Field of Capture Gamma Radiation with Energy up to 10 Mev for Metrological Support of Spectrometry and Dosimetry Instruments

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Field of Captured Gamma Radiation with Energy up to 10 MeV for Metrological Support of Spectrometry and Dosimetry Instruments

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Abstract— **The use of dosimeters calibrated in reference fields with corresponding energies for correct estimation of dose loads for personnel working in high-energy gamma-radiation fields with energies above 3 MeV is required. The creation of reference fields with gamma-radiation energies up to 7 MeV is essential for photon radiation dosimetry at nuclear power plants, where a significant gross dose rate component is stipulated by the radiation with an energy of 6.13 MeV associated with the $^{16}O(n, p)^{16}N$ reaction in the water cooling loop. Apart from nuclear power plants, such tasks occur on electron accelerators, widely used for therapeutic, industrial and other purposes.**

The state verification schedule (Republic of Belarus and Russian Federation) stipulates the use of ^{241}Am (0.06 MeV), ^{137}Cs (0.662 MeV) and ^{60}Co (1.250 MeV) radionuclides for reference dosimetry measurements of gamma radiation in the range from 0.06 to 3 MeV. No standard calibration and verification is performed for nuclear physics equipment in bremsstrahlung with an energy above 3 MeV generated by accelerators. Dosimeters calibrated in the radionuclide sources fields may not measure the dose rate from high-energy gamma radiation correctly. At the same time, there is a nomenclature list of instruments with various detector types, where the energy range has to be expanded to 7 MeV or 10 MeV following the relevant research is carried out.

High-energy capture gamma-radiation fields with energies up to 7 MeV (titanium target) and up to 10 MeV (nickel target) to calibrate the energy scale and verify the energy dependence of developed spectrometric and dosimetric measuring instruments were generated by AT140 Neutron calibration facility for radiation monitoring instruments according to the requirements of international standard ISO-4037:2019.

The report presents the results of experimental studies. The standard dosimeter AT5350/1 with a highly sensitive ionization chamber TM32002 was used to determine the air kerma rate and ambient dose equivalent rate of gamma radiation.

Keywords—high-energy captured gamma-radiation fields, AT140 neutron calibration facility, titanium target, nickel target.

I. INTRODUCTION

Correct assessments of dose loads on the personnel working in the fields of high-energy gamma radiation with energies more than 3 MeV should be carried out by dosimeters calibrated in the reference fields with appropriate energies. Creation of reference fields up to 7 MeV is of essential importance for dosimetry of photon radiation at NPPs, where a significant component of the total dose rate is due to radiation from the $^{16}O(n, p)^{16}N$ nuclear reaction with energy 6.13 MeV flowing in the water cooling circuit. In addition to NPPs, such problems arise at electron gas pedals and high-energy X-ray machines, which can be used for therapeutic and industrial purposes. At such facilities, the energy of secondary photon radiation can reach several tens of MeV.

The expansion of energy range of gamma radiation dose rate measurements up to 7 MeV is also dictated by the requirements of international standards, such as ISO 4037-1 and IEC 61017 recommendations [2, 3].

Gamma radiation fields with higher (E>3 MeV) energies, suitable for instrument calibration, are obtained by nuclear reactions. This method of forming reference calibration fields requires a significant amount of expensive laboratory equipment, which is available to several leading national institutes. The $^{19}F(p, \alpha\gamma)^{16}O$ reaction can generate photons with energies of 6.13, 6.92, and 7.12 MeV [4] and the $^{12}C(p, p'\gamma)^{12}C$ reaction can generate photons of 4.44 MeV [5]. In such field formation schemes, targets made of special materials are irradiated with a beam of protons accelerated by the gas pedal field. The irradiated target is a source of gamma rays. Such schemes have been implemented in the National Research Council of Canada (NRC), National Institute of Metrology of Germany (PTB), Japan Atomic Energy Agency (JAEA), etc. [5-7].

Gamma rays with energies up to 10 MeV are emitted during radiation capture of a thermal neutron, i.e., a nuclear reaction (n, γ). The location of a titanium target in the thermal neutron flux from a nuclear reactor allows the formation of a reference field up to 7 MeV, and a nickel target up to 10 MeV [8]. Also, neutron flux with thermal energies can be obtained from radionuclide sources of fast neutrons [9-11].

The purpose of this work is to study by means of the Monte Carlo method as well as experimentally the spectral characteristics of the trapped gamma ray field formed by thermal neutron geometry, the neutron radiation calibration setup AT140 with titanium and nickel targets.

II. MATERIALS AND METHODS OF RESEARCH

It is possible to use radionuclide sources of fast neutrons to create a compact laboratory source of trapped gamma radiation with a stationary in time field. The flux of fast neutrons from a radionuclide source ($^{238}PuBe$, ^{252}Cf, $^{241}AmBe$) is slowed to thermal energies in polyethylene and directed to the target. In this approach, the simplest capture radiation source consists of a fast neutron source, a moderator, and a target.

A container-collimator with thermal neutron geometry of the neutron calibration facility (AT140, *ATOMTEX SPE*) forms a collimated neutron beam with a significant component of thermal energy neutrons “Fig. 1”.

Fig.1. AT140 neutron calibration facility

A Monte Carlo model of a collimator container with a thermal insertion, premises, and ^{238}PuBe source of fast neutrons was developed [12, 13, 14]. In [11] the possibility of obtaining a trapped gamma ray source in “thermal” geometry with a ^{238}PuBe neutron source (type IBN-8-6) was investigated and variants of lead and polyethylene filters were proposed.

The gamma radiation field is formed in this case by 3 main sources:

1) Trapped radiation source from collimator materials and radiation scattered in the collimator.

2) Capture radiation source from the target.

3) Gamma radiation with an energy of 4.439 MeV accompanying the ^{9}Be(α,n)^{12}C reaction in the active part of the ^{238}PuBe - neutron source.

The features of the field produced in this way allow the trapped radiation from the target and the 4.439 MeV radiation to be used independently of each other using different filters “Fig. 2”.

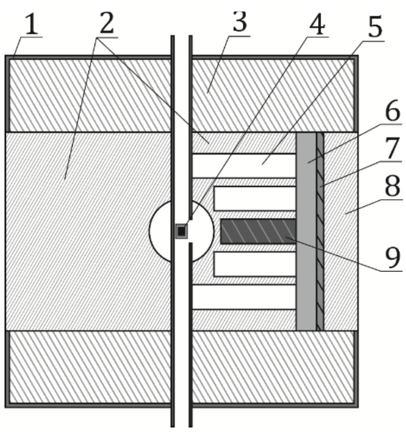

Fig.2. Monte–Carlo model of container–collimator with thermal neutrons geometry: 1 – aluminum casing; 2 – insert for thermal–neutron geometry; 3 – container–collimator; 4 – ^{238}PuBe fast–neutron source (IBN–8–6); 5 – air channels; 6 – lead; 7 – target; 8 – polyethylene; 9 – tungsten.

The central channel of the thermal insert is filled with tungsten to filter gamma radiation from the neutron source. The target is located in the collimator channel.

The international standard ISO 4037-1 recommends using titanium and nickel targets [2] for obtaining the reference gamma radiation field in the range up to 7 MeV and up to 10 MeV, for which the characteristics of gamma radiation capture lines are given in “Tab. 1”.

TABLE I. THE MOST INTENCE PROMPT NEUTRON CAPTURE GAMMA-RAY FOR TITANIUM AND NICKEL

Titanium target		**Nickel target**	
Photon energy, MeV	*Number of photons per 100 captures*	*Photon energy, MeV*	*Number of photons per 100 captures*
0,342	26,3	0,283	3,3
1,381	69,1	0,465	13
1,498	4,1	0,878	3,9
1,586	8,9	6,581	2,3
1,762	5,6	6,837	10,8
4,882	5,2	7,537	4,5
4,869	3,6	7,819	8,2
6,418	30,1	8,121	3,1
6,557	4,7	8,533	17
6,761	24,2	8,999	37,7

Titanium and nickel have separate lines with high gamma-quantum yield in their gamma capture spectra. Gamma radiation from structural and shielding materials must also be taken into account.

Targets in the form of disks (d=300 mm) made of titanium (plate VT 1-0 GOST 23755-79) 15 mm thick and nickel (nickel H-1 GOST 849-97) 10 mm thick.

III. RESULTS AND DISCUSSION

In the developed MCNP-4b model to determine the energy distribution of the flux density of trapped gamma rays at a given point, it is necessary to consider the propagation of both neutrons and photons. The active matter cell of an isotropic neutron source is the birthplace of neutrons in this problem, whereas gamma rays are secondary particles and are generated as a result of various interactions within the whole solution region of the problem. In MCNP-4b one can solve simultaneously the problem of neutron and gamma ray transport by including a special function mode N, P (mode N for neutrons, mode P for gammas). The gamma flux density was calculated for a sphere of 1 mm radius located 550 mm from the centre of the neutron source along the collimator axis, using the tally F4 map [12].

The energy distribution of photon flux density for a titanium target “Fig. 3” and a nickel target “Fig. 4” was obtained by Monte Carlo simulations (the result is normalised to the neutron yield from the source). The width of the energy interval is 50 keV.

The most intense lines are the titanium and nickel lines, the hydrogen capture line of 2.223 MeV, and the thermal neutron capture line of the ^{10}B nucleus by the ^{10}B(n,α)^{7}Li reaction with gamma ray release of 0.477 MeV [17]. The 4.439 MeV peak corresponds to inelastic scattering of fast neutrons by ^{12}C(n,n') ^{12}C* carbon nuclei [18]. There are no other fairly intense gamma-ray lines near the 6.418, 6.760 MeV lines for titanium and 8.533, 8.999 MeV for nickel.

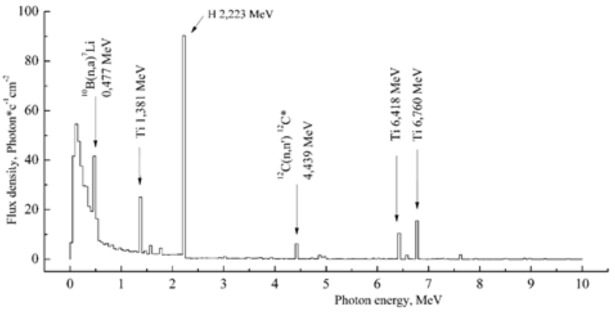

Fig.3. Spectrum of neutron capture gamma–ray for titanium target

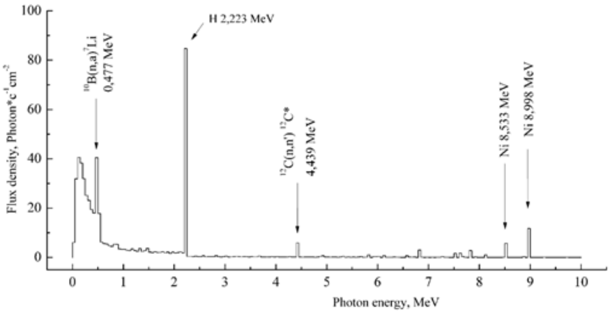

Fig.4. Spectrum of neutron capture gamma–ray for nickel target

A specialized spectrometric detection unit based on $LaBr_3$(Ce) crystal of dimensions Ø38×38 mm with nonlinear channel-energy conversion characteristic in the range up to 10 MeV (number of channels - 1024) was used for experimental investigation of spectral characteristics of the trapped radiation field. “Fig. 5” shows the mutual arrangement of the detection unit, collimator container and target.

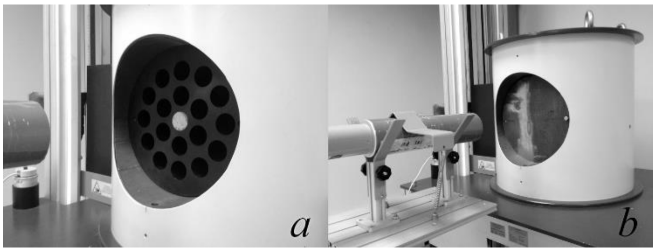

Fig.5. Container–collimator with thermal–neutrons geometry without target (*a*) and nickel target (*b*)

The gamma ray spectra were measured with a 5 cm polyethylene filter. A tungsten filter was placed in the central channel of the thermal insert. The experimental spectra, minus the intrinsic radioactivity of the $LaBr_3$(Ce) crystal and the background without neutron source are shown in “Fig. 6”.

The 4.439 MeV total absorption peaks from the ^{238}PuBe neutron source and reference lines from the target, accompanied by pronounced peaks of single escape (SE) and double escape (DE). A 5 cm polyethylene filter was used to increase the emission intensity of the target against the rest of the spectrum.

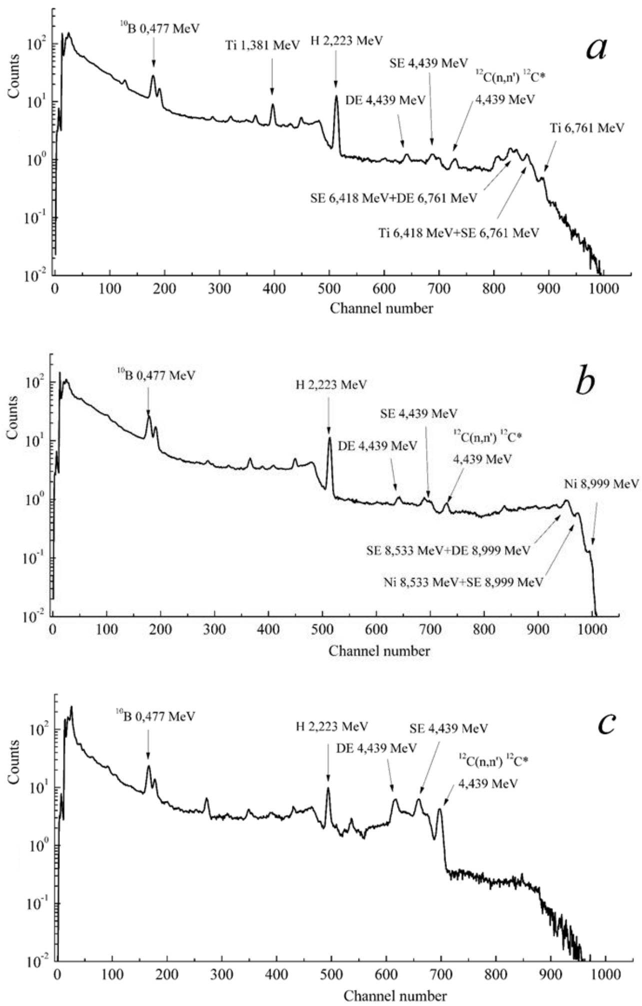

Fig.6. Experimental spectra for titanium target (*a*), nickel target (*b*) and bare ^{238}PuBe source (c)

From the hardware spectra obtained, it can be concluded that the spectrometric units can be calibrated in the trapped gamma ray field up to 10 MeV.

IV. Conclusion

Theplacement of titanium and nickel disks in the thermal neutron geometry collimator container channel allows the formation of a trapped gamma ray field with energies up to 7 MeV and up to 10 MeV. Monte Carlo simulations have shown that the most intense lines (except for target lines) correspond to thermal neutron capture by hydrogen and boron nuclei.

Experimental hardware spectra were obtained using a specialized spectrometric detection unit based on the $LaBr_3$(Ce) crystal of dimensions Ø38×38 mm with a nonlinear channel-energy conversion characteristic in the range up to 10 MeV. Analysis of experimental data has confirmed the possibility of calibration of spectrometers up to 10 MeV by trapped radiation lines.

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