

Sorption Method for Purification of Ittrium-90 Radionuclides and Separation of $^{90}\text{Sr}/^{90}\text{Y}$ Pair

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Abstract—Deep purification of the stripped ^{90}Y obtained after the $^{90}\text{Sr}/^{90}\text{Y}$ pair extraction separation with D_2EHPA from chemical impurities (Cr, Mn, Ni, Pb, Fe, Zr) employing the TODGA-containing sorbent AXIONIT MND 40T was considered. Also, a two-stage sorption separation of the $^{90}\text{Sr}/^{90}\text{Y}$ pair without using the extraction method was developed. At the first stage the ^{90}Y was separated from ^{90}Sr with Purolite D5041 phosphate cation exchange resin, and at the second stage, ^{90}Y deep purification was carried out on the AXIONIT MND 40T sorbent. The prepared ^{90}Y in radiochemical purity meets the requirements for radiopharmaceuticals.

Keywords: sorption, separation, strontium, yttrium, radiopharmaceutical

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INTRODUCTION

Radionuclide ^{90}Y is one of the first radioactive isotopes to be used for radiotherapy and the interest in ^{90}Y continues although more than 30 radionuclides are currently used for this purpose. This interest is due to its convenient nuclear-physical properties: a half-life of 64.2 h and a maximum β -energy of 2.27 MeV. ^{90}Y is used for a variety of therapeutic purposes including radioimmunotherapy with labeled antibodies, treatment of liver tumors and rheumatoid arthritis [1].

^{90}Y is formed during the decay of the long-lived radioisotope ^{90}Sr , which is a fission product of uranium. One of the important requirements for the safe clinical use of ^{90}Y is deep purification from ^{90}Sr , which has a high affinity for bone tissue and can cause bone marrow damage. The regulated ^{90}Sr content in the ^{90}Y radiopharmaceuticals used in nuclear medicine for therapeutic procedures should not exceed 2×10^{-6} Ci/Ci of ^{90}Y . In addition, there are strict requirements for the heavy metal content, which in a ^{90}Y radiopharmaceutical in total should not exceed 10 μg per 1 Ci of ^{90}Y [2, 3].

In order to produce the final product with the required purity, an ^{90}Y multistage purification from chemical and radiochemical impurities is carried out,

mainly by liquid extraction and ion exchange methods [1]. Each of these methods has its own limitations and disadvantages. Thus, ion-exchange methods for producing ^{90}Y are quite simple to implement, however, the long duration of sorption processes (18–20 h) leads to significant losses of the finished product due to its decomposition. In practice, isotope generators are often used. Their action is based on the sorption separation of the $^{90}\text{Sr}/^{90}\text{Y}$ pair on a sulfonic cation exchange resin, for example, Dowex 50W \times 8. In this case, the ^{90}Y yield is 90–98%, but the ^{90}Sr impurity gradually increases due to the radiation destruction of the resin. Moreover, additional operations of chemical treatment of eluates are required to convert ^{90}Y into a form suitable for further use (0.01 mol/dm³ HCl solution).

The method of liquid extraction employing di-2-ethylhexylphosphoric acid (D_2EHPA) is currently considered the most effective method for separating an equilibrium $^{90}\text{Y}/^{90}\text{Sr}$ mixture. The extraction proceeds rather quickly: the total time of the ^{90}Y extraction process is 30–60 min, the yield of the target product is more than 95%, and the ^{90}Sr content in the finished product is less than 10^{–6}%. However, the obtained ^{90}Y contains, in addition to residual amounts of ^{90}Sr , impurities of corrosion products (Fe, Ni, Cr, Pb, etc.)

and extractant radiolysis product, which brings about the need for additional purification of the stripped ^{90}Y .

In [4, 5], extraction-chromatographic methods of ^{90}Y extraction and purification are described, which combine the sorption and extraction advantages. The methods consist in passing a solution containing $^{90}\text{Sr}/^{90}\text{Y}$ vapor through columns with a D_2EHPA -based solid extractant (TVEX).

In addition to organophosphate compounds, extractants based on diglycolic acid diamides, in particular, tetraoctyldiglycolamide (TODGA), can be used as an active component in the TVEX composition. DGA resin sorbent based on styrene-divinylbenzene copolymer and TODGA is produced by Triskem International (France) and is used for the extraction and separation of radioactive REE and TPE for radioanalysis [6]. There is no information on the use of TODGA-containing sorbents to produce high-purity ^{90}Y .

The nature of the REE sorption (by the example of the ^{152}Eu sorption) on the TVEX-TODGA was previously considered in [7, 8]. Due to the fact that yttrium is a chemical analogue of REE, it can be assumed that the patterns of the europium and yttrium sorption on the studied sorbents will be similar.

In the study we investigated the possibility of deep purification of the yttrium-90 after extraction separation of ^{90}Y from ^{90}Sr with D_2EHPA using a TODGA-containing AXIONIT MND 40T, TVEX of Russian production, and we also studied the conditions for the sorption separation of ^{90}Y from ^{90}Sr using phosphate cation exchange resin and AXIONIT MND 40T sorbent.

EXPERIMENTAL

Sorption purification of stripped ^{90}Y . In the extraction separation of the $^{90}\text{Sr}/^{90}\text{Y}$ pair using D_2EHPA , the stripped ^{90}Y is obtained containing 5 M nitric acid, trace amounts of ^{90}Sr , and chemical impurities, mainly corrosion products of structural materials. Table 1 shows the composition of the model solution simulating the stripped ^{90}Y .

The experiments were carried out under dynamic conditions employing a TODGA-containing TVEX of AXIONIT MND 40T grade ("Axion-Rare and Precious Metals" JSC, Russia). A styrene-

divinylbenzene copolymer was used as a carrier. The TODGA content in the sorbent was 40 wt %, the granule size was 0.315–0.50 mm. For purification, the initial solution was passed through a plastic column filled with AXIONIT MND 40T sorbent, the volume of the sorbent in the column was 4 cm^3 . Before the experiments, the sorbent was treated in a column with a 5 M nitric acid solution for 2 h. At the sorption stage the initial solution was passed through the column at a rate of 6.0 column volumes per an hour [(c.v.)/h]. The filtrate at the column outlet was collected and tested for the amounts of chemical impurities.

After the end of the sorption, a 3 M HCl solution was passed through the column at a rate of 3.0 c.v./h to remove the initial solution residues. Desorption of ^{90}Y was performed with 0.01 M HCl. The passing rate was 3.0 c.v./h, the solution volume was 6 c.v. The supply of the solutions during pre-treatment and at all stages was carried out using a peristaltic pump from bottom to top. The total time of sorption purification was 5–6 h.

Sorption separation of the $^{90}\text{Sr}/^{90}\text{Y}$ pair. The $^{90}\text{Sr}/^{90}\text{Y}$ pair separation experiments were carried out employing a model solution containing 1.5 g/dm^3 strontium and 0.15 mg/dm^3 yttrium nitrates and 0.01–0.3 M nitric acid therewith a label of the equilibrium $^{90}\text{Sr}/^{90}\text{Y}$ pair was introduced into the model solution in an amount of about $10^5 \text{ Bq}/\text{dm}^3$.

At the first stage of separation, the initial solution was passed through a plastic column filled with 4.5 cm^3 D5041 phosphate cation exchange resin (Purolite, Great Britain). Then the sorbent was washed with a 0.01–0.3 M HCl solution and ^{90}Y was stripped with a 3 M HCl solution. The flow rate of the solutions was 3.0 c.v./h, the solution volume was 6 c.v. In the filtrate and desorbate, the specific total beta activity was determined.

At the second stage of separation, hydrochloric acid desorbate was passed through a plastic column filled with 4.5 cm^3 AXIONIT MND 40T sorbent. Then the sorbent was washed with a 3 M HCl solution and ^{90}Y was stripped with a 0.01 M HCl solution. The flow rate of the solutions was 3.0 c.v./h, the solution volume was 6 c.v. In the filtrate and desorbate, the specific total beta activity was determined for at least 35 days. The setup scheme is shown in Fig. 1.

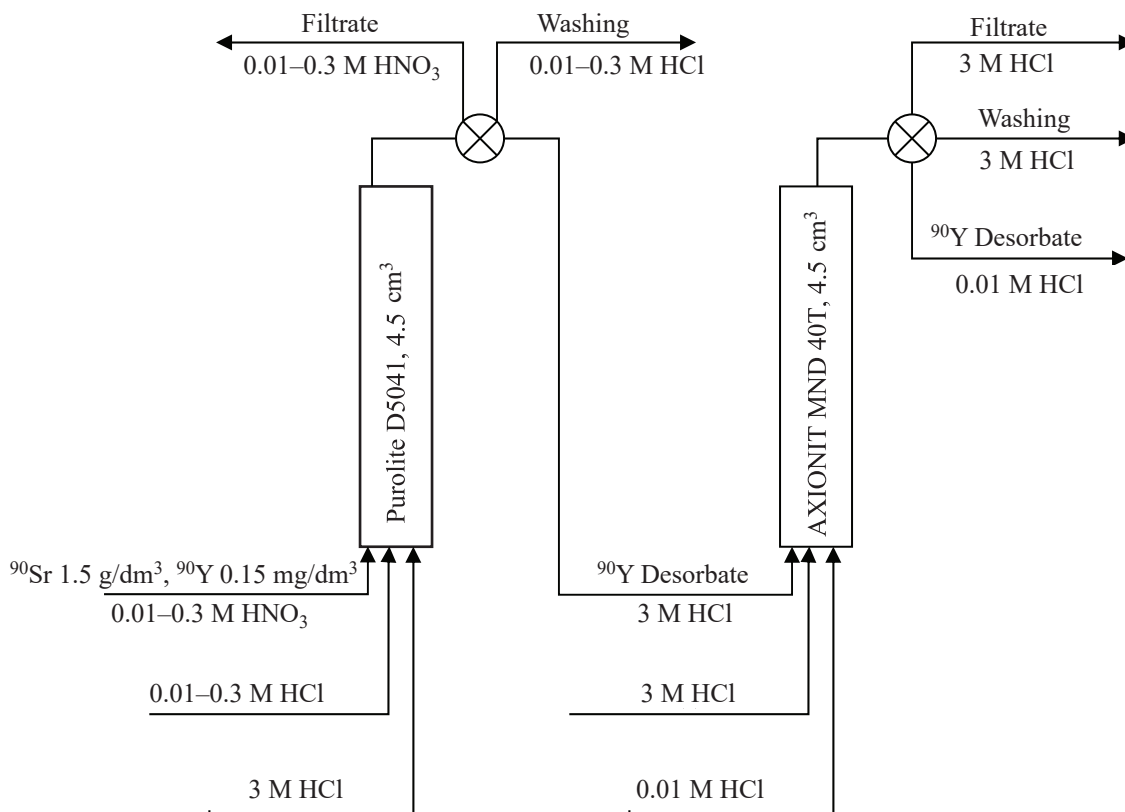


Fig. 1. Setup scheme for $^{90}\text{Sr}/^{90}\text{Y}$ pair sorption separation.

The analysis of solutions for the content of chemical elements was carried out by mass spectrometry by an Agilent 7500ce inductively coupled plasma mass spectrometer (ICP-MS) (Agilent Technologies, Japan). The specific activities of ^{90}Sr and ^{90}Y in solutions were determined by a direct radiometric method using an SKS-50M spectrometric complex (Green Star Technologies, Russia).

RESULTS OF DISCUSSION

Sorption purification of stripped ^{90}Y . The results of the sorption purification of the model solution

simulating the stripped ^{90}Y from strontium and other chemical impurities using the AXIONIT MND 40T sorbent are listed in Table 1.

The presented results show that when using the sorption method of purification, which includes the ^{90}Y sorption stages on the AXIONIT MND 40T sorbent, washing and elution of yttrium with 0.01 M HCl, deep purification of the stripped ^{90}Y from residual strontium amounts as well as from equipment corrosion products, is observed. The purification factors (K_{pur}) of yttrium from strontium, chromium, manganese, nickel, and lead are more than 100. The K_{pur} for iron and zirconium ions is 54 and 40, respectively. The lowest purification

Table 1. Compositions of the initial strip solution and the treated solution (desorbate)

Solution	Concentration in solution, mg/dm ³										
	Sr	Y	Al	P	Ca	Cr(III)	Mn(II)	Fe(III)	Ni	Zr	Pb
Initial (5 M HNO ₃)	14	0.14	24	3.5	21	27	26	97	27	0.4	24
Treated (0.01 M HCl)	0.12	0.15	8.9	0.9	5.8	0.1	0.09	1.8	0.15	0.01	0.1
Purification factor	117	–	2.7	3.9	3.6	270	289	54	180	40	240

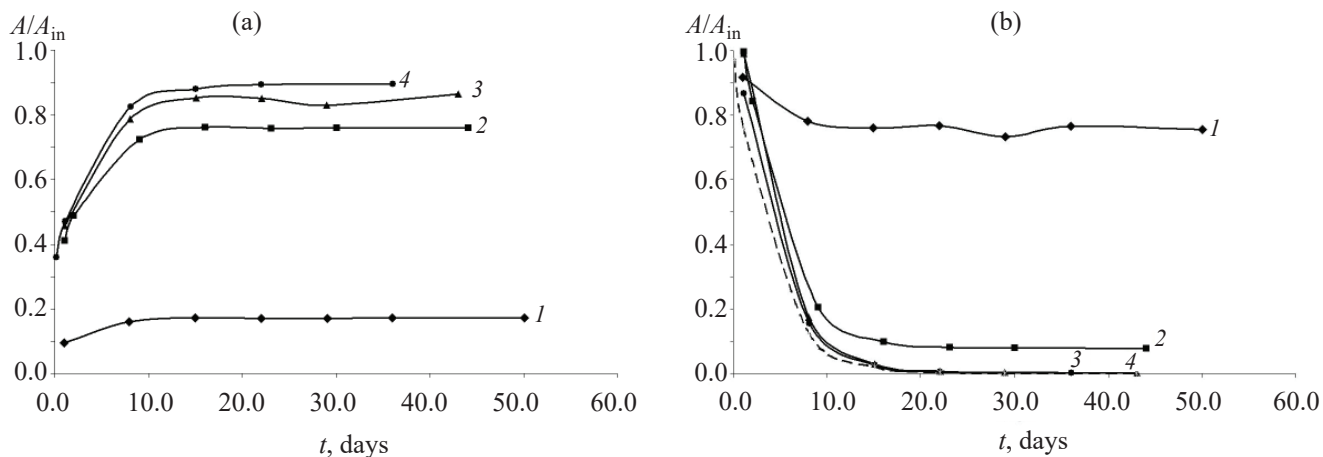


Fig. 2. Relative beta activity (A/A_{in}) vs. the exposure time of (a) filtrates and (b) desorbates in 3 M HCl obtained after sorption with a D5041 cation exchange resin. HNO_3 concentration in solution during sorption, M: (1) 0.01, (2) 0.1, (3) 0.2, (4) 0.3. The dotted line is the calculated ^{90}Y decay curve.

efficiency is observed for impurities of aluminum, phosphorus, and calcium ($K_{pur} = 2.7\text{--}3.9$).

During the experiments, three consecutive treatment cycles were carried out without replacing the sorbent. The results obtained showed that the purification factors remain at a constant level.

Sorption separation of the $^{90}\text{Sr}/^{90}\text{Y}$ pair. The sorption method was tested for direct separation of the $^{90}\text{Sr}/^{90}\text{Y}$ pair without using the extraction method. The sorption completeness of ^{90}Y and ^{90}Sr on the first column filled with phosphate cation exchange resin D5041 can be evidenced by the change in the relative beta activity (A/A_{in}) of the filtrate over 35–50 days. The results are shown in Fig. 2a, curve 1.

These results demonstrate that sorption from a 0.01 M HNO_3 solution is accompanied by the combined sorption of ^{90}Sr and ^{90}Y . The relative beta activity of the filtrate changes relatively little over time and its equilibrium value is about 20% of the initial value. With an increase in the nitric acid concentration the time dependence of the A/A_{in} value of the filtrate changes sharply. At a 0.2–0.3 M HNO_3 concentration at first the A/A_{in} value is ~ 0.4 , and the equilibrium value, 0.8–0.9. This fact indicates that during the sorption of the equilibrium $^{90}\text{Sr}/^{90}\text{Y}$ mixture in this acidity range, almost all ^{90}Sr remains in the filtrate, and ^{90}Y is completely sorbed on the column. When the sorbent is washed after sorption with 0.2–0.3 M HCl, additional elution of residual amounts of ^{90}Sr occurs.

The above is confirmed by the time dependences of the relative beta activity of hydrochloric acid desorbates (3 M) obtained after sorption with a D5041 cation exchange resin from solutions with different HNO_3 concentrations (Fig. 2b). Figure 2b shows, for clarity, the calculated decay curve of pure radionuclide ^{90}Y calculated according to the radioactive decay law.

The results on Fig. 2b show that hydrochloric acid desorbates obtained after the $^{90}\text{Sr}/^{90}\text{Y}$ pair sorption by the D5041 cation exchange resin from 0.2–0.3 M HNO_3 solutions and washing with HCl solutions of the same concentrations contain almost pure ^{90}Y . The residual activity of desorbates after keeping for 45 days does not exceed 0.1% of the initial activity of the solution, and the experimental and calculated decomposition curves of desorbates almost completely coincide.

Due to the fact that even deeper purification of ^{90}Y from ^{90}Sr is required for use in the production of radiopharmaceuticals, the obtained hydrochloric acid desorbates were subjected to additional purification with the TODGA-containing sorbent AXIONIT MND 40T. Sorbents of this type are capable of efficient sorption of REE and Y in strongly acidic media including hydrochloric acid. In acid solutions with a concentration of less than 0.1 M the sorption of REE(Y) sharply decreases, which makes it possible to carry out their desorption.

To experimentally verify this fact we used hydrochloric acid desorbate obtained after $^{90}\text{Sr}/^{90}\text{Y}$

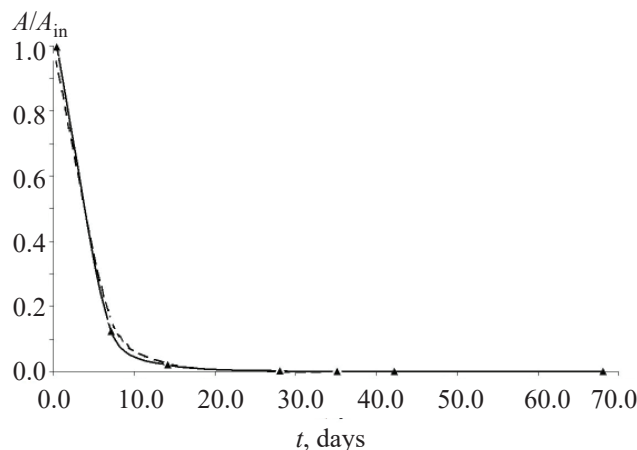


Fig. 3. Experimental (solid line) and calculated (dashed line) curve of the relative beta activity (A/A_{in}) vs. the exposure time of the desorbate (0.01 M HCl) after sorption by the AXIONIT MND 40T sorbent.

pair sorption by the cation exchange resin D5041 from a 0.2 M HNO_3 solution and washing with 0.2 M HCl. Desorbate containing 3 M HCl, ^{90}Y desorbed from the first column, and residual impurities were passed through a plastic column filled with 4.5 cm³ AXIONIT MND 40T sorbent. Then the sorbent was washed with a 3 M HCl solution and ^{90}Y was desorbed with a 0.01 M HCl solution. The passing rate of solutions was 3.0 c.v./h, the solution volume was 6 c.v. Figure 3 shows the experimental and calculated curves of the relative beta activity (A/A_{in}) vs. the exposure time of the desorbate (0.01 M HCl) after sorption by the AXIONIT MND 40T sorbent.

The results in Fig. 3 show that hydrochloric acid desorbates obtained after additional purification with the AXIONIT MND 40T sorbent contain only ^{90}Y . The residual activity of desorbates after keeping for 45 days is at the near the detection limits of the recording equipment. The portion of ^{90}Sr activity in ^{90}Y -containing desorbate is less than $10^{-6}\%$.

CONCLUSIONS

The studies carried out made it possible to develop a sorption method for deep purification of nitric acid ^{90}Y desorbate after extraction separation of a pair of $^{90}\text{Sr}/^{90}\text{Y}$ with D_2EHPA from ^{90}Sr and chemical impurities, corrosion products of equipment. The method consists in the features of ^{90}Y sorption by a TOGDA-based solid extractant—AXIONIT MND 40T sorbent. In HNO_3

solutions with a concentration above 3 M the complete yttrium extraction occurs, while the sorption of strontium and corrosion products on this sorbent practically does not occur. This allows at the sorption stage to carry out deep purification of ^{90}Y from ^{90}Sr and a wide range of chemical impurities (chromium, manganese, nickel, lead, iron, zirconium).

The unique sorption properties of the AXIONIT MND 40T sorbent make it possible to afford pure ^{90}Y radiopharmaceuticals without employing the extraction method that is complex in hardware implementation. At the first stage of the process, selective sorption of ^{90}Y from weakly acidic media is carried out on a phosphate cation exchange resin, where the main part of ^{90}Sr is separated and passed into the filtrate. Desorption of ^{90}Y from the phosphate cation exchange resin with 3 M HCl and then ^{90}Y sorption from the hydrochloric acid desorbate on the AXIONIT MND 40T sorbent allow deep purification both from residual amounts of ^{90}Sr and from chemical impurities of corrosion products. Elution of ^{90}Y from the AXIONIT MND 40T sorbent is easily carried out with a dilute solution of hydrochloric acid, which is the preferred medium for obtaining ^{90}Y -based radiopharmaceuticals.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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