METHODS OF BREMSSTRAHLUNG MONITORING FOR PHOTONUCLEAR TECHNOLOGIES

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The paper describes the methods and devices proposed for measuring the main parameters of high-power high-energy bremsstrahlung sources. It has been suggested that space-energy characteristics of radiation should be investigated by the method of combined (γ, n) activation of a set of foils that have different energy thresholds of the reaction. In each energy range, the geometrical characteristics of the radiation field are reconstructed from the foil surface activity distributions. The last ones are determined through one-dimensional scanning of the foils by a specially designed detecting head that includes a linear matrix from collimated CdZnTe-base detectors. For a continuous monitoring of the bremsstrahlung power flow it is suggested that the method of feed-free secondary emission should be used, with a plane-parallel detector having two plates of different thickness as the base. A preliminary analysis of the geometry and applicability conditions of each of the detector systems was performed by the method of computer simulation based on the PENELOPE software system.

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1. INTRODUCTION

The realization of promising photonuclear technologies (ecologically safe isotope production, radioactive waste handling, activation analysis, etc.) calls for the sources of high-energy ($E_\gamma \geq 10$ MeV) and high-intensity ($> 10^3$ W/cm^2) photons. These sources may be obtained by converting a beam from a high-current linear accelerator into bremsstrahlung (BS) [1].

The BS monitoring in the process of realization of photonuclear production of isotopes must solve two problems: (i) at the initial stage, the spatial-energy characteristics as well as the radiation intensity must be determined (to optimize the target size, positioning and to estimate the isotope production rate). (ii) With a further isotope production, a continuous monitoring of the photon flux on the target must be conducted. Thus, in the first case, the method must be developed to measure with a sufficiently high operational efficiency (preferably, no more than a few minutes), with good spatial (~1 mm) and energy (~1 MeV) resolutions. In the second case, the main requirement is to ensure a relative efficiency in the BS intensity on the target (e.g., no worse than 5% for a period of ~1000 hours) at a high radiation hardness of the sensor (no less than 10^9 Gy).

The paper describes the methods and means proposed by the authors for BS monitoring at each stage of photonuclear process realization.

2. DETERMINATION OF SPATIAL-ENERGY CHARACTERISTICS

2.1. To determine the parameters of the high-intensity bremsstrahlung coming from the converter, we propose the method of (γ,n) activation of a thin foil placed normally to the radiation flux under study (photonuclear converter – PNC). The spatial density distribution of the photon flux of energy $E_\gamma > -Q$ ((γ,n) reaction threshold in the PNC material) may be reconstructed by measuring the distribution of the surface activity of the flux (see Fig.1).

2.2. The possibilities of this approach were preliminarily studied by the computer simulation method. Consideration was given to a simplified geometry of 3.5 mm-thick molybdenum PNC activation by the reaction ^{100}Mo(γ,n)^{99}Mo → ^{99m}Tc (-Q =8.29 MeV).

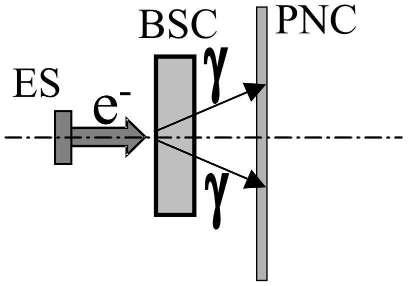


*Fig.1. Simulation conditions: **ES** – accelerated electron source, **BSC** – bremsstrahlung converter, **PNC** - photonuclear converter*

The results of simulation for an electron energy of 30 MeV, the electron source of 5 mm in diameter, and the BSC 4 mm in thickness, are given in Fig.2. It is obvious that at moderate distances from the axis (≤ 4 mm) the two distributions are practically coincident. At the periphery, the activity decay decreases more slowly due to an increase in the angle, at which the photons are interacting with the PNC.

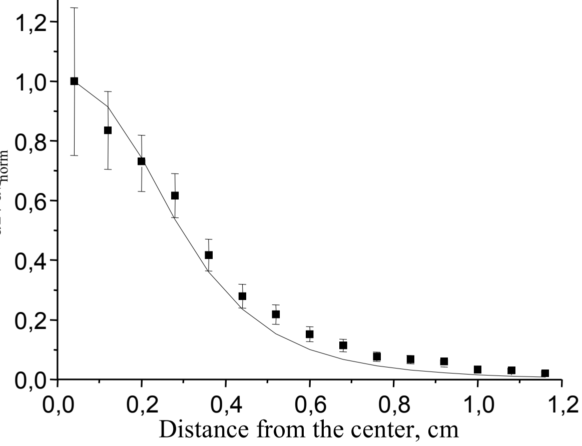


*Fig.2. BS photon density distribution (E_γ > 8.29 MeV – solid curve) and the **PNC** surface activity*

2.3. To measure the PNC surface activity distribution, it is proposed to use a collimated coordinate-sensitive γ-radiometer of special design. Structurally, the radiometer consists of a detecting head (DH) and a basic spectrometry unit.

The geometry of the measurement design (PNC+collimator+detector) was first optimized by the computer simulation method. It was established that a 5 mm thick Pb collimator with an aperture diameter of 1.5 mm may provide an adequate representation of the surface activity distribution through one-dimensional scanning of the PNC with a DH normally to the detector line. The spatial resolution is determined by the collimator size and the PNC activity (for better resolution the exposure time must be increased).

The DH (Fig.3) includes a linear matrix having 16 collimated semiconductor detectors based on CdZnTe (2×2×2 mm). Each detector has at its output a low-noise preamplifier PA. The DH measures 30×40×120 mm^3. It operates at room temperature (without cooling). The equivalent internal noise of the electron line of the radiometer is no more than 5 keV.

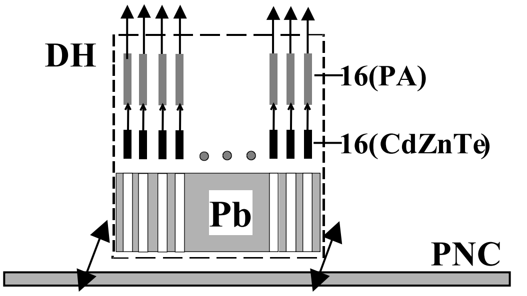


*Fig. 3. Arrangement of the detecting head on the **PNC***

2.4. The basic radiometer unit (Fig.4) includes a 16-channel shaping amplifier (AF-16), a discriminator (DC-16), a gated pulse counter (SC-16), a programmable gate driver (SG) and a high-voltage source (HV) for energizing the detector matrix. All blocks were made in the CAMAC standard.

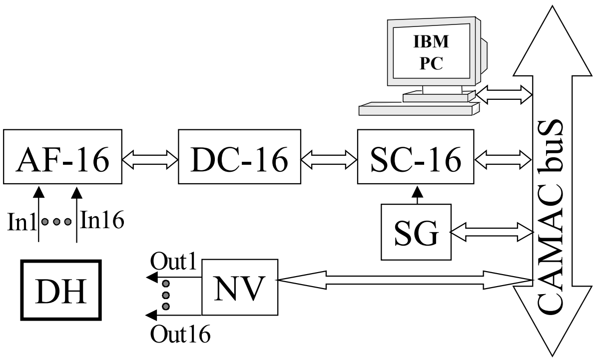


Fig. 4. Block diagram of the γ-radiometer

2.5. The possibilities of the proposed method have been demonstrated in the studies of the BS source on the basis of the accelerator KUT-20 [2]. Figure 5 shows the characteristic PNC (Mo) activity distribution obtained by scanning in two coordinates of the head prototype with one collimated CdZnTe-base detector.

3. CONTINUOUS MONITORING OF THE BS FLUX ON THE TARGET

3.1. To meet the above-given requirements for the BS monitoring at the stage of isotope production, a method has been proposed, based on the use of the secondary-emission monitor (SEM) with two plane-parallel plates of different thickness as the basis, without power supply.

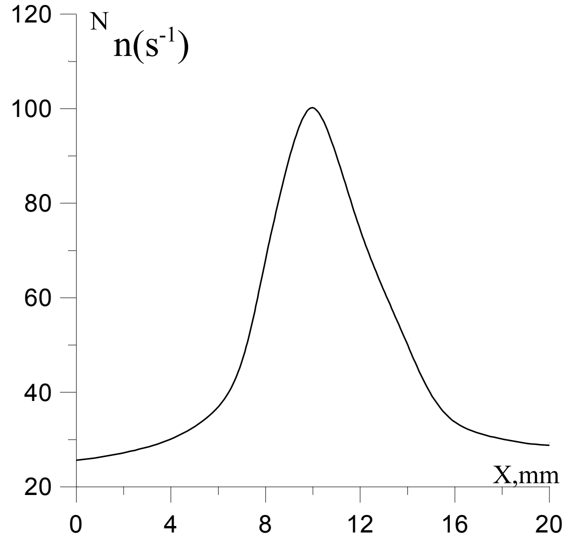
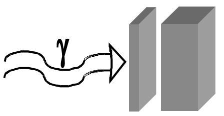
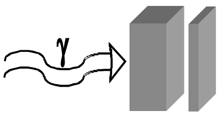


Fig. 5. Bremsstrahlung-induced activity distribution inPNC (Mo)

A preliminary study on the sensitivity of such a SEM was also performed with the computer simulation method. As a basis for the simulation, we took the conditions of a program really acting at the accelerator [2] on the radiation treatment of minerals with an electron beam of 23 MeV, and also, the conditions of isotope production at an electron energy of 40 MeV, planned for the accelerator KUT-20. In each case, aluminum was taken as monitor material, the plate thickness being 1 and 10 mm, with a 10 mm spacing between the plates. Taking into account the intensity and the geometrical characteristics of the bremsstrahlung flux of each source, the size of monitor plates was chosen to be 40×40 cm for EPOS, and 8×8 cm for KUT-20.

The simulation results for each sequence of sensor plates positioning relative to the photon flux are given in Table.

Charge difference of SEM plates per accelerated electron, e/e

	EPOS	(1.85±0.13)·10^{-4}
	KUT-20	(1.28±0.13)·10^{-3}
	EPOS	(3.74±0.14)·10^{-4}
	KUT-20	(-1.16±0.23)·10^{-3}

3.2. To provide a stable operation of the SEM-based measuring channel at conditions of a relatively weak signal against the background of substantial electromagnetic noise, typical of the accelerator, a special signal processing module was developed (Fig.6). It includes two current-voltage converters (I/V), a differential amplifier (DA), an integrator (∫) and an analogue-digital converter (ADC), The module output is connected to the LPT port of the personal computer.

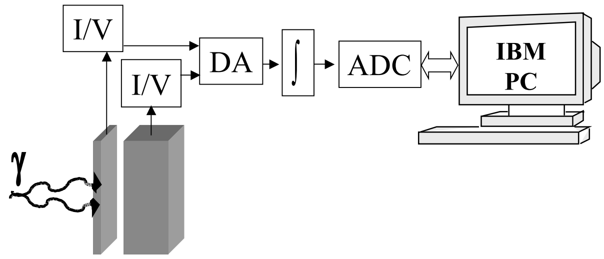


Fig. 6. Block diagram of continuous BS monitor

3.3. A powerful triode tube of 6C33C type was used in the demonstration experiment as a radiation-resistant probe. The signal is picked up from the anode and cathode of the tube (by design, the cathode is made as a plane plate parallel to the anode). The sensitivity of the measuring channel to the BS intensity in the pulse was measured to be about 10^{-12} A·cm^2/W.

4. CONCLUSION

The development and realization of nuclear technologies using powerful concentrated fluxes of high-energy bremsstrahlung call for special diagnostic methods and means. At the initial stage, the investigation and optimization of primary measuring sensors may be advantageously carried out by the computer simulation method with the use of certificated program systems.

The use of a set of thin photonuclear converters from the materials having different reaction thresholds, and also the instrumental complex developed by the authors make it possible to measure the BS characteristics with satisfactory spatial and energy resolutions. In particular, this method provides the tuning of the mode of accelerator operation and the target alignment for efficient generation of isotopes. The maintenance of these conditions may be controlled with the help of the measuring channel based on the secondary-emission monitor that operates without a power supply.

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МЕТОДЫ МОНИТОРИНГА ТОРМОЗНОГО ИЗЛУЧЕНИЯ ДЛЯ ФОТОЯДЕРНЫХ ТЕХНОЛОГИЙ

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Описаны предложенные авторами методы и средства измерения основных параметров мощных источников высокоэнергетичного тормозного излучения. Исследование пространственно-энергетических характеристик излучения предлагается выполнять методом совместного (γ,n)-активирования набора фольг из материалов, имеющих различный энергетический порог реакции. Геометрические характеристики поля излучения в каждом энергетическом диапазоне восстанавливают из распределений поверхностной активности фольг. Последние определяются путем одномерного сканирования фольг специально разработанной детекторной головкой, включающей линейную матрицу из коллимированных детекторов на основе CdZnTe. Для непрерывного мониторинга потока мощности тормозного излучения предложено использовать метод вторичной эмиссии без питания на основе плоскопараллельного детектора из двух пластин с различной толщиной. Предварительный анализ геометрии и условий применения каждой из детекторных систем выполнен методом компьютерного моделирования на основе программной системы PENELOPE/2001.

МЕТОДИ МОНІТОРИНГУ ГАЛЬМІВНОГО ВИПРОМІНЮВАННЯ ДЛЯ ФОТОЯДЕРНИХ ТЕХНОЛОГІЙ

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Описані запропоновані авторами методи і засоби вимірювання основних параметрів потужних джерел високоенергетичного гальмівного випромінювання. Дослідження просторово-енергетичних характеристик випромінювання пропонується виконувати методом спільного (γ,n) - активування набору фольг з матеріалів, що мають різний енергетичний поріг реакції. Геометричні характеристики поля випромінювання в кожному енергетичному діапазоні визначають з розподілів поверхневої активності фольг. Останні визначаються шляхом одномірного сканування фольг спеціально розробленою детекторною голівкою, що включає лінійну матрицю з колімованих детекторів на основі CdZnTe. Для безперервного моніторингу потоку потужності гальмівного випромінювання запропоновано використовувати метод вторинної емісії без живлення на основі плоскопаралельного детектора з двох пластин з різною товщиною. Попередній аналіз геометрії і умов застосування кожної з детекторних систем виконаний методом комп'ютерного моделювання на основі програмної системи PENELOPE/2001.