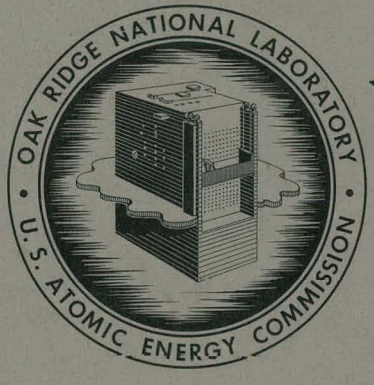
ORNL-2843
UC-4 – Chemistry-General
TID-4500 (15th ed.)

PURIFICATION OF Pm^{147} FROM FISSION-PRODUCED RARE EARTHS

R. S. Pressly



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ORNL-2843

Contract No. W-7405-eng-26

ISOTOPES DIVISION

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DATE ISSUED

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PURIFICATION OF Pm^{147} FROM FISSION-PRODUCED RARE EARTHS

R. S. Pressly

ABSTRACT

Promethium is purified from inactive and radioactive long-lived fission-produced rare earths by the use of Dowex 50 or Nalcite HCR cation exchangers and organic eluants. Americium and promethium, having hydrated ionic radii of the same size, are contained in the same fraction of the eluate.

Promethium is purified from americium by adsorbing both elements on Dowex 1 (thiocyanate form) and eluting promethium from the resin with ammonium thiocyanate solution.

Equilibrium studies were made in order to determine distribution coefficients of the long-lived radioactive rare earths. Elution curves based on analyses of solutions removed from anion and cation exchangers verify the relative values of the distribution coefficients. From Dowex 1 resin, rare earths 58 through 63 elute with ammonium thiocyanate in the order of increasing atomic number.

Conditions are established for the expansion of the present 50- to 100-curie-level processing to levels of 1000 to 5000 curies.

INTRODUCTION

During the early days of the Plutonium Project, investigators detected an approximately four-year half-life radioactivity in the rare-earth group present in the highly radioactive wastes from the plutonium separation process. With the development of ion exchange techniques, whereby the individual elements could be separated, Marinsky and Glendenin[1] purified microgram quantities of promethium and identified the source of this radioactivity as an isotope of element 61. By reasoning from the order of elution, the 11-day activity Nd^{147} was identified, and by decay studies it was proved to be the parent of Pm^{147}.

Parker and Lantz[2] placed 100 μg of very pure Pm^{147} in the Graphite Reactor for a one-week exposure. A 5.3-day half-life activity, with a 2.5-Mev beta and an 0.8-Mev gamma ray, was observed. By ion exchange techniques the new activity was identified as Pm^{148} produced by an (n,γ) reaction. The cross section for this reaction was calculated to be approximately 60×10^{-24} cm^2. This new activity produced by Parker and Lantz was the same as an activity observed by Law *et al.*[3] They had observed its formation by $Nd(p,n)$ and $Nd(\alpha,p)$ reactions.

Previous methods of separation of inactive rare earths relied heavily on fractional recrystallization, making use of differences of solubility, thermal stability, and other properties. More recently, homogeneous precipitation methods, which form the precipitant within the solution, and solvent extraction, which is based on the distribution of rare earths between two immiscible liquids, have been used for preparing concentrates of certain rare earths. Many pure rare earths, especially elements of the heavier rare-earth group, have been prepared.

Ion exchange methods have been applied in the laboratory and have been especially useful for the separation of radioactive fission products because of the comparative ease of operation and analysis. Separations of fission-produced rare earths have been made with ammonium lactate,[4,5] citrates,[6,7] and α-hydroxyisobutyrates[8]

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[1] J. A. Marinsky and L. E. Glendenin, *Clinton Laboratories, Chemistry Division, Report for Month of March 15 to April 15, 1945*, CN-2809, p 9.

[2] G. W. Parker and P. M. Lantz, *Separation of Milligram Quantities of Element 61 from Fission*, ORNL-75 (June 18, 1948).

[3] H. B. Law *et al.*, *Phys. Rev.* **59**, 936 (1941).

[4] R. H. Glass, *J. Am. Chem. Soc.* **77**, 807 (1955).

[5] L. Wish, E. C. Freiling, and L. R. Bunney, *J. Am. Chem. Soc.* **76**, 3444 (1954).

[6] B. H. Ketelle and G. E. Boyd, *J. Am. Chem. Soc.* **69**, 2800 (1947).

[7] R. S. Pressly and A. F. Rupp, *Purification of Fission Product Rare Earths by Ion Exchange*, ORNL-1313 (Apr. 20, 1953).

[8] G. R. Choppin, B. G. Harvey, and S. G. Thompson, *J. Inorg. & Nuclear Chem.* **2**, 66 (1956).

as eluants and with cation resins such as Dowex 50 and Nalcite HCR.

Americium and promethium are not effectively separated from each other by cation exchange methods when organic chelating agents are used. A method has been described[9] in which 12–13 *N* HCl is used to separate americium from promethium by means of cation exchange. Also, a precipitation method[10] may be used to separate macro quantities of americium and promethium. Americium is more strongly complexed in 3.0 *M* hydrofluosilicic acid, and promethium is precipitated as promethium fluoride.

According to Choppin and Surls,[11] the thiocyanate complex formed with actinide elements is stronger than the complex formed with lanthanide elements of comparable ionic radius. Coleman[12] demonstrated that americium could be separated from gram quantities of lanthanum, cerium, and heavier rare earths by adsorption on Dowex 1 resin from 5.0 *M* ammonium thiocyanate followed by elution with the same reagent.

In the present process of separating Cs^{137} and other fission products from long-decayed fission product solution, Pm^{147} is contained in the crude rare-earth fraction in varying ratio to Cs^{137}, depending on the time in the reactor and the time allowed for decay before separation and purification. Wastes that are allowed to decay for approximately two years after removal from the reactor contain approximately equal amounts of Cs^{137} and Pm^{147}.

There will be 100,000 to 200,000 curies of Cs^{137} produced by the Fission Product Pilot Plant located at ORNL. This plant will also produce an equal amount of Pm^{147} radioactivity. One hundred to two hundred grams of elemental promethium will be produced, associated with from 33 to 66 lb of inactive elemental fission rare earths.

As an intermediate process before the Fission Product Pilot Plant at Oak Ridge is in full production, concentrated fission product solution from the Arco Chemical Processing Plant, Arco, Idaho, is being processed to obtain promethium in quantities of 50 to 500 curies. Solvent extraction with 100% tributyl phosphate removes 80 to 90% of the total rare earths from this solution.[13]

Promethium is increasingly becoming a principal radioisotope because of its wide practical applications. Phosphors prepared with Pm^{147} are not destroyed by radiation. Because Pm^{147} is a pure beta emitter of 0.223 Mev energy, little shielding is necessary in tracer experiments; however, a beta of this energy can easily be counted by ordinary counting methods. X-ray and bremsstrahlung sources that are made by using promethium have energies not greater than 0.223 Mev.

To be more useful, promethium must be purified from inactive and radioactive contaminants to an extremely high degree. Ion exchange methods do effectively purify promethium to this extent.

Equilibrium and elution studies were made with the long-lived rare earths associated with promethium. These experiments were made in an effort to improve the chemical process now used for the purification of Pm^{147} and to aid in designing equipment to be used at 1000- to 5000-curie levels of operation.

EXPERIMENTAL

The raw material from which Pm^{147} is produced is the rare-earth concentrate from the Fission Product Pilot Plant, which contains rare earths (active and stable) between cerium and europium and also yttrium and americium. To determine the procedure for the separation of promethium, it is necessary to determine the chemical characteristics of the other constituents in the concentrate which is used as raw material.

In methods of separation by ion exchange, the most important variables which must be evaluated are distribution coefficients. These distribution coefficients vary with temperature, concentration and type of eluant, type of resin, and flow rate. The characteristics of a system can be predicted if distribution coefficients are known for simple systems and if there is no influence of one constituent on the other. This is not always a valid assumption, and conditions are changed when a radioactive tracer experiment is expanded to

[9] S. G. Thompson, *J. Am. Chem. Soc.* **76**, 6229 (1954).

[10] R. S. Pressly, *Separation of Americium and Promethium*, ORNL-2202 (Mar. 27, 1957).

[11] J. P. Surls and G. R. Choppin, *J. Inorg. & Nuclear Chem.* 4, 62–73 (1957).

[12] J. S. Coleman *et al.*, *J. Inorg. & Nuclear Chem.* 3, 327 (1956–57).

[13] C. L. Ottinger, ORNL, private communication.

much higher levels of concentration and radioactivity. It is sometimes expedient to determine the elution characteristics of a system first and to use the distribution coefficients as a guide in determining best conditions.

In these experiments, elutions were made from both anion and cation resins under different conditions, and distribution coefficients were determined for the more favorable systems.

The empirical structure and charge of the cerous-thiocyanate complex formed in ammonium thiocyanate solutions were determined from a knowledge of the capacity of Dowex 1 and an equilibrium study. By similar studies, one may investigate such effects as radiation damage to resins and eluants or calculate shielding requirements for radiation.

Radioactivities used in tracer experiments were obtained from the Isotopes Sales Department, ORNL. Only fission-produced rare earths were used in the large-scale ion exchange runs.

The resins used in equilibrium and column elution studies were air-dried for several days and placed in capped bottles to retain residual moisture. A weighed amount of the resin was dried for several days in a desiccator to obtain a comparative standard weight.

To obtain distribution coefficients of an activity, a small amount of tracer was added to a known volume of the solution and sampled for analysis. A weighed amount of resin was added to the solution and agitated for ½ hr. From analysis of the solution after equilibrium was established, the distribution coefficient was calculated by the formula:

$$K_d = \frac{\text{counts}\cdot\text{min}^{-1}\cdot\text{g}^{-1}\ \text{(resin)}}{\text{counts}\cdot\text{min}^{-1}\cdot\text{ml}^{-1}\ \text{(solution)}} .$$

Elution curves were drawn from tabulated results obtained from the tracer-level operation of small ion exchange columns and from results of plant-scale operations where the top one-tenth of the ion exchange bed was saturated. "Column volume" as used in this report is defined as the volume of the resin as it settles in the eluant after having been converted to the desired form.

The Am^{241} content was determined by drying aliquots of the solution on stainless steel disks, flaming the plates to red heat, and counting on a 2π alpha counter. Beta activity was detected by an end-window-type G-M counter or, when necessary for less energetic activities such as promethium and europium, by a beta proportional counter.

ELUTION STUDIES

Elution of Rare Earths from Dowex 50 with 0.5 *M* α-Hydroxyisobutyrate at pH 3.0

Separation of rare earths on a tracer scale was accomplished by using Dowex 50-X4 resin and α-hydroxyisobutyrate as eluant. From information reported by Hoffman and Smith,[14] conditions were established for separation of promethium from europium and neodymium on a curie level at a temperature of 30–33°C. The elution curve is shown in Fig. 1. Europium and neodymium were effectively separated from promethium. Americium

[14] H. L. Smith and D. C. Hoffman, *J. Inorg. & Nuclear Chem.* 3, 243–47 (1956).

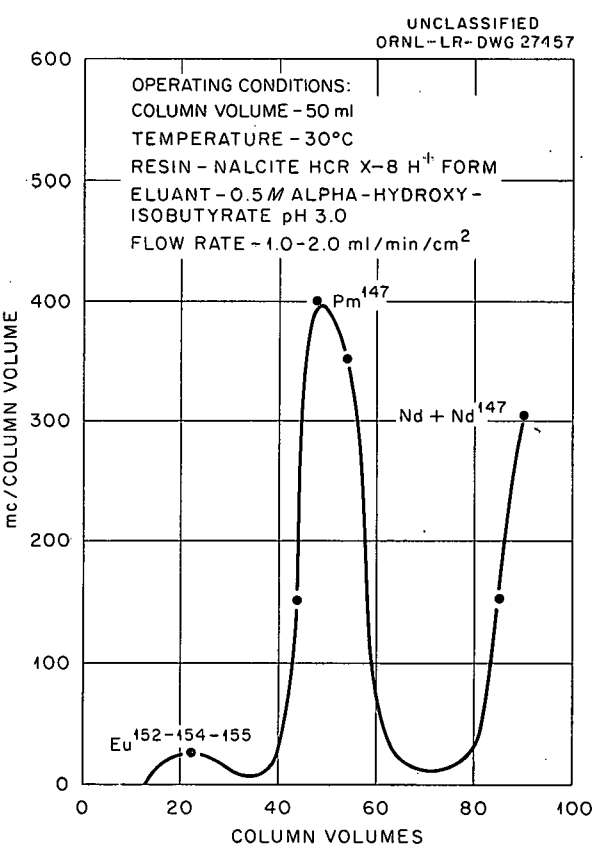

Fig. 1. Elution of Europium, Promethium, and Neodymium from Nalcite HCR-X8 Resin with 0.5 *M* α-Hydroxyisobutyrate.

accompanied the promethium, and, as expected from known separation factors, the peak of americium was after the peak of promethium. Approximately 4 curies of Pm^{147} was obtained from this run, and the final product contained less than 4 mg of neodymium per curie of promethium.

If this eluant is used in the same manner as shown in Fig. 1 and at 1000-curie levels, the cost of promethium is increased four dollars per curie because of the present cost of α-hydroxyisobutyric acid. Thus this process is economically unattractive for use in large-scale production.

Elution of Rare Earths from Dowex 50 with 0.2 *M* Citrate Solution

The starting solution for this ion exchange run contained 20 curies of mixed activities of Eu^{152}, Eu^{154}, Eu^{155}, Pm^{147}, and Am^{241}, plus inactive fission-produced neodymium. In order to trace inactive neodymium, 200 mc of short-lived Nd^{147} was added.

The rare earths were adsorbed on Dowex 50-X8 from 0.1 *N* HNO_3 solution at a temperature of 30–33°C. Elution was carried out with 0.2 *M* citrate, adjusted to pH 3 with NH_4OH, at a temperature of 90–95°C.

Europium separated from promethium, but the americium peak coincided with the promethium peak of activity. Neodymium separated (Fig. 2) within five column volumes following promethium. After the purity of the Nd^{147} had been established by beta absorption curves, the ratio of radioactive Nd^{147} to inactive neodymium was established. From the analyses, the separation factor of neodymium from promethium was calculated to be 2.7. Promethium products recovered from this run contained 14 mg of inactive neodymium per curie of Pm^{147}.

A second cation exchange processing would produce promethium containing less than 6 mg of neodymium per curie of Pm^{147}. This product would be suitable for many uses of Pm^{147}.

Elution of Rare Earths from Dowex 50 with 0.25 *M* Lactate Solution

Seventy-five curies of a mixed long-lived rare-earth activity was adsorbed on 100–200 mesh Nalcite HCR resin. These activities were eluted from the resin bed with 0.25 *M* lactate at pH 4.5 and at a temperature of 90–95°C.

Promethium was separated from europium with a separation factor of 1.4 as calculated from the

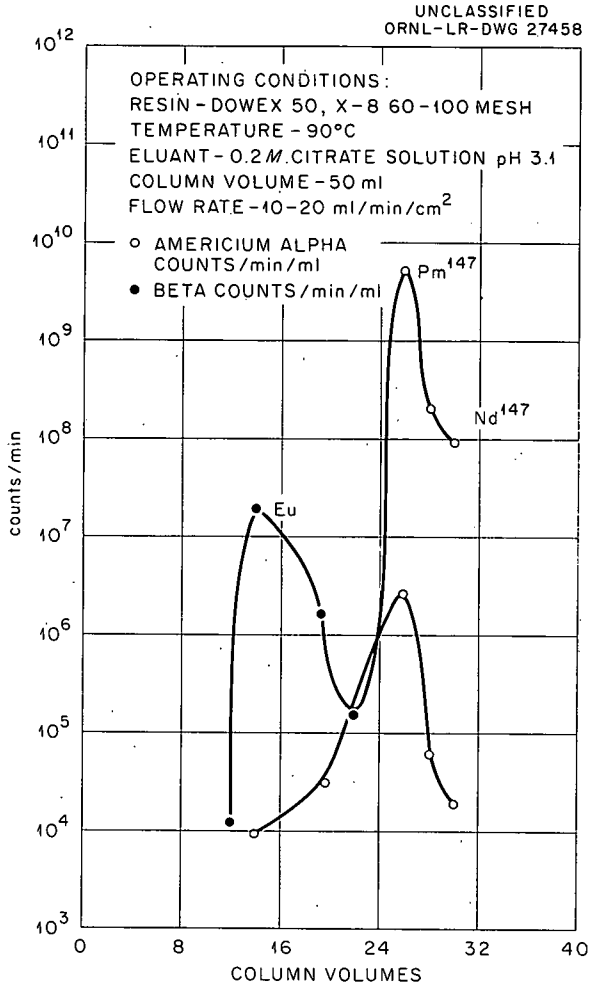

Fig. 2. Elution of Europium, Promethium, Neodymium, and Americium from Dowex 50-X8 Resin with 0.2 *M* Citrate.

elution volumes to the peaks of the activities. From the elution curve, as shown in Fig. 3, there was noticed a definite shift in the elution peak of americium as compared with the citrate elution. Americium elutes before promethium, and much of the americium accompanies the europium. Thus lactate solutions may be used for separating rare earths and are superior to citrate solutions.

Elution of Promethium and Americium from Dowex 1 Resin with 2.0 *M* Ammonium Thiocyanate Solution

Americium and promethium are difficult to separate by a cation exchange process. The promethium used in this experiment contained americium in the amounts that were removed from Dowex 50

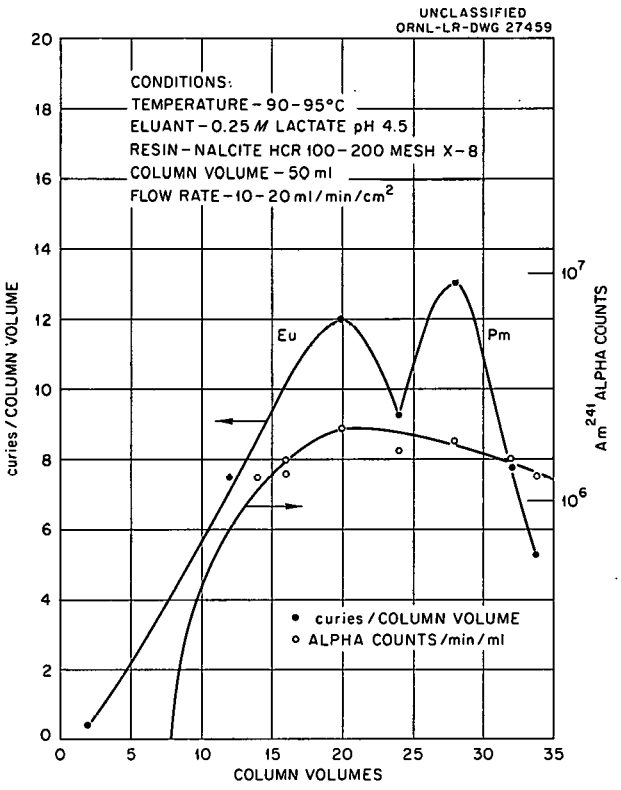

Fig. 3. Elution of Europium, Promethium, and Americium from Nalcite HCR-X8 Resin with 0.25 *M* Lactate.

resin with 0.2 *M* citrate solution. The two activities were adsorbed on a small Dowex 50 resin column, washed with distilled water, and removed with 2.0 *M* ammonium thiocyanate solution.

After sampling, the activities were adsorbed on a Dowex 1 anion exchange column that had been converted to the thiocyanate form by repeated washing with 2.0 *M* NH_4SCN solution. Elution with 2.0 *M* NH_4SCN removed promethium in a peak of activity separated from americium by a factor of 7.0 (see Table 1).

This indicated a large difference in the strength of the complexes of americium and promethium in 2.0 *M* ammonium thiocyanate solution. By the above process americium and promethium can be separated.

Elution of Promethium and Americium from Dowex 1 Resin with 5.0 *M* Ammonium Thiocyanate

The promethium that had been purified with respect to other rare earths by cation exchange methods still contained americium. These activities were adsorbed on a small Dowex 50 resin column and were eluted with 5.0 *M* ammonium thiocyanate solution. From this solution the activities were adsorbed on Dowex 1 resin which had been converted to the thiocyanate form and were then eluted with 5.0 *M* ammonium thiocyanate.

As shown in Fig. 4, promethium was removed from the column and was well separated from americium. Washing the column with seven column volumes of water removed 63% of the americium.

More than 98% of the promethium was recovered from the ammonium thiocyanate solutions by precipitation as $Pm(OH)_3$ upon addition of ammonium hydroxide to a concentration of 4.0 *M*.

Elution of Rare Earths from Dowex 1 Resin with 5.0 *M* Ammonium Thiocyanate

The thiocyanate complexes of Am^{241}, Ce^{144}, inactive neodymium, Pm^{147}, Eu^{152}, Eu^{154}, and Eu^{155} were formed by adding a 0.1 *N* HCl solution of the mixed radioactivities to 5.0 *M* ammonium thiocyanate solution.

The activities were adsorbed from the solution on the top portion of a Dowex 1 resin column. They were eluted with 5.0 *M* NH_4SCN (see Fig. 5). Cerium, neodymium, and promethium were removed in that order. Cerium-144 and promethium-147 were identified by differential absorption counting. The inactive neodymium peak was determined by precipitation of $Nd(OH)_3$ from the 5.0 *M* NH_4SCN solution.

Europium and americium remained on the resin bed; they were removed by washing the column with 0.1 *N* HCl solution.

The results of this experiment show that these rare earths can be separated from each other under the conditions of the experiment.

Elution of Rare Earths from Dowex 1 Resin with 6.0 *M* Ammonium Thiocyanate

Elution of the rare earths cerium through europium from Dowex 1 resin with 5.0 *M* ammonium thiocyanate solution removed promethium, well separated from europium and americium. There were traces of cerium and inactive neodymium in the first portion of the promethium peak.

The concentration of the eluant was increased to 6.0 *M* ammonium thiocyanate, and in order to analyze for inactive neodymium more accurately, tracer Nd^{147} was added to the rare earths adsorbed on the resin bed.

Table 1. Separation of Americium and Promethium by Anion Exchange

Conditions:

Temperature	30–33°C
Resin	Dowex 1-X10, thiocyanate form
Eluant	2.0 *M* ammonium thiocyanate
Column volume	18.0 ml
Flow rate	2 column volumes per hour (0.6 $ml \cdot min^{-1} \cdot cm^{-2}$)

Sample	Beta Activity ($counts \cdot min^{-1} \cdot ml^{-1}$)	Alpha Activity ($counts \cdot min^{-1} \cdot ml^{-1}$)	Beta Counts / Alpha Counts	Identification
	$\times 10^8$	$\times 10^4$	$\times 10^4$	
Pm-X	821	660	1.37	2.0 *M* NH_4SCN; starting solution
Pm-X-4	3.08	4.15	0.74	2.0 *M* NH_4SCN; eluate
Pm-X-5	1.76	2.18	0.80	2.0 *M* NH_4SCN; eluate
Pm-X-6	1.18	0.33	3.60	2.0 *M* NH_4SCN; eluate
Pm-X-7	0.78	0.45	1.73	2.0 *M* NH_4SCN; eluate
Pm-X-8	0.67	0.25	2.68	2.0 *M* NH_4SCN; eluate
Pm-X-9	1.30	0.45	2.80	2.0 *M* NH_4SCN; eluate
Pm-X-12	181.00	19.00	9.53	2.0 *M* NH_4SCN; eluate
Pm-X-13	6.34	5.25	1.21	2.0 *M* NH_4SCN; eluate

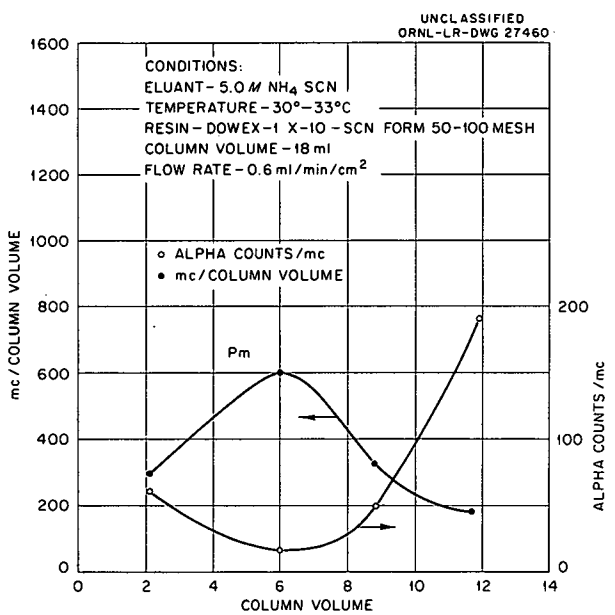

Fig. 4. Elution of Promethium and Americium from Dowex 1-X10 Resin with 5.0 *M* Ammonium Thiocyanate.

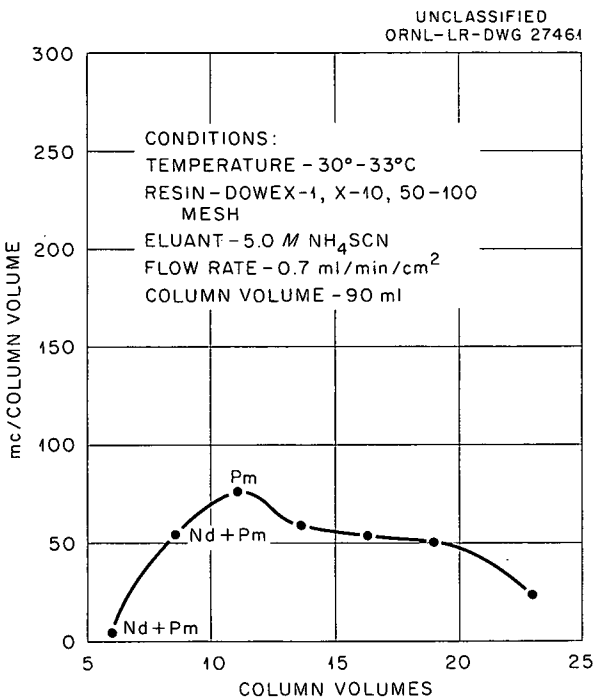

Fig. 5. Elution of Neodymium and Promethium from Dowex 1-X10 Resin with 5.0 *M* Ammonium Thiocyanate.

The elution curve is shown in Fig. 6. Cerium was removed first, followed by neodymium and promethium. A better separation of neodymium from promethium was effected by the increase in the concentration of the ammonium thiocyanate.

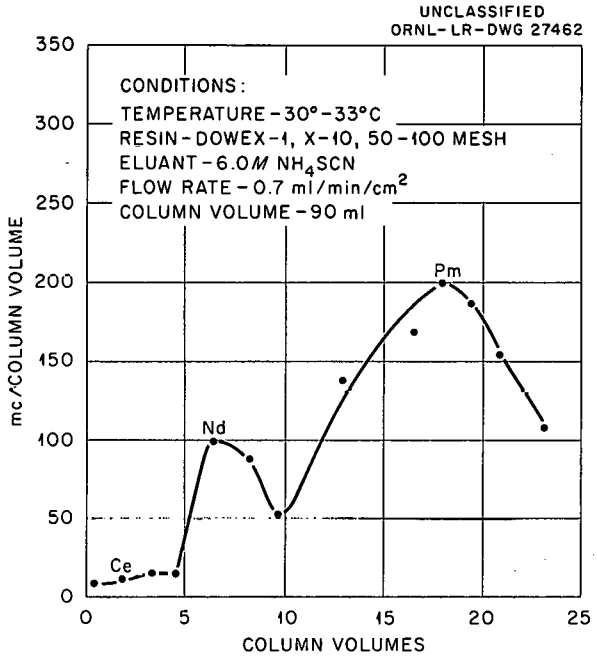

Fig. 6. Elution of Cerium, Neodymium, and Promethium from Dowex 1-X10 Resin with 6.0 *M* Ammonium Thiocyanate.

Europium and americium were removed from the column by washing with 0.1 *N* HCl solution. An analysis by a gamma scintillation spectrometer identified europium and americium. Figure 7 is a graph of the gamma energies usually identified with Eu^{152}, Eu^{154}, and Eu^{155} (1.3, 0.3, 0.7, 0.9, and approximately 1.2 Mev) and with Am^{241} (approximately 40 and 65 kev).

EQUILIBRIUM STUDIES

Determination of Rare-Earth Equilibrium Distribution Coefficients Between Ammonium Thiocyanate and Dowex 1 Resin

Elution of the rare earths cerium through europium from anion resin indicated that the order of elution was that of increasing hydrated ionic radii, or the order of increasing atomic number. Promethium was separated from a mixture of long-lived fission rare earths by anion exchange,

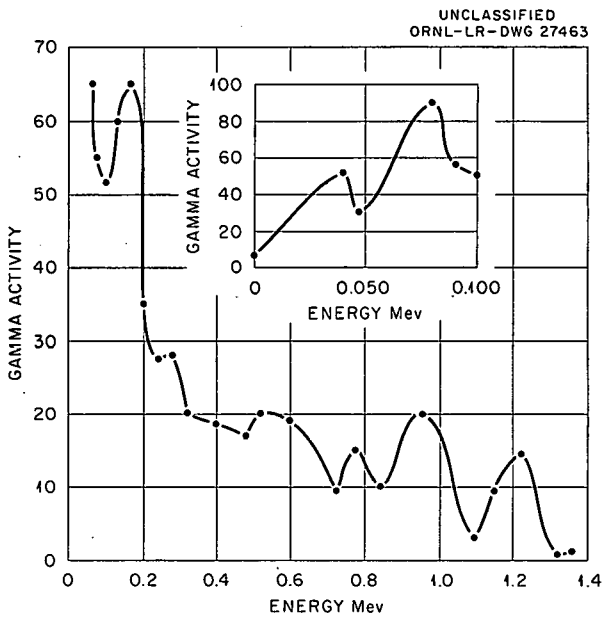

Fig. 7. Gamma-Ray Spectrum of Radioactivity Removed from Dowex 1 Resin by 0.1 *N* Hydrochloric Acid but Not by 6.0 *M* Ammonium Thiocyanate.

efficiently separated from cerium, europium, and americium. Spectrographic analyses indicated the presence of inactive neodymium.

Equilibrium studies, in which Dowex 1 resin and each individual radioisotope were used, showed the difference between the strengths of the complexes formed. Distribution coefficients were determined for cerium, europium, promethium, and americium in various concentrations of ammonium thiocyanate in contact with Dowex 1, 10% cross-linked, 50–100 mesh. The results of these experiments are shown in Figs. 8 and 9.

The distribution coefficient of each rare earth and also that of americium increase with increasing ammonium thiocyanate concentration. This indicates that there is no change in the formula of the complex of a given element after the complex forms in lower concentration.

A ratio of two distribution coefficients indicates the separation factor that may be achieved during ion exchange operations. Increasing the concentration of ammonium thiocyanate above 6.0 *M* does not change the separation factor between americium and promethium, but it does increase the separation factor between europium and promethium.

The order of elution of elements from an anion exchange bed is the same as the order of increasing distribution coefficients when calculated in the manner described. Thus the order of elution of the rare earths cerium through europium is confirmed by distribution coefficients to be the order of increasing atomic number. The distribution coefficient of americium is so large that it is completely separated from these rare earths.

Determination of Distribution Coefficients of Rare Earths in Citrate Solution in Contact with Dowex 1 Resin

Distribution coefficients for rare earths and americium in 0.2 *M* citrate solution in contact with Dowex 1 resin were determined. The purpose of this experiment was to evaluate an anion exchange process for separating americium from promethium, where the starting solution would be a citrate solution from the cation exchange process. Figure 10 shows the change of the distribution coefficients with change of the pH of 0.2 *M* citrate solution.

From this study one may conclude that no efficient separation of americium from promethium

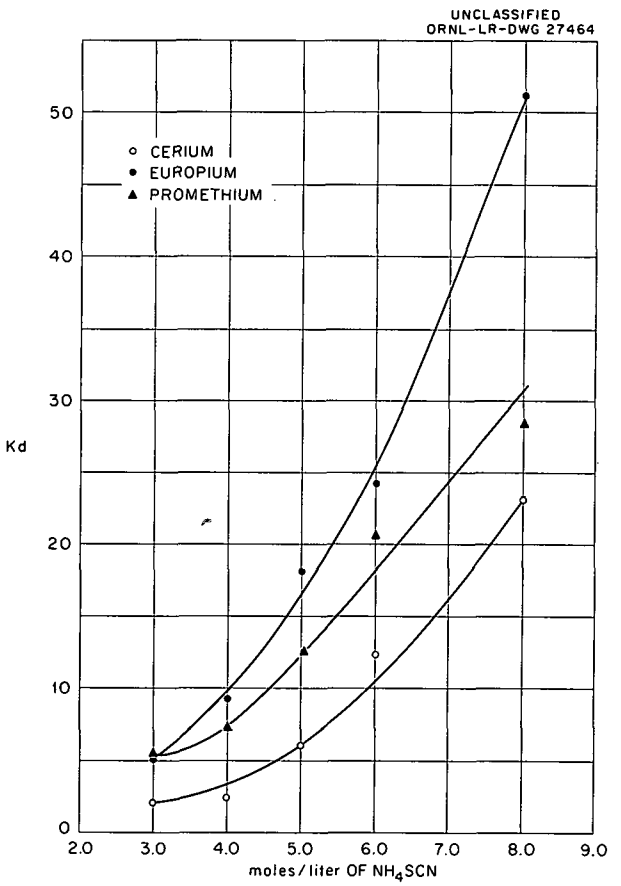

Fig. 8. Distribution Coefficients of Cerium, Promethium, and Europium Between Dowex 1-X10 Resin and Ammonium Thiocyanate Solutions.

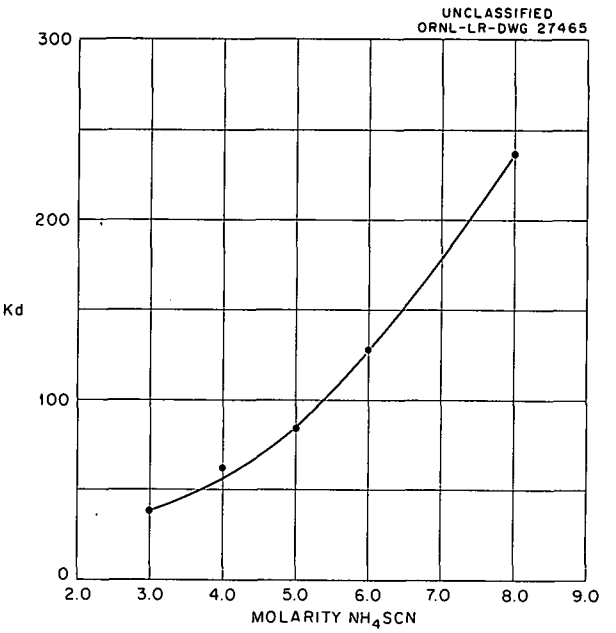

Fig. 9. Distribution Coefficient of Americium Between Dowex 1-X10 Resin and Ammonium Thiocyanate Solutions.

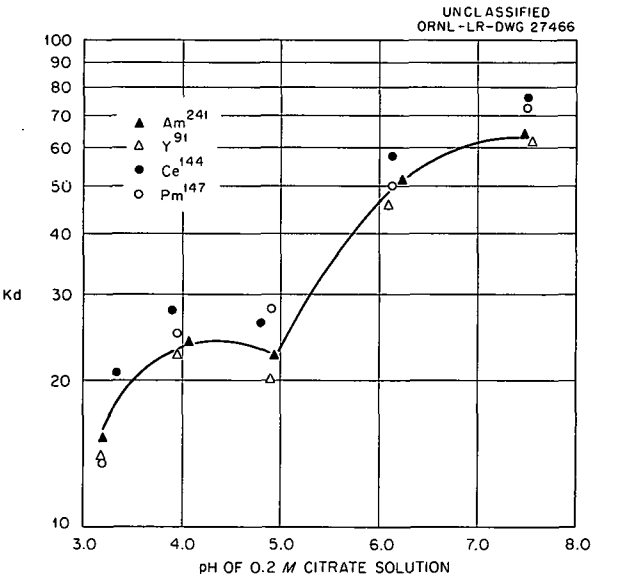

Fig. 10. Effect of pH on Distribution Coefficients of Yttrium, Cerium, Promethium, and Americium Between Dowex 1 Resin and 0.2 *M* Citrate.

would result from an anion exchange process using Dowex 1 resin and 0.2 *M* citrate solution as eluant. There was observed a definite change in the slope of the curves (Fig. 10), which indicates that the formula of the complex ion of rare earths and americium changes in the range of pH between 4 and 6.

Determination of Distribution Coefficients of Americium, Promethium, and Europium in Lactate Solutions in Contact with Dowex 50

Equilibrium studies were made to determine the distribution of americium, promethium, and europium between Dowex 50 (8% cross-linked, 50–100 mesh) and 0.25 *M* lactate solution at various pH's.

Figure 11 shows the change of the distribution coefficients with change of the pH. At a pH greater than 4.5, the distribution coefficient of americium becomes much less than that of promethium and approaches the value of the europium coefficient under the same conditions. This indicates that americium would separate along with europium when both elements are eluted from Dowex 50 with 0.25 *M* lactate at pH 4.5 or higher.

Promethium and europium are best separated when 0.25 *M* lactate is used, at pH 4.4. Under these conditions, the separation factor of promethium from americium, as calculated by a simple ratio of the distribution coefficients, is 1.96.

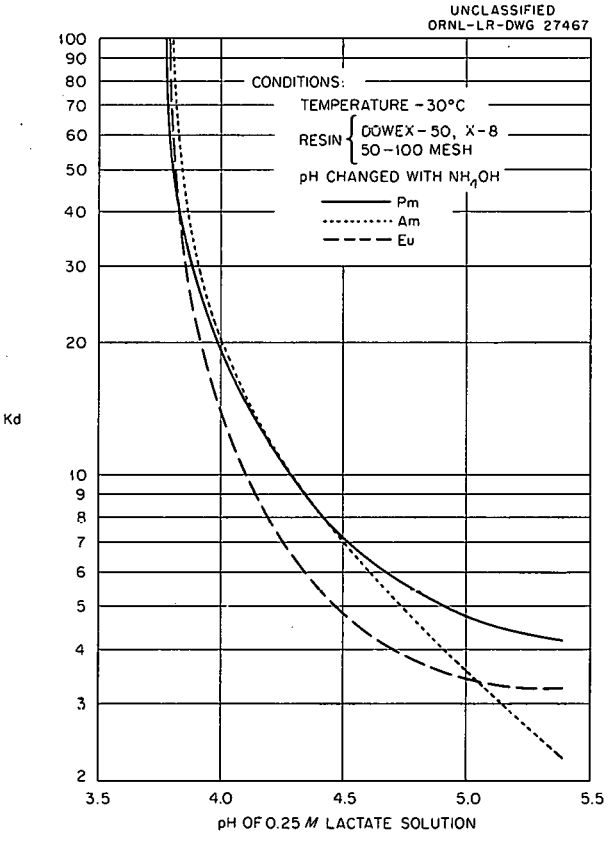

Fig. 11. Effect of pH on Distribution Coefficients of Promethium, Europium, and Americium Between Dowex 50-X8 Resin and 0.25 *M* Lactate.

DETERMINATION OF THE CHARGE AND FORMULA OF THE COMPLEX ION FORMED BY CEROUS ION IN AMMONIUM THIOCYANATE SOLUTIONS

The complexes formed by rare earths and americium in ammonium thiocyanate are the same for each element and differ by the strength of the complex. This is shown by Figs. 8 and 9 in that the slopes of the curves are, in general, constant.

Information concerning the structure of this type of complex aids in engineering and chemical process design, particularly where radiation shielding and radiation damage are important factors.

If Ce^{+++} ions are formed in a solution of NH_4SCN, the possible anions have the general formula $[Ce(SCN)_n]^{(n-3)-}$, where $n = 4, 5, 6, \ldots$. This n cannot equal 1, 2, or 3 because the complex is negatively charged and adsorbs on an anion resin.

The capacity of Dowex 1 resin is 3.2 ± 0.3 meq/g. Cerium-144 was added to a standardized inactive cerous nitrate solution, and the thiocyanate complex was formed by addition of ammonium thiocyanate solution. The resulting solution was added to a small ion exchange resin column containing a weighed amount of Dowex 1 resin. The quantity of the cerous-thiocyanate complex in the solution was estimated to exceed the capacity of the resin by a factor of 3 or 4, and the solution was sent back through the ion exchange column in order to approach equilibrium conditions.

From the tracer analyses one can calculate the empiricial structure of the complex:

Total activity in starting solution, counts/min	1.97×10^8
Total activity left in solution after passing through column, counts/min	1.34×10^8
Total activity adsorbed on resin, counts/min	0.63×10^8
Activity per milligram of cerium, counts/min	5.7×10^5
Weight of resin, g	0.855
Weight of cerium per gram of resin, mg	$\frac{0.63 \times 10^8}{0.57 \times 10^6 \times 0.855} = 129.8$
Milliequivalents of cerium per gram of resin	$\frac{129.8}{46.6} = 2.78$

From this information the composition and charge of the ion correspond to the formula $[Ce(SCN)_6]^{---}$.

CONCLUSION

The equilibrium studies for determining distribution coefficients at a tracer level, and elution curves based on analyses of fractions of eluates from anion and cation exchange processes at activity levels from 1 to 75 curies, establish conditions for the purification of promethium from the other inactive and long-lived radioactive rare earths and from americium produced during fission of U^{235}.

Promethium is purified from fission-produced rare earths by cation exchange using 0.2 *M* citrate, 0.25 *M* lactate, or 0.5 *M* α-hydroxyisobutyrate. A comparison of the efficiencies of the three eluants may be expressed in the following manner:

α-hydroxyisobutyrate > lactate > citrate .

Promethium is separated from americium by adsorbing both the americium and the promethium thiocyanate complexes on Dowex 1 resin and by eluting promethium with 5.0 to 6.0 *M* ammonium thiocyanate solution. Americium remains on the ion exchange column to be desorbed with 0.1 *N* HCl solution.

Radiation damage to resins and solutions is not expected to present difficulty when the process expands to 1000- to 5000-curie levels. Small resin columns were operated with the top portion of the column saturated with 75 to 100 curies of radioactivity. Separation factors as calculated from the column volumes to the elution peaks were as expected from equilibrium studies.

The rare earths cerium through europium may be separated from each other by elution from Dowex 1 resin with 6.0 *M* ammonium thiocyanate. The order of elution is now established to be the order of increasing atomic number. Elution of these activities from Dowex 1 resin with 6 or 8 *M* ammonium thiocyanate solution leaves europium and americium on the resin bed, after promethium is removed. Promethium, with most of the gamma emitters removed, may then be purified in quantities larger than 5000 curies by cation exchange.

The much larger scale operation will furnish solutions enriched in Sm^{151}. This long-lived radioactivity will eventually be ready for distribution.

ACKNOWLEDGMENT

Acknowledgment is made to H. A. Parker and the members of the Radioisotopes Laboratory of the Analytical Chemistry Division, ORNL, for their aid in analysis of the various fission products.

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