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Determination of the 15 MeV bremsstrahlung spectrum from thin W target on the microtron MT-17 accelerator

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Abstract. Bremsstrahlung energy spectrum from thin W target produced by 15 MeV incident electrons was determined by a combination of measurements and theoretical calculation. The shape of spectrum was calculated by Monte-Carlo method using the code EGS4. The photon flux measurements were performed based on the activation technique using the high pure metallic foils. The radioactivities of the irradiated foils were measured by using a gamma spectrometer with a high energy resolution HPGe detector. The experiments were carried out at the 15 MeV electron Microtron MT-17 accelerator located at Institute of Physics and Electronics, Hanoi.

1. Introduction

Electron accelerators with moderate energy are being used throughout the world for various scientific and technological fields [1-3]. The radiations used at electron accelerators are not only the primary electron beam, but also the secondary beams such as bremsstrahlung photons and neutrons. Bremsstrahlung photons are produced from direct interaction of fast electrons with the nuclei of the target. Neutrons are generated mainly from photonuclear reactions induced by the bremsstrahlung photons. A high intensity gamma source is a good tool for investigating photonuclear reactions, radiation affects mechanisms and photo activation analysis [1-3].

In order to analyze most experiments when bremmstrahlung radiation used, it is necessary to know the absolute magnitude of the bremsstrahlung spectrum as a function of the photon energy and of the emission angle. Many methods are available for the investigation of bremsstrahlung spectra. The theoretical prediction of bremsstrahlung spectra has been carried out using different method [4]. Among them the simulation of electromagnetic cascades by means of the Monte-Carlo method has been slowly gaining acceptance.

Despite the relatively advanced state of the theoretical calculation, a lot of accurate, absolute measurements have been made of the spectrum of bremsstrahlung photons [5,6]. There are many methods of measuring the bremsstrahlung such as direct method using detectors or through the use of compton magnetic spectrometers, and indirect methods such as the use of photoneutron time of flight or activation of special materials. The advantages and limitations of each method have been discussed elsewhere.

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The purpose of the present work was to investigate the energy spectrum of bremsstrahlung photons emitted from the thin W target bombarded by 15 MeV electron beam from the Microtron MT-17 accelerator at the Institute of Physics and Electronics.

In this study, the activation foil technique and gamma spectrum measurement was used to determine the photon flux. The main advantages of this method are high sensitivity, accuracy and the experimental procedure is rather simple and feasible. By this way, the photon intensity can be determined based on the activity of the activated different foils. From the absolute photon fluxes, we have constructed the bremsstrahlung energy spectrum based on the unfolding technique in combination with the spectrum shape which was calculated using the code EGS4. The EGS4 system (Electron Shower Gamma 4) is standard for Monte-Carlo calculations of radiation transport [4,7].

2. Experimental

The Microtron MT-17 accelerator can accelerate electron beam up to energy of 15 MeV and produce intense bremsstrahlung and photoneutrons. The accelerated electron beam hits the W-target to produce the bremsstrahlung. The dimension of the W-target is 40 mm in diameter and thickness of 1 mm. The induced bremsstrahlung spectrum covers the energy range from zero to 15 MeV.

During our experiments, the Microtron MT-17 accelerator was operated with an electron energy of 15 MeV and 10 μA beam current. The irradiation time was 137 min yielding enough the activities to be measured in a gamma-ray counting system.

In this study, we used Au and In foils as the threshold detectors for the photon flux measurements. All foils employed were disk-shaped with diameter of 20 mm and with thickness of 0.1 mm. For irradiation, the foils was positioned 4 cm far from the W target and at 90 degree with respect to the 15 MeV electron beam direction. The simplified experimental arrangement is shown in Fig.1. The main characteristics of the nuclear reactions investigated and decay data of the reaction products are presented in Table 1[9].

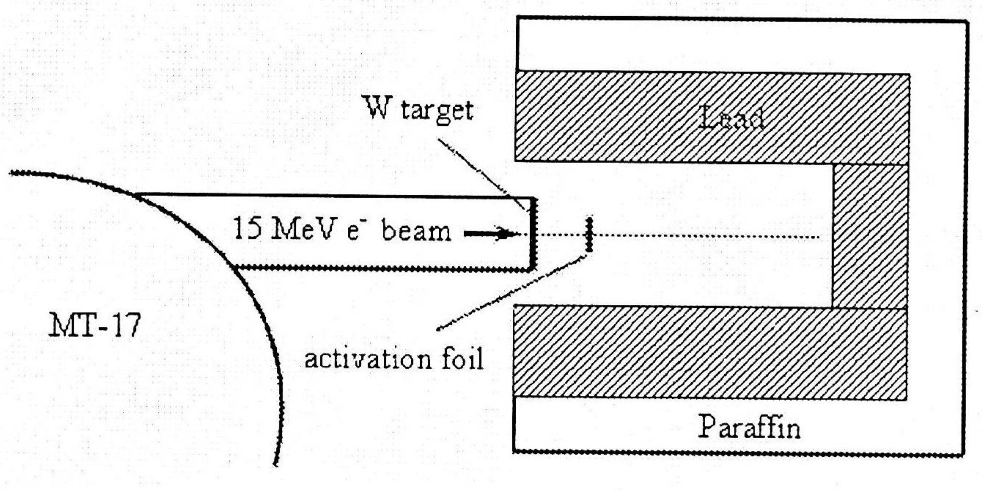

Fig. 1. Experiment arrangement for the investigation of Bremsstrahlung from the W target.

Table 1. Nuclear reactions used for bremsstrahlung spectrum measurements

Nuclear reaction	Threshold energy, E_{th} (MeV)	Half-life, $T_{1/2}$	Main gamma – rays		Isotopic abundance %
			Energy (keV)	Intensity, %	
$^{197}Au(\gamma,n)^{196}Au$	8.07	6.183 d	333.03	22.9	100
			355.68	86.9	
			1091.4	0.15	
$^{115}In(\gamma,n)^{114m}In$	9.23	49.51 d	190.27	15.4	95.7
			588.43	4.39	
			725.24	4.39	

In practice, the metal foils are activated by photons and radioisotopes formed after the irradiations were identified from the pulse-height spectrum by their gamma photopeak energies and half-lives. Their activities were determined from gamma photopeak area and detection efficiencies at the photopeak energy. The average activity of the activation foils served as photon flux to which the foils were exposed. The relation between the average photon flux, ϕ, and the number of detected gamma rays, C, can be expressed as follows:

$$\phi = \frac{C\lambda}{\sigma N_o \varepsilon I_\gamma F[1-\exp(-\lambda t_i)]\exp(-\lambda t_d)[1-\exp(-\lambda t_c)]} \quad (1)$$

where: N_o is the number of target nuclei; ε is the photopeak efficiency of the detector; I_γ is the branching ratio or intensity of the gamma ray ; λ is the decay constant; F is correction factor; t_i is the irradiation time; t_d is the decay time or the time between end of irradiation and start of counting; t_c is the measuring time.

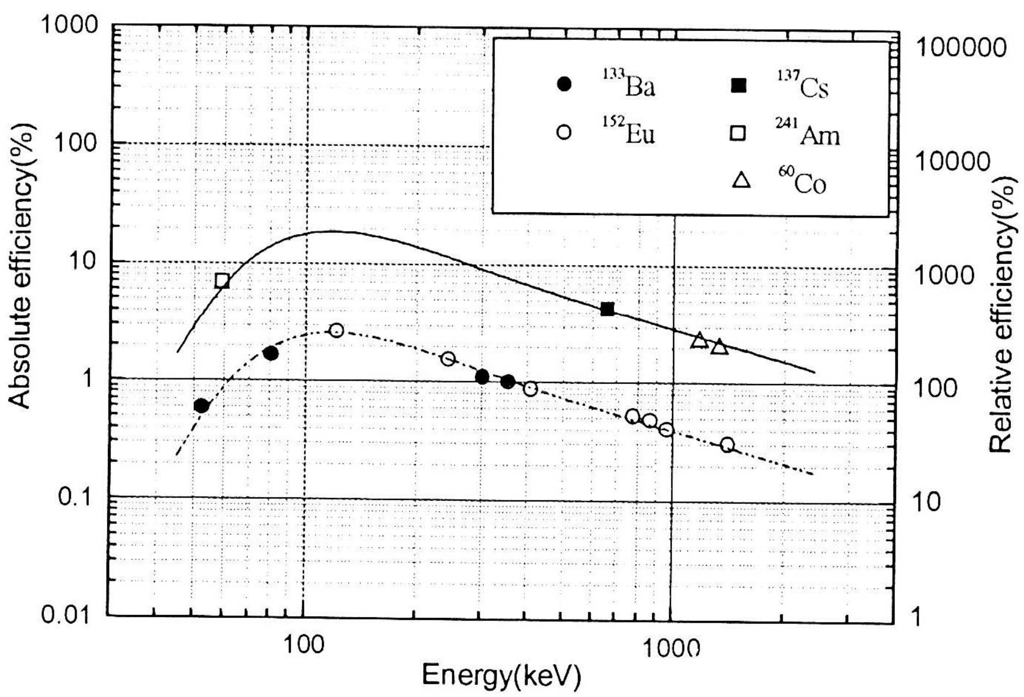

Fig. 2. Photopeak efficiency curves of the gamma spectrometer with HPGe detector --- relative efficiency curve, — absolute efficiency curve.

In activation method, the actual results of the measurements are the counting rates of the irradiated foils. After irradiations and appropriate cooling time, the foils were taken off and the induced gamma activities were measured by gamma spectrometer. It consists of a high purity coaxial germanium HPGe detector (CANBERRA), which is coupled to a computer based multichannel analyzer system. The energy resolution of the system is 1.8 keV at 1.332 of ^{60}Co standard source. The gamma spectra were measured and analyzed by the program S100 (Canberra).

The photopeak efficiency curve of the gamma spectrometer was calibrated with a set of standard sources such as ^{241}Am, ^{137}Cs, ^{60}Co, ^{152}Eu, ^{133}Ba and ^{226}Ra. The main steps of the procedure are (1) to determine the relative efficiency curve based on multi-energy gamma sources and then (2) to transform the measured relative efficiency curve to absolute one based on single energy gamma sources. The detection efficiencies were fitted by using the following function:

$$\ln \varepsilon = \sum_{n=0}^{5} a_n \ln E^n , \quad (2)$$

where ε is the detection efficiency, a_n represents the fitting parameters, and E is the energy of the photopeak. The relative and absolute efficiency curves were presented in Fig.2. [5].

3. Results and discussion

In this investigation, the threshold photonuclear reactions $^{197}Au(\gamma,n)\,^{196}Au$ and $^{115}In(\gamma,n)^{114m}In$ were used for the photon flux measurements. The induced gamma activities were measured by gamma spectrometer with HPGe detector. Each sample was measured several times in order to follow the decay of the different isotopes. Some typical gamma spectra of the activated foils under investigation are shown in Fig.3 and Fig.4, respectively. After making necessary corrections for the usual experimental errors such as dead time, pile-up, gamma ray branching ratio, self-absorption of gamma rays and detector efficiency, the photon fluxes can be derived from the measured activities based on equation (1). The activation cross sections used in our calculations were taken from reference [9].

From the photon fluxes determined based on different threshold reaction energies, we calculated the photon fluxes per kW beam power, ϕ (ph.s^{-1}. sr^{-1}.kW^{-1}), and presented in Table 2.

Table 2. Integral photon fluxes determined based on different threshold reaction energies.

Nuclear reaction	E_{th} (MeV)	ϕ (ph.s^{-1}.sr^{-1}.kW^{-1})
$^{197}Au(\gamma,n)\,^{196}Au$	8.07	$(1.06\pm0.09)\times10^{11}$
$^{115}In(\gamma,n)\,^{114m}In$	9.23	$(7.44\pm0.67)\times10^{10}$

Following, the differential photon flux in the energy bin $\Delta E = E_{th}(In) - E_{th}(Au)$ can be derived from the values of integral photon flux as follows:

$$\Delta\phi = \phi(Au) - \phi(In) \quad (3)$$

From the differential photon flux we can constructed an absolute bremsstrahlung energy spectrum by a combination with the relative spectrum calculated by using the code EGS4. The obtained bremsstrahlung spectrum is presented in Fig.5.

Fig. 5 show that the energy spectrum of bremsstrahlung is continuous the upper and that equals the kinetic energy of the bombarding electron. The slowing down of electrons due to ionization losses leads to reduction of the high energy part in relation to low-energy radiation. The shape of the obtained bremsstrahlung spectrum is similar to that reported by some other authors [8,9].

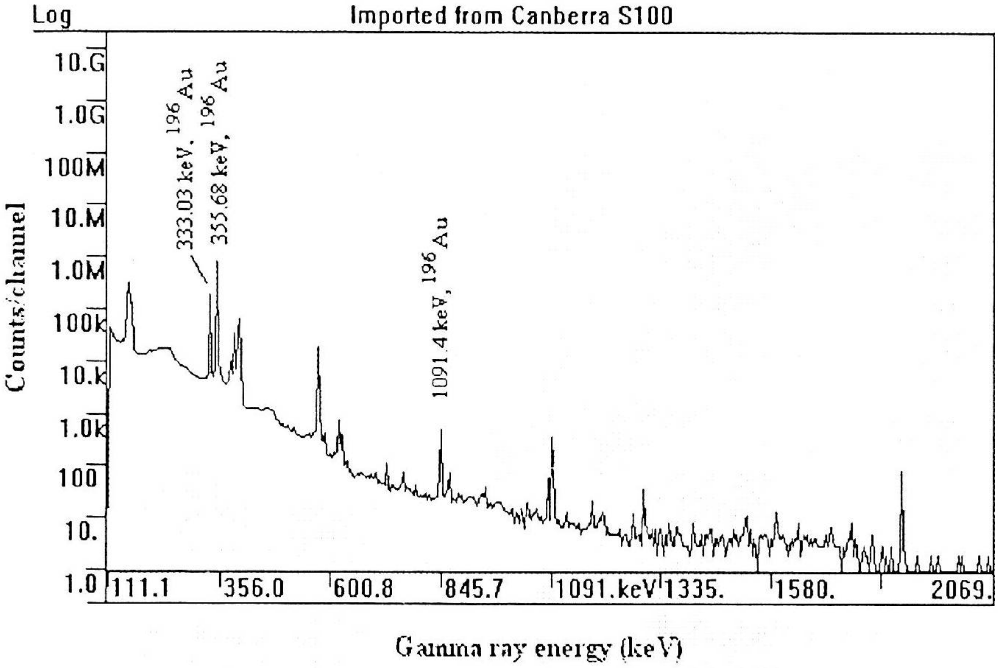

Fig. 3. Gamma-ray spectrum of Gold foil irradiated by 15 MeV Bremsstrahlung with irradiation time 137 min, the waiting time 8817 min, and the measuring time 30 min.

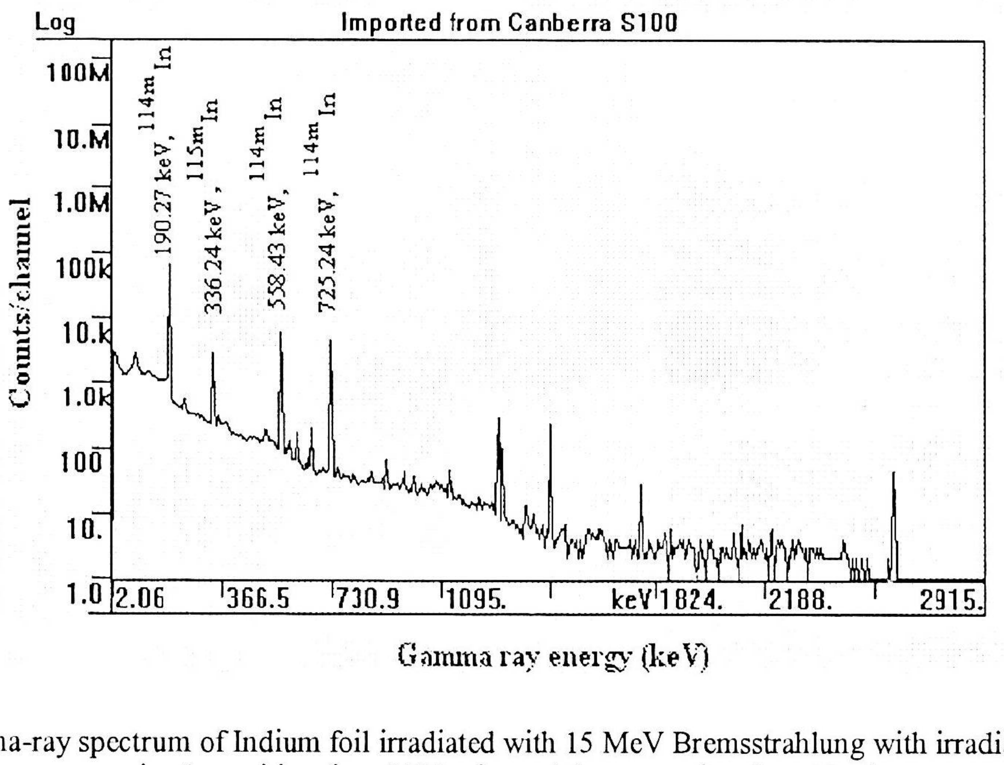

Fig. 4. Gamma-ray spectrum of Indium foil irradiated with 15 MeV Bremsstrahlung with irradiation time 137 min, the waiting time 3080 min, and the measuring time 30 min.

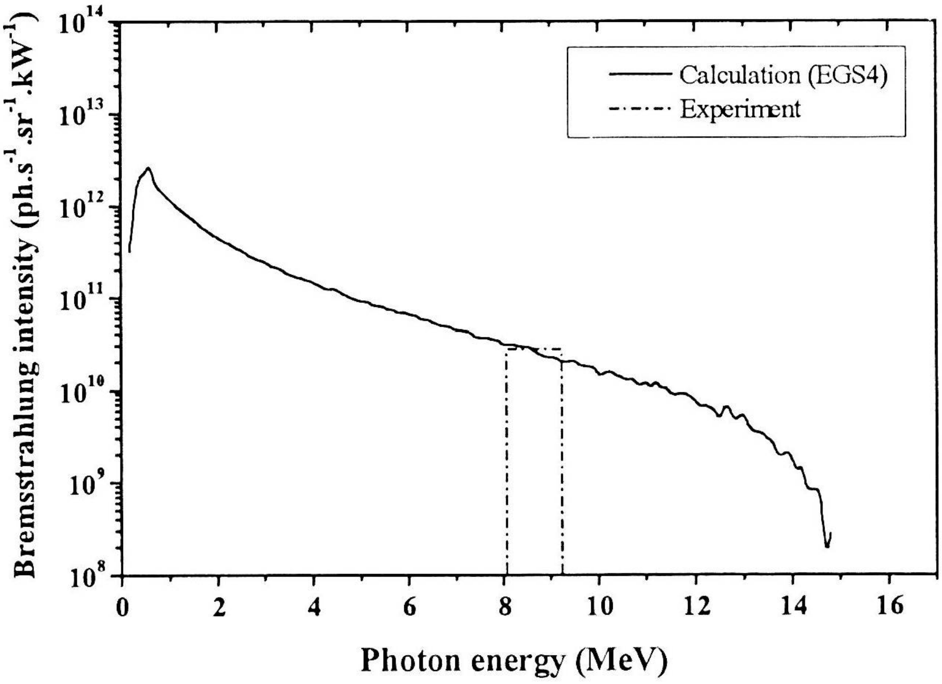

Fig. 5. Bremsstrahlung spectrum from W-target bombarded by 15 MeV electrons from MT-17 accelerator.

The main sources of the uncertainties for the present results were estimated due to statistical errors: (0.5÷ 1%), the geometrical factor for irradiation and measurement of the activation foils: (0.8÷1.5%), the detection efficiency: (2÷3%), nuclear decay data used such as half-life and gamma branching ratio: (2÷4%).

In this study, in order to limit the experimental errors, the (γ,n) photonuclear reactions for Au and In were used as activation detectors, because of their high reaction cross-section in the energy range of interest. Furthermore, the interferences caused by competing reactions were avoided.

In conclusion, we can say that the obtained energy spectrum of bremsstralung photons are useful not only for nuclear data measurements, but also help in understanding the nuclear interaction processes involved in the production of bremsstrahlung. For practical applications, the obtained data are useful in making detailed shielding calculations and photo activation analysis.

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