67	167	108	-	-	-	-	-	-	-
3	100	83	50	58	183	116	17	10.7	-	-	0.109	-	-
4	100	83	50	67	183	116	-	-	-	-	-	-	-
5	100	75	58	58	183	116	17	8.48	-	-	0.068	-	-
6	100	83	50	58	183	116	-	-	-	-	-	-	-
7	100	75	50	67	183	100	-	11.4	-	-	0.084	-	-
8	100	75	50	58	183	108	34	-	-	-	-	-	-
9	100	75	50	58	183	108	-	15.0	-	-	0.042	-	-
10	100	75	50	58	183	108	17	-	-	-	-	-	-
11	100	75	50	67	183	108	-	8.16	-	-	0.035	-	-
12	100	75	50	58	167	100	17	-	-	-	-	-	-
13	100	83	50	67	183	100	17	8.16	-	-	0.103	-	-
14	100	75	50	58	167	100	-	-	-	-	-	-	-
15	100	75	50	58	183	100	-	11.8	1.26	0.004	0.043	0.17	2.12

Table 11. Profiles of Column After 7 and 14 Hr of Continuous Operation: February 12 Run

Sample Port	After 7 hr U (g/liter)	After 14 hr U (g/liter)
Strip wash -1	0.0032	0.0056
2	0.0019	0.0021
3	0.0013	0.0013
Strip -1	0.047	0.036
2	0.146	0.141
3	0.275	0.290
4	0.571	0.620
5	0.768	0.904
6	1.36	1.60
7	2.24	2.48
8	3.67	4.52
9	9.25	10.9
10	15.8	11.0
11	9.66	4.65
Feed wash - 1	1.38	1.42
2	1.86	1.84
Feed - 1	8.09	8.58
2	6.56	6.04
3	5.14	4.70
4	3.89	3.16
5	2.10	1.45
6	0.714	0.188

Table 12. Conditions for Continuous Loading and Stripping of Uranous Sulfate: March 13 Run

Contactor: 2-in. dia
Loading section: 7.5 ft
Feed wash section: 2.0 ft
Strip section 8.5 ft
Strip wash section: 3.0 ft
Feed: 10.8 g/liter $U(SO_4)_2$--0.07 N H_2SO_4
Eluant: 4 N H_2SO_4
Resin: Dowex 21K, 20-40 mesh, ~50 liters
Resin flow rate: 25 ml/min

Run Time (hr)	Flow Rates (ml/min) Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	Product U (g/liter)	Product H^+ (N)	Waste U (g/liter)	Waste H^+ (N)
1	89	78	56	56	178	111	2.2	-	-	-	-
2	100	83	50	58	182	100	10	-	-	-	-
3	100	83	50	50	182	100	-	-	-	-	-
4	100	83	42	58	182	100	1.7	-	-	-	-
5	100	83	42	58	182	83	6.7	-	-	-	-
6	100	83	50	50	167	83	11	-	-	-	-
7	100	83	50	58	182	83	-	9.68	2.00	0.004	0.10

Table 13. Conditions for Continuous Loading and Stripping of Uranous Sulfate: March 14 Run

Contactor: 2-in. dia
Loading section: 7.5 ft
Feed wash section: 2.0 ft
Strip section: 8.5 ft
Strip wash section: 3.0 ft
Feed: 10.8 g/liter U $(SO_4)_2$--0.07 N H_2SO_4--2.83 g/liter Fe
Eluant: 4 N H_2SO_4
Resin: Dowex 21K, 20-40 mesh, ~50 liters
Resin Rate: 25 ml/min

Run	Flow Rates (ml/min)							Product			Waste		
Time (hr)	Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	U (g/liter)	H^+ (N)	Fe (g/liter)	U (g/liter)	H^+ (N)	Fe (g/liter)
1	100	83	50	58	142	100	1.7	10.5	-	-	0.0003	-	-
2	100	83	50	50	142	83	-	14.0	-	-	0.0003	-	-
4	100	83	50	50	167	83	10.5	9.75	-	-	0.0004	-	-
5	100	83	50	50	182	100	6.7	9.15	-	-	0.0004	-	-
6	100	83	50	50	182	83	10	15.6	-	-	0.0005	-	-
7	100	83	50	50	182	83	8	9.15	1.64	0.004	0.0008	0.10	1.85
8	100	83	50	50	182	83	13	7.67	-	-	0.0007	-	-
9	112	83	50	50	182	83	16	8.66	-	-	0.0006	-	-
10	100	83	50	58	167	100	11	10.5	-	-	0.0006	-	-
11	112	83	50	58	182	83	16	1.24	-	-	0.0004	-	-
12	100	83	50	50	167	83	11	10.8	-	-	0.0003	-	-
13	100	83	50	50	182	83	15	14.0	-	-	0.0003	-	-
14	100	83	50	50	182	83	16	13.5	1.89	0.010	0.0003	0.09	1.23

Table 14. Profile of Column After 6 and 13 Hr of Continuous Operation: March 14 Run

Sample Port	After 6 hr		After 13 hr	
	U (g/liter)	H^+ (N)	U (g/liter)	H^+ (N)
Strip Wash - 1	0.004	0.22	0.0025	0.22
2	0.0016	0.24	0.0006	0.23
3	0.0018	0.26	0.0005	0.25
4	0.0013	0.28	0.0004	0.27
Strip - 1	0.060	2.94	0.017	3.10
2	0.236	2.75	0.074	3.25
3	0.484	2.85	0.104	3.10
4	0.807	2.80	0.363	3.10
5	1.21	2.80	0.807	2.00
6	1.88	2.22	1.61	2.20
7	3.63	2.20	4.31	2.00
8	5.92	2.38	10.4	2.00
9	10.9	0.65	16.0	0.40
10	14.0	0.50	6.46	0.10
11	6.94	0.20	2.73	0.10
Feed Wash- 1	1.07	0.06	1.13	0.03
2	1.60	0.08	1.63	0.03
Feed - 1	6.62	0.13	5.33	0.04
2	2.41	0.15	4.31	0.04
3	1.05	0.16	2.48	0.04
4	0.103	0.18	1.08	0.05
5	0.015	0.17	0.189	0.05
6	0.003	0.16	0.041	0.06
7	0.003	0.17	0.018	0.05

6.0 APPENDIX III

CATION EXCHANGE CONVERSION FROM THE SULFATE TO THE CHLORIDE SYSTEM

Table 1. Conditions for Continuous Loading of Uranous Sulfate and Stripping of Uranous Chloride: March 27-April 1 Run

Contactor: 2-in. dia
Loading section: 7.5 ft
Feed wash section: 2.0 ft
Strip section: 8.5 ft
Strip wash section: 3.0 ft
Feed: 3.87 g/liter $U(SO_4)_2$--0.53 N H_2SO_4
Eluant: 10 N HCl
Resin: Dowex 50 W, 50-100 mesh-12%, ~50 liters
Resin Flow Rate: 12.5 ml/min

Run Time (hr)	Flow Rates (ml/min)								Product	Waste
	Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Waste Slip	Product Slip	U(g/liter)	U(g/liter)
1	200	25	33	33	220	67	-	-	-	-
2	220	25	42	42	250	67	3.3	8.3	-	-
5	244	30	39	36	270	61	2.2	14	-	-
6	200	27	42	33	267	67	1.7	2	-	-
8	233	33	42	33	250	67	1.7	12	5.87	1.24
10	220	30	42	33	233	67	10	16	6.46	1.18
11	233	33	42	50	233	-	13	20	-	-
13	208	25	42	33	233	67	-	6	-	-
15	220	25	42	33	233	67	10	18	8.85	0.315
16	233	17	17	50	233	42	8.3	15	-	-
17	220	8	50	42	233	75	7	-	-	-
18	220	17	42	42	233	83	7	-	-	-
19	265	25	42	42	233	67	3	11	-	-
20	250	25	42	42	267	67	5	13	6.52	1.45

Table 2. Profile of Column After 10 Hr of Operation: March 26 Run

Sample Port	U (g/liter)	H^+ (N)
Strip Wash - 1	0.001	0.004
2	0.0003	0.004
3	0.0001	0.004
4	0.0003	0.03
Strip - 1	0.105	-
2	0.444	-
3	0.915	-
4	1.43	-
5	1.74	-
6	2.69	-
7	3.98	-
8	5.25	-
9	0.420	-
10	0.009	-
11	0.001	-
Feed Wash - 1	0.0006	-
2	0.0005	-
Feed - 1	4.71	-
2	4.71	-
3	4.44	-
4	3.96	-
5	3.61	-
6	2.69	-
7	2.45	-

Table 3. Conditions for Continuous Loading of Uranous Sulfate and Stripping of Uranous Chloride: April 2 Run

Contactor: 2-in. dia
- Loading section: 7.5 ft
- Feed wash section: 2.0 ft
- Strip section: 8.5 ft
- Strip wash section: 3.0 ft

Feed: 3.23 g/liter $U(SO_4)_2$
Eluant: 10 N HCl
Resin: Dowex 50 W, 50-100 mesh-12%, ~50 liters
Resin Flow Rate: 12.5 ml/min

Run Time (hr)	Flow Rates (ml/min) Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Waste Slip	Product Slip	Product U (g/liter)	Product H^+ (N)	Waste U (g/liter)	Waste H^+ (N)
1	-	17	33	33	233	50	17	10	-	-	-	-
2	267	33	42	42	250	67	10	21	-	-	-	-
3	233	42	42	42	283	67	10	27	8.68	4.90	1.03	0.63
4	233	42	42	33	267	33	1.7	-	-	-	-	-
6	250	42	46	42	292	67	1.1	11	5.98	3.70	1.05	0.62
7	267	33	42	42	267	67	10	10	-	-	-	-

Table 4. Profile of Column After 6 Hr of Continuous Operation: April 2 Run

Sample Port		U (g/liter)
Strip Wash	-1	0.0002
	2	0.0002
	3	0.0001
	4	0.0013
Strip -	1	0.606
	2	1.26
	3	1.34
	4	1.37
	5	1.47
	6	1.95
	7	1.45
	8	2.49
	9	0.148
	10	0.027
	11	0.0006
Feed Wash -	1	0.0015
	2	0.0005
Feed -	1	3.78
	2	3.66
	3	3.55
	4	3.33
	5	2.81
	6	2.57
	7	2.34

Table 5. Conditions for Continuous Loading of Uranous Sulfate and Stripping of Uranous Chloride: April 23-25 Run

Contactor: 2-in. dia
- Loading section: 7.5 ft
- Feed wash section: 2.0 ft
- Strip section: 8.5 ft
- Strip wash section: 3.0 ft

Feed: 3.29 g/liter $U(SO_4)_2$--0.50 N H_2SO_4
Eluant: 6 N HCl
Resin: Dowex 50W, 10-50 mesh-12%, ~ 50 liters
Resin Flow Rate: 25 ml/min

Run Time (hr)	Flow Rates (ml/min) Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	Product U(g/liter)	Waste U(g/liter)
1	300	25	67	63	333	133	8.3	-	-
2	340	33	100	50	367	133	11.7	-	-
3	300	30	100	33	333	133	8.3	-	-
4	333	36	100	35	360	116	11.6	-	-
5	370	33	100	40	400	116	20.0	-	-
6	320	40	87	33	360	116	18.3	-	-
7	416	33	100	33	450	150	6.7	6.10	0.545
8	320	33	100	33	435	133	10	5.68	0.356
9	416	30	100	40	470	116	20	5.84	0.270
10	416	30	100	38	435	116	18	6.34	0.210
11	416	30	100	33	435	116	20	7.70	0.184
12	416	30	100	33	450	116	-	7.96	0.171

Table 6. Profile of Column After 11 Hr of Operation: April 23-25 Run

Sample Port	U (g/liter)	H^+(N)
Strip Wash -1	0.0012	0.03
2	0.0015	0.03
3	0.00089	0.04
4	0.008	0.54
Strip - 1	0.455	5.10
2	0.987	5.20
3	1.42	5.15
4	2.03	5.20
5	2.55	5.20
6	3.77	5.20
7	4.75	5.15
8	6.45	5.15
9	1.34	0.80
10	0.021	0.08
11	0.0027	0.04
Feed Wash- 1	0.0095	-
2	0.955	-
Feed - 1	2.54	-
2	1.46	-
3	1.15	-
4	1.08	-
5	0.970	-
6	0.822	-
7	0.699	-

Table 7. Conditions for Continuous Loading of Uranous Sulfate and Stripping of Uranous Chloride: May 1 Run

Contactor: 2-in. dia
Loading section: 7.5 ft
Feed wash section: 2.0 ft
Strip section: 8.5 ft
Strip wash section: 3.0 ft
Feed: 13.7 g/liter U $(SO_4)_2$--0.17 N H_2SO_4
Eluant: 6 N HCl
Resin: Dowex 50W, 10-50 mesh-12%, ~50 liters
Resin Flow Rate: 25 ml/min

Run Time (hr)	Flow Rates (ml/min) Feed	Feed Wash	Strip	Strip Wash	Waste	Product	Slip H_2O	Product U(g/liter)	Waste U(g/liter)
1	185	25	67	33	315	100	5	9.04	0.102
2	285	25	92	33	333	100	13	5.40	0.140
3	230	30	75	33	230	100	16	7.96	0.184
4	230	30	87	33	300	100	20	9.04	2.70
5	230	30	87	33	267	100	20	14.9	2.61
6	200	30	87	33	250	100	27	15.9	3.56
7	200	30	87	33	215	87	25	18.1	3.19
8	185	40	67	33	200	87	20	20.8	0.950
9	116	40	58	37	150	87	11.6	26.3	0.077
10	127	33	67	37	200	87	27	24.7	0.075
11	200	33	67	33	230	-	30	38.4	0.119
12	200	33	67	33	230	-	-	29.6	0.212
13	200	33	67	33	230	87	-	26.0	0.256
14	200	33	67	33	230	87	25	20.3	0.064
15	200	33	67	33	215	-	-	23.0	0.610

Table 8. Profiles of Column After 7 and 14 Hr of Continuous Operation: May 1 Run

Sample Port	U (g/liter)	U (g/liter)	H^+ (N)
Strip Wash - 1	0.0072	0.015	0.05
2	0.0004	0.0026	0.05
3	0.0019	6.79	4.90
4	0.016	3.68	4.83
Strip - 1	0.584	1.59	2.50
2	1.42	3.58	2.70
3	2.07	5.48	2.60
4	3.15	6.80	2.75
5	4.25	8.44	2.50
6	6.36	10.4	2.55
7	9.00	13.7	2.58
8	15.8	19.8	2.53
9	16.4	1.44	0.25
10	8.77	0.097	0.30
11	3.51	0.202	0.40
Feed Wash - 1	11.2	0.381	-
2	13.2	2.68	-
Feed - 1	13.7	13.4	-
2	13.7	13.0	-
3	13.8	12.2	-
4	13.8	11.5	-
5	13.7	10.4	-
6	13.2	6.90	-
7	12.1	4.25	-

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