Study of neutron interaction in PARIS phoswich detector

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A Photon Array for the Studies with Radioactive Ion and Stable beams (PARIS) is being developed to study the high energy γ rays from the decay of highly collective states in atomic nuclei [1, 2]. The array consists of ∼200 PARIS phoswich element. Each element is made up of $2'' \times 2'' \times 2''$ $LaBr_3$(Ce) crystal optically coupled to a $2'' \times 2'' \times 6''$ NaI(Tl) crystal (manufactured by Saint-Gobain Crystals) followed by a single PMT for signal readout. The detailed characterization of PARIS phoswich element over a wide range of γ ray energies is reported in Ref. [3]. In the high energy γ-ray measurement, the neutrons are the major source of backgrounds, which can be discriminated by time-of-flight (TOF) technique. The excellent time resolution of the $LaBr_3$ crystal enables TOF measurements at closer distances from the target, thereby enhancing the efficiency, which is important for low cross-section measurement. It is therefore important to understand the neutron interaction in $LaBr_3$ and NaI crystal of the phoswich detector. Low energy neutrons (E < 10 MeV) mainly interact via (n,γ) or (n, n$'\gamma$) reactions. The interaction probablity is high for the front part of the detector ($LaBr_3$) owing to its high density (5.08 gm/cc). This paper reports the study of neutron interactions in the PARIS phoswich detector and comparison with the GEANT4 [4] simulation.

The experiments were performed at TIFR, Mumbai using one phoswich detector, one BaF_2 detector and three neutron sources ^{252}Cf, ^{241}Am-^{9}Be and ^{239}Pu-^{13}C. The phoswich detector was placed at 50 cm from the neutron source and the BaF_2 detector was placed at very close to the source to detect the γ-rays. The neutrons are measured by the TOF technique, where the START and STOP triggers were taken from the BaF_2 detector and the phoswich detector, respectively. The data have been acquired using the CAEN make VME based digitizer V1751 (1 GHz, 1 Vpp, 10 bit). The timing information was extracted using an algorithm implementing constant fraction discriminator with a delay of 6 ns and 20% fraction, incorporated in the online WAVEDUMP acquisition software [3, 5]. The charges with short and long gate (Q_S and Q_L, respectively), corresponding to E_{LaBr_3} and E_{NaI}, are recored by integrating the output pulse from PMT for a gate width of 300 and 900 ns. A typical two dimensional Q_L-Q_S spectrum together with gates for discriminating the events corresponding to full energy deposition in $LaBr_3$ and NaI crystal, is shown in Fig 1. The TOF spectra for different neutron sources are shown in Fig 2. The neutron events in total phoswich and in only $LaBr_3$ & NaI have been extracted using the appropriate gates on TOF and Q_L-Q_S

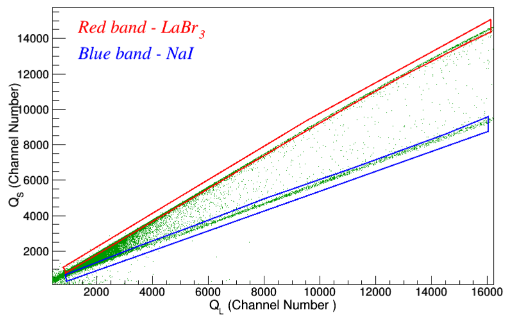

FIG. 1: Neutron gated Q_L vs Q_S Spectrum for ^{252}Cf source.

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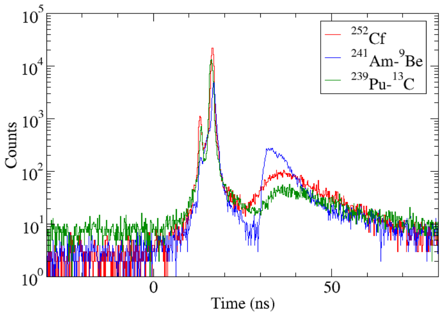

FIG. 2: Time-of-Flight Spectrum using three different neutron sources ^{252}Cf (red), ^{241}Am-^{9}Be (blue) and ^{239}Pu-^{13}C (green).

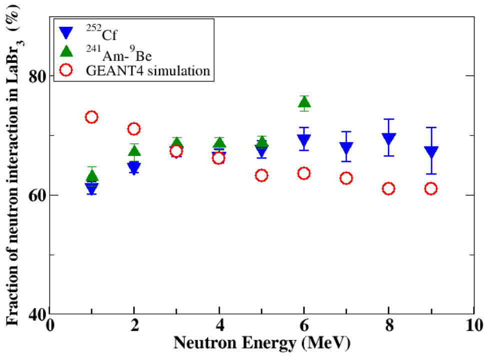

FIG. 3: Fraction of neutron events in $LaBr_3$ with respect to total events in Phoswich detector. The neutron energies are with uncertainty of $\pm$ 0.5 MeV

spectrum for different neutron energies. The neutron energies are derived from neutron TOF (T) with respect to the prompt γ-peak using the relation $E_n = \frac{1}{2}m(\frac{L}{T})^2$, where m and L are the mass and flight path of neutron. The data was also recorded without any neutron source to assess the background, which is found to be negligible small.

The fraction of neutron events in $LaBr_3$ crystal as a function E_n (1-9 MeV with an uncertainity of $\pm$0.5 MeV) is shown in Fig 3. It can be seen that 60 - 70 % of the neutron interaction take place in the $LaBr_3$ crystal of the phoswich detector. It is evident that (from Fig 3) the neutron interaction probability in $LaBr_3$ increases from 1 to 3 MeV and is nearly constant between 3-9 MeV. This is because the neutrons (<10 MeV) interact with the $LaBr_3$ crystal mainly via (n, n$'\gamma$). The neutron inelastic scattering cross-section in the $LaBr_3$ crystal increases from 1 to 4 MeV and is nearly constant between 4 to 10 MeV [6, 7], which is basically reflected in the experimental data. The present data for different sources were found to be consistent within the error bars. A GEANT4 simulation has also been carried out for the same experimental configuration and is also shown in Fig 3 for comparison. It can be seen that the simulations fail to reproduce the observed trend at energies below 3 MeV. This discrepancy could imply that the neutron interaction libraries in the simulation needs improvement, particularly at lower energy (also reported in Ref. [6, 7]).

In summary, the present study has shown that $\sim$70% of neutrons with E > 3 MeV have primary interaction in the $LaBr_3$ part of the PARIS phoswich detector and clear n-γ separation can be achieved even at $\sim$ 15 cm flight path. For energies below 3 MeV, the flight time is sufficiently large at 15-20 cm distance even in case of primary neutron interactions in NaI. Hence, over all neutron rejection with phoswich using TOF at close distances is feasible with flight paths of 15 cm.

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