

LaBr₃(Ce) gamma-ray detector for neutron capture therapy

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Abstract. Results of developing of a gamma-ray detector based on LaBr₃(Ce) scintillation crystal for neutron capture therapy are presented. An energy resolution of the detector measured by photomultiplier tube Hamamatsu R6233-100 is showed. It was 2.93% for gamma line 662 keV from a source ¹³⁷Cs. For radiative capture gamma line of isotope ¹⁰B (478 keV) and annihilation line (511 keV) the values were 3.33 and 3.24% respectively. Data analysis of gamma spectra for an estimation of energy resolution threshold required for visual identification gamma lines 478 and 511 keV was made.

1. Introduction

At the present time an increasing of cancer patients is observed. For their treatment different methods of radiotherapy based on the use of radiation sources with high ability are developing dynamically. During treatment session a maximum therapeutic effect is reaching by means of special pharmaceutical product and thermal neutron flux.

Every treatment session requires accurate dosimetry control of absorbed dose. For this purpose a gamma-detector based on scintillation LaBr₃(Ce) crystal was designed for registration of gamma-rays with energy 478 keV. The gamma-rays appear as a result of interaction of thermal neutrons and the pharmaceutical product based on isotope ¹⁰B. At the same time, high energy gamma-rays appear due to interaction of thermal neutrons with surrounding materials (for example, material detector and etc.). Positrons, appearing as a result of high energy gamma-rays interaction, annihilate with electrons and produce gamma-rays with energy 511 keV. Gamma-ray detector with high energy resolution is required for visual identification of the gamma lines with 478 and 511 keV.

2. Neutron capture therapy

The special pharmaceutical product based on isotope ¹⁰B (the isotope has large thermal neutron capture cross section about 3800 barns [1]) is administered into the patient. After reaching of optimum concentration of preparation in tumour tissue it is exposed by thermal neutron flux irradiation. Result of interaction between boron nucleus and neutron is showed below:



As result of nuclear interaction ionization radiation injuring cancer cells and gamma-rays with energy of 478 keV are appeared and a number of emitted gamma-rays are proportionate to number of interactions of thermal neutrons with ^{10}B . By means of the gamma-ray detection we can estimate the absorbed dose with high accuracy during the irradiation session.

3. Gamma-ray detector based on scintillation crystal $\text{LaBr}_3(\text{Ce})$

Gamma-ray detector consists of scintillation crystal $\text{LaBr}_3(\text{Ce})$ (25x25 mm) and photomultiplier tube Hamamatsu R6233-100 (diameter of the photocathode is 70 mm) [2]. The prototype of $\text{LaBr}_3(\text{Ce})$ single crystal with a height of 25 mm and a diameter of 25 mm was grown by the Stockbarger method at Institute of Solid State Physics Russian Academy of Sciences [3]. The crystal was placed into a hermetically sealed container with a quartz window at one of its ends. For processing electrical signals and for forming discrete code was used analog-to-digital converter, mounted in the board SBS-79 by GreenStar Company. For data acquisition and subsequent processing of results of measurements was used special software from the same company.

4. The test results of the gamma-ray detector

Tests of the gamma-ray detector were carried out using different radiation sources from a set of standard calibration gamma-ray sources. The main purposes of this experiment were determination of energy resolution using scintillation crystal $\text{LaBr}_3(\text{Ce})$ for gamma-rays with 478keV energy and estimation of capability detector to divide gamma lines with energies 478 and 511 keV. As results of experiment gamma spectra were obtained from isotopes: ^{137}Cs (figure 1), ^{60}Co , ^{133}Ba , ^{241}Am . Energy resolution for ^{137}Cs is $(2.93 \pm 0.03)\%$.

Based on results of experiment energy resolution as function of gamma-rays energy was fitted (figure 2).

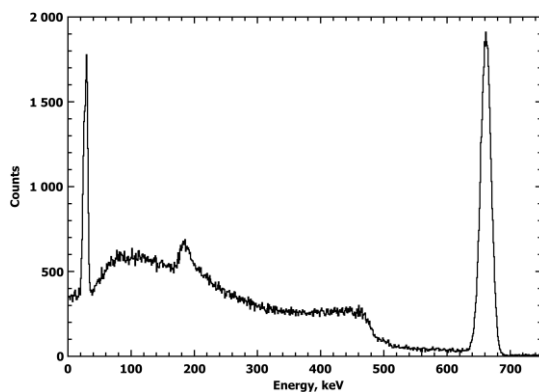


Figure 1. Gamma-ray spectrum from source ^{137}Cs .

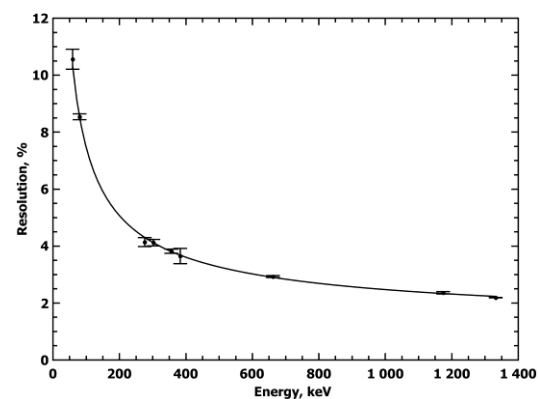


Figure 2. Energy resolution as function of gamma-rays energy.

Experimental data was approximated by the function:

$$\eta(E) = a + \frac{b}{\sqrt{E}} + \frac{c}{E},$$

where $a = 0.87 \pm 0.10$, $b = 43 \pm 3$ and $c = 224 \pm 25$.

Energy resolutions of the gamma-ray detector for gamma-rays with energies 478 and 511 keV are $(3.33 \pm 0.03)\%$ and $(3.24 \pm 0.03)\%$ respectively.

5. Energy resolution threshold estimation of gamma-ray detector for gamma lines 478 and 511 keV by Monte-Carlo simulation

Monte-Carlo simulation of energy peaks from gamma-rays with energies 478 and 511 keV carried out to estimate the energy resolution threshold of gamma-ray detector required to identify overlapping gamma peaks [4]. Two Gaussian distributions were created with standard deviations with values obtained during the testing of the detector. Amplitude distributions were equal intensity for both gamma-ray lines with energies 478 and 511 keV. To estimate energy resolution threshold standard deviations is gradually increased with a step of 1.1%. After that new construction of the spectrum with updated standard deviations for Gaussian distributions was obtained (figures 3 and 4).

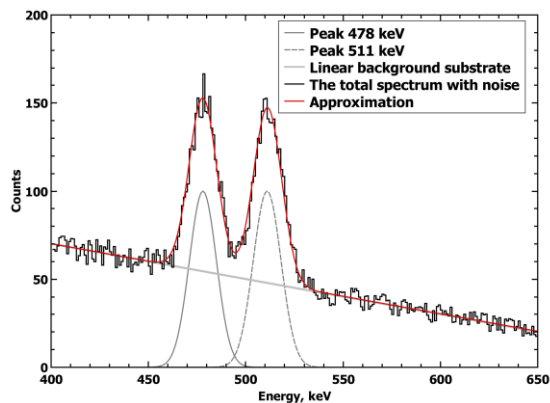


Figure 3. Energy resolutions for gamma lines 478 and 511 keV are 3.33 and 3.24%.

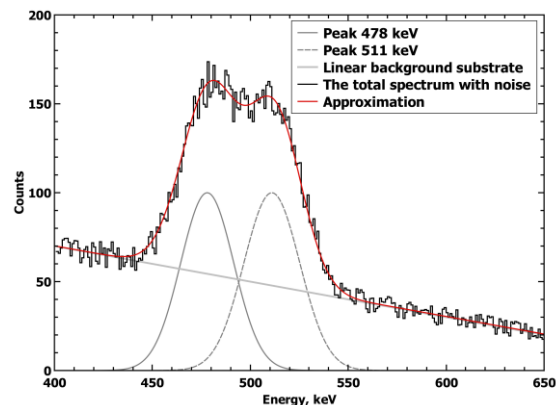


Figure 4. Energy resolutions for gamma lines 478 and 511 keV are 6.68 and 6.58%.

Further increasing of full width at half maximum for the peak (as a consequence of the deterioration of the energy resolution) was allowed to observe (figure 4) overlapping two gamma peaks. Finally visual identification without additional mathematical treatment is not possible. Threshold values of energy resolution for both gamma lines were $(6.68 \pm 0.06) \%$ and $(6.58 \pm 0.06) \%$ respectively.

6. Conclusions

According to the experiment the energy resolutions of the gamma-ray detector based on the scintillation crystal $\text{LaBr}_3(\text{Ce})$ at energy 662 keV from gamma source ^{137}Cs are 2.93% and for energies 478 and 511 keV 3.33 and 3.24 % respectively. Energy resolution thresholds were obtained by Monte-Carlo simulation and are equal 6.68 and 6.58 % respectively. The gamma-ray detector based on scintillation crystal $\text{LaBr}_3(\text{Ce})$ for neutron capture therapy allows to visually identify both gamma lines.

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References

- [1] Goorley J *et al.* 2002 *Med. Phys.* **29**(2) 145–56
- [2] Hamamatsu Photonics K.K. Editorial Committee 2012 *Photomultiplier tube and assemblies for scintillation counting & high energy physics* (Iwata: Hamamatsu Photonics K. K. Electron Tube Division) pp 22-33 (http://www.hamamatsu.com/resources/pdf/etd/High_energy_PMT_TPMO0007E.pdf)
- [3] Simutin A *et al.* 2013 *Instr. Exp. Techn.* **56**(5) 531–5
- [4] Zamenhof R *et al.* 1996 *Int. J. Radiat. Oncol. Biol. Phys.* **35** 383–97