

CHAPTER III

*Synthesis, characterization and analytical applications
of cerium(IV)iodotungstate cation exchanger*

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Abstract

A new inorganic ion exchanger, cerium(IV)iodotungstate has been synthesized and characterized by elemental analysis and IR spectroscopy. This material is highly stable towards thermal, chemical and radiation dose. It has fairly good ion exchange capacity for many metal ions. The separation of ^{90}Y from its parent ^{90}Sr from an equilibrium mixture has been successfully performed at pH 6.0 by employing this exchanger using $0.0063 \text{ mol. L}^{-1}$ (0.25 %) EDTA solution as eluent.

III.1. Introduction

^{90}Y is one of the useful therapeutic radioisotopes. Many successful studies of site-specific monoclonal antibody labeling involving ^{90}Y have been applied in radioimmuno-therapy [1-7]. Several methods for the separation of radiochemically pure ^{90}Y from ^{90}Sr have been reported, which include precipitation, solvent extraction [8, 9] and ion exchange chromatography [10-12]. Amongst these, ion exchange chromatography is used most frequently in ^{90}Y - ^{90}Sr generator system [13]. For example ^{90}Y has been eluted out from ^{90}Sr using cation exchanger Dowex-50, synthetic inorganic cation exchanger, and Aminex A-5 in conjunction with mobile phases like lactate, methanol and oxalate, oxalate, citrate or ethylenediaminetetraacetic acid (EDTA) solution, mineral acids or organic compounds [1].

A generator is a self-contained system housing a parent/daughter mixture in equilibrium, which is designed to yield the daughter for some particular purpose usually separated from the parent [14]. The daughter is a different element from that of the parent, and, hence, can be separated chemically from the parent by elution. The availability of short-lived radionuclides from radionuclide generators provides an inexpensive and convenient alternative of in-house radioisotope production facilities [15]. Due to the simplicity of operation, chromatographic based generators have been the method of choice to elute out the daughter from parent [16]. Generators based on ion exchanger are routinely used for the same purpose. To be useful, the parent's half-life must be long compared to the travel time required to transport the generator to the recipient. Cerium(IV)iodotungstate as ion exchanger is an efficient and selective for trace scale separation. In the present investigation, an attempt has been made to separate no-carrier-added [17, 18] ^{90}Y from its parent ^{90}Sr from an equilibrium mixture using a newly designed polyoxymetallate cerium(IV)iodotungstate as ion exchanger.

III. 2. Experimental

III.2.1. Synthesis of the cerium(IV)iodotungstate cation exchanger

To a solution of ammonium ceric nitrate (1.65 g, 3.0 mmol) in water (100.0 mL), glacial acetic acid (15.0 mL) was added followed by sodium tungstate (1.0 g, 3.0 mmol)

and potassium iodate (1.3 g, 6.0 mmol). The pH of the resulting solution was adjusted to 1.0 with nitric acid and stirred for 1 h. The mixture was filtered and the filtrate was kept overnight to precipitate out the material. The precipitate was washed several times with de-ionized water and then finally dried in vacuum for 24 h.

III.2.2. Elemental Analysis

An accurately weighed amount of the solid exchanger (0.5 g) was fused with 1.0 g of NaOH (solid) and 0.5 g of Na₂CO₃ fused in a Ni-crucible to estimate the amount of cerium and tungstate present in the exchanger. The determination of cerium was carried out titrimetrically and estimation of tungstate was performed gravimetrically following the established method [19] and Iodine was also measured titrimetrically.

III.2.3. Stability of the exchanger

The stability of the exchanger was determined in different chemical, thermal and radiation environments. Chemical stability was determined by taking a 0.5 g portion of the exchanger in 25.0 mL of acid or alkaline solution of various strengths. This mixture was then shaken for 48 h; the solid-exchanger was filtered off and washed with water. The exchange capacity of the compound for Na⁺ was checked after this acid or alkali treatment. Thermal stability of the resins was studied employing a thermo-gravimetric analysis technique. Radiation stability was checked by measuring the ion exchange capacity of the exchanger, before and after γ -irradiation dose rate of 4.0 kGy/h by a ⁶⁰Co radiation source.

III.2.4. Determination of ion exchange capacity (IEC)

Hydrogen ion capacity was determined by batch method. An accurately weighed (0.5 g) exchanger, previously treated with 2.0 mol. L⁻¹ HCl to make acidic form of the exchanger and washed out of adhering acid, was equilibrated with 20.0 mL 0.1 mol. L⁻¹ NaOH solution for 1 h at room temperature at stirring condition. The excess alkali was titrated with 0.1 mol. L⁻¹ hydrochloric acid solution to determine the total acidic hydrogen content.

The exchange capacities of the exchanger for different alkali and alkaline metal ions were determined by batch method [20]. To a glass-stoppered centrifuge tube (diameter 2.0 cm) containing 0.5 g of the dry solid-exchanger, 50.0 mL of 2.0 mol. L⁻¹ solutions of each of the different alkali and alkaline metal ions was added to the tube in each case; then the mixture was shaken for a period of 1 h. The exchanger was subsequently filtered and washed with doubly distilled water to remove the adhering H⁺ ions. The exchange capacities for the metal ions were determined by measuring the liberated acid by titration with standard alkali. (**Table III.1**).

The ion exchange capacity decreases with increase of atomic number within a group. Again the ion exchange capacities of the material for the alkali metal ions are higher than those for the alkaline earth metal cations.

III.2.5. pH metric titration

The pH titration of the exchanger material was performed using batch method. Dry exchanger (0.1 g) was equilibrated with 25.0 mL of the mixture NaCl-NaOH for 24 h at room temperature. To prepare these systems different volumes of 0.01 mol. L⁻¹ NaOH were mixed with 0.01 mol. L⁻¹ NaCl to make a final volume of 25.0 mL. The pH of each solution after equilibration was measured and plotted against milliequivalents of hydroxyl ions added (**Fig.III. 4**).

III.2.6. Determination of Distribution Coefficients

For the determination of distribution of coefficients of cations on this ion exchanger, different batches of the solid were equilibrated with known amount of trace cations for a period of 1 h, followed by measurement of radioactivity of the solution. Distribution coefficient was calculated from the formula:

$$K_D = \text{Counts per gram of the solid} / \text{Counts per mL of the solution}$$

The K_D data for the ⁹⁰Y and ⁹⁰Sr radionuclides have been determined under varying the pH using HCl solution and the data has been summarized in **Table III.2**. Maximum adsorption of the radionuclides occurs at pH 6.0.

III. 2.7. Studies of radiochemical Separation of Strontium and Yttrium

III.2.7.a. Batch Method:

To obtain the optimum condition for successful separation of ^{90}Y from its parent ^{90}Sr , batch extraction was carried out. Both ^{90}Sr and ^{90}Y are β - emitters and have no suitable γ energy. Thus to measured K_D values of ^{90}Sr and ^{90}Y in different batches, first separation of ^{90}Sr and ^{90}Y was carried out by already established literature method. The formation of ^{90}Y in ^{90}Sr fraction was assumed to be negligible as the batch experiments were performed immediately after separation of ^{90}Sr from its equilibrium mixture. Aqueous phase containing ^{90}Sr or ^{90}Y separately in varying pH was shaken with 0.20 g of ion exchanger for 5 min. After disengagement of the solid and aqueous phase, counts of 2.0 mL of aqueous phase was taken with the help of a GM counter and compared with a standard, which was prepared in a same way as above but without the exchanger. At pH 3.0-7.0, the exchanger was found to adsorb maximum amount of both the elements (Table III.2).

III.2.7.b. Column method:

For the studies on separation of ^{90}Sr - ^{90}Y parent-daughter pair, a glass column of length 10.0 cm and 1.0 cm internal diameter was packed with amorphous cerium(IV)iodotungstate and thoroughly washed with water to remove any traces of adhered acid and preconditioned at pH 7. Equilibrated mixture of ^{90}Sr - ^{90}Y (100 μL) maintaining a neutral pH was loaded over the column. About 10.0 mL distilled water was passed through the column and no activity came out from the column. Then ^{90}Y was eluted with 0.0063 mol.L⁻¹ EDTA solution. The rate of the elution was adjusted to 1.0 drop/min. Each 5.0 drops fraction was collected and measured for its radioactivity in a GM counting system after definite time intervals. Purity of the eluted solution was checked by calculating half-life of ^{90}Y from eluted solution with the help of decay curve (Fig. III.7) and finally confirmed by Feather analysis [21, 22]. Here Feather analysis was carried out taking the ^{60}Co as reference ($\beta_{\text{max}} = 0.32$ MeV) and aluminium absorber following the literature method [23].

III.3. Results and Discussions

III.3.1. Synthesis and characterization

The new inorganic material, cerium(IV)iodotungstate was prepared using ammonium cerium(IV) nitrate, sodium tungstate and potassium iodate in water-glacial acetic acid mixture adjusting the pH 1.0 of the resulting solution using nitric acid. The isolated compound was found to be insoluble in water, alcohol, moderately concentrated acid and alkali and other common organic solvents. The elemental analysis of the exchanger showed that it contain 4.7 % of cerium, 12.6 % of iodine and 23.7 % of tungstate and this analysis helps to dictate the mole ratio of 1:3:3 respectively. The broad reflections on the powder XRD pattern (Fig.III.1) suggest that the synthesized compound is amorphous in nature. IR spectrum (Fig.III.2) of the compound in KBr disc shows the peaks at 1629, 1384 and 834 cm^{-1} assignable to the characteristic stretching of the tungstate [24].

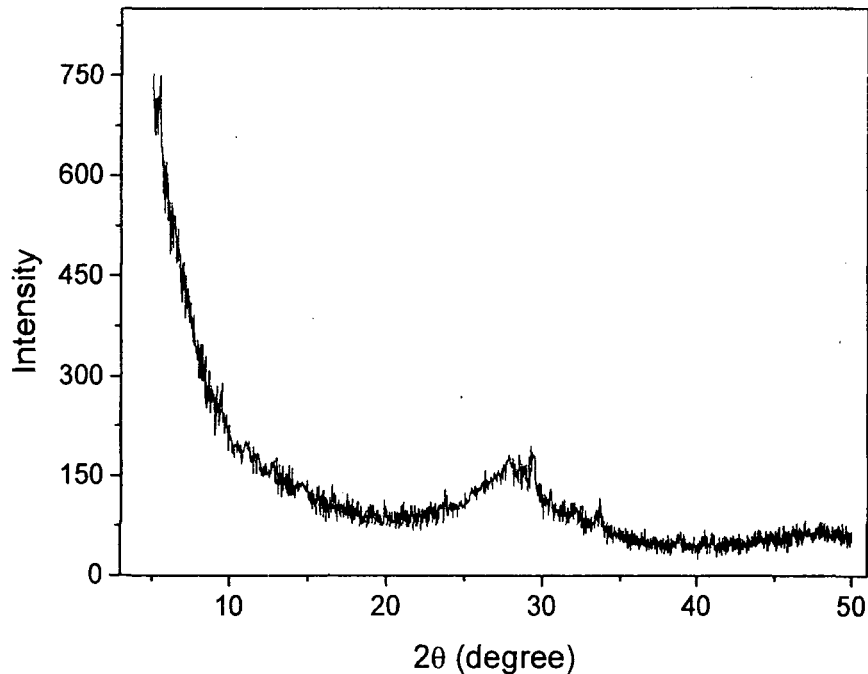


Fig.III.1. Powder XRD patterns of cerium(IV)iodotungstate

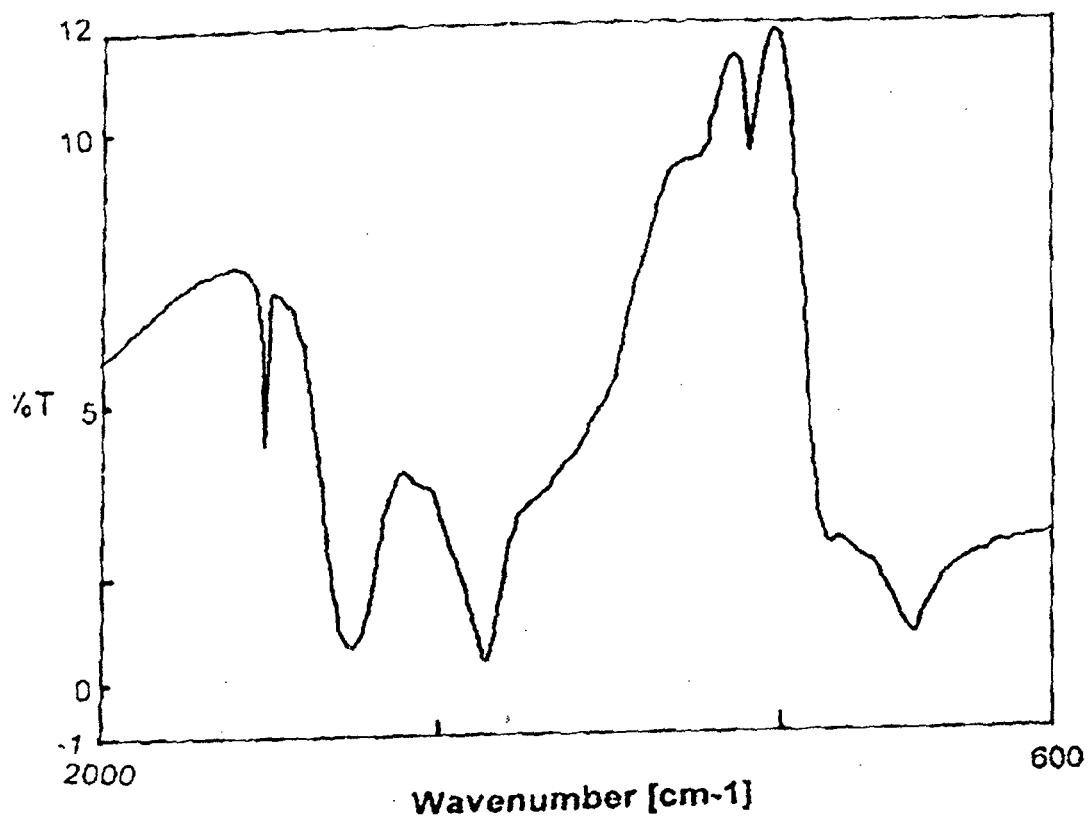


Fig. III.2. Infra-red Spectra of cerium (IV)iodotungstate exchanger

III.3.1a. Thermal, radiation and chemical stability

The thermal analysis of the exchanger shows that it is quite stable up to 230 °C (Fig.III.3).The radiation stability of the exchanger was studied by determining the exchange capacity of the exchanger before and after γ - irradiation at a dose rate of 4.0 KGy/hr. in the weight condition (in 0.01 mol. L⁻¹ HCL). The exchanger was found to retain its ion exchange capacity up to a total dose of 20.0 KGy. Moreover, the elution profile of the ⁹⁰ Sr and ⁹⁰Y remained the same in γ - irradiated exchanger as it was in the unirradiated material, which also suggested a high radiation stability of the exchanger. The exchanger was quite stable in normal chemical environment. The compound is stable up to 4.0 mol. L⁻¹ HCL, 4.0 mol. L⁻¹ HNO₃ and 2.0 mol. L⁻¹ NaOH solution.

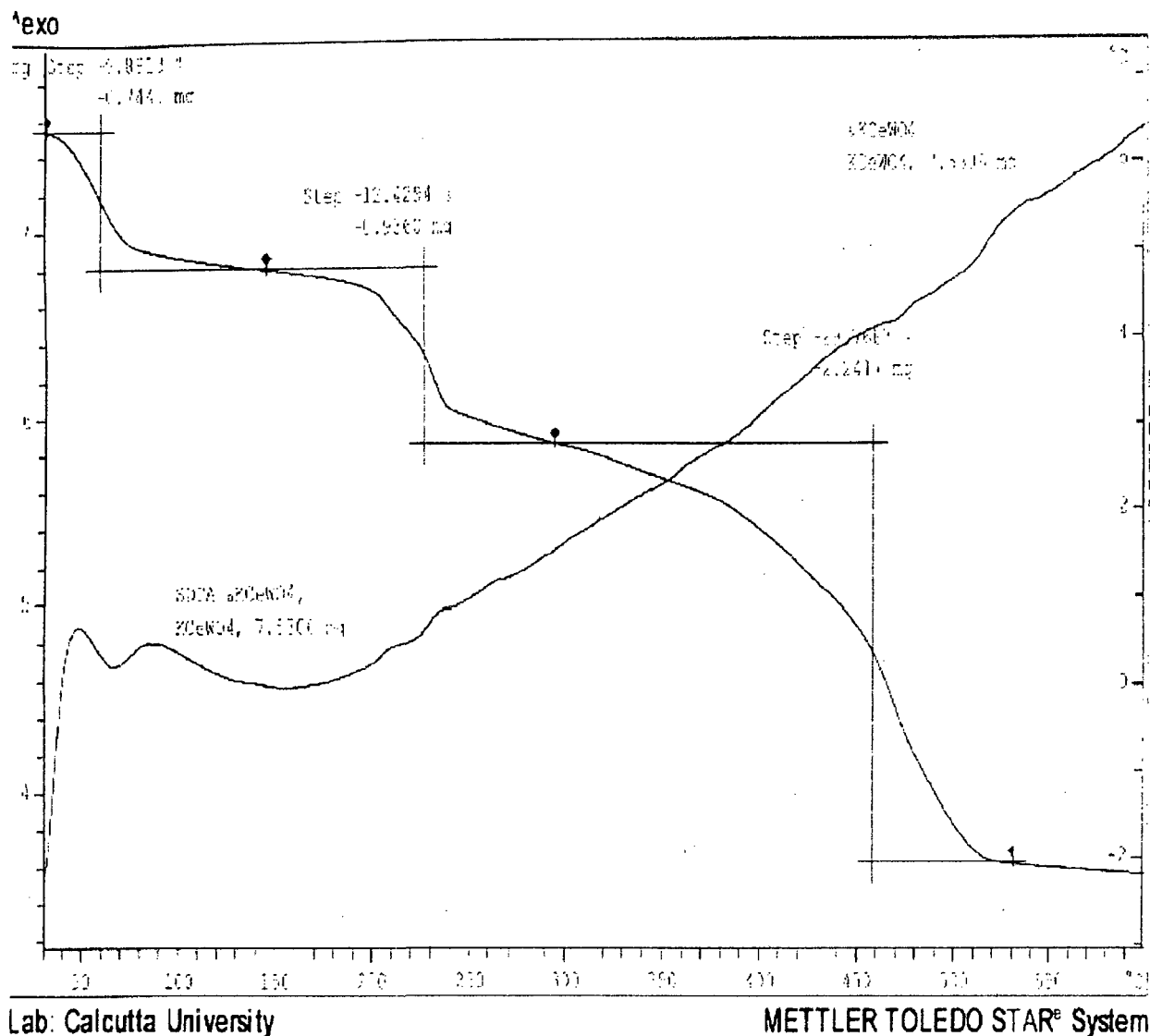


Fig. III.3: Thermogravimetric and differential thermal analysis curve of the exchanger

III.3.1b. pH metric titration curve

The variation of pH against the amount of alkali added is shown in Fig.II.6, which clearly indicates that the exchange capacity for sodium metal is nearly 2.7 meq/g of the exchanger and it is evident from the appearance of the only one inflexion point in the curve (Fig. III. 4).

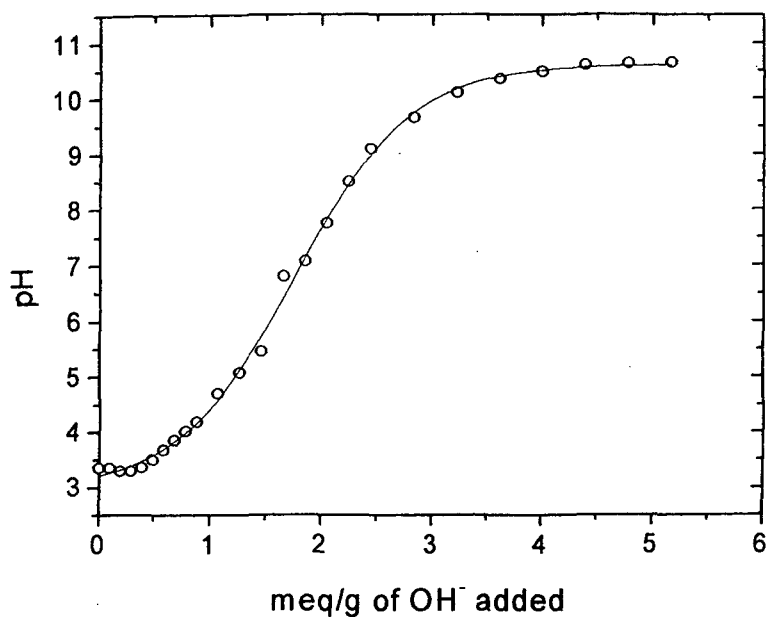


Fig. III.4: pH-metric titration of the exchanger

III.3.3. Sorption behavior of the metal ions

The exchange capacities of different alkali and alkaline metal ions are tabulated in **Table III.1**. From the table it is clearly shows that the ion exchange capacity for sodium ion is the highest and the exchange capacities are in the order $\text{Na}^+ > \text{Li}^+ > \text{K}^+ > \text{NH}_4^+ > \text{Cs}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} > \text{Sr}^{2+} > \text{Ba}^{2+}$. From the table it is also shows that the ion exchange capacities of alkali metal ions are higher than that of the alkaline earth metal ions.

Table III.1. Ion exchange capacity for different cations

Cation	Exchange capacity ^a (meq/g of exchanger)	Cation	Exchange capacity ^a (meq/g of exchanger)
Li^+	2.84 ± 0.03	Mg^{2+}	1.77 ± 0.03
Na^+	2.86 ± 0.03	Ca^{2+}	1.58 ± 0.02
K^+	2.72 ± 0.05	Sr^{2+}	1.39 ± 0.04
Cs^+	1.18 ± 0.03	Ba^{2+}	1.19 ± 0.05
NH_4^+	2.53 ± 0.08		

^aAverage of five determinations.

III.3.4. Distribution Coefficients

The K_D values of ^{90}Sr and ^{90}Y in various pH have been provided in **Table III.2**. It has been observed from the batch extraction data that the exchanger has a very high affinity for ^{90}Sr and at pH 5-7; $(K_D)_{\text{Sr}}$ is around 50. On the other hand, in this pH range, K_D value of ^{90}Y is quite low, which clearly indicates that the exchanger has a preferential affinity towards strontium and column chromatographic separation of ^{90}Sr - ^{90}Y pair might be possible using this exchanger.

Table III.2. K_D values of ^{90}Sr and no-carrier added ^{90}Y at different pH for the amorphous inorganic exchanger of cerium(IV)iodotungstate

pH	^{90}Sr	^{90}Y
1	0.98	0.21
2	1.01	0.61
3	41.21	0.97
5	52.23	1.44
6	56.59	1.76
7	53.03	1.89

III.3.5. Feather analysis

Purity of ^{90}Y was also checked by Feather analysis data [23]. Accordingly, ranges of β . absorption of both the eluted fraction (expected to be ^{90}Y) and a reference β^- emitter (here, ^{60}Co source) were determined in an end window G.M. counter. The energy of the β -activity of the reference (^{60}Co , $\beta_{\text{max}} = 0.32$ MeV) and the activity of the eluted fraction by $0.0063 \text{ mol.L}^{-1}$ were recorded against the thickness of aluminium absorber. These obtained data are tabulated in **Tables III.3** and **III.4**. The counts due to the activity of ^{60}Co was plotted against the thickness of the aluminium absorber and this exponential curve has been displayed in **Fig.III.5**.

Table III.3. Data for the β -activity of ^{60}Co (as reference, $\beta_{\text{max}} = 0.32 \text{ MeV}$) against the thickness of aluminium absorber

Thickness of aluminium absorber (mg/cm^2)	Counts (Net CPS)	Fractional Activity	Fractional range (mg/cm^2)
0	2400	1	-
3.8475	2010	0.8375	0.045
7.78	1460	0.608333	0.090994
11.63	1230	0.5125	0.136023
15.56	1100	0.458333	0.181988
19.4	810	0.3375	0.226901
23.34	660	0.275	0.272982
31.12	400	0.166667	0.363977
40.35	130	0.054167	0.47193
53.6	80	0.033333	0.626901
62.15	60	0.025	0.726901

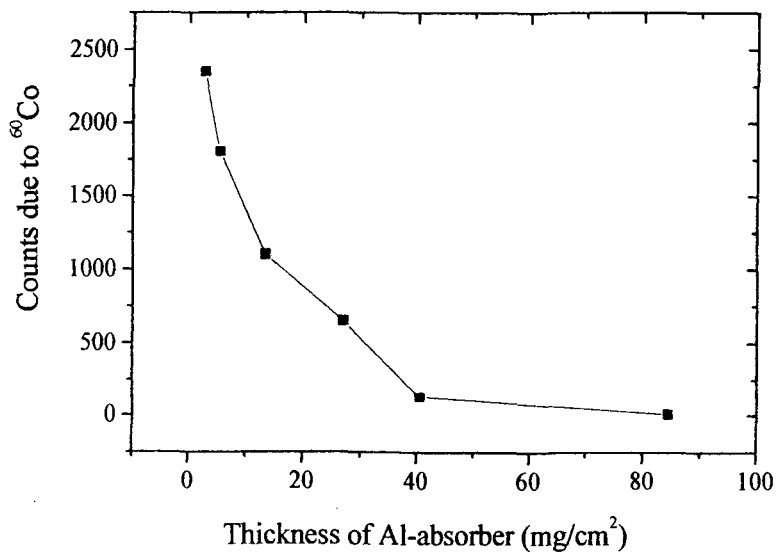


Fig. III. 5: Thickness of Al-absorber (mg/cm^2) vs. activity of reference (^{60}Co)

Table III.4. Data for the β -activity of the eluate (0.0063 mol. L⁻¹ EDTA) against the thickness of aluminium absorber

Thickness of aluminium absorber(mg/cm ²)	Counts (Net CPS)	Fractional Activity	Fractional range (mg/cm ²) ^a	Calculated range (mg/cm ²)
0	3700	1.00000	-	-
50	3100	0.837838	0.045	1111.111
100	2250	0.608108	0.090994	1098.974
150	1900	0.513514	0.136023	1102.755
200	1700	0.459459	0.181988	1098.974
250	1250	0.337838	0.226901	1101.802
300	1000	0.27027	0.272982	1098.974
400	625	0.168919	0.363977	1098.971
520	200	0.054054	0.47193	1101.858
690	125	0.033784	0.626901	1100.652
800	100	0.027027	0.726901	1100.563

^aObtained from **Table III.3**

The variation of the fractional range (mg/cm²) has been plotted against the calculated range (mg/cm²) of the eluted fraction (*vide* **Table III.4**) and the line obtained from this plot has been extrapolated upto the extrapolated line upto fractional range of 1.0 mg/cm² to acquire the maximum calculated range (R_{\max}). Here, the observed R_{\max} is 1101.09 mg/cm² for the eluted fraction. (*viz.* **Fig.III.6**)

From a comparison of fractional activity and fractional range, exact range of the unknown source was calculated. In this type of experiment, the maximum energy (E_{\max}) can be calculated with the help of the Glendenin empirical equations.

$$R_{\max} = 407(E_{\max})^{1.38} \quad \text{for } \beta \text{ energies } 0.15 \text{ MeV to } 0.8 \text{ MeV}$$

and

$$R_{\max} = 542E_{\max} - 133 \quad \text{for } \beta \text{ energies } 0.8 \text{ MeV to } 3.0 \text{ MeV}$$

Here, the maximum energy (E_{\max}) of ⁹⁰Y is 2.27 MeV, so the second empirical equation is valid to determine the β energy of the eluted fraction which contains ⁹⁰Y. So,

the maximum energy (E_{\max}) of the eluted fraction can be calculated by putting the value of $R_{\max} = 1101.09 \text{ mg/cm}^2$ in the second Glendenin empirical equation as follows.

$$E_{\max} = (1101.09 + 133)/542 \text{ MeV} \approx 2.277 \text{ MeV} \approx 2.28 \text{ MeV}$$

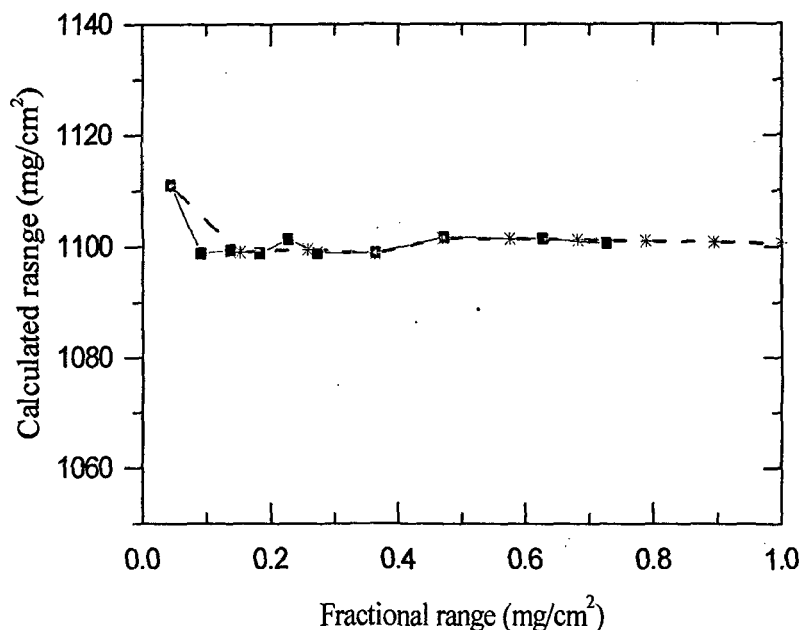


Fig.III.6: Variation of fractional range (mg/cm^2) with calculated range (mg/cm^2); the extrapolated line upto 1.0 as indicated by red dotted line.

The calculated value of the maximum energy (E_{\max}) of eluted fraction is 2.28 MeV which is very close to the theoretical value of β_{\max} of ^{90}Y (2.27 MeV). It confirms the presence of the ^{90}Y in the eluted fraction.

III.3.5 Application of the exchanger in Radiochemical separation

III.3.5.1. Separation of ^{90}Sr - ^{90}Y radionuclides

In batch method, the K_D values of ^{90}Sr and ^{90}Y at various pH have been provided in (Table III.2.). It has been observed from the batch extraction data that the exchanger has a very high affinity for ^{90}Sr and at pH 3- 7, ($K_D=50$). On the other hand, in this pH range, K_D value of ^{90}Y is quite low, which clearly indicates that the exchanger has a

preferential affinity towards strontium and column chromatographic separation of ^{90}Sr - ^{90}Y pair might be possible using cerium(IV) iodotungstate as stationary phase.

In column operation chromatographic separation of ^{90}Y from the equilibrium mixture of ^{90}Sr - ^{90}Y has been carried out. A 100 μL radionuclide mixture taken in near neutral medium was adsorbed on cerium (IV)iodotungstate bed from top of the column. After adsorption, about 10.0 mL water was passed through the column. However, no activity was found in the eluate. Then EDTA solutions of different strengths were used as eluting agent. It was found that 0.0063 mol. L^{-1} EDTA elute preferentially ^{90}Y while ^{90}Sr remains absorbed in the column in this condition. The activity of the eluted solution was checked with GM counter at different time intervals. The decay curve was linear (Fig.III.7).

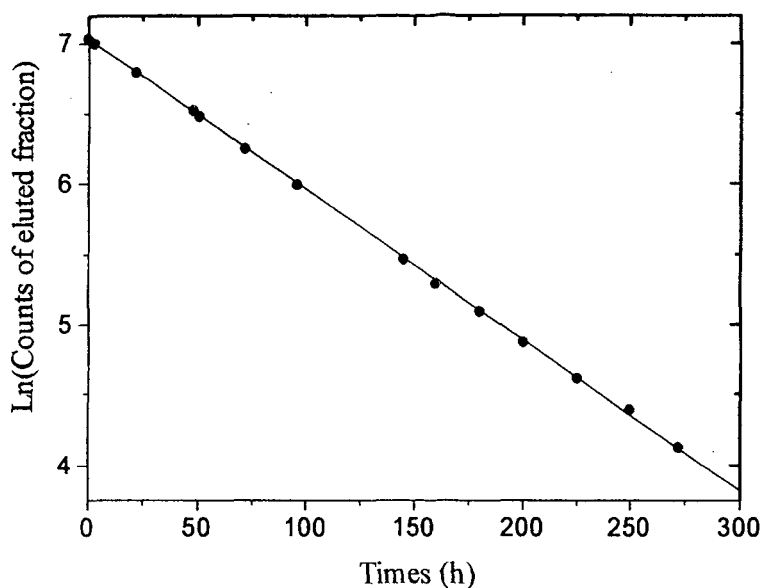


Fig.III.7: Decay curve (Slope = $-0.0107 \pm .000045$) of ^{90}Y [Half life ($t_{1/2}$) = 64.05 ± 0.6 h], very close to half-life ($t_{1/2}$) of ^{90}Y (64.08 h), taking the count of eluant (0.0063 mol. L^{-1} EDTA solution) from the column by GM counter.

From the slope, the half-life of the eluted solution was calculated and found to be 63.5 h, which matches with the half-life of ^{90}Y (64.08 h). Thus, it can be concluded that eluted solution contains radiochemically pure ^{90}Y . The trend in separation of ^{90}Sr - ^{90}Y is quite satisfactory. As Y (III) forms a stronger complex with EDTA than Sr(II), it could be desorbed from the column preferentially. Only 8.0 to 10.0 mL of

EDTA ($0.0063 \text{ mol.L}^{-1}$ or 0.25%) was sufficient for removal of ^{90}Y at a given moment (Fig.III.8) represents the elution profile of ^{90}Y . As the parent ^{90}Sr remain adsorbed in the column, it would produce ^{90}Y again after a considerable time and the same method can be repeated for milking ^{90}Y from ^{90}Sr after some days from the same column. Thus the exchanger is found to act as radionuclide generator system.

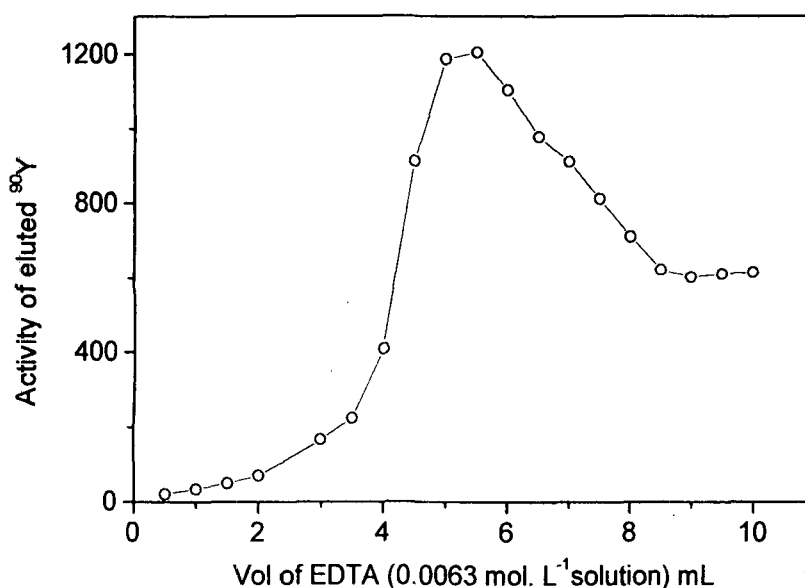


Fig.III.8: Elution profile of ^{90}Y by cerium (IV) iodotungstate

III. 4. Epilogue

The newly designed and characterized exchanger, cerium(IV)iodotungstate has shown successful separation and confinement of long-lived ^{90}Sr radionuclides. From the experimental result, it is revealed that this exchanger can also be safely employed in the separation of ^{86}Y from the mixture of ^{86}Y - ^{86}Sr as ^{86}Y ($t_{1/2} = 14.7 \text{ h}$, 66% EC, 34% β^+ , $E_{\beta^+\text{max}} = 3.2 \text{ MeV}$) is nowadays a promising positron emitting radionuclide capable of serving as a PET imaging surrogate to ^{90}Y [25-30]. It can also predict that the exchanger may be used for separation of other alkali metals from alkaline earth metals. Finally, the exchanger may be prescribed as a radionuclide generator for the present ^{90}Sr - ^{90}Y system and results encourage extrapolating in the hitherto unexploited region.

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