Neutron response of the LAMBDA spectrometer

Balaram Dey,* Deepak Pandit, S. Mukhopadhyay,
Surajit Pal, K. Banerjee, and S. R. Banerjee
Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata - 700064, INDIA

Barium Fluoride (BaF_2) is a very attractive scintillator material for gamma ray detection because of its very good timing property (a fast decay component of 0.6 ns) and high density (4.88 g/cc) [1]. Due to these properties, it could also be used potentially as neutron detectors by time of flight (TOF) technique. However, in recent past, they have only been employed to reject the neutron contamination by TOF in experiments measuring the high energy gamma rays. Instead of rejecting, the neutron energy spectrum can be simultaneously measured along with the high energy gamma rays to extract the inverse level density parameter for statistical model calculation. In general, the use of a neutron detector usually requires the knowledge of its intrinsic efficiency for neutron detection [2]. This efficiency depends upon many factors, such as, neutron energy, electronic threshold, dimension of the crystal, process of interaction etc. The intrinsic efficiency of the detectors for the neutrons can be measured using a ^{252}Cf source. The ^{252}Cf decays via α particle emission (96.91%) and spontaneous fission (3.09%) with a half-life of 2.65 years [3]. Usually the fission events are selected by means of fragment detectors. However, since large number of γ rays are also emitted in coincidence with neutrons in the fission process, one could also employ a γ ray detector (such as a BaF_2) placed very close to the source to select fission events, which also provides the start of the neutron time of flight (TOF) measurements. This method has several advantages as a safer sealed source can be used and the measurement does not require the use of evacuated scattering chamber and can be performed in air. In this paper, we describe the neutron response of the LAMBDA spectrometer [1] and compare its performance with respect to the standard liquid scintillator based neutron detector employed in the same experimental study. The LAMBDA spectrometer consists of 162 BaF_2 detectors each having 3.5×3.5 cm^2 cross-section and 35 cm length.

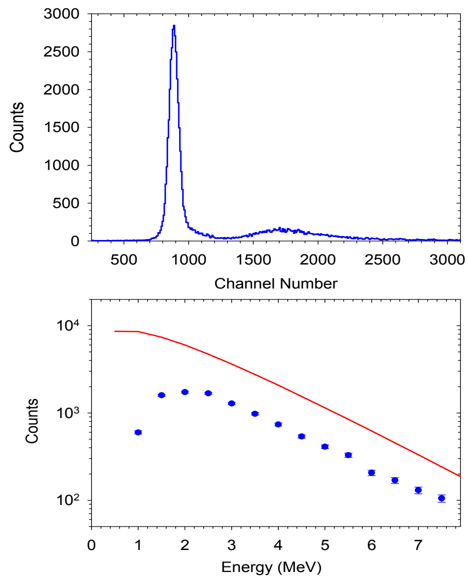

FIG. 1: *[Top panel] TOF spectrum for the BaF_2 detector. [Bottom panel] Neutron energy spectrum of BaF_2 array (filled circle) compared with the expected neutron energy spectrum from ^{252}Cf (continuous line).*

In the present measurement, four BaF_2 detectors from the LAMBDA spectrometer, arranged in 2×2 matrix were kept at a distance 80 cm from the ^{252}Cf source to study the neutron response of the detectors. Along with the large detectors, a 50 element gamma multiplicity filter [4] was used to detect the low energy discrete gamma rays emitted from the

*Electronic address: balaram.dey@vecc.gov.in

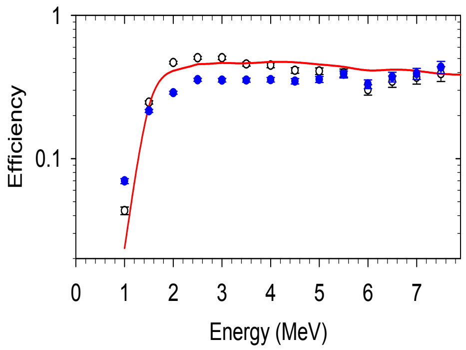

FIG. 2: *Efficiency of the BaF_2 array (filled circles) compared with that of BC501A scintillator detector (open circles). The continuous line represents the GEANT4 simulation for BC501A scintillator.*

decay of excited fission fragments in order to establish a correlation between the neutrons and the fission process as well as to get the start time trigger. The multiplicity filter was split into two blocks of 25 detectors each and placed on top and bottom of the source at a distance of 3 cm from the sealed ^{252}Cf source. The multiplicity setup covered 70% of the total solid angle that ensured a trigger efficiency of fission events close to 100%. Apart from the BaF_2 detectors, a liquid scintillator BC501A-based neutron detector (5 inch diameter and 5 inch length) [2] of known efficiency was also employed to measure the neutron energy in order to compare the efficiency of the BaF_2 array with that of the neutron detector. The neutron detector was kept on the other side of the source at a distance of 150 cm in order to equalize the solid angle of the two detectors. The neutron TOF technique was employed for neutron energy measurement in both the detectors using multiplicity filter as the start signal. Along with the time spectrum, the pulse height spectra of the neutron detector as well as of the BaF_2 array were also measured in order to apply energy thresholds in offline analysis. The typical TOF spectrum at a threshold of 350 keV (applied in offline analysis) for one of the BaF_2 detector in the array is shown in the top panel of Fig. 1.

The TOF spectrum has been converted to energy spectrum using the prompt gamma peak in TOF spectrum as the time reference. The neutron energy spectrum measured with the BaF_2 array is shown in Fig. 1 (filled circle in the bottom panel). The efficiency of the neutron detector and the BaF_2 array were determined by dividing the neutron energy spectrum per fission by the expected neutron energy distribution for ^{252}Cf taken from ref [3] with temperature T = 1.42 MeV, properly normalized with neutron multiplicity ν=3.77, the detector solid angle and the total number of fission detected. The energy dependent efficiency of BaF_2 array and neutron detector are shown in the Fig. 2. It is interesting to note that for neutrons of low energies, the BC501A neutron detector efficiency is higher than for the case of BaF_2 array. However, starting at 4 MeV the neutron efficiency for BC501A neutron detector monotonically decreases as a function of neutron energy whereas the efficiency of BaF_2 array increases sharply up to 2-3 MeV and reaches a plateau at efficiency $\sim$30% comparable with that of neutron detector at these energies. However, the BC501A has an extra advantage to discriminate the neutrons from gamma rays using pulse shape discrimination. A GEANT4 [5] simulation performed for neutron detector shows a good agreement with the experimental result thus validating the method presented here for efficiency estimation. A GEANT4 simulation for BaF_2 array is underway and will be presented during the conference. Thus, we expect that for neutrons of higher energy (>10 MeV), the BaF_2 crystal efficiency could be comparable or higher than the one of BC501A liquid scintillators and can be efficiently employed in various experiments.

References

[1] S. Mukhopadhyay et al, NIMA 582 (2007) 603.

[2] K. Banerjee at al, NIMA 608 (2009) 440.

[3] G.F. Knoll, Radiation Detection and Measurements, 3rd ed., Wiley, New York.

[4] Deepak Pandit et al, NIMA 624 (2010) 148.

[5] S. Agostinelli, et al, NIMA 506 (2003) 250.