Plastic scintillator detector for pulsed flux measurements

V V Kadilin, A A Kaplun and A A Taraskin
Department of Applied Nuclear Physics, National Research Nuclear University
MEPhI (Moscow Engineering Physics Institute), Kashirskoe highway 31, Moscow,
115409, Russia
E-mail: vvkadilin@mephi.ru

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) / 6LiF 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 10B isotope, because 10B 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 % 10B
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) / 6LiF
scintillator screens, similar to those, that are widely used in radiation monitors.

2. A review of scintillator screens capabilities
Each ZnS(Ag) / 6LiF screen consists of ZnS(Ag) scintillator granules mixed with a specific amount of LiF with 6Li 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) / 6LiF screens with 95% 6Li enrichment and 1:3 LiF to ZnS ratio. The detector area equals to 100 x 100 cm².

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).

| 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 252Cf was modelled as well. The model spectrum is shown on a figure 1 (squares).

A plane-parallel 1cm² neutron beam was used. Several simulations were performed with 5*10⁶ 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 cm² 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 1cm² 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