CONVERTING HIGH-CURRENT PULSED ELECTRON BEAMS OF SMALL TRANSVERSE DIMENSIONS

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1 INTRODUCTION

A wide application of radionuclides in medicine has required developing commercial methods of their production in reactors and on accelerators [1-3]. A preferable way to increase the radionuclide production on accelerators is increasing a mean accelerator current because the increase of the electron energy up to a value higher than the threshold of two-particle reactions results in production of undesirable impurities. Besides, the accelerator energy increase leads to the sharp increase in the radiation shield thickness and, consequently, the cost of the accelerator itself and its production raises. Therefore, for each particular radionuclide one should select its optimum energy of accelerated particles as only a high specific activity and productivity of radiochemical processes can ensure the competitive ability of isotope production at accelerators. To increase the maximum rate of producing radionuclide and its specific activity it is necessary to reach a maximum density of the photon beam on the target where radionuclides are produced. For this purpose the target should be approached to the converter. However, there are complicated problems on this way.

The most perfect calculations and description of experimental modelling of commercial ^{99}Mo production for small transverse dimensions of the nuclide-producing target are given in [3]. The calculations of ^{99}Mo production for the 350 μA mean current of accelerated electrons and its density more than 2700 μA/cm^2 at the energy of accelerated electrons E_o=40 MeV were performed without taking into account the heat loads. The experimental modelling of this process was conducted for the mean current of 15 μA. In [3] one does not explain how to cope with problems of heating in a case of the real experiment.

2 THE DENSITY OF PHOTONS AND ELECTRONS ON THE TARGET

To choose a real scheme of radionuclide production we have calculated the density of photons and electrons on the target for E_o=25 MeV and 40 MeV by the program "GEANT" for different thickness of tantalum converters. Distribution of the electron beam density on the converter was taken as Gaussian with σ=3 mm. The 29 MeV photons and electrons with an energy from 0 to E_o emerging from the target are grouped by angular intervals 5±5, 15±5, 25±5, and so on, degrees. The angular distribution of photons with energies higher than 9 MeV (threshold of the reaction ^{100}Mo(γ, n)^{99}Mo) at E_o=25 MeV and a converter thickness of 7 mm is represented in Fig. 1. The radionuclide production can be considered as proportional to the density of photons with the energy higher than the reaction threshold. The results are normalized to experimental data at E_o=22 MeV for the angle 0^o [4]. It is seen, that the angular distribution of photons with energies higher than 9 MeV is in accordance with experimental data for the angular distribution of ^{99}Mo production. For angles larger than 10^o the significant contribution of low-energy photons creating an additional target heating takes place.

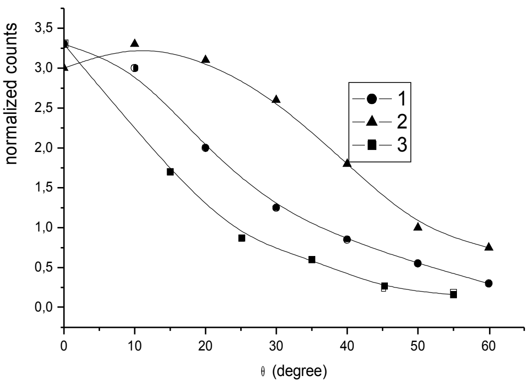

Fig. 1. Angular photon distribution: 1 - Experimental distribution of production of ^{99}Mo [4]; 2 – Calculated photon distribution with energy from 0 to 25 MeV [4]; 3 - Calculated photon distribution with energy from 9 to 25 MeV, thickness Ta 7 mm.

The angular distribution of the relative density of photons with energies more than 9 MeV for energies of accelerated electrons E_o and different thicknesses of tantalum converters is given in Table 1. It is seen that the density of the flow of photons emerging from all the converters is maximum for angles less than 10^o and raises sharply with the increasing energy of accelerated electrons.

Table 1

θ(degree)/$Å_0$	5	15	25	35	45	55
25 MeV, 7mm Ta	3.30	1.70	0.87	0.60	0.24	0.16
25 MeV, 3mm Ta	3.58	2.02	1.30	0.80		
40 MeV, 1mm Ta	14.57	4.22	0.71	0.105	0.021	0.0063

Fig. 2a and 2b represents the spectra of photons emerging from the tantalum converter 3 and 7 mm thick, respectively, at an angle 0^o-10^o and the energy of incident electrons E_o=25 MeV. The calculations show that the increase of the converter thickness from 3 to 7 mm decreases the photon yield approximately by 20%, but the photon beam contains considerably less number of electrons.

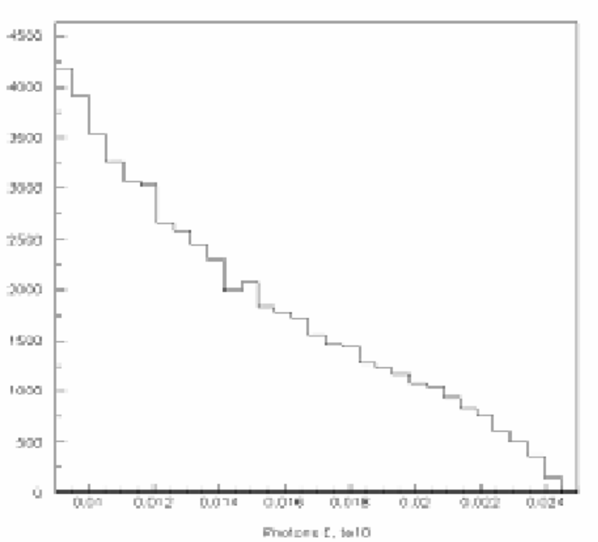

Fig. 2a.

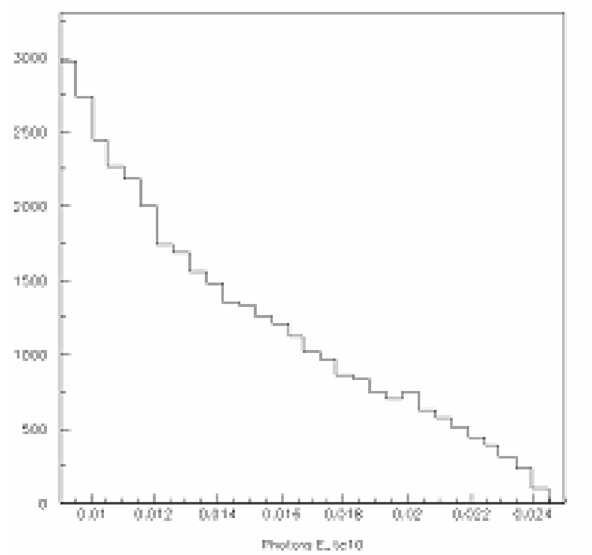

Fig. 2b.

Fig. 3a represents the spectrum of electrons emerging from the tantalum converter 1mm thick at an angle 0^o-10^o for E_o=40 MeV. The calculation shows that the photon beam on the target contains 30% of electrons of the number of electrons bombarding the converter. For electrons with the energy of 25 and 40 MeV the range of path in tantalum is 7 and 8 mm. It should be noted that it is difficult to eject through the output foil even such an electron beam, and it can melt the converter and the target. Therefore, we believe that the scheme of ^{99}Mo production on the accelerator according to the calculation of [3] will be hard-to realize in practice. Fig. 3b shows the spectrum of electrons emerging from the tantalum converter 7 mm thick at an angle of 0^o-10^o for E_o=25 MeV. In this case the number of electrons does not exceed 0.2% of the initial electron beams. In the target itself a small amount of heat will be released that can be removed by air-flow blowing.

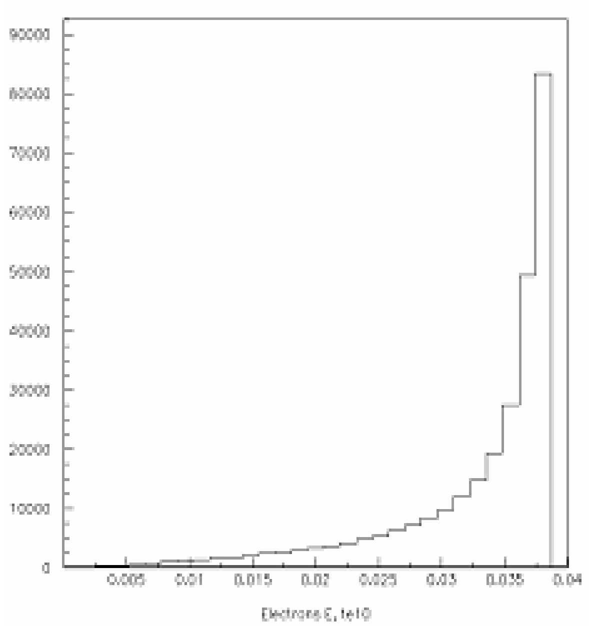

Fig. 3a.

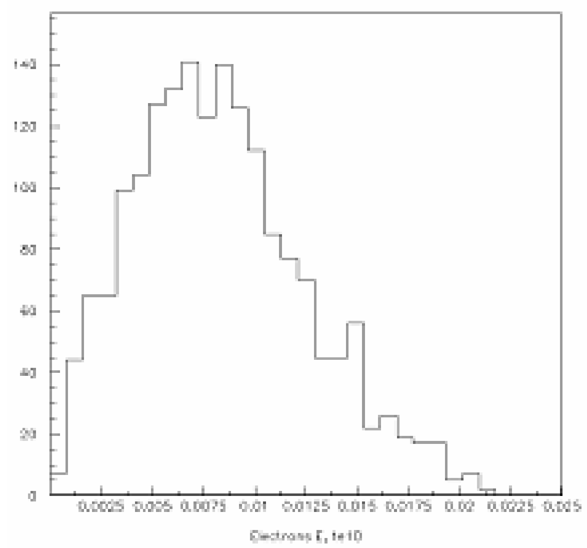

Fig. 3b.

However, at mean currents of 400 μA and σ=3 mm in the point of beam impinging on the immobile converter, during some seconds the temperature will increase up to the melting point of metal. The water cooling with this density of a heat power on the thick converter is impossible. The use of thin disks and cooling them with running water [5] increases considerably the converter thickness and, consequently, decreases the density of photon flow on the target. Moreover, there takes place the electron energy release in the water due to ionization losses and, as is seen from the Table 1, the effective value of E_o decreases drastically.

The use of targets made from expensive isotopes intends increasing the photon beam density on this target. It can be reached by increasing the total converter thickness and maximally approaching the target to the converter. As is seen from Fig. 3b there are very few electrons at an angle less then 10° beyond the tantalum converter and the target can be approached to the converter as far as the output foils can admit. The photon beam obtained is easy to eject from vacuum through the titanium foil even if it is thick. The decrease of the distance between the converter and the target from 20 to 10 mm with the beam dimensions on the converter σ=3 mm allows one to increase the photon density in the target of 15 mm length by a factor of 2.8.

3 THE ROTATING CONVERTER

To increase the area where the beam heat power is absorbed one should create a rotating target in the vacuum chamber of the accelerator in front of the output foil, and the heat of the converter should be removed by radiation as in [6]. The converter is made in the form of a disk rotating in vacuum. On the rim of the disk the tantalum plates of 2 cm width are fixed. As the electron beam is a pulsed one and during the pulse the converter almost does not move, the frequency of disk rotation is 1-6 Hz depending on the frequency of accelerator operation. The frequency of disk rotation is chosen so that in a time of one turn of the disk the beam can get along all the rim length. At the accelerated electron energy of 25 MeV and mean current of 400 μA about 60% of the beam power will be released in the form of heat within the tantalum rim. The increase of the accelerated electron energy from 25 to 35 MeV with one and the same current results in increasing the photon beam by a factor of 3-4, while the heat loads increase by 15%. The heat quantity irradiated by the tantalum rim is

$$Q = 2\sigma S\varepsilon\left(T_1\right)\left(T_1 - T_2\right),$$

where σ – Stephan-Boltzmann constant, S – area of the tantalum rim, $\varepsilon\left(T_1\right)$ – radiative power of tantalum, T_1 - radiation temperature of the tantalum converter, (K), T_2 – temperature of the water-cooled converter, (K).

The calculations show that with the given beam parameters a part of the converter volume, through which the electron beam is passing, will heat in a steady state at a frequency of 300 Hz by 46° per pulse. After some tens of seconds a heat equilibrium will set in between the radiating tantalum rim of 35 cm radius and the water-cooled casing. The temperature radial stress in a steady state at a distance of 2 mm from the beam center will be 6.9 kG/mm^2. Before reaching the temperature T_1 the converter will operate at high temperature stresses as the specific heat of Ta at T_1 is 2 times higher than at room temperature. Heat loads can be decreased by a factor of 2 if the converter is installed at the angle 30° to the beam.

It should be noted that such a converter can be used as a neutron source with a density up to $1.8\cdot10^{11}$ and $5.7\cdot10^{11}$ n/(cm^2·s) at a distance 2 and 1 cm from the converter, respectively, at E_0 = 25 MeV.

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