Comparative Studies of the Light Yield Non-Proportionality and Energy Resolution of CsI(Tl), LYSO and BGO Scintillation Crystals

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Abstract. This article, for comparison, the non-proportionality of light yield and energy resolution of BGO, LYSO and CsI(Tl) scintillators couple to the R1306 PMT readouts were investigated. At 662 keV from $^{137}$Cs source, the good energy resolution of 7.13% for CsI(Tl) superior than LYSO and BGO scintillators. The energy resolution on gamma-ray energy was also evaluated to expose the scintillator intrinsic resolution parameters. For non-proportionality of light yield, the study showed a light yield non-proportionality 0.35% of LYSO, the value is better than 4.82 % for CsI(Tl) and 1.53 % of BGO scintillators.

Introduction

Scintillation materials have been used in many field, such as, nuclear medicine, medical imaging (CT scanner, PET scanners) and high energy physics. The ideal scintillation material should convert the kinetic energy of the charged particles or gamma-ray into detectable light with high scintillation efficiency. The light yield should be proportional to the deposited energy over as wide a range as possible. As well as, the material should be of good optical quality and able to be manufactured in sizes large enough to be useful as a practical detector. In addition, the medium should be transparent to the wavelength of its own emission for good light collection. The decay time of the induced luminescence should be short so fast signal pulses can be generated but still no material meets all these criteria [1]. Under these conditions, fundamental properties of scintillation material are very important for example mass attenuation coefficient, energy resolution and non-proportionality of light yield. Non-proportionality and energy resolution collect several data of scintillators by Moszynski [2,3] and was found the non-proportionality appears to be the fundamental limitation of the energy resolution. Moreover, Dorenbos et al. [4], Taulbee et al. [5], Mengesha et al. [6], Valentine et al. [7], Balcerzyk et al. [8], Kapusta et al. [9], also have been studies on non-proportionality of light yield crystals.

The aim of this work, to characterize and comparative the non-proportionality of light yield and energy resolution of the scintillators Bi$_4$Ge$_3$O$_{12}$ (BGO), Y:Lu$_2$SiO$_5$ (LYSO) and CsI(Tl) measured with different gamma energies.

Experimental

LYSO, CsI(Tl) and BGO scintillators, from the dimension 10×10×10 mm$^3$ and 10×10 mm$^2$ of LYSO, CsI(Tl) and BGO respectively were used in this experimental. All measurements were performed at room temperature. From Fig. 1, the photomultiplier tube (PMT) an emission spectrum
peaks at 420 nm was produced by Hamamatsu Photonics number R1306 and using silicone grease coupled to the PMT a diameter 51 mm. The PMT with all crystals were wrapped in several layers of white Teflon tape and wrapped with black tape and covered with aluminum housing in order to minimize light leak. These were carried out using standards on nuclear instrument modules (NIM) for all measurements. The signal output from the PMT anode was passing through a Canberra 2007B preamplifier and was sent to Canberra 2022 an amplifier. A shaping time constant in the amplifier was used at 0.5 in all measurements. The energy spectra analyzed with Gamma Acquisition & Analysis software of Canberra MCA to record data.

In this article, undertaken a comparative study on the non-proportionality of light yield and energy resolution of BGO, LYSO and CsI(Tl) scintillators were measured at gamma energies in range 59.5 keV to 1332 keV by Bertolaccini method [10]. This experimental were used the different radioactive source, as follow, $^{241}$Am, $^{133}$Ba, $^{22}$Na, $^{137}$Cs, $^{60}$Co.

**Results and discussion**

**Energy Spectra of scintillation crystals.** Typical energy spectrum, the scintillators CsI(Tl), LYSO and BGO coupled R1306 PMT are shown in Fig. 2, measured with gamma energies at 662 keV ($^{137}$Cs source). The energy resolution was 7.13% for CsI(Tl) superior than 10.31% for LYSO and 16.59% for BGO crystals. Under the photpeak area, BGO show of the very large area than CsI(Tl) and LYSO crystals to indicate that the very high photoelectric interaction of BGO crystal.

**Fig. 1.** The diagram of gamma ray spectroscopy measured with BGO, LYSO and CsI(Tl) scintillators.

**Fig. 2.** Typical energy spectrum of 662 keV gamma rays from a $^{137}$Cs source measured with BGO, LYSO and CsI(Tl) scintillators.
**Energy resolution.** The energy resolution $(\Delta E/E)$, a full energy peak measured with a scintillator coupled to a PMT can be written as [11]

$$(\Delta E/E) = (\delta_{sc})^2 + (\delta_p)^2 + (\delta_{st})^2,$$

where $\delta_{sc}$ is the intrinsic resolution of the crystal, $\delta_p$ is the transfer resolution and $\delta_{st}$ is the statistical contribution of PMT to the resolution. In modern scintillation detectors the transfer resolution is negligible compared to the other components of energy resolution. The statistical uncertainty of the signal from the PMT can be described as [11]

$$\delta_{st} = 2.355 \times 1/N^{1/2} \times (1 + \varepsilon)^{1/2},$$

where $N$ is the number of the photoelectrons and $\varepsilon$ is the variance of the electron multiplier gain, equal to 0.1 for an R1306 PMT. Overall energy resolution and PMT resolution can be determined experimentally. If $\delta_p$ is negligible, intrinsic resolution $\delta_{sc}$ of a crystal can be written as follows [11]

$$(\delta_{sc})^2 = (\Delta E/E) - (\delta_{st})^2.$$
Table 1. Detailed experiment of the 662 keV energy resolution and density for CsI(Tl), LYSO and BGO scintillators.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Scintillation materials</th>
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<tbody>
<tr>
<td></td>
<td>BGO</td>
</tr>
<tr>
<td>Δ E/E [%]</td>
<td>16.59</td>
</tr>
<tr>
<td>δsc [%]</td>
<td>15.28</td>
</tr>
<tr>
<td>δst [%]</td>
<td>6.47</td>
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<tr>
<td>Density [g/cm³]</td>
<td>7.11</td>
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</tbody>
</table>

**Non-proportionality of light yield.** The Non-proportionality of light yield curve of CsI(Tl), LYSO and BGO scintillators, defined as the ratio scintillation light yield per energy unit is plotted relative to the light yield at 662 keV energy of the $^{137}$Cs source. Figure 4 over the energy range from 59.5 keV to 1332 keV, the non-proportionality is about 0.86 % of LYSO, which is better than that of about 4.82 % for CsI(Tl) and 1.53 % of BGO. These properties LYSO scintillator is good proportionality all of gamma-ray energy range than BGO and CsI(Tl) scintillator.

![Fig. 4. Non-proportionality of light yield of CsI(Tl), LYSO and BGO scintillators.](image_url)

**Summary**

In this research, the scintillation properties of CsI(Tl), LYSO and BGO scintillators were studied and compared. The results show that, the best energy resolution of 7.13% for CsI(Tl) superior than LYSO and BGO scintillators was measured with the R1306 PMT. The intrinsic resolution of all scintillators showed the noise and statistical contributions were small and the measured energy resolution was mainly affected by the intrinsic resolution over the whole energy range. The LYSO scintillator is a good proportionality all of gamma-ray energies range more than CsI(Tl) and BGO scintillators.

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