Characterization of CeBr$_3$-NaI(Tl) phoswich detector for PARIS collaboration

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Introduction

For study of high energy γ-rays in reactions involving low intensity radioactive ion beams (RIB), a high efficiency detector array PARIS (Photon Array for the Studies with Radioactive Ion and Stable beams) is being developed [1, 2]. The PARIS array is based on the concept of phoswich detector, where a LaBr$_3$(Ce) crystal ($2''\times2''\times2''$) is optically coupled to a NaI(Tl) crystal ($2''\times2''\times6''$) and both detectors are read out by a single Photo Multiplier Tube (PMT). The phoswich detector design was developed by Saint-Gobain Crystals. Recently, CeBr$_3$ detectors are also shown to be comparable to LaBr$_3$(Ce) detector, in terms of energy and time resolution [3]. Moreover, the CeBr$_3$ is free from internal activity which can be advantageous when low background levels are desired. With this motivation, the PARIS collaboration has also explored the CeBr$_3$-NaI(Tl) phoswich detector configuration. This paper reports the test results of the CeBr$_3$-NaI(Tl) phoswich detector. A comparison with the LaBr$_3$(Ce) -NaI(Tl) phoswich is also presented.

Experimental Details and Data analysis

Four CeBr$_3$-NaI(Tl) phoswich detectors manufactured by M/S Scionix, Netherlands, were tested at TIFR, Mumbai using different radioactive sources. Each detector was coupled to R13089-100 PMT, with a typical operating bias of -1 kV. Detectors were also tested with a R7723-100 PMT, which is a PARIS standard. Typical pulses in CeBr$_3$-NaI(Tl) phoswich detector for 662 keV γ-ray are shown in Fig. 1. It can be seen that pulses corresponding to CeBr$_3$ (rise time ∼12 ns) and NaI(Tl) are clearly separated. The data have been acquired using V1730 CAEN digitizer (2 Vpp, 14-bit, 500 MS/s) and digitTES-4.2.6 data acquisition software [5]. This digitizer, specially developed for the PARIS collaboration, has an in-built constant fraction discrimination (CFD) algorithm and gives the time stamp, pulse shape discrimination (PSD) and energy information [5]. The C++ based ROOT framework [6] is used for data analysis. Data were taken with $^{137}$Cs and $^{60}$Co sources for individual pulses, CeBr$_3$-NaI(Tl) phoswich detector.

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\[
\text{PSD} = \frac{Q_L - Q_S}{Q_L} 
\]

A 2-dim plot of PSD vs $Q_L$ is shown in

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Fig. 2, where separate band corresponding to full energy deposition in CeBr$_3$ and NaI(Tl) as well as mixed events are clearly visible.

![Image of a PSD spectrum with $^{60}$Co source in Detector D.](image)

**FIG. 2:** A PSD spectrum with $^{60}$Co source in Detector D.

Energy spectra for CeBr$_3$ and NaI(Tl) detectors are obtained by suitable gates on PSD and are shown in the Fig. 3. The measured resolution for all the detectors are tabulated in Table I. It also lists ‘peak to valley ratio’, defined as ratio of peak intensity of 1173 keV to intensity at valley point between two peaks in the $^{60}$Co spectrum, which is an additional figure of merit.

**TABLE I:** Resolution of CeBr$_3$ and NaI(Tl) crystals.

<table>
<thead>
<tr>
<th>Detectors</th>
<th>Measured (%)</th>
<th>Peak to Valley ratio</th>
</tr>
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<tbody>
<tr>
<td>CeBr$_3$</td>
<td></td>
<td>NaI(Tl)</td>
</tr>
<tr>
<td>A</td>
<td>4.9</td>
<td>7.6</td>
</tr>
<tr>
<td>B</td>
<td>5.1</td>
<td>8.4</td>
</tr>
<tr>
<td>C</td>
<td>5.9</td>
<td>8.2</td>
</tr>
<tr>
<td>D</td>
<td>4.7</td>
<td>8.0</td>
</tr>
</tbody>
</table>

*aError in resolution is $\sim$ 0.5%.

It is observed that one of the detector (C) has relatively poorer resolution. Similar resolution was obtained with Hamamatsu R7723-100 PMT.

A comparison of $\gamma$-ray spectra using LaBr$_3$(Ce)-NaI(Tl) [4] and CeBr$_3$-NaI(Tl) phoswich detectors is shown in Fig. 4. The internal activity in LaBr$_3$ due to $^{138}$La is clearly visible as peak at 1468 keV.

In summary, measurements of CeBr$_3$-NaI(Tl) phoswich detectors have been carried out with two different PMTs. On the average, the resolution of CeBr$_3$ ($\sim$ 5% at 662 keV) is only slightly worse than that of LaBr$_3$ ($\sim$ 4.5% at 662 keV). In high energy experiments, where the recoil velocity is large and results in significant Doppler broadening, this difference in the intrinsic resolution may not be significant. Moreover, CeBr$_3$ being free of internal activity, has lower background. Thus, CeBr$_3$-NaI(Tl) phoswich detector is shown to be a viable option for the PARIS array.

**Acknowledgments**

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**References**