Liquid and plastic scintillator detectors for detecting antineutrinos from reactors - A GEANT4 simulation study

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Introduction

Reactors are copious sources of electron antineutrinos. Improved calculations done on the expected neutrino flux from reactors by [1] shows that the ratio of the observed to detected neutrinos is less than unity (0.943 ± 0.023) at source to detector distances < 100 m. This has been termed as the *Reactor Antineutrino Anomaly*. The oscillation of the electron antineutrino to a sterile neutrino is a possible explanation for this anomaly. It is also possible to monitor reactors remotely utilizing the difference in the energy spectrum of neutrinos emitted by the fissioning isotopes (^{235}U and ^{239}Pu) in a reactor [2, 3]. As a feasiblity study for setting up an experiment at the DHRUVA reactor facility at BARC, for sterile neutrino search and reactor monitoring, we are performing GEANT4 [4] simulations on scintillation detectors with different geometries.

1. Geometries

We consider two types of geometries: One with a liquid scintillator and the other with a Plastic scintillator. Fig. 1, shows the two geometries modelled in GEANT4.

The liquid scintillator geometry shown in Fig. 1(a), has a 1 t Gd doped liquid scintillator (0.25 %)(sand color) in a steel cylindrical tank coupled to 5$''$ PMTs (brown color) arranged in a hexagonal array on both sides using perspex disks (pink color) of 25 cm thickness.

The Plastic scintillator geometry shown in Fig. 1(b), consists of a matrix of 100 plastic scintillator bars of $100 \times 10 \times 10$ cm^3 dimension coupled directly to 3$''$ PMTs on both sides so as to form a cube of side 1 m. Each bar is wrapped with 25 μm thick aluminized mylar coated with Gd paint (density 4.8 mg/cm^2) to reflect light as well as facilitate neutron capture.

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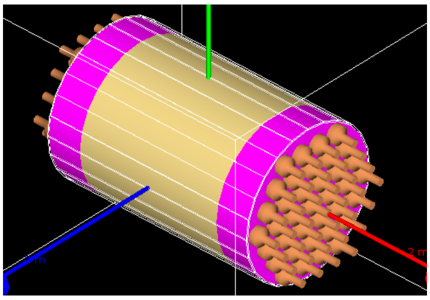
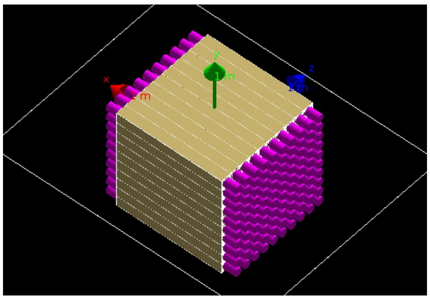


(a) Liquid Scintillator



(b) Plastic Scintillator

FIG. 1: Scintillator geometries.

2. Simulations

The inverse neutron decay reaction is the signal utilized to detect antineutrinos in most of the reactor experiments. Neutrons were generated at random positions inside the scintillators. The energy of the neutrons were derived from the neutrino energy spectrum shown in Fig. 2 generated by refering to [3, 5, 6] assuming that the detector is at a distance of 10 m from the core of the reactor and also that only ^{235}U undergoes fission. The reactor power is assumed to be 100 MW. Neutron capture positions in both the geometries in the cross sectional view is shown in Fig. 3(a) and Fig. 3(b) respectively. We see that in the liquid case, neutron capture is uniform, whereas, in the plastic case, the capture is concentrated near the

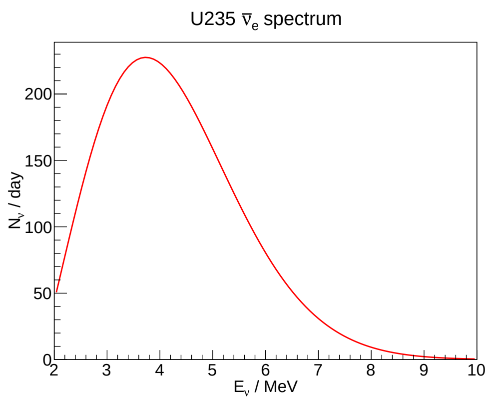


FIG. 2: Energy spectrum of neutrinos from fissioning U235.

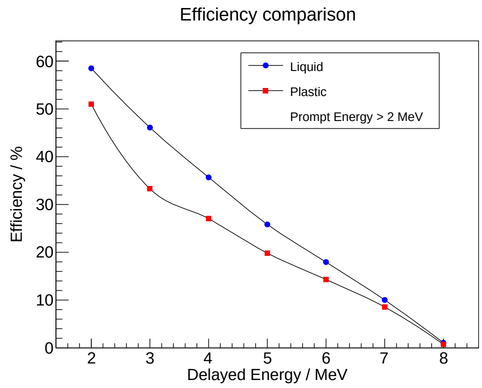
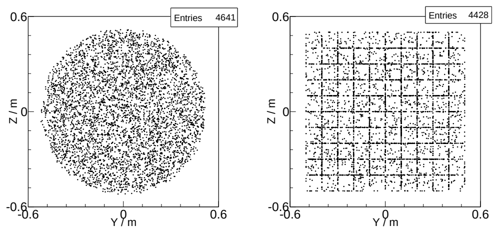


FIG. 4: Efficiency comparison of liquid and plastic scintillators for neutrino detection.



(a) Liquid Scintillator (b) Plastic Scintillator

FIG. 3: Neutron capture positions in liquid and plastic scintillators.

edges of the bars where Gd wrapping exists. The No. of neutrons captured in the liquid scintillator is more compared to the plastic scintillator. For 5000 events generated, Tab. I compares the two types of scintillators for neutron capture. In inverse neutron decay, the prompt signal is from the positron (K.E of positron + Annihilation gamma) and the delayed signal is from the radiative capture of the neutron ($\sim$8 MeV gamma cascade). Inverse neutron decay event was simulated in the detectors using the angular correlation described in [6]. The efficiencies of the two detectors when we vary the delayed energy threshold keeping the prompt signal threshold $>$ 2 MeV is shown in Fig. 4.

	Neutrons Captured	
	Gadolinium	Hydrogen
Liquid	93 %	6 %
Plastic	71 %	27 %

TABLE I: Comparison of neutron capture in Liquid and plastic scintillators.

3. Outlook

At this point of time both the options look feasible. Liquid and plastic have their own advantages and disadvantages. From safety point of view (flammability, handling, transportation etc..) the plastic scintillator option looks to be good. PSD (Pulse Shape Discrimination) properties and low cost of the liquid scintillator makes it a strong candidate. Further simulations and knowledge of the background will help in determining the right detector for the experiment.

References

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