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ELECTROLYTIC PRECIPITATION OF URANIUM
FROM RAND LEACH SOLUTIONS

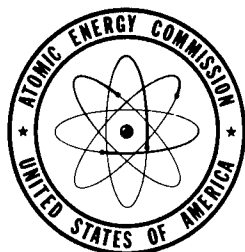
By
Galen W. Clevenger

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February 28, 1951

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TOPICAL REPORTELECTROLYTIC PRECIPITATION OF URANIUM FROM RAND LEACH SOLUTIONS

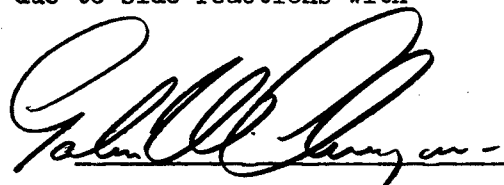
By

Galen W. Clevenger

February 28, 1951

A B S T R A C T

Various electrolytic tests were made using leach liquors derived from Blyvooruitzicht residues and synthetic solutions similar to the leach liquors. Using pure solutions a high grade uranium precipitate was obtained with less than one kilowatt hour of electric power per pound of U_3O_8 . Electrolysis of leach liquors produced low-grade precipitates and consumed excessive amounts of power due to side reactions with impurities.



Approved for A. M. Gaudin, Director

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ELECTROLYTIC PRECIPITATION OF URANIUM FROM RAND LEACH SOLUTIONS

By

Galen W. Clevenger

I. INTRODUCTION

Some preliminary work done at the MIT Mineral Engineering Laboratory^{1/} concerning the removal of uranium from Rand "Y" leach solution^{2/} by electrolysis indicated that 95 per cent of the uranium could be precipitated in a product of 9 per cent U_3O_8 grade. Another test showed a 34 per cent recovery in a product of over 30 per cent U_3O_8 grade. The electrolysis was carried on in a diaphragm type of cell using a copper cathode and a graphite anode. Unsatisfactory results were obtained without a diaphragm. The work here reported was done in an attempt to better understand the phenomenon and appraise it as a possible commercial method for uranium precipitation. For this reason lead was substituted for graphite, so the data obtained would be applicable for anodes commercially usable in sulfate solutions. Cathodes were of copper or aluminum.

The problem was approached by studying both simple artificial solutions and actual leach solutions. Electrolytic precipitation would be attractive only if a relatively high-grade product could be obtained with the savings in reagents over other methods of precipitation at least as great as the cost for the electric power necessary in any electrolytic process. Under certain conditions removing a precipitate from a cathode might be a more feasible operation than filtering.

Other work has been done on electrolytic precipitation. The South African Government Metallurgical Laboratory reports a process^{3/} where uranium was recovered in a product of about 15 per cent U_3O_8 grade using copper and phosphate in addition to over 100 kilowatt hours of power per pound of uranium precipitated. Experiments with various types of electrolytic cells at the MIT laboratory in November 1948 showed electrolysis not to be a promising method for recovery of uranium from strong phosphoric acid solutions (MITG-215). The present investigation is by no means intended to be complete, but rather to explore the situation sufficiently to determine if and in what directions further investigations should be conducted. This work was carried on during the months of August - October, 1950.

^{1/} Memo - Wilfred Freyberger to John Dasher - April 26, 1950.

^{2/} For method of preparation of "Y" leach solution see MITG-A92.

^{3/} GML Progress Report No. 28. Dated June 1950.

II. SUMMARY AND CONCLUSIONS

Electrolytic precipitation of uranium from Rand "Y" leach solution has been investigated. The term "electrolytic precipitation" as used here is a loose one and is meant to apply to the phenomenon occurring when a direct electric current is passed between electrodes submerged in the solution. Little has been learned of the nature of the cathode deposit formed and of the conditions required for optimum uranium precipitation. It was shown that from pure uranyl sulfate solutions the uranium precipitated quite completely using less than a kilowatt hour of electric power per pound of U_3O_8 precipitated. Addition of various impurities, including iron, manganese, and copper resulted in the setting up of side reactions which consumed electric power to such a degree that a precipitation process would be uneconomic. These impurities are present in the Rand leach liquors and their effect was demonstrated by testing actual leach solutions on a batch basis and also continuously, with pH controlled by feeding fresh leach liquor.

Little evidence was found to indicate that electrolytic recovery of uranium from these solutions would be economic. With few exceptions the precipitates were too low grade (under 5 per cent U_3O_8) to warrant the quantity of electric power consumed (50 KWH per pound of U_3O_8). A number of higher-grade products were produced (up to 28 per cent U_3O_8) by adding phosphate, but results were difficult to duplicate.

It is postulated that the uranium is precipitated at the cathode as a hydroxide due to a high concentration of (OH) ions or if (PO_4) is present, as a phosphate. Reduction takes place in the compartment and the uranium is at least partially in the uranous state. If further work is to be done with electrolysis as a method of uranium recovery from these solutions it should be from a fundamental approach so that information as to what reactions are actually going on will be available to help guide any possible practical application.

III. EXPERIMENTAL WORK

(A) APPARATUS

All tests were run in cells consisting of 400-ml beakers. Electrodes were suspended from integral header bars resting on bus bars at the side and above the beaker. Provision was made so that nine such cells could be operated simultaneously in a temperature-controlled water bath. The nine cells were connected in series electrically to eliminate the current variable between tests that were being run at any one time. Any number of tests, up to nine, could be conducted simultaneously. The operating voltage of each cell and the current flowing were determined by averaging readings taken with ordinary Weston meters.

Cathodes were of 1/16" copper or aluminum as indicated. Anodes in every case were 8-pound chemical sheet lead. Electrode size was 2 3/8" x 3" which gave a cathode area of about 0.1 square foot including both sides of the electrode. Two anodes were used, spaced equally on each side of the cathode. The distance between anodes was 1". The diaphragm consisted of a 12 oz cotton twill bag surrounding the cathode. These bags were wet with water and stretched over a board slightly wider than the cathode and 1/2" thick. A piece of 8-lb chemical sheet lead the same size as the cross section of this board was pushed to the bottom of the bag to add weight and help maintain the rectangular cross section after the board was removed. The bag was then ready to be placed in the spade between the anodes to form the cathode compartment. With 300 ml of electrolyte in the cell 80 ml or 26.7 per cent of the total was in the cathode compartment.

Direct current was supplied by 2 mercury vapor rectifiers operating to give full wave rectification. Current was regulated by a variable resistance in series with the circuit.

(B) EXPERIMENTAL PROCEDURE

Before the start of each test both cathodes and anodes were thoroughly cleaned by wet brushing with a wire brush until the electrode was bright and free of grease or previous deposits. Following the assembly of the cells the solutions to be electrolyzed were added, care being taken to fill the cathode compartment at least as rapidly as the remainder of the cell in order to prevent the diaphragm bag from floating out of position.

Samples of the electrolyte were taken immediately following the electrolysis. The uranium precipitated was calculated from the assay of the electrolyte in the cathode compartment. There was no indication that any significant amount of uranium had been depleted from the anolyte. The precipitates which in most cases adhered to the cathode were washed by submerging the cathode in water. The cathode was then dried under an infrared lamp and the powdery deposit removed for assay by scraping with a spatula.

(C) DISCUSSION OF RESULTS

(1) Artificial Solutions In an attempt to gain some information on the nature of the precipitation and the effect of various impurities present in the actual leach solutions, a number of electrolyses were made using artificial sulfate solution containing 1 gram U_3O_8 per liter. This solution was electrolyzed using both aluminum and copper cathodes. Initially the solution was pH 3.6. Current was passed for only a few seconds when the voltage began to increase at a rapid rate. In five minutes the ohmic resistance of the cell had reached a point where it was possible to pass only a negligible amount of current and the electrolysis was stopped. Table 1 summarizes the data for the electrolysis of pure uranyl solutions.

Table 1. Electrolysis of Pure Uranyl Sulfate Solutions
(1 g U_3O_8 per liter - pH 3.6)

Test No.	Cathode Material	Average		Final pH		% Pptd from Catholyte	KWH per lb U_3O_8
		Amps	Volts	Catholyte	Anolyte		
Art CE38	Cu	0.1	23.5	5.7	3.6	93.5	0.73
Art CE41	Al	0.1	25.5	5.8	3.7	97.6	0.76

In both of these experiments only 0.05 ampere hours flowed. About 0.75 gram of uranium was precipitated. The electrochemical equivalent of uranium is 0.41117 mg per coulomb or 1.4802 grams per ampere hour. Consequently, enough current passed to theoretically deposit only one tenth of this amount. This evidence makes it unlikely that the precipitation was the result of an electrochemical reaction directly involving the uranium, but was probably caused by concentration of (OH) ions in the cathode compartment, particularly at the surface of the cathode. This was indicated by an increase in the pH of the catholyte. The precipitate was on the surface of the cathode, but the quantity was insufficient for analysis. The material deposited on the aluminum cathode was yellow while that on the copper cathode was dark in color. If a hydroxide precipitate is assumed, this would mean that the uranous instead of the uranyl hydroxide was precipitated indicating that the copper electrode was effective in reducing the solution while the aluminum was not.

Further experiments to obtain adequate quantities of precipitate were not made. Instead solutions containing various amounts of some of the elements known to be present in the actual leach liquors were tested. These will be discussed separately.

(a) Manganese: Manganese was added as the sulfate in amounts of 1, 2, 5, and 10 grams of Mn per liter. With each amount ohmic resistance of the electrolyte decrease and cell voltage was correspondingly reduced approximately 80 per cent (from about 25 volts per cell to about 5 volts).

During the electrolysis a violet permanganate color formed in the anolyte and MnO_2 was precipitated at the lead anodes. Assays indicated that manganese was also precipitated from the catholyte, presumably as the metal in sponge form. The grade of the precipitate varied from 1.7 per cent U_3O_8 for the solution containing 10 grams Mn per liter to 7.5 per cent U_3O_8 when 1 gram Mn per liter was present. While the voltage was much lower than with pure uranyl sulfate the overall power requirements were much greater due to the increased time of electrolysis.

(b) Iron: Iron was added as ferrous sulfate to give 1, 2, 5, 10, and 20 grams Fe per liter. The lower concentrations (1 and 2 g Fe/l) gave solutions of low ionic strength with high resistivity which resulted in a high consumption of power for the amperage consumed. In general, less iron precipitated than did manganese. Consequently, the precipitates were somewhat higher grade, the maximum assay being 10 per cent U_3O_8 .

(c) Copper: Copper added as the sulfate was tried in amounts of 1, 2, 5, 10, and 20 grams of Cu per liter. Copper is not present to any great extent in the Rand leach solutions, but a few tests were run to determine its value as a coprecipitant. The same current was consumed in each of the tests. Where 1 or 2 grams of Cu per liter were initially present, 90 per cent or more of both the copper and uranium precipitated in products assaying over 10 per cent U_3O_8 . With amounts of copper, in excess of that possible to remove as the metal with the current passed, the uranium precipitation fell off. A low of 15 per cent was obtained where 20 grams Cu per liter had been initially present, indicating a selectivity for copper over uranium. Figure 1 shows the effect of the various copper concentrations on the amount of uranium and copper precipitated. Except for the experiment with 1 gram added Cu per liter, where the voltage was excessively high, the power consumed per gram of uranium precipitated was similar to that used where manganese was present alone.

(d) Phosphate: Both sodium ortho and pyrophosphates were tested. Since uranyl phosphates are insoluble at comparatively low pH the uranyl sulfate solution was acidified to pH 1.0 prior to the phosphate addition. The solution was electrolyzed in the usual manner for 1 hour. The solution containing the orthophosphate showed no precipitation of uranium, while 25 per cent of the uranium was precipitated from the solution containing the pyrophosphate probably as uranous pyrophosphate due to reduction having taken place at the cathode.

Complete data for these and other tests discussed in this section will be found in Appendix A.

(2) "Y" Leach Solutions: The "Y" leach solution tested was pH 3.2. Figure 2 shows the effect of increasing amounts of current on the per cent precipitation of uranium and on precipitate grade. Current was varied by increasing time, the actual amperes and consequently the current density remaining constant. The precipitates were low-grade and it is thought that they were the result of reduction of the uranium at the cathode and subsequent precipitation as a hydroxide along with iron and aluminum, which according to spectrographic

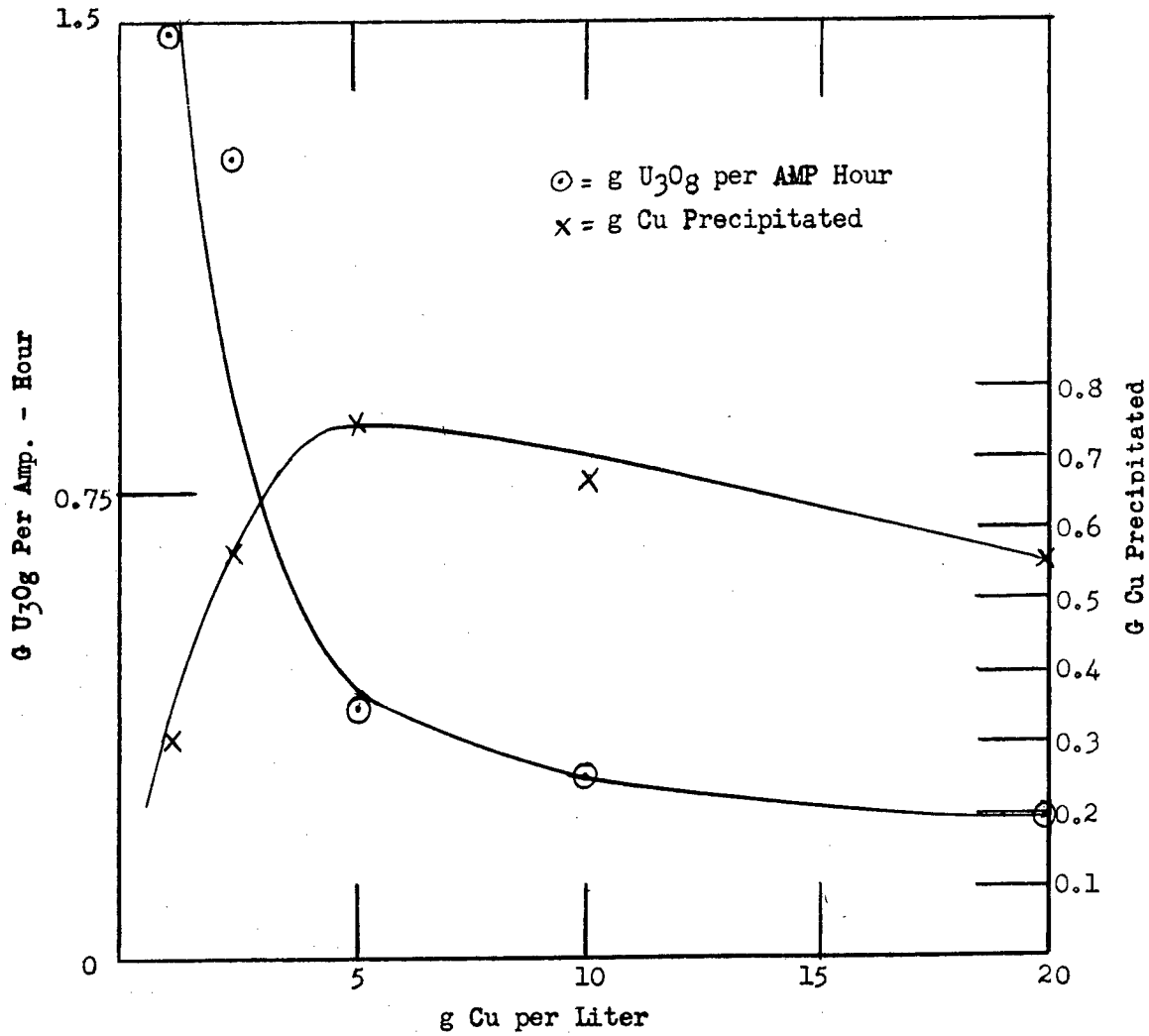


Figure 1. Effect of Cu Concentration on Uranium Precipitation

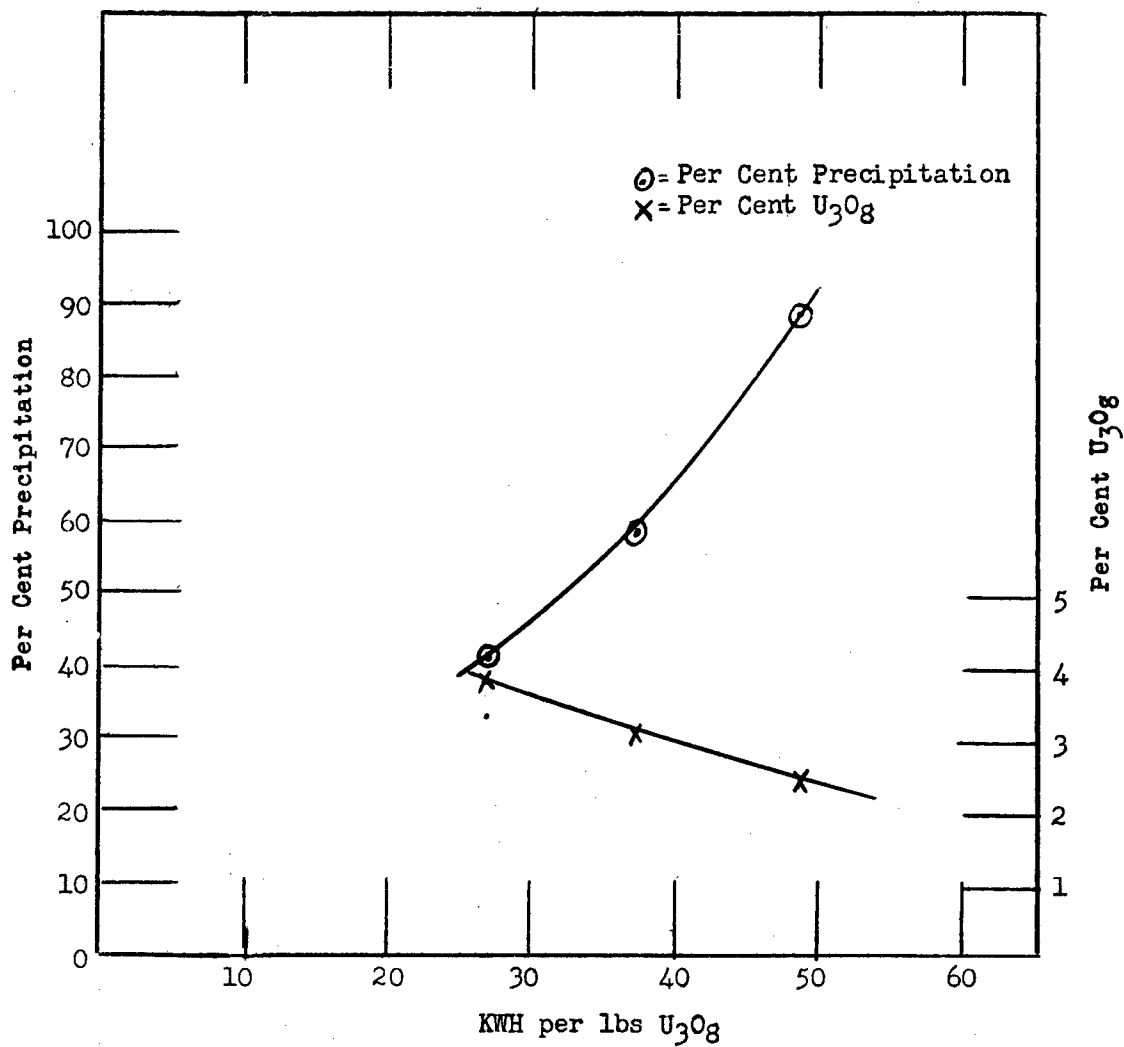


Figure 2. Electrolytic Precipitation from "Y" Leach Solutions
(Final Catholyte pH 2.8)

analysis were the major impurities in the precipitate. Considerable amounts (over 1 per cent) of calcium, copper, magnesium, manganese, silica, and zinc were also reported.

Figure 3 shows the change of platinum vs saturated calomel EMF with time for 2 tests. This indicates that some reduction took place in the catholyte and oxidation in the anolyte.

(a) Copper: The effect of added copper was tested. One of the tests shown in Figure 3 contained 0.5 gram Cu per liter. While the Pt vs S.C.E. EMF was not as low with copper present, the copper apparently had a stabilizing effect. In both tests the uranium is assumed to be reduced to the plus four state.

Figure 4 shows the results obtained when various amounts of copper were added to the electrolyte. One half gram of copper per liter seemed to interfere slightly while 1 and 2 grams per liter gave results considerably better, particularly at the lower recoveries. At 75 per cent recovery only 20 KWH of power per pound of U_3O_8 was consumed with copper present while without the copper over 2 times this amount was used.

(b) Phosphates: Sodium ortho and pyrophosphates were added to "Y" leach liquors prior to electrolysis. After pH adjustment with H_2SO_4 , 2 moles of phosphate were added for each mole of UO_2 present. Tests were run at pH 1.0, 1.5, and 2.0. Following electrolysis for 1 hour the catholyte pH showed an increase. Figure 5 shows the effect of pH on the uranium precipitation and power consumption. Maximum precipitation of 95 per cent occurred when the initial pH was 2.0. At this point the current consumption was at a maximum. All of the precipitates in this series of tests as well as all precipitates obtained from "Y" solutions up to this point had assayed about 3 per cent U_3O_8 . However, with sodium orthophosphate at pH 1.0 (63-CE-69) a cathode deposit resulted which assayed 27.9 per cent U_3O_8 . The recovery was low (50 per cent) so an attempt was made to duplicate the results except for a higher recovery.

Three tests were run keeping the initial pH at 1.0 in each test. Phosphate was added and electrolysis started continuing for 1.0, 1.5, and 2 hours. The 1-hour test duplicated the previous test except that the recovery was 95 per cent and the precipitate grade 18.8 per cent. Increasing the time above 1 hour resulted in slightly higher recoveries and a precipitate grade below 3 per cent U_3O_8 . Apparently the uranium precipitated selectively (probably as a phosphate). The results obtained are shown graphically in Figure 6. Results were not improved by adding 0.5 gram Cu per liter with the phosphate. Complete data for these tests will be found in Appendix B.

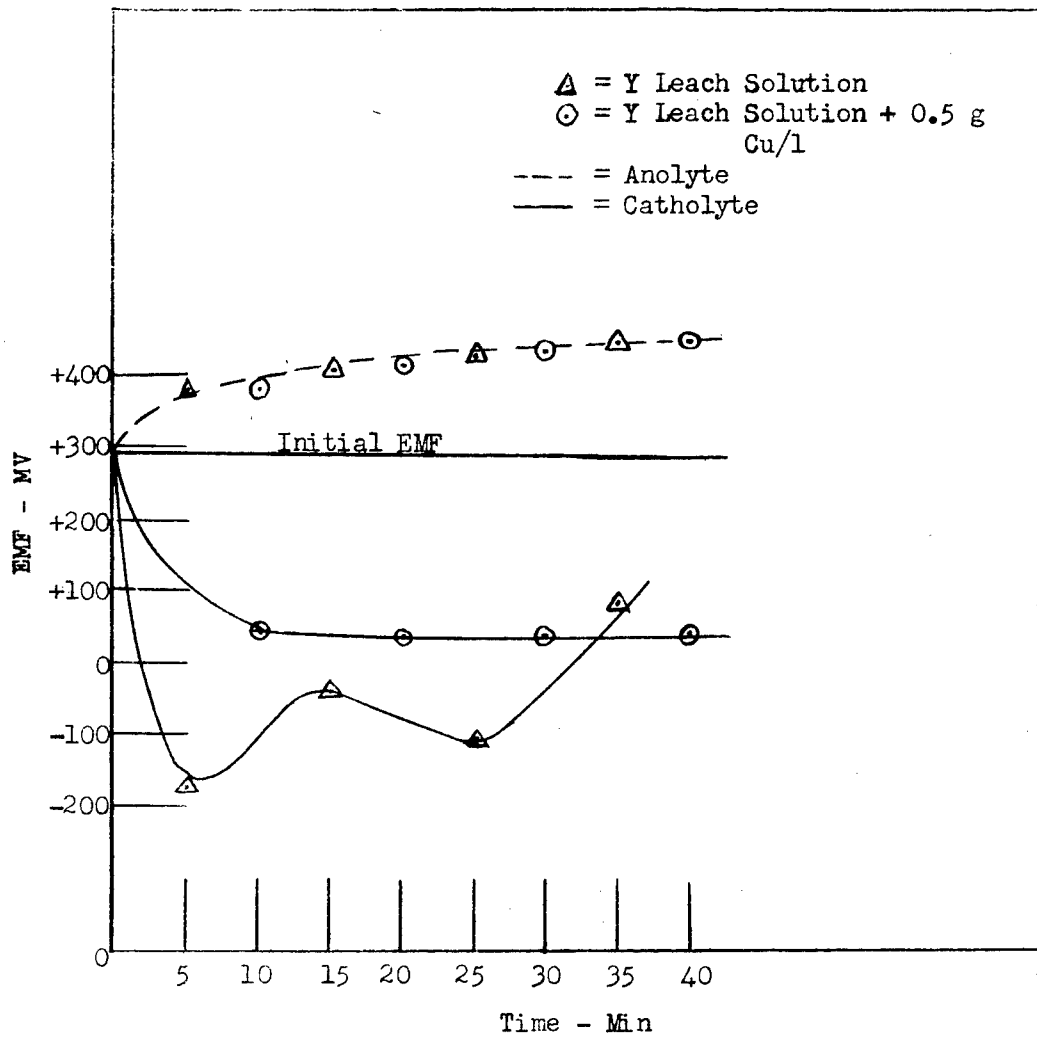


Figure 3. Effect of Electrolysis of "Y" Leach Solutions on Pt -S.C.E. EMF
(13 Amperes Per Square Foot)

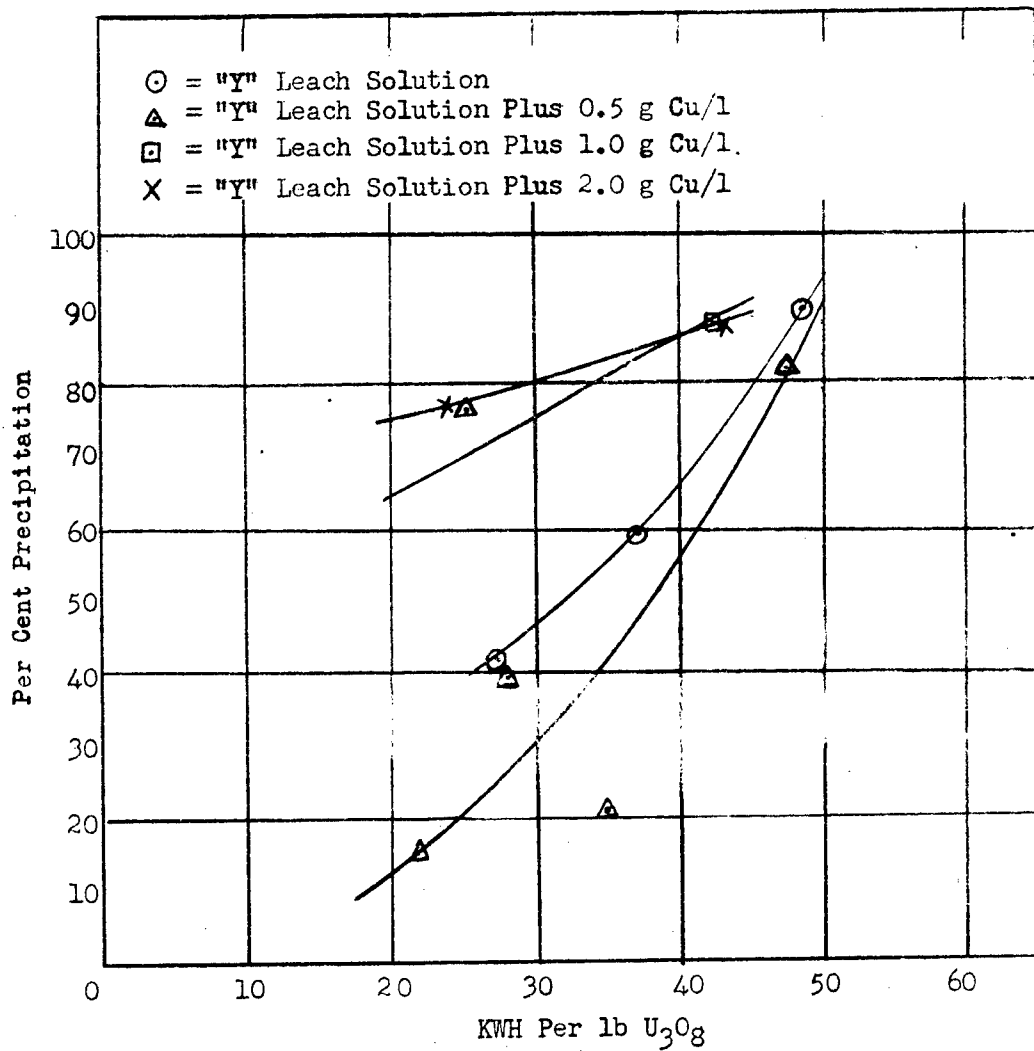


Figure 4. Effect of Copper on the Electrolytic Precipitation of Uranium from "Y" Leach Solution

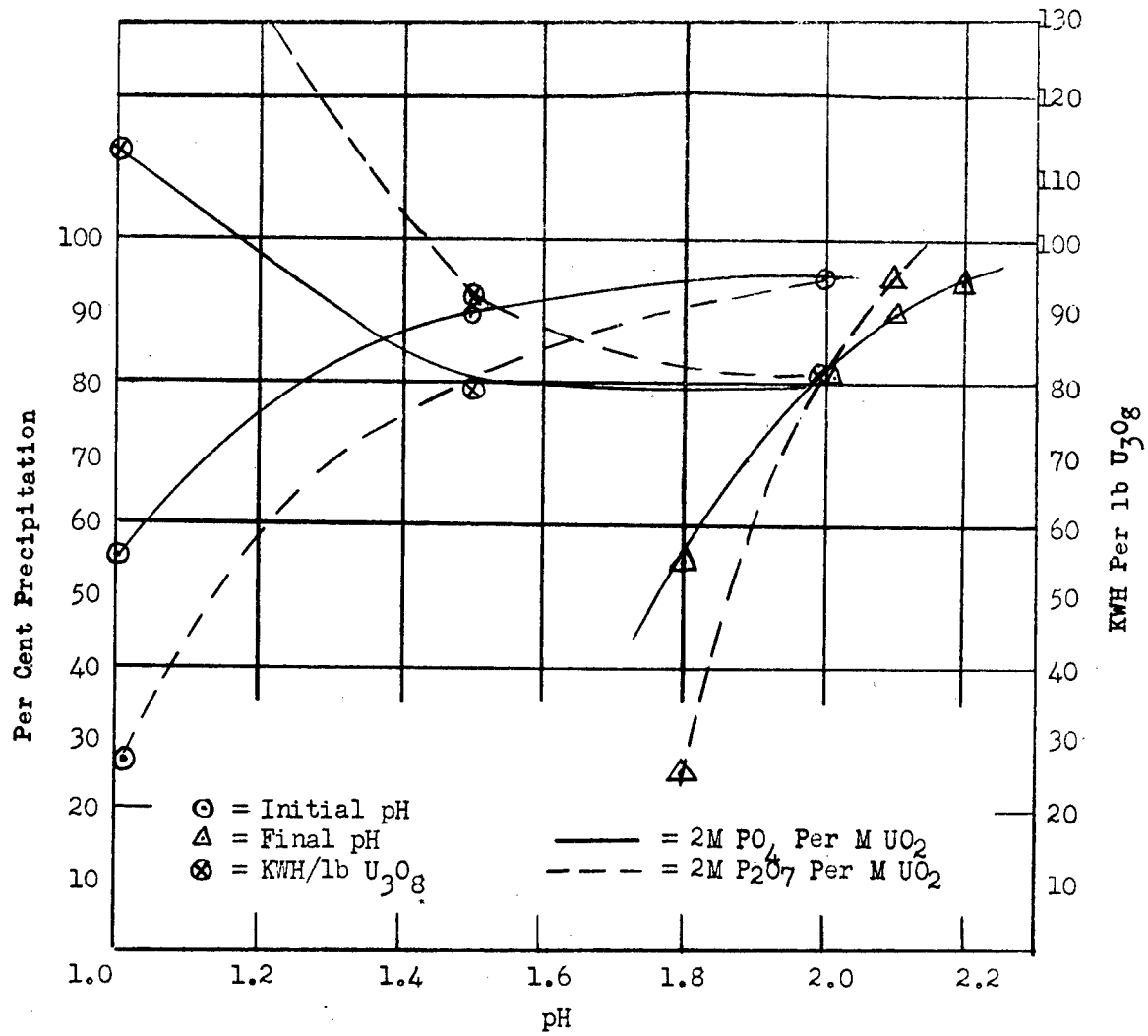


Figure 5. Effect of pH on Electrolytic Precipitation from "Y" Leach Solutions Containing Phosphates

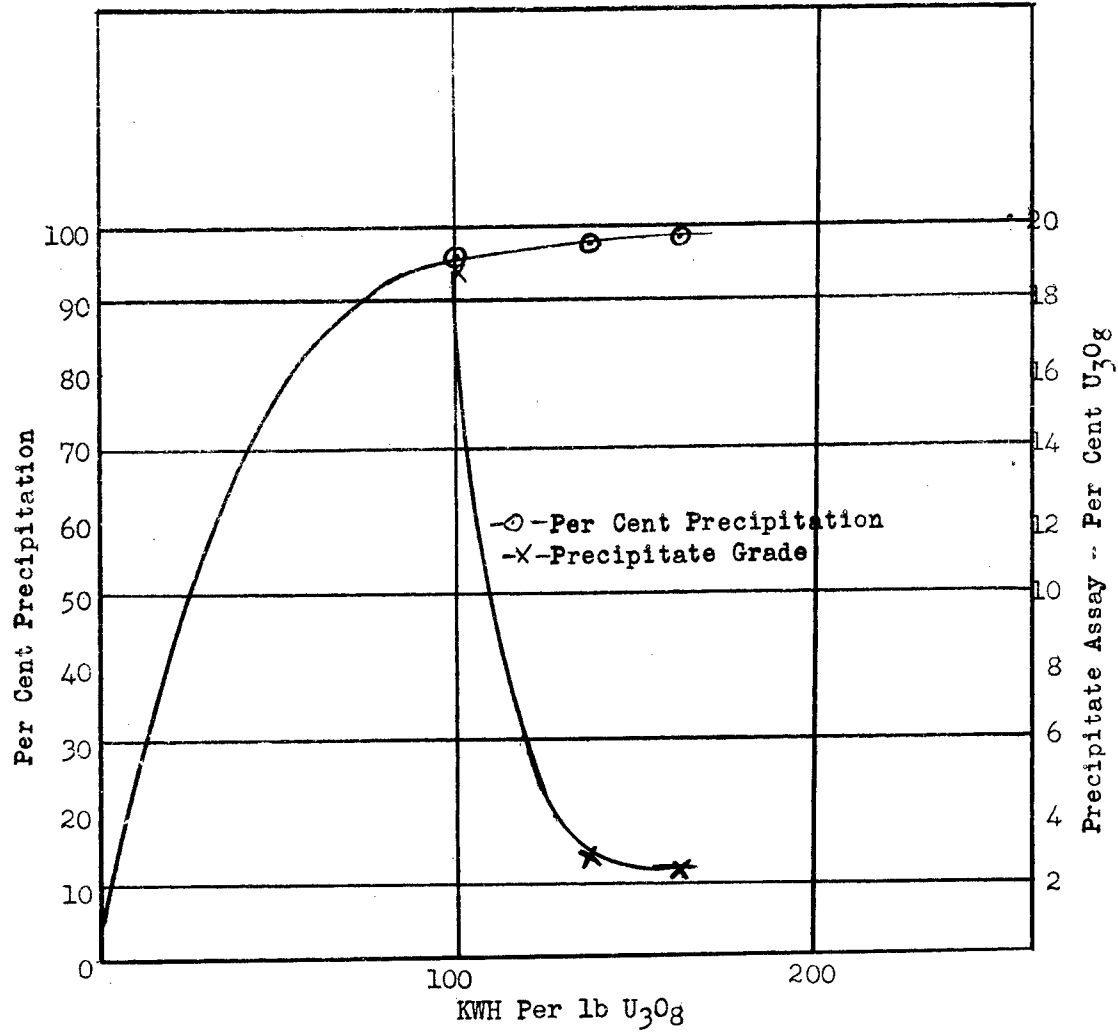


Figure 6. Effect of Increasing Current on "Y" Leach Solutions Containing Phosphate

(3) Continuous Tests - Y Leach Solutions: The object of the continuous tests was to repeat any of the batch experiments which showed promising results using a continuous feed of pregnant solution to the electrolytic cell giving a constant pH. The cell used was similar to that of the batch tests except that an overflow spout was provided in the upper part of the beaker wall. Fresh solution was fed to the cathode compartment at the rate necessary to maintain the desired pH. Solution was displaced through the diaphragm to the anode part of the cell causing an overflow through the overflow spout. Short circuiting of some solution was unavoidable and nearly complete recoveries would require more than 1 cell in series with regards to solution flow. Such cells could also be in series electrically so that no more amperage would be required, but since the total power would equal the amperes multiplied by the sum of cell voltages it would increase by as many times as there were cells. In the tests run, only one cell was used. The most satisfactory results were obtained in batch tests with phosphate added at an initial pH of 1.0 and a final pH, following electrolysis of 1.7 or 1.8.

Three tests were run with pH controlled by feeding acidified "Y" leach solution continuously. One at pH 1.7, one at pH 1.9 and one at pH 2.1. Maximum precipitation was 31.4 per cent at pH 2.1 with a precipitate grade of 2.3 per cent U_3O_8 . At pH 1.9 the U_3O_8 assay was highest (27.6 per cent U_3O_8) but only about 8 per cent of the uranium was recovered. This low recovery resulted in a very high power consumption which would become ridiculous if the solution were passed through multiple cells to increase recovery. One test was run with phosphate and 0.5 gram Cu per liter at pH 1.7. This resulted in a precipitate assaying 14 per cent U_3O_8 with a 58 per cent recovery. Power consumed was over 100 KWH per pound of U_3O_8 . Detailed data are given in Appendix C.

APPENDIX A

ELECTROLYTIC PRECIPITATION OF PURE URANYL SULFATE SOLUTIONS (1 g U₃O₈ per liter)

Test No.	Art CE	Additions	Initial pH	Cathode Material	Avg. Volts	Avg. Amps	Time Hours	Final pH		U ₃ O ₈ Metal Added	KWH per lb U ₃ O ₈	Precipitate Assay % U ₃ O ₈	
								Catholyte	Anolyte				
20	Al	1 g Fe/1	3.6	Al	33.	0.4	1.00	4.4	3.0	87.2	38.0	85.6	9.35
21	Al	2 g Fe/1	3.6	Al	30.	0.4	1.00	5.4	3.0	100.0	97.1	68.1	2.50
22	Al	5 g Fe/1	3.6	Al	5.7	0.4	1.00	3.2	3.0	86.7	56.4	15.0	9.90
23	Al	10 g Fe/1	3.6	Al	3.2	0.4	1.00	3.2	3.0	78.0	32.2	9.37	10.00
24	Al	20 g Fe/1	3.6	Al	2.6	0.4	1.00	3.2	3.0	67.5	23.5	8.74	9.05
25	Al	1 g Mn/1	3.6	Al	5.8	0.4	1.00	3.8	3.0	90.4	81.0	14.6	7.45
26	Al	2 g Mn/1	3.6	Al	3.8	0.4	1.00	3.1	3.0	70.4	--	12.3	6.90
27	Al	5 g Mn/1	3.6	Al	4.1	0.4	1.00	3.2	3.0	72.6	63.4	12.8	6.92
28	Al	10 g Mn/1	3.6	Al	14.95	0.4	1.00	5.7	3.0	99.9	97.8	33.8	1.74
29	Al	1 g Cu/1	3.6	Al	92.0	0.2	1.00	6.9	1.9	99.9	100.0	104.0	10.4
30	Al	2 g Cu/1	3.6	Al	4.7	0.2	1.00	4.8	1.8	89.7	94.1	5.93	11.5
31	Al	5 g Cu/1	3.6	Al	1.9	0.2	1.00	2.0	1.8	26.0	50.0	8.22	0.156
32	Al	10 g Cu/1	3.6	Al	2.1	0.2	1.00	2.0	1.9	18.5	22.0	12.7	0.105
33	Al	20 g Cu/1	3.6	Al	1.7	0.2	1.00	2.4	2.0	15.4	9.0	12.9	0.104
34	Al	PO ₄ ³⁻	1.0	Al	3.0	0.2	1.00	1.1	1.0	nil	--	--	--
35	Al	PO ₄ ³⁻	1.0	Al	3.0	0.2	1.00	1.1	1.0	nil	--	--	--
38	Cu	--	3.6	Cu	23.5	0.1	0.05	5.7	3.6	93.5	--	0.73	5/
39	Al	--	3.6	Al	13.5	0.1	0.05	4.5	3.5	88.9	--	0.45	5/
40	Cu	--	3.6	Cu	43.5	0.1	0.05	7.2	4.0	97.7	--	1.28	5/
41	Al	--	3.6	Al	25.5	0.1	0.05	5.8	3.7	97.6	--	0.76	5/
67	Al	P ₂ O ₇ ³⁻	1.0	Al	2.6	0.2	1.00	1.1	1.0	18.0	--	16.9	--
68	Al	P ₂ O ₇ ³⁻	1.0	Al	2.6	0.2	1.00	1.1	1.0	25.2	--	11.8	--

1/ Initial pH's below 3.6 obtained by adjustment with H₂SO₄.

2/ Computed from solution assays of catholyte

3/ 2 moles of PO₄ or P₂O₇ per mole of UO₂ added as Na₂PO₄·12 H₂O or Na₂P₂O₇·10 H₂O.

4/ 4 moles of PO₄ or P₂O₇ per mole of UO₂ added as Na₂PO₄·12 H₂O or Na₂P₂O₇·10 H₂O.

5/ Precipitate formed on cathode in amount insufficient to scrape off for assay.

6/ Evidence of dissolution of aluminum cathode present.

APPENDIX B

ELECTROLYTIC PRECIPITATION OF RAND "P" SOLUTION

Test No.	Additions	Initial pH ^{1/}	Cathode Material	Average Volts	Amps	Time Hours	Final Catholyte	pH Anolyte	% Precipitation ^{3/} U ₃ O ₈	KWH Per Lb U ₃ O ₈	Precipitate Assay % U ₃ O ₈
63	CE	3.2	Al	3.5	0.2	1.00	3.1	2.0	66.7	25.4	2.58
37	--	3.2	Cu	3.1	0.2	1.00	2.9	1.9	50.0	30.0	2.64
42	--	3.2	Al	4.5	0.5	2.00	3.2	1.5	75.6	144.0	3.25
43	--	3.2	Al	4.7	0.5	1.50	3.0	1.6	91.9	93.2	1.67
44	--	3.2	Al	4.4	0.5	1.00	3.1	1.8	91.5	58.4	1.26
45	--	3.2	Al	4.0	0.5	0.50	3.5	2.0	66.4	36.7	1.02
46	1 g Cu/1	3.2	Al	3.1	0.5	1.00	2.8	1.6	88.1	42.6	1.99
47	1 g Cu/1	3.2	Al	3.0	0.5	0.50	3.0	1.8	70.5	25.8	3.11
48	2 g Cu/1	3.2	Al	3.1	0.5	1.00	2.8	1.7	87.6	43.0	2.67
49	2 g Cu/1	3.2	Al	3.0	0.5	0.50	3.0	1.9	77.0	23.7	3.40
50	0.5 g Cu/1	3.2	Al	3.2	0.5	1.00	2.7	1.8	81.6	47.5	2.54
51	0.5 g Cu/1	3.2	Al	3.2	0.5	0.50	2.9	2.0	77.0	25.2	3.28
52	0.5 g Cu/1	3.2	Al	3.2	0.5	0.25	2.8	2.3	39.8	25.8	3.04
53	0.5 g Cu/1	3.2	Al	3.3	0.5	0.17	3.0	2.6	21.0	34.9	3.58
54	0.5 g Cu/1	3.2	Al	3.4	0.5	0.08	3.0	2.4	15.4	4.10	4.10
55	--	3.2	Cu	3.6	0.5	1.00	2.8	1.7	89.9	48.6	2.40
56	--	3.2	Cu	3.6	0.5	0.50	2.8	1.9	59.0	37.2	3.18
57	--	3.2	Cu	3.6	0.5	0.25	2.8	2.1	41.9	27.4	3.84
61	0.5 g Cu/1	0.5	Al	2.4	0.5	0.50	0.5	0.5	Nil	--	--
58	0.5 g Cu/1	1.0	Al	2.5	0.5	0.50	1.1	1.0	Nil	--	--
59	0.5 g Cu/1	1.5	Al	2.6	0.5	0.50	2.2	1.4	Nil	--	--
60	0.5 g Cu/1	2.0	Al	2.9	0.5	0.50	2.7	1.7	54.4	32.1	5.40
62	0.5 g Cu/1	1.0	Al	2.3	0.5	1.00	1.0	0.9	Nil	--	--
63	0.5 g Cu/1	1.5	Al	2.7	0.5	1.00	2.2	1.3	68.9	47.6	5.70
64	--	1.0	Cu	2.7	0.5	1.00	1.3	1.0	Nil	--	--
65	--	1.5	Cu	2.9	0.5	1.00	2.3	1.2	129.0	129.0	4.90
69	PO ₄ ³⁻	1.0	Cu	3.1	1.0	1.00	1.8	1.0	50.5	112.0	27.9
70	PO ₄ ³⁻	1.5	Cu	3.9	1.0	1.00	2.1	1.2	89.5	79.1	2.37
71	PO ₄ ³⁻	2.0	Cu	4.3	1.0	1.00	2.2	1.3	94.5	82.4	1.64
72	P ₂ O ₇ ⁴⁻	1.0	Cu	3.2	1.0	1.00	1.8	1.0	26.2	220.0	--
73	P ₂ O ₇ ⁴⁻	1.5	Cu	4.1	1.0	1.00	2.0	1.1	80.2	92.6	2.34
74	P ₂ O ₇ ⁴⁻	2.0	Cu	4.3	1.0	1.00	2.1	1.2	94.5	82.4	1.82
75	0.5 g Cu/1 + PO ₄ ³⁻	1.0	Cu	2.7	1.0	1.00	1.7	1.0	77.4	63.3	2.24
76	0.5 g Cu/1 + PO ₄ ³⁻	1.5	Cu	3.5	1.0	1.00	2.2	1.2	95.9	66.3	2.29
77	2.5 g Cu/1 + PO ₄ ³⁻	2.0	Cu	4.2	1.0	1.00	2.5	1.3	89.5	85.1	1.56
93	PO ₄ ³⁻	1.0	Cu	3.2	1.5	1.00	1.7	0.7	95.2	99.2	18.8
94	PO ₄ ³⁻	1.0	Cu	3.4	1.5	1.50	1.8	0.7	97.4	127.0	2.86
95	PO ₄ ³⁻	1.0	Cu	3.3	1.5	2.00	1.8	0.7	98.4	162.0	2.44

1/ For method of preparation of "w" leach solution see MITG A92.

2/ Initial pH's below 3.2 obtained by adjustment with H₂SO₄.

3/ Computed from solution assays of catholyte.

4/ 2 moles of PO₄ or P₂O₇ per mole of UO₂ added as Na₂PO₄·12 H₂O or Na₄P₂O₇·10 H₂O.

APPENDIX C

CONTINUOUS TESTS WITH "Y" LEACH SOLUTION WITH ADDED PHOSPHATE

Test No.	pH	Feed Ml/Min	pH	Average		Time Hours	KWH/lb U ₃ O ₈	% Precipitation			Pot Assay % U ₃ O ₈	
				Volts	Amps			U ₃ O ₈	Fe	Mn		Cu
63C-198	1.7	4.8	1.0	5.3	3	3.50	--	4.9	1.8	4.4	--	3.55
99 ^{1/}	1.7	6.1	1.0	4.6	3	2.75	118	58.6	3.5	1.3	69.9	14.1
100	1.7	6.2	1.0	4.9	3	2.67	--	1.5	59.6	--	--	3.08
101	1.9	4.0	1.0	5.9	3	4.17	--	7.8	--	--	--	27.6
102	2.1	7.4	1.5	6.8	3	2.25	310	31.4	--	--	--	2.32

Note: 2 Moles PO₄ per mole UO₂ added in all tests except 63C-1100

^{1/} 0.5 g Cu per liter.