DEVELOPMENT OF NEW ELECTRON IRRADIATION BASED TECHNOLOGY FOR TECHNETIUM-99m PRODUCTION*

N.P.Dikiy, A.N.Dovbnya, V.L.Uvarov
Kharkov Institute of Physics & Technology, 310308, Kharkov, Ukraine

Abstract

Technetium-99m provides up to 90% analysis in nuclear medicine diagnostic. Traditional technology of its parent isotope molybdenum-99 production is based on fission radiochemistry that is rather complicated and potentially dangerous for environment. Authors demonstrated earlier a possibility of M-99 generation using irradiation of Mo- target of natural isotopic content with bremsstrahlung of high-current electron linac [1]. Preliminary test of Tc-based radiopharmaceuticals thus produced confirmed their high isotopic purity. Report contents the results of investigation of physical ground of new technology including computer modelling of beam-target interaction and experimental data concerning optimization of Mo-99 processes as well.

1 INTRODUCTION

Effect with electron beam (20…25 MeV) on high-Z converter is accompanied by an emission from the latter a mixed stream of bremsstrahlung photons, photoneutrons and electrons. As a rule, an analysis of ^{99}Mo generation in thus irradiated target of natural molybdenum is conducted mainly considering photonuclear channel on ^{100}Mo isotope which content in a natural Mo makes 9.63% [2,3]. Taking into account extremely high cost of enriched ^{100}Mo isotope (up to $1000 per gm.) there is a special interest in research of all possible mechanisms for Mo-99 generation in natural target under influence of mixed radiation as well as other attendant isotopes.

2 COMPUTER SIMULATION

For optimization of ^{99}Mo generation in photonuclear reactions we developed a computer model based on software code GEANT [4]. Within the limits of a model the generation of e,γ-radiation from the Ta-converter of actual structure (cooled with water) was investigated and also interaction of this radiation with the Mo-target (the cylinder of 100 gm. – is determined by conditions of the further radiochemical treatment). The analysis executed in 2D-geometry has shown that the optimal thickness of the Ta-plate for energy of electrons E=20MeV makes 2 mm and not less than 10% of initial beam power is absorbed in the target. Considering the proposed electron beam power (up to 20 kW) there are some problems in cooling of such target.

3 EXPERIMENTAL RESULTS

*3.1.*The experimental research of ^{99}Mo-generation mechanisms was carried out using electron linac EPOS [5] having beam parameters

energy of electrons, MeV	up to 30
average beam current, μA	500

Within exit window of the accelerator a beam is scanned in a vertical plane with frequency of 3 Hz. The transversal size of an electron flow in experiments exceeded much more the size of targets, that ensured geometry of their irradiation similar to parallel-plane. During an exposure the targets were cooled with water that determined essential increase of photoneutron flow.

*3.2.*For an experimental research of ^{99}Mo yield dependence on converter thickness and material the 0.1 mm plates of natural Mo were placed just behind Ta- and W- plates of various thickness and irradiated with accelerated electrons. After irradiation the induced γ-activity of Mo-plates was measured along photon energy line E_γ=739.7 keV corresponding to ^{99}Mo. The measurements were carried out with the help of Ge(Li) detector. The data were reduced to identical electron fluence. The specific ^{99}Mo yield dependences on converter thickness thus obtained are represented in Figure 1.

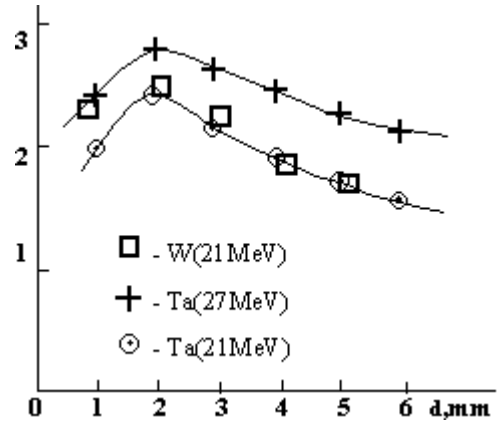

Figure 1: Mo-yield (arbit. un.) as a function of converter thickness

The yield of generated "background" isotopes ^{95}Nb, ^{96}Nb and ^{88}Zr was determined simultaneously (Fig.2)

*3.3.*For determination of dependence ^{99}Mo of specific yield on Mo-target thickness the package consisting of 100 Mo-plates was placed behind Ta-converter of optimal thickness (2 mm). After irradiation the partial activity of plates along the line E_γ=739.7 keV with allowance for depth of their location in package was measured. The outcome is given in Fig.3.

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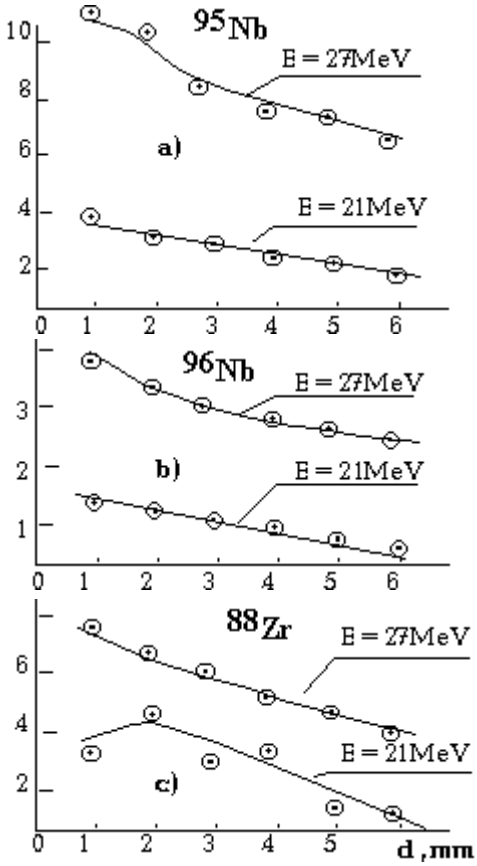

Figure 2: The yield of attendant isotopes (arbit.un.)

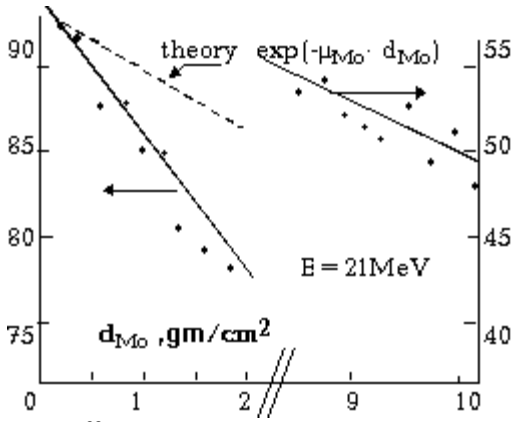

Figure 3: ^{99}Mo yield as a function of target thickness

*3.4.*For learning contribution of various components of radiation interacting to the target in ^{99}Mo yield the exposure of Mo-plates in geometry outlined in Figure 4 was carried out. The results are represented in Figure 5.

DISCUSSION

The analysis of experimental data (Fig.1and 5) shows that the noticeable yield of ^{99}Mo has a place during direct effect with accelerated electrons on the target, that it is possible to explain in (e,e′n) and (e,e′p)-reactions on ^{100}Mo isotope. In the latter case the generation of ^{99}Mo

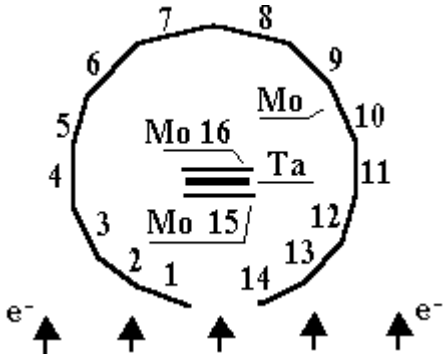

Figure 4: Target configuration

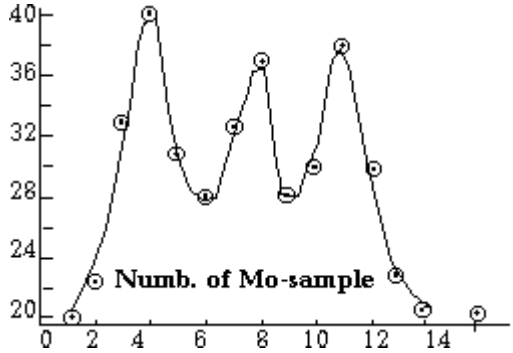

Figure 5: ^{99}Mo fractional yield in the samples (Fig.4)

goes under the scheme ^{100}Mo(e,e′p)^{99}Nb($T_{1/2}$=15s)→^{99}Mo. These reactions apparently determine also initial site of represented in Fig.3 dependence (the total thickness of the converter and target up to 5…6gm./cm^2). The last conclusion confirm the data in Fig.2 also. So, ^{95}Nb and ^{96}Nb dependences on converter thickness do not have a maximum corresponding to bremsstrahlung flow maximum nearly d_{Ta}=2 mm. This feature appears in similar dependence for ^{88}Zr (Fig.2^c, E=21MeV), meanwhile in the corresponding dependence for E=27MeV ^{92}Mo(e,e′α)^{88}Zr reaction apparently prevails.

The data in Figures 4,5 also, under our judgment, demonstrate a superposition of different channels of ^{99}Mo generation in natural molybdenum. So, the main contribution in activity of samples 1,14,15 it is possible to explain with (e,e′)-reactions. Observed in samples 4,8,11 maximums of activity it is possible to connect with the additional contribution of the photonuclear channel both under bremsstrahlung out of converter and at the expense of photon generation in Mo-plates themselves (4,11). The absolute maximum of ^{99}Mo specific yield observed in a sample 16 (10μCi/μA·hr·gm.Mo) it is possible to explain, apart from of the mentioned mechanisms, also by manifestation of ^{98}Mo(n,γ) ^{99}Mo-channel.

For an evaluation of its contribution behind the converter the sample of a molybdenum enriched with the isotope ^{98}Mo(95%) was located. The ^{99}Mo yield measured in a sample after irradiation shows that in the target of a natural molybdenum up to 50% ^{99}Mo can be generated by photoneutrons (especially at presence of water).

CONCLUSIONS

The executed research has shown that by an irradiation of the target of a natural molybdenum with accelerated electrons it is possible to carry out an effective generation of ^{99}Mo due to a number of reactions with ^{100}Mo and ^{98}Mo isotopes. An estimation shows that in case of electron energy in range 20…25 MeV and beam current of 1 mA it is possible to produce per operating day up to 1 Ci ^{99}Mo. This activity has enough for supporting of needs of region with the population in some millions persons.

The application of an electrolysis of the dissolved irradiated Mo-target for selection of technetium-99m ensures it sufficient isotope purity that have confirmed medical test of ^{99m}Tc-based radiopharmaceuticals thus obtained [5].

The offered technology allows to produce ^{99m}Tc in ecologically secure conditions using rather inexpensive electron accelerators. Its additional benefit is compatibility with other traditional for such accelerators programs (sterilization, activation analysis, radiation modification of materials etc.).

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