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A study of Gd-based parallel plate avalanche counter for thermal neutrons by MC simulation

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ABSTRACT

In this work, we demonstrate the feasibility and characteristics of a single-gap parallel plate avalanche counter (PPAC) as a low energy neutron detector, based on Gd-converter coating. Upon falling on the Gd-converter surface, the incident low energy neutrons produce internal conversion electrons which are evaluated and detected. For estimating the performance of the Gd-based PPAC, a simulation study has been performed using GEANT4 Monte Carlo (MC) code. The detector response as a function of incident neutron energies in the range of 25–100 meV has been evaluated with two different physics lists. Using the *QGSP_BIC_HP* physics list and assuming 5 μm converter thickness, 11.8%, 18.48%, and 30.28% detection efficiencies have been achieved for the forward-, the backward-, and the total response of the converter-based PPAC. On the other hand, considering the same converter thickness and detector configuration, with the *QGSP_BERT_HP* physics list efficiencies of 12.19%, 18.62%, and 30.81%, respectively, were obtained. These simulation results are briefly discussed.

1. Introduction

Parallel plate avalanche counters are considered as useful, simple and inexpensive devices that are utilized as timing detectors. These detectors are also used in fission and heavy-ion experiments [1,2]. PPACs provide advantageous properties such as fast response, good time resolution, and position measurement capability. In addition, their effective mass is quite low (~100 mg/cm^2) which makes them transparent to slow neutron beams [2].

All these features indicate that a PPAC could possibly be suited also for the detection of thermal neutrons. Moreover, it could be an useful option to construct a neutron detector which is not only fast but also allows to cover large areas at low costs [3]. Of course, neutron detection by means of a PPAC is only feasible if the electrode surfaces of the chamber are coated by some appropriate material that converts neutrons into charged particles.

In order to stimulate the development of such a novel device, we have performed a simulation study applying GEANT4 MC code for a PPAC-based neutron detector which uses gadolinium-oxide (Gd_2O_3) as converter material. Upon falling on the Gd-converter surface, the incident slow neutrons produce internal conversion electrons which are then evaluated and detected.

2. PPAC useful features and working principle

Some of the useful features related with the PPAC include: fast response and stable counting rate characteristics up to a value of 10^7 Hz/cm^2 with almost 100% detection efficiency [4,5]. The simple design and the inexpensive materials involved in their construction make them suitable for the construction of large area detectors [6,7]. So far they have been utilized as detection devices for heavily ionizing particles [6] in several nuclear and other physical sciences experiments [8]. PPACs have also some possible applications in future experiments on the LHC, including forward muon calorimetry [4].

The standard configuration of a parallel-plate avalanche counter (PPAC) consists of a single gap filled with a suitable gas and operates in the avalanche (Townsend) gas-amplification mode [3,9–11]. The chamber is usually composed of two metal electrodes that are spaced 0.5–2.0 mm apart. The separation between the electrodes is maintained by precision spacers. Furthermore, to provide a means for creating a high and uniform electric field in the gap, the inner surfaces of the electrodes are carefully polished. The flatness and parallelism are kept to an accuracy of 5.0–10 μm. Clearly, the required accuracy increases with decreasing gap width. The dimensions of the PPAC electrodes also may vary from

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$10 \times 10\ mm^2$ to $100 \times 100\ mm^2$. Evidently, the total thickness of the PPAC chamber depends both on its material and its design. As a general rule, it is kept at about a few millimeters [4].

3. Gd-converter characteristics

Since neutrons are charge-less particles their detection can only be performed after their interaction with a suitable material, known as converter, which has the role of generating ionizing particles. Since such converter material plays a crucial role in the detecting system, its choice requires special attention [12,13]. Especially suitable materials are Gd, LiF, and B_4C due to their large capture cross-section [14].

Among all materials the most interesting candidates for converters are ^{157}Gd and ^{155}Gd since their capture cross-section is extremely large, in the order of 10^5 barns. Upon capturing of a thermal neutron natural Gd produces, in about 60% of the cases, an electron from internal conversion. The released energy of this process ranges from 30 to 200 keV, with a main peak at about 70 keV. Clearly, this energy range defines the optimal thickness of the converter coating [12,15].

Thus, upon considering such advantages we have selected Gd-oxide (Gd_2O_3) as converter material for thermal neutron detection. The Gd-oxide is attached to the inner surface of the aluminum electrodes of the PPAC chamber as a solid layer (Fig. 1).

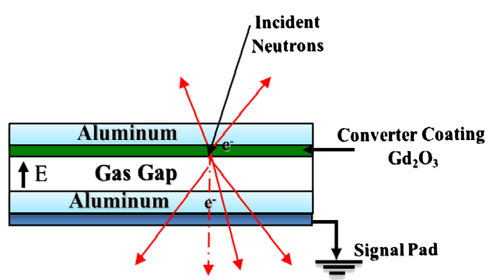

Fig. 1. The configuration of the PPAC detector utilized in the work.

4. Detector configuration

The simulated configuration of a single-gap PPAC has been built in C^{++} and interfaced with the GEANT4.9.2 MC program code [16]. The active area of the Gd-coated PPAC is kept as $5 \times 5\ cm^2$. In order to make the detector sensitive to thermal neutrons, a Gd-foil is attached to the electrode plate of the chamber. The basic PPAC configuration consists of a single gas-filled gap, sandwiched between two electrode layers. The thickness of the gas gap is set as 2 mm [9] and the electrodes are made of a 6 mm thick aluminum layer. Isobutane ($i\text{-}C_4H_{10}$), which is commonly used in low pressure avalanche counters [17], is utilized as counting gas.

The produced charged particles and ions are collected onto the electrodes by applying a sufficiently high voltage between the two electrodes of the PPAC chamber.

5. Simulation response and discussion

Using a similar technique as reported in [12,15], Gd-converters were attached to the forward and backward electrodes of the PPAC setup. Such type of detector has been simulated with the GEANT4.9.2 MC code [16] for low energy neutrons in the range of 25–100 meV using two different physics lists, *QGSP_BIC_HP* [18] and *QGSP_BERT_HP* [19], for evaluation.

The detection efficiency, ε, of the detector has been evaluated as the probability for impinging neutrons to produce charged particles coming out of the converter layer [12]. In order to achieve a sufficiently small statistical uncertainty, 10^6 neutrons have been simulated for each event run.

The forward, backward, as well as the total converter response of this detector configuration, as evaluated with both physics lists, is shown in Fig. 2 vs. the thickness of the Gd-converter coating for incident thermal neutrons with an energy $E_n = 25$ meV. It is evident that the response taken with the backward converter configuration remains always higher than that of the forward configuration.

The simulation results obtained for 25 meV neutrons show that the detection efficiency reaches its maximum at a converter thickness of about 3–5 μm, and then decreases gradually with

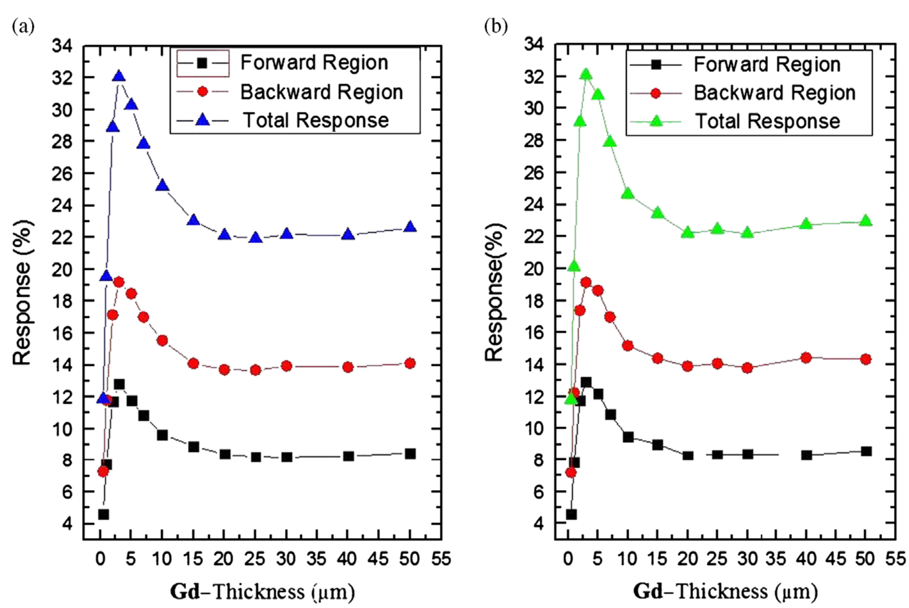

Fig. 2. Detection efficiencies evaluated for thermal neutrons ($E_n = 25$ meV) as a function of the GD-converter thickness with the two different physics lists *QGSP_BIC_HP* and *QGSP_BERT_HP* [18,19].