A POSSIBILITY OF HIGH-ENERGY BREMSSTRAHLUNG DOSIMETRY BY INDIUM ACTIVATION

A.N. Dovbnya, V.V. Mytrochenko, V.I. Nikiforov, S.A. Perezhogin, Yu.V. Rogov, V.A. Shevchenko, I.N. Shlyakhov, B.I. Shramenko, A.Eh. Tenishev, V.L. Uvarov#, NSC KIPT, Kharkov, 61108, Ukraine

Abstract

Development of a number of promising photonuclear technologies is connected with the use bremsstrahlung (X-ray) sources having end-point energy up to 100 MeV and average power of tens kW. Commonly, such radiation sources are created on the basis of electron linacs. A possibility of dosimetry of high-energy bremsstrahlung by means of activation of a target from indium of natural composition and establishment of absorbed dose on the specific activity of the ^{115m}In isomer is reported. Preliminary study of isomer activation as well as yield of reference reactions from natural molybdenum in the energy range 8…70 MeV was conducted by simulation technique. Joint measurement of ^{115m}In, ^{90}Mo, ^{99m}Mo activity as well as absorbed dose in the PMMA standard dosimeters were carried out at LU-10 and LU-40 electron linacs of NSC KIPT.

INTRODUCTION

It is known that photoactivation of isomeric states in some nuclei is characterized by low energy threshold values. For example, the threshold of the ^{115}In(γ,γ′)^{115m}In reaction equals 1078 keV [1]. The ^{115m}In isomer goes into the ground state with the half-life $T_{1/2}$=4.48 h, emitting in the process the gamma-quantum of energy 336.2 keV, which is convenient for detection. Owing to a low reaction threshold, the natural indium (the ^{115}In abundance makes 95.8%) can be activated by practically all photons of the bremsstrahlung spectrum. This circumstance allows suggest the presence of a relationship between the specific activity of ^{115m}In and the bremsstrahlung absorbed dose.

In a number of studies, the ^{115}In(γ,γ′)^{115m}In reaction has been used for dosimetry in γ-facilities having ^{60}Co sources [2, 3]. In that case the activation of indium was realized with the photons of energy near the reaction threshold. The present communication deals with the conditions of the method applicability for high-energy bremsstrahlung.

MATERIALS AND TECHNIQUES

Experimental studies on indium activation processes were performed at NSC KIPT linear accelerators LU-10 (electron energy E_0=8…12 MeV) and LU-40 (E_0=35…95 MeV). For absorbed dose measurements, Harwell Red 4034 (HR) detectors were used. They represent 30x11x3 mm plates made from dyed PMMA, commonly used as a standard dosimetry material [4].

To investigate the relationship between the specific activity of ^{115m}In and the dose absorbed in the PMMA, it was suggested that the natural indium detectors together with the HRs should be exposed to X-ray under conditions of electron equilibrium. Besides, each target incorporates a natural molybdenum foil to check the activation conditions against the yields of the reference reactions ^{92}Mo(14.84%)(γ,2n)^{90}Mo and ^{100}Mo(9.63%)(γ,n)^{99}Mo.

The bremsstrahlung-induced γ-spectra of indium and molybdenum were measured with the HPGe detector, which provided FWHM of 1.3 keV at 1332 keV.

For independent analysis of the photoactivation processes and absorption of radiation energy in the detectors, we have used the simulation method based on a modified transport code PENELOPE-2008 [5]. The cross sections for the reference reactions on the ^{92}Mo and ^{100}Mo isotopes (see Figs. 1 and 2) were taken from the database [6]. In the case of the ^{115}In(γ,γ′)^{115m}In reaction the situation has turned out to be more complicated. Namely, the data on its cross section, reported in different works, have shown considerable variations (see Fig. 3).

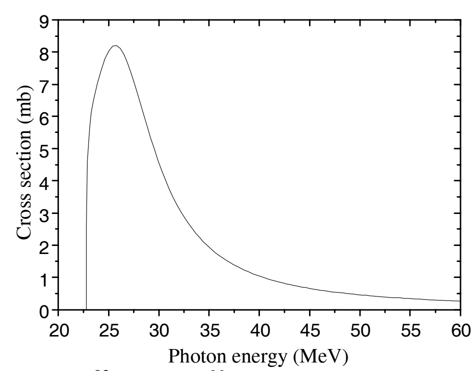

Figure 1: ^{92}Mo(γ,2n)^{90}Mo reaction cross section.

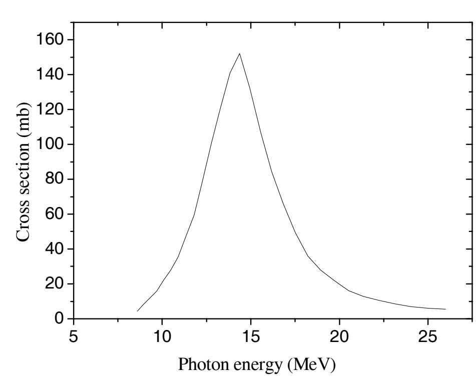

Figure 2: ^{100}Mo(γ,n)^{99}Mo reaction cross section.

uvarov@kipt.kharkov.ua

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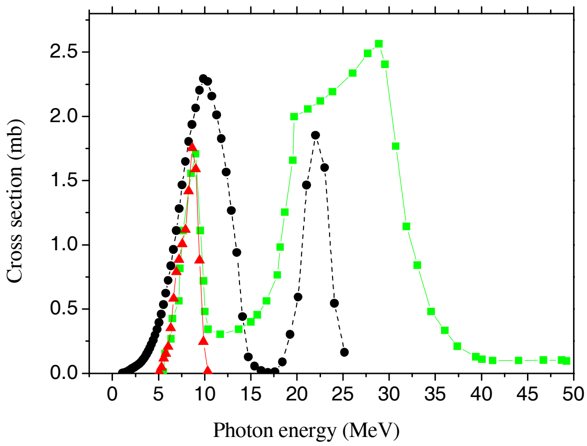

Figure 3: [115]In(γ,γ') [115m]In reaction cross section: ● - [7]; ▲- [8]; ■ - [9].

Therefore, we calculated the ^{115m}In yield for different variants of cross section description. Then, the data obtained were compared with the experimental results.

EXPERIMENTAL CONDITIONS

For experimental studies, we have used the output device, which schematic is shown in Fig. 4.

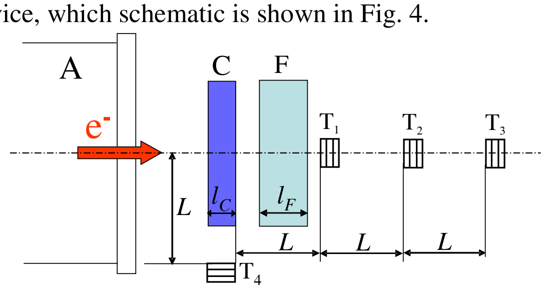

Figure 4: Schematic of the output device.

Behind the exit window of the accelerator A, downstream of the electron beam there follow in succession the converter C as a set of tantalum plates of total thickness l_C, the aluminum electron filter of thickness l_F, and the set of three targets $T_1 \ldots T_3$. The targets were placed at regular intervals L=10 cm one after another. The target T_4 was arranged at the same distance normally to the beam axis in the converter plane. Each target was composed of an indium plate, 2x1x0.1 cm in size, contacting with the HR detector and the molybdenum foil measuring 2x1x0.01cm. The given geometry of the output device permitted the radiation field of various intensity and composition to act upon the targets in one run. In this case, the targets T_1 and T_4 were used for evaluating the contribution of photoneutrons via the (n,n') channel to the ^{115m}In yield. Table 1 lists the parameters of the radiation formation path and target exposure.

Table 1: Characteristics of target irradiation conditions

Accel.	E_0,MeV	l_C,cm	l_F,cm	I_e,μA	Exp.,h
LU-10	9	0.24	1.4	20.0	0.2
	35	0.4	5	3.7	1.0
LU-40	52.5	0.4	7	4.9	0.2
	71	0.4	9	4.0	0.5

RESULTS AND DISCUSSION

Experimental and simulation methods were used to determine the ratio S of the specific activity of the ^{115m}In isomer in indium plates to the absorbed dose in the HR detectors being in contact with the plates. Figure 5 shows the function S(E_0) in the low-energy part of the electron energy range studied. In simulation, the data on the ^{115m}In photoactivation cross section, taken from ref. [8], were used. It can be seen that the calculated results are in good agreement with the experimental data. It should be noted, that in the energy range up to 9 MeV the reported data on the ^{115}In(γ,γ′)^{115m}In reaction cross section are also sufficiently close (see Fig. 3).

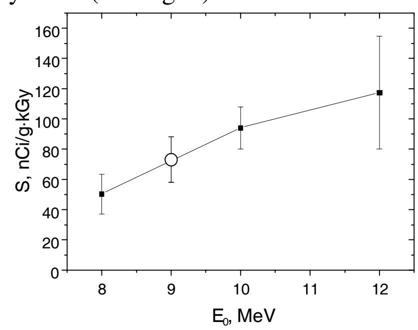

Figure 5: Ratio of specific ^{115m}In activity in indium plate to X-ray absorbed dose in PMMA (○- experiment, ■– calculation).

Figures 6 and 7 show, respectively, the data on the absorbed dose rate and, also, on ^{90}Mo and ^{99}Mo yields in the targets T_2 and T_3 in the electron energy range 26 to 71 MeV. The observed compliance of the computed data with the experimental results bears witness to both the adequacy of the method of radiation process simulation and the accuracy of description of reaction cross sections for molybdenum isotopes. At the same time, the ^{115m}In yield data obtained by the two techniques are essentially different (see Fig. 8).

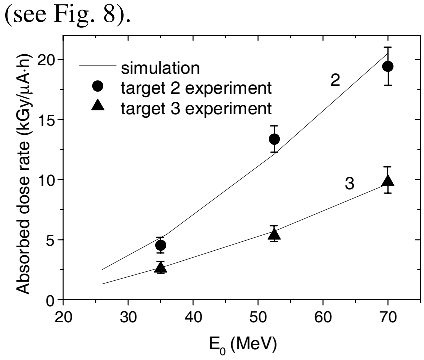

Figure 6: X-ray dose rate in PMMA as function of electron energy.

The comparison between the T_1 and T_4 target activities has shown that even at the photoneutron flux values being the highest for all irradiation regimes (at E_0=71 MeV), the contribution of the (n,n') channel to the ^{115m}In yield is no more than 1%.

Figure 9 shows the function S(E_0). It was obtained by averaging of measuring results on the targets T_2 and T_3. It can be seen that in the E_0 range between 35 MeV and

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71 MeV the S value decreases by ~ 10%.

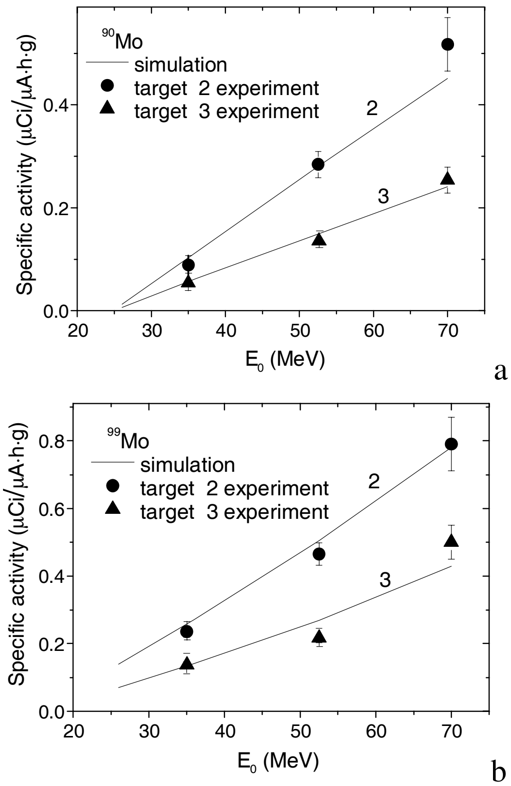

Figure 7: Yield of ^{90}Mo (a) and ^{99}Mo (b) versus electron energy.

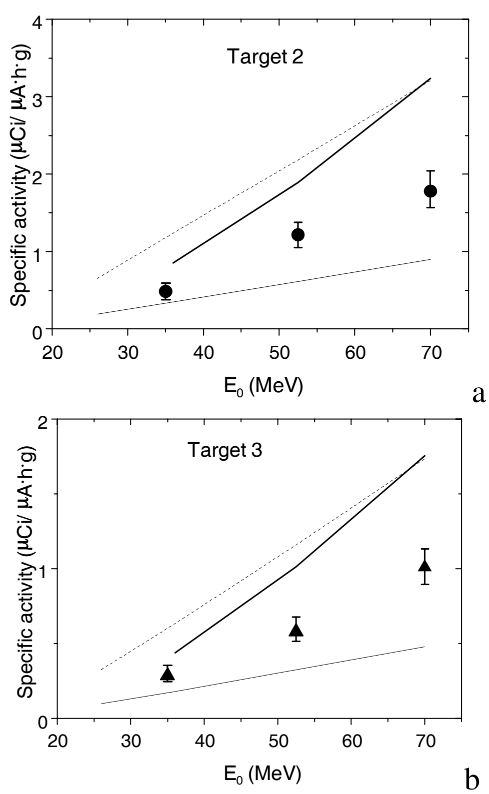

Figure 8: ^{115m}In yield versus electron energy:
a) target T_2, b) target T_3 (•,▲- experiment; ----, —, **—** calculations with cross section data according to [7], [8] and [9], respectively).

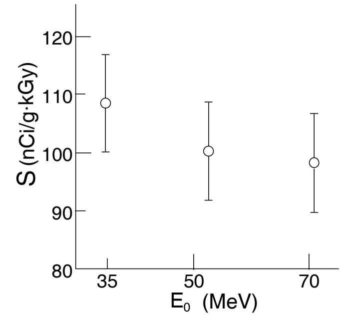

Figure 9: Ratio of specific ^{115m}In activity to absorbed dose in PMMA.

CONCLUSION

The undertaken studies have demonstrated that the $^{115}In(\gamma,\gamma')^{115m}In$ reaction can be used for dosimetry of bremsstrahlung with the spectrum end-point energy up to 70 MeV and higher.

The highest measured X-ray absorbed dose is determined by the boiling temperature of indium and makes no less than 2 MGy (at adiabatic conditions). The safe level of the In activity can be readily provided by the appropriate choice of the detector mass.

REFERENCES

[1] M. Korsunsky, F. Lange and V. Shpigel, Rep. USSR Acad. Sci. 26(1940) 145.

[2] J.-H. Chao, P.-Ch. Hsu and H.-M. Liu, Appl.Rad.Isot. 55(2001) 549.

[3] A. Murataka, S. Endo, Y. Kojima and K. Shizuma, J.Radiat.Res. 51(2010) 197.

[4] ISO/ASTM 51276:2002. Standard Practice for Use of a Polymethylthacrylate Dosimetry System.

[5] F. Salvat, J.M. Fernandez-Varea and J. Sempau, "PENELOPE-2008 A Code System for Monte Carlo Simulation of Electron and Positron Transport" (OECD Nuclear Energy Agency, Issy-les-Moulineous, France, 2008).

[6] Handbook of photonuclear data for applications: Cross sections and spectra, IAEA-TECDOC-1178, IAEA, 2000.

[7] V. Bokhinyuk et al. Ukr.J.Phys. 51(2006) 657.

[8] Ju. Gangrsky and V. Mazur, Phys. Elem. Part. Atom. Nucl. 32(2002) 158.

[9] K. Kosako et al. J.Nucl.Sci. and Technol. 47(2010) 286.

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