SIMULATION RESPONSE OF RESISTIVE PLATE CHAMBER FOR FAST NEUTRONS USING GEANT4 MC CODE

M. JAMIL[1,2], J.T. RHEE[1*], H. Y. JO[1], FARZANA AHMAD[3], Y. J. JEON[3*]

[1] Institute for Advanced Physics, Deptt. of Physics, Konkuk University, Seoul 143-701, Korea
[2] Division of International Studies, University College, Konkuk University, Seoul 143-701, Korea
[3] Department of Chemistry, Konkuk University, Seoul 143-701, Korea
E-mail: jtrhee@konkuk.ac.kr; E-mail: yjjeon@konkuk.ac.kr

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This paper describes a possibility of using the resistive plate chamber for the detection of fast neutrons. In this technique, a thin polyethylene layer has been coated on the resistive electrode as a fast neutron converter. The converter layer makes RPC sensitive to fast neutrons. Two types of RPC configurations with polyethylene as converter material were simulated by GEANT4 MC Code using the *QGSP_BERT_HP* and *QGSP_BIC_HP* physics lists. For the purpose, fast neutrons in the energy range of 1.0–20.0 MeV, and upto higher energies 100.0 MeV were inserted on the chamber surface. With 0.5 mm thick converter, using the fast neutrons the detection efficiencies for the forward and backward converter-coated RPC configurations were 1.58×10^{-2} and 2.38×10^{-2} using *QGSP_BERT_HP* respectively. With the same detector's configuration and source the efficiencies were 1.55×10^{-2} and 2.04 $\text{x}10^{-2}$ with *QGSP_BIC_HP*. The results predict that the response of fast neutrons could be computed successfully with RPC-detector equipped with polyethylene converter.

Key words: Fast Neutrons, Resistive Plate Chamber, Polyethylene, GEANT4, Monte Carlo Simulation.

1. INTRODUCTION

Resistive Plate Chambers (RPC) have been widely employed both in high energy physics and cosmic ray experiments [1]. These detectors were introduced in 1981, as an alternative to the remarkable "localized discharge spark counters" [2], which have a good time resolution of 25 ps [3]. The resulting detector, being by construction free from damaging discharges and enjoying a time resolution of the order of 1 ns, has found very good acceptance in high energy and astroparticle Physics [4].

RPCs are built from the two parallel phenolic resin (Bakelite) plates with a bulk resistivity of 10^{-10}-$10^{-11}\Omega$cm, separated by a gas gap of a few millimeters. Alternatively glass electrodes can be employed instead of bakelite ones. The whole structure is made gas tight. The outer surfaces of the resistive material are coated with conductive graphite paint to form the HV and ground electrodes. The read-out is performed by means of aluminum or copper strips [5].

RPC is a gaseous detector which is sensitive to high energy charged particles and ionizing particles like gamma rays, and cosmic rays [6]. A combination of RPC with the charged particle converter can be a good candidate for the detection of fast neutrons. The current work is an attempt to utilize RPC technology to detect fast neutrons. Such fast neutrons while falling on the RPC surface can generate secondary protons in the converter layer, which further pass through the gas gap and cause an avalanche in the gas gap [6]. Such an avalanche generates charged particle signals, that are collected on the readout strips. In the earlier works many authors have reported the improvement of neutron response using RPCs [7–9]. Usually hydrogen-rich materials like polyethylene (PE) film can be a useful choice for fast neutron-to-charged particles converters for energetic neutrons [10].

The objective of this work is to develop a fast neutron detector based on RPC combined with hydrogen rich material converter. For this purpose a thin polyethylene layer is coated on the surface of glass electrode. As the neutrons interact with the converter layer, the charged conversion products protons are produced, that can ionize the operating gas of the RPC. Electrons and ions in the gas produce avalanche in a strong electric filed and charge signals are collected on the readout strips [6]. This type of neutron detector has excellent time resolution, which makes it particularly suitable for neutron time of flight measurements. However it is worth to mention that in the previous work, multigap-RPC with six gaps was employed. In the current study we have utilized converter-based single-gap RPC for the evaluation of fast neutron detection.

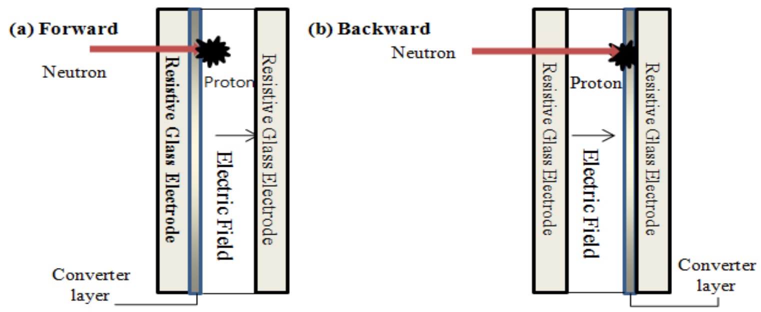

Fig. 1 – Schematic diagram of the (a) forward and (b) backward set-up of the Polyethylene-coated RPC, fast neutrons detector.

2. FAST NEUTRON RPC CONFIGURATION

In this study, a single-gap RPC coated with polyethylene film is configured in *C*++ object oriented language. The converter is coated onto the RPC electrodes both in the forward direction and backward direction respectively [11]. Fig. 1 shows the schematic view of the both RPC configurations utilized in this work.

GEANT4 [12] Monte Carlo simulation package is used to simulate detector's response for fast neutrons. To enhance the neutron sensitivity, 0.5 mm thick polyethylene films are coated on the surface of glass plate. Glass-plates, with 2 mm thickness are chosen for the resistive plate of RPC. The bulk resistivity of the glass plates was ~ 10^{12} Ωcm. The thickness of the gas gap for each gap was taken as 2.0 mm. A gas mixture that contains 97% tetra-fluoro-ethane and 3% iso-butane is utilized. A square shaped copper pad are used for the readout strips [13].

To estimate the performance of the detector, suitable simulation study has been carried out. A GEANT4.9.3 [12] based MC simulation code (with the *QGSP_BERT_HP* and *QGSP_BIC_HP* physics lists [14,15] has been developed, taking into account all the physics processes, *i.e.*, interaction of the incident fast neutron, the emission of secondary proton with correct energy spectrum, its passage through the converter layer and its entrance into the detector active gas volume. It must be noted that the conversion proton, in order to be detected, must exit the converter layer towards the gas gap. The simulations are performed for 10^7 primary histories of fast neutrons impinging randomly over the whole forward area of the detector. The incidence is spread randomly within an open angle. All interactions are treated in a three-dimensional geometry of RPC, following the appropriate cross-sections [16].

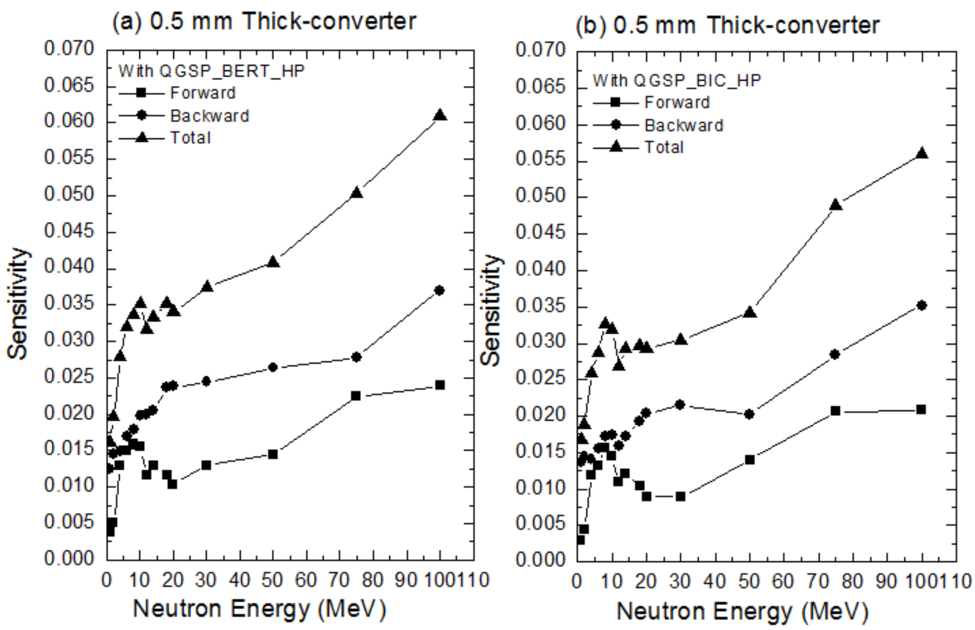

Fig. 2 – A spectra of the Polyethylene-coated RPC detectors response for fast neutrons at different neutron energies, taken with GEANT4 MC code.

3. DETECTOR's RESPONSE

Detector response also known as sensitivity is defined in the MC code as the probability for a neutron to produce a secondary proton coming out of the converter layer [17]. Actually neutrons go into the RPC surface from one side and interact with the converter and produce secondary protons that can be detected on the other side of the chamber. For estimating the response of the converter-coated RPC detector for fast neutrons, two types of detector's configurations were considered: (a) a forward configuration of chamber on the direction of the charged particle emission relative to the gas gap and (b) a backward configuration of chamber on the direction of the charged particle emission relative to the gas gap [11, 18]. Fig. 2 shows the simulated results of fast neutron detection efficiency taken with the 0.5 mm thick converter based-RPC as a function of fast neutron energy, for the two respective set-ups. For investigating the detector's response, two different physics lists naming *QGSP_BERT_HP* and *QGSP_BIC_HP* were utilized and evaluated response of the detector can be seen in Fig. 2(a) and (b). Fig. 2(a) obtained by *QGSP_BERT_HP* physics list, predicts that the detection efficiency of the forward configuration for 0.5 mm converter thickness is about 1.58 x10^{-2} at E_n =10 MeV. While, with the same energy range for the backward configuration the detector efficiency is about 1.98 x10^{-2}. A similar but lower detector response has been achieved using the *QGSP_BIC_HP* physics list as shown in Fig. 2(b).

Table 1

Fast neutron detection efficiencies of 0.5 mm thick converter-RPC, using *QGSP_ BERT_HP* physics list

Neutron Energy (MeV)	Forward Set-up Sensitivity	Backward Set-up Sensitivity	Total Sensitivity
4.0	1.28x10^{-2}	1.49x10^{-2}	2.77x10^{-2}
8.0	1.58x10^{-2}	1.79x10^{-2}	3.37x10^{-2}
10.0	1.54x10^{-2}	1.97x10^{-2}	3.51x10^{-2}
12.0	1.17x10^{-2}	1.98x10^{-2}	3.15x10^{-2}
14.0	1.28x10^{-2}	2.04x10^{-2}	3.32x10^{-2}
18.0	1.15x10^{-2}	2.36x10^{-2}	3.51x10^{-2}
20.0	1.03x10^{-2}	2.38x10^{-2}	3.41x10^{-2}
30.0	1.29x10^{-2}	2.44x10^{-2}	3.74x10^{-2}
50.0	1.44x10^{-2}	2.63x10^{-2}	4.08x10^{-2}
75.0	2.24x10^{-2}	2.78x10^{-2}	5.02x10^{-2}
100.0	2.39x10^{-2}	3.70x10^{-2}	6.09x10^{-2}

Table 1 shows the neutron sensitivity of both forward and backward detectors set-ups with 0.5 mm thick converter layer taken with *QGSP_BERT_HP* physics list. The energy of the incident fast neutron is in the range of 4.0 MeV to 20.0 MeV and upto higher energy ranges 100.0 MeV. The results for both detector's setups shows that as long as the incident fast neutron energy is low, the sensitivity remains low.

As the incident neutron energy increases around 6.0 to 8.0 MeV, the sensitivity increases. However the sensitivity decreases beyond this energy ranges. On further moving to higher energy ranges from 20.0 to 30.0 MeV, the sensitivity increases with the incident neutron energies. A similar behavior of the detector has been found using the *QGSP_BIC_HP* physics list. A comparison of these results with previous findings taken with MCNP code at available energies [6], predict that the current results are comparatively higher. The reason behind this could be since in the previous study 0.13 mm thick converter was utilized with MRPC set-up, which resulted in lower response of the detector.

In order to have more clear understanding of the detector's behavior, the conversion efficiency of the different polyethylene film thicknesses has been evaluated shown in Table 2. Form this table it is clear as the converter thickness increases the conversion efficiency of the detector also increases. Similarly with more thicker converter coating higher response of the chamber can be achieved. Fig. 3 illustrates this behavior evaluated with 1.0 mm to 3.0 mm thick converter, obtained by employing *QGSP_BERT_HP* physics list. A similar response of the detector was evaluated with *QGSP_ BIC_ HP* physics list.

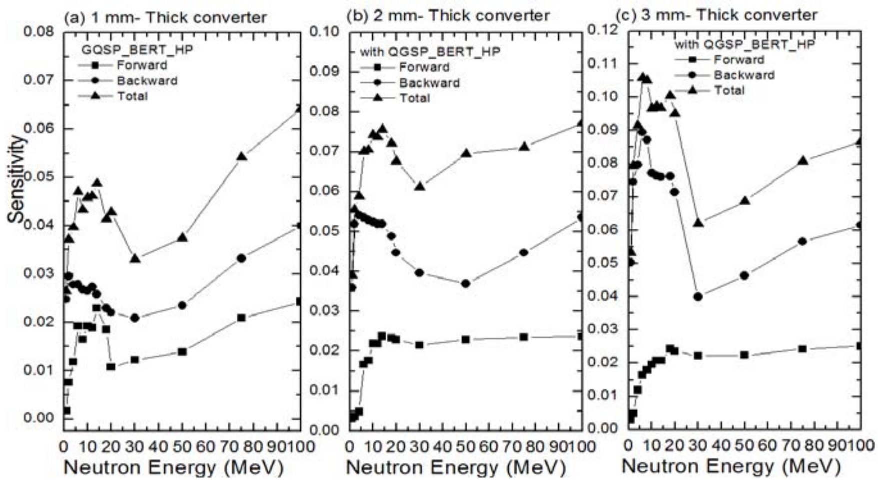

Fig. 3 – Fast neutron detection efficiency with Polyethylene-coated RPC, taken with QGSP_BERT_HP physics list.

4. CONCLUSIONS

A study has been performed on two RPC configurations with polyethylene-converters, for the detection of fast neutrons. Using the GEANT4.9.2 MC simulation the sensitivities of fast neutrons of energies 1.0 MeV–20 MeV and upto higher energy 100.0 MeV have been evaluated. The obtained results predict that RPC is capable of detecting fast neutrons with high detection efficiency.

By attaching 0.13 mm thick polyethylene converter coating, using the fast neutrons, a total detection efficiency $3.51x10^{-2}$ and $3.27x10^{-2}$ was obtained by employing *QGSP_ BERT_HP* and *QGSP_BIC_HP* physics lists respectively. Alternatively the thick-converter coated detectors can be fabricated which results in higher detection efficiency. This type of detector can be utilized in finding the energy and intensity spectrum of fast neutrons [6]. For the this case the energy transferred to a proton depends on the energy of the incident neutron and the scattering angle [19].

Table 2

Proton conversion efficiency taken with different polyethylene film thicknesses

Detector's Configuration	Thickness (mm)	Conversion Efficiency	
		With QGSP_BERT_HP	With QGSP_BIC_HP
Forward Converter Based-Set-up	0.5	$1.58x10^{-2}$	$1.55x10^{-2}$
	1.0	$1.91x10^{-2}$	$1.82x10^{-2}$
	2.0	$2.19x10^{-2}$	$2.06x10^{-2}$
	3.0	$2.42x10^{-2}$	$2.22x10^{-2}$
Bakcward Converter Based-Set-up	0.5	$1.97x10^{-2}$	$1.73x10^{-2}$
	1.0	$2.78x10^{-2}$	$2.65x10^{-2}$
	2.0	$5.40x10^{-2}$	$5.28x10^{-2}$
	3.0	$8.95x10^{-2}$	$7.89x10^{-2}$

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