# POSSIBILITY OF $^{99m}Tc$ PRODUCTION AT NEUTRON GENERATOR

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Possibility of application of the neutron generator with intensity of a thermal neutrons flux $10^{12}\, n \cdot cm^{-2} \cdot s^{-1}$ for $^{99m}Tc$ production is considered. Estimations are made on the base of $^{98}Mo(n,\gamma)^{99}Mo \rightarrow {}^{99m}Tc$ nuclear reaction.

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## 1. INTRODUCTION

Among the isotopes that applied in a nuclear medicine generating nuclides are very important. Generating nuclides is a system of two connected between themselves radionuclides (RN), one of which - more short-living (daughter (D)) is constantly formed as a result of decay of another (maternal (M)) which has essentially larger a half-life period ($T_{1/2}$). Among radioisotope generators the greatest application in nuclear medicine has the generator $^{99}Mo \rightarrow {}^{99m}Tc$.

One of possible ways of the $^{99}Mo$ production is a nuclear reaction $^{98}Mo(n,\gamma)^{99}Mo$. The isotope $^{99}Mo$ which is created by an irradiation, emits $\beta^-$ particles (100%) with the maximum energy $1210\, keV$ and the main $\gamma$-quanta with energy 181.1, $739.4\, keV$ (intensity of $\gamma$-lines $I_\gamma = 6.08\%$, 12.1% respectively). As a result of $\beta^-$ decay $^{99}Mo$ ($T_{1/2} = 65.9\, hours$) transforms in $^{99m}Tc$ ($T_{1/2} = 6.02\, hours$) which emits photons with the basic energy $140.5\, keV$ ($I_\gamma = 87.7\%$).

The present work is devoted a quantitative estimation of $^{99m}Tc$ production by created in NSC KIPT small-sized neutron generator (NG) with intensity of thermal neutron flux of $10^{12}\, n \cdot cm^{-2} \cdot s^{-1}$.

## 2. $^{99}Mo$ YIELD IN $(n, \gamma)$ REACTION

One of the important parametres which characterize neutron penetration across real samples, is a macroscopic cross-section $\Sigma = \rho\sigma_{eff} cm^{-1}$ [1], where $\rho$ is a density of nuclei, $\sigma_{eff}$ is an effective interaction cross-section. The quantity $\Sigma$ is similar to a linear damping coefficient usefully determined for photon beam in a medium. It can be used for estimation of the neutron flux weakening at its interaction with a nuclear medium.

Intensity of the neutron flux crossed a layer of substance ($x$), without the contribution of multiple scattering is:

$$I(x) = I_0 e^{-\Sigma_t x}\,, \qquad (1)$$

where $I_0$ is the intensity of the initial neutron beam. $\Sigma_t$ is a total macroscopic cross-section characterising all of the processes of neutron interaction with substance.

The thickness of the target which is received in according to (1), is equal to $x = 0.216\, cm$. The calculation is fulfilled at following parameters: molybdenum density of the natural isotope composition ($^{Nat}Mo$) is $10.2\, g/cm^3$; the total interaction cross-section $\sigma_t = 7.22\, barn$ that corresponds to an average value of the thermal neutron energy $0.038\, eV$ at the temperature $T = 300\, K$; $\Sigma_t = 0.462\, cm^{-1}$; a reduction of the neutron flux by a back wall of the sample is 10%.

The number of $^{98}Mo$ nuclei, containing in the target, is calculated in according to the expression:

$$N = 6.02 \cdot 10^{23} \cdot \beta m/A\,, \qquad (2)$$

where $\beta = 24.13\%$ is $^{98}Mo$ isotope content in a natural molybdenum; $m = 43.25\, g$ is the target weight, $A = 98$ is a mass number. In this case $N$ is equal to $6.41 \cdot 10^{22}$ nuclei.

For calculation of $^{99}Mo$ isotope activity $A_M$ is stored in the sample during of an irradiation time $t_{irr}$, the formula from [2] was used:

$$A_M = \sigma I_0 N (1 - e^{-\lambda_M \cdot t_{irr}}), \qquad (3)$$

where $I_0 = 0.95 \cdot 10^{12}\, n/cm^{-2} \cdot s^{-1}$ is an average quantity of a neutron flux in the irradiated sample, $\lambda_M = 0.693/T_{1/2} = 2.92 \cdot 10^{-6}\, s^{-1}$ is a radioactive decay constant of $^{99}Mo$, $\sigma = 0.13\, barn$ is the reaction cross-section on thermal neutrons. Expression (3) is written for a case when the incident particle beam is monoenergetic.

The estimations are done for two expositions of irradiation: $t_{irr}^{(24)} = 24$, $t_{irr}^{(66)} = 66\, hours$. At the above enumerated parameters, the activity of $^{99}Mo$ is equal $A_M^{(24)} = 17.6 \cdot 10^8$, $A_M^{(66)} \sim 0.4 \cdot 10^{10}\, Bq \sim 0.1\, Ci$ and specific activity $4.07 \cdot 10^7$, $9.2 \cdot 10^7\, Bq/g$ correspondingly.

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It is interesting to compare this result to the data of other authors, for example, [3–5]. In work [3] it is shown that at molybdenum irradiation in the reactor neutron flux $10^{15}\,n \cdot cm^{-2} \cdot s^{-1}$ within 5 days specific $^{99}Mo$ activity can reach $14.5\,Ci/g$ for natural $Mo$. The calculations of specific activity of the data [3] carried out by the above described method with effective cross-section $0.5\,barn$ [3] and neutron flux of $10^{12}\,n \cdot cm^{-2} \cdot s^{-1}$ give practically the same value. The specific activity of $47.5\,mCi/g$ for $^{99}Mo$ is obtained in [4]. In this case the neutron flux was $10^{13}\,n \cdot cm^{-2} \cdot s^{-1}$ and $t_{irr}^{(24)} = 24\,hours$. An estimation of the data [4] for neutron flux $10^{12}\,n \cdot cm^{-2} \cdot s^{-1}$ gives specific activity which is different of the our value about 10%. The received results show that the technique of an estimation of $^{99}Mo$ yield is correct enough and can be used for forecasting of the yield of others RN.

$^{99}Mo$ activity in $^{100}Mo(\gamma,n)^{99}Mo$ reaction was calculated in [5]. The following parameters were used: an electron beam energy - $20\,MeV$, an average beam current - $1\,mA$, a target - metallic $^{Nat}Mo$, a sample thickness $\leq 15\,g/cm^2$, an exposition of irradiation - 66 hours. The value of $^{99}Mo$ activity was found of $\sim 0.8\,Ci$.

As it was shown above, our estimation for the $^{99}Mo$ activity in reaction $^{98}Mo(n,\gamma)^{99}Mo$ at the exposure $66\,hours$ gives the activity of $\sim 0.1\,Ci$. It is visible that for the given conditions the activity predicted in the $^{100}Mo(\gamma,n)^{99}Mo$ reaction is bigger than in the $^{98}Mo(n,\gamma)^{99}Mo$ reaction.

## 3. THE $^{99m}Tc$ YIELD. DISCUSSION.

At a decay of the maternal isotope, which has an activity $A_M$, the daughter RN activity $A_D$ will reach quantity [4]:

$$A_D = A_M \frac{\lambda_D}{\lambda_D - \lambda_M} \left\{1 - \exp\left[-(\lambda_D - \lambda_M)t\right]\right\}\,, \quad (4)$$

where t – time of $^{99m}Tc$ production in mixture of matrernal RN after irradiation. Substituting in (4) corresponding parameters: $t = 24\,hours$, $\lambda_M = 2.92 \cdot 10^{-6} s^{-1}$, $\lambda_D = 3.19 \cdot 10^{-5} s^{-1}$, $A_M^{(24)} = 17.6 \cdot 10^8$, $A_M^{(66)} = 0.4 \cdot 10^{10}$, and considering that only 82.4% of the $^{99}Mo$ will be transformed in $^{99m}Tc$ [4] and $I_\gamma$ of $^{99m}Tc$ 87.7%, we receive the $^{99m}Tc$ activity $A_D^{(24)} = 12.84 \cdot 10^8$ and $A_D^{(66)} = 31.80 \cdot 10^8\,Bq$.

For diagnostics of the vital person's systems a certain activity of $^{99m}Tc$ radioisotope [6] is required. For example, for research of cardiovascular system activity of $\sim 55\,MBq$ is necessary, for diagnostics of the central nervous system one is $\sim 240\,MBq$, for scenogramma of a brain tumour one is $\sim 370\,MBq$ etc. (By the way, according to the International Atomic Energy Agency experts an average diagnostic dose is $10\,mCi$). Thus, the $^{99m}Tc$ activity accumulated for 24 hours is sufficient for inspection (depending on studied of a body or a life-support system) on the average from 4 to 23 and from 9 to 58 patients respectively.

It is clear that in laboratory conditions the $^{99m}Tc$ activity may be somewhat smaller than in an ideal case as effectiveness of the isotope extraction is less than 1. Hence it is necessary to find ways for increasing of the $^{99m}Tc$ yield. For example, the yield can be increased:

1) in 4.1 times maximum applying the enriched target, containing the $^{98}Mo$ isotope only;

2) almost 2 times as many at increasing the target thickness up to $4.8\,mm$, that corresponds to 20% reducing flux of neutrons on the sample back side;

3) by exposition increase $t_{irr} > T_{1/2}$;

4) in case of simultaneous irradiation of more than one target, that is provided by the NG design.

## 4. CONCLUSIONS

The possibility of the neutron generator application with the flux of thermal neutrons $10^{12}\,n \cdot cm^{-2} \cdot s^{-1}$ for the $^{99m}Tc$ production on the basis of the $^{98}Mo(n,\gamma)^{99}Mo$ nuclear reaction is considered. It is shown, that the neutron generator can in principle produce the $^{99m}Tc$ radioisotope with activity sufficient for application in nuclear medicine.

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## ВОЗМОЖНОСТЬ НАРАБОТКИ $^{99m}Tc$ НА НЕЙТРОННОМ ГЕНЕРАТОРЕ

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Рассмотрена возможность применения нейтронного генератора с интенсивностью потока тепловых нейтронов $10^{12}$ н/см$^2$/с для получения изотопа $^{99m}Tc$ на основе ядерной реакции $^{98}Mo(n,\gamma)^{99}Mo \rightarrow {}^{99m}Tc$.

## МОЖЛИВІСТЬ НАПРАЦЮВАННЯ $^{99m}Tc$ НА НЕЙТРОННОМУ ГЕНЕРАТОРІ

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Розглянута можливість застосування нейтронного генератора з інтенсивністю потока теплових нейтронів $10^{12}$ н/см$^2$/с з метою отримання ізотопу $^{99m}Tc$ на основі ядерної реакції $^{98}Mo(n,\gamma)^{99}Mo \rightarrow {}^{99m}Tc$.