Modeling of an electrically cooled HPGe detector

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Introduction

The suppression of surrounding background is of paramount importance for the rare event experiments such as neutrinoless double beta decay and dark matter experiment. Such measurements are carried out in close geometry for higher efficiency [1]. Modern electrically cooled HPGe detectors are suitable for long term counting and low background spectroscopy in remote underground location. Therefore, the CRADLE (Cryocooled detector for RAre Decay and Low background Experiment) has been set up and characterized. This paper presents the details of the detector model and simulations for close geometry efficiency and long term stability.

Experimental Details & Data Analysis

The HPGe detector is GEM (GEM30P4-83-RB) series coaxial (p-type) detector with CFG-X-COOL-III-230 cooler having the crystal size $\sim$ 6 cm (dia) $\times$ 6 cm. The detector is specially designed for low background measurement with the external carbon fiber body (1.6 mm thick). The detector is surrounded by low activity Pb shield (5 cm of <0.3 Bq/kg & 5 cm of <19 Bq/kg). It has a provision to add annular CsI/BGO Compton shield. The data is acquired using CAEN DT6724 digitizer (14-bit, 100 MS/s) and it is analyzed in C++ based Root framework [2] and LAMPS [3].

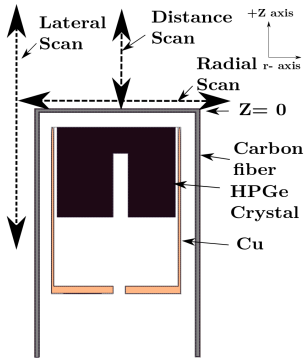

FIG. 1: A schematic of detector showing the scanning coordinates.

The resolution of the detector is $\sim$ 2.1 keV at 122 keV and 2.5 keV at 1408 keV.

TABLE I: Sources used for different scan.

Scan	Sources	Energy (keV)
Radial Scan (at z = 5 mm)	^{241}Am	59
	^{57}Co	122
	^{65}Zn	1115
Lateral Scan (at r = 50 mm)	^{241}Am	59
	^{57}Co	122
	^{65}Zn	1115
Distance Scan	^{241}Am	59
	^{57}Co	122
	^{65}Zn	1115
	^{54}Mn	835
	^{51}Cr	320
	^{60}Co	1173, 1332
	^{152}Eu	122 to 1408

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For the modeling of the detector, measurements are performed over radial, lateral and distance scan. The orientation of scan shown in fig. 1. The various measurements were done with different sources, as mentioned in Table I.

For the top and side dead layer thickness measurements, two special collimators were used. The one with a straight (C_0) and another at an angle 30^0 (C_{30}) with respect to z-axis having narrow hole (dia $\sim$ 1 mm). The γ-ray yields of 122 keV ($Y(C_0)$ & $Y(C_{30})$) were measured with C_0 and C_{30} on top and side of the detector. The ratio of $Y(C_0)$ and $Y(C_{30})$ is used to determine top and side dead layer thickness. The front gap & initial estimate of crystal Radius-Length (R-L) was obtained from distance measurement with both mono and poly energetic sources. The poly-energetic sources were placed at a distance greater than 10 cm. The radial scan and lateral scan ($\sim$ z=5 mm) are used to optimize the volume using 1115 keV γ- ray. The hole radius & length is taken as specified by the manufacturer. Monte Carlo (MC) simulations are done with Geant4 tool kit [6]. The model is benchmarked with [4, 5]. The relative deviation (σ_R) is used as convergence parameter between experimental and simulation data.

$$\sigma_R = \frac{1}{n}\sum_{i=1}^{n}\frac{\epsilon_i^{exp} - \epsilon_i^{simu}}{\epsilon_i^{simu}} \qquad (1)$$

TABLE II: The optimized detector parameters.

Detector parameter	Nominal (mm)	optimized (mm)
Crystal Radius (R)	58.7	54.7
Crystal length (L)	59.7	54.7
Hole radius (h)	4.35	4.35
Top dead layer (t_d)	0.0	1.2
Side dead layer (t_s)	0.7	1.5
Side dead layer (t_s)	0.0	4.0
Front gap (g)	4	5
Top carbon fiber	1.6	1.6
side carbon fiber	0.9	0.9
Cu cup thickness	3.0	3.0

The optimized detector parameters obtained with initial simulation is shown in table II. These are consistent with observed 20% relative deviation in overall efficiency with respect to manufacturer data.

With the optimized parameter, efficiency is plotted against distance which is consistence within 1-5% relative deviation (fig. 2) .

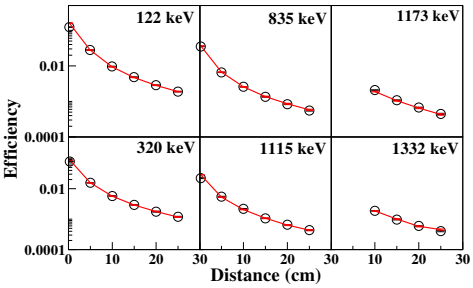

FIG. 2: The distance scans with optimized parameter for E_γ = 122 keV, 320 keV, 835 keV, 1115 keV,1173 keV, 1332 keV

During the past two years this detector is being continuously used for radio purity measurements and other spectroscopic studies. It has been found to be stable.

Summary

CRADLE is setup at TIFR using a cryocooler based detector for radiation background studies related to rare decay. For efficiency determination in close geometry, Geant4 based model is developed.

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