Article

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Reprinted from
RADIOISOTOPES, Vol.63, No.11
November 2014

Japan Radioisotope Association
http://www.jrias.or.jp/

RADIOISOTOPES, **63**, 501-513 (2014)

Article

A Mass-Production Process of a Highly Pure Medical Use ^{99m}Tc from Natural Isotopic Mo(n, γ) ^{99}Mo without Using Uranium

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Received May 7, 2014

A new method to produce highly pure ^{99m}Tc of maximum 500 Ci (1.85 e+13 Bq) per batch from a low specific activity ^{99}Mo made from natural-Mo(n, γ) method is presented in this study.

Authors developed a novel procedure to provide ^{99m}Tc of high specific activity and purity from ^{99}Mo with a low specific activity obtained by the (n, γ) method. This process named TcMM (technetium master milker) with a new principle found out by the authors involves the selective adsorption of ^{99m}Tc onto an activated charcoal column, followed by an elution of ^{99m}Tc by warm alkaline solution, and final purification through an alumina column, which would be applicable to routine production of a large amounts of ^{99m}Tc from ^{nat}Mo (with ^{99}Mo) within a short processing time and with a low cost.

By the experiment using a high radioactivity of ^{99}Mo of 1 e+12 Bq levels, a highly pure ^{99m}Tc free from ^{nat}Mo (with ^{99}Mo) was obtained in a sterile saline solution within 30 − 50 min. as the chemical form of $^{99m}TcO_4^-$, and the average ^{99m}Tc milking rate repeated 10 times got 93.5% and the radiochemical purity of the range of 6 N − 7 N.

In the labeling experiments using several radiopharmaceutical kits, ^{99m}Tc collected from the TcMM process gave the target medicines in a highly radiochemical purity.

As the result of investigating the disposition behaviors of the above-mentioned ^{99m}Tc-pharmaceuticals using small animals (mouse), ^{99m}Tc collected from TcMM gave the same result as it eluted from the conventional ^{99m}Tc generator.

The findings in this study suggest that the present method using natural isotopic ^{98}Mo(n, γ)^{99}Mo reaction would constitute as an alternative to the Fission Method using HEU to provide ^{99m}Tc useful for clinical studies.

Key Words: technetium-99m, molybdenum-99, technetium master milker, production technology, radiopharmaceutical, activated carbon

1. Introduction

Since the development of ^{99}Mo-^{99m}Tc generator, ^{99m}Tc has been used extensively as a diagnostic nuclear medicine. Now, technetium-99m (^{99m}Tc) is used in 30 million diagnostic practices every year in the world, which represents approximately 85% of nuclear medicine diagnostic practices.

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Table 1 Comparison of (n, γ) methods as the viewpoint of ^{99m}Tc master milker for producing many tens and hundreds Ci

Method	Fission method or (n,γ) method	feature	Ref.
Alumina	Fission	Practical for fission-^{99}Mo	1~6
Sol-Gel	(n,γ)	Difficult for master milker.	1, 6~9
MEK extraction	(n,γ)	Difficult for producing a high quality ^{99m}Tc.	1, 10
Sublimation	(n,γ)	Problem for master milker.	11
PZC	(n,γ)	Suitable for a small generator. Problem for master milker.	12~14
Activated carbon and Alumina	**(n,γ)**	**Practical for (n,γ)**	**This study**

The majority of the ^{99m}Tc used in the medical work is produced by extracting the ^{99}Mo as one of fission nuclides from irradiated HEU (highly enriched uranium) targets in a nuclear reactor, called the nuclear fission method (hereafter mentioned as 'fission method'). The specific activity of fission-^{99}Mo is very high, e.g. 1.85 − 3.7×10^{14} Bq (5 000 − 10 000 Ci)/g(Mo). Since a small amount of ^{99}Mo is loaded on an alumina column, the ^{99}Mo-^{99m}Tc generator that produces ^{99m}Tc of high specific activity is available all over the world. However, ^{99}Mo generated by the nuclear fission method has the problem in unstable supply as we have encountered recently. In addition, the major ^{99}Mo producing reactors were built in the 1950 − 1960's and are close to their end of lifetime. Furthermore, HEU has the problem of the Nuclear Nonproliferation Treaty, and efforts are made to switch from HEU to lowly enriched uranium.

It is well known that ^{99}Mo is also produced by the neutron activation reaction of natural isotopic Mo, ^{nat}Mo-^{98}Mo(n, γ)^{99}Mo; ^{98}Mo isotope includes 24.1% in natural isotopic Mo, hereafter mentioned as '(n, γ) method'. The ^{99}Mo produced by the (n, γ) method has several advantages over the fission method, such as free from the use of uranium, smaller radioactive wastes and lower costs for production. However, the (n, γ) ^{99}Mo has a serious problem of very low specific activity compared with the fission-produced ^{99}Mo (about 1/5 000 − 1/10 000 times lower), which hinders the application of ^{99}Mo produced by the (n, γ) method.

Table 1 summaries the generator system so far proposed to separate ^{99m}Tc from ^{nat}Mo (with ^{99}Mo) or ^{99}Mo. The alumina/saline is currently being used to produce ^{99m}Tc from ^{99}Mo of high specific activity by the fission method[1) − 7)]. The Sol-Gel generator system would suffer from a difficulty in producing high amount of Mo gel and the resulting high amount of radioactive wastes[1), 8) − 12)]. The MEK extraction method might generate radiolysis products at high ^{99}Mo/^{99m}Tc radioactivity levels[1), 13) − 16)]. The sublimation method requires a complicated large scale device for separation of ^{99m}Tc in the form of Tc-oxide from $^{nat}MoO_3$ (with ^{99}Mo) at high

temperature[17)－20)]. In addition, since PZC method[21)－23)] developed also by the authors was designed to prepare a small ^{99m}Tc generator with the maximum level of hundreds mCi, this method would not be applicable to prepare ^{99m}Tc at higher radioactivity levels due to low capacity of PZC to ^{nat}Mo(with ^{99}Mo)prepared by the (n, γ) method.

In this study as how to collect ^{99m}Tc from low specific activity ^{99}Mo, authors show a new process named "TcMM(technetium master milker)" which means the production of large amount of ^{99m}Tc is composed of 6 steps as follows ; 1) dissolve neutron irradiated natural isotopic MoO_3 contained ^{99}Mo generated by alkali(NaOH) solution, 2) adsorb ^{99m}Tc specifically in activated carbon(AC) column by feeding the ^{nat}Mo(with ^{99}Mo) solution, 3) rinse out ^{nat}Mo(with ^{99}Mo) remained in the AC, 4) elute ^{99m}Tc from the AC column using a warm alkali solution, 5) adjust the pH by flowing acid alumina colum and NaCl concentration of the ^{99m}Tc solution, and 6) collect highly pure ^{99m}Tc by flowing again another alumina column.

2. Materials and methods

2・1 Materials

In the following experiments, common high purity reagents were used.

2・1・1 Preparation of a sample ^{99}Mo solution

The ^{99}Mo was generated by the ^{98}Mo(n, γ) reaction of a natural isotopic Mo compound(actually, MoO_3 ; 99.9% purity, made by Taiyo-Koukou Co., Tokyo, Japan) irradiated by the neutron in the nuclear reactor(JRR-3 atomic reactor, Japan Atomic Energy Agency). By the neutron irradiation for 7 days of MoO_3 15 pellets sintered by Spark Plasma Sintering method[24)] of total 293.4 g(195.6 g as Mo), the generated ^{99}Mo was total 2.99 e＋12 Bq with the specific activity of 1.48 e＋10 Bq/g(Mo) immediately after irradiation. The irradiated MoO_3 pellets was dissolved in 679 mL of 6M-NaOH solution. The chemical amount of the daughter nuclide ^{99m}Tc present in the Na_2MoO_4 solution was calculated to be 10^{-16}－10^{-17} times lower than that of Mo.

2・1・2 Activated carbon

In order to collect ^{99m}Tc present in the Na_2MoO_4 solution, the activated carbon(hereafter"AC") column was used in packing AC of 5 g, which is Shirasagi-charcoal as palm shell raw material, LH2c 20/48 ss(particle size : 0.30－0.85 mm) made by Japan-Environment Chemicals Co(Osaka, Japan).

2・1・3 Activated alumina

In order to purify the recovered ^{99m}Tc, the activated alumina(hereafter"AL") column for removing trace amount of ^{nat}Mo(^{99}Mo), and radioactive niobium and other impurities generated from molybdenum stable isotopes was used in packing AL of 5 g, which is made by MP Biochemicals(Santa Ana, CA, USA), Cat. No.06031 with particle size of 0.063－0.20 mm and pH 4.3(acid alumina).

2・1・4 ^{99m}Tc radiopharmaceuticals

In order to measure the NaCl concentration, pH and the radiochemical purity of collected ^{99m}Tc solution, the NaCl concentration meter with measurement reliability 0.02% NaCl(TOA DKK MM-60 R/CT-57101 B, Tokyo, Japan), and pH meter(TOA DKK RM-31 P/ELP 035) and Ge semiconductor detector(ORTEC GMX-20190-P-PLUS, Oak Ridge, TN, USA) were used respectively.

Next, in order to confirm the chemical form and quality as the radiopharmaceutical of ^{99m}Tc recovered from TcMM process by comparing the conventional ^{99m}Tc generator, several analytical methods such as γ-TLC (thin layer chro-

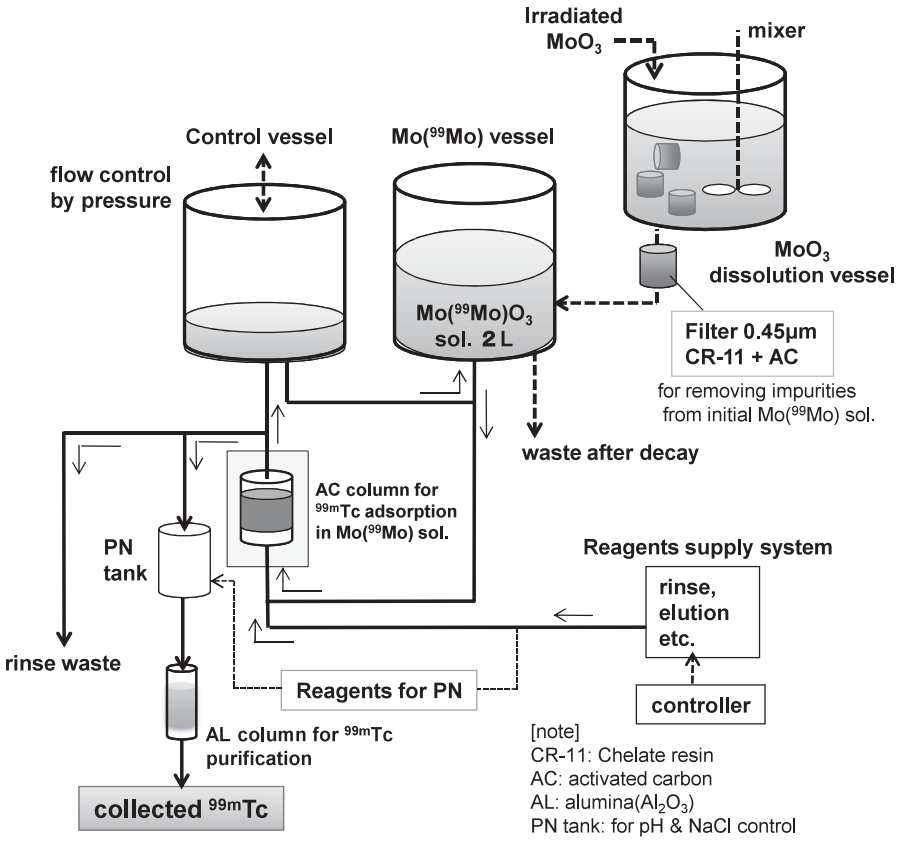

Fig. 1 Composition of experimental apparatus for ^{99m}Tc collection.

matography with γ-ray detector ; γ-mini GITA Star, Raytest, Strubenhardt, Germany), CAE (Cellulose Acetate film Electrophoresis), RP-HPLC (Reversed Phase-High Performance Liquid Chromatography ; Hitachi-L2130/Ratest-GABI Star, Tokyo Japan and Strubenhardt, Germany) with Unison US-C18 column and SPECT/CT (Single Photon Emission Computed Tomography/CT ; Triumph SPECT4/CT, TriFoil Imaging Inc., Chatsworth, CA, USA) were performed by the labeling experiments using the conventional ^{99m}Tc generators, radiopharmaceutical kits of MAG_3 (mercaptoacetylglycylglycylglicine), HM-PAO (hexamethylpropyleneamine oxine), MIBI (methoxyisobutylisonitrile), MDP (methylene diphosphonate) and Tetrofosmin, which were purchased from Nihon Medi-Physics and Fujifilm RI Pharma (both ; Tokyo, Japan).

2・2 Methods—Experimental method and its apparatus for confirming ^{99m}Tc collection process

The basic process of ^{99m}Tc collection from the $Na_2Mo(^{99}Mo)O_4$ solution consisted in 6 steps as shown below, and the outline of the experimental apparatus used for the confirmation of ^{99m}Tc collection process is shown in Fig. 1.

The verification outcome of each steps of TcMM process (6 steps) for ^{99m}Tc collection from (n, γ) ^{99}Mo is described below.

Step-1) Making the ^{nat}Mo (with ^{99}Mo) solution

by dissolving raw material MoO_3

MoO_3 dissolves completely according to the acid-base reaction [$MoO_3 + 2NaOH \rightarrow Na_2MoO_4 + H_2O$] with alkali (NaOH) of the double molar amounts, and becomes the Mo solution of the neutral pH. Therefore, by adding the double molar amounts of 6M-NaOH 679 mL to the irradiated MoO_3 pellets of 293.4 g (Mo 195.6 g) contained ^{99}Mo radioactivity of 2.99 e + 12 Bq measured by Ge semiconductor detector, it becomes transparent colorless solution of the neutral pH, then the Na_2MoO_4 solution of 1 L adjusted by adding H_2O is prepared.

Step-2) Adsorbing collection of ^{99m}Tc in ^{nat}Mo (with ^{99}Mo) solution

The Na_2MoO_4 solution 1 L contained large amount of ^{nat}Mo (with ^{99}Mo) is flowed into the AC column packed with crushed activated carbon of 5 g (packing size : 10.2 mmφ × 141 mmH) at the flow velocity of 21 − 50 mL/min measuring with a flow meter in the condition of upward flow. Even if the maximum velocity of 50 mL/min, ^{99m}Tc of 98% or more in the ^{nat}Mo (with ^{99}Mo) solution is selectively adsorbed into the AC column and the adsorption phenomena have superior reproducibility.

It can be understood that the AC has an excellent adsorption property by the reason why the ^{99m}Tc of extremely small amount of 10^{-16} − 10^{-17} against Mo (200 g) is selectively and almost adsorbed with high efficiency under the high column velocity of ^{nat}Mo (with ^{99}Mo) solution.

Step-3) Rinse out ^{nat}Mo (^{99}Mo) from AC adsorbed with ^{99m}Tc

By flowing a high density ^{nat}Mo (with ^{99}Mo) solution in AC column, though Mo does not adsorb in it, it cannot be avoided that as much as approximately 0.5 − 1.0 g of Mo remains in the micro hole of AC. If a remained Mo in AC is not rinsed out, it causes the contamination of ^{nat}Mo (with ^{99}Mo) by mixing in ^{99m}Tc collection liquid in the following ^{99m}Tc elution collection steps.

In order to remove the contamination of ^{nat}Mo (with ^{99}Mo) remained in AC, by the sequential treatments flowing firstly H_2O of 100 mL for 4 min., next 1.3M-NaOH solution of 30 mL for 10 min., and finally again H_2O of 5 mL for 1 min. This treatment can remove Mo less than approximately 5 mg in AC, and moreover it serves as the alkali impregnation operation to the AC column adsorbed ^{99m}Tc for next Tc recovery process as step-4.

Step-4) ^{99m}Tc elution from AC column

After rinsing out remained ^{nat}Mo (with ^{99}Mo) contamination, the AC column is heated up to 80 ℃, then H_2O of 30 mL are flowed into the AC column by the flow rate of 5 mL/min. By this procedure, a little alkaline solution contained ^{99m}Tc of the whole quantity mostly can be collected.

Step-5) Adjustment of pH and NaCl density of ^{99m}Tc eluted solution

The eluted alkaline solution (30 mL) contained ^{99m}Tc collected by the treatment of step-4 is mixed 30%-NaCl of 5 mL and adjusted to be pH neutral by flowing in AL (6 g, packing size : 10.2 mmφ × 76 mmH) column. It is also a merit using acid alumina that pH is neutrally controllable only by flowing to the AL column by itself.

Step-6) ^{99m}Tc purification

After step-5, further the AL column is rinsed by 0.9%-NaCl of 10 mL, then the saline (40 mL) contained ^{99m}Tc and 0.9%-NaCl of 15 mL are sequentially flowed again in a new AL (10 g : packing size : 10.2 mmφ × 126 mmH) column for advanced refining treatment. The dynamic adsorption rate of ^{99}Mo to alumina doesn't change so much even if flowing velocity changes, and the whole quantity of ^{nat}Mo (with

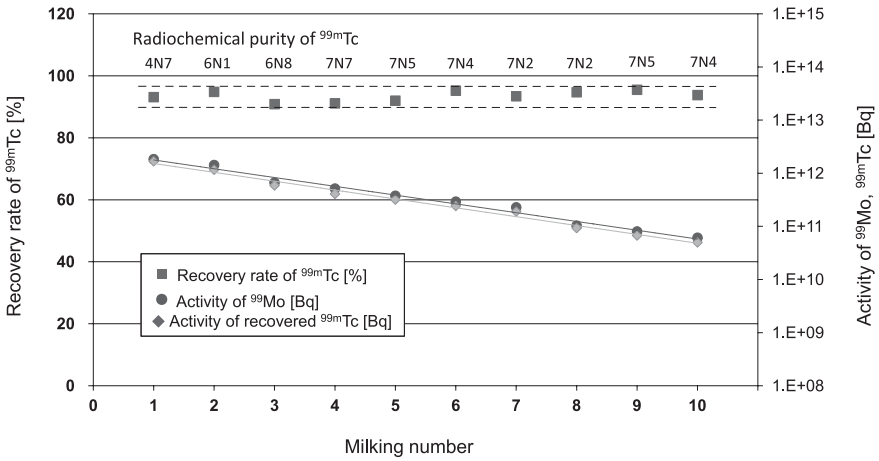

Fig. 2 Repeatability of ^{99m}Tc collection from highly radioactive (n, γ) ^{99}Mo.

^{99}Mo) is adsorbed from the column entrance to about 20 mm. Moreover, the loss of adsorbed ^{99m}Tc in the step of AL column purification was 5% or less. By this procedure, the collected ^{99m}Tc solution purified by the alumina is saline (0.9%-NaCl) with the pH neutral, and the radiochemical purity is 4N (99.99%) or more.

According to the regulation of the Japanese pharmacopoeia, the NaCl concentration and pH value of collected ^{99m}Tc solution are within NaCl 0.85 − 0.95% and pH 4.5 − 7.0 respectively, and it must not contain other different nuclides.

The quality and chemical form of collected ^{99m}Tc were evaluated by γ-TLC using acetone as the developmental solvent, electrophoresis and HPLC, furthermore the labeling experiment using radiopharmaceutical kits were performed to confirm the qualities and to observe the disposition behavior in a small animal. The radiochemical purity of collected ^{99m}Tc solution was measured and evaluated after disintegration of ^{99m}Tc.

According to the basic ^{99m}Tc recovery process consisted in the above-mentioned six steps, a large amount of highly pure ^{99m}Tc is collectable from a large amount of molybdenum solution contained (n, γ) ^{99}Mo.

It is possible to operate the TcMM process automatically, and it can expect the stable production and high quality of ^{99m}Tc by automatic operation.

3. Results

3・1 Recovery rate and producing time of ^{99m}Tc

The amount of initial radioactivity of ^{99}Mo began on 1 e + 12 Bq levels, and the ^{99m}Tc milking was performed once a day and repeated the operation 10 times. By the results, the rate of an average ^{99m}Tc collection became 93.5% as shown in Fig. 2.

The recovery rate of ^{99m}Tc was not influenced by the radioactivity of ^{99}Mo or ^{99m}Tc from micro-Ci level to 50 Ci (e + 4 − 2 e + 12 Bq), and the recovery rate of 90 − 98% was stably obtained. The producing time of ^{99m}Tc is 30 − 50 min. per batch influenced by the liquid volume of Mo (^{99}Mo) solution.

3・2 Quality confirmation of collected ^{99m}Tc

As shown in Fig. 2, the radiochemical purity of collected ^{99m}Tc was set to 6 N − 7 N on the

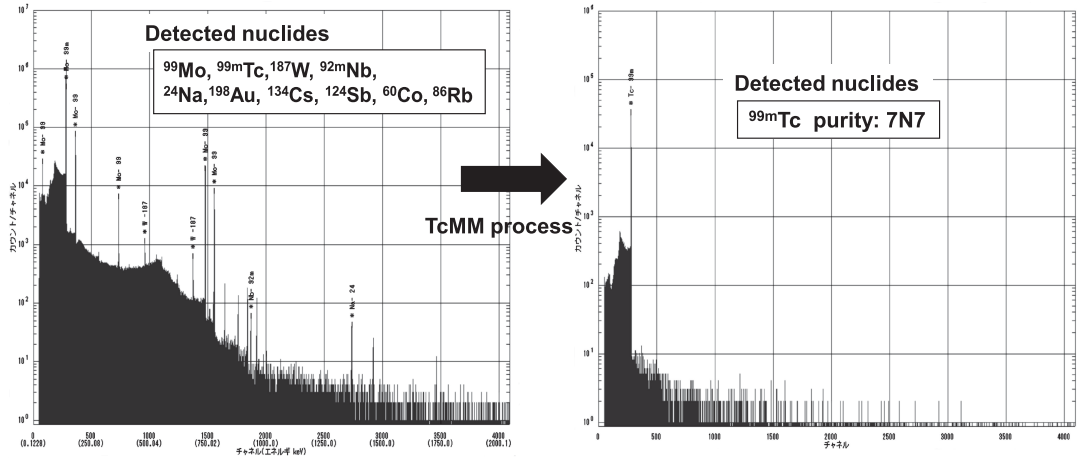

Fig. 3 γ-spectra of Mo(^{99}Mo), and ^{99m}Tc collected by TcMM process.

average, although the start was 4 N.

The Mo(^{99}Mo) solution has many kinds of radioactive impurities such as radioactive niobium (^{92m}Nb, ^{95}Nb and ^{96}Nb generated from Mo stable isotopes) and other radionuclides (^{60}Co, ^{187}W, ^{198}Au, etc.), however the collected ^{99m}Tc solution treated by TcMM process has never such impurities including ^{99}Mo, as shown in Fig. 3.

The γ-TLC and CAE analyses showed that the collected ^{99m}Tc exhibited a single peak at a Rf values similar to those of $^{99m}TcO_4^-$, and it was confirmed a single form of $^{99m}TcO_4^-$ (pertechnetate) as well as the form of ^{99m}Tc made from Fission-^{99}Mo raw material, and not to contain other forms, as shown in Fig. 4 (γ-TLC).

The labeling experiments using radiopharmaceutical kits of ^{99m}Tc-tetrofosmin, ^{99m}Tc-MIBI, ^{99m}Tc-HMPAO and ^{99m}Tc-MAG_3 using ^{99m}Tc collected from the TcMM provided TLC, RP-HPLC and CAE profiles similar to those of ^{99m}Tc-labeled radiopharmaceuticals prepared with ^{99m}Tc solutions eluted from ^{99}Mo/^{99m}Tc generator system. The result in case of ^{99m}Tc-HMPAO is shown in Fig. 5.

Further, ^{99m}Tc-HMPAO and ^{99m}Tc-MIBI using ^{99m}Tc from Tc-MM demonstrated SPECT/CT images of murine brain and heart similar to those obtained from each radiopharmaceutical using generator eluted ^{99m}Tc, as shown in Fig. 6 (a) and (b).

3・3 Wastes accompanying ^{99m}Tc production

In the case of ^{99}Mo amount mentioned above, the radioactive wastes generated in the TcMM process are the rinsing liquid of 30 − 300 mL/d (batch) and the Mo(^{99}Mo) stock solution of 2 L/w after disintegrated ^{99}Mo radioactivity as the liquid wastes, furthermore the solid waste are AC of 0.5 − 5 g/batch and AL of 1 − 20 g/batch.

It is judged that such quantity of the generated waste is not so extensive from comparison with other methods.

From the all-inclusive TcMM development result shown in Table 2, the ^{99m}Tc mass-produc-

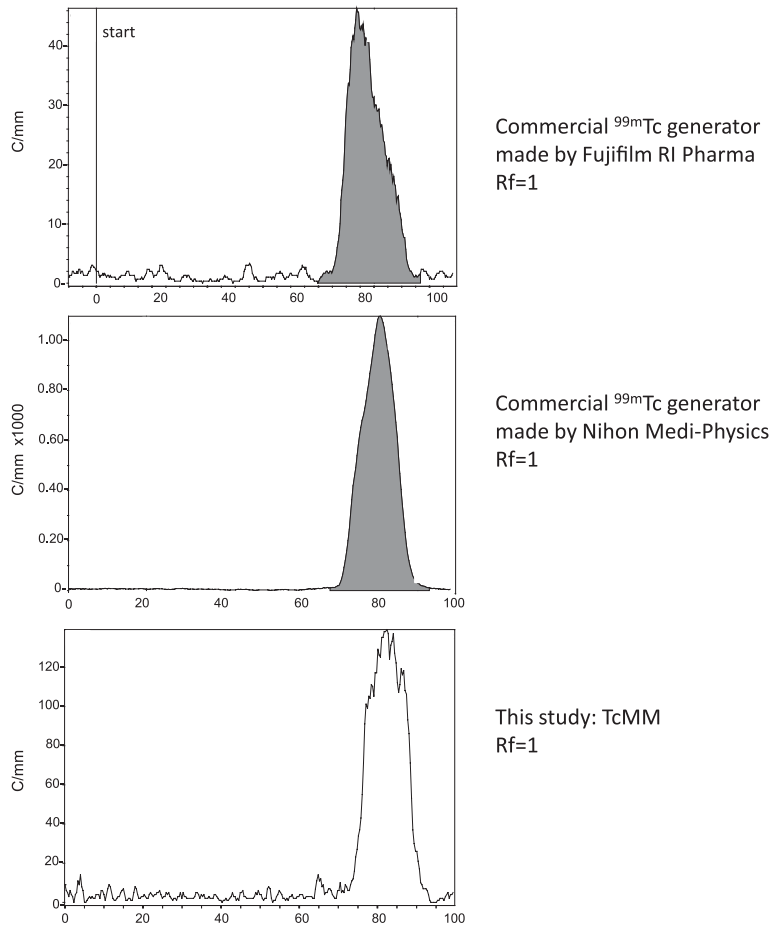

Fig. 4 γ-TLC data of ^{99m}Tc collected from TcMM and 2 kinds of conventional ^{99m}Tc generator.

ing TcMM process using natural isotopic Mo(n, γ) ^{99}Mo has the capability which be equivalent to the conventional fission method and can replace it.

4. Discussion

The development of TcMM process was started at an accidental discovery of rhenium (Re) selective adsorption phenomenon to AC; the chemical property of Re is almost equivalent to Tc. In order to develop a practical ^{99m}Tc producing method from natural isotopic Mo(n, γ)^{99}Mo without using uranium, the TcMM process was developed based on the extremely-numerous experiments of trial and error.

4・1 Exclusion performance of neutron activated impurities

The natural isotopic Mo consists of seven kinds of stable isotopes (^{92}Mo, ^{94}Mo, ^{95}Mo, ^{96}Mo, ^{97}Mo, ^{98}Mo, ^{100}Mo), and only ^{98}Mo (the natural abundance : 24.1%) in that is available for ^{99}Mo production. By the neutron irradiation of the natural isotopic MoO_3, the radioactive niobium of ^{92m}Nb, ^{95}Nb, and ^{96}Nb generates from the stable isotopes of ^{92}Mo, ^{95}Mo and ^{96}Mo, respectively,

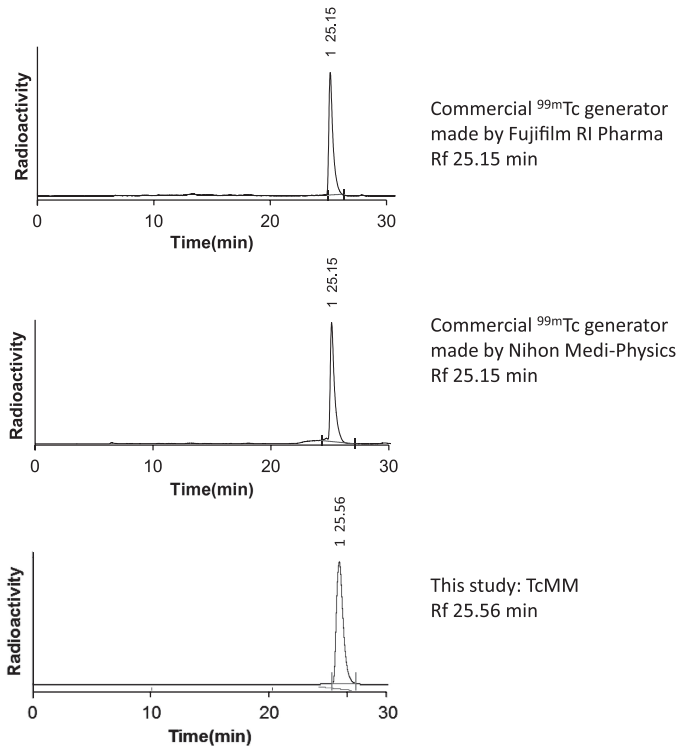

Fig. 5 HPLC data of HMPAO labeled with ^{99m}Tc collected from TcMM and 2 kinds of conventional ^{99m}Tc generator.

and other radioactive impurities, e.g. ^{60}Co, ^{65}Zn, ^{86}Rb, and ^{134}Cs, etc., generate from impurities in Mo raw material.

Although many impurities, such as radioactive Nb generated from stable Mo isotopes and other radioactive impurities, e.g. ^{60}Co, ^{65}Zn, etc., are contained in Mo(^{99}Mo) solution for ^{99m}Tc production, a highly pure ^{99m}Tc which does not contain these impurities by the TcMM process is recoverable.

4・2 Assumption of the mechanism regarding the AC adsorption of ^{99m}Tc in high density Mo(^{99}Mo) solution, and desorption from AC

The principle of selective adsorption with the AC of ^{99m}Tc is uncertain yet. However, the AC adsorbing phenomenon of an extremely small amount of ^{99m}Tc ($^{99m}TcO_4^-$) in a high density Mo solution in this study is well-reappeared.

In addition, in order to desorb the ^{99m}Tc adsorbed in AC, it is possible to desorb it by making the concentration gradient of NaOH surrounding AC after occlusion of a higher concentrated NaOH. The assumption of the mechanism of adsorption and desorption between the AC and ^{99m}Tc is shown in Fig. 7.

Moreover, the adsorption isotherm measured as Freundlich type between the AC and Re(^{99m}Tc) is shown in Fig. 8.

5. Conclusion

From the development results regarding

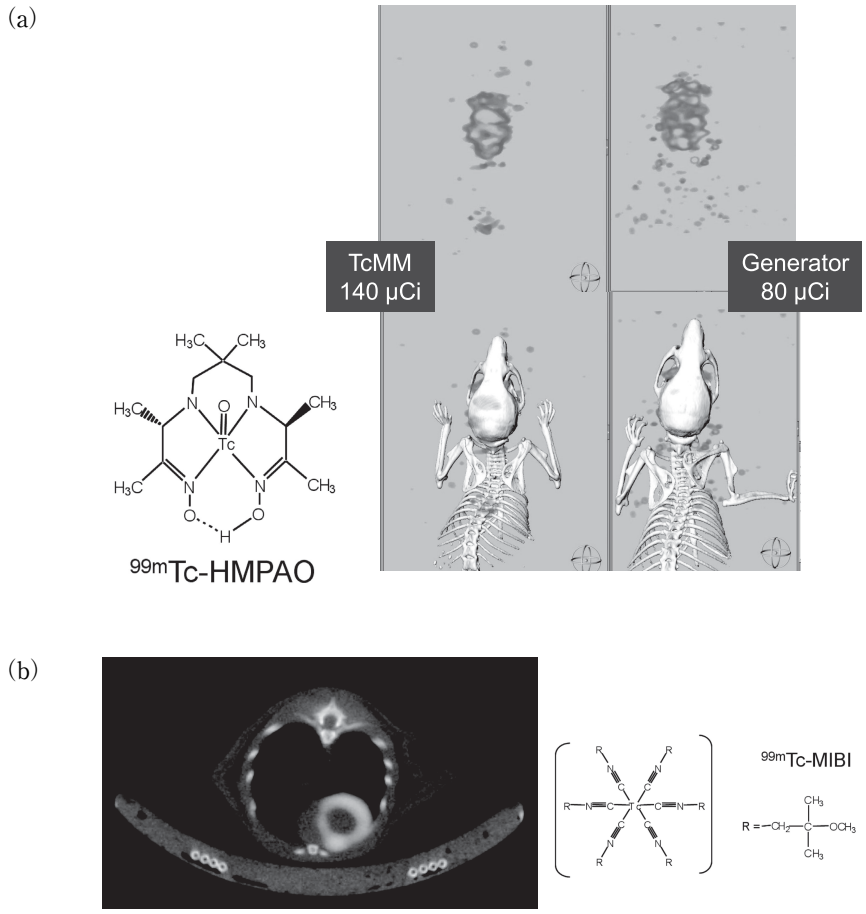

Fig. 6 SPECT/CT image of mice injected with (a) ^{99m}Tc-HMPAO and (b) ^{99m}Tc-MIBI.

TcMM process of ^{99m}Tc mass-producing method, ^{99m}Tc quality and the waste generation accompanying ^{99m}Tc production, the TcMM process has the ability as the practical ^{99m}Tc mass-production method with the large production capacity of several tens or hundreds Ci (1 e + 12 − 13 Bq) per batch.

View

Recently, the uncertainty of the stable production and supply of Fisson-^{99}Mo is being increased. On the other hand, the production of (n, γ) ^{99}Mo without using uranium as raw material has the feature with not-generating nuclear waste and a low production cost.

Therefore, it seems that it becomes a big factor growing the nuclear medicine diagnosis up to spread in the developing country where the medical procedure will progress in the future, and the social significance and value may be high.

Since ^{99m}Tc recovery method of this study can be used to a low specific activity ^{99}Mo generated by using a natural isotopic Mo or a specific concentration Mo isotope as raw materials, either the method of carrying out neutron irradiation at a nuclear reactor or the method of irradiating by an accelerator neutron source is

Table 2 Evaluation of TcMM process for mass-producing ^{99m}Tc from (n, γ) ^{99}Mo

Producing process of ^{99m}Tc	➢Equivalent ^{99m}Tc recovery rate in a varied dose (microcurie - 50Ci) ➢Recovery of ^{99m}Tc : 90~98% ➢Concentration of ^{99m}Tc solution: more than 1Ci/mL ➢Producing time: 30~50 min/run
Quality of recovered ^{99m}Tc	➢^{99m}Tc solution: sterile saline solution ➢Revovered chemical form of ^{99m}Tc: $^{99m}TcO_4^-$ (pertechnetate) ➢Endotoxin-inspection: negative ➢Radiochemical purity: >4N~7N ➢The results of recovered ^{99m}Tc chemical form, medical-supplies adjustment, and a mouse inside-of-the-body dynamic state suggest a useful thing to adjustment of a radiopharmaceutical. ➢In the labeling experiment using five kits of ^{99m}Tc-MDP, ^{99m}Tc-tetrofosmin, ^{99m}Tc-MAG_3, ^{99m}Tc-HMPAO and ^{99m}Tc-MIBI, even if it used the technetium eluted from TcMM, the target medicine was given with high radiochemical purity.
Waste for production	➢Liquid waste: 30~300mL/run ➢Solid waste: AC 0.5~5g/run, AL 1~20g/run, column casing

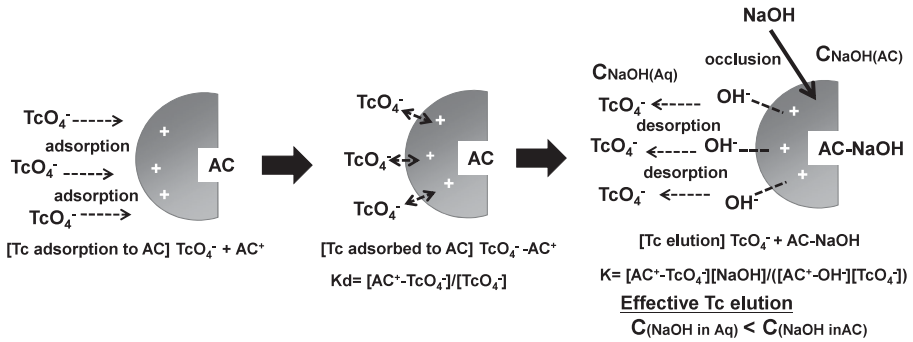

Fig. 7 Assuming mechanism of adsorption and desorption (elution) of ^{99m}Tc.

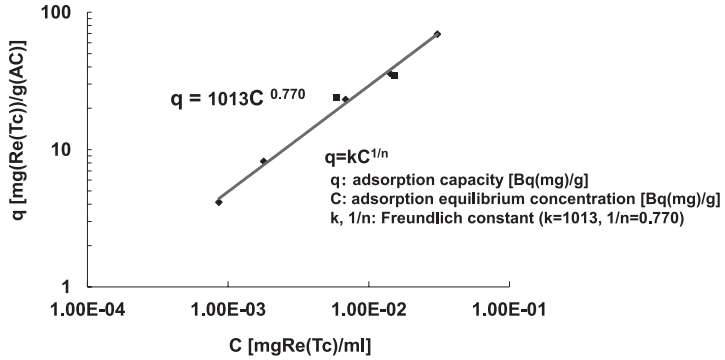

Fig. 8 Isothermal curve of Re (^{99m}Tc) adsorbing to AC.

applicable as the ^{99}Mo generation method.

It can be expected that the establishment of the system that obtains ^{99m}Tc from ^{99}Mo generated by neutron activation (n, γ) method of the natural isotopic Mo compound will support the nuclear medicine in the future.

Acknowledgment

The authors wish to express our gratitude to Ms. Tomomi Ueda and Ms. Yuli Natori with whom it cooperated, and also express gratitude to the researchers of JAEA-NUCEF group who realized the high activity experiments of ^{99}Mo - ^{99m}Tc and performed the cooperation of radioactivity measurements.

This study is conducted as "Developmental project of ^{99m}Tc domestic production in Japan" by supporting with Japan Science and Technology Agency.

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