



Original Article

DOI: 10.36959/349/550

Development of a Stationary Chromatography Radionuclide Generator of Technetium-99m

Ulugbek T Ashrapov^{1*}, Saydakhmat S Khujaev² and Ilkham I Sadikov¹



¹Department of Nuclear Energy and Nuclear Technologies of the Institute of Nuclear Physics of Academy Sciences of Republic Uzbekistan

²Laboratory of Nuclear Chemistry of the Institute of Nuclear Physics of Academy Sciences of Republic Uzbekistan

Keywords

Target, Irradiation, Sorbent, Column, Generator Technetium-99m, Eluent, Elate, Radiochemical Purity

Abbreviations

^{99m}Tc - radionuclide technetium-99 metastable; E_γ - energy of gamma rays, keV; E_β - beta radiation energy, keV; T_{1/2} - radionuclide half-life, hour Ci - measure of radioactivity, curie; ⁹⁸MoO₃ - molybdenum oxide labeled with the Mo-98 isotope; Al₂O₃ - aluminum oxide; r - sorbent particle size, mm; pH - pH value; N - normality of the solution; M - molarity of solution; D - radionuclide distribution coefficient; FA - fuel assembly (nuclear fuel); TcO₄⁻ - pertechnetate anion (^{99m}Tc); OSGI - industry standard calibrated source; r.p. - radiochemical purity of the eluate, %.

Introduction

Radionuclide technetium-99m is used for diagnostics and scintigraphy (scanning) of the thyroid and salivary glands, brain, and radionuclide angiocardiology, and also ventriculography. For example, myocardial perfusion scanning plays an important role in diagnosing and making therapeutic decisions in heart disease. For example, technetium-99m sestamibi or technetium-99m tetrofosmin radiopharmaceuticals are often used to scan myocardial perfusion in SPECT (single photon ejection computed tomography) techniques [1].

Elution of the daughter nuclide ^{99m}Tc from its portable generators or "milking" of the generator is expediently performed every 6 hours twice a day. Since the half-life of ⁹⁹Mo is 66 hours, the supply of the original product is depleted to an insufficient level in about one week, so the generator must be replaced with a fresh generator. Meanwhile, for large cities with a population of one million people, where there are several dozen clinics, it may be more promising to manufacture a stationary generator with an activity of 15-20 Ci (555-740 GBq) in a radiochemical laboratory and centrally deliver the finished preparation of sodium pertechnetate solution (^{99m}Tc) to clinics. In this case, the problems associated with the operation of generators, with ensuring radiation safety in clinics, are positively solved, and production costs are also reduced.

The purpose of this work is to study the radiochemical foundations of the chromatographic stationary radionuclide generator Tc-99m, to develop a radiochemical scheme for

the manufacture of a stationary Tc-99m generator and to manufacture pilot models of the stationary Tc-99m generator.

In this work, a scheme of radiochemical technology for manufacturing a stationary radionuclide generator ⁹⁹Mo/^{99m}Tc of the chromatographic type on sorbent of aluminum oxide is developed, which makes it possible to obtain the radionuclide ^{99m}Tc in the form of a solution of sodium pertechnetate (^{99m}Tc) with high specific activity and radiochemical purity for the needs of nuclear medicine.

Materials and Methods

Molybdenum oxide crystalline grade "special purity" and isotopically enriched in Mo-98 molybdenum trioxide were used as a target for irradiation at the WWR-SM reactor.

In the experiments hydrochloric acid, sulfuric acid, caustic soda, sodium chloride, sodium nitrate, disubstituted

***Corresponding author:** Ulugbek T Ashrapov, Department of Nuclear Energy and Nuclear Technologies of Institute of Nuclear Physics of Academy Sciences, 100214, poselok Ulugbek, Republic Uzbekistan, Tel: +998-99-490-27-71; Fax: +998-71-289-31-18

Accepted: February 02, 2024

Published online: February 04, 2024

Citation: Ashrapov UT, Khujaev SS, Sadikov II (2024) Development of a Stationary Chromatography Radionuclide Generator of Technetium-99m. J At Nucl Phys 5(1):107-116

sodium phosphate - chemically pure reagents were used. To obtain the parent radionuclide molybdenum-99 by neutron irradiation of the WWR-SM reactor, samples with the natural isotopic composition of molybdenum (MoO_3) and enriched in the isotope ^{98}Mo with an enrichment in the isotope Mo-98 of at least 97% were used.

Aluminum oxide (Al_2O_3) of the "for chromatography" type with a $r = 0.1-0.2$ mm was used as a sorbent for stationary chromatographic columns. The sorbent was activated by preliminary treatment with a 3 M hydrochloric acid solution during 1 hour, then washed with distilled water until the wash water reaches the value of $\text{pH} = 2.0$, than obtained product dried at a temperature of 120°C during 3 hours. To carry out experiments in dynamic modes, generator columns of various volumes (25-200 ml) with ordinary glass taps were used.

Radiometric and spectrometric measurements of the activity of samples and solutions were carried out on a measuring complex consisting of a DGDK-EMS-666/V detection unit, an NTA-1024 pulse analyzer, an Aspect SU-01P gamma spectrometer with a Ge-Li detector of the DGDK-120 type, and used beta-gamma spectrometer "Progress BG(II)" BDEB 3-2U with software "Progress 5". Static experiments were carried out in chemical glass beakers with periodic mixing of the liquid and solid phases. Experiments in the dynamic mode were carried out in special glass columns made of molybdenum glass, equipped with communications, consisting of an eluent line (inlet) and an eluate line (outlet). The yield of $^{99\text{m}}\text{Tc}$ was studied by washing sorbents in generator columns containing the adsorbed parent radionuclide ^{99}Mo .

Static experiments on the study of the sorption of molybdenum on aluminum oxide weighing 1g were made by periodic mixing of the aqueous and solid phases in 50 ml glasses. The volume of the aqueous phase was 3-5 ml; the contact time was 1 hour.

The distribution coefficient of ^{99}Mo under static sorption conditions (D_{Mo}) was calculated by the formula:

$$D_{\text{Mo}} = \frac{A_s}{A_w} \cdot \frac{V_w}{M} \quad (1)$$

Where: A_s and A_w are radioactivity ^{99}Mo in the solid phase and the aqueous (water) phase, impulses/sec; V_w is water phase volume, ml; M is mass of dry sorbent, g.

The distribution coefficient of $^{99\text{m}}\text{Tc}$ under static sorption conditions (D_{Tc}) was calculated by the formula:

$$D_{\text{Tc}} = \frac{A_0 - A_1}{A_0} \cdot \frac{V}{m} \quad (2)$$

Where: activities of initial and final solutions (before and after sorption), impulses/sec; V - is water phase volume, ml; m - mis mass of dry sorbent, g.

Laboratory experiments in dynamic mode were carried out in columns with drain cocks in the lower part made of ordinary glass with a volume of 5-20 ml. Industrial generators with significant Mo activity were tested in columns with a volume of 5 ml (small columns) and 200 ml (large columns) of molybdenum glass. The generator columns with the sorbent in two ways were loaded: 1) ^{99}Mo was initially sorbed statically in a beaker, then the sorbent with ^{99}Mo was transferred into the column; 2) Sorption of ^{99}Mo was carried out directly in the column in dynamic mode with a preliminary filled sorbent by the method of descending and ascending chromatography.

The calculation of the output of the daughter radionuclide Tc and the slip of the parent radionuclide Mo from the generator column under dynamic conditions was carried out according to the following formulas

$$\text{Output } ^{99\text{m}}\text{Tc} = \frac{A_{\text{ed}}}{A_{\text{rd}}} \cdot 100\% \quad (3)$$

where: A_{ed} is the total radioactivity of the $^{99\text{m}}\text{Tc}$ radionuclide in the eluate, imp/sec; A_{rd} is the equilibrium radioactivity of the daughter radionuclide in the ^{99}Mo - $^{99\text{m}}\text{Tc}$ system, imp/sec.

Results of the Study of the Chemical Forms of Molybdenum in Solutions

Table 1 shows the main nuclear characteristics of ^{99}Mo , $^{99\text{m}}\text{Tc}$ and ^{99}Tc in a $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$ generator system.

Passing a saline solution through a generator column with adsorbed ^{99}Mo leads to the elution of soluble $^{99\text{m}}\text{Tc}$, as well as ^{99}Tc . Since ^{99}Tc cannot be separated from $^{99\text{m}}\text{Tc}$, this by-product, which is part of the eluate, has no medical benefit and is not a contaminant. The eluate will also include a small amount of ^{99}Mo and some aluminum, the latter two substances being contaminants that must be limited according to IAEA standard [1].

Table 1: Basic nuclear-physical characteristics of ^{99}Mo , $^{99\text{m}}\text{Tc}$ and ^{99}Tc in the $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$ generator system.

| | ^{99}Mo | $^{99\text{m}}\text{Tc}$ | ^{99}Tc |
|------------------------|--------------------------------------|--------------------------|------------------------|
| $T_{1/2}$ | 66.02 hours | 6.02 hours | $2.13 \cdot 10^5$ year |
| Type of nuclear decay | β -decay | isomeric transition | β -decay |
| E_{β} , keV (%) | 450 (17%) 1230 (13%) | - | 300 (100%) |
| E_{γ} , keV (%) | 180 (10%) 740 (12%) 780 (4.5%) | 140 (99%) | - |

Table 2: Influence of the pH of an aqueous solution on the sorption of molybdenum.

| Volume added 1N HCl solution to 1 mg of Na ₂ MoO ₄ , ml | pH | Mo concentration on the sorbent (Al ₂ O ₃), mg/g |
|---|-------|---|
| 1.0 | 5.0 | 23.2 ± 2.0 |
| 2.0 | 4.0 | 27.0 ± 2.0 |
| 2.5 | 3.0 | 36.0 ± 2.7 |
| 3.0 | 2.5 | 38.0 ± 2.6 |
| 4.0 | 2.0 | 38.0 ± 2.7 |
| 5.0 | < 2.0 | 9.0 ± 0.7 |

Table 3: Sorption of Mo on Al₂O₃ (conditions for processing the sorbent: 3.0 mol/l HCl, t = 400 °C, mass Al₂O₃ is 3.0g, form of Mo is isopolymolybdate).

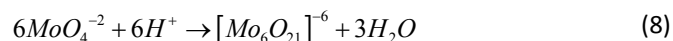
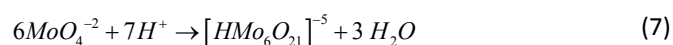
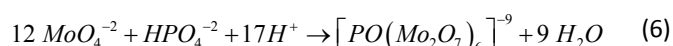
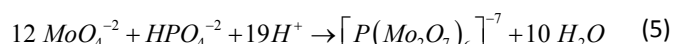
| Amount of molybdenum in solution, mg | Sorption of Mo on acid-treated aluminum oxide, % | Sorption of Moon untreated aluminum oxide, % |
|--------------------------------------|--|--|
| 66.0 | ≈100.0 | 100.0 |
| 110.0 | ≈100.0 | 90.0 |
| 154.0 | 90.6 | 80.0 |
| 198.0 | 79.5 | 67.6 |
| 242.0 | 77.2 | 59.5 |

Normal molybdates (MoO₄)⁻² in neutral and alkaline solutions are formed [2]:

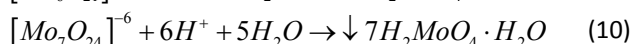
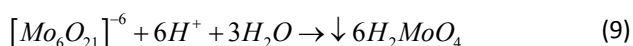


The study of the forms of molybdenum in its solutions was a very important condition for choosing an appropriate system for the sorption of the parent radionuclide ⁹⁹Mo on the sorbent (Al₂O₃).

In acidic solutions (pH 3÷4) complex ions of molybdenum phosphomolybdate (5,6) and isopolymolybdate (7) are formed according to the following formulas:



Here must be taken into account that with a stronger acidification of the solution (pH < 2.0), the formation of slightly soluble molybdic acid can occur, which precipitates [3]:



The chemical form of molybdenum in solutions depends on the acidity of the aqueous phase, and this factor can affect the completeness of molybdenum sorption. The study of the dependence of molybdenum sorption on the hydrogen index (pH) showed that the most optimal pH values are 2.0-3.0 (Table 2).

Figure 1 shows the gamma spectrum of an equilibrium ⁹⁹Mo-^{99m}Tc mixture, which shows the characteristic ⁹⁹Mo gamma lines with gamma radiation energies of 188 keV, 372 keV, 740 keV and 780 keV, as well as ^{99m}Tc gamma lines with an energy of 140 keV.

The chemical form of the molybdenum-98 carrier and the non-carrier ⁹⁹Mo parent radionuclide in solution depends on the properties of the sorbent and, therefore, it is important for the manufacture of the ⁹⁹Mo/^{99m}Tc generator system. For research, the adsorption-chromatographic version of the ^{99m}Tc generator was chosen as the most promising, because aluminum oxide is a radiation resistant sorbent of natural origin.

As an eluent due to its isotonic properties a solution of 0.9% NaCl was used, which is one of the main requirements for medical generators. The output of ^{99m}Tc from generator systems is calculated relative to the activity of the accumulated daughter radionuclide ^{99m}Tc:

$$A_{(Tc-99m)} = A_{(Mo-99)} \cdot 0.875 \quad (11)$$

Where: A (^{99m}Tc) and A (⁹⁹Mo) activities of the daughter ^{99m}Tc and parent ⁹⁹Mo radionuclides at the time of elution; 0.875 - coefficient taking into account the decay of the parent radionuclide according to the scheme:



Preliminary activation of aluminum oxide makes it possible, on average, to increase the sorption of molybdenum on the sorbent by 13% (Table 3).

The study of molybdenum sorption on Al₂O₃, both in static and dynamic modes, showed that the maximum capacity of the sorbent is 75-80 mg Mo/g Al₂O₃ (Figure 2). Taking into account that a high concentration of molybdenum in the solid phase can lead to contamination of the eluate with ⁹⁹Mo impurities, for the manufacture of stationary generators, the Mo concentration was limited to 25-30 mg/g Al₂O₃. At these values, the content of ⁹⁹Mo in the eluates did not exceed 10⁻²%. The optimal concentration of molybdenum in an aqueous solution for carrying out the sorption process turned out to be 15-20 mg/ml. In this case, there is a more uniform

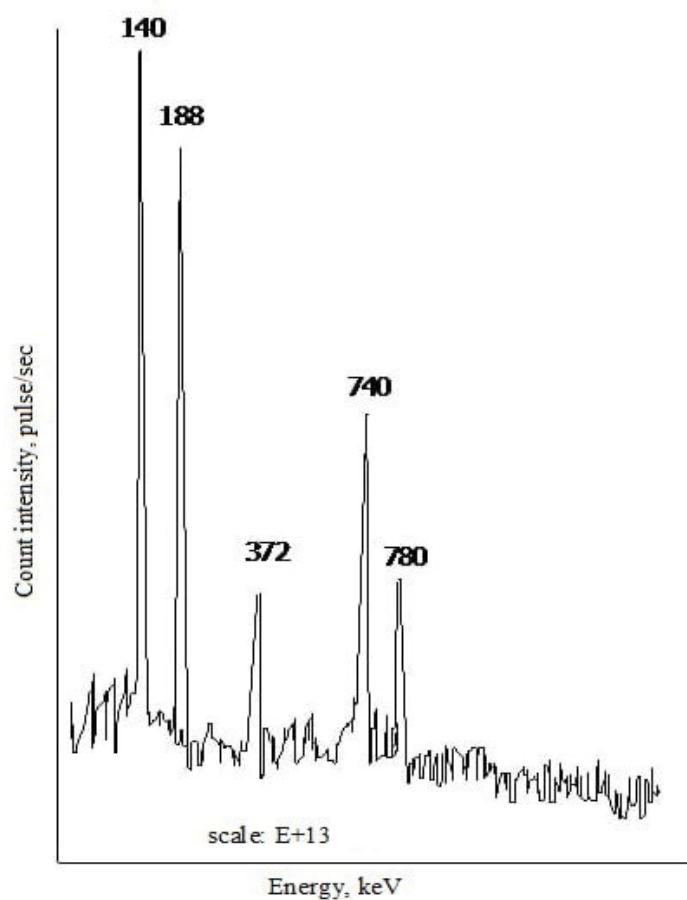


Figure 1: Gamma spectrum of an equilibrium ^{99}Mo - $^{99\text{m}}\text{Tc}$ mixture.

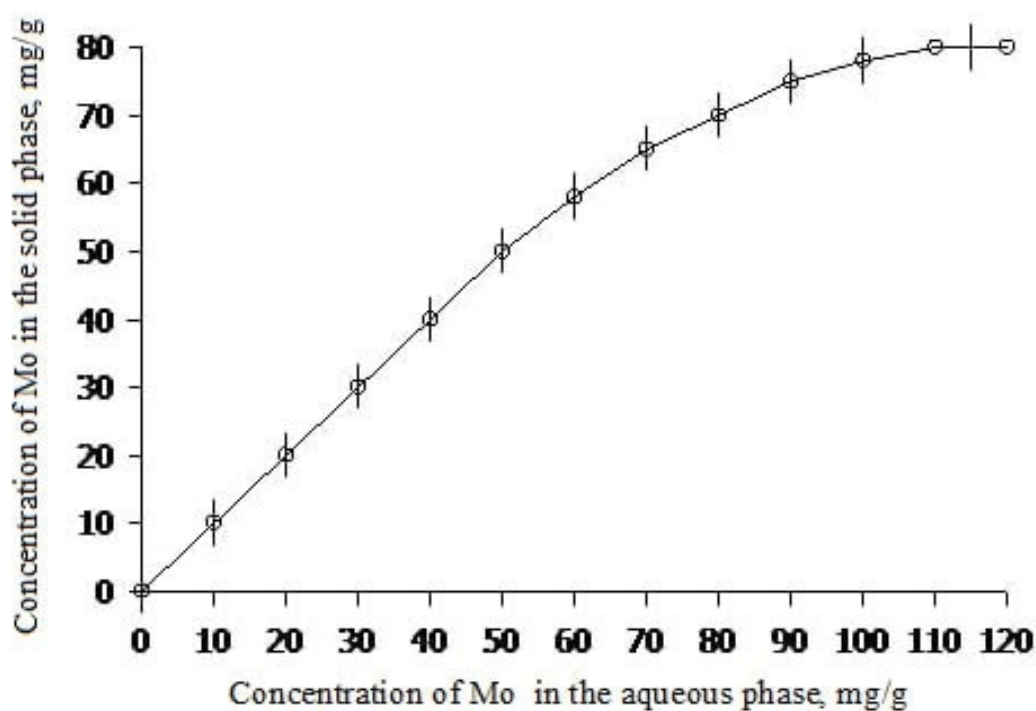


Figure 2: Sorption isotherm of molybdenum on aluminum oxide.

distribution of ^{99}Mo on the sorbent and the loss of ^{99}Mo in the sorption process (molybdenum slippage) is reduced.

For experiments in the dynamic mode, a glass column with an inner diameter of 33 mm and a height of 200 mm was made, which had a glass filter and a drain cock in the lower part to release the liquid phase. Activated alumina pre-moistened with distilled water and acidified with hydrochloric acid solution to pH 2-3 was placed in the column. The mass of aluminum oxide in the column was 110g. Sorption and elution were carried out according to the principle of descending chromatography. To study the effect of the rate of passage of a molybdenum solution through a layer of sorbent on its sorption, a special experiment was set up, the result of which is shown in Figure 3. The study of this dependence made it possible to determine the optimal flow rate of the solution, which turned out to be 2-4 ml/min (Figure 3).

In dynamic modes, the value of molybdenum sorption also affects the rate of passage of the solution through the sorbent layer of the generator column. Under experimentally selected conditions (the height of the sorption layer of the column is 160 mm, the Mo concentration in the isopolymolybdate solution is 20 mg/ml, the pH of the solution is 2.0, the mass of the sorbent is 110g, the rate of transmission of the isopolymolybdate solution through the aluminium oxide is ≈ 2 ml/min), sorption of ^{99}Mo was carried out on the sorbent of the generator column. Under such conditions, the sorption of molybdenum was more than 99.0%, the total amount of sorbed molybdenum was 3.55g.

To study the distribution of molybdenum in the sorption layer of the generator column after sorption of ^{99}Mo , the column was broken by layer-by-layer removal of the mass of the sorbent by 5.0g of the column. By measuring the

radioactivity of each layer, the amount and strength of molybdenum in each plate along the entire length of the column is increased (Figure 4).

The Figure 4 shows that the maximum concentration of molybdenum on alumina is 65 mg/g. Molybdenum on 72% of alumina with an average sorbent load of 30 mg/g was sorbed. The lower part of the generator column with 28% alumina (from 0 to 43 mm) is completely free of molybdenum with a free volume of the generator column of 77 ml. The main part of ^{99}Mo is concentrated in the upper part of the column, while the lower layer of the sorbent, remaining free, serves as a filter layer for retaining ^{99}Mo . A parallel experiment showed the same result: The main part of molybdenum is in the upper part of the generator column with a total sorbent weight of 66g (60%) with an average molybdenum concentration of 46.3 mg/g; in the middle part of the column there is up to 243 mg of molybdenum with a sorbent weight of 13g (12%) with an average molybdenum concentration of 18.7 mg/g; in the lower part of the column with a sample of aluminum oxide 31g (28%), molybdenum is completely absent and this is very important as a filter layer to retain the parent radionuclide ^{99}Mo .

Results of Production of Experimental Stationary Generators and Their Study

Samples of stationary generators were both laboratory (low-active) and pilot-industrial (up to 10 Ci for molybdenum-99 per generator). The manufacture and testing of pilot industrial generators with greater activity was carried out in hot chambers of technological lines at the «Radiopreparat» enterprise at the Institute of Nuclear Physics of the Academy of Sciences of the Republic of Uzbekistan.

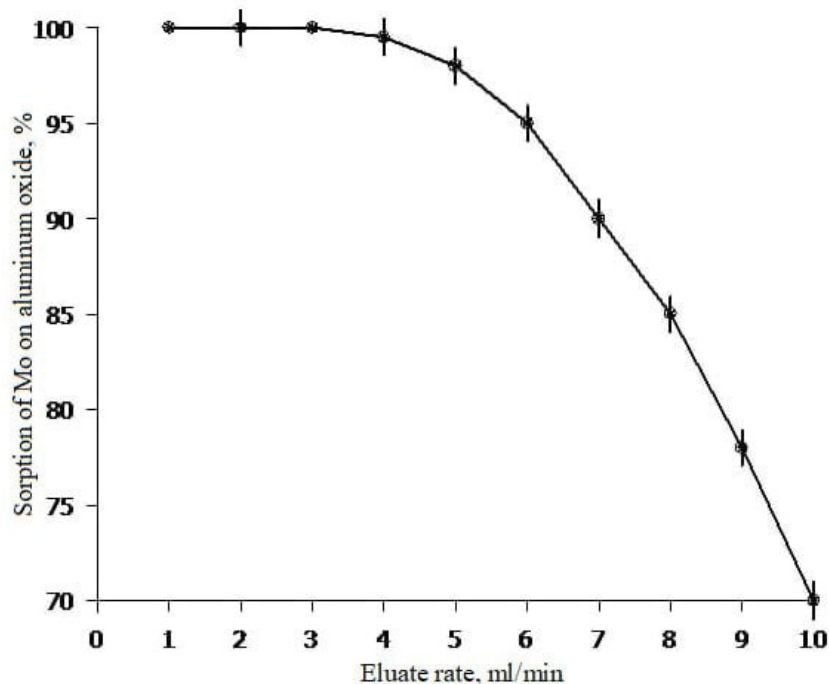


Figure 3: Dependence of the sorption of molybdenum on the aluminum oxide of the generator column on the rate of transmission of the isopolymolybdate solution.

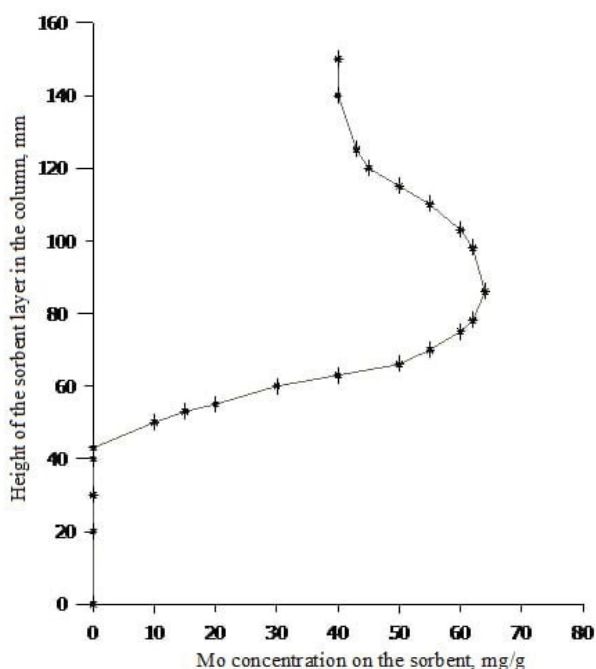


Figure 4: Layer-by-layer distribution of molybdenum on the sorbent (Al₂O₃) of a stationary generator column.

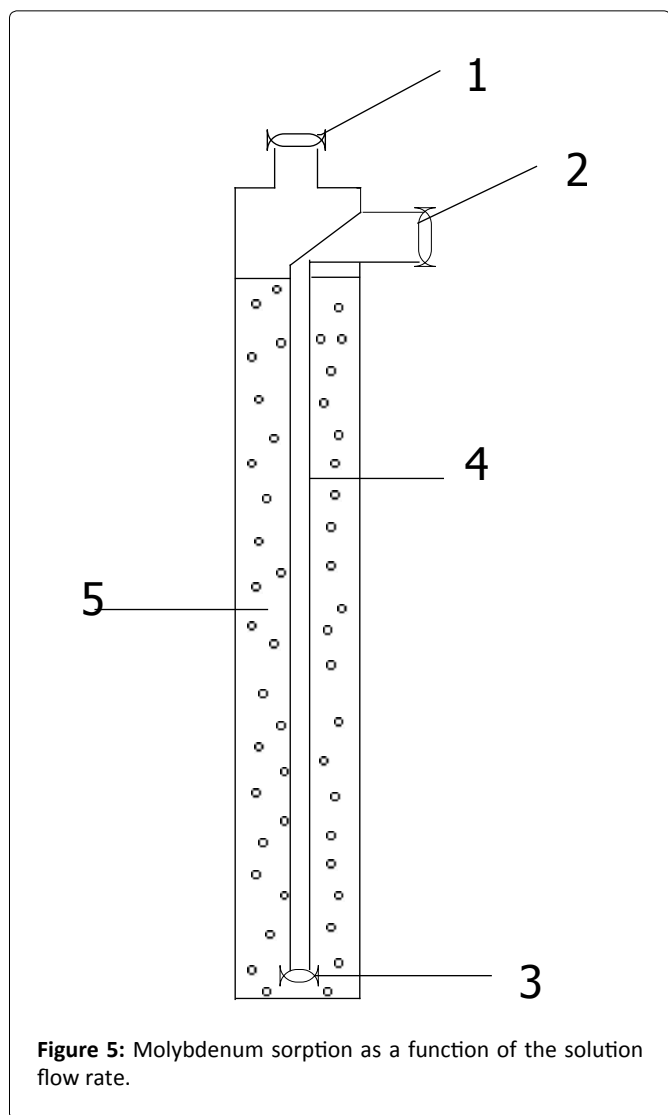


Figure 5: Molybdenum sorption as a function of the solution flow rate.

Figure 5 shows a schematic representation of a stationary generator. The generator is a molybdenum glass chromatographic column 25 mm in diameter, filled with oxide, ⁹⁹Mo adsorbed on it. The column has: An inlet pipe 1, through which oxide is loaded, passing a radioactive solution of ⁹⁹Mo and a solution for elution of ^{99m}Tc (eluent line); outlet pipe 2, through which both wash solutions and ^{99m}Tc eluate are supplied (eluate line); inner tube 4 with glass filter 3; sorbent (aluminum oxide) for sorption of Mo 5. Rubber caps with silicone capillaries inserted into them are put on the inlet and outlet pipes. The rate of supply of solutions to the generator column is controlled by a peristaltic pump and is 5-8 ml/min, with eluting ^{99m}Tc and 1-4 with sorption of ⁹⁹Mo.

Discussion of Technical Characteristics of Stationary Generators Tc-99m

To develop experimental industrial stationary generators Tc-99m, we studied the sorption of molybdenum by the method of descending elution in dynamic mode in a column with dimensions of 25 mm in diameter and 350 mm in height. The height of the sorbent layer in the column is 280-285 mm; The amount of sorbed molybdenum is 99% at an average sorbent load 30 mg/g. The results of these experiments allowed us to determine the optimal dimensions of the generator column, the conditions for performing the processes of Mo-99 sorption on the sorbent of the generator column, and the required weight of the sorbent in the column and molybdenum, taking into account the nominal activity of industrial generators - more than 10 Ci for molybdenum-99.

Stationary generators of technetium-99m No. 1 and No. 3 were made on irradiated target of molybdenum trioxide containing natural molybdenum and target was irradiated with thermal neutrons flux density is $f = 1.1 \cdot 10^{14}$ n/cm²-sec, FA is IRT-3M 36% enrichment of U-235, nominal power of the

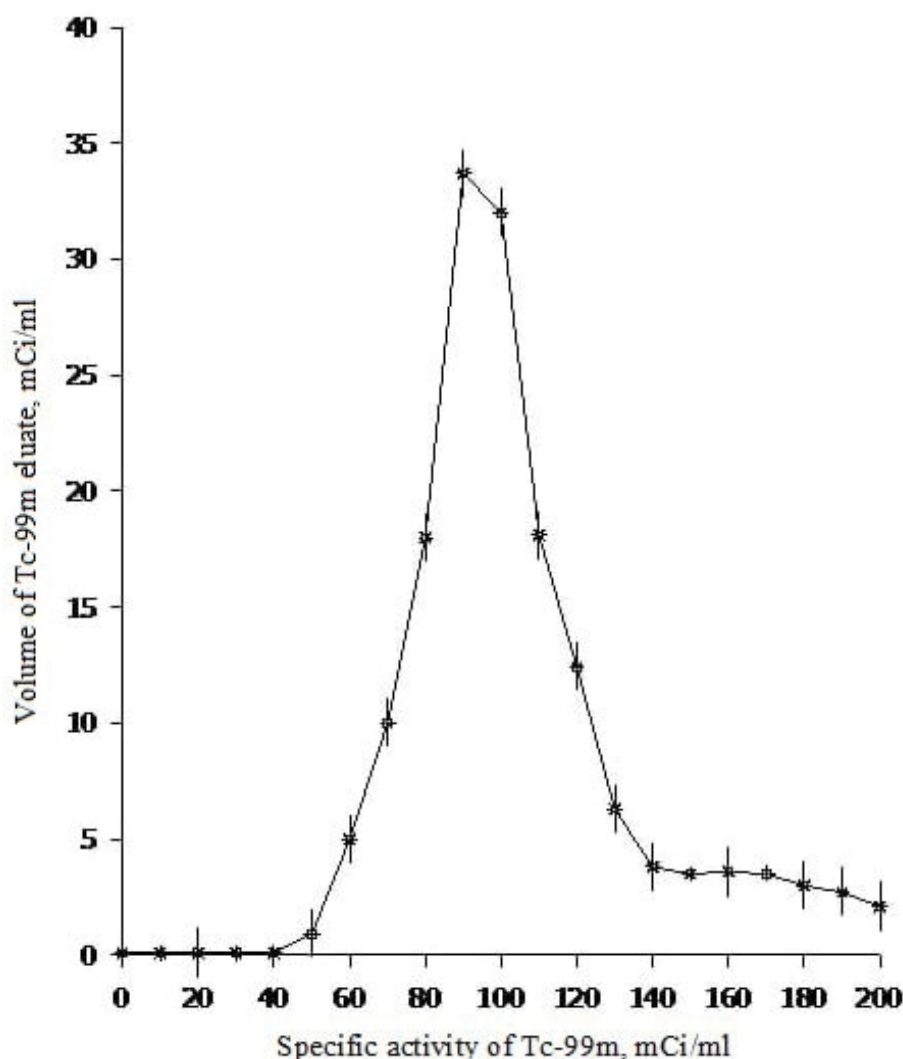


Figure 6: Elution curve of ^{99m}Tc from experimental generator No. 3.

Table 4: Technical characteristics of experimental stationary generators Tc-99m.

| Number stationary generator | Rated activity ⁹⁹ Mo, Ci | Sodium pertechnetate eluate volume, ml | Volumetric activity ^{99m} Tc in the eluate, mCi/ml | Output ^{99m} Tc, % |
|-----------------------------|-------------------------------------|--|---|-----------------------------|
| 1 | 2.7 | 100 | 10.7 | 49.7 |
| 2 | 10.7 | 100 | 71 | 80.0 |
| 3 | 3.2 | 100 | 14.7 | 56.1 |

WWR-SM nuclear reactor is 10 MW. Generator No. 2 was made on target molybdenum trioxide enriched in molybdenum-98, which also was irradiated by thermal neutrons flux density - $f = 7.2 \cdot 10^{13} \text{ n/cm}^2 \cdot \text{sec}$, FA is IRT-3M 36% enrichment of U-235, nominal power of the WWR-SM nuclear reactor was 10 MW.

Each generator column contained 100g of alumina, on which Mo-99 was adsorbed in dynamic mode (sorption rate 2 ml/min) from an isopolymolybdate solution with a molybdenum concentration of 25 mg/ml. Washing of generator columns was carried out with acidified water (pH = 3.0). The elution of technetium-99m was carried out with a

0.9% NaCl solution with pH = 2.0. Technical characteristics of generators are given in the Table 4.

In the Table 5, the results of the chemical analysis of sodium pertechnetate solutions (^{99m}Tc) on the first day of elution from experimental stationary generators are shown.

Description of the Manufacturing Technology of the Stationary Generator Technetium-99m No 3

For the manufacture of stationary generator No. 3, a molybdenum trioxide target irradiated with neutrons with

Table 5: The results of the chemical analysis of sodium pertechnetate solutions (^{99m}Tc) on the first day of elution from experimental stationary generators.

| Name of eluate parameter | Eluate from generator No. 1 | Eluate from generator No. 2 | Eluate from generator No. 3 |
|-----------------------------------|-----------------------------|-----------------------------|-----------------------------|
| The appearance of the solution | colorless clear solution | colorless clear solution | colorless clear solution |
| Radiochemical purity, % | 99.0 | 99.9 | 99.7 |
| pH | 4.5 | 4.5 | 4.7 |
| Content ^{99}Mo , % | $1.5 \cdot 10^{-4}$ | $0.6 \cdot 10^{-4}$ | $1.5 \cdot 10^{-3}$ |
| Content Al^{+3} , mcg/ml | 3.5 | 2.5 | 2.5 |
| Content Fe^{+2} , mcg/ml | 1.5 | 0.5 | 0.5 |
| Content Cu^{+2} , mcg/ml | 0.05 | 0.06 | – |
| mcg/ml | | | |

Table 6: The distribution of ^{99m}Tc over fractions of the sodium pertechnetate eluate (^{99m}Tc) of generator No.3.

| Eluate No. | Volumetric activity of the eluate ($\text{Na}^{99m}\text{TcO}_4$), mCi/ml | Total activity of the eluate ($\text{Na}^{99m}\text{TcO}_4$), mCi | Radionuclide impurity ^{99}Mo , % |
|------------|---|---|--|
| 1 | 0.3 | 1.3 | 0.15 |
| 2 | 0.27 | 1.2 | 0.037 |
| 3 | 0.16 | 1.4 | 0.43 |
| 4 | 0.11 | 1.1 | 0.63 |
| 5 | 0.9 | 9 | 0.88 |
| 6 | 6.15 | 61.5 | 0.0081 |
| 7 | 14.1 | 141 | 0.014 |
| 8 | 16.35 | 163.5 | 0.045 |
| 9 | 33.7 | 337 | 0.022 |
| 10 | 32.3 | 323 | 0.006 |
| 11 | 18.1 | 182 | - |
| 12 | 12.4 | 124 | 0.04 |
| 13 | 6.3 | 63 | 0.095 |
| 14 | 3.8 | 38 | 0.0026 |
| 15 | 3.5 | 35 | 0.014 |
| 16 | 3.6 | 36 | - |
| 17 | 3.5 | 35 | 0.014 |
| 18 | 3.6 | 36 | 0.014 |
| 19 | 2.7 | 27 | - |

a natural content of Mo-98 weighing 6g was used. In the vertical channel of reactor WWR-SM the thermal neutron flux density was $f = 7.2 \cdot 10^{13}$ n/cm²·sec. The target irradiation time was 296 hours.

After irradiation, the target was dissolved in 85 ml of 1.0N NaOH solution, the resulting alkaline solution was acidified with 1.0N hydrochloric acid solution (70 ml), and 5 ml of bromine water was added to prevent reduction of molybdenum (VI) to molybdenum blue ($\text{Mo}_2\text{O}_5 \cdot \text{MoO}_3 \cdot 6\text{H}_2\text{O}$) [3]. From the resulting solution of isopolymolybdate with an activity of 3.2 Ci in ^{99}Mo , with a concentration of molybdenum in a solution of 25 mg/ml, molybdenum was adsorbed on a column in a dynamic mode. The weight of the sorbent (Al_2O_3)

in the column was 100g, the flow rate of the isopolymolybdate solution was 2 ml/min. The average loading of molybdenum on alumina was 40 mg/g. Then, the generator column was washed with 150 ml of acidified water with pH = 3.0, and then 0.9% NaCl solution with pH = 3.0 was injected into the column. Analysis of the wash water showed that ^{99}Mo is absent in the wash water, which indicates a sorption value of more than 99%. A day later, Tc-99m was eluted from the generator column with a 0.9% NaCl solution pH = 3.0.

Samples of eluates were taken, 10.0 ml each, and chemical analysis was carried out according to the Russia State Pharmacopoeia 13 (XIII) [4]. The following characteristics of the eluate were determined: Identity (by

spectrometric analysis), volumetric activity of technetium-99m (by radiometry), content of radionuclide impurities, radiochemical purity (by paper chromatography), content of sodium chloride and inactive impurities. The distribution of ^{99m}Ts over fractions of the sodium pertechnetate eluate (^{99m}Ts) of generator No. 3 is shown in Table 4.

Samples of eluates were taken, 10.0 ml each, and each was subjected to chemical analysis according to the Russia State Pharmacopoeia 13 (XIII) [4]. The following characteristics of the eluate were determined: Identity (by spectrometric analysis), volumetric activity of technetium-99m (by radiometry), content of radionuclide impurities, radiochemical purity (by paper chromatography), content of sodium chloride and inactive impurities. The distribution of ^{99m}Tc over fractions of the sodium pertechnetate eluate (^{99m}Tc) of generator No. 3 is shown in Table 6.

The results of the chemical analysis of the eluates showed that the eluates from the generators meet the requirements of Pharmacopoeia Monograph 42-2837-92. 0083-2002 [5].

In Figure 6 the elution curve of ^{99m}Tc from experimental generator No. 3 is shown.

Specifications of sodium pertechnetate solution (^{99m}Tc) from experimental stationary generator Tc-99m No. 2 are shown in the Table 7.

The results of the analysis of the distribution of the elution of Tc-99m by fractions on the first day of the test and the results obtained on the 8th day of the test are shown in Table 8.

The results of the table show that over time, the activity of Tc-99m in the main fractions decreases from 96.2% to 90%, and the proportion of Tc-99m in the first fraction slightly increases (from 0.15% to 6.78%). Apparently, there is some movement of Mo-99 in the column, and this leads to an increase in the concentration of Tc-99m in the first fraction and an insignificant increase in the content of impurity Mo-99 in all fractions.

Conclusion

The patterns of molybdenum sorption on aluminum oxide, its distribution between the solid and liquid phases of the generator system and in the chromatographic

Table 7: Specifications of sodium pertechnetate solution (^{99m}Tc) from experimental stationary generator Tc-99m No. 2.

| Controlled parameter | Eluate from experimental generator | Norm according to Pharmacopoeia Monograph No. 42-2837-92. 0083-2002 |
|--|------------------------------------|---|
| Rated activity of the generator according to Mo-99 | 15.84 Ci | Not standardized |
| The appearance of the solution | Clear, colorless solution | Clear, colorless solution |
| pH | 4.5 | 4.0-7.0 |
| Radiochemical purity, % | 99.5 | ≥ 99.0 |
| Volumetric activity on the 1st day of elution, Ci/ml | 70.6 | ≥ 26.0 |
| The content of sodium chloride in the eluate, g/l | 8.9 | 8.0-10.0 |
| Impurity content ⁹⁹ Mo, % | 2·10 ⁻³ | 2·10 ⁻² |
| Content of inactive impurities, mcg/ml | | |
| Al | 2.0 | ≤ 5.0 |
| Fe | 1.0 | ≤ 1.0 |
| Cu | 0.05 | ≤ 0.2 |
| Pb | – | ≤ 5.0 |

Table 8: Distribution of Tc-99m activity by eluate fractions.

| Fraction number | Volume concentration of ^{99m} Tc, mCi/ml | Total activity of ^{99m} Tc, mCi | ⁹⁹ Mo impurity content, % |
|---|---|--|--------------------------------------|
| on the 1st day of elution | | | |
| 1 | 0.26 | 10.7 | 4·10 ⁻⁴ |
| 2 | 70.6 | 7062 | 1·10 ⁻³ |
| 3 | 4.3 | 260 | 4·10 ⁻⁵ |
| on the 8th day of elution | | | |
| 1 | 1.6 | 64 | 4·10 ⁻² |
| 2 | 8.5 | 850 | 1·10 ⁻² |
| 3 | 0.5 | 30 | 4·10 ⁻² |

column of the generator have been established. The optimal conditions for the sorption of molybdenum on aluminum oxide, which provide at least 99% of its sorption, are determined:- The chemical form of molybdenum in solutions is isopolymolybdate, with a molybdenum concentration of 20-25 mg/ml, pH = 2-3; - the rate of passing the solution through the generator column 1-4 ml/min; - optimal load of Mo on the sorbent is 30-40 mg/g.

A technological scheme for the manufacture of a stationary technetium-99m chromatographic generator, prototypes of stationary technetium-99m generators were manufactured and tested, and eluents of sodium pertechnetate solution fully meeting the requirements of the international standards [6,7] were obtained.

References

1. Angelides G, Jamouzis G, Karagiannis G, et al. (2017) SPECT and PET with ischemic heart failure. *Heart Fail Rev* 22: 243-261.
2. Steigman J (1981) The chemistry of the technetium generator. *Trans Amer Nucl Soc* 38: 55-56.
3. Alikina EN (2019) Analytical chemistry. Qualitative analysis. Perm state national research university. Perm 202.
4. Narkevich IA (2018) State Pharmacopoeia of the Russian Federation in modern pharmaceutical analysis practice. 35-37.
5. Sodium pertechnetate solution ^{99m}Tc from the generator. ^{99m}Tc Pharmacopoeia Monograph of Republic of Uzbekistan No. 42-2837-92. 0083-2002. 8.
6. Sodium pertechnetate (^{99m}Tc) injection (fission). EUROPEAN PHARMACOPOEIA 7.0. 01/2008:0124 corrected 7.0.
7. US PHARMACOPOEIA. Sodium pertechnetate ^{99m}Tc injection. Pertechnetate acid (H^{99m}TcO₄), sodium salt. Sodium pertechnetate (Na^{99m}TcO₄).

DOI: 10.36959/349/550