Measurement of average interaction length of neutrons in BaF_2 crystal

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Introduction

A Large Area Modular BaF_2 Detector Array (LAMBDA) [1], developed inhouse, has been efficiently employed for the last few years to measure the high energy γ-rays from the dacay of giant dipole resonance built on excited states [2]. Recently, it has been shown that its intrinsic neutron detection efficiency (in the energy range of 0.5 - 8 MeV) is comparable to that of the liquid scintillator based neutron detector (BC501A) [3]. As a result , the spectrometer can also be effectively utilized to measure the neutron energy spectrum from which one can extract the nuclear level density (NLD) parameter required for the statistical model calculations. In general, the neutron energy (E) is estimated from its time-of-flight (T) using the relation,

$$E = \frac{1}{2}m(\frac{L}{T})^2. \quad (1)$$

where, m and L are the mass and the flight length of the neutron, respectively, while the energy resolution is given by the relation,

$$\left(\frac{\delta E}{E}\right)^2 = \left(2\frac{\delta T}{T}\right)^2 + \left(2\frac{\delta L}{L}\right)^2 \quad (2)$$

δT is the time resolution of the detector and δL is the flight path spread due to the detector size. Untill now , as the interaction point of neutrons in the detector volume was not known, the total length of the detector was taken as the uncertainity in the flight path of the neutron to measure the time-of-flight (TOF) energy resolution. Since the density of the BaF_2 material is high (4.88 gm/cm^3), the neutrons will interact (via n, γ or n, n$'\gamma$) mostly in the initial part of the detector volume. Hence, the average interaction length of neutrons in the BaF_2 scintillator should be estimated to precisely determine the TOF energy resolution. In this paper, we report on the distribution of neutron interaction points along the length of the BaF_2 detector to calculate the average interaction length and compare it with the GEANT4 [4] simulation.

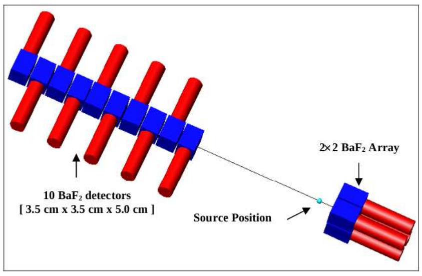

FIG. 1: *Experimental set-up for the measurement of average interaction length of neutrons in BaF_2 material.*

Experimental Details

The interaction point of neutrons in the BaF_2 crystals was measured using the detector elements of gamma multiplicity filter [5]. The length of each detector element is 5 cm and its cross-sectional area is same as that of a LAMBDA detector (3.5 × 3.5 cm^2). Ten BaF_2 detectors of multiplicity filter were arranged linearly (as shown in Fig. 1) one after another so that the effective length was 35 cm (same as the length of the LAMBDA detector). Next, the detectors were gain matched and equal thresholds were applied to all (300 keV). A ^{241}Am-^{9}Be source was kept at a dis-

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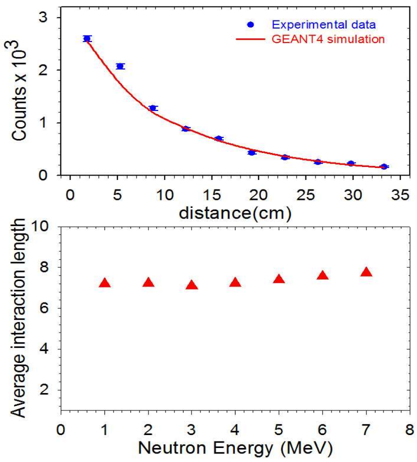

FIG. 2: *[Top panel] Variation of the number of events as a function of distance corresponding to the number of detectors. Filled circles are the experimental data points and continuous line represents GEANT4 simulation. [Botom panel] Average interaction length vs neutron energy.*

tance of 50 cm from the first of the ten detectors kept in line to measure TOF spectrum for each detector elements. The start trigger for the TOF measurement was taken from another set of identical BaF_2 detectors that were arranged in a 2×2 matrix and kept at a distance of 5 cm on the other side of the source. A schematic view of the experimental set-up is shown in Fig. 1.

Result and Discussion

The TOF spectrum was converted to the energy spectrum using prompt gamma peak as a time refference. As a flat overall background was observed in the TOF spectrum, the background counts were subtracted by selecting the same channels (as for energy bins) from the left of the gamma peak. The total number of neutron events in the energy range of 3 - 6 MeV was calculated for all the 10 detectros and shown in the Fig. 2 (Top pannel). It has been shown that the total number neutron events is highest for the first detector and decreases for subsequent detectors, pointing towards the fact that the interaction of neutrons in the BaF_2 detector decreases exponentially with increase in distance. A complete GEANT4 simulation was also carried out to obtain the distribution of the neutron interaction points along the length of detector for this experimental set-up. As could be seen from Fig. 2, the experimental data and the simulation results (continuous line in Fig. 2, Top panel) match remarkably well with each other. This excellent match between the experimental data and the simulation provided us with the required confidence in GEANT4 simulation in order to calculate the average interaction length of neutron in BaF_2 detector on any dimension. The cross-talk probability was also measured for this set-up and was found to be less than 1%.

Next, we performed a GEANT4 simulation to estimate the average interaction length of neutron in the BaF_2 detector (one element of LAMBDA spectrometer) having 3.5 x 3.5 cm^2 cross-sectional area and 35 cm in length. The interaction points of neutron in the BaF_2 detector were found to decrease according to the relation exp(-μx) where $\mu = 0.13$ cm^{-1}. Using this distribution, the average interaction length of neutrons in this BaF_2 was estimated and found to be 7.6 cm when kept at a distance of 80 cm from the source. As a result, the energy resolution at 4 MeV using equation (2) was found to be $\pm$ 0.4 MeV, corresponding to $\delta T = 0.96$ ns (intrinsic time resolution of the detector). Finally, we have also shown that the average interaction length of neutron (1 - 10 MeV) of our BaF_2 detector was found to be almost constant. So, it can be concluded that the LAMBDA spectrometer can be utilized to measure the neutron energy spectrum with a good energy resolution.

References

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