# Efficiency of $CeBr_3$ detector: Simulations and measurements using a positron emitter

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## Introduction

Cerium Bromide ($CeBr_3$) scintillation detector has emerged as one of the best scintillation detectors having properties similar to that of Cerium doped lanthanum halide detectors. Due to its high light output (~68 photons/keV), high effective atomic density (~5.2 g/cm$^3$), good energy resolution (~4% at 662 keV), high stability in light output during temperature changes, possibility for growing in large volume, excellent timing resolution (~90ps at 511 keV), etc. $CeBr_3$ has become the preferred scintillator in many applications [1-2]. One of the advantages of $CeBr_3$ over lanthanum halides is its higher radio-purity. It has been reported that the overall internal radioactivity of $CeBr_3$ was 7-8 times less than that in $LaBr_3$:Ce and $LaCl_3$:Ce detectors, making $CeBr_3$ more sensitive to low count rate applications [3]. There is an ongoing global effort to understand the overall performance of the $CeBr_3$ detector. In the literature, very few data is available on energy dependent absolute efficiency (both total detection and photo-peak) of $CeBr_3$ detector. In particular, no data is available on the detection efficiency when the radioactive source is placed close to the detector front surface.

The efficiency determination using mono-energetic gamma-rays source is quite easy and can be done from photo peak area and the activity of the source. Due to lack of good number of mono-energetic gamma-ray sources in laboratory, we are bound to use sources that emit two more gamma rays in cascade. In case of double gamma-ray emitters, due to simultaneous detection of both gamma rays an additional peak arises in the energy spectrum, known as true coincidence summing. This situation generally occurs when the time difference between the emission of cascade gamma rays is much smaller than the resolving time of detectors. Subsequently, there will be loss of counts from the individual photo-peaks making accurate determination of absolute efficiency (both total detection and photo-peak) inaccurate. In order to calculate true efficiencies accurately, it is compulsory to correct the apparent counts for true coincidence summing. The effect of true coincidence summing depends on the parameters related to detector and radioactive source such as gamma energies, source-detector geometry, angular correlation between gamma rays, decay intensities of gamma rays, etc. Variety of techniques have been proposed in the literature for coincidence summing correction.

When a positron emitter, such as $^{22}$Na, is used for absolute efficiency determination, then the correction method has to include the absorption properties of materials surrounding the source in order to take into account the number of 511 keV gamma rays emitting due to interaction between positron and material surrounding the source [4]. The method was successfully tested to determine the absolute efficiencies of a large volume $LaBr_3$:Ce detector corresponding to gamma energies of 511 keV and 1275 keV directly from the areas under individual photo-peaks and sum-peak in the $^{22}$Na energy spectrum. In the present work, we aim to check the validity of this method to calculate the absolute efficiency of a $CeBr_3$ detector. The studies involve experimental measurements and realistic simulations of coincidence summing correction factor in $CeBr_3$ scintillation detector.

## Simulations and measurements

GEANT4 toolkit has been used in the present work to simulate the response of a 1″ × 1″ cylindrical $CeBr_3$ detector for gamma rays emitted from $^{22}$Na. The geometrical information, as provided by the manufacturer, describing the $CeBr_3$ crystal was incorporated in the detector construction class. The general particle source (GPS) module, low-energy EM package and radioactive-decay module have been used in the simulations. The simulations were carried out for large number of events (of the order of $10^6$), under the assumption of an isotropic point source placed at the center of the front surface of the detector, taking all possible physics processes into account. The effect of plastic is prominent in case of $^{22}$Na, as expected, due to the interaction of positrons with the atomic electrons in the plastic that results in the production of more number of 511 keV gamma rays. As the simulations have been carried out for very large number of events, the statistical uncertainty has been found to be negligible. We have also simulated the efficiencies of the detector for mono-energetic gamma rays of energies 511 keV and 1275 keV for comparison.

Experimentally, we have studied coincidence summing in a 1"×1" $CeBr_3$ detector (supplied by Scionix company) by using a calibrated $^{22}$Na point source. The source was at the center of 25 mm diameter × 5 mm thick plastic disc and covered with 1mm thick plastic lid.

## Data Analysis

From the observed count rates corresponding to 511 keV, 1275 keV and 1786 keV, the corrected absolute efficiencies for 511 keV and 1275 keV gamma rays were calculated using [4]

$$\varepsilon_{p,511} = \frac{\varepsilon_{\min} + \varepsilon_{\max}}{2}$$

where

$$\varepsilon_{\min} = \frac{N'_{1786}}{2N'_{1275}}\left[\left(\frac{1}{2I_{\beta+}} - 1\right) + \sqrt{\left(\frac{1}{2I_{\beta+}} - 1\right)^2 + \frac{4N'_{511}N'_{1275}}{AI_{\beta+}N'_{1786}}}\right]$$

$$\varepsilon_{\max} = \frac{(N'_{511} - N'_{1275}) + \sqrt{(N'_{511} - N'_{1275})^2 + 4AN'_{1786}}}{4AI_{\beta+}}$$

and
$$\varepsilon_{p,1275} = \frac{N'_{1786}}{2AI_{\beta+}\varepsilon_{p,511}}$$

The net uncertainties in the corrected efficiencies can be estimated from the uncertainty due to the method and the statistical uncertainty, resulting from the propagation of uncertainties in the count rates obtained from the photo-peaks and sum-peak and in the source activity A.

## Results and Discussion

Fig. 1 shows the measured spectrum of $^{22}$Na source recorded using $CeBr_3$ detector. A sum peak at 1276 keV can be clearly seen in the figure. From the careful analysis of spectrum and using above-mentioned equations, we have calculated absolute corrected efficiencies and found to be in good agreement with those obtained using simulations made using $^{22}$Na source and also using monoenergetic gammas of similar energies. Fig.2 shows the simulated plot of photo peak efficiency versus energy. Detailed measurements and simulations will be presented and discussed.

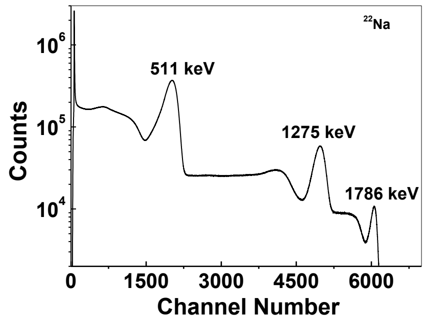


Fig.1: Measured spectrum of $^{22}$Na recorded using $CeBr_3$ detector.

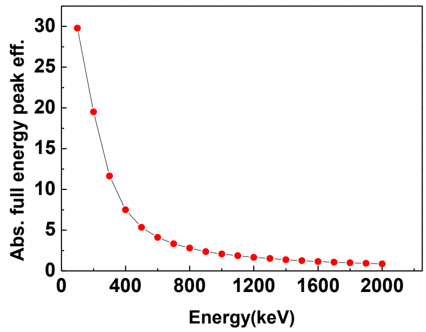


Fig.2: Simulated plot of photo peak efficiency versus gamma energy

## References

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[2] Litvak *et al.*, NIM-A 848 (2017) 19.
[3] Naqvi *et al.*, Appl. Rad. Isot., 114 (2016) 50.
[4] Dhibar *et al.*,Appl. Rad. Isot.,118 (2016) 32.