ELECTRON ACCELERATOR'S PRODUCTION OF TECHNETIUM-99m FOR NUCLEAR MEDICINE*

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Abstract

At present Technetium-99m provides up to 90% isotopic products used in nuclear medicine [1]. His generator Molybdenum-99 is mainly produced in fission reactors. Most of reactors used for this production are approaching the end of their exploitation [2]. One suggests to use photonuclear reactions in ^{100}Mo under influence of bremsstrahlung of powerful electron accelerator as an alternative method of ^{99m}Tc production. Report contents both an analysis of some technical, economical and ecological aspects of method and the results of experimental production of ^{99m}Tc with KIPT electron linac, as well as results of medical test of produced radiopharmaceuticals.

INTRODUCTION

By 1994 the medicine radionuclides turnover around the globe had reached the figure of 1.2 M$ [1]. Most of them are pharmaceuticals based on ^{99m}Tc. This radionuclide is produced via ^{99}Mo. As the analysis of nuclear physics data shows [3], the ^{99}Mo nuclide generation can be effectively performed by a high-energy photon irradiation (photon energy E_γ>20 MeV) of a target, containing ^{100}Mo nuclide to yield in the ensuing reaction the following:

^{100}Mo(γ,n)^{99}Mo(reaction threshold, E_t=9,1MeV) (1)

simultaneously, the parallel reaction channels are:

^{100}Mo(γ,p)^{99}Nb($T_{1/2}$=15s)$\rightarrow^{99}$Mo(E_t=16,5MeV) (2)

^{100}Mo(γ,p)^{99m}Nb($T_{1/2}$=2.6m)$\rightarrow^{99}$Mo(E_t=16,9MeV) (3)

^{100}Mo (n,2n)^{99}Mo (E_t= 8,3 MeV) (4)

^{98}Mo (n,γ) ^{99}Mo (5)

(reactions (4), (5) will be noticeably observable in the case of a "thick" target, only).

A high-energy photon flux can be obtained readily as bremsstrahlung if accelerated electrons strike a converter-target made of high-Z material (commonly, Tantalum or Tungsten). Calculations, made on reactions (1)...(5) indicate that for a successful ^{99}Mo and ^{98}Nb generation via ^{100}Mo-target irradiation by bremsstrahlung flux the optimum electron energy should be 25 MeV. In this case, the specific yield of the above nuclides would be 1.2μCi/μA·hour·g(^{100}Mo). By way of a certain optimization of the irradiation conditions and target geometry the final value from the calculations can be raised by a factor of two. If one use a Mo target of natural isotopic composition in which ^{100}Mo were ~10% then the above appraisal should be lower by an order of magnitude [3].

1 ^{99}MO GENERATION SETUP

In order to study the process of ^{99}Mo generation, using electron linac, we designed a facility, the schematic of which is given in Fig.1.

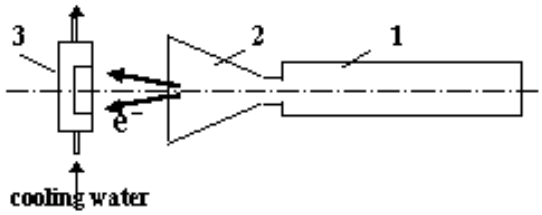

Fig.1. Schematic of experimental setup: 1-electron linac, 2-beam scanning device, 3-target device

As high-energy electron source we used the accelerator test stand LU-20 (item 1), operating in the following mode:

- Electron energy, MeV 20
- Average beam current, μA 500
- Beam pulse width, μs 3
- Rep rate, Hz 150

Considering that the average electron beam power should be 10 kW and in order to avoid the hazards of the accelerator exit foil melt up, the exiting beam, before striking the foil, is swept out into a vertical line, using a specially designed scanning device (item 2), which operates with rep rate of 3 Hz, beam sweep-out length being 12 cm and its width 1cm. These parameters determine the main geometrical characteristics of the target (item 3). Besides, inasmuch as the principal electron beam portion is absorbed into the target volume, the target needs being continuously water-cooled.

In order to run the evaluation experiments we used a target construction of unoptimized geometry, the structure of which is given in Fig.2.

This device consists of aluminum casing 1, made air-tight on face joints with flanges (not shown in the

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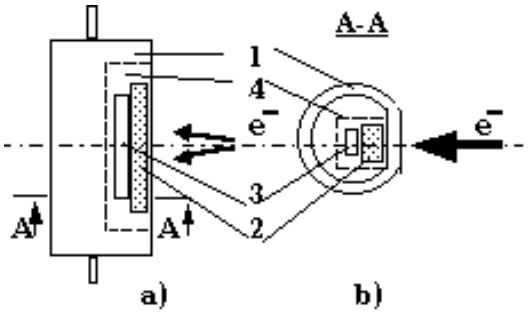

Fig.2. Experimental target device setup: a) A lateral view, b) A cutaway view
1 - Casing, 2 - Converter, 3 - Mo-target, 4 - Cassette

schematic), where the outlets are used for pumping the cooling water in and out. The target device was placed immediately after the exit window of accelerator. Circulating water was then fed on to the construction, and the target was irradiated for 10 hours running. This done, the beam was turned off and Mo-target taken out of the cassette.

2 ^{99M}TC EXTRACTION TECHNOLOGY

A fraction of ^{99m}Tc atoms in the target, immediately after the 10h-irradiation in the linac, with electron beam intensity being 500 μA, was ~10^{-16} off Mo atoms. An extraction of such concentrations, even with analytic chemistry methods, is difficult to realize into practice. Electrochemical analytical detection techniques are known to have the lowest thresholds, as compared to many other detection methods. For instance, the inverse V-A anode measurements have the detection threshold 10^{-11} - 10^{-12} g/g. Considering this, we expected that utilization of the electrochemical yield techniques would allow us to solve the problem of ^{99m}Tc extraction from solutions with such a low concentration.

We used electrolysis to obtain a pertechnetate solution which was soon thereafter evaporated in order to achieve a high specific activity. In this case, it was 20 MBq/mg.

The content of ^{99m}Tc and radioactive impurities in the pertechnetate solution was measured using a Ge(Li) detector with the volume 50 cm^3 and energy resolution 1.8 keV along the 1333 keV line. The only radioactive impurity present in the solution after electrochemical precipitation had been done, was ^{99}Mo. Its content in the pertechnetate solution did not exceed 1.5% of ^{99m}Tc. Considering the fact that a relative radiation intensity off the line 140.5 keV ^{99m}Tc is 89.6%, with that of the most intense line 733.4 keV ^{99}Mo being 12.8%, such an ^{99}Mo inventory does not specifically affect the processes of gamma-scintigraphy. Another electrolysis of the pertechnetate solution allowed to lower the ^{99}Mo content down to 0.15%. Fig.3 presents the emission spectrum of an irradiated Mo-sample.

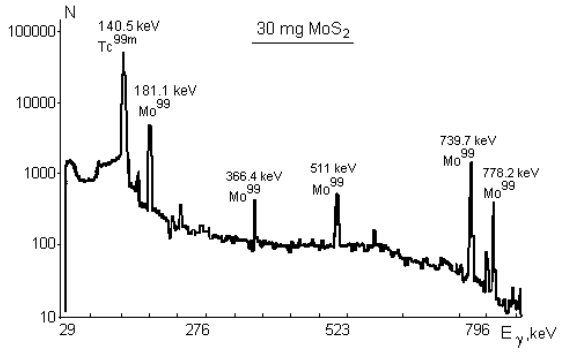

Fig.3. An experimental activities spectrum of an irradiated Mo-target with natural isotopic content

3 PREPARATION OF RADIOPHARMACEUTICALS AND THEIR TEST

The re-agent, thus obtained, was used for studies on the effects of various radiopharmaceuticals during diagnostics, involving the radionuclide. In case of gamma-scintigraphy the standard re-agent kits (Technefit, Pentatech, Citratech) were used.

It was established for a fact that the radiopharmaceuticals, involving ^{99m}Tc and the standard kits of Technefit, Pentatech and Citratech re-agents, after having been administered intravenously at the level of about 0.5 MBq, propagated adequately through rats' tissues, resulting in the organ under scrutiny being clearly visible on the Ohio Nuclear gamma-chamber screen.

In all cases, rats were closely watched after during the week subsequent to the administration of the radiopharmaceuticals, with an overall examination of the animals being made constantly. No harmful after-effects were found [4].

CONCLUSIONS

As a result of our studies, we demonstrate a feasibility of ^{99}Mo generation, using an energetic electron beam, which shows more environmentally-safe conditions of ^{99m}Tc production, as compared with the traditional fission reactor techniques. Our assessments indicate that the proposed technique meets, at the existing accelerator parameters, the economic challenge of in-reactor radionuclide generation. In case of a dedicated R & D on a high-power linac whose beam would meet the optimum requirements of electron-induced photonuclear reactions and target irradiation geometry, the proposed technique has the promise of returning very high profits in a not too-distant future.

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