CONCEPTION OF MEDICAL ISOTOPE PRODUCTION AT ELECTRON ACCELERATOR[*]

A.N. Dovbnya, N.P. Dikiy, V.I. Nikiforov, V.L. Uvarov[#], NSC "KIPT", Kharkov, 61108, Ukraine

Abstract

A photonuclear method with the use of high-energy bremsstrahlung ($E_\gamma > 8$ MeV) of high intensity ($>10^3$ W/cm^2) provides a possibility of the ecologically safe production of a number of isotopes for nuclear medicine. The conditions of generation of the radiation field having such characteristics as well as the features of photonuclear production of Pd-103, Cu-67, In-111 and other radionuclides are considered in the report. At the initial stage the study of the isotope production is performed by means of the computer simulation in a simplified 2D geometry of the Linac output devices. The code on the base of the PENELOPE/2001 program system supplemented with the data on the excitation functions of the corresponding reactions was developed. The dependences of the isotope yield (gross and specific activity) on the electron energy (30…45,MeV), as well as, the data on absorbed energy of radiation in the targets of natural composition are represented. The experimental results confirm the data of modelling. Main trends of realization of the photonuclear method for isotope production and the necessary conditions of the increase of its yield are analysed.

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. These features restrict the radionuclide yields in both the gross and specific activity [1]. 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].

In nuclear production of radionuclides for medicine with the use of heavy particles (n, p, ions) the region of nuclear reaction occurrence is limited mainly by the region of interaction between the primary particles and the target. The feature of photonuclear production lies also in the delocalization of this region due to the incorporation of an additional target, i.e., bremsstrahlung

converter, into the nuclear process. The converter also serves as a quasi-isotropic photoneutron source. The photoneutron flux may attain 10^{13} n/s and more for the accelerator with the parameters typical of photonuclear production (> 20 MeV, ≥ 10 kW). Photoneutrons may exert a substantial effect on the composition of the isotope product produced. Besides, the predominant yield of (γ,n) reactions limits the possibilities of obtaining a carrier-free isotope product.

A separate problem in the process is the removal of heat from the converter and the target during their interaction with a concentrated high-power electron flux.

In view of the aforesaid it follows that for organization of isotope production at the electron accelerator it is necessary at the initial stage to optimize the production technology with due regard for all its peculiarities.

THE RADIATION FIELD STRUCTURE

The space distribution of activity and isotopic composition of radionuclides produced with the use of the electron accelerator is determined by the target geometry, composition, and also by the radiation field characteristics (see Fig.1).
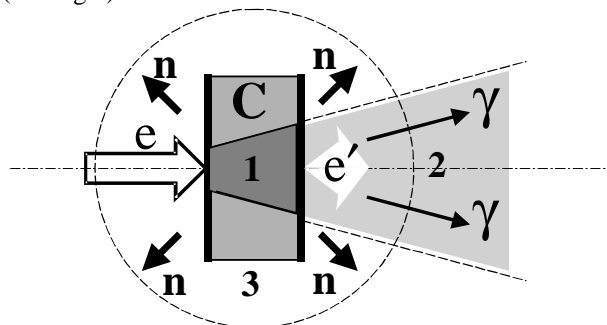

Figure 1: Radiation field configuration at photonuclear production of isotopes

As it is obvious from the figure, three main zones can be distinguished in the radiation field resulting from the interaction of the accelerated electron beam with the converter **C**. The composition of radiation and the main types of reactions occurring in each zone are presented in Table 1.

Table 1: Main Types of Radiation and Reactions at Electron Accelerator

Zone No	Characteristics of zone	Radiation types	Main types of reactions
1	Electron beam-converter interaction region	*e, e′, γ, n*	*(ee′,n)* *(γ,n), (n,γ)*
2	Truncated cone axially symmetric to the electron beam	*e′, γ, n*	*(γ,n), (γ,p), (γ,α), (n,γ)*
3	Quasi-isotropic flux from zone 1	*n*	*(n,γ)*

SIMULATION CONDITIONS

General arrangement

To optimize the isotope generation conditions, and also, to investigate the radiation heating of output device components, computer simulation with the use of the PENELOPE/2001 code was performed [3]. The realistic structure consisting of a water-cooled exit window of the accelerator, converter and the target station was taken as the basis. The arrangement of the output devices is schematically shown in Fig.2.
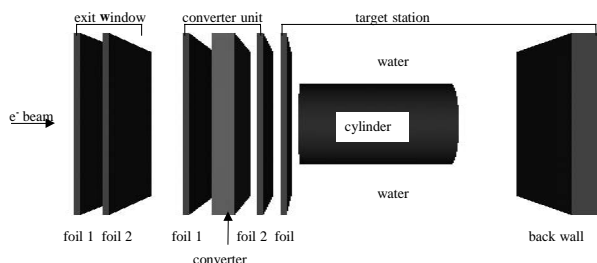

Figure 2: Arrangement of output devices.

The electron source

The electron source is circular, 0.5 cm in diameter and provides homogeneous and monoenergetic electron flux. The electrons are emitted parallel to the Z axis. The computations were made for electron energies $E_0 = 30, 35, 40, 45$ MeV.

The exit window unit

The 0.05 mm thick foils 1 and 2 are made from titanium. The spacing between the foils of the exit window is filled with water. The foils separation is 0.3 mm.

The converter unit

Foils 1 and 2, 0.05 mm in thickness, are made from titanium. The 0.4 cm thick tantalum converter is placed between the foils. The interfoil separation is 1 cm. The spacing between the foils and the converter is filled with water.

The spacing between the converter unit and the exit window unit makes 2 cm.

The target station

The titanium foil is 0.05 mm in thickness. The back wall of the unit is made from 0.5 cm thick titanium. The distance between the foil and the back wall is 5 cm. The target is cylindrical. The axis of the cylinder is coincident with the Z axis of the electron source. The separation of the cylinder from the foil is 0.2 cm. The spacing between the foil, the back wall and the cylindrical target is filled with water. The distance of the target unit from the converter unit is 0.3 cm.

RADIATION HEATING

The generalized data on the absorbed radiation power in different units of output devices are presented in Fig.3.
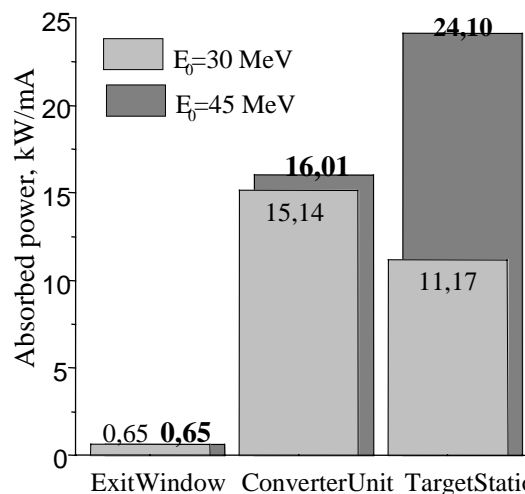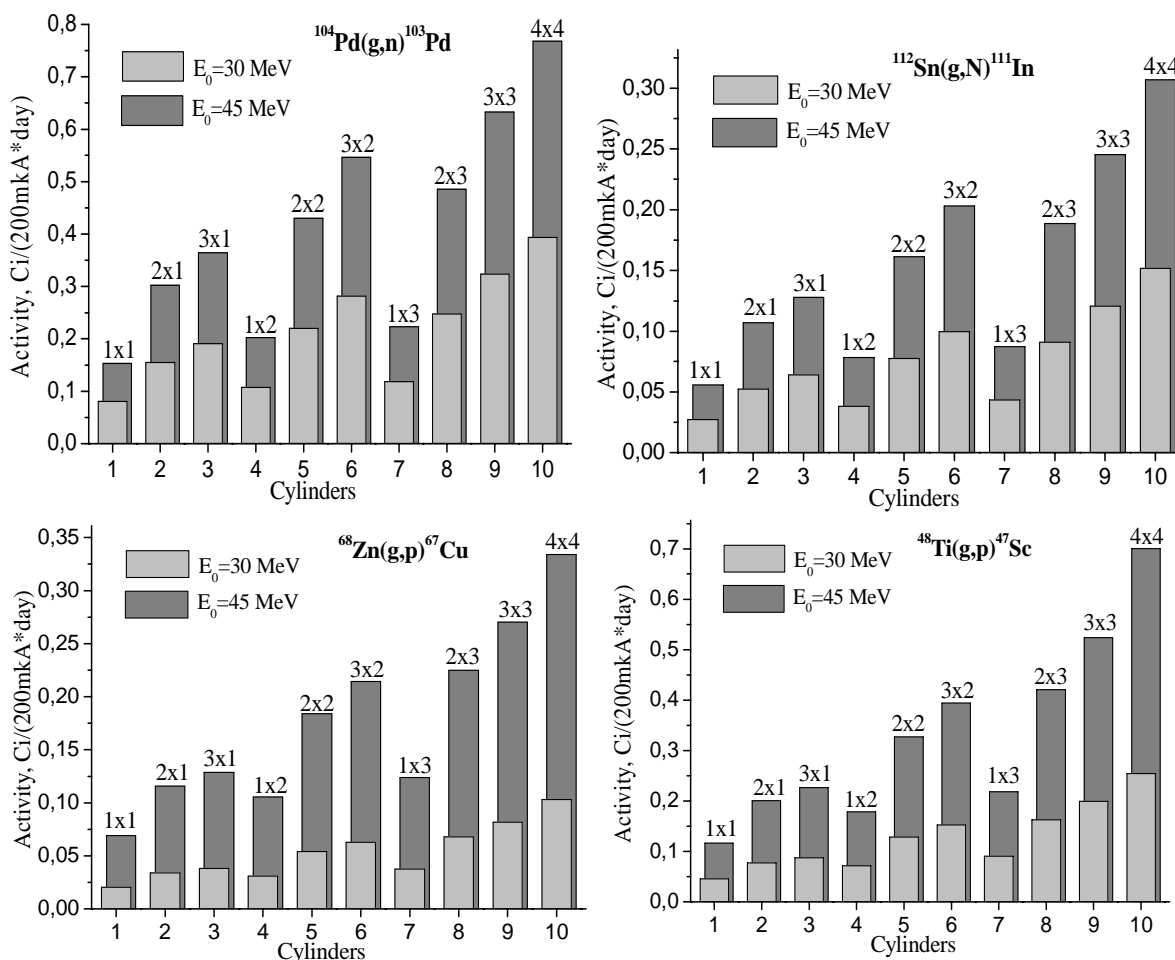

Figure 3: Comparative data on power absorption in output device units (beam current of 1 mA)

YIELD OF ISOTOPES

The experimental results on specific activity of the isotopes in the irradiated targets (E_0=30MeV) are listed in the Table 2. The results obtained by simulation for a number of isotopes and targets of natural composition are given in Fig.4.

Table 2: Yield of Isotope Products and Admixtures

Target (nature)	Final radionuclide, ($T_{1/2}$)	Principal reaction	Yield, mCi/g* 200µA*h	Principal admixture ($T_{1/2}$)	Relat. yield of admixture, %
Ti	^{47}Sc (3.35d)	^{48}Ti(γ,p) ^{47}Sc	0.214	^{48}Sc (43.7 h) ^{46}Sc (83.8 d)	7.2 0.7
Zn	^{67}Cu (61.8 h)	^{68}Zn(γ,p) ^{67}Cu	0.029	^{69m}Zn (13.8 h) ^{65}Zn (243.2 d)	79 34.3
Ni	^{57}Co(270 d)	^{58}Ni(γ,n)^{57}Ni, ^{58}Ni(γ,p) ^{57}Co	0.0127	^{56}Ni (6.10 d) ^{58}Co (70.8 d)	1.18 3.21
Sn	^{111}In (2.83 d)	^{112}Sn(γ,p)^{111}Sn$\rightarrow^{111}$In	0.027	^{117m}Sn (13.6 d) ^{115m}In (4.49 h)	44.5 48

08 Applications of Accelerators, Technology Transfer and Industrial Relations
U01 Medical Applications

Figure 4: Comparative data on isotope yield in the cylindrical targets **dxh** (**d** – diameter, **h** – height)

CONCLUSION

- The special feature of photonuclear production lies in the presence of three zones of particles of different types in the radiation field generated by the electron accelerator. This fact must be taken into account when choosing the materials to be placed in each zone.

- The results of computer simulation suggest that the yield of isotope products in the photonuclear channel (gross and specific activities) should increase with the electron energy by the law close to the linear one. In this case, the activities produced for the targets of natural composition at an electron beam current of 200 μA range between ~ 10^{-2} Ci/day (In-111) and ~ 1Ci/day (Ir-192), depending on the target isotope abundance and the reaction cross section. The specific activity value is also determined by the coefficient of photon attenuation in the target; the latter causes its decrease in the light-nuclei region.

- The maximum gross/specific activity values of targets may be provided by the following methods:
  - increase in the target exposure time up to ~ $2T_{1/2}$ ($T_{1/2}$ - half-life);
  - increase in the average current of the accelerator up to the values limited by the heat resistance of the output setups;
  - transition to isotopically enriched targets (in this case, the problem of the most admixtures can be solved also but it is usually necessary to solve the problem of target material regeneration due to its high price);
  - increase in the electron energy (this variant is connected with the appearance of additional channels, i.e., with an increased production of radionuclide impurities).

- The advantages of photonuclear production are a relative ease of realization and a small quantity of accompanying radioactive wastes (the last ones being mainly short-lived [4]).

REFERENCES

[1] N.P. Dikiy, A.N. Dovbnya, S.V. Maryokhin and V.L. Uvarov, Problems of Atomic Science and Technology. Series: "Nuclear Physics Investigations" 34 (1999) 91

[2] R.G. Bennet et al., Nuclear Technology 126 (1999) 102

[3] J. Sepman et al., Nuclear Instrum. & Meth. B207 (2003) 107

[4] N.P. Dikiy, Yu.V.Lyashko, V.L. Uvarov et al., Problems of Atomic Science and Technology. Series: "Nuclear Physics Investigations" 42 (2004) 191