Measurement of neutron response function using quasi mono-energetic neutrons produced in the $^7Li(p, n)^7Be$ reaction

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Liquid organic scintillator based detectors are preferred for fast neutron spectroscopic studies in the mixed radiation environment of neutrons (n) and γ-rays due to their excellent pulse shape discrimination property, good time resolution and reasonably high detection efficiency. However, most of the liquid scintillator detectors suffer many potential problems, like toxicity, chemical hazards, leakage, and low flash point. The above problems could be avoided by using new plastic scintillator based detectors capable of discriminating neutrons and γ-rays using the pulse shape discrimination technique which was missing in the traditional plastic scintillators. Attempts have been continuously made to achieve and improve the pulse shape discrimination property in plastic scintillator detectors. The first of this kind of plastic scintillator detector having reasonable pulse shape discrimination property was reported by Natalia et al. [1]. The commercial version of this new kind of plastic scintillator was developed by Eljen Technology [2]. To judge the suitability of these detectors over the traditional liquid scintillator based detectors detailed comparative studies are required. Recently, we made one such attempt where the performance of the LS and PS detectors have been compared using a standard ^{252}Cf neutron source [3].

Here we report the pulse height response for both liquid scintillator based detector (BC501A, developed in VECC [4]) as well as plastic scintillator based detector (EJ299-33A, developed by Scionix Inc.) of the same dimension using quasi mono-energetic neutrons of energies between ~ 3 - 10 MeV.

The pulse height response of the detector plays an important role to estimate the light yield generated in the interaction of neutrons with the detector material. Experimentally measured pulse height response for mono-energetic neutrons is also required to critically examine the accuracy of the data libraries used in the generalized simulation codes like Geant4, FLUKA [5, 6].

The mono energetic neutrons were generated using the $^7Li(p,n)^7Be$ reaction with proton beams from the K130 Cyclotron at VECC at four different beam energies, (E_p = 7 MeV, 8.2 MeV, 10 MeV, 12 MeV) bombarded on ^7Li target. Possible exit channels for neutrons associated with different ^7Be states are given in Tab. 1, where n_0, n_1 and n_2 are the neutrons associated with the ground , 1st and 2nd excited states of ^7Be, respectively, whereas n are the breakup neutrons which have continuous energy distribution. Q-values and threshold energies (E_{th}) of different reaction channels are also indicated.

Tab. 1: Exit channels in $^7Li(p, n)^7Be$.

Exit ch.	**Q Value (MeV)**	**E_{th} (MeV)**
$n_0 + {}^7Be$ (g.s.)	-1.644	1.8814
$n_1 + {}^7Be^*$ (0.43 MeV)	-2.073	2.371
$n + {}^3He + {}^4He$	-3.230	3.694
$n_2 + {}^7Be^*$ (4.57 MeV)	-6.214	7.107

A natural Li target of thickness ~ 4 mg/cm^2 was placed inside a thin walled reaction chamber. Six liquid scintillator detectors (5”×5”) and two plastic scintillator detectors (5”×5”) were placed at different angles in between 10^0 – 150^0 with respect to the beam direction and at a distance of ~ 1 meter from the target centre. In the time of flight (TOF) measurement the start time was taken either from the cyclotron RF or using the ancillary detectors. We have used both the techniques in our measurements. An array of 50 BaF_2 detectors [7], divided into two blocks of 25 detectors each, was placed on top and bottom of the chamber covering 56% of the total solid angle. The pulse height, zero crossover (ZCO) time and TOF were measured on event by event basis. Neutron energies were measured from the time of flights of the neutrons and using position of the γ peak as the time reference. Energy spectra were corrected for detector efficiency. Pulse height spectra were calibrated using Compton edge of the standard γ-ray sources (^{22}Na, ^{137}Cs, ^{241}Am-^{9}Be).

In Fig.1 a measured typical 2D plot of TOF vs. ZCO time are shown in the scatter plot for the ^{7}Li(p, n)^{7}Be reaction. The figure shows a clear separation between neutrons and γ rays. Data taken using BaF_2 trigger shows only one peak (Fig. 2) which is associated with the 1st excited state of ^{7}Be, since it is the only state which decays by a γ-ray emission of energy 429 keV. The second excited state of ^{7}Be does not have any associated γ-ray which can trigger the BaF_2 detector array, hence no other peak is visible in the energy spectrum acquired using BaF_2 trigger. Whereas in the RF-trigger we could see both the peaks associated with the 1st and 2nd excited states (Fig. 2). The energy difference between these two peaks is found to be ~ 4 MeV. The ground state and the 1st excited state are, however, not resolved due to the short flight path used in our measurement.

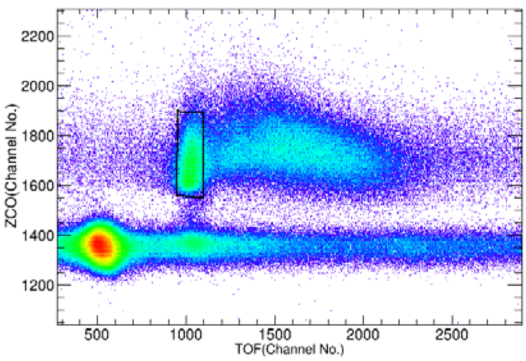

Fig. 1: Typical 2D plot of TOF vs. ZCO showing the neutrons from the 1st excited state of ^{7}Be along with the breakup neutrons.

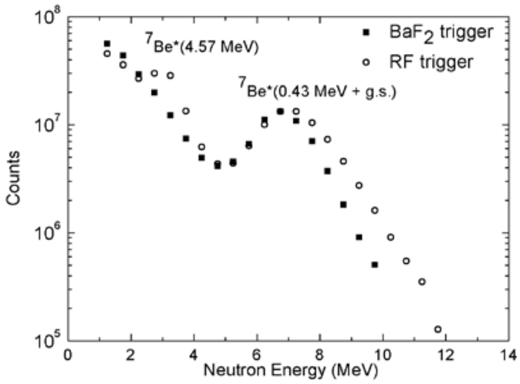

Fig. 2: Measured neutron energy spectrum for 12 MeV protons (angle = 87.5^{o}).

The pulse height response of quasi mono-energetic neutrons (E_n) was extracted by selecting a suitable time gate in the time spectrum as shown in the Fig. 1. The pulse height responses of both the types of detectors for different neutron energies are shown in Figs. 3 and 4. The average pulse height of both the detectors for each energy is shown in the Tab. 2, which shows that liquid scintillator has higher average light output, < **L** > in comparison to the plastic scintillator detector (EJ 299-33A). The results are in agreement with our earlier measurement performed using ^{252}Cf neutron source [3]. Liquid scintillator detector also seems to have better pulse height resolution in comparison to the plastic scintillator detector. Further details will be reported during the symposium.

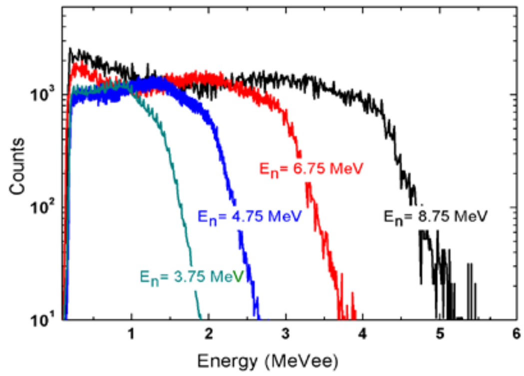

Fig. 3: Pulse height response of liquid scintillator (BC501A) detector for different neutron energies (E_n)

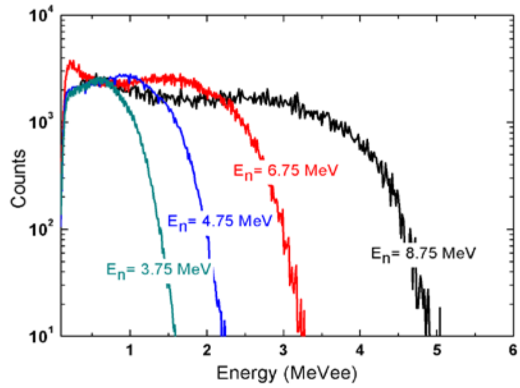

Fig. 4: Same as Fig. 3 for plastic scintillator detector (EJ 299-33A).

Tab. 2: Average pulse height for different neutron energies.

E_P (MeV)	**< E_n > (MeV)**	**< L > (keVee)**	
		BC 501A	**EJ 299-33A**
7	3.8	793	624
8.2	4.8	1146	884
10	6.8	1548	1250
12	8.8	2046	1995

References

[1] N Zaitseva *et al.*, NIM A **668**, 88 (2012).
[2] Eljen Technology, (http;//www.eljentech-nology.com)
[3] Pratap Roy, *et al.*, NIM A **901**, 198 (2018).
[4]M. Gohil *et al.*, NIM A **664,** 304 (2012).
[5] A. R. Garcia *et al.*, NIM A **868,** 73 (2017).
[6] K. Banerjee *et al.*, NIM A **608**, 440 (2009).
[7] D. Pandit., *et al.*, NIM A **624**,148 (2010).