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ANION EXCHANGE OF NEPTUNIUM IN NITRATE SOLUTIONS

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by

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ABSTRACT

The absorption and elution of the anionic nitrate complex of neptunium (IV) were studied with several anion exchange resins and under a wide variety of conditions.

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ANION EXCHANGE OF NEPTUNIUM IN NITRATE SOLUTIONS

INTRODUCTION

This investigation was prompted by interest in the recovery of neptunium from solutions produced in the chemical processing of irradiated uranium. Previous work⁽¹⁾ had shown the advantages of separating plutonium by anion exchange of Pu(IV) in nitrate solutions. Because of the similarity of Np and Pu chemistry,⁽²⁾ anion exchange was expected to provide a convenient method for isolating Np.

The objective of this study was to provide a technical basis for selecting process conditions for the recovery of Np. The variables affecting the absorption and elution of the anionic nitrate complex of Np(IV) required study, as did methods of controlling the valence of Np.

SUMMARY

Neptunium (IV) in strong nitric acid - nitrate salt solutions forms an anionic nitrate complex that is absorbed by anion exchange resins. This behavior offers an attractive possibility for the recovery and purification of Np from plant solutions. In this study, the effects of variables that influence the absorption on anion resins were determined by batch equilibrations. The batch equilibration data were evaluated and the absorption and elution characteristics of Np were confirmed by experiments on fixed columns of resin.

Np(IV) is produced when the nitric acid - nitrate salt solution is reduced by a number of reagents, including ferrous sulfamate, hydrogen peroxide, ferrous sulfamate with hydrazine, and ascorbic acid with sulfamic acid. The combination of ferrous sulfamate and hydrazine is recommended because it has greater stability and causes less gassing in the resin bed than do the other reagents.

As absorbents for the neptunium (IV) anion complex, both "Dowex" 1-X4, 50 to 100-mesh resin and "Permutit" SK, 40 to 80-mesh resin combine effective absorption with high capacity. The Np is eluted from either resin at a high concentration. For the most effective recovery of Np, both absorption and elution are performed at approximately 25°C at relatively low flows.

DISCUSSION

CHEMISTRY OF NEPTUNIUM IN NITRATE SOLUTIONS

Neptunium can exist in the (IV), (V), and (VI) oxidation states in nitric acid solution. All three valences can exist together in nitric acid, and in most solutions an oxidizing or reducing agent is necessary to fix the Np in a single oxidation state.

The only oxidation state of importance with respect to the formation of an anionic nitrate complex is the (IV) state.⁽²⁾ Np(IV) is relatively stable in 8M nitric acid containing sulfamate ion, due to the combined effects of the nitrate complexing of the Np(IV) and the sulfamate scavenging of the nitrite ion. At 60°C, Np(IV) in 8M nitric acid oxidizes slowly to Np(VI). In more dilute nitric acid, the Np(IV) is less stable, oxidizing relatively rapidly to (V); however, further oxidation to (VI) is slow.

Standard oxidation potentials indicate that Fe(II) will reduce Np(VI) to (V) at 1M hydrogen ion concentration. Np(V) is rapidly reduced to Np(IV) with ferrous sulfamate in 8M nitric acid or in a solution containing 8M nitrate ion that is at least 1M in hydrogen ion. The reduction to the (IV) state involves a power dependence on the hydrogen ion concentration and is, in addition, promoted by the shift in potential due to nitrate complexing of Np(IV). Sulfamate ion, hydrazine, or some other holding reductant is necessary to increase the stability of the Fe(II) in the nitric acid - nitrate solutions in order to ensure complete reduction to Np(IV).

Semicarbazide and hydrazine rapidly reduce Np(VI) to Np(V) in nitric acid. Reduction from the (V) to the (IV) state, however, is very slow with these reagents. In 8M nitric acid, the time required for reduction to Np(IV) with 0.05M hydrazine at 25°C is approximately 24 hours; at 65°C approximately one hour. By contrast, a combination of 0.05M hydrazine and 0.05M ferrous ion gives complete reduction to Np(IV) in less than 30 minutes at 25°C.

Reduction of Np(VI) or (V) to the (IV) state can also be accomplished with hydrogen peroxide or ascorbic acid in strong acid solutions. Reduction by hydrogen peroxide in 4 to 8M nitric acid is complete in less than 30 minutes at 25°C. Reduction by ascorbic acid in 8M nitric acid is also rapid at 25°C, but the ascorbic acid is rapidly decomposed by the nitric acid, even with 0.05M sulfamic acid present.

By analogy with the known chemistry of plutonium⁽¹⁾, it is assumed that in solutions containing a high concentration of nitrate ion the anionic nitrate complex of Np(IV) is $\text{Np}(\text{NO}_3)_6^-$, and that this complex is strongly absorbed by anion exchange resins according to the following equation.

The absorption reaches a maximum in the range of 7 to 9M nitrate ion, and is quite efficient over the range 6 to 10M nitrate. Elution from the resin is favored by a low nitrate concentration that causes ionization of the absorbable anionic complex.

The relative absorbabilities of the actinides in various valence states are shown in the following table.

Relative Absorbability of Actinides

Element	Distribution Ratio ^(a) , R_D
Np(IV)	600
Np(V)	<10
Np(VI)	<25
Pu(III)	<10
Pu(IV)	1000
Th(IV)	150
U(VI)	20

(a) Distribution ratio after one-hour equilibration of actinide in 8M nitric acid with "Dowex" 1-X4 resin

EXPERIMENTAL PROCEDURE

All resins used in this work were converted to the nitrate form by washing the chloride form, as-received from the vendor, with 2M nitric acid until the effluent showed no test for chloride with silver nitrate.

Batch distribution ratios, R_D , were determined to evaluate the effects of variables on the affinity^D of the resins for neptunium. A 20 to 50-ml solution containing Np(IV) was equilibrated with 1 ml of resin for one hour. The distribution ratio (R_D), as used in this report, is defined as the ratio of Np absorbed per ml of resin to the Np unabsorbed per ml of solution after one hour of equilibration. The reproducibility of the distribution ratios was $\pm 10\%$, and the values were lower than the equilibrium distribution coefficients because of the slow diffusion of the anionic nitrate species into the resin beads.

In addition to the batch distribution measurements, the absorption and elution of Np were studied with solutions of different composition in small laboratory columns of anion exchange resins. The effects of flow, solution composition, and type of resin on both absorption and elution were determined in fixed beds of resin 25.5 cm long with a cross-sectional area of 0.4 cm².

For convenience, the absorption data were evaluated by comparison of "breakthrough" curves; 10% breakthrough was taken as indication of a significant loss of product to the effluent solution and is defined as the point at which $C/C_0 = 0.1$, where C is the instantaneous concentration of Np in the effluent and C_0 is the concentration of Np in the feed solution. The breakthrough curves are plotted as a function of bed volumes of solution. A bed volume is defined as the bulk volume, in settled form, of the resin in the bed.

The variables affecting the elution of Np from the resin were evaluated by comparing elution curves that show the instantaneous concentration of the Np in the eluate.

ABSORPTION OF NEPTUNIUM ON ANION EXCHANGE RESINS

EFFECT OF NITRIC ACID AND NITRATE ION CONCENTRATION

The distribution ratio for Np(IV) reached a maximum of approximately 600 at 8.3M nitric acid. The dependence of the distribution ratio on nitric acid concentration is shown in Figure 1. These data were obtained with a solution containing 1.3 mg of Np per liter. The Np was reduced to the (IV) state with 0.03M ferrous sulfamate. The absorption of neptunium from 8M nitric acid by a column of resin is shown in Figure 2. The breakthrough volume ($C/C_0 = 0.1$) was 505 bed volumes, which confirmed the affinity of the resin for the anionic neptunium nitrate complex.

FIG. 1 EFFECT OF CONCENTRATIONS OF NITRIC ACID AND SULFATE ON DISTRIBUTION RATIO FOR NEPTUNIUM

Np was also effectively absorbed from nitric acid - nitrate salt mixtures with "Dowex" 1-X4, 50 to 100-mesh resin; the distribution ratio was approximately 700 from a solution 6.4M nitric acid - 1.35M sodium nitrate - 0.1M potassium nitrate - 0.01M manganous nitrate - 0.03M ferrous sulfamate - 10 mg Np per liter. The breakthrough volume was 535 bed volumes. With the same feed, but with "Dowex" 1-X4, 20 to 50-mesh resin, the breakthrough volume was 315, see Figure 6.

EFFECT OF SULFATE

The absorption of Np(IV) is decreased markedly when sulfate ion is present in the 8M nitric acid solution. The deleterious effect of sulfate on the absorption of Np is shown in Figures 1 and 2. Figure 1 shows that the distribution ratio decreases with increased sulfate in the feed; Figure 2 shows that breakthrough of Np in a fixed bed of resin occurs with less throughput when sulfate is present in the feed.

EFFECT OF NEPTUNIUM CONCENTRATION

The distribution ratio for Np(IV) remained constant at 600, within limits of the experimental error, when the concentration of Np in solution was varied from 1 to 120 mg per liter. The solution used in these measurements was 8M nitric acid containing 0.03M ferrous sulfamate to ensure the presence of Np(IV). All solutions were equilibrated for one hour at 23°C with "Dowex" 21K resin.

The effect of Np concentration on column performance is shown in the following table and Figure 3. The breakthrough volume on a fixed bed was approximately 15% greater for feed containing 1.3 mg of Np per liter than it was for feed containing 10 mg per liter, at a feed flow of 10 ml/(min)(cm²). At a flow of 5 ml/(min)(cm²) with feed containing 110 mg of Np per liter, the number of bed volumes to breakthrough was 435 compared to 60 for a feed concentration of 1050 mg of Np per liter.

Effect of Flow and Concentration of Np on Absorption

Np in Feed, mg/l	Feed Flow, ml/(min)(cm ²)	Breakthrough	
		Bed Volumes	Np Absorbed, g/l resin
1.3	10	515	0.67
10	10	455	4.55
110	5	435	48
1050	5	60	63

EFFECT OF REDUCTANTS

The effectiveness of various reducing agents for producing Np(IV) in 8M nitric acid was evaluated by treating Np(V) and (VI) solutions with

the reagents and then determining distribution ratios and column breakthrough curves. The results are shown in the following table and in Figure 4.

Effect of Reductants on Absorption

Solution: 1 to 10 mg Np/l in 8M HNO₃

Procedure: Add reductant, hold solution at temperature for specified time, cool to 23°C, equilibrate one hour with "Dowex" 21K resin

Reductants	Conditions	Distribution Ratio, R _D
0.05M N ₂ H ₄ - 0.05M Fe(NH ₂ SO ₃) ₂	23°C for 30 min	650
0.05M Fe(NH ₂ SO ₃) ₂	23°C for 30 min	550-650
0.1M H ₂ O ₂	23°C for 30 min	500
0.1M NH ₂ SO ₃ H - 0.05M ascorbic acid	23°C for 30 min	600
0.05M N ₂ H ₄	23°C for 30 min	100-300
0.05M FeSO ₄	23°C for 30 min	40
0.05M N ₂ H ₄	60°C for 30 min	300-700
0.05M N ₂ H ₄ - 0.3M Fe(III)	60°C for 30 min	1300
0.05M semicarbazide - 0.3M Fe(III)	60°C for 30 min	1100

The use of hydrazine plus ferrous sulfamate is recommended for reduction of Np to the (IV) state for recovery by anion exchange from 8M nitric acid. Although recovery is adequate when ferrous sulfamate is used alone, the presence of hydrazine decreases the volume of gas produced in the resin bed. Gassing is quite severe when hydrogen peroxide is used as the reductant. Some process solutions contain several tenths molar ferric ion. Addition of hydrazine or semicarbazide to an 8M nitric acid solution containing 0.3M ferric ion, followed by heating to 60°C for 30 minutes, produced a solution that gave a distribution ratio and breakthrough volume somewhat higher than other solutions. The reason for this effect was not established.

COMPARISON OF ANION EXCHANGE RESINS

A number of strong base resins are suitable for absorption of the anionic nitrate complex of Np(IV) from nitrate solutions; these include "Dowex" 1-X4, "Dowex" 21K, and "Permutit" SK resins. The ion exchange sites in the "Dowex" resins are furnished by quaternary ammonium groups, and in the "Permutit" resin by pyridinium groups. Diffusion of the

anionic complex is more rapid in "Dowex" resins than in "Permutit" resin. Diffusion is slower in 8% cross-linked "Dowex" 1 than in the 4% resin; therefore the lower cross-linked resin is preferred for the absorption of Np. Resins with less than 4% cross-linking are subject to excessive volume changes when contacted with varying acid concentrations; therefore they were not used. Little is known about the cross-linking of "Permutit" SK and "Dowex" 21K resins.

In column operation, "Dowex" 21K and "Dowex" 1-X4, 50 to 100-mesh resins and "Permutit" SK, 40 to 80-mesh resin have a higher capacity per unit volume of resin for Np than other resins tested. From 8M nitric acid the distribution ratio for these resins was 600, approximately double the ratio obtained with "Amberlite" IRA 401, 20 to 50-mesh, "Dowex" 1-X4, 20 to 50-mesh, and "Permutit" SK 20 to 50-mesh resins. The higher distribution ratios were reflected by increased absorption capacities on fixed resin beds. The data are summarized in the following table and in Figure 5. The lower capacity for Np of the larger resin particles is partially attributed to slow diffusion, since, with "Permutit" SK, 20 to 50-mesh resin, decreasing the flow from 10 to 5 ml/(min)(cm²) increased the breakthrough capacity from 155 to 265 bed volumes, as shown in Figure 5. The effect of resin particle size with "Dowex" 1-X4 was described in a previous section and is shown in Figure 6.

Neptunium Capacities of Anion Resins

Feed: 10 mg Np/l in 8M HNO₃
0.03M Fe(NH₂SO₄)₂

Equilibrated one hour at
23°C for R_D determinations

Resin Type	Absorption Flow, ml/(min)(cm ²)	Breakthrough Capacity, bed volumes	Batch Distribution Ratio, R _D
"Dowex" 21K (50-100 mesh)	10	430	600
"Dowex" 1-X4 (50-100 mesh)	10	385	550
"Permutit" SK (40-80 mesh)	5	530	600
"Permutit" SK (20-50 mesh)	10	155	300
	5	265	-
"Amberlite" IRA 401 (20-50 mesh)	No fixed bed test	-	350
"Dowex" 1-X2 (50-100 mesh)	Bed plugged because of large change in resin volume	-	450

EFFECT OF TEMPERATURE

The absorption of Np is less favorable at higher temperatures; the distribution ratio was 600 at 23°C but only 190 at 70°C. The effect of temperature was confirmed by tests on a fixed bed of resin; a resin bed absorbed less than two-thirds as much Np at 55°C as it did at 23°C. All tests were made with 8M nitric acid containing approximately 1.3 mg of Np per liter. The data are summarized below and in Figure 7.

Effect of Temperature on the Absorption of Neptunium

Solution: 1.3 mg of Np per liter in 8M HNO₃
0.03M Fe(NH₂SO₃)₂

Equilibrated with "Dowex" 21K one hour

<u>Solution Temperature, °C</u>	<u>Distribution Ratio, R_D</u>
5	700
23	600
55	300
70	190

EFFECT OF FLOW

The capacity of a resin bed decreased as the flow was increased. The decrease in capacity is a result of slow diffusion of the anionic nitrate complex into the resin beads. The effect of flow was greater with resins of larger particle size and with increased Np concentration in the feed. These data are summarized in the following table.

Effect of Flow on Absorption of Neptunium

Feed: 8M HNO₃
0.03M Fe(NH₂SO₃)₂

<u>Resin Type</u>	<u>Np Concentration, mg/l</u>	<u>Flow, ml/(min)(cm²)</u>	<u>Breakthrough Capacity, bed volumes of feed</u>
"Dowex" 1-X4	1.3	5	550
(50-100 mesh)	1.3	10	515
"Dowex" 1-X4	10	5	450
(50-100 mesh)	10	10	390
"Permutit" SK	10	5	265
(20-50 mesh)	10	10	155

FIG. 2 ASSORPTION OF NEPTUNIUM ON A COLUMN OF RESIN

FIG. 3 EFFECT OF NEPTUNIUM CONCENTRATION ON ABSORPTION

FIG. 4 EFFECT OF REDUCTANTS ON ABSORPTION OF NEPTUNIUM

FIG. 5 EFFECT OF TYPE OF RESIN ON ABSORPTION OF NEPTUNIUM

FIG. 6 ABSORPTION OF NEPTUNIUM FROM A NITRATE SALT SOLUTION

FIG. 7 EFFECT OF TEMPERATURE ON ABSORPTION

ELUTION OF NEPTUNIUM FROM ANION EXCHANGE RESINS

EFFECT OF NITRIC ACID CONCENTRATION

Elution of Np from the resin is favored by a low concentration of nitric acid, which causes ionization of the absorbable anionic complex. Concentrations lower than 0.35M nitric acid are avoided to prevent formation of undesirable polymeric species of Np(IV). Comparative data for 0.35M and 0.75M nitric acid showing the decreased efficiency of elution at the higher acid concentration are summarized in the following table and in Figure 8.

Effect of Acid Concentration on Elution

Resin: "Dowex" 1-X4, 50-100 mesh

Flow: 1 ml/(min)(cm²)

<u>Elutriant</u>		<u>Per Cent of Total Np Eluted</u>
<u>HNO₃, M</u>	<u>Bed Volumes</u>	
0.35	2	99
0.75	5.5	90

EFFECT OF NEPTUNIUM SATURATION ON THE RESIN

The concentration of Np in the eluate is a function of the initial Np saturation on the resin. The elution data summarized below and in Figure 9 are for columns loaded to $C/C_0 = 0.4$ to 0.6; therefore, the concentrations in the eluate were somewhat higher than those obtained from columns loaded to $C/C_0 = 0.1$. An elution made at 55°C gave about the same results as elutions made at 23°C.

Effect of Saturation on Elution

Resin: "Dowex" 21K, 50-100 mesh

Resin Column: Area 0.4 cm², height 25.5 cm

Temperature: 23°C

<u>Conc. of Np on Resin, g/l</u>	<u>Peak Conc. of Np, g/l</u>	<u>Conc. of Np for 97% Elution, g/l</u>
0.7	1.4 ^(a)	0.7
6	9.2 ^(a)	4.7
62	72 ^(b)	58
75	87 ^(b)	69

(a) Elution flow 1 ml/(min)(cm²)

(b) Elution flow 0.5 ml/(min)(cm²)

COMPARISON OF ANION EXCHANGE RESINS

The elution of Np from anion resins is dependent on the type and particle size of the resin. Higher concentrations of Np were obtained from "Permutit" SK resin than from "Dowex" 1-X4, and Np was eluted more readily from resins of smaller particle size. Data for resins of different types and particle sizes are given in the following table and in Figures 10, 11, and 12.

Comparison of Anion Resins

Elutriant: 0.35M HNO₃

Flow: 1 ml/(min)(cm²)

<u>Resin Type</u>	<u>Bed Volumes of Eluate</u>	<u>Per Cent of Total Np Eluted</u>
"Permutit" Sk (20-50 mesh)	2.5	99
"Dowex" 1-X4 (20-50 mesh)	3	90
"Permutit" SK (40-80 mesh)	1.5	99
"Dowex" 1-X4 (50-100 mesh)	2	99

EFFECT OF FLOW

Np was eluted from the resin at higher concentrations when lower flows were used. The data are summarized in the following table and in Figure 13.

Effect of Flow on Elution

Elutriant: 0.35M HNO₃

<u>Resin Type</u>	<u>Elutriant</u>		<u>Per Cent of Total Np Eluted</u>
	<u>Flow, ml/(min)(cm²)</u>	<u>Bed Volumes</u>	
"Dowex" 1-X4 (50-100 mesh)	1	2	99
"Dowex" 1-X4 (50-100 mesh)	5	5	94
"Permutit" SK (20-50 mesh)	1	2.5	99
"Permutit" SK (20-50 mesh)	5	5	95

FIG. 8 EFFECT OF ACID CONCENTRATION ON ELUTION

FIG. 9 EFFECT OF Np SATURATION ON ELUTION

FIG. 10 EFFECT OF TYPE OF RESIN ON ELUTION

FIG. 11 EFFECT OF RESIN PARTICLE SIZE ON ELUTION

FIG. 12 EFFECT OF RESIN PARTICLE SIZE ON ELUTION

FIG. 13 EFFECT OF FLOW ON ELUTION

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FLWSHEET FOR RECOVERY OF NEPTUNIUM FROM NITRATE SOLUTIONS

Np can be recovered by anion exchange with less than 1% loss from 350 bed volumes of feed solution containing 8M nitrate ion and 1 to 50 mg of Np per liter. At higher concentrations of Np, the same recovery efficiency is attainable, but the volume of solution fed to the resin bed must be decreased. Np(IV) is obtained by adjusting the feed to 0.05M ferrous sulfamate and 0.05M hydrazine. Although reduction to Np(IV) is complete with ferrous sulfamate, hydrazine stabilizes the ferrous ion and is also very effective in decreasing the amount of gassing in the resin bed. If sulfate is present in the feed, it is necessary to process a smaller volume to maintain low losses.

"Dowex" 1-X4, "Dowex" 21K, and "Permutit" SK, 50 to 100-mesh resins, all provide adequate recovery. "Permutit" SK is reported to be more stable to radiation; and Np is eluted from "Permutit" SK at a higher concentration.

After absorption of the anionic nitrate complex on the resin, special wash solutions⁽²⁾ may be used to provide separation from fission products and plutonium. Typical wash steps are included in the flowsheet, Figure 14. The concentration of neptunium in the eluate depends on the concentration of neptunium on the resin, flow, and type of resin.

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BIBLIOGRAPHY

1. Ryan, J. L. and E. J. Wheelwright. The Recovery, Purification, and Concentration of Plutonium by Anion Exchange in Nitric Acid. General Electric Co., Hanford Atomic Products Operation, Richland, Wash. AEC Research and Development Report HW-55893, 104 pp. (January 1959).
2. Ryan, J. L. Concentration and Final Purification of Neptunium by Anion Exchange. General Electric Co., Hanford Atomic Products Operation, Richland, Wash. AEC Research and Development Report HW-59193 (Rev.), 18 pp. (September 1959).

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FIG. 14 FLOWSHEET FOR NEPTUNIUM RECOVERY

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