γ-ray and neutron rate measurements at Dhruva reactor for the ISMRAN experiment

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Introduction

The measurement of reactor based anti-neutrino ($\bar{\nu}$) yields are been pursued actively across the world by many groups [1]. These measurements would not only demonstrate the capabilities of remotely monitoring the reactors using $\bar{\nu}$ but also would address an important physics program of sterile neutrino search. The detection of sterile neutrinos, predicted to be the fourth generation of neutrinos, may help in understanding the differences in the theoretical and measured yields from the reactor. A one ton detector setup, Indian Scintillator Matrix for Reactor Anti-Neutrinos (ISMRAN), consisting of plastic scintillator bars (10cm×10cm×100cm) wrapped with Gadolinium coated mylar foils is proposed to measure the $\bar{\nu}$ signal from the Dhruva reactor at BARC. The interaction of $\bar{\nu}$ with the plastic scintillators via inverse beta decay will produce a positron and neutron pair. The annihilated γ-rays from positron and cascade γ-rays from the neutron capture in Gd foils would give us the prompt and delayed signals, respectively. The average time difference between prompt and delayed signal is $\sim$40 μs and can be exploited to filter the $\bar{\nu}$ events in the detector. This time difference, on an event-by-event basis, could be of the order of few 100 μs and would potentially introduce high accidental coincidence events from various background sources. Due to this large time differences in the prompt and delayed signals, it is crucial to estimate and reduce the background rate. In this paper, we present measurement of γ-ray and neutron background yields using the NE-213 liquid scintillator. We further study the feasibility of $\bar{\nu}$ detection using the twenty plastic scintillator bars, which have been recently procured and are in the process of characterization and installation.

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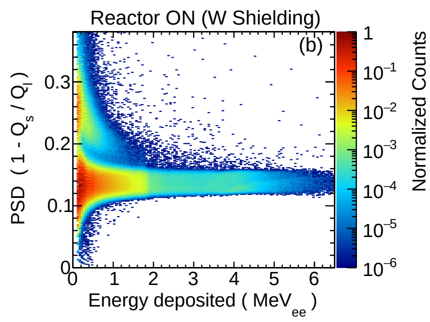

FIG. 1: Pulse shape discrimination of neutrons and γ-ray using NE-213 liquid scintillator in the Dhruva reactor hall.

γ-ray and neutron measurements at Dhruva

The γ-ray and neutron measurements are performed using a 5″ diameter, NE-213 liquid scintillator, kept inside a shielding of 10 cm thick lead (Pb) and 1 cm thick boronated rubber sheets. The pulse shape discrimination (PSD) technique is used to separate neutrons and γ-rays. For the data acquisition, CAEN V1730 waveform digitizer with the PSD firmware was used. The integrated charge in short (Q_s) and long (Q_l) gates were defined to get the optimum PSD parameter for γ-ray and neutron separation in the current setup. The detector was calibrated using the energy deposition by γ-rays from known sources. Fig. 1 shows the PSD parameter as a function of energy deposited (Q_l) in the detector. The upper and lower bands correspond to the γ-ray and neutron, respectively, when the reactor was operational at an average $\sim$95 MW power.

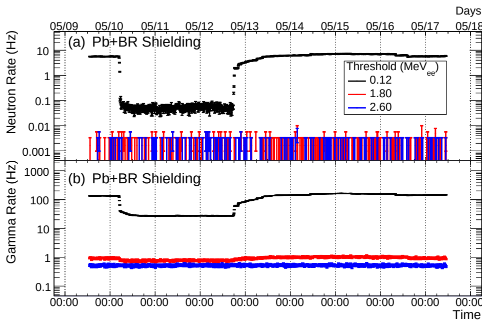

FIG. 2: γ-ray and neutron rates for different detector thresholds at Dhruva reactor hall. The sudden drop in rates is the reactor shut down period.

Fig. 2 shows the efficiency uncorrected neutron (top) and γ-ray (bottom) rates over a long period of reactor operation with different detector threshold selections. The γ-ray and neutron rates with minimum threshold (0.12 MeV$_{ee}$) on the detector in reactor-ON conditions are $\sim$10 Hz and $\sim$100 Hz respectively. This reduces to $\sim$0.1 and $\sim$40 Hz in the reactor-OFF conditions. The use of higher threshold (2-3 MeV$_{ee}$) leads to a reduction by a factor >100 for the dominant γ-ray background. Fig. 3 shows the variation of γ-ray

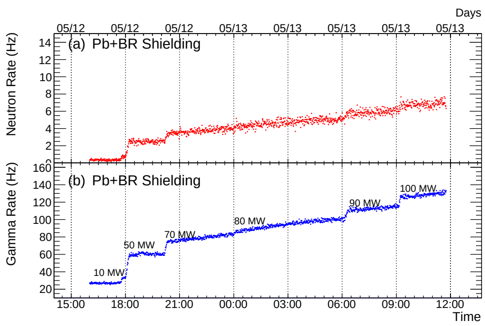

FIG. 3: Variation of γ-ray and neutron rates for different reactor power.

and neutron rates for different reactor powers. The background γ-ray and neutron rates monotonically increases with increase in reactor power.

For the ISMRAN detector setup with plastic bars, the discrimination of γ-ray and neutron is not possible. The combined γ-ray and neutron background rate measurements with existing plastic scintillator setup at Dhruva [2], have been performed inside a shielding stucture consisting of a 10 cm thick Pb and 1 cm thick boronated rubber sheets. Based on these measurements a singles background rate of N$\sim$5KHz in one scintillator bar (10cm$\times$10cm$\times$100cm) is expected. For a 20 scintillator array, this would lead to a random coincidence trigger rate ($^{20}C_2N^2\tau$) of $\sim$240 Hz, in a pair of bars with an assumed time window of τ=50 ns for both prompt and delayed signals. Assuming a reduction factor of >100 for $\sim$ 2-3 MeV threshold on the delayed signal and a reduction factor of >10 for the prompt signal with cuts due to small thresholds and event topology, we expect a background rate of $\sim$500 per day within a prompt-delayed time gate window of 100 μs. Assuming a signal of 10 $\bar{\nu}$s per day, as estimated from the simulations, a detection sensitivity of 3σ level can be obtained in 40 days of measurement, which can be reduced to 10 days with a four times better suppression of background.

Summary

We have measured the γ-ray and neutron rates separately using a NE-213 liquid scintillator and studied the variation of background rates with different detection thresholds. Further, an estimation of the detection sensitivity of $\bar{\nu}$s from Dhruva reactor have been made for the twenty scintillator array based on measured background rates and realistic chance coincidence suppression factors.

Acknowledgments

We thank the reactor operation group for their excellent support during the measurements.

References

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