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Review Article

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

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ABSTRACT

Introduction: Technetium-99m is widely used in nuclear medicine for diagnostic purposes. This work describes the technology for manufacturing a stationary sorption generator of technetium-99m and provides a method for obtaining Tc-99m with high activity.

Methods: A stationary generator of Tc-99m is manufactured in a radiochemical laboratory in a protective box with manipulators in a special generator column and Tc-99m is remotely eluted in the form of sodium pertechnetate (^{99m}Tc).

Results: The patterns of sorption of molybdenum on aluminum oxide of the generator column have been established, the distribution of molybdenum between the solid and liquid phases of the generator system, as well as in the chromatographic column of the generator, has been studied. The optimal conditions for the sorption of molybdenum on aluminum oxide have been determined. The target product is obtained by elution from the generator column - a solution of sodium pertechnetate (^{99m}Tc) with high specific activity and radiochemical purity.

Conclusion: Studies have shown that the eluate solution obtained from the Tc-99m stationary generator in the form of a sodium pertechnetate solution (^{99m}Tc) fully complies with the requirements of established standards and can be used in the nuclear clinical medicine.

Keywords: Molybdenum trioxide; Irradiation; Nuclear ractor; Sorbent; Column; Generator; Molibdenum-99; Tehnetium-99m; Eluent; Eluate; Radiochemical purity

ABBREVIATIONS

^{99m}Tc: Radionuclide Technetium-99 Metastable; Eγ: Energy of Gamma Rays, keV; E_β: Beta Radiation Energy, keV; $T_{1/2}$: Radionuclide Half-Life, Hour; Ci: Measure Of Radioactivity, Curie; $^{98}MoO_3$: Molybdenum Oxide Labeled with the Mo-98 Isotope; Al_2O_3: γ-Aluminum Oxide; r: Sorbent Particle Size, mm; pH: pH Value; N: Normality of the Solution; M: Molarity of the Solution; D: Radionuclide Distribution Coefficient; FA: Fuel Assembly; TcO^{4-}: Pertechnetate Anion (^{99m}Tc).

INTRODUCTION

Radionuclide Tc-99m is used for diagnostics and scintigraphy (scanning) of the thyroid and salivary glands, brain, radionuclide angiocardiography, and ventriculography also. Myocardial perfusion scanning plays an important role in diagnosing and making therapeutic decisions in heart disease. Tc-99m sestamibi or Tc-99m tetrofosmin radiopharmaceuticals are often used to scan myocardial perfusion in SPECT (single photon ejection computed tomography) techniques [1], and ʇechnefor, ^{99m}Tc (complex of technetium-99m with oxabiphor (oxa-bis-(ethylenenitrilo) tetramethylenephosphonic acid) is used for scintigraphy and skeletal scanning for the purpose of diagnosing pathological changes of various etiologies (primary and metastatic malignant tumors, osteomyelitis, osteoarticular tuberculosis, arthritis of various origins, etc.) [2]. Even today, over 70% of diagnostic investigations are still performed with this single isotope of Tc-99m [3].

Elution of the daughter nuclide ^{99m}Tc from it`s the portable generators or "milking" of the generator is expediently performed every 6 hours twice a day. Since the half-life of ^{99}Mo 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, also production costs are 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.

A scheme of radiochemical technology for manufacturing a stationary radionuclide generator ^{99}Mo/^{99m}Tc of the chromatographic type on sorbent of aluminum oxide was 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 sodium phosphate-chemically pure reagents were used. To obtain the parent radionuclide Mo-99 by method of irradiation of the WWR-SM reactor neutrons, samples with the natural isotopic composition of molybdenum trioxide (MoO_3) and MoO_3 enriched in the isotope ^{98}Mo with an enrichment at least 97% was used. Aluminum oxide (Al_2O_3) of the "for chromatography" type with 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 pH = 2.0, than obtained product dried at a temperature of 120°C during 3 hours. To conduct experiments in dynamic modes, generator columns of various volumes (25-200 ml) with conventional glass taps at the end of the column 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 was made in special glass columns from molybdenum glass, with equipped by communications, consisting of an eluent line (inlet) and an eluate line (outlet). The yield of ^{99m}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 1 g were made by method 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 formula:

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

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 ^{99m}Tc under static sorption conditions (D_{Tc}) was calculated by the formula:

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

where: activities of initial and final solutions (before and after sorption), impulses/sec; V is water phase volume, ml; m is 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

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

ww: A_{ed} is the total radioactivity of the ^{99m}Tc radionuclide in the eluate, imp/sec; A_{rd} is the equilibrium radioactivity of the daughter radionuclide in the ^{99}Mo-^{99m}Tc system, imp/sec.**4. Results**

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

Passing a saline solution through a generator column with adsorbed ^{99}Mo leads to the elution of soluble ^{99m}Tc, as well as ^{99}Tc. Since ^{99}Tc cannot be separated from ^{99m}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,

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

	^{99}Mo	^{99м}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 %)	–

the latter two substances being contaminants that must be limited according to IAEA standard [3].

Normal molybdates $(MoO_4)^{-2}$ in neutral and alkaline solutions are formed [4]:

$$MoO_3 + 2\,Na\,OH = Na_2MoO_4 + H_2O \quad (4)$$

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 ^{99}Mo on the sorbent (Al_2O_3).

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

$$12\,MoO_4^{-2} + HPO_4^{-2} + 19\,H^+ \longrightarrow [P(Mo_2O_7)_6]^{-7} + 10\,H_2O \quad (5)$$

$$12\,MoO_4^{-2} + HPO_4^{-2} + 17\,H^+ \longrightarrow [PO(Mo_2O_7)_6]^{-9} + 9\,H_2O \quad (6)$$

$$6\,MoO_4^{-2} + 7\,H^+ \longrightarrow [HMo_6O_{21}]^{-5} + 3\,H_2O \quad (7)$$

$$6\,MoO_4^{-2} + 6\,H^+ \longrightarrow [Mo_6O_{21}]^{-6} + 3H_2O \quad (8)$$

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 [5]:

$$[Mo_6O_{21}]^{-6} + 6\,H^+ + 3H_2O \longrightarrow \downarrow 6\,H_2MoO_4 \quad (9)$$

$$[Mo_7O_{24}]^{-6} + 6\,H^+ + 5H_2O \longrightarrow \downarrow 7\,H_2MoO_4 \cdot H_2O \quad (10)$$

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 ^{99}Mo-^{99m}Tc mixture, which shows the characteristic ^{99}Mo 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 Mo-98 carrier and the non-carrier ^{99}Mo parent radionuclide in solution depends on the properties of the sorbent and, therefore, it is important for the manufacture of the ^{99}Mo/^{99м}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 (yield) of ^{99m}Tc from generator

systems is calculated relative to the activity of the accumulated daughter radionuclide ^{99m}Tc:

$$A_{(Tc\text{-}99м)}=A_{(Mo\text{-}99)}\cdot 0.875 \quad (9)$$

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

$$^{99}_{42}Mo \rightarrow {}^{99m}_{43}Tc + {}^{0}_{-1}\beta \quad (10)$$

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 Al_2O_3, both in static and dynamic modes, showed that the maximum capacity of the sorbent is 75-80 mg Mo/g Al_2O_3 (Figure 2). Taking into account that a high concentration of molybdenum in the solid phase can lead to contamination of the eluate with ^{99}Mo impurities, for the manufacture of stationary generators, the Mo concentration was limited to 25-30 mg/g Al_2O_3. At these values, the content of ^{99}Mo 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 distribution of ^{99}Mo on the sorbent and the loss of ^{99}Mo in the sorption process (molybdenum slippage) is reduced.

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_2MoO_4, ml	pH	Mo Concentration on the Sorbent (Al_2O_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

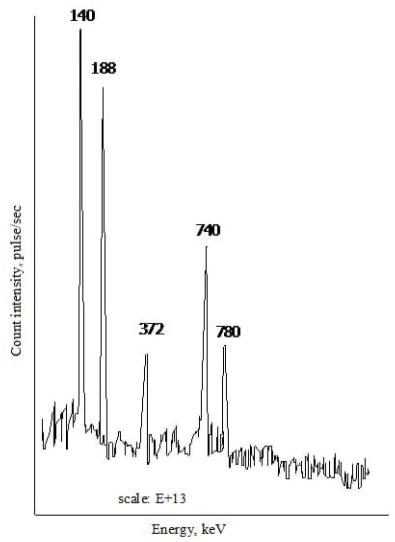

Figure 1: Gamma spectrum of an equilibrium ^{99}Mo-^{99m}Tc mixture.

Table 3: Sorption of Mo on Al_2O_3 (conditions for processing the sorbent: 3.0 M/l HCl, Al_2O_3 mass is 3.0 g, chemical form of Mo is isopolymolybdate solution).

Amount of Molybdenum in Solution, mg	Sorption of Mo on Acid Treated Aluminum Oxide, %	Sorption of Mo on 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

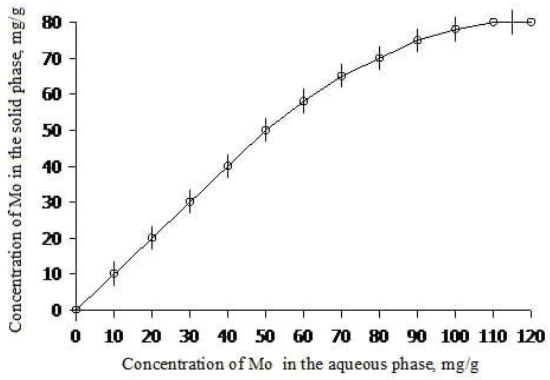

Figure 2: Sorption isotherm of molybdenum on aluminum oxide.

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 110 g.

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 study of this dependence made it possible to determine the optimal flow rate of the molybdenum 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 110 g, the rate of transmission of the isopolymolybdate solution through sorbent 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 3.55 g. 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 5.0 g of the column. By measuring the radioactivity of Mo-99 in each portion of sorbent with the same mass extracted from the bottom of the column, the distribution of Mo-99 along the entire length of the column was determined (Figure 4).

Figure 4 shows that the maximum concentration of molybdenum on sorbent is 65 mg/g. Molybdenum on 72% of sorbent with an average sorbent load of 30 mg/g was sorbed. The lower part of the generator column with 28 % Al_2O_3 (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 molybdenum and, accordingly, radionuclide ^{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 66 g (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 13 g (12%) with an average molybdenum concentration of 18.7 mg/g; in the lower part of the column with a sample of aluminum oxide 31 g (28%), molybdenum is completely absent and this is very important as a filter layer to retain the parent radionuclide ^{99}Mo.

Samples of stationary generators were both laboratory (low-active) and pilot-industrial (up to 10 Ci for Mo-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 enterprise of «Radiopreparat» of the INP AS RUz.

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

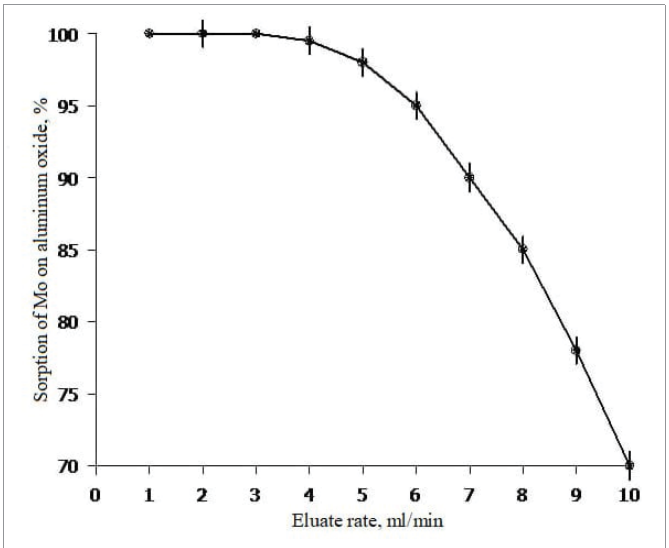

Figure 3: Dependence of the sorption of molybdenum on the aluminum oxide of the generator column on the rate of transmission of the isopolymolybdate solution.

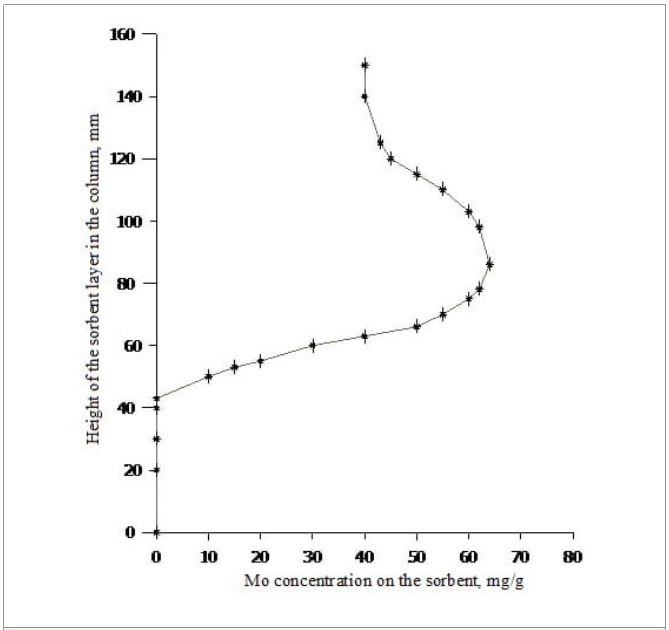

Figure 4: Layer-by-layer distribution of Mo^{-99} on the sorbent of generator column.

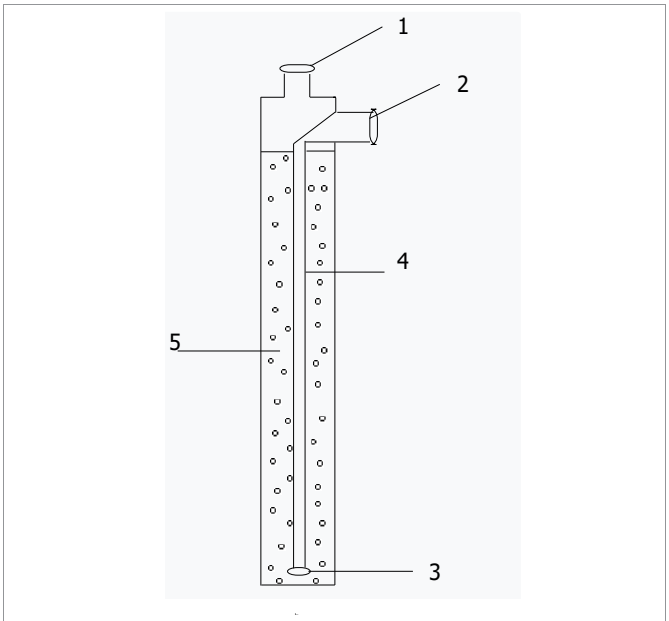

Figure 5: Scheme of a stationary generator column: 1-inlet pipe; 2-outlet pipe; 3-glass filter; 4-inner tube; 5-sorbent (Al_2O_3).

DISCUSSION

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. Height of the sorbent layer in the column was 280-285 mm. Under these conditions, 99% of molybdenum was sorbed on aluminum oxide with an average sorbent loading of 30 mg/g (Figure 4). 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 Mo-99.

Stationary generators of Tc-99m No. 1 and No. 3 were made on irradiated target of MoO_3 containing natural Mo (24.29%) and target was irradiated in the following mode: thermal neutrons flux density is $f = 1.1 \cdot 10^{14}$ n/cm^2·sec, FA is IRT-3M 36% enrichment of U-235, nominal power of WWR-SM nuclear reactor is 10 MW. Generator No. 2 was made on target molybdenum trioxide enriched in molybdenum-98, which also was irradiated in the following mode: thermal neutrons flux density was $f = 7.2 \cdot 10^{13}$ n/cm^2·sec, FA was IRT-3M type (36% enrichment of U- 235), nominal power of the WWR-SM nuclear reactor was 10 MW.

Each generator column contained 100 g 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. Table 4 shows technical characteristics of stationary generators.

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

To manufacture stationary generator No. 3, a target made of molybdenum trioxide with a natural content of Mo-98 was used, the mass of the irradiated target was 6.0 g, the thermal neutron flux density in the vertical channel of the reactor was $f = 1.1 \cdot 10^{14}$ n/cm^2·sec and the target irradiation time was 296 hours.

After irradiation, the target was dissolved in 85 ml of 1.0 N NaOH solution, the resulting alkaline solution was acidified with 1.0 N hydrochloric acid solution (70 ml), and 5 ml of bromine water was added to prevent reduction of molybdenum (VI) to sediment of molybdenum blue ($Mo_2O_5 \cdot MoO_3 \cdot 6H_2O$) [5]. 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 generator column in a dynamic mode. The weight of the sorbent (Al_2O_3) in the column was 100 g, 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.

From stationary generator samples of eluates were taken, 10.0 ml each, and each was subjected to chemical analysis according to the State Pharmacopoeia of the Russian Federation [6]. The following characteristics of the eluate were determined: identity (by spectrometric analysis), volumetric activity of Tc-99m (by radiometry), content of radionuclide impurities, radiochemical purity (by paper chromatography), content of sodium chloride and inactive impurities. Table 6 shows the distribution of ^{99m}Tc over fractions of the sodium pertechnetate eluate (^{99m}Tc) of generator No. 3.

The results of the chemical analysis of the eluates showed that the eluates from the stationary generators meet the requirements of the Pharmacopoeia Monograph of Republic of Uzbekistan 42-2837-92. 0083-2002 and the requirements of the Tc-99m generator produced at the «Radiopreparat» enterprise of the INP AS RUz [7].

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

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}, µg /ml	3.5	2.5	2.5
Content Fe^{+2}, µg /ml	1.5	0.5	0.5
Content Cu^{+2}, µg/ml	0.05	0.06	–

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 ($Na^{99m}TcO_4$), mCi/ml	Total Activity of the Eluate ($Na^{99m}TcO_4$), 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	-

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

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

Table 8 shows 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.

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.

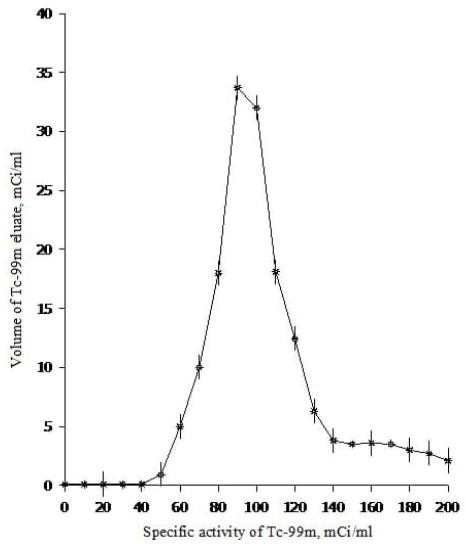

Figure 6: Elution curve of ^{99m}Tc from experimental generator No. 3.

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

Controlled Parameter	Eluate from Experimental Generator	Norm According to Pharmacopoeia Monograph No. 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, %	$2 \cdot 10^{-3}$	$2 \cdot 10^{-2}$
Content of inactive impurities, μg /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, %
Results on day 1 of generator elution			
1	0.26	10.7	$4 \cdot 10^{-4}$
2	70.6	7062	$1 \cdot 10^{-3}$
3	4,3	260	$4 \cdot 10^{-5}$
Results on day 8 of generator elution			
1	1.6	64	$4 \cdot 10^{-2}$
2	8.5	850	$1 \cdot 10^{-2}$
3	0.5	30	$4 \cdot 10^{-2}$

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 column of the generator was established. The optimal conditions for the sorption of molybdenum on aluminum oxide, which provide at least 99% of its sorption was determined, where 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 is 1-4 ml/min; optimal load of Mo on the sorbent is 30-40 mg/g.

Stationary technetium-99m generators pilot model were manufactured and tested, in which eluents of sodium pertechnetate solution (^{99v}Tc) fully meeting the requirements of the international standards [8,9] were obtained.

CONFLICTS OF INTEREST

The authors of this article have no conflicts of interest.

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