Plastic scintillator detector for pulsed flux measurements

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Abstract. A neutron detector, providing charged particle detection capability, has been designed. The main purpose of the detector is to measure pulsed fluxes of both charged particles and neutrons during scientific experiments. The detector consists of commonly used neutron-sensitive ZnS(Ag) / ^{6}LiF scintillator screens wrapping a layer of polystyrene based scintillator (BC-454, EJ-254 or equivalent boron loaded plastic). This type of detector design is able to log a spatial distribution of events and may be scaled to any size. Different variations of the design were considered and modelled in specialized toolkits. The article presents a review of the detector design features as well as simulation results.

1. Introduction

When using plastic scintillator, the most used technique is to dope it with natural boron containing approx. 19% of ^{10}B isotope, because ^{10}B has a significant (about 3840 barn) thermal neutron capture cross-section. The two widely used examples of boron loaded plastics are Saint-Gobain Crystals BC-454 [1] and Eljen Technology EJ-254 [2].

The use of boron plastics for neutron detection tasks has some advantages. Plastics can be made of different sizes and shapes and provide moderately well light gathering along a sensitive area. Another advantage is that organic scintillators have a high concentration of hydrogen (> 50 % of total number of atoms) thus acting as neutron moderator themselves producing recoil protons which, in turn, can also be detected. Boron loaded plastics share some common organic scintillator advantages such as fast (of the order of a nanosecond) decay. They tend to have emission spectra suitable for silicon photomultipliers (SiPMs).

However, plastic neutron detectors have some issues as well. First of all, adding boron to a plastic increases its opacity (light attenuation length drops by the factor of 1.5-2 in comparison to a “clean” plastic [1] [3]) which makes light gathering more difficult in cases of large sensitive areas. Furthermore, increasing boron concentration gradually decreases light output [4]. For example, 10 % boron enriched plastic has 38 % of Anthracene light output [1] while having only about 1 % ^{10}B atomic concentration.

As can be seen from the above, increasing neutron detection capabilities of plastics decreases their overall performance. A neutron detector design, discussed below, is an attempt to increase neutron detection characteristics of large plastic scintillators by combining them with ZnS(Ag) / ^{6}LiF scintillator screens, similar to those, that are widely used in radiation monitors.

2. A review of scintillator screens capabilities

Each ZnS(Ag) / ^{6}LiF screen consists of ZnS(Ag) scintillator granules mixed with a specific amount of LiF with ^{6}Li isotope atomic concentration up to 90-95% of the total amount of lithium atoms. Due to particular qualities of light gathering in this scintillator, these screens are usually made with a thickness of about 0.3 – 0.5 mm [5]. Scintillator screens have their emission spectra similar to plastic scintillators and decay times ~100 ns, i.e. in combination with a plastic they would significantly lower a time resolution. However, these screens are almost transparent to gamma-rays due to their little thickness.

Thus scintillator screens may be used in a plastic detector when one needs to take separated neutron and charged particle measurements using a single detector. This situation may occur during space experiments, when there is a need in charged particle detectors, and neutron detection can provide some additional functionality, such as p/e discrimination tasks, solar or earth albedo neutrons detection, etc.

3. A new plastic detector design tests.

3.1. The detector design

Two main designs were considered in the simulations. In both of them a single 12 mm polyvinyltoluene plastic scintillator detector was used. The scintillator layer is wrapped between two 0.45 mm thick ZnS(Ag) / ^{6}LiF screens with 95% ^{6}Li enrichment and 1:3 LiF to ZnS ratio. The detector area equals to 100 x 100 cm^{2}.

The first design considers various (0-10 %) natural boron enrichment values in the plastic layer. The second design has constant concentration of boron (10 %) however with another 12 mm layer made of high-density polyethylene (HDPE) placed behind the detector. Thus overall detector thickness in the second case is about 25 mm.

3.2. Neutron detection efficiency tests

Detection efficiency tests were performed for a single polyvinyltoluene 12 mm layer plastic scintillator (design 1). The results show, that "clean" scintillator (no boron) has ~0.2% neutron detection efficiency for the 2.3 MeV neutrons, which is similar to a scintillator screen efficiency value. 10 % boron loading increases the overall neutron detection efficiency up to 2.1 % (table 1).

Table 1. Neutron detection efficiency for a single 12 mm plastic scintillator wrapped between two scintillator screens for different boron concentrations.

Natural boron concentrations (%)	2.3 MeV neutron detection efficiency (%)
0	0.2
1	0.9
5	1.6
10	2.1

3.3. Using HDPE as a second layer

For the second detector design the energy spectrum of ^{252}Cf was modelled as well. The model spectrum is shown on a figure 1 (squares).

A plane-parallel 1cm^{2} neutron beam was used. Several simulations were performed with 5*10^{6} primary events per test. The source was placed in air at 1 m distance from the detector. Scattered neutron flux and alpha particle production are localized inside the 10 x 10 cm^{2} area (figure 2 and figure 4), i.e. such detector should have a relatively good spatial homogeneity of neutron detection.

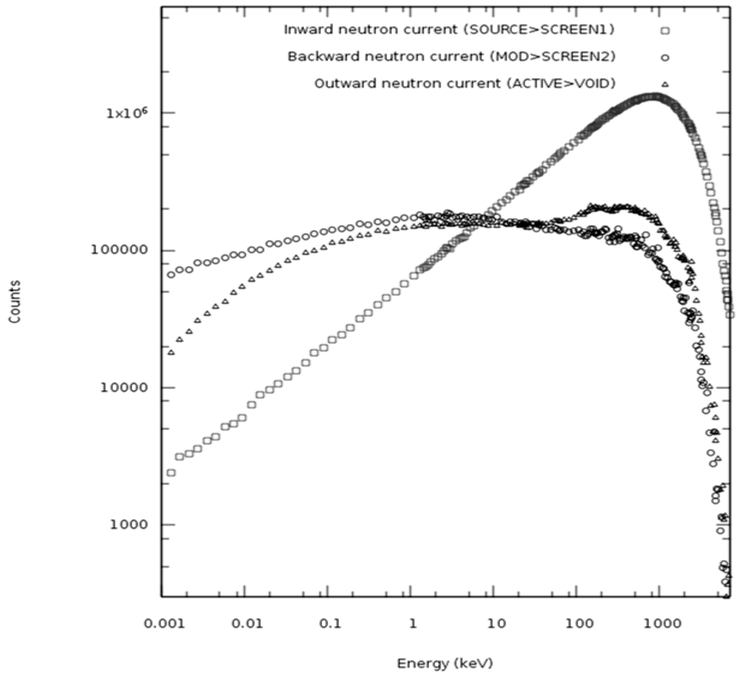

Figure 1. Neutron currents in the detector planes as a function of energy.

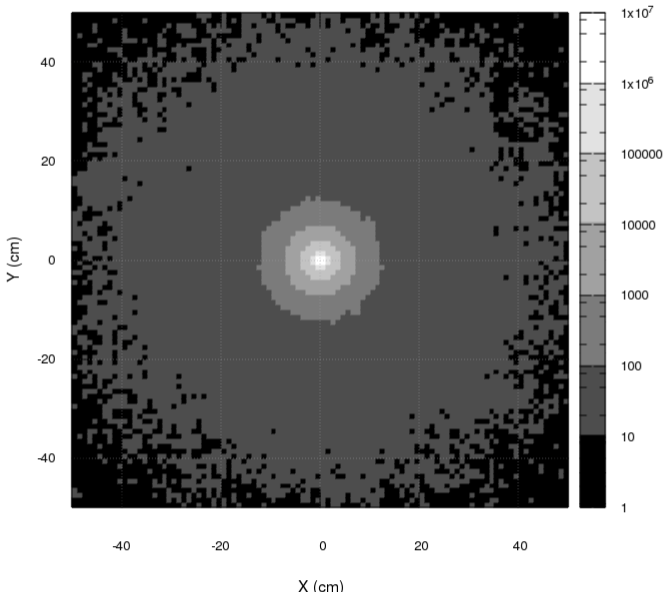

Figure 2. Neutron fluence in the XY plane at the scintillator screen layer. Each pixel corresponds to a $1cm^2$ area.

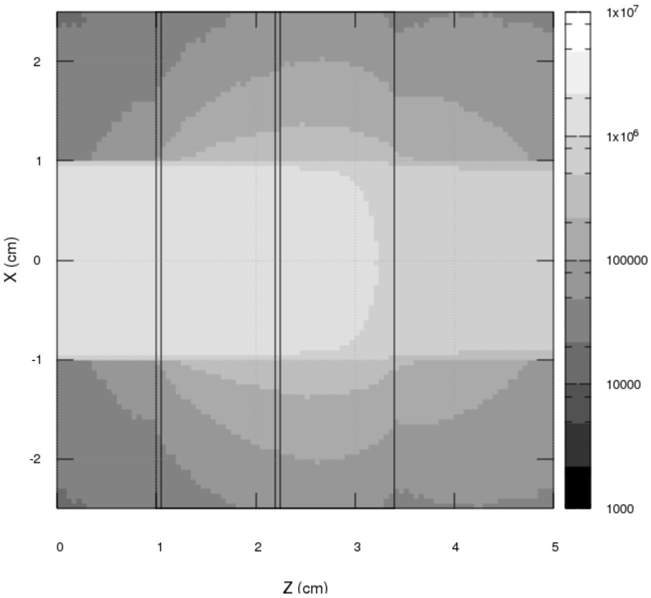

Figure 3. Neutron fluence in the XZ plane at the middle of the beam (Y=0).

References

[1] Saint-Gobain Inc. *BC-454 Natural Boron-loaded Premium Plastic Scintillator Data Sheet 07-08* 2008

[2] Eljen Technology *EJ-254 Data Sheet* 2016

[3] Saint-Gobain Inc. *BC-400, BC-404, BC-408, BC-412, BC-416 Premium Plastic Scintillators Data Sheet 01-08* 2005

[4] Pawelczak I A, Glenn A M *et al*. 2014 Boron-loaded plastic scintillator with neutron-γ pulse shape discrimination capability *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **751** (Elsevier) pp 62-9

[5] Scintacor *Data Sheet TECH/NEUTRON-SCREENS* 1 Sept 2015