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Energy resolution, peak to total ratio, peak to Compton ratio of cerium bromide crystal scintillator

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ABSTRACT

Background: $CeBr_3$ Inorganic scintillator is a favorite scintillator in various fields, especially in medical imaging and X-rays/gamma rays detectors. One is important before being applied in any application is the fundamental properties that it has to measure such as energy resolution, PTR, PCR, and light yield.

Objectives: In this research, a $CeBr_3$ crystal was carried out trial for calculating the energy resolution, peak to total (PTR), and peak to Compton (PCR) values.

Materials and methods: When high photon energy undergoes with the $CeBr_3$ crystal, the crystal will occur to interact with photon energy by energy's absorptions via the interaction ternary as the photoelectric absorption, Compton scattering, and pair production. The nuclear instrument module (NIM) was used in this experiment. The crystal will generate light and come into a photomultiplier tube (PMT 9256 KB) for amplifying the light signal via the radiation sources as Ba-133, Na-22, Cs-137, and Co-60, which generated the energies at 0.356 MeV, 0.511 MeV, 0.662 MeV, 1.173 MeV, and 1.332 MeV, respectively.

Results: The result found that the energy resolution of $CeBr_3$ showed the energy resolution of $CeBr_3$ crystal showed a linear pattern of inverse the square root of the energy and found the energy resolution values were increased when the photon energy decreased. The PTR and PCR values decreased with increasing energy ranges via experiment of each full energy peak of radiation sources.

Conclusion: From the fundamental properties of $CeBr_3$ crystal showed a good energy resolution and is a possible candidate to apply for any application such as radiation detection and high-energy physics. Anywise, other properties should be also considered, for example, light yield, decay time, and nonproportionality of light yield.

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Introduction

Advantages of high photon energies were widely used in fields such as medicine, academic and scientific, industrial application, nuclear power plant, and so on.[1] Medically, A medical tool that takes advantage of radiation for the patient radiotherapy is an important to appropriate consideration. Positron Emission Tomography (PET) utilizes isotopes that emit positrons that annihilate to produce two 511 keV gamma rays emitted in the back-to-back opposite direction and can be detected quickly by the scintillation detectors.[2] The detector's design is tied to the PET's equipment. The detectors should be designed so that the maximal annihilation photons may be traced along the decay line by specifying the two interaction channels.[3]

Scintillation detectors are the most widely used detectors for determining gamma rays[4] and constitute the foundation of virtually all PET scanners. Other detectors, such as a solid-state photodetector, block detector, continuous gamma camera detector, position-sensitive multichannel photomultiplier tube, depth-encoding detector, and avalanche photodiode, are also applied in PET. Normally, scintillation detectors consist of crystal material that responds with gamma rays and photons of high energy, and properties of these scintillator materials should have a high resolution for identification of full energy peaks. After absorbing energy, they release visible light. After detecting this light, a visible photon detector turns it into an electrical current and occurs imaging in the next process of the PET scan mechanism.[1-3,5,6] The $CeBr_3$ scintillator is one of the most popular to use in various applications because of its very high density effective atomic number and high light output. These properties would be possible to develop for a high-energy resolution scintillation detector, which shows the ability of a detector to identify particles of different energies. Anyway, the basic properties should be considered first such as the peak to total ratio (PTR) which is related to the photopeak area, Compton continuum area, and peak to Compton ratio (PCR) which shows the height of the photopeak and Compton continuum by including energy resolution to keep as a basic physics database.

In this work, the radiation source Ba-133, Na-22, Ce-137, and Co-60 at energies 0.356 MeV, 0.511MeV, 0.662 MeV, 1.173 MeV, and 1.332 MeV were used to experiment for calculating the peak to a total ratio (PTR), and peak to Compton ratio (PCR) of $CeBr_3$ crystal and included the energy resolution.

Materials and methods

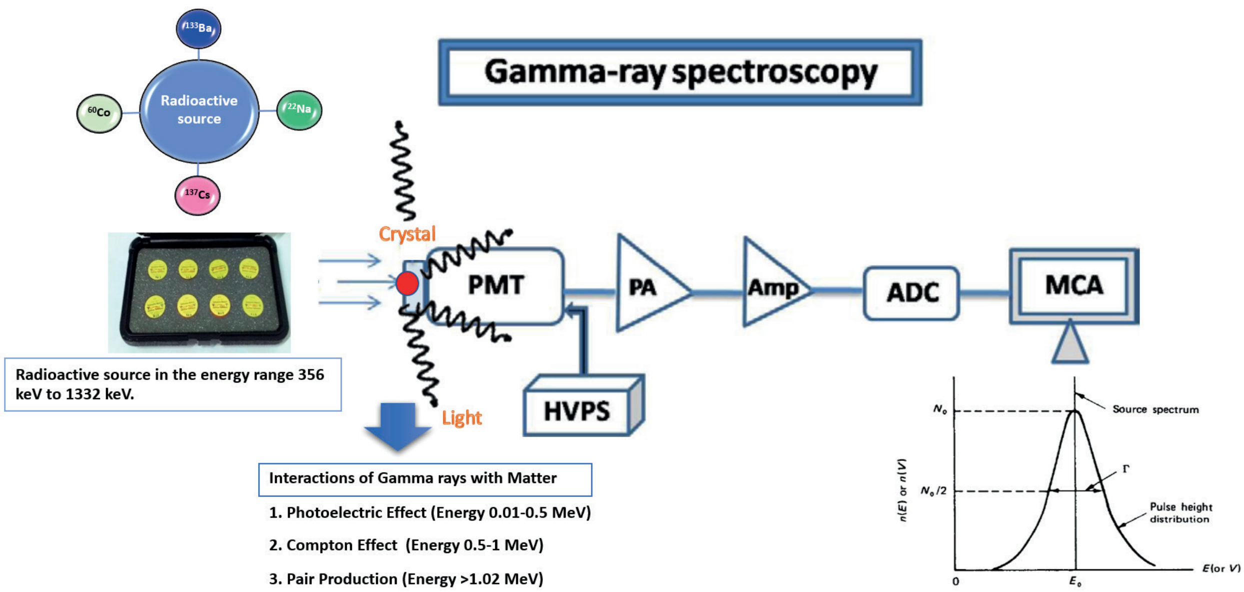

Figure 1 *Measurement process of a $CeBr_3$ crystal.*[6]

The $CeBr_3$ sized 10x10x10 mm^3 from (Kinheng Crystal Co.LTd) is connected with a photomultiplier tube (PMT) by using silicone grease on the top surface of the PMT, and wrapped with black Teflon for protecting against external light. When high photon energy undergoes with the $CeBr_3$ crystal, the crystal will occur to interact with photon energy by energy's absorptions via the interaction ternary as the photoelectric absorption, Compton scattering, and pair production. The crystal will generate light and come into a photomultiplier tube (PMT 9256 KB) for amplifying the light signal, which is an analog signal change to be a digital signal into a multichannel analyzer (MCA). Then, the energy resolution, peak to total ratio, and peak to Compton ratio have experimented via the radiation source as Ba-133, Na-22, Ce-137, and Co-60 at energies 0.356 MeV, 0.511 MeV, 0.662 MeV, 1.173 MeV, and 1.332 MeV, respectively. The energy resolution can be calculated from equation (1), which is the detector's ability to identify particles of energy by E_0 is the energy peak centroid. The full width at half maximum (FWHM) was designated by[6,7]

$$\%R = \frac{FWHM}{E_0} \times 100\% \qquad (1)$$

Peak to total ratio (PTR) is the ratio between the area of the photopeak and the entire area of the spectrum, which may be calculated using the equation: (2).[6,7]

$$PTR = \text{area of photopeak } (N_p)/\text{total area in Compton continuum } (N_t) \quad (2)$$

Peak to Compton ratio (PCR), which may be calculated using the equation, is the ratio of the height of the photopeak to that of the Compton continuum (3).[6,7]

$$PCR = \text{Heigh of photopeak } (C_p)/\text{average heigh of Compton continuum } (C_c) \quad (3)$$

Results and discussion

The energy resolution of $CeBr_3$ experimented at 0.356 MeV, 0.511 MeV, 0.662 MeV, 1.173 MeV, and 1.332 MeV at full energy peak of the Ba^{133}, Na^{22}, Cs^{137}, and Co^{60} via the equation 1. Figure 2 shows the energy resolution of the $CeBr_3$ scintillation detector in the photon energy range of 0.356-1.332 MeV. The results found that the energy resolution of the crystals was responsible for a linear pattern of inverse the square root of the photon energy and found the energy resolution values were increased when the photon energy decreased. The energy resolution result of $CeBr_3$ was reported at 6.7%, 6.4%, 5.6%, 5.4%, and 5.3%, respectively (Figure 3). The peak to a total ratio (PTR) and peak to Compton ratio (PCR) values of $CeBr_3$ crystal at 0.511 MeV to 1.332 MeV of the energies can calculate from peak area on the spectrum of Na^{22}, Cs^{137}, and Co^{60} of full energy peaks by using the equation 2 and 3 (Figure 3). The experimental results of both PTR and PCR values were shown in Table 1. The results illustrate the PTR and PCR values of the crystal decreased with increasing energy due to increasing photon energy affected by the reduction of the photoelectric absorption when compared with the Compton scattering interaction (Figure 4 and Figure 5). As a result, the highest points that showed the absorption peak ratio of each energy are reduced. However, due to the Ba^{133} generated low energy, photoelectric is dominant which appeals to the Compton scattering ratio is very less and affected to the PTR and PCR values of the crystal at 0.356 MeV.

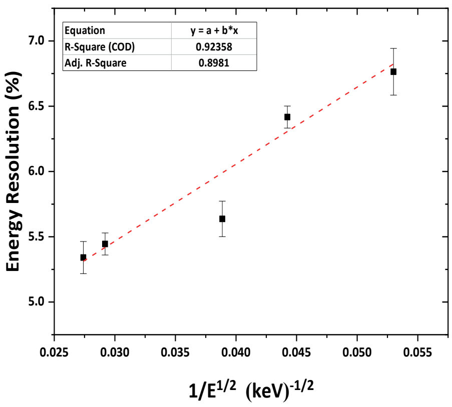

Figure 2 *Energy resolution of $CeBr_3$ crystal measured with Ba-133, Na-22, Cs-137, and Co-60 by the photomultiplier tube 9256 KB.*

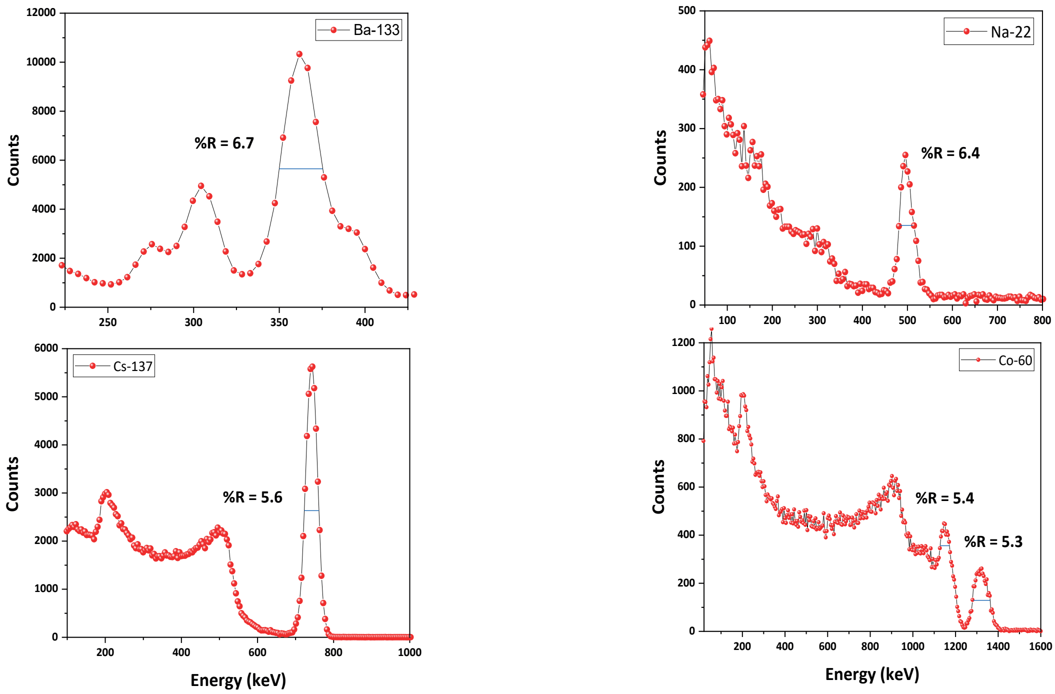

Figure 3 *Spectrum of $CeBr_3$ crystal measured with Ba-133, Na-22, Cs-137, and Co-60 by the photomultiplier tube 9256 KB.*

Table 1 PTR and PCR values of $CeBr_3$ crystal at the energy 0.511 MeV to 1.332 MeV.

Energy (MeV)	PTR	PCR
0.511	0.15	2.53
0.662	0.12	2.00
1.173	0.07	0.90
1.332	0.05	0.53

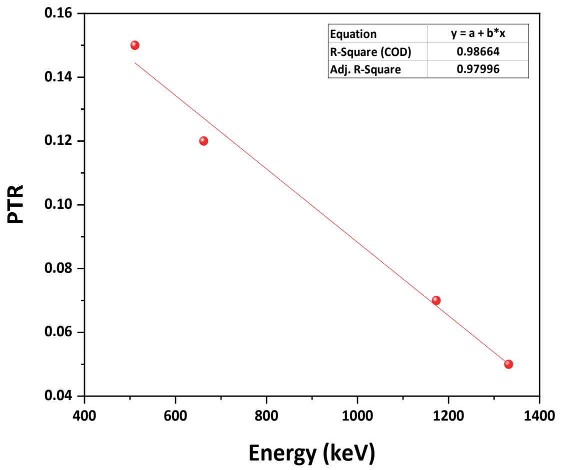

Figure 4 *Peak to total ratio of $CeBr_3$ crystals at 0.511 MeV to 1.332 MeV.*

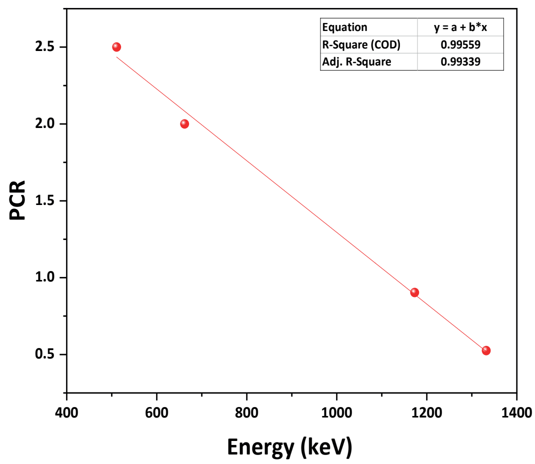

Figure 5 *Peak to Compton ratio of $CeBr_3$ crystals at 0.511 MeV to 1.332 MeV of the energies.*

Conclusion

Successfully of this experimental with $CeBr_3$ scintillation crystal, the radiation source Na-22, Ce-137, and Co-60 was used to experiment for calculating the energy resolution, PTR, and PCR values at 0.356 MeV to 1.332 MeV of the photon energies. The energy resolution of $CeBr_3$ crystal showed a linear pattern of inverse the square root of the energy and found the energy resolution values were increased when the photon energy decreased. The PTR and PCR values showed to decrease with increasing energy ranges. However, it is the investigation of primary scintillation properties, which are fundamental data of scintillation material for manufacturing advanced medical equipment applications such as PET scans in the future.

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References

[1] Verma R, Jain GK, Chougule A. Implementation of safety and security standards for high dose rate brachytherapy sealed radioactive source used in a medical radiation facility. Radiat Med Prot [Internet]. 2020; 1: 166-70. doi.org/10.1016/j.radmp.2020.11.004.

[2] Townsend DW. Positron Emission Tomography/Computed Tomography. Semin Nucl Med. 2008; 38: 152–166. doi: 10.1053/j.semnuclmed.2008.01.003.

[3] Krause P, Rogers E, Birowosuto MD, *et al*. Design rules for Time of Flight Positron Emission Tomography (ToF-PET) heterostructure radiation detectors. Heliyon. 2022; 8: e09754. doi.org/10.1016/j.heliyon. 2022. e09754.

[4] Hosoda M, Iwaoka K, Tokonami S, *et al*. Comparative Study of Performance using Five Different Gamma-ray Spectrometers for Thyroid Monitoring under Nuclear Emergency Situations. Health Phys. 2019; 116: 81-7. doi: 10.1097/HP.0000000000000954.

[5] Tambe V, Kathar U, Raval N, *et al*. Positron emission tomography as a noninvasive tool in pharmacokinetic studies [Internet]. Biopharm. Pharmacokinet. Considerations Vol. 1 Adv. Pharm. Prod. Dev. Res. INC; 2021. doi.org/10.1016/B978-0-12-814425-1.00013-9.

[6] Tsoulfanidis N. and Landsberger S. MEASUREMENT and DETECTION of RADIATION. 4th Ed. CRC Press is an imprint of Taylor & Francis Group, an Informa business; 2015: 273-283.

[7] Limkitjaroenporn P, Hongtong W, Kim HJ, *et al*. PTR, PCR and Energy Resolution Study of GAGG: Ce Scintillator. J Phys Conf Ser. 2018; 970. doi:10.1088/1742-6596/970/1/012016.