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Very truly yours,

Arthur E. Bearse

Arthur E. Bearse
Project Director

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BMI-244

ESTIMATED MANUFACTURING COSTS FOR THE RECOVERY OF THORIUM AND
URANIUM FROM MONAZITE SAND

by

G. D. Calkins
R. B. Filbert, Jr.

September 15, 1950

BATTELLE MEMORIAL INSTITUTE

Columbus, Ohio

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BMI-244

ESTIMATED MANUFACTURING COSTS FOR THE RECOVERY OF THORIUM AND URANIUM
FROM MONAZITE SAND

by

G. D. Calkins
R. B. Filbert, Jr.

ABSTRACT

Costs have been estimated for the production of uranium and pure thorium from monazite concentrates by a process involving (1) reaction of the monazite with ^{NaOH} caustic soda, (2) dissolution of the hydrous oxides in ⁴hydrochloric acid, (3) separation from the bulk of the rare earths by hydroxide precipitation of thorium and ²⁴uranium, and (4) purification by solvent extraction.

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ESTIMATED MANUFACTURING COSTS FOR THE RECOVERY OF THORIUM AND URANIUM
FROM MONAZITE SAND

INTRODUCTION

This is a special report dealing with the determination of the probable manufacturing costs of the process, developed under Contract No. AT-30-1-Gen-228, for the recovery of thorium and uranium from monazite sand concentrates. The technical details of this process are discussed in reports BMI-243 and -243A, September 15, 1950.

The specifications for this process were:

- (1) That the over-all recovery of thorium and uranium be in excess of 95 per cent.
- (2) That the thorium product contain less than one part each of uranium and rare earths per million parts of thorium.
- (3) That the uranium product be as pure as possible without placing an undue burden on the over-all process.
- (4) That the bulk of the rare earths be recovered in a usable form.

Monazite concentrates consist mainly of the orthophosphates of the rare earth metals together with thorium and smaller amounts of uranium.

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A typical analysis is:

	<u>Per Cent</u>
ThO ₂	6.50
U ₃ O ₈	0.17
(RE) ₂ O ₃	59.2
P ₂ O ₅	26.0
TiO ₂	1.75
Fe ₂ O ₃	0.51
SiO ₂	2.16

The process developed consists of the following operations,

Figure 1:

- (1) Reaction of the monazite sand with a hot concentrated aqueous solution of sodium hydroxide. This converts the metal phosphates to hydrous metal oxides and trisodium phosphate.
- (2) Separation of the hydrous metal oxides from the sodium phosphate and excess sodium hydroxide.
- (3) Dissolution of the hydrous metal oxides in hydrochloric acid.
- (4) Separation from the rare earths by selective hydroxide precipitation of the thorium and uranium.
- (5) Preparation of a feed solution for solvent extraction by dissolution of the hydroxide precipitate in nitric acid.
- (6) Solvent extraction of the nitrate solution to (a) separate the thorium and uranium from impurities and (b) to separate the uranium from the thorium.

FIGURE 1. SIMPLIFIED SCHEMATIC DIAGRAM OF PROCESS FOR THE RECOVERY OF THORIUM AND URANIUM FROM MONAZITE SAND

- (7) Final precipitation of the thorium as thorium oxalate and of the uranium as uranyl hydroxide.

SUMMARY

The estimated manufacturing costs for the recovery of thorium and uranium from monazite sand were calculated from data collected in laboratory experiments and laboratory production-unit investigations. Although many assumptions were involved in scale-up of the process, the data have been organized to show as clearly as possible the suitability of the process for commercial application.

Calculations were made for two rates of thorium production, 5 and 25 tons per month. These estimates showed total manufacturing costs per pound of purified thorium of 5.19 and 3.17 dollars, respectively, as shown in Table 1. In calculating these costs, credits were allowed for by-product uranium, rare earths, and trisodium phosphate. It was assumed that the market for rare earths would be sufficiently large to consume all of the rare earths produced by this process.

DATA FOR ESTIMATING MANUFACTURING COSTS

The basic information used to estimate the manufacturing costs of thorium produced from monazite sand concentrates was derived from laboratory experiments and laboratory production-unit investigations. The latter were performed generally with 10-pound batches of monazite concentrates. At some points in the process, individual runs were combined to produce quantities of material equivalent to 50 pounds of concentrates.

TABLE 1. ESTIMATED TOTAL MANUFACTURING COSTS FOR PRODUCING THORIUM
AND URANIUM FROM MONAZITE SAND

	Cost, Dollars Per Pound of Thorium at Production Rates of	
	5 Tons/Month	25 Tons/ Month
Raw materials and chemicals cost (1)	1.015	1.015
Conversion cost (2)	<u>4.171</u>	<u>2.157</u>
Total manufacturing costs	5.186	3.172

(1) From Table 2.

(2) From Table 3.

All of the experimental and production-unit data obtained were evaluated, reduced, and summarized, and are presented in Table A and the associated flowsheet, Figure A in the Appendix of this report.

In order to make the cost estimates for manufacturing thorium at rates of 5 tons and 25 tons per month, it was necessary to use the size, yield, and composition data obtained from the small-scale operations. The minimum scale-up factors involved were about 240 and 1200, respectively, for the small and large plants. Consequently, although the composition data may be used with reasonable confidence, the application of size and yield data is reasonably subject to doubt. The final cost figures for manufactured thorium are, therefore, only indicative, and not by any means conclusive.

CALCULATION OF MANUFACTURING COSTS

The manufacturing costs were calculated for two rates of production of thorium, 5 and 25 tons per month. The method which was used is discussed briefly in the following sections.

Raw Materials and Chemicals Costs

The raw materials and chemicals costs are outlined in Table 2. The net cost included credits for the by-products produced, i.e., tri-sodium phosphate, rare earths, and uranium. Although the value of the by-product rare earths was arbitrarily considered to be equal to the cost of the monazite sand, actually the rare earths should have a substantially higher value because of their high state of purity. It is assumed that the market for rare earths would be large enough to consume all the by-product rare earths produced by this process.

TABLE 2. RAW MATERIALS AND CHEMICALS COSTS⁽¹⁾

Charges	\$/Lb.	Lb./Lb. Th	\$/Lb. Th (5- and 25-Ton Scale)
1. Raw materials			
Monazite sand concentrate	0.15	17.7	<u>2.655</u>
Sub-total			2.655
2. Chemicals			
HNO ₃ , 42° Baumé (tanks)	0.035	7.20	0.252
NaOH, 73% liq. (70% Na ₂ O)	0.019	27.4	0.522
HCl, 22° Baumé	0.013	26.7	0.346
NH ₄ CH ₃ , 29% NH ₃	0.038	0.068	0.003
H ₂ C ₂ O ₄ ·2H ₂ O	0.157	1.14	0.179
Tributyl phosphate	0.57	0.074	0.042
Gulfspray Naphtha	0.077	0.021	<u>0.002</u>
Sub-total			1.346
Total raw materials and chemicals costs			4.001
<u>Credits</u>			
1. By-products			
Na ₃ PO ₄	0.0195 ⁽²⁾	12.2	0.238
(RE) ₂ O ₃	0.259 ⁽³⁾	10.2	2.655
U	4.63 ⁽²⁾	0.02	<u>0.093</u>
Total			2.986
Net raw materials and chemicals costs			1.015

(1) June, 1950, costs.

(2) One-half of market value.

(3) Arbitrarily selected so that value of rare earths was equal to cost of monazite sand concentrate.

Conversion Costs

The conversion costs for producing thorium from monazite sand in a commercial plant, having a capacity of 5 or 25 tons per month, are shown in Table 3. Under direct conversion cost, the first five items represent the best estimate of expected actual requirements. The remainder of the items were estimated or derived from the capital investment figures shown in Table 4, following a system outlined by Dybdal(1). It has been assumed that the thorium plant would be constructed and operated as part of an existing chemical plant.

In determining the capital investment needed to produce thorium at rates of 5 and 25 tons per month, the fundamental unit of capital was the cost of installed process equipment. A categorical distribution of this cost is shown in Table 5. From the total equipment cost were determined the other items of capital investment, as shown in Table 4. An operating month of 600 hours was used in calculating equipment sizes and labor requirements. There was no allowance made for standby items of equipment. Materials of construction were taken as those generally recommended for the type of chemical being handled.

GDC/RBF/jb
November 1, 1950

(1) Dybdal, E. C., "Engineering and Economic Evaluation of Projects", Chem. Eng. Prog., 46, page 57 (February, 1950).

TABLE 3. CONVERSION COSTS FOR PRODUCING THORIUM
FROM MONAZITE SAND

Direct Conversion Cost	Units	Quantity per lb. Thorium at Production Rates of		Unit Cost, Dollars	Dollars per lb. Thorium at Production Rates of	
		5 Tons/Month	25 Tons/Month		5 Tons/Month	25 Tons/Month
Labor	Man-Hours	0.6	0.216	1.75	1.050	0.378
Supervision	Man-Hours	0.12	0.036	3.00	0.360	0.108
Steam	1000 Pounds	0.475	0.475	0.60	0.285	0.255
Electricity	Kilowatt Hrs.	18.2	16.9	0.02	0.364	0.338
Water-Cooling	1000 Gals.	0.025	0.025	0.03	0.001	0.001
-Process	1000 Gals.	0.045	0.045	0.15	0.007	0.007
Repairs	5% of total installed machinery and equipment, per year ⁽¹⁾				0.261	0.148
Supplies	0.5% " " " " " "				0.028	0.015
Laboratory	12,000 dollars per year				0.100	0.020
Payroll Charges ⁽²⁾	15% of labor plus supervision				0.212	0.073
Total					2.688	1.373
<u>Indirect Conversion Cost</u>						
Depreciation-Machinery and Equipment	20% of total installed M & E, per year				1.124	0.594
-Building	20% of building cost, per year				0.212	0.112
Taxes	2% of total physical cost, per year				0.134	0.071
Insurance	0.2% " " " " "				0.013	0.007
Total					1.483	0.784
Total Conversion Cost ⁽³⁾ , dollars per pound of thorium metal					4.171	2.157

(1) Capital investment figures shown in Table 4. Based on June, 1950, ENR construction cost index of 506.

(2) Includes charges for social security, workmen's compensation, pensions, etc.

(3) General reference and bibliography - Dybdal, E.C., "Engineering and Economic Evaluation of Projects", Chem. Eng. Prog., 46, p.57 (Feb., 1950).

TABLE 4. CAPITAL INVESTMENT FOR PLANT TO PRODUCE THORIUM
FROM MONAZITE SAND

	<u>Dollars, for Plant Capacity</u>	
	<u>5 Tons/Month</u>	<u>25 Tons/Month</u>
Installed process equipment (I.P.E.) (1)	507,000	1,340,000
Piping - 20% of I.P.E. (2)	101,000	268,000
Instrumentation - 10% of I.P.E.	51,000	134,000
Auxiliary equipment - 3% of I.P.E.	<u>15,000</u>	<u>40,000</u>
Total installed machinery and equipment	674,000	1,782,000
Building (3) - 25% of I.P.E.	<u>127,000</u>	<u>335,000</u>
Total physical cost (T.P.C.)	801,000	2,117,000
Engineering and construction - 25% of T.P.C.	200,000	529,000
Contingencies - 25% of T.P.C.	200,000	529,000
Size factor (4) - 10% of T.P.C. and 5% of T.P.C.	<u>80,000</u>	<u>106,000</u>
Total investment capital, dollars	1,281,000	3,281,000

- (1) From Table 5, based on June, 1950, Engineering News - Record Construction Cost Index of 506.
- (2) Percentage figures from Chilton, C. H., "Cost Data Correlated", Chem. Engr., 56, No. 6, page 97 (June, 1949).
- (3) Includes manufacturing facilities only; no provision for housing, rail facilities, roads, etc.; assumes addition to existing plant in accessible locality.
- (4) The size-factor allowance is to take into account the fact that some costs are relatively independent of size of plant, hence represent a larger percentage of total physical cost of a small plant than of a large plant.

TABLE 5. COST OF INSTALLED PROCESS EQUIPMENT⁽¹⁾ FOR PLANT
PRODUCING THORIUM FROM MONAZITE

	Cost Installed, Dollars, For Plant Capacity	
	5 Tons/Month	25 Tons/Month
Tanks and bins	90,000	260,000
Pumps	17,000	38,000
Reactors	48,000	145,000
Filters	65,000	200,000
Settlers	88,000	170,000
Driers	20,000	77,000
Columns ⁽²⁾	30,000	67,000
Evaporator	15,000	26,000
Ball mill	7,000	21,000
Miscellaneous	<u>21,000</u>	<u>54,000</u>
Installed process equipment (ENR C.C.I. of 400) ⁽³⁾	<u>401,000</u>	<u>1,058,000</u>
Installed process equipment (ENR C.C.I. of 506)	507,000	1,340,000

(1) From Chilton, C. H., "Cost Data Correlated", Chem. Engr., 56, No. 6, page 97 (June, 1949).

(2) From correspondence with manufacturer.

(3) Engineering News - Record Construction Cost Index: Base, 1913 = 100
June, 1950 = 506.

A P P E N D I X

TABLE A. FLOWSHEET DATA-RECOVERY OF THORIUM AND URANIUM FROM MONAZITE

Stream No. (See Figure A)	Name of Stream	Distribution, per Cent										Composition of Stream, Per Cent										Quantity Per Pound of Thorium Produced		
		Total in Monazite Sand(1)																						
		Th	U	R.E.	Ti	Fe	Si	P	Na ⁺ as NaOH	Cl ⁻ as HCl	NO ₃ ⁻ as HNO ₃	Th	U	R. E.	Ti	Fe	Si	P	NaOH	Cl ⁻ as HCl	NO ₃ ⁻ as HNO ₃	H ₂ O		
1	Monazite sand	100	100	100	100	100	100	100	-	-	-	5.71	0.12 ⁽²⁾	50.6	1.05	0.36	1.00	11.34	-	-	-	0	17.7	-
2	Ball-mill discharge	100	100	100	100	100	100	100	-	-	-	2.86	0.06 ⁽²⁾	25.3	0.53	0.18	0.50	5.67	-	-	-	50	35.4	2.56
3	Classifier-settler return	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.33	0.76
4	Wet sand charge	100	100	100	100	100	100	100	-	-	-	3.48	0.07 ⁽²⁾	30.8	0.64	0.22	0.61	6.90	-	-	-	39.2	29.1	1.80
5	Make-up caustic soda - 73% liquid	-	-	-	-	-	-	-	100	-	-	-	-	-	-	-	-	-	73.0	-	-	25	26.3	1.85
6	Recycle caustic soda liquor	-	2.2	-	-	-	31	0.7	40.9	-	-	-	0.003	-	-	0.014	0.34	0.10	47.4	-	-	50	16.1	1.31
7	Water-vapor loss from reactor	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	14.1	1.69	
8	Dilution wash solution	-	0.2	-	-	-	3	2.9	4.5	-	-	-	-	-	-	0.007	0.07	0.74	-	-	99	84.1	9.83	
9	Caustic filtrate	-	5.3	-	-	-	75	100.4	137.7	-	-	-	0.001	-	-	0.004	0.11	1.64	14.8	-	-	75.8	123	11.6
10	Wash water	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	88.5	10.6	
11	Hydrous oxide cake	100	96.9	100	100	95	56	0.3	2.4	-	-	4.46	0.09	39.5	0.82	0.27	0.44	0.03	-	-	-	33	22.7	-
12	Water vapor from evaporator	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	73.6	8.85	
13	Recovered caustic soda liquor	-	4.9	-	-	-	69	1.6	91.0	-	-	-	0.003	-	-	0.014	0.34	0.10	47.4	-	-	50	35.8	2.92
14	Neutralization caustic soda liquor	-	2.7	-	-	-	38	0.9	49.9	-	-	-	0.003	-	-	0.014	0.34	0.10	47.4	-	-	50	19.7	1.61
15	Wet sodium phosphate crystals	-	0.4	-	-	-	6	98.8	46.7	-	-	-	0.001	-	-	0.003	0.08	14.4	9.0	-	-	13	13.9	-
16	Water from crystal dryer	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	1.72	0.21	
17	Dry sodium phosphate crystals	-	0.4	-	-	-	6	98.8	46.7	-	-	-	0.001	-	-	0.003	0.09	16.4	10.2	-	-	0.6	12.2	-
18	Hydrochloric acid - 37%	-	-	-	-	-	-	-	-	100	-	-	-	-	-	-	-	-	-	37	-	63	26.6	2.69
19	Chloride solution	100	96.9	100	100	95	56	0.3	-	100	-	2.06	0.045	18.2	0.38	0.12	0.20	0.012	-	20	-	-	49.2	3.94
20	Dilution water for acid solution	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	89.6	11.7	
21	Dilution water for neut. caustic soda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	9.2	1.05	
22	Caustic soda solution for partial neut.	-	1.0	-	-	-	14	0.3	18.7	-	-	-	0.002	-	-	0.01	0.23	0.06	32.4	-	-	66	10.6	0.96
23	Partial neut. slurry	100	97.9	100	100	95.9	70	0.6	-	100	-	0.68	0.014	6.0	0.12	0.04	0.08	0.01	-	6.6	-	-	150	15.3
24	Settled slurry No. 1	99.7	97.3	11.1	-	-	-	-	-	-	-	1.65	0.034	1.63	-	-	-	-	-	-	-	-	61.1	6.11
25	Decantate No. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	38.5	9.51
26	Filtrate No. 1	0.3	0.6	88.9	-	-	-	-	-	90.9	-	0.002	0.0001	6.1	-	-	-	-	-	6.85	-	-	42.1	4.53
27	Wet cake No. 1	99.7	97.3	11.1	-	-	-	-	-	9.1	-	5.33	0.109	5.27	-	-	0.65	-	-	4.75	-	70.4	18.9	-
28	Settled slurry No. 2	99.7	97.3	3.4	-	-	-	-	-	-	-	1.98	0.041	0.60	-	-	-	-	-	-	-	-	51.0	5.86
29	Decantate No. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	93.3	11.1
30	Filtrate No. 2	0.3	0.6	8.8	-	-	-	-	-	9.0	-	0.002	0.0001	0.60	-	-	-	-	-	0.68	-	-	37.3	4.44
31	Wet cake No. 2	99.7	97.3	3.4	-	-	-	-	-	1.2	-	7.41	0.152	2.25	-	-	0.91	-	-	0.87	-	79.3	13.6	-
32	Wash water	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	125	15.0
33	Settled slurry No. 3	99.4	96.7	2.3	-	-	-	-	-	-	-	2.32	0.047	0.48	-	-	-	-	-	-	-	-	43.3	5.10
34	Decantate No. 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	94.9	11.3
35	Filtrate No. 3	0.3	0.6	1.1	-	-	-	-	-	1.1	-	0.002	0.0001	0.079	-	-	-	-	-	0.86	-	-	30.4	3.63
36	Wet cake No. 3	99.4	96.7	2.3	-	-	-	-	-	0.1	-	7.78	0.16	1.60	-	-	0.96	-	-	0.76	-	80.4	12.9	-
37	Water from cake dryer	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	10.1	1.21
38	Dry cake	99.4	96.7	2.3	-	-	-	-	-	0.1	-	36.4	0.74	7.45	6.73	2.21	4.47	0.44	-	0.36	-	0	2.76	-
39	10-molar nitric acid solution - 48.5%	-	-	-	-	-	-	-	-	-	43	-	-	-	-	-	-	-	-	-	48.5	51.5	7.46	0.69
40	16-molar nitric acid solution - 71%	-	-	-	-	-	-	-	-	-	57	-	-	-	-	-	-	-	-	-	71	29	6.75	0.57

TABLE A. (Continued)

Stream No. (See Figure A)		Distribution, Per Cent of Total in Monazite Sand ⁽¹⁾										Composition of Stream, Per Cent										Quantity Per Pound of Thorium Produced		
		Th	U	R.E.	Ti	Fe	Si	P	Na ⁺	Cl ⁻	NO ₃ ⁻	Th	U	R.E.	Ti	Fe	Si	P	NaOH	Cl ⁻	NO ₃ ⁻	H ₂ O	Pounds	Gallons
									as NaOH	as HCl	as HNO ₃								as NaOH	as HCl	as HNO ₃			
41	Water	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	1.18	0.14
42	Nitrate solution	99.4	96.7	2.3	100	96.0	70	0.6	-	0.1	100	5.52	0.113	1.13	1.02	0.33	0.67	0.07	-	0.06	46.1	-	18.2	1.45
43	Filter aid slurry	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	90	3.0	0.32
44	Filtered nitrate solution	92.9	90.1	1.9	28.2	79.0	-	0.19	-	0.09	93.8	5.63	0.115	1.01	0.31	0.3	-	0.02	-	0.06	47.1	-	16.7	1.35
45	Wash water	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	3.48	0.42
46	Wet insoluble residue ⁽³⁾	0.4	0.7	0.3	70	11.6	70	0.4	-	-	-	0.23	0.01	1.54	7.43	0.42	7.06	0.46	-	-	-	62.6	1.75	-
47	Adjusting nitric acid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	71	29	0	0
48	Adjusting wash water	6.1	5.9	0.1	1.8	5.1	-	0.01	-	0.01	6.2	1.8	0.04	0.9	0.1	0.1	-	0.01	-	0.02	14.9	-	3.48	0.38
49	Solvent-extraction feed solution	99.0	96.0	2.0	30	85	-	0.2	-	0.1	100	4.97	0.101	0.89	0.28	0.27	-	0.02	-	0.05	41.5	-	20.2	1.73
50	Combined decantates and filtrates	0.6	1.2	97.7	-	-	-	-	-	99.9	-	0.002	0.0001	3.35	-	-	-	-	-	3.76	-	-	261	29.3
51	Caustic soda solution for rare earth pptn.	-	1.7	-	-	2.0	24	0.6	31.2	-	-	-	0.002	-	-	0.01	0.23	0.06	32.4	-	-	66	18.2	1.64
52	Settled rare earth slurry	0.6	2.9	97.7	-	2.6	24	0.6	-	99.9	-	0.004	0.0004	6.08	-	0.001	0.03	0.01	-	-	-	-	144	15.3
53	Decantate waste	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.9	-	-	136	15.7
54	Filtrate waste	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	89.5	10.3
55	Wet rare earth cake	0.6	2.9	97.7	-	2.6	24	0.6	-	-	-	0.01	0.001	16.2	-	0.003	0.08	0.02	-	1.8	-	81	54.1	-
56	Water from cake dryer	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	41.9	5.03
57	Dry rare earth cake	0.6	2.9	97.7	-	2.6	24	0.6	-	-	-	0.05	0.005	73.1	-	0.014	0.35	0.09	-	8.1	-	-	12.2	-

TABLE A. (Continued)

Stream No. (See Figure A)	Name of Stream	Distribution, Per Cent of Total Monazite Sand						Composition of Stream, Per Cent										Composition, Parts per Million Parts of Thorium					Quantity Per Pound of Thorium Produced	
		Th	U	R.E.	Ti	Fe	P as PO_4	Th	U	R.E.	Ti	Fe	P as PO_4	HNO_3	TBP	OSN	$H_2C_2O_4$	U	R.E.	Ti	Fe	P as PO_4	Pounds	Gallons
101	Aqueous feed, Column 1	99	96	2.0	30	85	0.2	5.0	0.10	0.90	0.3	0.3	0.03	34	-	-	-	20×10^3	18×10^4	56×10^3	53×10^3	62×10^2	20	1.7
102	Aqueous scrub, Column 1	-	-	-	-	-	-	-	-	-	-	-	-	31	-	-	-	-	-	-	-	-	8.5	0.86
103	Organic extractant, Column 1	-	-	-	-	-	-	-	-	-	-	-	-	-	55	44	-	-	-	-	-	-	19	2.6
104	Aqueous raffinate, Column 1	0.1	0.1	2.0	30	85	0.2	-	-	0.7	0.2	0.2	0.02	31	0.01	-	-	-	-	-	-	-	27	2.6
105	Organic feed, Column 2	99	96	$<5 \times 10^{-4}$	0	0.2	$<2 \times 10^{-3}$	5.3	0.11	-	-	-	-	7.9	52	42	-	20×10^3	-	-	-	-	20	2.6
106	Organic solvent	-	-	-	-	-	-	-	-	-	-	-	-	-	55	44	-	-	-	-	-	-	9.5	1.3
107	16M HNO_3	-	-	-	-	-	-	-	-	-	-	-	-	71	-	-	-	-	-	-	-	-	0.39	0.033
108	Organic scrub, Column 2	-	-	-	-	-	-	-	-	-	-	-	-	2.3	54	43	-	-	-	-	-	-	10	1.3
109	Aqueous strip, Column 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	33	3.9
110	Aqueous thorium product	99	7×10^{-2}	$<5 \times 10^{-4}$	0	0.2	$<2 \times 10^{-3}$	2.9	4×10^{-5}	-	-	-	-	3.9	0.02	-	-	15	<44	200	100	<70	34	3.9
111	Oxalic acid solution	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	11	1.3
112	Thorium oxalate slurry	99	7×10^{-2}	$<5 \times 10^{-4}$	0	0.2	$<2 \times 10^{-3}$	2.9	4×10^{-5}	-	-	-	-	3.8	0.02	-	-	15	<44	200	100	<70	45	5.2
113	Oxalic acid wash	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	34	4.0
114	Thorium oxalate product	99	1×10^{-2}	$<5 \times 10^{-4}$	5×10^{-3}	4×10^{-2}	$<2 \times 10^{-3}$	56	1×10^{-4}	-	-	-	-	-	-	-	44	2	<44	5	20	<50	1.8	-
115	Oxalic acid waste	$<1 \times 10^{-3}$	6×10^{-2}	$<5 \times 10^{-4}$	0	0.2	$<2 \times 10^{-3}$	$<1 \times 10^{-4}$	2×10^{-5}	-	-	-	-	2.0	0.02	-	0.6	-	-	-	-	-	78	9.2
Composition, Parts Per Million Parts of Uranium																								
		Th	R.E.	Ti	Fe	P																		
116	Organic feed, Column 3	$<3 \times 10^{-3}$	96	$<1 \times 10^{-3}$	$<1 \times 10^{-2}$	1×10^{-2}	1×10^{-4}	$<1 \times 10^{-4}$	7×10^{-2}	-	-	-	-	0.1	54	43	-	<2000	<4000	<1000	300	100	29	3.9
117	Aqueous strip, Column 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	1.3
118	Aqueous uranium product	$<3 \times 10^{-3}$	96	$<1 \times 10^{-3}$	$<1 \times 10^{-2}$	1×10^{-2}	1×10^{-4}	$<3 \times 10^{-4}$	3×10^{-2}	-	-	-	-	<0.05	0.01	-	-	<2000	<4000	<1000	300	100	11	1.8
119	Concentrated NH_4OH (28%)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.007	0.003
120	Uranyl hydroxide slurry	$<3 \times 10^{-3}$	96	$<1 \times 10^{-3}$	$<1 \times 10^{-2}$	1×10^{-2}	1×10^{-4}	$<3 \times 10^{-4}$	3×10^{-2}	-	-	-	-	-	0.01	-	-	<2000	<4000	<1000	300	100	11	1.8
121	Uranyl hydroxide product	$<3 \times 10^{-3}$	96	$<1 \times 10^{-3}$	$<1 \times 10^{-2}$	1×10^{-2}	1×10^{-4}	6×10^{-6}	83	-	-	-	-	-	-	-	-	<2000	<4000	<1000	300	100	0.024	-
122	NH_4OH waste	-	1×10^{-3}	-	-	-	-	-	-	-	-	-	-	-	0.01	-	-	-	-	-	-	-	11	1.8
123	Organic solvent recycle	-	2×10^{-2}	-	-	-	-	-	-	-	-	-	-	-	55	44	-	-	-	-	-	-	23	3.2
124	Organic solvent to pretreatment	-	6×10^{-3}	-	-	-	-	-	-	-	-	-	-	-	55	44	-	-	-	-	-	-	5.8	0.78
125	Tributyl phosphate	-	-	-	-	-	-	-	-	-	-	-	-	-	99	-	-	-	-	-	-	-	0.073	0.01
126	Gulf spray naphtha	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	-	-	-	-	-	0.025	0.004
127	Organic solvent to pretreatment	-	6×10^{-3}	-	-	-	-	-	-	-	-	-	-	-	-	56	43	-	-	-	-	-	5.8	0.79
128	HNO_3 wash waste	-	-	-	-	-	-	-	-	-	-	-	-	8	0.01	0.01	-	-	-	-	-	-	1.4	0.16
129	Organic solvent	-	6×10^{-3}	-	-	-	-	-	-	-	-	-	-	-	56	43	-	-	-	-	-	-	5.8	0.78
130	1M NaOH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.8	0.31
131	Organic solvent	-	-	-	-	-	-	-	-	-	-	-	-	-	55	44	-	-	-	-	-	-	5.8	0.78
132	Wash water	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.8	0.22
133	Water waste	-	-	-	-	-	-	-	-	-	-	-	-	-	0.01	0.01	-	-	-	-	-	-	1.8	0.22
134	Organic solvent	-	-	-	-	-	-	-	-	-	-	-	-	-	55	44	-	-	-	-	-	-	5.8	0.78
135	10M HNO_3 , recycle	-	-	-	-	-	-	-	-	-	-	-	-	48	-	-	-	-	-	-	-	-	7.5	0.69

TABLE A. (Continued)

Stream No. (See Figure A)	Name of Stream	Distribution, Per Cent of Total in Monazite Sand					Composition of Stream, Per Cent										Composition, Parts Per Million Parts of Uranium					Quantity Per Pound of Thorium Produced	
		Th	U	R.E.	Fe	P as PO_4	Th	U	R.E.	Tl	Fe	P as PO_4	HNO_3	TBP	GSN	$H_2C_2O_4$	Th	R.E.	Tl	Fe	P	Pounds	Gallons
136	6M HNO_3 , recycle	-	-	-	-	-	-	-	-	-	-	-	31	-	-	-	-	-	-	-	-	8.6	0.87
137	1.6M HNO_3 , Solvent wash	-	-	-	-	-	-	-	-	-	-	-	9	-	-	-	-	-	-	-	-	1.74	0.16
	Miscellaneous use	-	-	-	-	-	-	-	-	-	-	-	9	-	-	-	-	-	-	-	-	6.2	0.71
138	HNO_3 waste	0.1	0.1	2.0	85	0.2	3×10^{-2}	6×10^{-3}	5	2	2	0.2	55	0.1	-	-	-	-	-	-	-	3.4	0.17
139	NaOH waste to neutralization	-	6×10^{-5}	-	-	-	-	-	-	-	-	-	-	0.04	0.01	-	-	-	-	-	-	2.8	0.31
140	Neutralized waste slurry	0.1	0.1	2.0	85	0.2	2×10^{-2}	3×10^{-3}	3	1	1	0.1	-	0.05	-	-	-	-	-	-	-	6.2	0.48

- (1) Does not refer to materials not found in monazite sand, i.e., NaOH, HCl, and HNO_3 . Figures for these are based on streams which show 100 per cent of particular material.
- (2) These head compositions are based on total uranium found in process streams.
- (3) Does not include filter aid.