



**REMOVAL OF RADIORUTHENIUM FROM ALKALINE INTERMEDIATE LEVEL
RADIOACTIVE WASTE SOLUTION : A LABORATORY INVESTIGATION**

by

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Process Engineering and Systems Development Division**

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60 Abstract : Various methods were investigated in the laboratory for the removal of radioruthenium from alkaline intermediate level radioactive waste solutions of reprocessing plant origin. The methods included batch equilibration with different ion exchangers and sorbents, column testing and chemical precipitation. A column method using zinc-activated carbon mixture and a chemical precipitation method using ferrous salt along with sodium sulphite were found to be promising for plant scale application.

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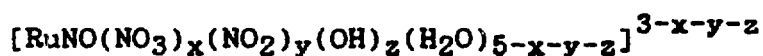
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1. INTRODUCTION

Because of its complex chemistry and high radioactivity, Ru-106 is one of the major radionuclides of concern in aqueous radwastes generated at spent nuclear fuel reprocessing plants. In the PUREX flowsheet, dissolution of the spent fuel in nitric acid leads to the conversion of fission product ruthenium into numerous complex species containing the nitrosylruthenium (Ru-NO) group, which is very stable and persists through the various processing stages. Such complexes in nitric acid solution can be represented by the general formula [1] :



Depending on the number and type of ligands attached to the RuNO group, the complex species may be cationic, neutral or anionic in nature.

In this report, we are concerned with the effective

removal of Ru-106 from intermediate level aqueous radwastes. Large volumes of such wastes generated at spent fuel reprocessing plants are presently stored in underground carbon steel tanks. These waste solutions are alkaline and have a high concentration of dissolved salts (mainly NaNO_3). The major radioisotope present in these solutions is Cs-137 ($t_{1/2} = 30$ yrs). Other radionuclides present include Sr-90 ($t_{1/2} = 28$ yrs) and Ru-106 ($t_{1/2} = 1$ yr), the quantity of the latter depending upon the storage period of these wastes because of its relatively short half life.

As part of a programme to formulate a suitable treatment scheme for the alkaline salt loaded IL waste solutions, an ion exchange process has already been developed and demonstrated for the selective removal of radiocesium from these solutions [2,3]. The process utilises the high selectivity of a RESORCINOL-FORMALDEHYDE POLYCONDENSATE RESIN (RFPR) [4,5] for cesium from alkaline solutions even in the presence of large quantities of sodium ions. When Sr-90 is also present, it is possible to remove it using a chelating resin containing iminodiacetic acid functional groups. The present work deals with the results of laboratory investigations on developing a suitable method for removal of Ru-106 which, along with its daughter Rh-106, becomes a major contributor to gross β activity after removal of radiocesium and radiostrontium.

The nature of ruthenium species when acid-PUREX waste solutions are neutralised with alkali is not known with

certainty. It appears that partial or complete removal of the nitrate or nitro groups by hydroxide groups in alkaline solutions will result in radioruthenium remaining as species that are either soluble or colloidal in nature. Because of the difficulty in simulating ruthenium species that are actually present, most of the work reported here has been done with a real waste solution of reprocessing plant origin. Some initial results using a simulated test solution are also included for the sake of comparison.

2. EXPERIMENTAL DETAILS

2.1. SCREENING OF SORBENTS AND ION EXCHANGERS

A number of sorbents and ion exchangers were used in this investigation for possible uptake of radioruthenium. While some of these were commercial products, others were prepared in the laboratory. The details of the preparation of the materials, however, are not included in this report.

2.1.1. Tests with Simulated Waste Solution

Initially, a number of sorbents and ion exchangers were tested with a simulated waste solution containing 1.0 M NaNO_3 and 0.1 M NaOH with Ru-103 as tracer for ruthenium. The ruthenium in this tracer was present as the simple Ru(III) ion. For equilibration, 50 ml of the test solution was equilibrated with 0.1 g of the sorbent/ion exchanger for 24 hours. The Ru-103 activity in the solution before and after equilibration was determined using a NaI(Tl) gamma scintillation counter assembly.

The distribution coefficient, K_d , defined as the ratio of the ruthenium activity per gram of the sorbent/ion exchanger to the ruthenium activity remaining per ml of the solution at equilibrium, was calculated from the following equation :

$$K_d = \frac{C_i - C_f}{C_f} \cdot \frac{V}{W}, \quad \text{ml/g} \quad \dots(1)$$

where C_i and C_f are the activities (cpm/ml) of Ru-103 in the solutions before and after equilibration, V is the volume of equilibrating solution (50 ml) and W is the mass of sorbent/ion exchanger taken (0.1 g). The results of tests using the simulated waste solution are shown in Table 1.

2.1.2. Tests with Actual Waste Solution

The actual waste solution used in these experiments was the effluent obtained after removal of most of the major radionuclide Cs-137 from an intermediate level alkaline waste stream of reprocessing plant origin, using an ion exchange process based on a RESORCINOL FORMALDEHYDE POLYCONDENSATE RESIN (RFPR) developed in the laboratory [2]. Ru-106 was the major radionuclide present in this solution after removal of radiocesium. The composition is shown in Table 2.

In this case, 10 ml of the waste solution was used for equilibration with 0.1 g of the sorbent/ion exchanger for 24 hours. In addition to tests with the highly alkaline original solution, equilibrations were also done with the waste solution

adjusted with nitric acid to various lower pH values. Prolonged equilibration periods (72 hours) were also provided for some of the tests.

For all tests with actual waste solution, the uptake of radioruthenium was monitored by measuring the gross gamma activity of the solutions. Since Cs-137 activity was much lower compared to Ru-106, the reduction in gross gamma activity was taken as a conservative estimate of the uptake of radioruthenium. The results of equilibration tests with sorbents/ion exchangers using actual waste solution are given in Tables 3-5.

2.2. TESTS WITH ZINC-ACTIVATED CARBON

2.2.1. Batch Tests

A mixture of zinc metal powder (2 g) and coconut shell activated carbon (2 g) was used in this test. The waste solution was adjusted to pH 2.0 with nitric acid and the zinc-activated carbon mixture added to it. The mixture was magnetically stirred daily for 8 hours and then left overnight. Samples (1 ml) of the solution were drawn periodically through a sintered disc filter tube and counted for gross gamma activity to determine the Decontamination Factor (DF) which is defined as the ratio of activities (cpm/ml) before and after equilibration with zinc-activated carbon. The results are given in Table 6.

2.2.2. Column Tests

A glass column with PTFE stopcock and sintered disc support was used for filling the zinc-activated carbon mixture.

Special care was taken to ensure that the zinc and activated carbon formed an intimate mixture rather than separate layers in the column. The waste feed solution adjusted to pH 2.0 was passed from top to bottom at a flow rate of about 5 bed volumes per hour using a Watson-Marlow peristaltic pump. Effluent samples were collected at regular intervals, filtered and analysed for gross gamma activity. A schematic diagram of the experimental assembly is shown in Fig.1.

Two different zinc-activated carbon column tests were done with the same waste solution. The conditions were similar except for a difference in the ratio of zinc to activated carbon and the grade of activated carbon used. Another difference was that the second column test was done after a period of almost two years and since the half life of Ru-106 is one year, this meant that its activity had decayed to 1/4 of its initial value during this period. The results of these two column tests are shown in Fig.2 and Fig.3.

2.3. CHEMICAL PRECIPITATION METHOD

A series of experiments were conducted to study the possibility of using chemical precipitation method for ruthenium decontamination. In these tests, ferric/ferrous hydroxides were precipitated in the waste solution in the presence and absence of a reducing agent like sodium sulphite. In each experiment, requisite quantity of chemicals were added to 10 or 20 ml of the waste solution and allowed to equilibrate by shaking on a wrist action shaker. The solutions were then filtered and analysed for

gross gamma activity. While in some experiments, the precipitants were added to the highly alkaline original waste solution, in others the waste solution was adjusted to pH 2.0, the chemicals added and then the pH raised to about 9 to bring about precipitation of the hydroxides. Table 7 gives the results of these precipitation experiments.

3. RESULTS AND DISCUSSION

3.1. SCREENING OF SORBENTS AND ION EXCHANGERS

A wide variety of substances have been reported in the literature for the uptake of radoruthenium from aqueous waste solutions [1,6,7]. These include both inorganic sorbents and the organic functional polymers like ion exchange and chelating resins. Activated carbon has also been reported as effective in removing Ru-106 from aqueous solutions. Noteworthy amongst the inorganic sorbents studied are the hydrous oxides, various sulphides, zeolites, etc. The organic polymers include various conventional cation and anion exchange resins and chelating polymers having functional groups incorporated to coordinate the ruthenium species present.

3.1.1. Tests with simulated waste solution

Based on available information, a number of sorbents and ion exchangers were studied in the laboratory for ruthenium uptake. Initial tests were done with a simulated waste solution containing 1.0 M NaNO_3 + 0.1 M NaOH with Ru-103 isotope present as the simple Ru(III) ion. From the results shown in Table 1,

it is seen that conventional strong and weak cation/anion exchange resins, chelating resins containing iminodiacetate groups and synthetic molecular sieve zeolites are not effective. A thiourea-formaldehyde resin (Tu-F) was synthesized as a possible candidate for the uptake of ruthenium but it did not show any selectivity. Same was the case with CdS which was loaded on a macroporous anion exchange resin. Two different grades of activated carbon, viz., Hychar SCG7 and SGC, were tested. The former showed somewhat higher K_d (280 mlg^{-1}) but its ruthenium uptake decreased drastically on oxidation. The oxidation was done with the idea of generating additional functional groups on the carbon surface. Of all the substances tested with the simulated waste solution, the most promising appears to be hydrous ferric oxide (HFO). This sorbent was precipitated inside the pores of activated carbon and a macroporous anion exchange resin, the purpose being to have a sorbent with good column properties if found effective. The results in Table 1 show that HFO loaded on activated carbon gives a K_d value of 540 mlg^{-1} compared to 120 mlg^{-1} for the resin-loaded sample and hence activated carbon can be considered to be a better support material in this case.

3.1.2. Tests with Actual Waste Solution

The results in Table 2 show that none of the sorbents is very promising when tested with actual waste solution. Hydrous ferric oxide loaded activated carbons were more effective than the other sorbents in this case also though the K_d values were not very high. It appears that heating the HFO sorbent to 100°C

is beneficial since it increases the K_d value to some extent. The effect of particle size in the range studied was not very significant. It is noteworthy that hydrous titania was not effective though it has been reported to show uptake of ruthenium nitrosyl complexes from aqueous sodium carbonate media [8]. Another product, Tulsion MR-200, containing isothiuronium groups, was also ineffective.

Since no sorbent proved effective when directly used with the alkaline waste solution, some tests were done with the waste solution adjusted to various lower pH values with nitric acid. In the case of HFO loaded activated carbon, it is seen that K_d values are higher when the pH is near neutral. In the case of sulphides, K_d values increase with a decrease in pH as compared to those measured in the alkaline waste solution. The uptake, however, is still too low to be useful. A potassium cobalt(II) hexacyanoferrate(II) was also tested and found to give k_d value of 210 ml g^{-1} at pH 10.3 with the actual waste solution. A special combination tested was a mixture of activated carbon and iron or zinc metal powder. The uptake as measured by K_d values was significant though not very high.

Since ruthenium nitrosyl complex species are known to undergo very slow equilibration amongst themselves, a series of tests were done where batch equilibration was carried out for 72 hours, instead of 24 hours done earlier. From the results shown in Table 5, it is seen that uptakes are slightly better for the HFO product. The most striking increase in K_d value was

observed for iron-activated carbon mixture with K_d value reaching upto 730 mlg^{-1} . The sulphides, once again, did not prove effective.

It is thus evident that no sorbent or ion exchanger amongst those tested can be considered to possess high selectivity towards ruthenium species present in alkaline (or acidic) intermediate level salt-loaded waste solutions of reprocessing plant origin. The low K_d values ($< 10^3 \text{ mlg}^{-1}$) indicate that it will not be possible to have a fixed-bed sorption column whereby hundreds of bed volumes of such waste solutions can be efficiently decontaminated from radioruthenium. Thus, hydrous ferric oxide loaded activated carbon, which showed higher K_d values around neutral pH, was tested for its efficacy in the column mode. It was found that the cumulative DF was 8 after passing only about 17 bed volumes of the waste solution adjusted to pH 7.3 with nitric acid through a 10 ml bed of this sorbent at a flow rate of 3 bed volumes per hour. In static equilibration also, the DF obtained was around 3 to 4 on contacting 200 ml of waste solution (pH 7.3) with 2.0 g of HFO loaded activated carbon for 100 hours. This shows that this sorbent will not be very effective for batch or column mode of application.

The only other promising candidate is a mixture of activated carbon and iron or zinc metal powder. However, the waste pH has to be reduced to 2-3 for this combination to be effective. The results of further studies carried out using this combination are discussed below.

3.2. TESTS WITH ZINC-ACTIVATED CARBON

The combination of activated carbon and iron or zinc metal powder for ruthenium uptake was included in our study on the basis of reports about the use of this type of mixture for removing ruthenium from waste solutions generated during the production of ^{99}Mo by the $^{235}\text{U}(n,f)$ reaction [9]. Amongst the various metal-activated carbon combinations tried, zinc was found to be the best. As mentioned already, both zinc and iron metal powders were used in our batch equilibration studies. Preliminary column tests showed zinc to be better than iron powder and hence for further detailed investigations, only zinc-activated carbon mixture was used. The results of these investigations, some of which have been published elsewhere [10], are discussed below.

3.2.1. Batch Tests

From the results in Table 3, it is seen that batch equilibration with zinc-activated carbon mixture is also effective to some extent for ruthenium decontamination from actual waste solution adjusted to pH 2.0 with nitric acid. The DF obtained increases with contact time, rising from 10 in 5 hours to 25 after 72 hours. After prolonged contact (25 days), the DF is 100, signifying 99% removal of radioruthenium.

3.2.2. Column Tests

The results of two column tests, viz., column run no-1 and column run no-2, are shown in Fig.2 and Fig.3 respectively.

as breakthrough curves for ruthenium. In the former case, a 1:1 mixture of zinc metal powder and activated carbon (Hychar SCG7) was used. As mentioned earlier, the reduction in gross gamma activity has been taken as indicative of ruthenium decontamination. An important observation in the column tests was that the effluent pH rises to 6-7 from the initial feed value of 2-3 after passage through the column. In the first column test, a DF of 20 (5% breakthrough) was obtained in the effluent coming out after about 35 bed volumes. A cumulative DF of 36.6 was obtained in this run after 40 bed volumes.

The results of the second column run (Fig.3) were better than the first one. In this case, the zinc:activated carbon ratio was 1.4 (instead of 1.0 in the previous case) and the activated carbon was of a different grade, viz., ACC-60. Another significant difference was in the L/D ratio of the zinc-activated carbon bed. It was substantially higher in the second run (L/D = 12.1) than in the first run (L/D = 4.63). It is possible that all these factors contributed to the better performance of the second column run. As can be seen in Fig.3, even after about 130 bed volumes the effluent coming out of the column was showing a DF of 20. The experiment was terminated after 157 bed volumes, at the end of which the cumulative DF measured was 29.7, signifying the removal of 96.6% of the ruthenium activity.

These results show that a properly prepared mixture of zinc metal and activated carbon of the right quality can be used

in fixed-bed sorption columns for the removal of radioruthenium from actual waste solutions. An essential requirement is that the waste will have to be adjusted to pH 2.0 for this method to be effective.

Efforts were also made to periodically regenerate the efficiency of the bed by percolating few bed volumes of pH 2.0 water as reported in the literature [9]. The recovery of efficiency was, however, only marginal in this case.

3.3. CHEMICAL PRECIPITATION METHOD

From the results given in Table 7, it is evident that direct precipitation of $\text{Fe}(\text{OH})_3$ or $\text{Fe}(\text{OH})_2$ in the alkaline waste solution (pH 10.1) is not effective in removing ruthenium. When the waste is initially adjusted to pH 2.0 and precipitation brought about by raising the pH to about 9 after adding the chemicals, the results are better. In this case, Fe^{2+} is better than Fe^{3+} and the addition of a reducing agent like Na_2SO_3 (0.01M) enhances the DF significantly when Fe^{2+} (as FeSO_4) is used. A mixture of Fe^{2+} and Fe^{3+} was also tried in the presence of 0.01M Na_2SO_3 . It was found that the DF obtained increased with the concentration of Fe^{2+} and Fe^{3+} ions in solution, rising from 2.40 when their concentration was 70 ppm each to 4.98 at 140 ppm and 7.10 at 280 ppm. Finally, a single dosage of 560 ppm Fe^{2+} alone was found to be nearly equivalent to a mixture of 280 ppm each of Fe^{2+} and Fe^{3+} ions in the presence of 0.01M Na_2SO_3 . Repeated precipitations made under these conditions were found to give reproducible results.

It thus appears that even chemical precipitation method has substantial potential in reducing ruthenium activity in waste solutions.

4. CONCLUSIONS

Various inorganic sorbents, zeolites, activated carbons, conventional ion exchange resins and chelating functional polymers were tested for removal of Ru-106 present in intermediate level alkaline salt loaded radwaste solutions stored at reprocessing plant sites. None of them was found to show sufficiently high uptake of radioruthenium and hence cannot be considered for effective application. Adjustment of pH of the waste solution to lower values also did not improve the situation.

The only method found to be promising is based on a mixture of zinc metal powder and activated carbon packed in a column. The alkaline waste solution has to be acidified to pH 2-3 and then passed through the column at about 5 bed volumes per hour. It is expected that Ru-106 can be removed with a DF of 10 or more from a few hundred bed volumes of waste solution. This process can thus be considered for plant scale application.

Apart from this fixed-bed process, a process based on simple chemical precipitation also showed promising results. The steps involved in this process are acidification of waste solution to pH 2, addition of requisite amounts of ferrous sulphate and a reducing agent like sodium sulphite and finally precipitation of ferrous hydroxide by raising the pH.

Radioruthenium gets carried down along with the precipitate and a DF of 7-8 is obtained. This chemical precipitation method is also expected to be useful in plant scale application for removing Ru-106 from waste solutions.

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TABLE - 1

**K_d VALUES FOR VARIOUS SORBENTS AND ION EXCHANGERS
IN SIMULATED WASTE SOLUTION**

Sorbent : 0.1 g

Equilibration Period : 24 hours

Test Solution : 50 ml (1.0 M NaNO₃ + 0.1 M NaOH + Ru-103 Tracer)

SL. NO.	SORBENT	NATURE OF SORBENT	K _d ml/g
1	Hychar SCG7 -50+60 mesh	Coconut-shell activated carbon	280
2	Hychar SCG7 -50+60 mesh (oxidised)	Coconut shell activated carbon after surface oxidation with nitric acid	16
3	SGC -50+60 mesh	Coconut-shell activated carbon	65
4	A27(MP)/HFO Heated at 100°C	Hydrous ferric oxide loaded on macroporous strong base anion exchange resin	120
5	Hychar/HFO -50+60 mesh	Hydrous ferric oxide loaded on Hychar SCG7 grade active carbon	540
6	A27(MP)/CdS	Cadmium sulphide loaded on macroporous strong base anion exchange resin	10
7	TULSION T-42(H ⁺)	Strong acid cation resin	37
8	INDION 236(H ⁺)	Weak acid cation resin	26
9	TULSION A27(MP)	Strong base anion resin(Cl ⁻)	23
10	TULSION A2X(OH ⁻)	Weak base anion resin	10
11	TU-F	Thiourea-Formaldehyde resin	0
12	AMBERLITE IRC-718 (H ⁺ -form)	Macroporous chelating resin with iminodiacetate groups	23
13	AR1 (Mordenite)	Molecular sieve zeolite	30
14	4A	Molecular sieve zeolite	40
15	13X	Molecular sieve zeolite	65

TABLE - 2 .

COMPOSITION OF ACTUAL IL WASTE SOLUTION

Sl. No.	Component	Value
1	Specific gravity	1.12
2	Dissolved solids	19.45 % w/v
3	Total alkalinity	0.29 N
4	Carbonate	0.18 N
5	Hydroxide	0.11 N
6	Uranium	0.1 g/L
7	Cs-137	7.6×10^{-4} mCi/L
8	Ru-106	1.1×10^{-1} mCi/L

TABLE - 3

K_d VALUES FOR VARIOUS SORBENTS IN ACTUAL IL WASTE SOLUTION

Sorbent : 0.1 g

Equilibration Period : 24 hours

ILW Solution : 10 ml Actual IL Waste (pH > 12)

SL. NO.	SORBENT	NATURE OF SORBENT	K _d ml/g
1	Hychar/HFO -50+60 mesh Air dried	Hydrous ferric oxide loaded on Hychar SCG7 grade active carbon	50
2	Hychar/HFO -50+60 mesh Heated at 100°C	Hydrous ferric oxide loaded on Hychar SCG7 grade active carbon	85
3	Hychar/HFO -80+100 mesh Heated at 100°C	Hydrous ferric oxide loaded on Hychar SCG7 grade active carbon	75
4	A27(MP)/HFO Heated at 100°C	Hydrous ferric oxide loaded on macroporous strong base anion exchange resin	50
5	A27(MP)/CdS	Cadmium sulphide loaded on macroporous strong base anion exchange resin	0
6	A27(MP)/FeFC	Ferric hexacyanoferrate(II) loaded on macroporous strong base anion exchange resin	15
7	FeS	Ferrous sulphide granules	5
8	HTO	Hydrous Titania	12
9	TU-F	Thiourea-Formaldehyde resin	0
10	TU-R-F	Thiourea-Resorcinol-Formaldehyde resin	10
11	IRC-718(H ⁺)	Amberlite chelating resin with iminodiacetate groups	3
12	MR-200	Tulsion special resin with isothiuronium groups	12

TABLE - 4

K_d VALUES FOR VARIOUS SORBENTS IN ACTUAL IL WASTE SOLUTION**EFFECT OF SOLUTION pH**

Sorbent : 0.1 g

Equilibration Period : 24 hours

ILW Solution : 10 ml Actual IL Waste Solution adjusted to different pH values with nitric acid.

SL. NO.	SORBENT	NATURE OF SORBENT	Initial pH	K _d ml/g
1	Hychar/HFO -50+60 mesh Heated at 100°C	Hydrous ferric oxide loaded on Hychar SCG7 grade active carbon	2.0	175
			3.7	95
			6.2	225
			7.1	265
			9.0	165
2	Hychar/Fe	Mixture(1:1) of Iron powder & Hychar SCG7 grade active carbon	3.1	160
3	Hychar/Zn	Mixture(1:1) of Zinc powder & Hychar SCG7 grade active carbon	3.1	130
4	A27(MP)/CdS	Cadmium sulphide on macroporous strong base anion resin	2.0	40
5	FeS	Ferrous sulphide granules	2.0	55
			7.3	12
6	CoFC	Cobalt(II) Hexacyano- ferrate(II)	1.9	5
			10.3	210

TABLE - 5

K_d VALUES FOR VARIOUS SORBENTS IN ACTUAL IL WASTE SOLUTION**EFFECT OF PROLONGED EQUILIBRATION**

Sorbent : 0.1 g Equilibration Period : 72 hours

ILW Solution : 10 ml Actual IL Waste Solution adjusted to different pH values with nitric acid.

SL. NO.	SORBENT	NATURE OF SORBENT	Initial pH	K _d ml/g
1	Hychar/HFO -50+60 mesh Heated at 100°C	Hydrous ferric oxide loaded on Hychar SCG7 grade active carbon	1.1	65
			2.5	400
			5.9	260
			7.3	330
			9.0	340
			>12	80
2	A27(MP)/HFO	Hydrous ferric oxide on macroporous strong base anion resin	7.3	140
3	Hychar/Fe	Mixture(1:1) of Iron powder & Hychar SCG7 grade active carbon	2.5	730
4	A27(MP)/CdS	Cadmium sulphide on macroporous strong base anion resin	1.1	75
5	A27(MP)/CoS	Cobalt sulphide on macroporous strong base anion resin	1.1	20
			2.5	55
			5.9	10

TABLE - 6

RUTHENIUM REMOVAL BY ZINC-CARBON SYSTEM

BATCH EQUILIBRATION

Zinc : 2 gm (powdered metal)
Carbon : 2 gm (Hychar SCG7 grade, -80+100 mesh)
ILW solution : 100 ml Actual IL Waste Solution adjusted to pH 2.0 with nitric acid.

RESULTS

EQUILIBRATION TIME	% Ru-106 REMOVED	DF
0.5 Hours	64.3	2.8
1.0 Hours	71.4	3.5
3.0 Hours	81.1	5.3
5.0 Hours	89.6	9.6
24.0 Hours	92.1	12.6
48.0 Hours	94.0	16.7
72.0 Hours	96.0	25.0
25 Days	99.0	100.0

TABLE - 7

**RUTHENIUM REMOVAL FROM ACTUAL IL WASTE SOLUTION
BY CHEMICAL PRECIPITATION**

SL. NO.	WASTE VOLUME ml	pH	Fe ³⁺ ppm	Fe ²⁺ ppm	Na ₂ SO ₃ M	DF
1	10	10.1	280	-	-	1.63
2	10	10.1	-	280	-	1.46
3	10	10.1	-	280	0.01	1.13
4	10	2.0	280	-	-	1.28
5	10	2.0	560	-	-	1.39
6	10	2.0	-	280	-	1.67
7	10	2.0	-	280	0.01	3.58
8	10	2.0	280	-	0.01	2.59
9	10	2.0	280	280	0.01	10.47
10	20	2.0	280	280	0.01	8.70
11	20	2.0	280	280	0.01	7.10
12	10	2.0	140	140	0.01	4.98
13	10	2.0	70	70	0.01	2.40
14	10	2.0	-	560	0.01	8.25

NOTE : In the case of serial nos. 4 to 14, the pH of the solution was increased to about 9 after addition of the reagents.

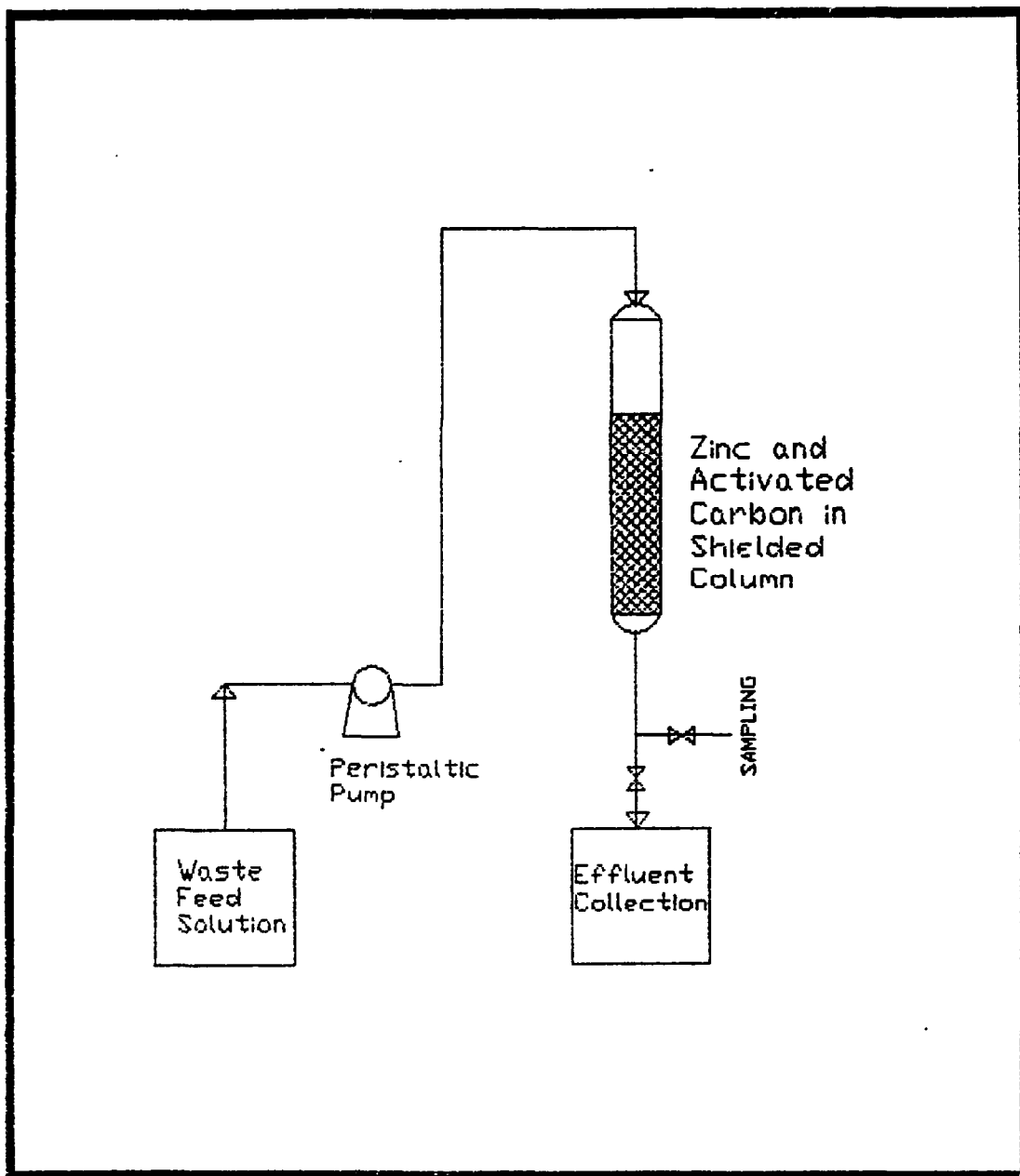


FIG.1 LABORATORY SETUP FOR COLUMN STUDIES

COLUMN RUN NO - 1

Zinc (powder)	: 4.0 gm	Flow rate	: 5 BV/Hr
Carbon (Hych-SCG7)	: 4.0 gm	Duration of run	: 8 Hours
Column diameter	: 1.34 cm	Total vol. passed	: 360 cm ³
Bed height	: 6.2 cm	Total bed volumes	: 40
Bed volume	: 8.7 cm ³	Influent pH	: 1.9

BREAKTHROUGH CURVE

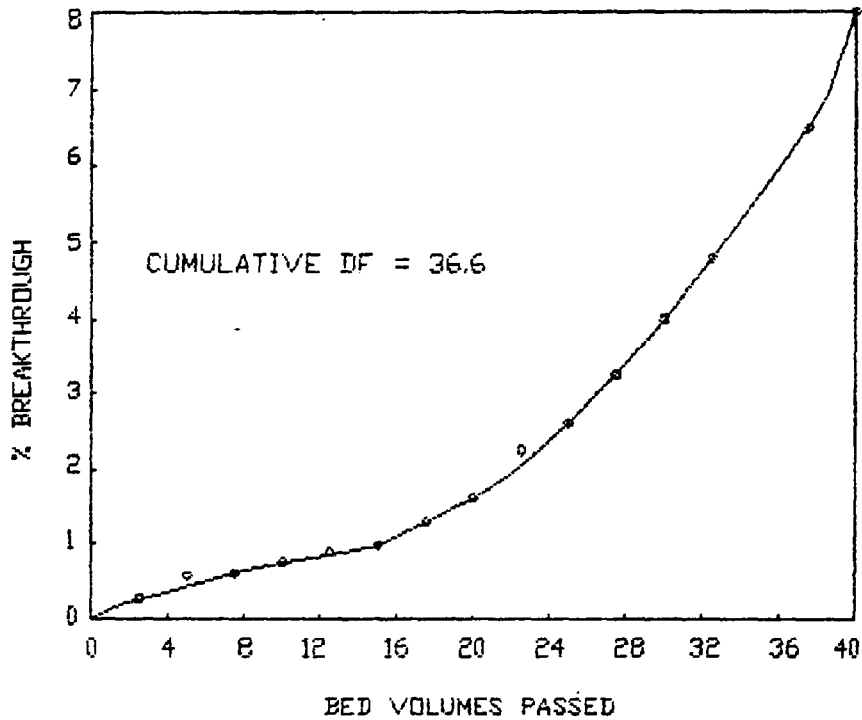


FIG.2 RUTHENIUM REMOVAL USING ZINC-ACTIVATED CARBON

COLUMN RUN NO - 2

Zinc (powder)	: 3.7 gm	Flow rate	: 4.9 BV/Hr
Carbon (ACC-60)	: 2.6 gm	Duration of run	: 32 Hours
Column diameter	: 0.95 cm	Total vol. passed	: 1.26 Litres
Bed height	: 11.5 cm	Total bed volumes	: 157
Bed volume	: 8.05 cm ³	Influent pH	: 2.0

BREAKTHROUGH CURVE

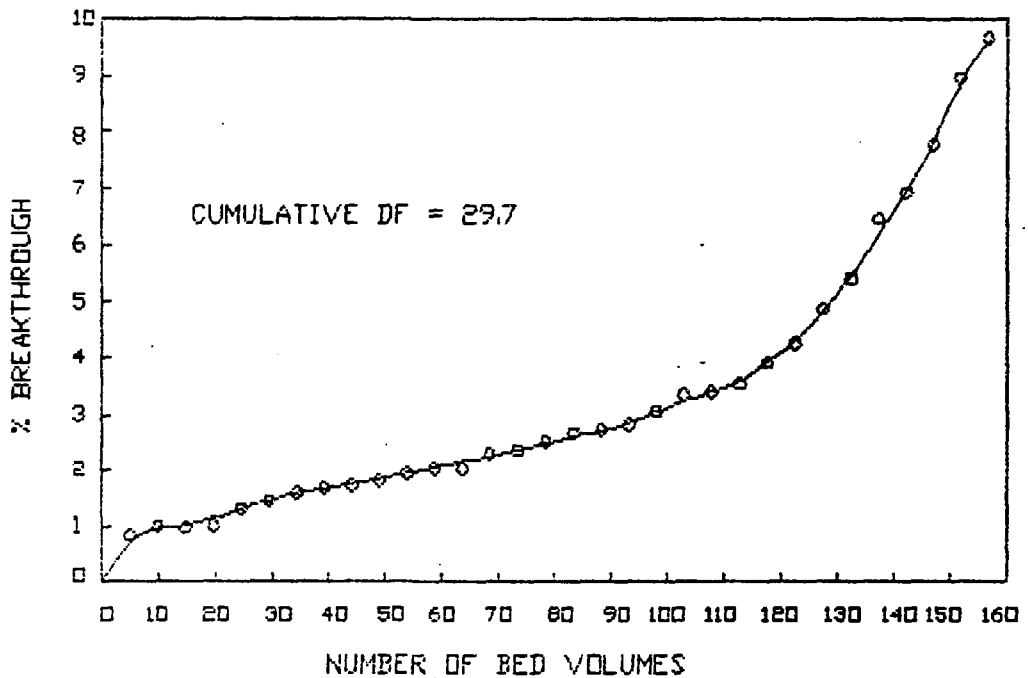


FIG.3 RUTHENIUM REMOVAL USING ZINC-ACTIVATED CARBON

