Simulation studies for ISMRAN at DHRUVA reactor

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Introduction

The phenomena of neutrino oscillation have been established by several experiments using neutrinos form different sources. Presently, the study of neutrino physics is in the precision era. Although there is a well understood 3-neutrino paradigm, several short baseline(SBL) experiments are underway and others will start taking data soon to discover or exclude the existence of sterile neutrino in near future. To search the active-sterile neutrino oscillation, reactor neutrino is one of the available source at SBL. Also the reactor antineutrino measurements may be used for monitoring and safeguarding the nuclear reactor. There are various measurements show a different anomaly, named as "reactor antineutrino anomaly", is associated with an apparent reduction of the flux of reactor electron anti-neutrinos with respect to its expected value. The reactor antineutrino anomaly may be a miscalculation of one or more of the four electron antineutrino ($\overline{\nu}_e$) fluxes or/and active-sterile neutrino oscillations. To measure this reactor anti-neutrino, an experimental set up is underway at DHRUVA reactor hall using Indian Scintillator Matrix for Reactor Anti-Neutrino (ISMRAN) detector set-up. An array of 10×10 plastic scintillator will be used to detect the $\overline{\nu}_e$ produced by the reactor. In this work, we have focused on the estimation of the detector efficiency due to gamma produced from captured neutron and annihilated positron.

Detection and simulation methods

The reactor $\overline{\nu}_e$ detection is based on inverse beta decay (IBD) process, $\overline{\nu}_e + p \rightarrow e^+ + n$. The protons in plastic scintillator (PS) act as target. The coincidence of a prompt positron signal and a delayed signal from neutron capture by Gadolinium (Gd) uniquely identifies the IBD event. The prompt signal includes the energy of 1.02 MeV as two γ-rays from the positron annihilation in addition to positron kinetic energy. The delayed signal produces cascade γ-rays with the total energy of $\sim$8 MeV. To reconstruct the individual energy, a Monte Carlo based GEANT4 toolkit has been used for the detailed simulation of detector considering mono energetic positron and neutron. The detector which is modeled consists of 100 plastic scintillator bars, each having a dimension of 100cm × 10cm × 10cm arranged to form a cube of 1m^3. Each bar is wrapped with a 25μm Mylar foil coated with Gd paint ($\sim$ 4mg/cm^2) which has very high neutron capture cross section ($\sim$10^5). The scintillator ($C_{10}H_{11}$) material with a density of 1.032g/cm^3 will act as the target as well as the detector. The shielding material consist-

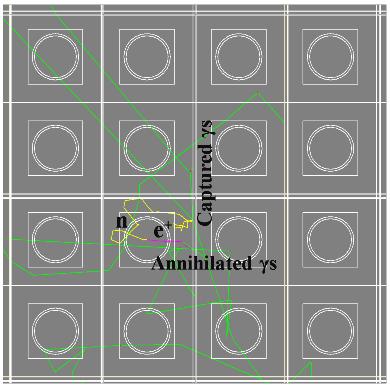

FIG. 1: Simulated $\overline{\nu}_e$ event display in GEANT4. Positron, neutron and gamma are represented by magenta, yellow and green lines, respectively.

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*Electronic address: `shibu.behera@gmail.com` ing of lead (Pb 10cm) and borated polythene (BP 10cm) was also implemented in the detector geometry. A sample of 10^5 simulated events containing positron and neutron are generated within the detector volume to reconstruct gamma energy due to positron annihilation and captured neutron.

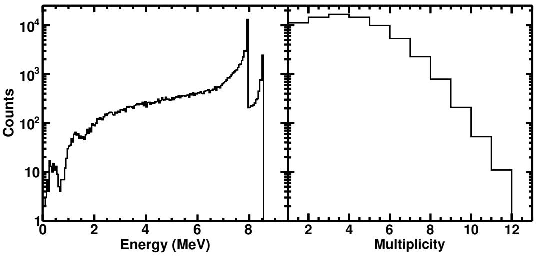

FIG. 2: Gamma energy spectrum (left panel) and multiplicity (right panel) due to neutron captured in Gd.

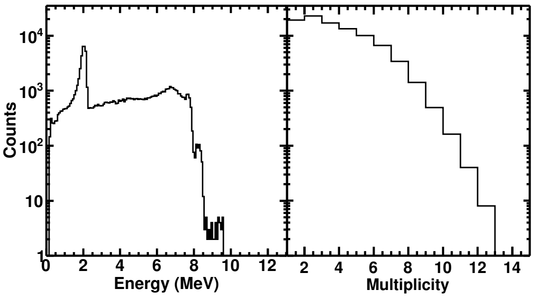

FIG. 3: Total sum energy (left panel) and cross-talk (right panel) of gamma due to neutron capture in Gd and H in PS.

TABLE I: Efficiency of scintillator array for reconstructing gamma energy spectrum due to n-capture

Energy cut on individual bar(MeV)	Reconstruction Efficiency(%)	
	5.0-8.6 MeV	7.5-8.6 MeV
0.0	37	9.8
0.15	35	5.1
0.20	34	4.4
0.25	33	4.0

Results and Discussions

The neutron produced in IBD process is captured by Gd and H. It has been estimated that ∼75% and ∼24% of neutrons are captured in Gd and H, respectively. The neutron of energy 10keV generated at fixed vertex close to the centre of the detector volume gets fully captured within a radius of 20cm. However, for random vertices generated within a volume of single PS bar, that is placed closed to the centre of scintillator array shows ∼97% neutron captured efficiency. In Fig. 2, the left panel shows the cascade gamma energy spectrum and the right panel shows its multiplicity due to n-captured in Gd. It is observed that ∼15% gammas, from Gd deexcitation, are produced with multiplicity 1 in the energy range 7.9 MeV to 8.5 MeV. The total gamma energy due to neutron captured in Gd/H is shown in left panel of Fig. 3. The peak at 2.2 MeV is due to n-captured in H and peaks at 7.9 MeV and 8.5 MeV are due to n-captured in Gd. The cross-talk due to gamma is shown in right panel of Fig 3 with a cut 0.2 MeV energy deposition in the individual PS. The efficiency of detector for gamma energy reconstruction due to neutron captured in Gd is shown in Table I. In the given energy range, the reconstructed efficiency for gamma decreases with increase of energy cut applied in each PS bar. Similar estimation has been carried out for various positron at several energies. It has been observed that detection of positron is almost 100%. At an energy of 3 MeV positron, it is found that the reconstruction efficiency of gamma due to positron annihilation is about 79%. In addition, the spallation neutron produced due to cosmic muon has been estimated using CRY[2] event generator. The fraction (average energy in MeV) of spallated neutrons produced due to cosmic muon (∼4 GeV) in Pb, BP and PS are 97%(1.10), 0.1%(3.90), 1.5%(4.43), respectively. Further studies are going on to estimate the neutron produced in each part of the detector volume and also to estimate the fiducial volume of the detector.

References

[1] J. Allison *et al.*, IEEE Trans. Nucl. Sci. **53**, 270 (2006).

[2] C. Hagmann, D. Lange, and D. Wright, Proc. IEEE Nuclear Science Symp. Conf. Rec., **2**, 1143(2007).