HIGH-INTENSITY BREMSSTRAHLUNG MONITORING SYSTEM FOR PHOTONUCLEAR TECHNOLOGIES*

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Abstract

The realization of promising photonuclear technologies (a soft technology for medical isotope production, radioactive waste handling, activation analysis, etc) calls for the sources of high-energy ($E_\gamma \geq 10$MeV) and high-intensity ($\geq 10^3$W/cm^2) photons [1,2]. Such sources may be obtained by converting a beam from a high-current electron Linac into bremsstrahlung. The method of combined (γ,n) activation of a set of foils that have different energy thresholds of the reactions (-Q) is proposed to determine the space-energy characteristics of such radiation. In each energy range the geometrical characteristics of the radiation field are reconstructed from the foil surface γ-activity distribution. The last one is determined through one-dimensional scanning of the foils by a specially designed detecting head that includes a linear matrix of 16 collimated semiconductor detectors (CdZnTe; 2x2x2,mm). A preliminary analysis of the system geometry and applicability of the method was performed by computer simulation based on the PENELOPE software [3]. A developed PC based measuring system with CAMAC interface is described.

OPTIMIZATION OF HEB MONITORING CONDITIONS

At the initial stage of realization of photonuclear technologies it is necessary to determine the space-energy characteristics and the intensity of high-energy bremsstrahlung (HEB) in order to optimise the size of the target and its positioning in the radiation field.

To determine the parameters of a high-intensity flux of bremsstrahlung photons, the method is proposed, which is based on (γ,n) activation of a thin foil placed normally to the radiation under study (photonuclear converter - PNC method).The possibilities of such approach were prestudied by the computer simulation method. Consideration was given to a simplified geometry of molybdenum PNC activation by the reaction ^{100}Mo(γ,n)^{99}Mo → ^{99m}Tc(-Q = 8.29 MeV) - Fig.1.

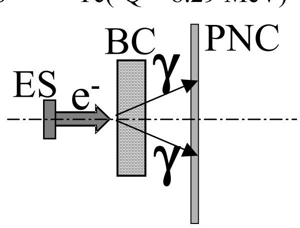

Figure 1: Simulation conditions: ES – accelerated electron source, BC – bremsstrahlung converter, PNC – photonuclear converter.

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The simulation results for electron energies of 100 MeV, electron source diameter of 5 mm and the BC (4 mm tantalum), are presented in Fig.2. For comparison, Fig.2 shows the surface activity distributions of the PNC, 1mm and 3.5 mm in thickness.

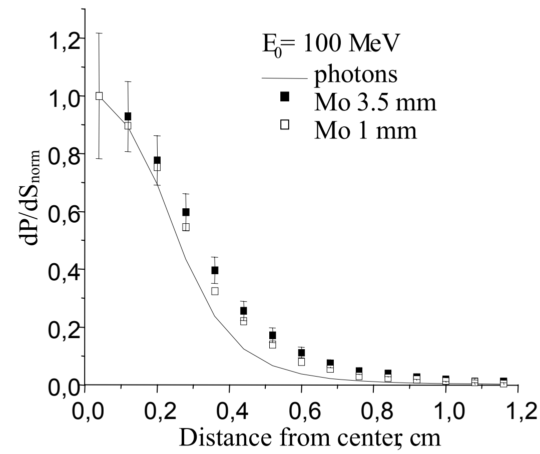

Figure 2: Comparison of normalized radial density distributions of photons incident on the target and having the energy higher than the activation threshold (solid curves) and the PNC surface activity.

OPTIMIZATION OF THE HEB MONITORING SYSTEM

To measure the PNC surface activity distribution, it was proposed to use a specially designed collimated coordinate-sensitive radiometer of γ radiation. By design, the radiometer consists of a detector head (DH) and the main spectrometry block. The detector head (Fig.3) includes a linear matrix with 16 collimated semiconductor detectors based on CdZnTe crystals (2x2x2 mm^3).

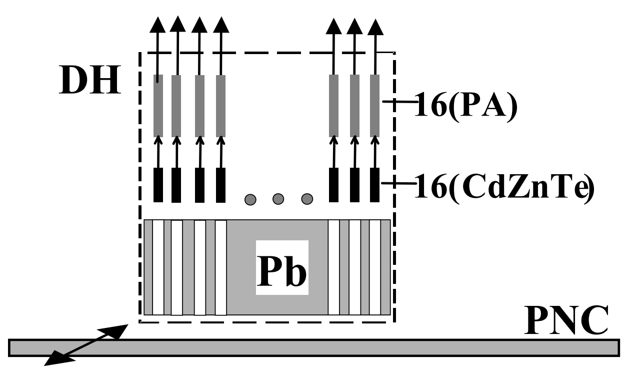

Figure 3: Arrangement of the detector head on the PNC.

Each detector has at its output a low-noise preamplifier PA. The head measures 30x40x120 mm^3. The measurement of detector signals as the head is linearly moving along the PNC makes it possible to determine the two-dimensional PNC activity distribution which represents the density distribution of the HEB flux. The geometry of the measuring circuit (PNC+collimator+detector) has been pre-optimized by the computer simulation method. Thus, Figs.4,5 show the efficiencies of the total/useful signals of the detector as functions of the Pb collimator thickness and photon energy.

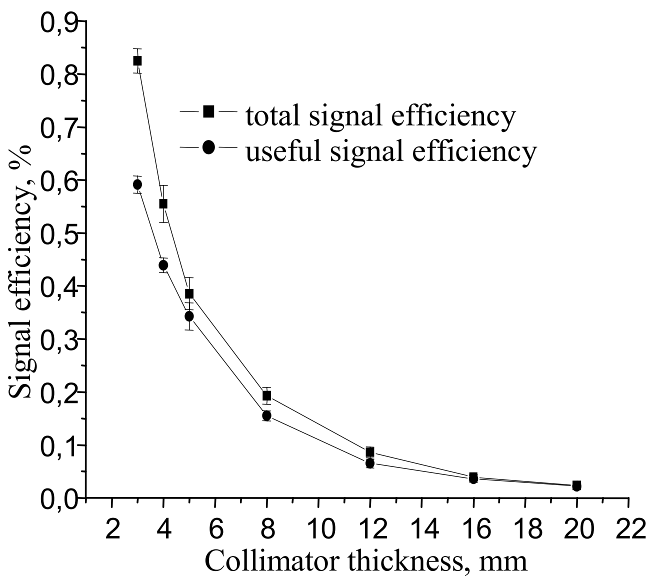

Figure 4: Total (useful) signal efficiencies versus collimator thickness.

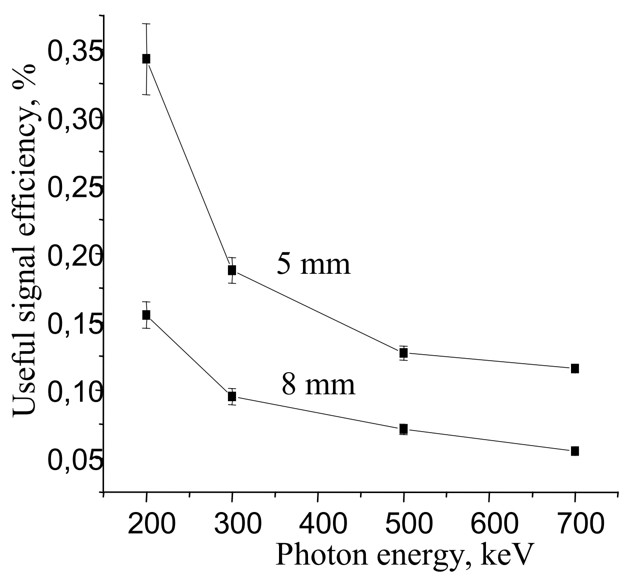

Figure 5: Useful signal efficiency versus photon energy of gamma-active plate for two collimator thickness values

THE SCANNING SYSTEM OF PHOTONUCLEAR CONVERTER

The system is intended for visualization of the induced-activity density distribution of the PNC. Structurally, the system consists of the following units:

- precision hardware;
- detector head;
- electronic modules and a computer.

The Mechanical System

This system is made as an independent unit that provides the shifting of the PNC holding carriage back and forth with respect to the detector slide rule arranged in the plane of the table of device.

The main characteristics of the system are as follows:

- overall dimensions 400x150x120 mm;
- weight no more than 3.5 kg;
- minimum step of carriage motion ~0.14 mm;
- maximum displacement rate ~7 mm/s;
- setup time no more than 1 minute;
- uptime no less than 10000 hours.

The Detecting System

Structurally, the detection system is a "line" of lead-collimated 16 CdZnTe-base detectors arranged in the plane of the device (Fig.6).

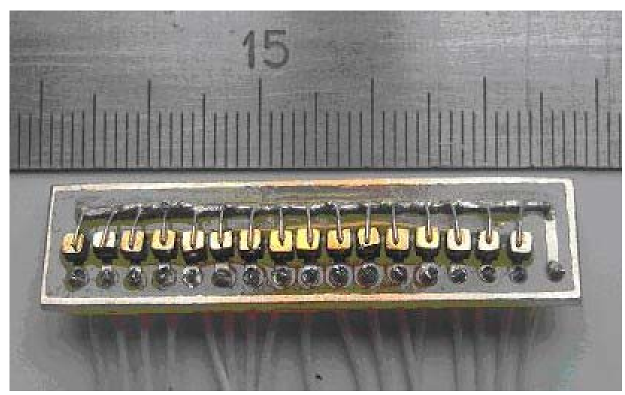

Figure 6: Detector rule.

The Electronic System

The block diagram of the system measuring the PNC surface activity distribution is presented in Fig.7.

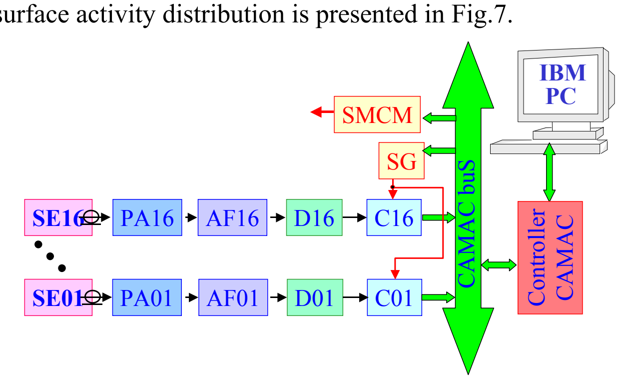

Figure 7: Block diagram of the PNC measuring system.

The system includes:

- preamplifier (PA);
- sharpener amplifier (AF);
- discriminator (D);
- 150 MHz counter (C);
- step motor control module (SMCM);
- strobe generator (SG).

STUDIES OF THE PROTOTYPE HEB SOURCE

To investigate experimentally the characteristics of HEB, a prototype source was created for electron energy of 40 MeV using the electron accelerator LU-40 as the basis [4]. The general scheme of the prototype with the radiation diagnostic means is presented in Fig.8.

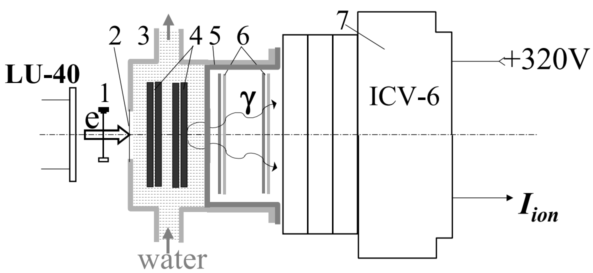

Figure 8: Scheme of the prototype HEB source.

Directly at the output of the accelerator LU-40, a beam position monitor 1 is placed. It performs monitoring of the electron beam as regards the coincidence of its axis with the axis of the converter device. The last one includes the Al body frame 3 , which houses four Ta plates (4), each being 1 mm thick. The plates are cooled with water. The electron beam is incident on the Ta plates through the entrance window 2 (stainless steel, 0.3 mm). In the rear part of the body frame 3 there is a pressure sealing cap-cup 5, inside which two at a time Mo and Cu foils (6) – PNC are placed. The spacing between the foil sets makes 45 mm. This geometry was chosen to provide the possibility for measuring both the spatial-energy distribution of bremsstrahlung photons and their angular divergence. After the converter unit, there is a thick-walled free-air ionization chamber 7 of Type ICV-6.

The data from PNC activity measurements at separate points were processed by the spline interpolation method (see Fig.9).

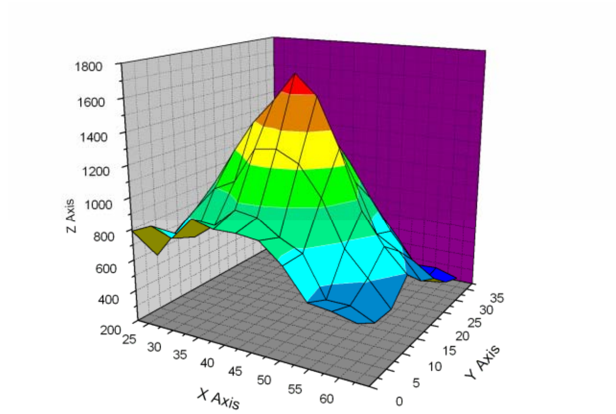

Figure 9: HEB intensity distribution.

CONCLUSIONS

- The analysis of the simulation results for PNC activation by HEB shows that the radial distribution of induced activity is somewhat wider than the corresponding photon distribution due to an angular divergence of the photon flux emitted from the converter. With decreasing electron energy and PNC thickness the difference between the distributions also decreases.
- The equipment developed for diagnostics of the bremsstrahlung flux with the use of a photonuclear converter makes it possible to determine the space-energy radiation distribution, the knowledge of which enables one to optimize the target size and the target arrangement in the highest photon flux, and also, to estimate the rate of isotope generation.

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