OPTIMIZATION OF CONDITION OF TARGET IRRADIATION FOR RADIONUCLIDE PRODUCTION

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In this report the different target arrangement relative to the bremsstrahlung beam have been considered. The analyses of spectral and angular distributions of bremstrahlung from different targets and as function of incident electron energy have been done. The worked out activity dependence on parameters of radionuclide target and bremstrahlung converter has been investigated. The different target arrangements relative to the bremsstrahlung beam have been considered. The analyses of spectral and angular distributions of bremstrahlung from different targets and as function of the incident electron energy have been done. The worked out activity dependence on parameters of a radionuclide target and a bremsstrahlung converter has been investigated. The recommendations concerning the optimal bremsstrahlung converter and target arrangement intention and the beam efficiency have been developed.

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INTRODUCTION

Production of medical radioisotopes is characterized by that the obtained preparation must have high radionuclide purity and the target must be subjected to minimum radiation damage. High radioisotope purity is provided by selection of target nucleus and minimization of the contribution (γ,2n), (γ,3n), (γ,pn) reactions leading to the formation of by-products of radionuclides. These demands restrict the maximum bremstrahlung energy and waste electron current on the target. The most of experiments that constrained with generation of radionuclides may be realized with beam power lower then 800 W that makes easier the selection of converter material and absorber of waste electron current. The converter material must possess a large atomic number Z, high density, and must be sufficiently easy at mechanical processing. For the next calculations and experiments tantalum has been chosen as it meets the above-mentioned requirements and is inexpensive. The maximum bremstrahlung yield in the region of giant resonance for making irradiation of experimental targets must be achieved. This one can be realized by variation of the initial target thickness or less by variation of the initial electron energy that is restricted by accelerators' technical ability.

MATERIALS AND METHODS

The important characteristics of irradiation devices are maximal specific activity of radionuclides, the volume and the shape of irradiating targets. For example, when production of ^{15}O, ^{18}F, ^{11}C, ^{99m}Tc is realized, incorrect choice of target shapes and volume leads to insignificant decreasing in the specific activity of above - mentioned radionuclides. When Ta, V, Os, Ir, Ti or In are irradiated, foil targets or wire targets of variable thickness are manufactured. Therefore, the problem of selection of target volume and shape is related to the problem of irradiation targets with isotropic or anisotropic γ-rays distribution. The problem of irradiation with isotropic distribution has been resolved in work [1].

Calculations have been carried out by formula:

$$A = \int_v \sigma \Phi e^{-\alpha d} dv , \qquad (1)$$

where Φ - flux density of initial radiation, σ-cross-section of gamma activation, d- distance from the center of converter to the elementary volume dv. In case of irradiation by the electron accelerator the part of anisotropic γ-rays distribution must be added in formula (1).

Analytic expression of angular distribution of bremstrahlung from thick targets is very unwieldy and we use the changed Shieff's formula listed in work [2]:

$$\frac{J(\theta)}{J(0)} = \frac{-E_i\left\{-(E_{\gamma m}\theta)^2 \dfrac{\ln(183Z^{-1/3})}{1580\cdot 8t_p}\right\} + E_i\left\{-\dfrac{(E_{\gamma m}\theta)^2}{1{,}78 m_0}\right\}}{\ln\left\{\dfrac{1580\cdot 8t_p}{m_0 \ln(183Z^{-1/3})}\right\} - 0{,}5772} \qquad (2)$$

where J(θ) and J(0) – radiation rate at the angle θ and 0, respectively, Ei –integral function $E_i(y) = -\int_{-y}^{\infty} \frac{e^{-x}}{x} dx$, $E_{\gamma m}$ –maximum energy of the bremsstrahlung spectra, Z – converter atomic number, t_p – thickness of converter (rad. length), m_0 – mass of electron. Satisfactory agreement with experiment if we use formula (2) has been provided. In the interval of angle of 0…40 discrepancy [illegible] with experiment is less then 12%. We have two variants of a relative position of the converter and the target: A – when the target axis coincides with the γ-beam axis, B – when the target axis is perpendicular to the γ-beam axis shown in fig.1.

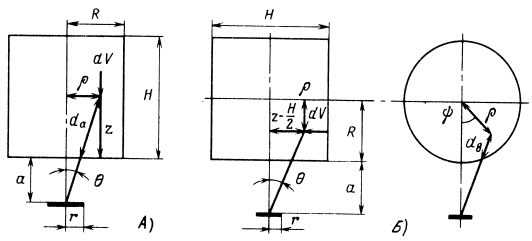

Fig.1. Chart variants of relative position of converter and target. A – target axis coincides with γ-beam axis; B – target axis is perpendicular to the γ-beam axis

The target was irradiated from the converter having a radius r and positioned at a distance a from the target, target has a radius R and a height H. Calculations of values of Φ, d and □ in formulas (1), (2) respectively has been performed in work [3]. In the below-given formulas the indices A and B relate to variant A and B in fig.1 respectively.

$$A_A = \int_0^{2\pi} d\varphi \int_0^{H} dz \int_0^{R} \Phi_A \exp(-\mu d_A) \frac{J_A(\theta)}{J_A(0)} \rho\, d\rho \;; \qquad (3)$$

$$A_Б = \int_0^{H} dz \int_0^{R} \rho\, d\rho \int_0^{2\pi} \Phi_Б \exp(-\mu d_Б) \frac{J_Б(\theta)}{J_Б(0)} d\varphi \,. \qquad (4)$$

The similar calculations for variant A have been performed in work [4].

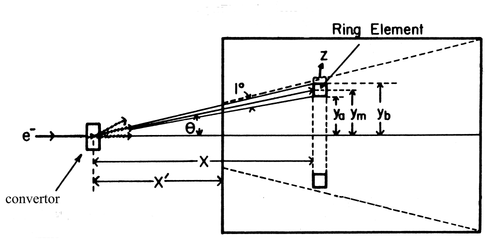

Fig. 2. Model of irradiation for determination of the optimal target geometry

As shown in fig.2, the calculation of full target activity is performed by integration over the volume of elementary ring activity. Activity of the elementary ring volume is defined by the formula:

$$A_r = A(E,\theta)C_p\left(\frac{(285)^2}{x^2 + y_m^2}\right)\cdot \exp\{-0.1\mu\,[\sqrt{x^2 + y^2} -$$

$$- \sqrt{x'^2 + (x' y_m / x^2}\,]\}\cdot[\pi \cdot z(y_b^2 - y_a^2)] \qquad (5)$$

where A_r – total activity in the given ring element; A – activity produced per 1g of target nuclide located at an angle □ from the electron beam; C_p – density of target nuclide of target material; E –energy of electron beam; □ – linear attenuation coefficient for a given target material; the rest marking is clearly shown in fig.2.

RESULTS AND DISCUSSION

Estimation of the total activity yield of target using formulas (2), (5) for ^{11}C, ^{15}O, ^{13}N nuclides with different distances from the bremsstrahlung converter has been done. The values of the total activity ^{15}O for different geometries of irradiation calculated by this method are shown in fig.3. The irradiation conditions are the following: electron energy – 25 MeV, time of irradiation – 10 min, mean electron current – 100 μA.

The obtained calculated data allow selecting of the target position geometry for various purposes of irradiation. Maximum specific activity takes place in the case of using small diameter targets, but the total activity in this case is not high. This geometry may be recommended when use targets without prolonged radiochemical treatment.

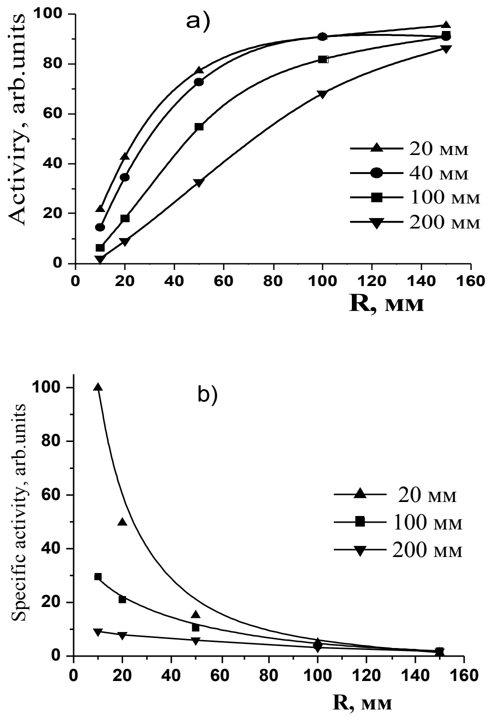

Fig.3. Total activity (a) and specific activity (b) versus of target radius at the distance between target and converter 20; 40; 100; 200 mm

The programs for optimization of bremsstrahlung converter with the use of the library GEANT4 were written. These programs allow one to simulate the processes particle passage through matter by the Monte-Carlo method. Initial parameters of the converter being varying in the optimization process have been selected as follows: thickness of tantalum foils 1.5…2.5 mm, cross dimensions 50×40 mm. Calculated optimal thickness is in the good agreement with works by other authors [4,5]. The calculation of experimental specific activity any isotopes with the use of tables of photonuclear cross-sections [6] and the optimal geometry of target position have been done. The specific activity of several isotopes is shown in table, time of irradiation is 1 hour.

Measured activity of several isotopes

Energy, MeV	Specific activity, Bq/g × μA			
	^{11}C	^{18}F	^{13}N	^{15}O
25	$3\cdot10^7$	$5\cdot10^7$	$4\cdot10^6$	$2{,}8\cdot10^6$

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ОПТИМИЗАЦИЯ УСЛОВИЙ ОБЛУЧЕНИЯ МИШЕНЕЙ ДЛЯ ПРОИЗВОДСТВА РАДИОНУКЛИДОВ

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Рассмотрены различные варианты расположения мишеней по отношению к пучку тормозных фотонов. Проведен анализ спектральных и угловых распределений тормозных фотонов от различных тормозных мишеней и при различной энергии падающих электронов. Исследована зависимость величины нарабатываемой активности от параметров радионуклидной мишени и тормозного конвертора. В результате исследований даны рекомендации по выбору оптимального тормозного конвертора и оптимальной геометрии расположения мишеней в зависимости от цели облучения и выбранного коэффициента использования пучка.

ОПТИМІЗАЦІЯ УМОВ ОПРОМІНЕННЯ МІШЕНЕЙ ДЛЯ ВИРОБНИЦТВА РАДІОНУКЛІДІВ

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Розглянуті різні варіанти розташування мішеней стосовно пучка гальмових фотонів. Проведено аналіз спектральних і кутових розподілів гальмових фотонів від різних гальмових мішеней і при різній енергії падаючих електронів. Досліджено залежність величини активності, що напрацьовується від параметрів радіонуклідної мішені і гальмового конвертора. У результаті досліджень дані рекомендації з вибору оптимального гальмового конвертора й оптимальної геометрії розташування мішеней у залежності від мети опромінення й обраного коефіцієнта використання пучка.