Measurement of non-reactor background and effect of borated polyethylene shielding for ISMRAN

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Introduction

The observation of Reactor Anti-neutrino ($\bar{\nu}_e$) Anomaly (RAA) [1] along with use of $\bar{\nu}_e$ for non-intrusive probing of reactor power and fissile inventory [2] are active areas of research currently being pursued across the world. The International Atomic Energy Agency (IAEA) plans to exploit this non-intrusive nature of $\bar{\nu}_e$s (interaction cross-section ($\sim10^{-43}$cm^2)) for monitoring purposes under its 'Safeguards Regime'. These guidelines suggest setting up ∼1 ton by weight above-ground detector in vicinity of reactor sites. In view of this, the Indian Scintillator Matrix for Reactor Anti-Neutrino (ISMRAN) detector setup, comprising of 10×10 matrix of 100cm×10cm×10cm Plastic Scintillator bar (PS) wrapped with Gd (Gd_2O_3) foil, is proposed at the Dhruva research reactor facility at Bhabha Atomic Research Center (BARC) India. To detect such rare events a shielding of 10cm Pb followed by 10cm borated polyethylene (BP) outside is being set up in the reactor hall. The above-ground operation of ISMRAN close to Dhruva (∼13m) requires substantial background reduction from natural and cosmic sources. In this paper we present the results of background measurements performed in the non-reactor environment and demonstrate its reduction through the use of BP shielding.

Detection principle and measurement setup

$\bar{\nu}_e$ from reactor will interact with a proton in scintillator volume through inverse beta decay(IBD) producing a positron and a neutron

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

The prompt signal in detector will comprise of the kinetic energy deposited by positron and two 0.511 MeV gammas from its annihilation. The neutron would eventually thermalize in the active volume of the detector and would be captured by a Gd nucleus. The cascade of gamma rays, coming from the deexcitation this nucleus, forms the delayed signal. The current studies have been performed using 16% of the proposed detector which comprises of 16 bars in a symmetric 4×4 arrangement with the data being read through CAEN V1730 digitizers as shown in the Fig 1.

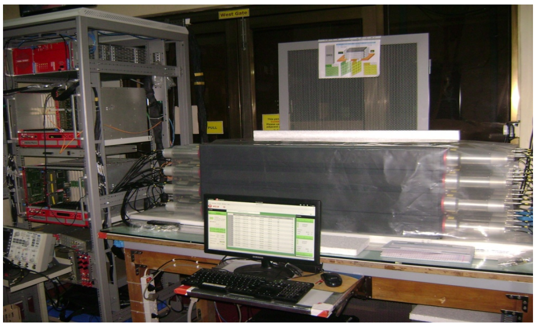

Fig 1: Prototype detector setup of 4×4 PS bars with digitizer DAQ in non-reactor environment

Non-reactor background measurements without shielding

Natural gamma and muon background studies were performed in non-reactor environment without any shielding. The prominent background sources for our detector are

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^{40}K and ^{208}Tl gamma rays. Cosmic muons also lose $\sim 2 \frac{\text{MeV}*\text{cm}^2}{\text{gm}}$ adding up to ~20 MeV energy for 10cm×10cm cross section plastic bar. Apart from these, minor contribution to gamma background come from ^{214}Bi, ^{232}Th and ^{238}U. Table I below lists the above background sources along with the respective energy regions in which the average rates are measured for each bar of the 4×4 matrix without shielding. The 'Region-of-interest' corresponding to expected prompt delay signal energies is also calculated. See also Fig 2, for the observed spectral nature.

Table I: Sources of background for PS bar and their average rates per bar

No.	Background source	Energy range (MeV)	Rate per bar (Hz)
1.	^{40}K(1.460 MeV)	1.1−1.5	~27
2.	^{208}Tl(2.614 MeV)	1.8−2.7	~10
3.	Cosmic muon(~20 MeV)	17.0−32.0	~6
4.	Region-of-interest	0.2−7.0	~132

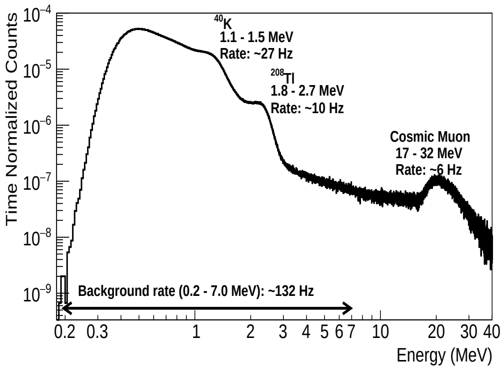

Fig 2: Typical natural background spectrum recorded in a PS bar. ^{40}K and ^{208}Tl Compton edges are visible along with a cosmic muon peak at higher energies.

Measurements done with borated polyethylene shielding

Borated polyethylene (BP) is a useful shielding material especially for neutrons in thermal region (capture cross sections: ^{10}B ~3840 barns and ^{11}B ~0.005 barns). In order to test the background shielding provided by the BP material(having 30% Boron) a 31.5cm×31.5cm×5cm test sample was placed over the 'top bar' (see inset Fig 3) of the 4×4 stack, shielding it from a high intensity Am−Be source. This source produces both: a 4.4 MeV gamma and neutron whose average energy lies in the 3−4 MeV range. The spectra in diagonally opposite 'bottom bar' shows reduction of ~25% in time normalized counts due to BP as shown in Fig 3. A noticeable rise at 2.2 MeV and at energies beyond 4.4 MeV can be attributed to radiative neutron capture on H and Gd, with BP assisting the thermalization forming an artificial source of background to the $\bar{\nu}_e$ signal.

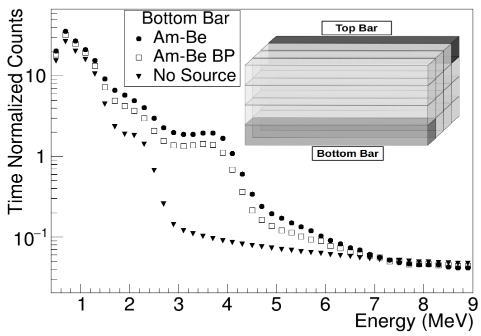

Fig 3: Gamma spectra from Am−Be source with and without BP (5cm thick) shield. No source spectra is also shown for reference.

Conclusion and Outlook

The natural and cosmic background sources have been identified and their rates in the plastic bars are quantified. Also, effect of 5cm BP shield sample was studied, which shows ~25% reduction in time normalized counts. The setup has been recently moved to Dhruva Reactor Hall where elaborate shielding studies in both Reactor ON and OFF conditions with enhanced 10cm BP and 10cm Pb shield are currently underway.

References

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