Characterization of a HPGe detector with γ and neutron sources for possible use in background measurements for CEνNS experiment

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Introduction

Background understanding and mitigation are relevant in rare-event physics-search experiments, including searches for Coherent Elastic Neutrino-Nucleus Scattering (CEνNS) [1]. The sensitivity of these measurements are primarily determined by the background level within the region of interest (ROI). In CEνNS studies, the predominant background arises from radioactive γ-rays radiation. Moreover, cosmic muon-induced interactions with shielding materials around the detector generate an irreducible secondaries of γ-rays and neutrons. Consequently, it is essential to mitigate these backgrounds effectively. To achieve this, the detector parameters need to be optimized through detailed measurements of energy responses with γ-rays and neutron sources that cover the energy range of interest. This study focuses on the characterization of a high-purity germanium (HPGe) detector with a photopeak efficiency of 0.25%, where the radioactive sources are placed within a composite shielding of lead (Pb) and copper (Cu). The energy response of the HPGe detector was simulated using GEANT4 [2] with both γ and neutron sources, and the simulated results were compared against experimental data.

Experimental detail

A HPGe detector (Model: GC3018) weighing ~1 kg, with a diameter of 61.7 mm and a length of 40 mm, is encased in a 1.5 mm thick aluminum housing. This assembly is further shielded by a composite layer of 10 cm thick lead (Pb) and 2 cm thick copper (Cu) plates and is mounted on a base structure, as shown in Fig. 1. A reverse bias voltage of −2900 V was applied to the detector using an integrated unit from CANBERRA, that consists of the power supply, digital amplifier, and MCA.

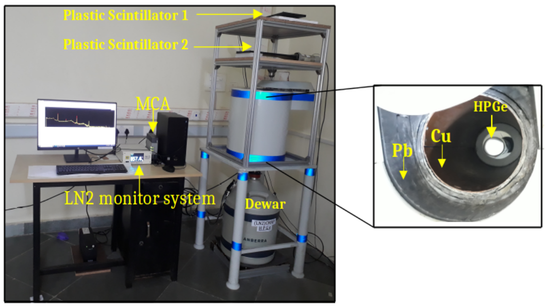

FIG. 1: Experimental set-up of Gamma ray spectroscopy at NISER.

Data acquisition and control is performed by the software package Genie 2000 from Mirion Technologies [3]. The pre-amplifier (Model: IPA-SL10) output is connected to shaping amplifier with 10.8 μs shaping time. The output of the shaping amplifier is connected to analog input of a 14-bit flash analog to digital converter (ADC). Data analysis was carried out using ROOT [4].

Results and discussion

A detailed analysis of the experimental spectrum was performed. Absolute photopeak efficiency (ϵ_γ) is defined as the ratio of counts in a photopeak to the number of γ emitted by the source. As efficiency varies with the γ-energy (E$_\gamma$), therefore, efficiency calibration is carried out using different radioactive γ-rays sources, and the efficiency corresponding to γ is calculated from the formula,

$$\epsilon_\gamma = \frac{Y}{I_\gamma \times A(t) \times T} \quad (1)$$

where, I_γ is the absolute intensity, Y is area under the photopeak, $A(t)$ is the activity of radioactive

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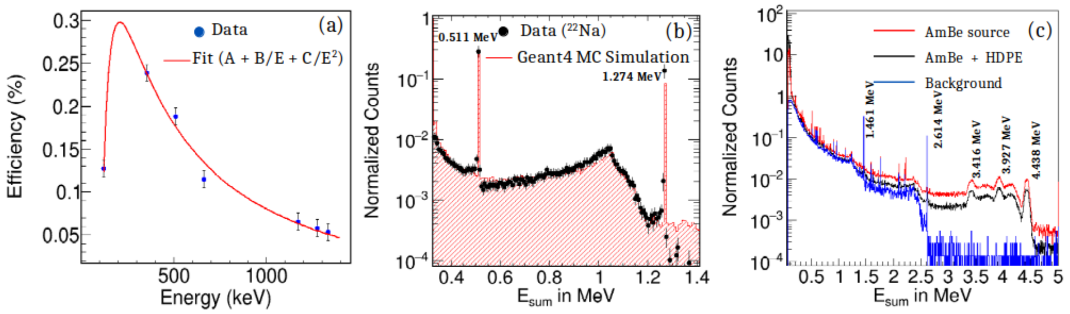

FIG. 2: (a) Energy dependent efficiency curve in HPGe detector. (b) Data-MC comparison of γ response with ^{22}Na source. (c) Experimental γ-spectrum of neutron interactions From AmBe source with HPGe detector.

source at the time of experiment and T is the time interval. Fig. 2 (a) shows the energy dependent efficiency of HPGe detector and the formula used to fit the efficiency with photopeak energy E is given by,

$$\epsilon(E) = A + \frac{B}{E} + \frac{C}{E^2} \tag{2}$$

We obtained a photopeak efficiency of 0.25% for the HPGe detector at 356 keV. A GEANT4-based Monte Carlo (MC) simulation framework was developed to investigate the γ response of the HPGe detector, which was then compared with the measured response for a ^{22}Na source after background subtraction, as shown in Fig. 2(b). A reasonable agreement was observed between the overall spectral shape, including the Compton edge, of the MC simulation and the efficiency-corrected experimental results.

Interactions of neutrons with a high-purity germanium detector were studied experimentally and by simulations using the GEANT4. Elastic and inelastic scattering of fast neutrons as well as neutron capture on Ge nuclei were observed. Fig. 2 (c) shows the comparative energy distributions due to neutron between with and without HDPE shielding. In addition, peaks due to inelastic scattering of neutrons on Cu and Pb nuclei, including the well-known peak of ^{208}Tl at 2.614 MeV, were also observed.

Since natural radioactive gamma background terminates at the 2.614 MeV (^{208}Tl), we used a 1 mCi AmBe source to shine 4.438 MeV gamma rays on the HPGe detector to extend its calibration upto 5 MeV. The first and second escape peaks can also be observed in the spectrum shown in Fig. 2(c).

Conclusion and outlook

The energy-dependent efficiency of the HPGe detector was evaluated to be 0.25% at 356 keV. The gamma energy response was benchmarked against a GEANT4-based Monte Carlo (MC) simulation using a ^{22}Na source.

Additionally, experimental investigations with neutron activation of shielding materials using high density polyethylene (HDPE) sheets with AmBe source and muon induced background is being done. This comprehensive study will significantly enhance the ability to evaluate the backgrounds at experimental sites looking for CEνNS using the HPGe detector.

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