FINAL REPORT

on

DISTRIBUTION OF RARE-EARTH TRACERS BETWEEN AQUEOUS
AND TRIBUTYL PHOSPHATE-DILUENT PHASES

by

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ABSTRACT

Data are presented on the effect of several variables on the distribution of rare earths between aqueous and tributyl phosphate-diluent phases. The investigation was carried out using rare-earth tracers to obtain fundamental information needed to develop a solvent-extraction process for the purification of thorium nitrate.

The distribution ratios (organic/aqueous) of the rare earths vary directly with tributyl phosphate (TBP) concentration of the organic phase and nitric acid concentration, and inversely with thorium concentration.

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INTRODUCTION

This investigation on the distribution of rare earths between aqueous and tributyl phosphate-diluent phases was undertaken as part of a larger investigation on the development of a process for purifying thorium nitrate by solvent extraction. Since some of the rare earths, especially gadolinium, samarium, and europium, are especially undesirable impurities in thorium because of their high cross sections, and since the rare earths represent a major impurity in commercial thorium nitrate, fundamental information was needed on their behavior during solvent extraction.

The use of tracer techniques appeared to offer definite advantages over the usual analytical methods of determining the relative amounts of individual rare earths present in organic and aqueous phases after equilibration. The use of tracers made it possible to obtain considerable information in a relatively short time, without taxing the facilities of the analytical laboratory.

Factors studied included those variables which might be significant in affecting distribution coefficients in a solvent-extraction process, using tributyl phosphate as the active solvent and nitric acid as the salting agent. These variables included nitric acid concentration, type of hydrocarbon diluent, concentration of tributyl phosphate in the solvent mixture, concentration of mixed rare earths in the system, and concentration of thorium nitrate in the organic and aqueous phases.

Since it did not appear to be feasible or necessary to carry out experiments with each individual rare earth found in commercial thorium nitrate, the program was restricted to the following rare earths which could be obtained readily in radioactive form: cerium, europium, thulium, samarium, holmium, ytterbium, and yttrium. It is believed that these are fairly typical of the various groups of rare-earth elements.

SUMMARY

Data obtained in this investigation on the distribution of several radioactive rare earths between aqueous and tributyl phosphate phases have indicated the feasibility of reducing rare-earth impurities in thorium to very low levels by solvent extraction. Even under the most unfavorable conditions prevailing in the solvent-extraction system, the distribution coefficient

for thorium nitrate (organic/aqueous) is many times the coefficient for any individual rare-earth nitrate. In this work, cerium was maintained in the cerous form, since ceric nitrate is much more extractable than cerous.

The solvent-extraction experiments were conducted as follows: an equal volume of the organic phase, pre-equilibrated with nitric acid, was mixed with an aqueous phase containing known quantities of the rare-earth tracer, mixed rare-earth oxides, thorium nitrate, and nitric acid. After equilibration, the phases were separated by centrifuging and their radio-activity was measured with a dip-counter Geiger tube.

The effects of several significant variables on the distribution ratios of the rare earths in the solvent-extraction system were investigated.

The rare earths appear to fall into three groups when the distribution ratios are considered as a function of nitric acid concentration. The distribution ratios (organic/aqueous) of the lighter rare earths increased rapidly with increasing nitric acid up to about 1.5 normal, then they decreased steadily with increasing nitric acid concentration. The distribution ratios of the heavier rare earths increased with increasing nitric acid up to about 3.0 normal and then continued to increase but at a lower-rate with increasing nitric acid concentration. The distribution ratios of the rare earths from the middle group of rare earths increased rapidly with increasing nitric acid up to about 1.0 normal and then remained practically unaffected by increasing nitric acid concentration to about 5 normal.

The distribution ratios of the rare earths investigated increased nearly logarithmically with increasing TBP concentration.

The distribution ratios of the rare earths were practically independent of the mixed rare-earth concentration in the aqueous phase from zero to 56.6 grams of mixed rare-earth oxides per liter.

Some attention was given to the effect of the nature of the diluent used for the tributyl phosphate on rare-earth distribution ratios. When work was started on the thorium-purification process, it was planned that a refined kerosene, such as Sohio Solvent or Gulf Spray naphtha, would be used as the diluent. However, it was later found that an aromatic type of diluent was required to prevent the formation of three liquid phases at high thorium levels. Some of the earlier tracer experiments were carried out with Sohio Solvent, before the significance of the nature of the diluent was realized. With Sohio Solvent as the diluent, the tributyl phosphate was 1.5 to 2.5 times as effective in extracting rare earths from the aqueous phase as when benzene or Solvesso 100 was used as the diluent.

Increasing the thorium concentration decreased the distribution ratios of the rare earths, suggesting the desirability of maintaining high thorium levels in the organic phase in the extraction process.

There was essentially no difference between the distribution ratios during successive extractions and scrubs at the various concentrations of the rare earths obtained during the scrubbing process.

PREPARATION OF MATERIALS

Purification of Mixed Rare Earths

Nine hundred grams of mixed rare earths obtained from a representative sample of mixed rare earths separated from monazite sand in an earlier thorium program (See BMI-243 and -243A) were purified by successive hydroxide precipitations at pH 5.5 and about 9.0. The residual radioactivity of the purified rare earths was reduced to zero by this treatment. A stock solution of the purified rare earths containing 82.9 g./l. of $(RE)_2O_3$ was prepared for use in the distribution studies. A spectrographic analysis of the mixed rare earths is given below:

<u>Element</u>	<u>Per Cent</u>	<u>Element</u>	<u>Per Cent</u>
Cerium	40	Holmium	< 0.1
Lanthanum	21	Ytterbium	< 0.03
Neodymium	20	Erbium	< 0.05
Praseodymium	5.3	Lutecium	< 0.03
Samarium	2.5	Thulium	< 0.1
Dysprosium	< 0.2	Yttrium	ca. 0.2
Gadolinium	ca. 0.5	Zirconium	< 0.05
Terbium	< 0.3	Iron	< 0.02

Separation of Thorium From Impurities

The thorium nitrate used in the experiments was pretreated to remove the radioactivity resulting from the various radioactive daughters of thorium. This was accomplished by solvent extraction with TBP (tributyl phosphate) and benzene (50-50). The solvent was saturated with thorium by extraction of an excess of solid mantle-grade thorium nitrate. The organic solution

was scrubbed once with one-twentieth volume of water. A quantity of an aqueous phase of the thorium sufficient for one of the experiments was prepared by extracting the solvent with one-tenth volume of water. Checks on the radioactivity of the extracted thorium as a function of time indicated that corrections of the organic counts would be necessary only for large (50 g./l.) concentrations of thorium and at low counts (100 counts per minute) of rare-earth tracer if the experiments were completed within eight hours.

Source of Various Radioactive Rare Earths

Four of the rare-earth tracers were obtained directly from Oak Ridge National Laboratory. These were cerium-144, europium-152, -154, thulium-170, and yttrium-91. Both cerium and yttrium tracers were carrier-free and spectrographic analyses were furnished on their purity. Since less information concerning the radiochemical purity was known for thulium and europium radioisotopes received from Oak Ridge, successive organic extractions of the same aqueous feed solution containing these tracers were made. Constant distribution ratios were obtained with both isotopes through four successive extractions which suggested that the rare-earth isotopes were reasonably pure.

Fifty milligrams each of five rare earths of high purity were obtained from the Ames Laboratory. Samples of samarium, holmium, and ytterbium were sent to Oak Ridge for neutron irradiation. A summary of the method of procurement of the various radioactive rare-earth isotopes and their activities is presented in Table 1.

EXPERIMENTAL PROCEDURE

The investigation of the distribution of rare-earth tracers in the tributyl phosphate solvent-extraction system was carried out in the following manner.

Preparation of Organic Phase

The organic phase was prepared by mixing the desired volume of TBP with the diluent and contacting the mixture with an aqueous phase containing the necessary amount of nitric acid to pre-equilibrate the organic phase with respect to the acidity of the rare-earth feed solution.

TABLE 1. SOURCE OF VARIOUS RADIOACTIVE RARE EARTH ISOTOPES

Isotope Used	Activity, mc./ml.	Source	Remarks
Cerium-144	2.72 ± 10%	Oak Ridge National Laboratory	Carrier free, in equilibrium with praseodymium-144
Europium-152	5.7*	Oak Ridge National Laboratory	Combined with europium-154
Thulium-170	0.638	Oak Ridge National Laboratory	Concentrated chloride solution
Samarium-153	0.29*	10 mgs. Sm ₂ O ₃ from Ames Laboratory	Neutron irradiation at Oak Ridge National Laboratory for one week in 14-B-36 level
Holmium-166	2.3*	20.1 mgs. Ho ₂ O ₃ from Ames Laboratory	Neutron irradiation at Oak Ridge National Laboratory for one week in 14-B-2 level
Ytterbium-175	2.1*	20.3 mgs. Yb ₂ O ₃ from Ames Laboratory	Neutron irradiation at Oak Ridge National Laboratory for one week in 14-B-27 level
Yttrium-91	3.07 ± 10%	Oak Ridge National Laboratory	Carrier free

*Calculated activity from counts made during experiments carried out at various nitric acid concentrations.

Preparation of Aqueous Phase

The aqueous phases for the solvent-extraction experiments were prepared by adding known quantities of the stock rare-earth solution, an amount of radioactive rare-earth tracer sufficient to give about 10,000 counts per minute per ml., nitric acid, and water to produce the desired nitric acid and rare-earth concentrations. When thorium was added to the aqueous phase, the purified thorium solution, described above, replaced part of the water normally used in the preparation of the aqueous phase.

In carrying out the determination of rare-earth distribution ratio between the organic and aqueous phases, equal volumes of the aqueous and organic phases were contacted by stirring for five minutes at room temperature. Solutions containing thorium nitrate were stirred for ten minutes to insure complete mixing of the heavier aqueous solution with the organic phase. After equilibration, the phases were separated by centrifuging for one minute and their radioactivity was measured in the counting apparatus described in the following paragraph.

Counting Technique

All the radioactive counts were made with dip-counter Geiger tube, Model D-52 (Nuclear Instrument and Chemical Corporation, Chicago, Illinois). Ten milliliters of the radioactive solutions placed in uniform glass counting tubes, were counted behind two-inch lead shields. Counts were recorded by a scaler, Model 162 (Nuclear Instrument and Chemical Corporation). At least three two-minute counts were recorded for each sample; however, longer counts were made on samples containing less than 100 counts per minute.

RESULTS

Effect of Nitric Acid

The distribution ratios of various rare earths between an aqueous phase and an organic phase, 50-50 TBP-Sohio Solvent, were determined as a function of nitric acid concentration in the absence of thorium. The data

for the cerium-praseodymium, thulium, europium, samarium, holmium, ytterbium, and yttrium rare earths are given in Table 2 and are plotted in Figure 1. It is obvious that there are marked differences in the extraction of the individual rare earths by TBP. The data show that it probably would be possible to design a solvent-extraction process for separating the various rare earths into groups, since the rare earths appear to fall into three groups when the distribution ratios are considered as a function of nitric acid. The distribution ratio of the cerium-praseodymium mixture increases rapidly with increasing nitric acid concentrations at low acidities and decreases continuously above a nitric acid concentration of about 1.5 normal. The distribution ratios of samarium and europium increase more rapidly than the cerium-praseodymium mixture with increasing nitric acid concentration up to about 1.0 normal, and then the distribution ratios decrease above a nitric acid concentration of about 3.0 normal, but at a much slower rate than that of the cerium-praseodymium mixture. The distribution ratios of thulium, ytterbium, holmium, and yttrium increase rapidly with increasing nitric acid concentration up to about 1.0 normal and then continue to increase but at a declining rate up to 7.0 normal nitric acid, the highest acid concentration used in the equilibrium experiments.

Effect of TBP Concentration

The distribution ratios of the rare earths investigated increase almost logarithmically with increasing TBP concentration in the organic phase, Table 3.

Effect of Rare Earths

The effect of mixed rare-earth concentrations on the distribution of the cerium-praseodymium and samarium tracers was investigated. It was found, Table 4, that the distribution ratios of these rare earths were independent of the mixed rare-earth concentration in the aqueous phase from zero to 56.6 grams of mixed rare-earth oxides per liter. The concentration of the rare earths introduced with the tracer solutions was about 10^{-13} and 10^{-4} gram of cerium-praseodymium and samarium per liter, respectively. These were the tracer concentrations for the experimental points at zero mixed rare earths.

Effect of Diluent

The effect of diluent on the distribution of rare earths was determined using different diluents, other conditions being the same. The data, Table 5,

TABLE 2. EFFECT OF NITRIC ACID ON DISTRIBUTION RATIO (ORGANIC/AQUEOUS) OF RARE EARTHS

Solvent = 50-50 TPB - Sohio Solvent; thorium concentration = zero;
 mixed rare-earth oxide concentration = 16,58 g./l.⁽¹⁾

Nitric Acid Normality	Distribution Ratio, organic/aqueous						
	Cerium- Praseodymium	Thulium	Europium	Samarium	Holmium	Ytterbium	Yttrium
0.025	0.0093	0.0033	0.012	0.011	-	-	-
0.10	0.013	0.0053	0.017	0.017	0.00074	0.00051	0.0017
1.0	0.045	0.030	0.092	0.087	0.041	0.013	0.018
3.0	0.039	0.081	0.13	0.13	0.11	0.048	0.071
5.0	0.023	0.12	0.10	0.095	0.12	0.086	0.085
7.0	0.013	0.19	0.089	0.074	0.15	0.18	0.15

(1) Mixed rare-earth concentration for holmium, ytterbium, and yttrium experiments was 0.0069 g./l.

FIGURE I. DISTRIBUTION RATIOS OF RARE EARTHS AS A FUNCTION OF NITRIC ACID CONCENTRATION

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TABLE 3. EFFECT OF TRIBUTYL PHOSPHATE
CONCENTRATION ON THE DISTRIBUTION OF RARE EARTHS

Diluent = Sohio Solvent; thorium concentration = zero;
nitric acid = 5.0 normal

TBP Volume per cent of organic phase	Distribution Ratio, organic aqueous	
	Cerium- Praseodymium ⁽¹⁾	Samarium ⁽²⁾
20	0.002	0.012
25	0.003	0.019
30	0.006	0.027
35	0.008	0.039
40	0.011	0.052
50	0.018	0.084

(1) Mixed rare-earth oxides concentration = 16.6 g./l.

(2) Mixed rare-earth oxides concentration = 0.0069 g./l.

TABLE 4. EFFECT OF RARE-EARTH CONCENTRATION
ON DISTRIBUTION OF CERIUM-PRASEODYMIUM
AND SAMARIUM

Cerium-praseodymium experiments: Thorium =
zero g./l.; HNO_3 aqueous = 5 normal, organic =
1.2 normal; Solvent = 50-50 TBP - Sohio Solvent

Samarium experiments: Thorium = zero g./l.; HNO_3
aqueous = 5 normal, organic = 0.72 normal; Sol-
vent = 30-70 TBP - Sohio Solvent

Concentration of Mixed $(\text{RE})_2\text{O}_3$, Total, g./l.	Distribution Ratio, E_A^0	
	Cerium- Praseodymium	Samarium
56.6	0.021	0.035
16.6	0.022	0.032
5.0	0.022	0.033
0.69	0.024	0.034
0.35	0.022	0.032
0.069	0.022	0.034
0.0069	0.022	0.033
0 ⁽¹⁾	0.022	0.034

(1) a. Cerium-praseodymium concentration was about 10^{-13} g./l. as a
result of adding Ce^{144} - Pr^{144} tracer.

b. Samarium concentration was 1.4×10^{-4} g./l. as a result of adding
 Sm^{153} tracer.

TABLE 5. EFFECT OF DILUENT ON DISTRIBUTION OF RARE EARTHS

Solvent = 30-70 TBP - Diluent; thorium concentration = zero g./l.; nitric acid concentration = 1.0 normal aqueous; mixed (RE)₂O₃ = zero g./l.

Rare Earth ⁽¹⁾	Diluent	Distribution Ratio, E_A^0
Cerium	Sohio Solvent	0.014
Cerium	Benzene	0.0053
Cerium	Solvesso 100	0.0066
Europium	Sohio Solvent	0.021
Europium	Benzene	0.015
Europium	Solvesso 100	0.014
Thulium	Sohio Solvent	0.0070
Thulium	Benzene	0.0039
Thulium	Solvesso 100	0.0045

(1) Concentration of rare-earth oxide from tracer: Ce₂O₃ = 1.0 x 10⁻⁶ g./l.; Eu₂O₃ = 5.0 x 10⁻⁴ g./l.; Tm₂O₃ = 2.0 x 10⁻⁴ g./l.

indicate that the distribution ratio obtained with Sohio Solvent as the diluent was about 2.5 times that obtained with benzene or Solvesso 100 when cerium was used as the tracer, and about 1.5 times when europium and thulium were used as the tracers. The distribution ratios obtained with benzene and Solvesso 100 were substantially the same for the three rare-earth tracers.

Effect of Thorium

The effect of thorium on the distribution ratios of cerium-praseodymium mixture, thulium, and europium was determined at three TBP concentrations, 25, 40, and 50 per cent, aqueous phase 5.0 normal with respect to nitric acid, Table 6 and Figures 2 and 3. Data for the effect of thorium on the distribution ratio of samarium were determined at 30 per cent TBP and 5 normal nitric acid, Table 6. The effect of thorium on the distribution ratio of cerium-praseodymium mixture, europium, holmium, thulium, ytterbium, and yttrium was determined at 30 per cent TBP for three nitric acid concentrations, 1, 3, and 5 normal with respect to the aqueous phase, and at three thorium concentrations, 0, 82, and 90 per cent saturation in the organic phase, Table 7. The effect of thorium on the distribution ratios of cerium-praseodymium mixture and europium was determined at 30 per cent TBP for 2 normal nitric acid concentration with respect to the aqueous phase and at four thorium concentrations, 0, 50, 60, and 70 per cent saturation in the organic phase, Table 8.

The distribution ratio of the rare earths may be decreased by decreasing the nitric acid concentration, or by increasing the thorium concentration.

Effect of Successive Extractions and Scrubs

The effect of successive organic extractions of the same aqueous phase on the distribution of samarium, holmium, and ytterbium was investigated using 30 per cent TBP, Table 9. The organic phases, used for the successive extractions, were pre-equilibrated with respect to nitric acid. The distribution ratios were found to be constant through the successive organic extractions.

The effect of successive scrubs on an organic phase on the distribution of samarium, holmium, and ytterbium was investigated using a 5 normal nitric acid scrub solution pre-equilibrated with respect to nitric acid and TBP. The organic phase was prepared by extraction of an aqueous feed

TABLE 6. EFFECT OF THORIUM ON THE DISTRIBUTION RATIO E_A^0 OF RARE EARTHS

Mixed rare-earth concentration = 16.6 g./l.

Approximate HNO ₃ Normality		Approximate Equilibrium Thorium Concentration, g./l.		Cerium-144 Praseodymium-144	Thulium-170	Europium-152, -154	Samarium-153 ⁽¹⁾
Aqueous	Organic	Aqueous	Organic				
<u>Solvent = 25 Per Cent TBP - 75 Per Cent Benzene</u>							
5	0.55	205	47	0.00014	0.00094	0.00069	-
5	0.55	120	42	0.00017	0.00096	0.0012	-
5	0.60	50	33	0.00051	0.0017	0.0022	-
5	0.60	20	22	0.0011	0.0030	0.0044	-
5	0.60	8	12	0.0012	0.0048	0.0070	-
5	0.60	4	6	0.0012	0.0056	0.010	-
5	0.60	1.5	3	0.0023	0.0076	0.011	-
5	0.60	0	0	0.0034	-	0.013	-
<u>Solvent = 40 Per Cent TBP - 60 Per Cent Benzene</u>							
5	0.86	173	78	0.00034	0.0021	0.0019	0.0027
5	0.87	95	70	0.00074	0.0031	0.0031	0.0030
5	0.97	34	50	0.0015	0.0060	0.0069	0.0035
5	1.00	12.5	30.5	0.0031	0.014	0.016	0.0084
5	1.00	4.5	15.5	0.0063	0.023	0.029	0.013
5	1.00	1.6	8.4	0.0063	0.030	0.038	0.019
5	1.00	0.6	3.8	0.0076	0.036	0.042	0.022
5	1.00	0	0	0.0095	-	0.049	0.027
<u>Solvent = 50 Per Cent TBP - 50 Per Cent Benzene</u>							
5	1.1	152	100	0.00038	0.0033	0.0024	
5	1.1	75	90	0.0011	0.0060	0.0046	

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TABLE 6. (Continued)

Approximate HNO ₃ Normality		Approximate Equilibrium Thorium Concentration, g./l.		Cerium-144 Praseodymium-144	Thulium-170	Europium-152, -154	Samarium-153 ⁽¹⁾
Aqueous	Organic	Aqueous	Organic				
<u>Solvent = 50 Per Cent TBP - 50 Per Cent Benzene</u>							
5	1.2	23	61	0.0023	0.013	0.013	-
5	1.3	7	35	0.0065	0.032	0.032	-
5	1.4	2	18	0.011	0.055	0.045	-
5	1.4	0.7	9.3	0.013	0.068	0.069	-
5	1.4	0.2	4.2	0.018	0.075	0.073	-
5	1.4	0	0	0.018	0.12 ⁽²⁾	0.083	-

(1) Mixed rare-earth concentration = 0.0069 g./l. Organic acid concentration varied from 0.70 normal to 0.80 normal because of 30 per cent TBP - benzene.

(2) Diluent was Sohio Solvent.

FIGURE 2. EFFECT OF THORIUM CONCENTRATION ON DISTRIBUTION OF Ce-Pr (5N HNO₃ IN AQUEOUS PHASE)

FIGURE 3. EFFECT OF THORIUM CONCENTRATION ON DISTRIBUTION OF THULIUM (5N HNO_3 IN AQUEOUS PHASE)

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TABLE 7. EFFECT OF THORIUM ON THE DISTRIBUTION RATIO E_A^0 OF RARE EARTHSSolvent⁽¹⁾ = 30-70 TBP - Solvesso 100Mixed (RE)₂O₃ = 0.069 g./l.

Approximate Thorium Saturation of Organic, per cent	Approximate HNO ₃ Normality		Approximate Equilibrium Thorium Concentration g./l.		Distribution Ratio, E_A^0					
	Aqueous	Organic	Aqueous	Organic	Cerium-Praseodymium (2)	Europium (3)	Holmium (4)	Thulium (5)	Ytterbium (6)	Yttrium (7)
90	5.0	0.5	320	67.5	0.000087	0.00069	0.0011	0.00092	0.00076	0.00053
82	5.0	0.5	228	62	0.00013	0.0014	-	0.0013	0.0011	0.00093
0	5.0	0.5	0	0	0.0030	-	-	0.016	-	0.020
90	3.0	0.3	382	72	0.000038	0.00042	0.00078	0.00068	0.00036	0.00039
82	3.0	0.3	274	66	0.000095	0.0010	-	0.00090	0.00060	0.00060
0	3.0	0.3	0	0	0.0061	-	-	0.015	-	0.015
90	1.0	0.1	480	76.5	0.000043	0.00023	0.00056	0.00035	0.00017	0.00016
82	1.0	0.1	347	70	0.00017	0.00070	-	0.00065	0.00035	0.00035
0	1.0	0.1	0	0	0.0050	-	-	0.0047	-	0.0045

(1) Diluent for experiment with holmium was 95-5 Sohio Solvent-benzene.

(2) Cerium (Ce₂O₃) concentration was increased by 8.3×10^{-5} g./l. as a result of adding Ce¹⁴⁴ tracer.(3) Europium (Eu₂O₃) concentration was increased by 2.4×10^{-2} g./l. as a result of adding Eu¹⁵²⁻¹⁵⁴ tracer.(4) Holmium (Ho₂O₃) concentration was increased by 3.8×10^{-2} g./l. as a result of adding Ho¹⁶⁶ tracer.(5) Thulium (Tm₂O₃) concentration was increased by 1.7×10^{-3} g./l. as a result of adding Tm¹⁷⁰ tracer.(6) Ytterbium (Yb₂O₃) concentration was increased by 2.1×10^{-1} g./l. for the first three samples and 8.4×10^{-2} g./l. for the last three samples as a result of adding Yb¹⁷⁵ tracer.(7) Yttrium (Y₂O₃) concentration was increased by 1.4×10^{-7} g./l. as a result of adding Y⁹¹ tracer.

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TABLE 8. EFFECT OF THORIUM ON THE DISTRIBUTION
RATIO E_A^0 OF CERIUM AND EUROPIUM

Solvent = 30-70 TBP - Solvesso 100; mixed $(RE)_2O_3 = 0.069$ g./l. nitric acid:
Aqueous = 2.0N, organic = 0.2N

Approximate Thorium Saturation of Organic, per cent	Approximate Equi- librium Thorium Concentration, g./l.		Distribution Ratio, E_A^0	
	Aqueous	Organic	Cerium- Praseodymium ⁽¹⁾	Europium ⁽²⁾
0	0	0	0.010	0.031
50	60	40	0.0020	0.0089
60	90	48	0.0012	0.0044
70	132	56	0.0007	0.0030

(1) Cerium (Ce_2O_3) concentration was increased by 1.7×10^{-5} g./l. as a result of adding Ce^{144} tracer.

(2) Europium (Eu_2O_3) concentration was increased by 1.0×10^{-2} g./l. as a result of adding Eu^{152} , Eu^{154} tracer.

TABLE 9. EFFECT OF SUCCESSIVE EXTRACTIONS ON THE DISTRIBUTION RATIO E_A^0 OF RARE EARTHS

Solvent = 30-70 TBP - Sohio Solvent; mixed (RE)₂O₃ concentration = 0.069 g./l.; nitric acid concentration = 5.0 normal aqueous and 0.72 normal organic; thorium concentration = zero g./l.

Extraction	Distribution Ratio, E_A^0		
	Samarium-153 ⁽¹⁾	Holmium-166 ⁽²⁾	Ytterbium-175 ⁽³⁾
First	0.036	0.04	0.024
Second	0.038	0.05	0.024
Third	0.038	0.05	0.023
Fourth	0.038	0.05	0.024
Fifth	-	0.05	0.023

(1) Samarium (Sm₂O₃) concentration was increased by 1×10^{-4} g./l. as a result of adding Sm¹⁵³ tracer.

(2) Holmium (Ho₂O₃) concentration was increased by 7.6×10^{-2} g./l. as a result of adding Ho¹⁶⁶ tracer.

(3) Ytterbium (Yb₂O₃) concentration was increased by 2.1×10^{-1} g./l. as a result of adding Yb¹⁷⁵ tracer.

solution which contained 0.069 gram per liter of mixed rare-earth oxides and was 5 normal in nitric acid. The data, Table 10, show that there is essentially no difference between the distribution ratios during successive extraction and scrubs at the various concentrations of the rare earths obtained during the scrubbing process.

TABLE 10. EFFECT OF SUCCESSIVE SCRUBBING ON THE DISTRIBUTION RATIO E_A^0 OF RARE EARTHS

Solvent = 30-70 TBP - Sohio Solvent; mixed $(RE)_2O_3$ concentration = 0.069 g./l.; nitric acid concentration = 5.0 normal aqueous and 0.72 normal organic; thorium concentration = zero g./l.

Scrub	Distribution Ratio, E_A^0		
	Samarium-153 ⁽¹⁾	Holmium-166 ⁽¹⁾	Ytterbium-175 ⁽¹⁾
Extraction	0.042	0.05	0.02
After first aqueous scrub	0.043	0.05	0.02
After second aqueous scrub	0.046	0.03 ⁽²⁾	0.02
After third aqueous scrub	-	0.03 ⁽²⁾	0.02
After fourth aqueous scrub	-	0.05	-
After fifth aqueous scrub	-	0.04 ⁽²⁾	-

(1) Tracer concentration same as in Table 9, except samarium was 3×10^{-4} g./l.

(2) Radioactivity balance approximately 80 per cent.