# A Trilayer Phoswich Arrangement for the discrimination of Thermal Neutrons and Gamma Radiation

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## Introduction

Thermal neutron detection plays a critical role in identifying nuclear threats, detecting illicit nuclear material trafficking, and conducting basic research such as neutron scattering experiments [1]. Since neutron flux is often accompanied by gamma radiation, distinguishing between thermal neutrons and gamma radiation is essential. In recent years, pulse shape discrimination (PSD) methods have gained attention for their improved accuracy across all energy ranges compared to pulse height discrimination (PHD) techniques [2]. Scintillators like CLYC and NaIL have been developed to differentiate between thermal neutrons and gamma radiation. However, issues such as crystal growth challenges and the low thermal neutron detection efficiency in compact detector volumes remain significant limitations. One alternative approach has been the development of phoswich detectors, which consist of multiple scintillators stacked in sequence. These detectors can discriminate between different types of radiation—such as alpha, beta, and gamma rays—based on their distinct scintillation decay pulses. Various scintillator combinations have been explored to achieve neutron-gamma discrimination, including CsI:Tl + $Gd_3Ga_3Al_2O_{12}$:Ce [3], $CeBr_3$ + GGAG:Ce [4], and NaI:Tl + LiI:Eu [5]. However, these combinations have the problem with superimposition of low energy background and thermal neutrons in scintillation decay pulse.

In this study, we developed a phoswich detector using three scintillators: $Bi_4Ge_3O_{12}$ (BGO), LiI:Eu, and $LaBr_3$:Ce. These materials were selected for their distinct decay times, which allow for effective discrimination between thermal neutrons, gamma rays, and suppress the low energy background. BGO, with a decay time of approximately 300 ns for gamma radiation is commonly used for detecting both gamma rays and charged particles. $^6$LiI:Eu, known for its high thermal neutron sensitivity, has a decay time of around 1 µs [6]. $LaBr_3$:Ce, with a decay time of about 21 ns and excellent energy resolution (less than 4% at 662 keV), is ideal for gamma spectroscopy [7]. This phoswich detector can efficiently discriminate thermal neutrons from low & high energy gamma rays. Additionally, the arrangement reduces low-energy gamma interference in LiI:Eu, thus minimizing background and enhancing accuracy in neutron detection.

## Experimental

As crystal growers, we successfully grew single crystals of BGO using the Czochralski technique, and LiI:Eu and $LaBr_3$:Ce using the Bridgman technique. These crystals were processed and prepared for detector fabrication with the following dimensions: LiI:Eu had a thickness of approximately 2 mm, BGO around 1 mm, and $LaBr_3$:Ce approximately 20 mm, with all crystals having a diameter of 1 inch. The grown crystals underwent thorough characterization of their optical and scintillation properties. Transmission spectra were recorded using a SHIMADZU UV-VIS-NIR spectrophotometer, covering the wavelength range of 200-800 nm. The radioluminescence emission spectra were measured by irradiating the crystals with a Mini-X X-ray tube, and the emitted light was detected using an Avantes ULS-3648 spectrometer in the 200-700 nm range. For scintillation characterization, each crystal was coupled to Hamamatsu R6095 photomultiplier tube (PMT) using optical grease, and measurements were performed at room temperature. The scintillation decay times were evaluated using a Tektronix MD03102 oscilloscope, with $^{60}$Co as the irradiation source. Additionally, the neutron response of the LiI:Eu scintillator was tested using a $^{241}$Am-Be source within a standard thermal assembly in graphite. For pulse shape discrimination (PSD) measurements, a CAEN DT-5790 digitizer was employed, enabling effective discrimination between various types of radiation.

## Results and Discussion

Based on emission and transmission spectra, the optimal arrangement of the scintillator single crystals is as follows: LaBr$_3$:Ce should be mounted in the PMT, followed by LiI:Eu and then BGO. Both LiI:Eu and LaBr$_3$:Ce are hygroscopic, hence BGO serves as a window material capable of detecting or stopping low-energy photons (X-rays). The scintillation decay characteristics of BGO, LiI:Eu, and LaBr$_3$:Ce scintillators are distinct from each other as shown in Fig. 1. Therefore, interactions of different radiation in these scintillators can be differentiated using the digital pulse shape discrimination (PSD) method

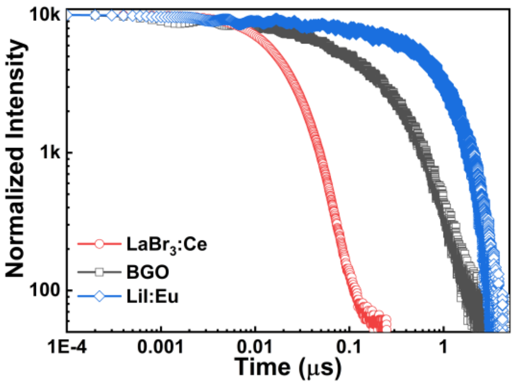

**Fig. 1** Scintillation decay profile of LaBr$_3$:Ce, BGO and LiI:Eu for $^{60}$Co.

Further, we have tested the phoswich detector for the pulse shape discrimination in the presence of mixed gamma and neutron field. Figure 2 depict the PSD 2D plot in a mixed neutron and gamma field. In this arrangement, low-energy photons, thermal neutrons, and high-energy gamma rays are segregated into three distinct PSD bands. The PSD band centered at 0.8 PSD parameter is attributed to thermal neutron interaction in LiI:Eu, the middle band is associated with low energy photons interaction in BGO, and the lower band corresponds to high-energy gamma interaction in LaBr$_3$:Ce.

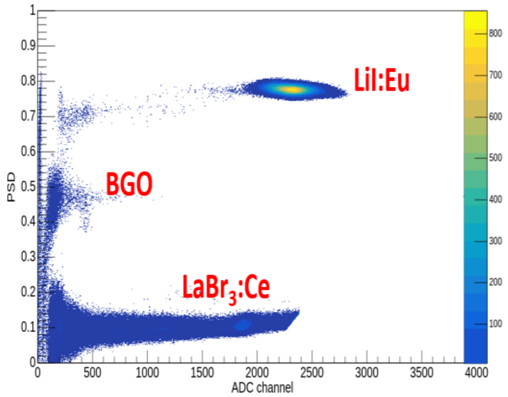

**Fig. 2** PSD 2D histogram of 3-layer phoswich arrangement.

## Conclusion

A phoswich detector consisting of BGO (front), LiI:Eu (middle), and LaBr$_3$:Ce (near the PMT) was developed for discriminating between low-energy photons, thermal neutrons, and high-energy gamma radiation.

## References

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