Geant4 simulation of pulse-height response function of liquid scintillator based neutron detector

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Organic liquid scintillator based detectors are widely used for neutron detection in a mixed field of neutron and gamma rays due to their properties viz. high light output, good detection efficiency, fast decay time and excellent neutron-gamma discrimination. A BC501A liquid scintillator based time of flight (TOF) neutron detector array is being developed for neutron spectroscopic studies at the Variable Energy Cyclotron Centre, Kolkata [1]. A Geant4 based simulation code has been developed to estimate the response function of these neutron detectors. Here, we report our measurement of response functions of these detectors for neutron using neutron emitted from ^{252}Cf source as well as α(35 MeV) + ^{181}Ta reaction, using TOF technique and presents the comparison with the results obtained from Geant4 simulation.

The mono-energetic neutron response function was simulated using the Geant4 toolkit version 4.9.2 [2]. The code takes into consideration the full complexity of the light production inside the detector, wall effect and nonlinear light response for secondary charged particles. All relevant physical processes for γ-rays and neutrons in the energy range in question were included in the simulation. For γ-ray interactions, the data file G4EMLOW version 6.2, containing cross-sections for low energy electromagnetic processes, was used. For neutron, cross section data library G4NDL3.13 as well as Geisha routine based data library, in which models of Elastic, Inelastic, Capture and Fission process are incorporated, have been used. G4NDL3.13 is the recently updated high precision data library for neutron while Geisha routine based data library is default data library for all hadronic process in Geant4.

Beam experiment has been performed using α(35 MeV) beam from K130 Cyclotron at VECC on ^{181}Ta target. The experimental neutron response was measured using the neutron detector of size 7" × 5" placed at a distance 150 cm from the target. For measurement with ^{252}Cf source, source was kept at the target position. Neutron events were separated from γ events by Pulse-shape-discrimination method (PSD). Mono-energetic neutron response was extracted from continuous neutron spectrum by selecting a particular window in (TOF) spectrum. Window in TOF spectrum for a particular neutron energy E was selected by calculating energy resolution of TOF technique given by equation,

$$\left(\frac{\Delta E}{E}\right)^2 = \left(\frac{2\Delta\tau}{t}\right)^2 + \left(\frac{2\Delta l}{l}\right)^2 \qquad (1)$$

where $\Delta\tau$ is the time resolution, l is flight path of neutron, Δl is the flight path spread due to the length of detector. It is seen that the shape of neutron response function is strongly influenced by small variation of neutron energy; hence, to compare the simulated spectrum with spectrum measured using TOF technique, energy resolution of TOF was also included in the simulation by generating a neutron pencil beam of energy having a Gaussian distribution with centroid at E and

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FWHM equal to the corresponding ΔE.

The energy deposited in the detector was converted into light output using Cecil's prescription [3] as described below.

$$L(E_p) = 0.83E_p - 2.82(1 - \exp(-0.25E_p^{0.93}))$$

$$L(E_\alpha) = 0.41E_\alpha - 0.59(1 - \exp(-0.065{E_\alpha}^{1.01}))$$

$$L(E_{^{12}C}) = 0.017E_{^{12}C}$$
$$L(E_{e^-}) = E$$

where E_p, E_α, $E_{^{12}C}$ and E_{e^-} are energies of scattered proton, α, ^{12}C and e^- respectively.

The pulse-height resolution ΔL(FWHM) of the neutron detector can be parameterized [4], in the terms of scintillator light output L in the units of electron energy equivalent (MeVee),

$$\Delta L = \sqrt{\alpha^2 L^2 + \beta^2 L + \gamma^2} \qquad (2)$$

where parameter α, β and γ are obtained from the fitting of simulated pulse-height spectrum of γ-source ^{137}Cs with experiment pulse-height spectrum. For $7^" \times 5^"$ neutron detector, we obtained $\alpha = 0.15$, $\beta = 0.15$ and $\gamma = 0.02$ respectively. Pulse-height resolution function $\Delta L/L$ was taken into account by folding the calculated light output with Gaussian distribution having FWHM equal to the corresponding pulse-height resolution ΔL.

Mono-energetic neutron response has been simulated for neutron of energy 4 MeV using two different cross-section data libraries, viz. G4NDL3.13 and Geisha routine based data libraries. Fig.1 (top, bottom)shows the comparison of simulated and measured pulse height distributions for the neutrons from ^{252}Cf source and reaction α (35 MeV)+ ^{181}Ta, respectively. Neutron response functions were also calculated with the NRESP7 [5] code to compare with GEANT4 result and experimental result. It is seen that the neutron spectrum obtained from ^{252}Cf source as well as obtained in the reaction α(35MeV) + ^{252}Ta, are very well reproduced by the Geant4 code.

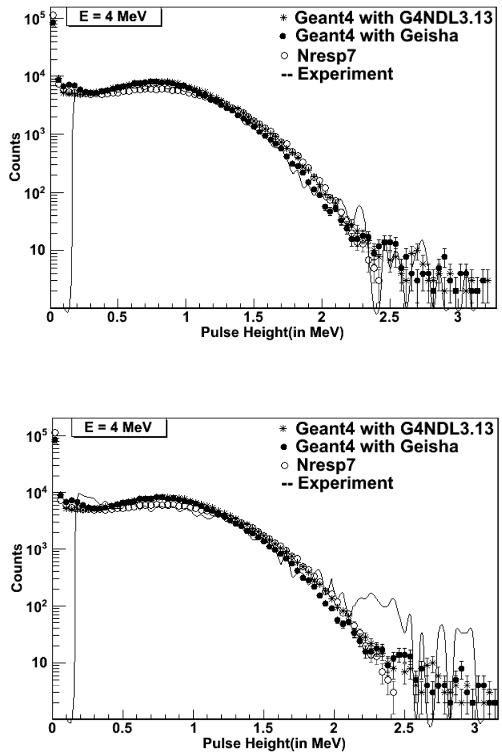

FIG. 1: Comparison of Experimental, GEANT4 simulated and NRESP7 simulated pulse height spectra at neutron energy 4 MeV. Experimental spectra were obtained from ^{252}Cf source (Top) and α (35 MeV)+ ^{181}Ta reaction (Bottom).

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