Optimization of neutron and gamma shielding for reactor antineutrino measurement at DHRUVA

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Introduction

The reactor antineutrino ($\overline{\nu}_e$) disappearance has been firmly observed to determine the smallest neutrino mixing angle θ_{13}. The successful measurement of a rather large θ_{13} value opens the possibility of searching for CP violation in the leptonic sector and determining the neutrino mass ordering. However, there are several anomalous results from the measurements and theoretical calculations do not fit the existing framework of production and oscillation of reactor antineutrinos. The reactor $\overline{\nu}_e$ measurements observe a 5.6% deficit in the absolute flux as compared to the theoretical prediction, which is called as reactor antineutrino anomaly. This deficit has led to the hypothesis of oscillation involving a sterile neutrino state with mass of the order ∼1 eV. A simultaneous measurement of reactor $\overline{\nu}_e$ flux and it's energy spectrum may help to address this anomaly. In addition to the study of this new physics, the measurement of the $\overline{\nu}_e$ spectrum from the reactor has found applications in monitoring of the reactor power and the fissile material production [1].

In the reactor ON condition, the gamma spectrum measured by BGO has an energy range from ∼0.5 MeV to 15 MeV. The background rate in the reactor ON condition is in the order of 4 higher as compared to reactor OFF condition. However, in the energy range of 3 MeV to 8 MeV is crucial, since it corresponds to gamma energy at neutron capture by Gd. In order to estimate possibility of suppressing gamma radiation background at an operating reactor, one needs to find out the optimal thickness of shielding. In addition, neutron background from the reactor as well as resulting from the interaction of cosmic muons with lead (Pb) nuclei, other elements of the detector or material present in the reactor hall has be to shielded by considering the proper materials like borated polythene (BP) for thermal neutron and paraffin (Pf) for fast neutron. There are many ways to reduce the different backgrounds that can mimic the signal in the detector. In the present simulation, we focus on optimizing thickness of shielding material for background neutron and gamma keeping in mind the proposed $\overline{\nu}_e$ experiment at DHRUVA reactor at BARC.

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Detection Principle and Simulation Procedure

The reactor $\overline{\nu}_e$ is detected through the inverse beta decay (IBD) interaction, $\overline{\nu}_e + p \rightarrow e^+ + n$, with free protons in plastic scintillator (PS). The coincidence of a prompt positron signal and a mean time of ∼50 μs delayed signal from neutron capture by Gadolinium (Gd) uniquely identifies the IBD event. The prompt signal releases energy of 1.02 MeV as two γ-rays from the positron annihilation in addition to the positron kinetic energy. The delayed signal produces several γ-rays with the total energy of ∼8 MeV. In order to optimize the thickness of various shielding material, the object oriented simulation toolkit GEANT4 has been used for the detailed simulation of the detector for gamma and neutron. The detector which is modeled consists of 100 plastic scintillator bars, each having a dimension of 100 cm × 10 cm × 10 cm arranged to form a cube of 1 m^3. Each bar is wrapped with a 25 μm mylar foil coated with Gd paint (∼ 4 mg/cm^2)

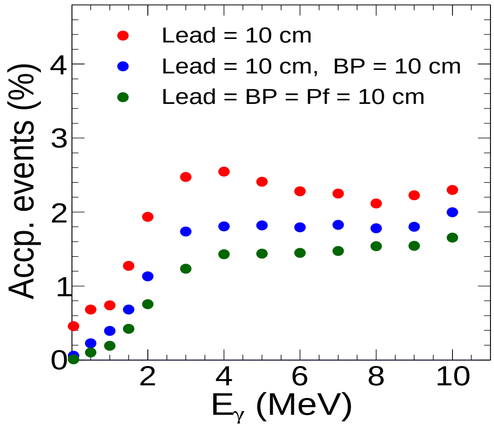

FIG. 1: Effect of shielding using Pb, BP and Pf on incident γ energies.

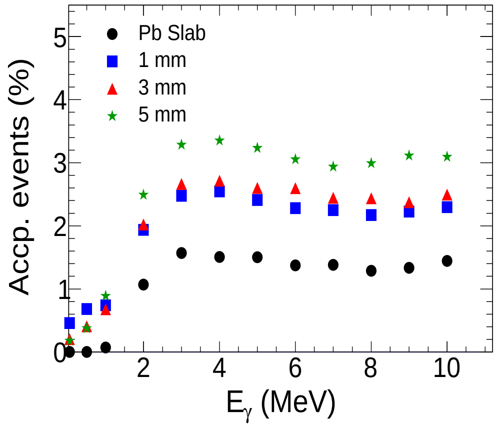

FIG. 2: Effect of different gaps between the Pb bricks as a function of γ energies.

which has very high neutron capture cross section ($\sim 10^5$). The scintillator ($C_{10}H_{11}$) material with a density of 1.032 g/cm^3 will act as the target as well as the detector. A sample of 10^5 events with energies upto 10 MeV are randomly put from the outside on the shielding of the detector array.

Results and discussion

The effect of gamma shielding by Pb, BP and Pf is shown in Fig. 1. It shows that accepted number of events are less than 2% for $E_\gamma < 2$MeV and it increases with increase in energy and saturates beyond 4 MeV. At low energy the photo electric absorption is more and with increase of energy it reduces. With addition of BP and Pf, it further reduces from $\sim$ 2.6% to 1.6%. Further study has been carried out for shielding the gamma rays using Pb-slab and Pb-bricks of 20 cm $\times$ 10 cm $\times$ 10 cm with 1 mm , 3 mm and 5 mm air gaps between adjacent bricks. It may be noted that, along with Pb we have also put BP and Pf. Figure 2 shows with increase of gaps among the lead bricks, the number of gamma rays reach the detector increases from 1.4% to 3.2% from Pb-slab to bricks with 5mm gap. Figure 3 shows the reduction of neutrons from AmBe source with the different shielding material. The accepted number of thermal neutron reach the detector array is less than 1% by using borated rubber of thickness 10 cm. The detailed simulation results will be presented.

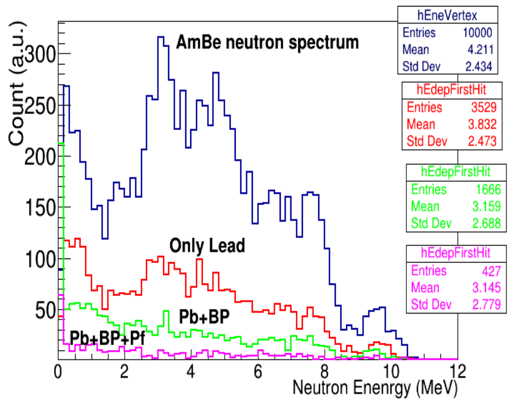

FIG. 3: Effect of different shielding materials (Pb, BP and Pf) on incident neutron energies.

References

[1] S. Oguri et al., Nucl. Instrum. Meth. A **757**, 33 (2014).
[2] V. K. S. Kashyap et al., Proceedings of this symposium.