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Preliminary Study of Double Beta Decay: Simulation of $CaMoO_4$ Scintillation Detector Response Function to the Gamma Ray Radiation

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Abstract

$CaMoO_4$ crystal is a material candidate for the scintillation detector and double beta decay experiment to determine a neutrino mass. The objective of this work is to analyze the response function of $CaMoO_4$using Monte Carlo GEANT4 simulation. Penelope-low energy method was used as an interaction type for the electromagnetic process. The simulation results show that the presence of the photopeak energies of gamma ray from Cs-137, Co-60 and K-40 sources can be identified and observed in the energy 0.662 MeV, 1.17 MeV, 1.33 MeV and 1.5 MeV. The photoelectric cross section interaction of $CaMoO_4$is lower than NaI(Tl), but in other hand the incoherent cross section is vice versa.

Keywords: Scintillation, $CaMoO_4$, GEANT4, Gamma ray

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1. Introduction

Double beta decay (DBD) is important source information about the fundamental neutrinos character such as neutrino mass. ^{100}Mo is a material element for the neutrinoless double beta decay (0νDBD) searching except for the ^{82}Se, ^{116}Cd and ^{76}Ge elements [1,2]. As a detector material, $CaMoO_4$is a promising material candidate for the scintillation detector and double beta decay experiment to determine a neutrino mass.

In order to analyze the presence of 0νDBD peak, the information about the detector response function (DRF) is an important in the identification of the peak energy, especially in the presence of the internal and the external background radiation. Computer simulation could be done as a preliminary step for analyzing the DRF characteristic of a detector material and Monte Carlo simulation is one approach that can be applied.

Monte Carlo simulation has been established as an appropriate method for modeling and useful for predicting the experiment results, especially for validation of the detector model [3]. In the previous study, we have successfully simulated the DRF of NaI(Tl) scintillation crystal using Penelope Monte Carlo GEANT4 [4]. Furthermore, in this work we focus to study the response function characteristic of $CaMoO_4$crystal detector to the gamma ray radiation. The work was conducted based on the Monte Carlo simulation method using the GEANT4 simulation toolkit.

2. Methodology

2.1. Scintillation Detector

The unstable nuclide emits a type of radiation, such as α, β, or γ rays to become a stable nuclide and the amount of energy will be released in these processes. Identification of the energy based on the detected radiation, which is presented as an energy spectrum distribution.

In the energy spectrum distribution, spectral peaks can be treated as simple Gaussian. The energy resolution (R) is a parameter that describing the characteristic of the detector response function (DRF) of the energy radiation from a source.

$$R \cong \frac{FWHM}{H_0} \tag{1}$$

where FWHM is the full width at one-half of the maximum height peak and H_0 is a photopeak energy.

GEANT4 (*GEometry ANd Tracking*) is a type of Monte Carlo simulation that used to simulate the photon through the matter. This simulation, give a chance for user to reconstruct a detector model, detection system and physical interaction process involved [5]. In the GEANT4, the electromagnetic interaction process like a photoelectric effect, Compton scattering, Rayleigh scattering and pair production are implemented in the standard and low energy packages (Livermore and Penelope). They are differentiated based on the energy range for each process [6].

2.2. Simulation

Schematic design of the simulation was reconstructed as shown in Fig. 1(a). In this work, the detector model construction for the 3 in. x 3 in. was adopted from detector information [7, 8]. The precise dimension of the detector and its position must be entered in the detector construction code of GEANT4 simulation except the detail of photomultipliers. The interaction type for the GEANT4 electromagnetic process is a Penelope-low energy package with the beamon setup is about 5.0 x 10^7 beamon. Cs-137, Co-60 and K-40 of energy radiation are used for gamma ray point source setup.

In order to perform the counting events result in the Gaussian curve energy distribution (smearing curve) using ROOT analysis, we convert the energy resolution (R) or the full width at one-half of the maximum height (FWHM) to the Gaussian deviation (σ) based on the following formula [9].

$$\sigma = \frac{FWHM}{2.35} \tag{2}$$

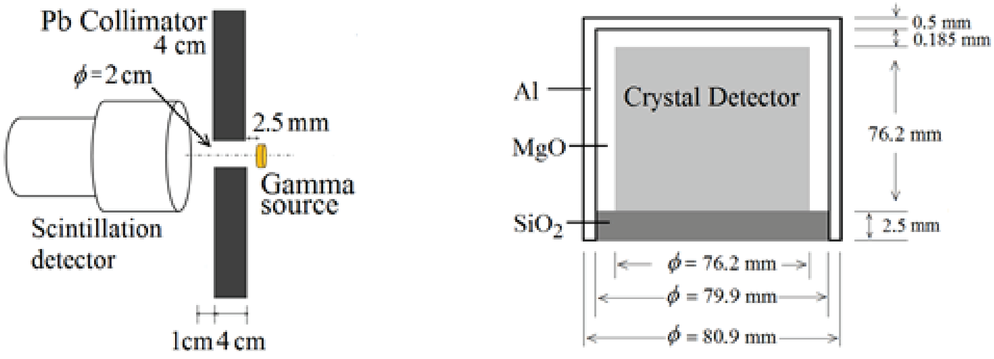

Figure 1: Schematic design of detector and simulation geometry construction.

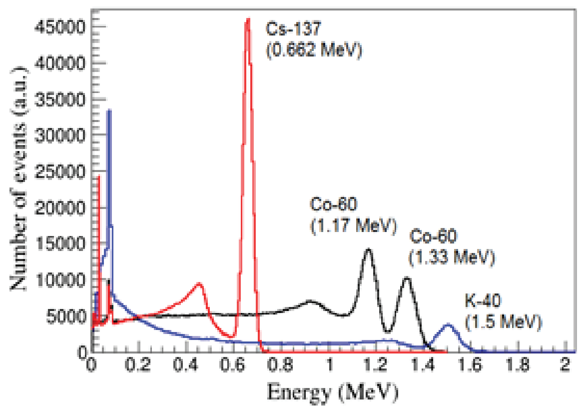

Figure 2: Energy spectrum distribution of Cs-137, Co-60 and K-40 detected using $CaMoO_4$.

3. Results and Discussion

The response function of $CaMoO_4$detector (DRF) for the several energy radiation source was described as an energy distribution curve as shown in Fig. 2. The comparison of detector response to the Cs-137 energy in the Fig. 3 shows that the photopeak (photoelectric effect) energy of Cs-137 which detected in the CaMoO4 is lower than NaI(Tl). Although, the entries of detector that making interaction of the NaI(Tl) is less than $CaMoO_4$i.e. 1065970 and 117412. On the other hand, the Compton edge peak of $CaMoO_4$ is higher than NaI(Tl). Fig. 4 shows the Gaussian peak of the photopeak for the several gamma energy sources like Cs-137, Co-60 and K-40.

The result shown that the photoelectric cross section interaction of the NaI(Tl) is higher than $CaMoO_4$ and for the incoherent cross section is vice versa. According to the XCOM program analysis of the value of total attenuation coefficient, these results have the same trend. The attenuation of photoelectric absorption of 0.66 MeV for NaI(Tl) is about 1.736 x 10^{-2} (cm^2/g) and $CaMoO_4$ is 8.466 x 10^{-4} (cm^2/g). The attenuation of incoherent scattering of 0.66 MeV for NaI(Tl) is about 6.604 x 10^{-2} (cm^2/g) and 7.549 x 10^{-2} (cm^2/g) for $CaMoO_4$.

In addition, we are also simulating the detector response to beta ray radiation from the Cs-137 source as an initial process for beta ray detection. The energy distribution of beta rays was described by the blue line curve as shown in the Fig. 5.

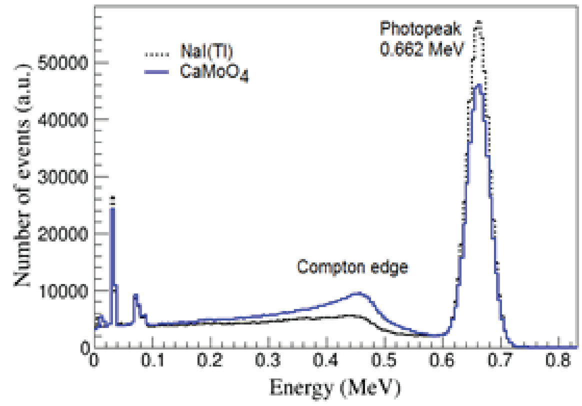

Figure 3: Energy spectrum distribution of Cs-137 detected by NaI(Tl) and $CaMoO_4$.

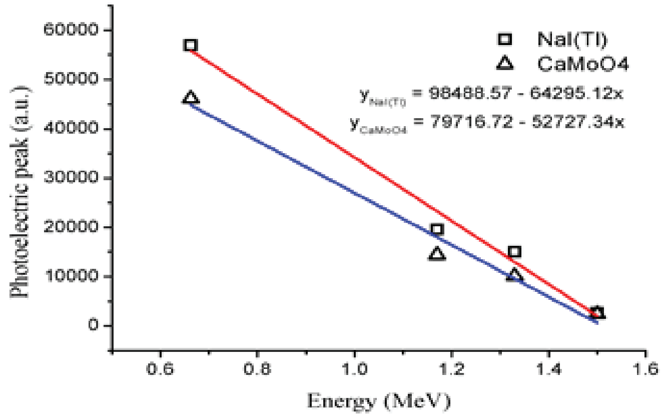

Figure 4: Gaussian peak of photopeak energy for the NaI(Tl) detector and $CaMoO_4$.

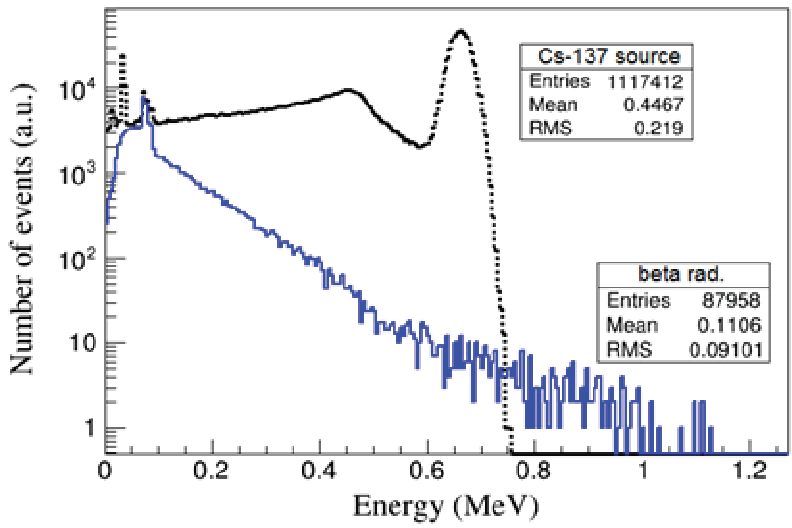

Figure 5: Energy spectrum distribution of beta radiation from Cs-137 source for $CaMoO_4$ detector.

As we know that the beta radiation is a continuous energy spectrum as depicted in the Fig. 5. The beta energies spectrum is lower than the gamma energy spectrum. In particular, double beta decay is second weak and rare process when single beta decay energetically not allowed. Therefore, to observe the present of double beta decay energy spectrum, we need to set up the condition for the low background radiation.

4. Conclusions

The response function of $CaMoO_4$detector (DRF) for the Cs-137, Co-60 and K-40 radiation sources was simulated using Monte Carlo GEANT4. The photoelectric cross section interaction of $CaMoO_4$is lower than NaI(Tl), but in other hand the incoherent cross section of $CaMoO_4$ is higher than NaI(Tl). Set up condition of low background radiation is needed in order to observe the beta radiation.

5. Acknowledgment

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