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Separation of Fission Products by Ion Exchange Method

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ABSTRACT

The sequential separation of Ru-103, Cs-137 and Ce-144 was carried out by organic cation exchanger, Amberlite CG-120, and inorganic ion exchangers, silica gel and montmorillonite. The optimum conditions of Ru-103, Cs-137 and Ce-144 on Amberlite CG-120 are 0.01M-, 0.01M- and 0.1M- hydrochloric acid for the adsorption, and 3M-, 3M- and 5M-hydrochloric acid for the desorption, respectively. The optimum conditions of Ru-103, Cs-137 and Ce-144 on silica gel are pH 8, pH 8 and pH 8 for the adsorption, and 3M-, 1M- and 1M-hydrochloric acid for the desorption, respectively. The optimum conditions of Ru-103, Cs-137 and Ce-144 on montmorillonite are pH 8, 0.01M-hydrochloric acid and pH 4 for the adsorption, and 1M-, 5M- and 3M-hydrochloric acid for the desorption, respectively.

The adsorption which occurs at lower ionic strength and the differences in desorption ionic strength are utilized for the separation of tracer mixture in continuous experiments. The individual separation of Ru-103, Cs-137 and Ce-144 can be carried out more efficiently with montmorillonite than with silica gel and Amberlite CG-120.

INTRODUCTION

The binary fission of uranium-235 by thermal neutron yields nuclides of 37 elements; that is, from zine to dysprosium or in atomic numbers from 30 to 66, and their atomic masses are distributed between 72 and 161. Cs-137 is important in determining the radioactivity of fission products after long decay periods and is an important biological hazard in old wastes. Recovered from wastes, this isotope is a useful long-lived gamma source. Ce-144, lanthanide element, contributes greatly to the activity of mixed fission products with its short-lived daughter, 17.5-min Pr-144. Ru-103 and Ru-106, both in significant yields, contribute an important part of fission activity. Although Ru-106 emits no gamma rays, it is accompanied by its gamma

emitting daughter, 30-sec Rh-106. Ru-106 is one of the most important fission product contaminants in fuel reprocessing because of its multiple valance states and its complex chemistry in aqueous solutions. In the presence of strong oxidizing agents ruthenium exists as the volatile RuO_4 .

The separation technique of fission products in liquid state covers precipitation¹⁻³⁾, solvent extraction⁴⁻⁶⁾, and ion exchange.⁷⁻¹⁷⁾ Precipitations from solutions have disadvantages of coprecipitation which result in contaminated products. The processes of mixing, precipitation and subsequent filtration and washing do not promote rapid separation. Solvent extraction is widely used for isolation and purification of many radio-nuclides. Ion exchange method is very efficient for the selective separation of tracer amounts of radioactive element from a solution.

Ion exchange techniques are applicable to all

the elements through proper choice of organic resins, media, oxidation and complexing reactions. The techniques are simple and rapid, when short columns are used at moderately rapid flow rates. Synthetic organic ion exchangers have greater uniformity and higher exchange capacity, than natural inorganic exchangers. However, they are more susceptible to radiation damage. Changes in selectivity and capacity occur on exposure to radiation, and degradation takes place at the high temperature. Inorganic ion exchangers are used for the high temperature separation of ionic components in radioactive wastes.

F. Nelson et al.¹²⁾ studied the cation exchange behavior of the elements in HCl and HClO₄ solutions, including Ru-103, Cs-137 and Ce-144. Many elements are strongly adsorbed from concentrated HClO₄ solutions. There are large differences in adsorbility between HCl and HClO₄ solutions. Slower increase of distribution coefficients with molarity in HCl compared with HClO₄ is due to the formation of non-adsorbable chloride complexes.

E. Akatsu et al.¹³⁾ determined the distribution ratios of about 50 elements by batch method. Aqueous phases were 0.1N-10N nitric acid and 0.01-10 M ammonium nitrate solutions.

M. El Garhy et al.¹⁷⁾ used 6N-hydrochloric acid containing a few drops of very dilute HNO₃ in separating ⁹⁵Zr-⁹⁵Nb activity from uranium fission products on silicagel. They found silica gel is highly selective for adsorbing Zr-95 at low acidities, compared with the anion-exchanger Dowex-2 when using chloride media.

Sorption and fixation of microquantities of Cs by montmorillonite were studied by B.R. Sawney.¹⁴⁾ Montmorillonite sorbed more Cs in the presence of K than in the presence of Ca, but did not fix significant amounts of Cs against replacement by neutral salts.

In this study, the sequential separation of Ru-103, Cs-137 and Ce-144 was carried out by cation exchangers: Amberite CG-120 (phenolic methylene sulfonic acid), montmorillonite (aluminium silicate), and silica gel (silicic acid). By using the solutions of different pH and hydrochloric acid of different concentrations as eluant, optimum concentration of the pH

or acid to separate sequentially the radioisotopes was determined by batch and continuous experiments.

EXPERIMENTAL

1. Materials

The tracers used for the experiments were obtained from Radiochemical Centre, Amersham, England. Ru-103 ($t_{1/2}=39.35d$), 1 millicurie per 1 millilitre, ruthenium chloride in 4M-hydrochloric acid, was diluted with distilled water to 0.1 μ Ci/ml. Cs-137 ($t_{1/2}=30.1y$), 10 millicurie per 1 millilitre, cesium chloride in 1M-hydrochloric acid, was diluted with distilled water to 0.1 μ Ci/ml. Ce-144 ($t_{1/2}=284.4d$), 1 millicurie per 1 millilitre, cerous chloride in 1M-hydrochloric acid, was neutralized with sodium hydroxide, i.e. 0.22 μ Ci/ml.

Amberite CG-120, 200-400 mesh, was obtained from Philadelphia, U.S.A., silica gel, Wakogel Q-50, 60-200 mesh, from Wako Pure Chemical Ind. Ltd., Osaka, Japan and montmorillonite from Ward's Natural Science Establishment, New York, U.S.A. All the reagents used in the chemical procedure were of A.R. quality and therefore were used without further purification. The pH value of the solution was adjusted with sodium hydroxide or hydrochloric acid.

2. Procedures

2.1 Batch Experiments

0.05g of Amberite CG-120 were stirred for 3 hours with 0.05ml of the tracer and 5ml of solutions of pH 4 and hydrochloric acid of various molarities, i.e. 0.01M-, 0.05M-, 0.1M-, 0.5M-, 1M-, 2M-, 3M-, 4M-, 5M-, 6M-, 7M-, 8M-hydrochloric acid. After stirring by a Wrist Action Shaker, 3ml of the solution were taken into a centrifuge tube and centrifuged. After settling, 1ml of the solution was pipetted into a test tube and its activity was measured by Nuclear Chicago Model 3725 NaI(Tl) crystal well-type gamma scintillation counter. The Kd value was calculated by the formula.

$$K_d = \left(\frac{\text{counting rate of initial solution}}{\text{counting rate of supernatant solution}} - 1 \right) \times \frac{\text{ml of the aqueous phase}}{\text{g of the adsorbent}} \text{ ml/g}$$

0.05g of montmorillonite were stirred for 3 hours with 0.05ml of the tracer and 5ml of solutions of various pH and hydrochloric acid of various molarities. Acid strengths of 0.01M-, 0.05M-, 0.1M-, 0.5M-, 1M-, 2M-, 3M-, 4M-, 5M-, 6M-, 7M-, 8M-hydrochloric acid and solutions of pH 4, pH 8 and pH 10, were used. The experiment was carried out by the procedure similar to that of Amberite CG-120.

0.05g of silica gel were stirred for 3 hours with 0.05ml of the tracer and 5ml of solutions of various pH and hydrochloric acid of various molarities. Acid strengths of 0.01M-, 0.1M-, 1M-, 3M-, 5M-, 7M-hydrochloric acid and solutions of pH 4 and pH 8, were used. The experiment was carried out by the procedure similar to that of Amberite CG-120.

2.2 Continuous Experiments

The continuous experiments were carried out by using a glass column containing the exchanger bed 5mm (inside diameter) by 12cm long.

Amberite CG-120 on the column was first conditioned by treatment with 3M-hydrochloric acid in case of Ru-103 and Cs-137, and 5M-hydrochloric acid in Ce-144, respectively. 0.1 ml of Ru-103 in 0.01 M-hydrochloric acid, 0.05ml of Cs-137 in 0.01M-hydrochloric acid and 0.05ml of Ce-144 in 0.1M-hydrochloric acid, were added to the top of the columns, respectively, and then washed with 0.01M-hydrochloric acid in case of Ru-103 and Cs-137, and 0.1M-hydrochloric acid in Ce-144. The flow rate through the columns was 0.1 millilitre per 1 minute. The effluent was collected in 1ml portions and the activity in successive samples was measured. The columns were eluted with 3M-hydrochloric acid in case of Ru-103 and Cs-137, and 5M-hydrochloric acid in Ce-144, respectively. The eluate was collected and the activity in samples was measured.

Silica gel on the column was first conditioned by treatment with 3M-hydrochloric acid in case of Ru-103, and 1M-hydrochloric acid in Cs-137 and Ce-144, respectively. 0.1ml of Ru-103, and 0.05ml of Cs-137 and 0.05ml of Ce-144 in pH 8 solution, respectively, were added to the top of the columns, and then washed with pH 8 solution. The flow rate

through the columns was 0.1 millilitre per 1 minute. The effluent was collected in 1ml portions and the activity in successive samples was measured. The columns were eluted with 3M-hydrochloric acid in case of Ru-103, 1M-hydrochloric acid in Cs-137 and Ce-144, respectively. The eluate was collected and the activity in samples was measured. 0.05ml of the mixture in pH 8 solution were treated by the procedure similar to that of the experiment, carried out with each tracer, Ru-103, Cs-137 and Ce-144. The column was washed with pH 8 solution, and eluted with 3M-hydrochloric acid. The activity portions of the sample solutions were collected and analyzed by the method of paper electrophoresis.¹⁸⁾

The continuous experiment for montmorillonite was used with the stirring apparatus. 0.05g of montmorillonite were stirred for 3 hours with 0.1ml Ru-103 and 5ml of pH 8 solution, 0.05ml Cs-137 and 5ml of 0.01M-hydrochloric acid solution, and 0.05ml Ce-144 and 5ml of pH 4 solution, respectively. After stirring by a Wrist Action Shaker, 3ml of the solution were taken into a centrifuge tube and centrifuged. After settling, 1ml of the solutions was pipetted into a test tube and its activity in sample was measured. The tracer on the montmorillonite was desorbed with 5ml of 1M-hydrochloric acid in case of Ru-103, 5M-hydrochloric acid in Cs-137, and 3M-hydrochloric acid in Ce-144, respectively. After stirring, centrifuging and settling, the activity in sample was measured. The procedure was continued with appropriate solutions.

0.05ml of the mixture were treated by the procedure similar to that of the experiment, carried out with each tracer, Ru-103, Cs-137 and Ce-144. The tracers on the montmorillonite was stirred with pH 8 solution, and desorbed with 1M-hydrochloric acid. The activity in sample was measured and analyzed by the method of paper electrophoresis.

RESULTS AND DISCUSSION

1. Adsorption and desorption on Amberite CG-120

The results of the batch experiment studies

Table 1. Batch Experiment. Adsorption of ¹⁰³Ru, ¹³⁷Cs and ¹⁴⁴Ce from solutions of pH 4 and hydrochloric acid of various molarities by Amberite CG-120.

Soution	Kd, ml/g		
	Ru-103	Cs-137	Ce-144
pH 4	316	256	10019
0.01M-HCl	357	1240	2784
0.05M-HCl	205	194	7120
0.1M-HCl	129	166	72290
0.5M-HCl	223	135	8910
1M-HCl	7	32	2423
2M-HCl	1	-0.6	-0.7
3M-HCl	-1	-2.6	1
4M-HCl	0.4	0.4	1
5M-HCl	0.4	-0.1	-3.1
6M-HCl	0.4	0.9	0.1
7M-HCl	-3	-0.7	1.4
8M-HCl	1.4	-1.8	-0.2

obtained from 0.05g of Amberite CG-120 by stirring for 3 hours with 0.05ml of Ru-103, Cs-137 and Ce-144, and 5ml of solutions of pH 4 and hydrochloric acid of various molarities are shown in Table 1.

The Kd value for Ru-103 shows maximum in 0.01M-hydrochloric acid. Adsorption of Ru-103 by Amberite CG-120 increases from pH 4 to 0.01M-hydrochloric acid and decreases rapidly with incre-

asing hydrochloric acid from 0.01M- to 2M-, and then levels off. With solutions of hydrochloric acid greater than 2M-, Ru-103 is little adsorbed on Amberite CG-120.

The Kd value for Cs-137 shows maximum in 0.01M-hydrochloric acid. Adsorption of Cs-137 by Amberite CG-120 increases from pH 4 to 0.01M-hydrochloric acid. The adsorption decreases slowly from 0.01M- to 0.1M- and decreases rapidly with increasing hydrochloric acid from 0.1M- to 2M- and then levels off. With solutions of hydrochloric acid greater than 2M-, Cs-137 is little adsorbed on Amberite CG-120.

The Kd value for Ce-144 shows maximum in 0.1M-hydrochloric acid. Adsorption of Ce-144 by Amberite CG-120 decreases from pH 4 to 0.01M-hydrochloric acid and increases from 0.01 M- to 0.1M-. The adsorption decreases rapidly with increasing hydrochloric acid from 0.1M- to 2 M- and then levels off. With solutions of hydrochloric acid greater than 2M-, Ce-144 is little adsorbed on Amberbed CG-120.

The optimum conditions for the adsorption and the desorption of Ru-103, Cs-137and Ce-144 are found from Table 1, that is, maximum adsorption in 0.01M-, 0.01M- and 0.1M-hydrochloric acid, respectively, and effective desorption in 3M-, 3M- and 5M-hydrochloric acid, respectively.

The results of the continuous experiment studies for the separation of Ru-103, Cs-137 and Ce-144 by

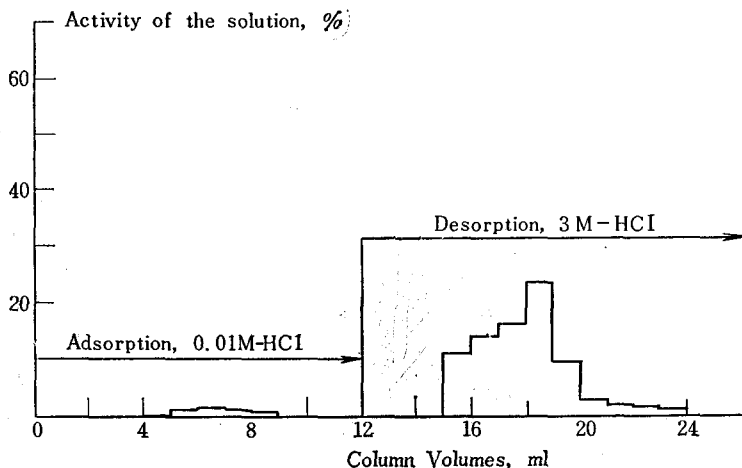


Fig. 1. Continuous Experiment. Adsorption and desorption of Ru-103 by Amberite CG-120.

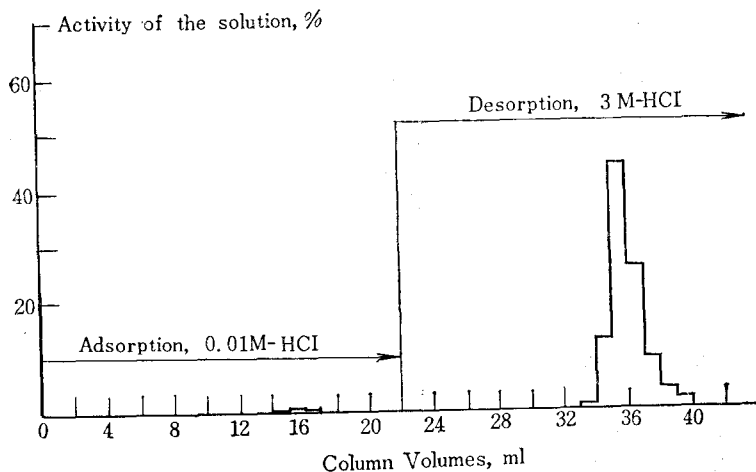


Fig. 2. Continuous Experiment. Adsorption and desorption of Cs-137 by Amberlite CG-120.

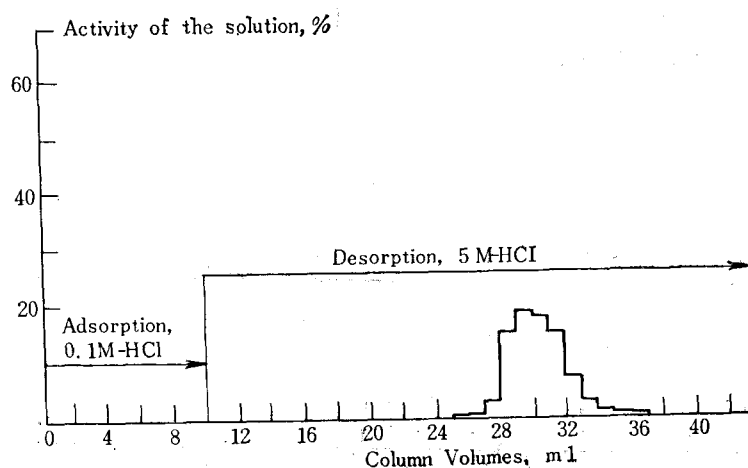


Fig. 3. Continuous Experiment. Adsorption and desorption of Ce-144 by Amberlite CG-120.

Amberlite CG-120 are shown in Figures 1, 2 and 3. In Figures, the radioactivities of the effluents and the eluates from the column are plotted against the volume of the effluents and the eluates.

On the separation of Ru-103 from 0.1ml of the initial solution using Amberlite CG-120 adsorption and 3M-hydrochloric acid as eluant, 84.6% of Ru-103 is desorbed by this strength of hydrochloric acid. 3.4% of Ru-103 is not adsorbed in the solution of 0.01M-hydrochloric acid.

On the separation of Cs-137 from 0.05ml of the initial solution using Amberlite CG-120 adsorption and 3M-hydrochloric acid as eluant, 95.5% of Cs-137 is desorbed by this strength of hydrochloric acid. 0.8% of Cs-137 is not adsorbed in the solution of 0.01M-hydrochloric acid.

On the separation of Ce-144 from 0.05ml of the initial solution using Amberlite CG-120 adsorption and 5M-hydrochloric acid as eluant, 81.1% of Ce-144 is desorbed by this strength of hydrochloric acid. 100% of Ce-144 is adsorbed in the solution of 0.1M-hydrochloric acid.

2. Adsorption and desorption on silica gel

The results of the batch experiment studies obtained from 0.05g of silica gel by stirring for 3 hours with 0.05ml of Ru-103, Cs-137 and Ce-144, and 5ml of solutions of various pH and hydrochloric acid of various molarities are shown in Table 2.

The K_d value for Ru-103 shows maximum in the solution of pH 8. Adsorption of Ru-103 by silica gel decreases rapidly from pH 8 to pH 4.

Table 2. Batch Experiment. Adsorption of ¹⁰³Ru, ¹³⁷Cs and ¹⁴⁴Ce from solutions of various pH and hydrochloric acid of various molarities by silica gel.

Solution	Kd, ml/g		
	Ru-103	Cs-137	Ce-144
pH 8	166	47	34831
pH 4	7	16	1269
0.01M-HCl	2	8	1030
0.1M-HCl	2	0.4	34
1M-HCl	0.9	-4.6	0
3M-HCl	-2.4	-2.0	1
5M-HCl	4.1	-4.3	2
7M-HCl	2.8	-3.6	2

The adsorption decreases slowly from pH 4 to 0.01M-hydrochloric acid and then levels off. With solutions of hydrochloric acid greater than 0.01M-, Ru-103 is little adsorbed on silica gel.

The Kd value for Cs-137 shows maximum in the solution of pH 8. Adsorption of Cs-137 by silica gel decreases slowly from pH 8 to 0.1M-hydrochloric acid and then levels off. With solutions of hydrochloric acid greater than 0.1M-, Cs-137 is little adsorbed on silica gel.

The Kd value for Ce-144 shows maximum in the solution of pH 8. Adsorption of Ce-144 by silica gel decreases slowly from pH 8 to 0.01M-hydrochloric acid and decreases rapidly with increasing from 0.01M- to 1M- and then levels off. With

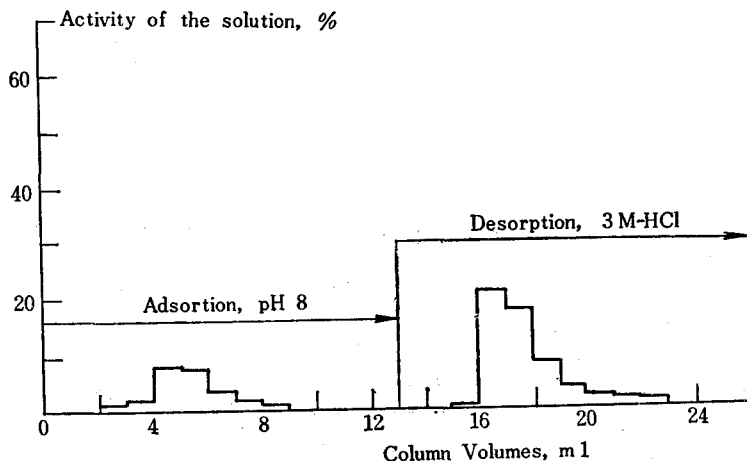


Fig. 4. Continuous Experiment. Adsorption and desorption of Ru-103 by silica gel.

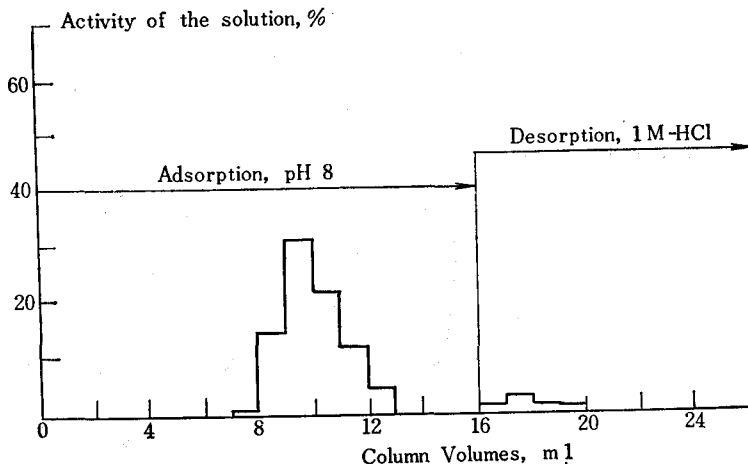


Fig. 5. Continuous Experiment. Adsorption and desorption of Cs-137 by silica gel.

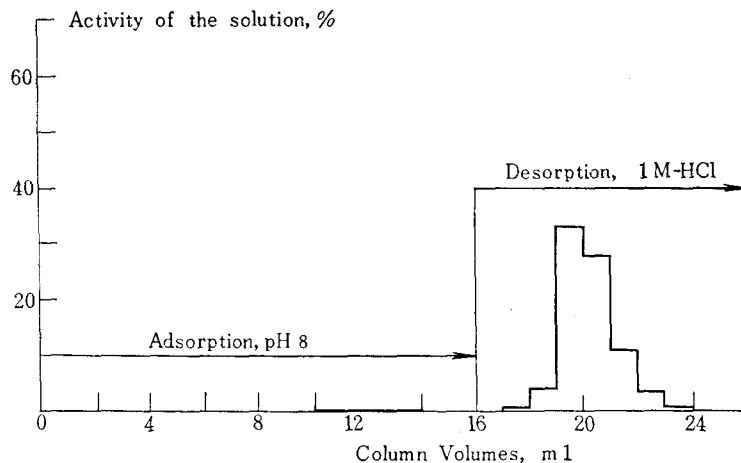


Fig. 6. Continuous Experiment. Adsorption and desorption of Ce-144 by silica gel.

solutions of hydrochloric acid greater than 1M-, Ce-144 is little adsorbed on silica gel.

The optimum conditions for the adsorption and the desorption of Ru-103, Cs-137 and Ce-144 are found from Table 2, that is, maximum adsorption in pH 8, pH 8 and pH 8, respectively, and effective desorption in 3M-, 1M- and 1M-hydrochloric acid, respectively.

The results of the continuous experiment studies for the separation of Ru-103, Cs-137 and Ce-144 by silica gel are shown in Figures 4, 5 and 6.

On the separation of Ru-103 from 0.1ml of the Initial solution using silica gel adsorption and 3M-hydrochloric acid as eluant, 54.9% Ru-103 is desorbed by this strength of hydrochloric acid. 22.0% of Ru-103 is not adsorbed in the solution of pH 8.

On the separation of Cs-137 from 0.05ml of the initial solution using silica gel adsorption and 1M-hydrochloric acid as eluant, 5.9% of Cs-137 is desorbed by this strength of hydrochloric acid. 83.5% of Cs-137 is not adsorbed in the solution of pH 8.

On the separation of Ce-144 from 0.05ml of the initial solution using silica gel adsorption and 1M-hydrochloric acid as eluant, 79.4% of Ce-144 is desorbed by this strength of hydrochloric acid. 0.4% of Ce-144 is not adsorbed in the solution of pH 8.

In the paper electrophoresis histogram of the concentrated solutions, which obtained from the

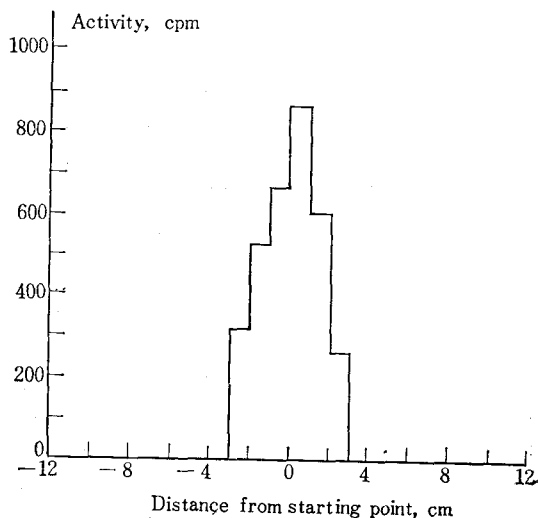


Fig. 10. Paper electrophoresis histogram of tracer mixture by silica gel.

high activity portions of the desorbed solutions in the experiment with tracer mixture, the radioactivity appears one peak as shown in Fig. 10. The peak at +1cm is identified as Ru-103, which is in agreement with the results reported in the literature.¹⁸⁾

3. Adsorption and desorption on montmorillonite

The results of the batch experiment studies obtained from 0.05g of montmorillonite by stirring:

Table 3. Batch Experiment. Adsorption of ¹⁰³Ru, ¹³⁷Cs and ¹⁴⁴Ce from solutions of various pH and hydrochloric acid of various molarities by montmorillonite.

Solution	Kd, ml/g		
	Ru-103	Cs-137	Ce-144
pH 10	1401	2323	26536
pH 8	2724	2124	42185
pH 4	2326	3690	45004
0.01M-HCl	50	5126	41503
0.05M-HCl	28	3166	22853
0.1M-HCl	14	799	7067
0.5M-HCl	1	508	761
1M-HCl	-1.1	146	-9.1
2M-HCl	1	142	-4.0
3M-HCl	1	127	-11.0
4M-HCl	-0.4	72	0.8
5M-HCl	-0.6	-1.0	-0.7
6M-HCl	0.4	-0.7	-2.1
7M-HCl	-1.5	1.4	-0.9
8M-HCl	-0.6	0	-2.3

for 3 hours with 0.05ml of Ru-103, Cs-137 and Ce-144, and 5ml of solutions of various pH and hydrochloric acid of various molarities are shown in Table 3.

The Kd value for Ru-103 shows maximum in the solution of pH 8. Adsorption of Ru-103 by montmorillonite increases from pH 10 to pH 8. The adsorption decreases slowly from pH 8 to pH 4 and

decreases rapidly from pH 4 to 1M-hydrochloric acid and then levels off. With solutions of hydrochloric acid greater than 1M-, Ru-103 is little adsorbed on montmorillonite.

The Kd value for Cs-137 shows maximum in 0.01M-hydrochloric acid. Adsorption of Cs-137 by montmorillonite decreases from pH 10 to pH 8 and increases from pH 8 to 0.01M-hydrochloric acid. The adsorption decreases hydrochloric acid from 0.01M- to 3M- and decreases rapidly with increasing hydrochloric acid from 3M- to 5M- and then levels off. With solutions of hydrochloric acid greater than 5M-, Cs-137 is little adsorbed on montmorillonite.

The Kd value for Ce-144 shows maximum in the solutions of pH 4. Adsorption of Ce-144 by montmorillonite increases slowly from pH 10 to pH 4 and decreases slowly from pH 4 to 0.1M-hydrochloric acid. The adsorption decreases rapidly with increasing hydrochloric acid from 0.1M- to 1M-. With solutions of hydrochloric acid greater than 1M-, Ce-144 is little adsorbed on montmorillonite.

The optimum conditions for the adsorption and the desorption of Ru-103, Cs-137 and Ce-144 are found from Table 3, that is, maximum adsorption in pH 8, 0.01M-hydrochloric acid and pH 4, respectively, and effective desorption in 1M-, 5M- and 3M-hydrochloric acid, respectively.

The results of the continuous experiment studies for the separation of Ru-103, Cs-137 and Ce-144 by montmorillonite in Figures 7, 8 and 9.

On the separation of Ru-103 from 0.1ml of the

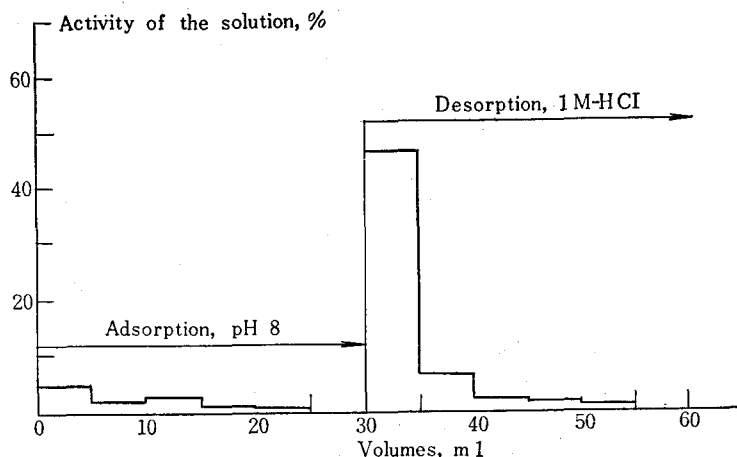


Fig. 7. Continuous Experiment. Adsorption and desorption of Ru-103 by montmorillonite.

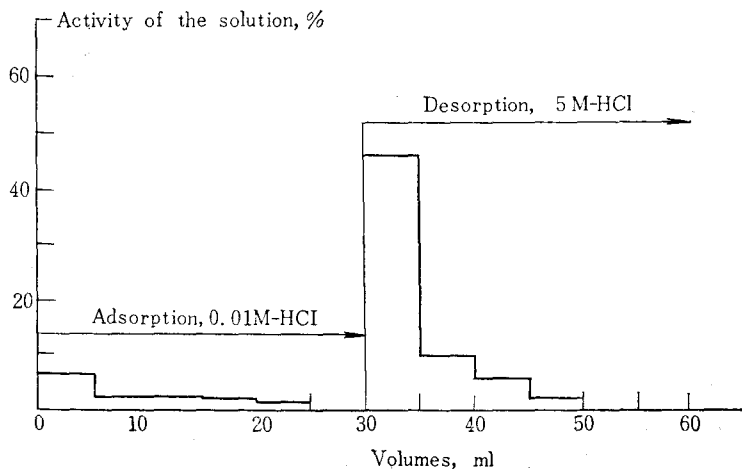


Fig. 8. Continuous Experiment. Adsorption and desorption of Cs-137 by montmorillonite.

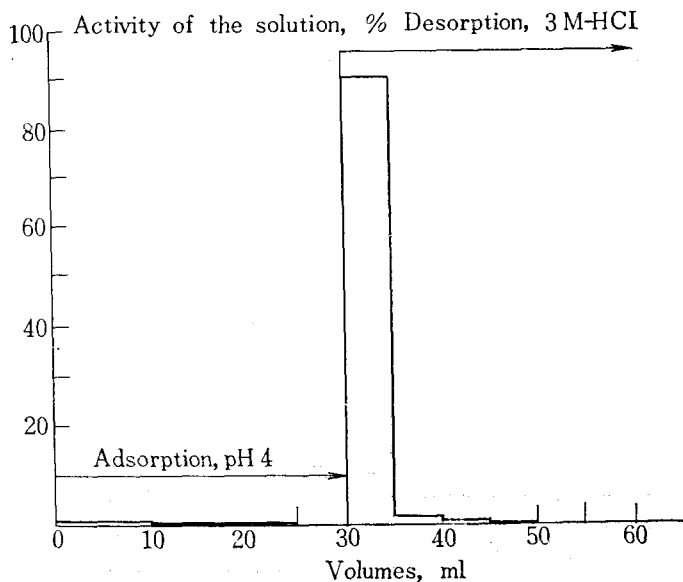


Fig. 9. Continuous Experiment. Adsorption and desorption of Ce-144 by montmorillonite.

initial solution using montmorillonite adsorption and 1M-hydrochloric acid as eluant, 57.4% of Ru-103 is desorbed by this strength of hydrochloric acid. 11.0% of Ru-103 is not adsorbed in the solution of pH 8.

On the separation of Cs-137 from 0.05ml of the initial solution using montmorillonite adsorption and 5M-hydrochloric acid as eluant, 62.5% of Cs-137 is desorbed in this strength of hydrochloric acid. 15.0% of Cs-137 is not adsorbed in the solution of 0.01M-hydrochloric acid.

On the separation of Ce-144 from 0.05ml of the initial solution using montmorillonite adsorption and 3M-hydrochloric acid as eluant, 93.2% of Ce-144 is desorbed by this strength of hydrochloric acid. 1.4% of Ce-144 is not adsorbed in the solution of pH 4.

In the paper electrophoresis histogram of the concentrated solutions, which obtained from the high activity portions of the desorbed solutions in the experiment with tracer mixture, the radioactivity appears one peak as shown in Fig. 11. The peak

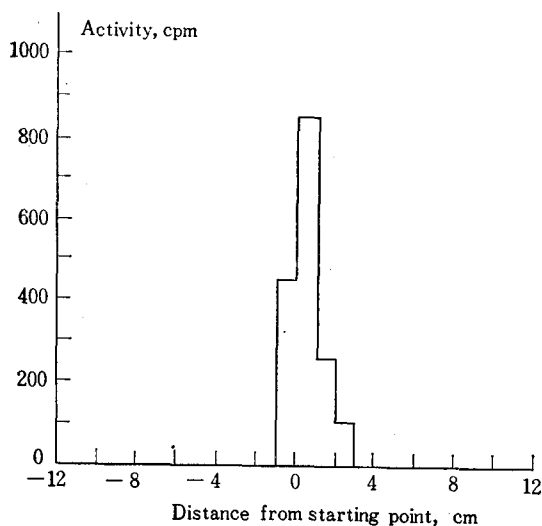


Fig. 11. Paper electrophoresis histogram of tracer mixture by montmorillonite.

at +1cm is identified as Ru-103, which is in agreement with the results reported in the literature.¹⁸⁾

CONCLUSION

The adsorption which occurs at lower ionic strength and the differences in desorption ionic strength are utilized for the separation of elements both individually and in groups.

The cation exchange data for Ru-103, Cs-137 and Ce-144 in the solutions of various pH and hydrochloric acid of various molarities shows that the separation of Ru-103, Cs-137 and Ce-144 can be carried out more efficiently with montmorillonite than with silica gel and Amberlite CG-120.

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< 論 文 >

이온 교환법에 의한 핵분열生成物の分離

이 병 현 · 방 제 건

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요 지

Ru-103, Cs-137 그리고 Ce-144를 차례로 분리하는 방법을 유기양이온 교환체 Amberite CG-120, 무기이온 교환체, silica gel과 montmorillonite를 가지고 검토하였다. Amberite CG-120으로 Ru-103, Cs-137 그리고 Ce-144를 흡착 및 탈착하는 최적조건은 각각 0.01M-, 0.01M-, 0.1M-HCl과 3M-, 3M-, 5M-HCl이다. Silica gel로 Ru-103, Cs-137 그리고 Ce-144를 흡착 및 탈착하는 최적 조건은 각각 pH 8, pH 8, pH 8과 3M-, 1M-, 1M-HCl이다. Montmorillonite로 Ru-103, Cs-137 그리고 Ce-144를 흡착 및 탈착하는 최적 조건은 각각 pH 8, 0.01M-HCl, pH 4와 1M-, 5M-, 3M-HCl이다.

낮은 이온강도에서 일어나는 흡착 그리고 탈착 이온강도의 차이는 연속적인 실험에서 혼합핵종의 분리를 위하여 이용된다. Ru-103, Cs-137 그리고 Ce-144 혼합물의 개별분리는 Amberite CG-120, silica gel에서보다 montmorillonite에서 더욱 효과적이다.