ESTIMATION OF MEDICAL RADIONUCLIDE YIELDS IN PHOTONUCLEAR PRODUCTION

N.P. Dikiy, A.N. Dovbnya, V.I. Nikiforov, V.L. Uvarov
[1]NSC KIPT, Kharkov, Ukraine
E-mail:uvarov@kipt.kharkov.ua

The present paper reports the results from computer simulation of the processes of radionuclide production, namely, Sc-47, Co-57, Cu-67, Mo-99, Pd-103, In-111, W-181 and Ir-192. Consideration was given to a simplified 2D-geometry version of the target device that includes a 4 mm thick tungsten bremsstrahlung converter and a cylindrical target of natural isotopic composition that follows the converter. Radionuclide yields (gross and specific activities) were obtained as functions of electron energies (30 to 100 MeV) at an accelerator current of 200 μA.

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1.INTRODUCTION

The special features of photonuclear production of isotopes lie in relatively low reaction cross sections and a great transport length of bremsstrahlung photons in a substance [1]. These features restrict the radionuclide yields in both the gross and specific activity. At the same time, great ionization losses of heavy particles in the target quickly remove them from the resonance region. Therefore, in a number of cases the output of useful products in the photonuclear channel appears even higher than in the use of heavy particle beam [2]. The advantages of photonuclear production are also a relative ease of realization and a small quantity of accompanying radioactive wastes (the last ones being mainly short-lived [3]). Previously, the authors have developed the technology of photonuclear production of the basic diagnostic isotope Mo-99/Tc-99m, and also Co-57 used for gamma camera calibration [4].

The present paper is concerned with the effectiveness of photonuclear production of a variety of medical-purpose radionuclides. The studies were made by the computer simulation method with the use of the PENELOPE program system supplemented with the data on the excitation functions of the corresponding reactions.

2. BASIC REACTIONS

At the present time, the combined-purpose isotopes Sc-47, Cu-67, In-111, etc. are considered in nuclear medicine as holding much promise. In addition to γ-radiation, they also emit β-particles, i.e., the isotopes may be simultaneously used for both therapy and diagnostics. The radionuclides may be produced in the following photonuclear reactions:

$^{48}Ti(\gamma,p)^{47}Sc$, $^{68}Zn(\gamma,p)^{67}Cu$, $^{112}Sn(\gamma,p)^{111}In$.

The isotopes Pd-103 and Ir-192, widely used in brachytherapy, may be produced by the reactions

$^{104}Pd(\gamma,n)^{103}Pd$, $^{193}Ir(\gamma,n)^{192}Ir$.

The isotopes Tc-99m and Co-57, which can be also produced by the photonuclear method ($^{100}Mo(\gamma,n)^{99}Mo \rightarrow {}^{99m}Tc$ and $^{58}Ni(\gamma,p)^{57}Co$) find their application in gamma-scintigraphy.

3. SIMULATION CONDITIONS AND RESULTS

3.1. For preliminary estimation of isotope production, we have considered a simplified geometry of the output device of the electron linac (Fig.1). It includes an electron source **1**, an exit foil **2** (0.05 mm thick **Ti**), a converter **3** (tungsten plate) and a target **4** itself.

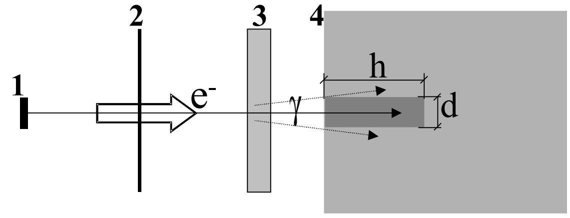

Fig. 1. Geometry of the output device

3.2. At the initial stage, we have investigated the relative yield of high-energy photons (E_γ>7.2 MeV being the lowest threshold value of the above-mentioned photonuclear reactions) as a function of the converter thickness in the electron energy range of practical interest E_0=30…100 MeV (Fig.2). It can be seen that in this range a converter thickness of 4 mm appears close to the optimum. Therefore, the further calculations of isotope production were performed for this thickness.

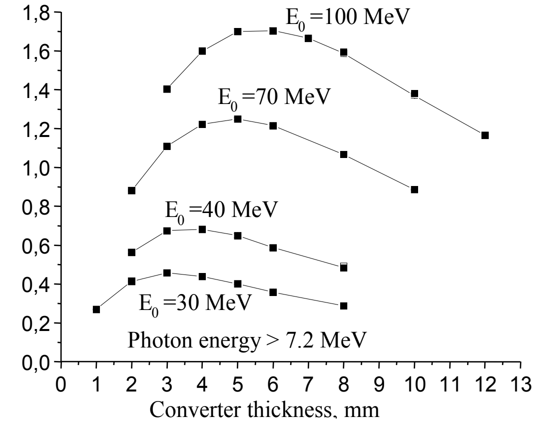

Fig. 2. Relative yield of high-energy photons (the vertical axis shows the number of high-energy photons per accelerated electron)

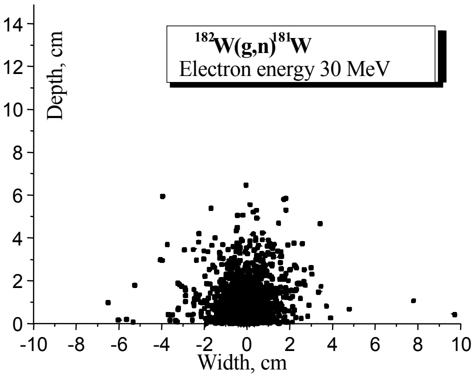

Fig. 3. Distribution of W-181 nuclei in the target

Materials of natural isotopic composition were used as a target. To analyze the effectiveness of photonuclear production, the simulation results were reduced to the activity produced for a day of accelerator operation at an average beam current of 200 μA, the beam diameter being 0.5 cm. To exemplify, Fig.3 shows the spatial density distribution of W-181 nuclei produced in the natural tungsten target as a result of the reaction $^{182}W(\gamma,n)^{181}W$. It is obvious that this density is substantially nonuniform. Therefore, to optimize the target dimensions inside the initial target (half-space geometry), a number of cylinders of increasing size and axially symmetrical to the beam were brought into consideration. For each cylinder, the activity of the radionuclide product comprised in it was determined. The data for different isotopes are presented in Fig.4.

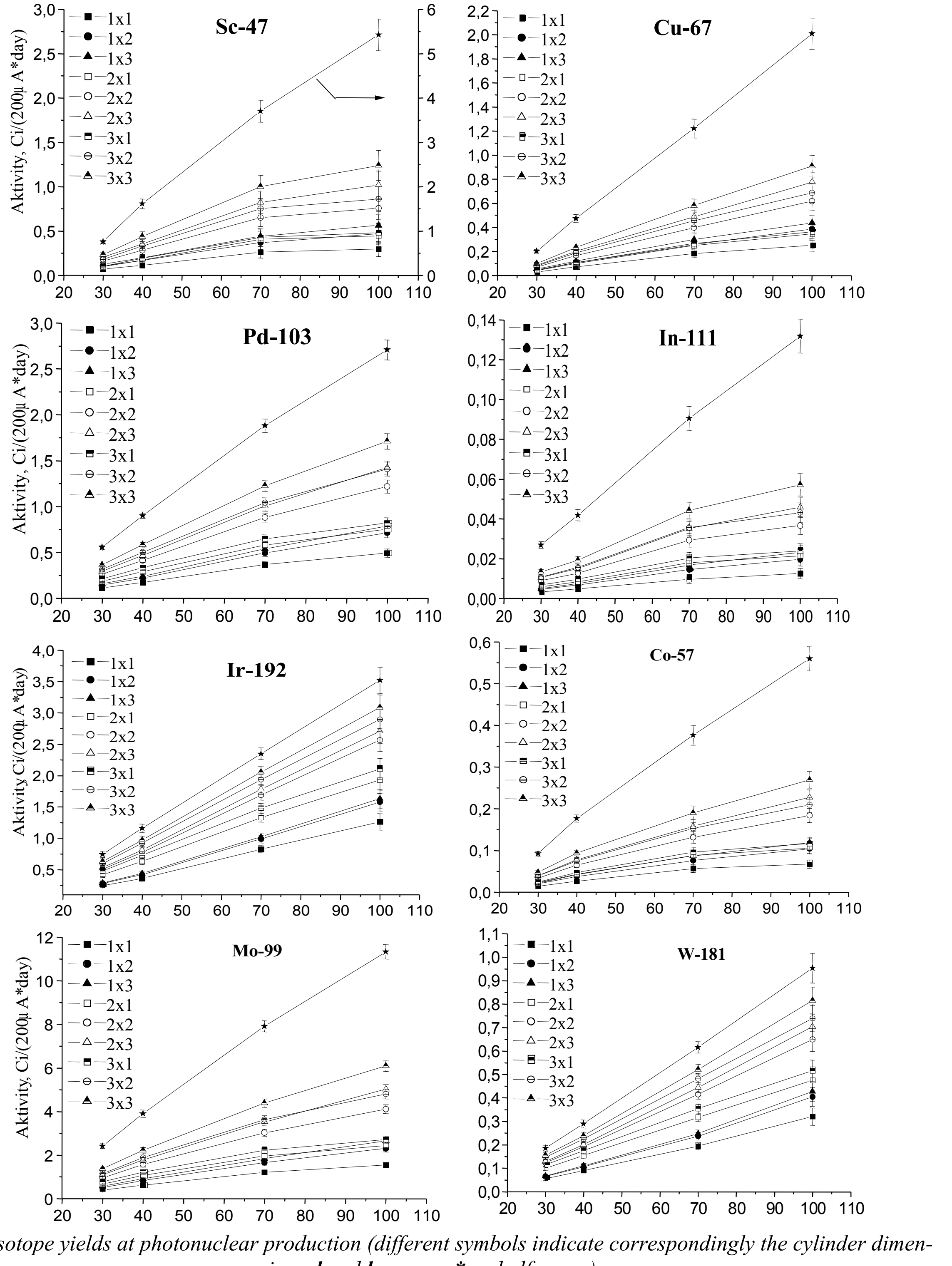

*Fig. 4. Isotope yields at photonuclear production (different symbols indicate correspondingly the cylinder dimensions **d** and **h**, cm; - - * - - half-space)*

4. CONCLUSION

4.1. The analysis of the present results has shown that practically for all the reactions considered the yield of isotope products (gross and specific activities) increases with electron energy by the law close to the linear law. In this case, the produced activity values lie within the limits from ~10^{-2} Ci/day (In-111) to ~1 Ci/day (Ir-192, Mo-99), depending on the isotope-target abundance and the reaction cross section. The specific activity value is also determined by the coefficient value of photon attenuation in the target. This accounts for the reduction in the specific activity with advance to the region of light nuclei.

4.2. The maximum values of activities of the targets may be provided by the following methods:

- increase in the time of target irradiation up to ~ $2T_{1/2}$ (half-life);
- rise in the average current of the accelerator up to the values limited by the heat resistance of the output devices;
- change-over to isotopically enriched targets (generally, in this case, it is necessary to solve the problem of target material regeneration in view of costliness of the material);
- increase in electron energy (this variant entails the appearance of additional channels, i.e., increase in the production of radionuclide impurities).

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REFERENCES

1. N.P. Dikiy, A.N. Dovbnya, Yu.N. Lyashko at al. Production of Medical Isotopes at Electron Accelerators // *Problems of Atomic Science and Technology. Series: Nuclear Physics Investigations.* 2000, №2(36), p.58-61.
2. R.G. Bennet et al. A System of ^{99m}Tc Production Based on Distributed Electron Accelerators and Thermal Separation // *Nuclear Technology*. 1999, p.102-121.
3. N.P. Dikiy, Yu.V. Lyashko, V.L. Uvarov et al. Ecological Aspects of ^{99}Mo/^{99m}Tc Production at an Electron Accelerator // *Problems of Atomic Science and Technology. Series: Nuclear Physics Investigations.* 2004, №1(42), p.191-193.
4. N.P. Dikiy, A.N. Dovbnya, V.L. Uvarov. *Electron Accelerator Based Soft Technology for Medical Imaging Isotopes Production*. Proc. of EPAC'02. Paris. 2002, p.2760-2762.

ОЦЕНКА ВЫХОДА МЕДИЦИНСКИХ РАДИОНУКЛИДОВ ПРИ ФОТОЯДЕРНОМ ПРОИЗВОДСТВЕ

Н.П. Дикий, А.Н. Довбня, В.И. Никифоров, В.Л. Уваров

В сообщении приведены результаты компьютерного моделирования процессов фотоядерной наработки радионуклидов Sc-47, Co-57, Cu-67, Mo-99, Pd-103, In-111, W-181 и Ir-192. Рассмотрен упрощенный вариант 2D-геометрии мишенного устройства, включающий конвертер тормозного излучения из вольфрама толщиной 4 мм и размещенную за ним цилиндрическую мишень природного изотопного состава. Получены зависимости выхода радионуклидов от энергии электронов (30…100 МэВ) при величине тока ускорителя 200 мкА.

ОЦІНКА ВИХОДУ МЕДИЧНИХ РАДІОНУКЛІДІВ ПРИ ФОТОЯДЕРНОМУ ВИРОБНИЦТВІ

М.П. Дикий, А.М. Довбня, В.І. Нікіфоров, В.Л. Уваров

У повідомленні приведені результати комп'ютерного моделювання процесів фотоядерного напрацювання радіонуклідів Sc-47, Co-57, Cu-67, Mo-99, Pd-103, In-111, W-181 і Ir-192. Розглянуто спрощений варіант 2D-геометрії мішеного пристрою, що включає конвертер гальмівного випромінювання з вольфраму товщиною 4 мм і розміщену за ним циліндричну мішень природного ізотопного складу. Отримано залежності виходу радіонуклідів (загальна і питома активність) від енергії електронів (30…100 МеВ) при величині струму прискорювача 200 мкА.