Simulation studies of Neutron-Induced Background for $0\nu\beta\beta$ decay in ^{124}Sn from underground rock activity at INO

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Introduction

The TIN.TIN detector (The INdia-based TIN detector) comprising cryogenic bolometer array of Tin detector elements is under development for a feasibility study to search for $0\nu\beta\beta$ decay in ^{124}Sn [1]. Given the rarity of the process of $0\nu\beta\beta$ decay where $T_{1/2} > 10^{20}$ yrs, understanding and minimization of background is very important. Of the different sources of background, neutrons are the most difficult to suppress and hence crucial to understand. It is crucial to estimate the contribution of neutron induced background in an underground laboratory and from the surrounding detector materials [2]. The simulation studies for neutron spectra in the INO cavern and the shield design have been initiated. Some of the results are presented here.

Details of Monte Carlo Simulations

Neutrons are produced in the spontaneous fission of $^{\text{nat}}$U (mainly ^{238}U), Th present in the rocks and the surrounding materials. In addition, (α, n) reactions on light nuclei present in the rocks can produce neutrons. Very high energy neutrons ($E_n \sim$ GeV) are produced by muon-induced interactions in the rocks and materials surrounding the detector.

A GEANT4-based simulation study has been done employing the Bodi West Hills (BWH) rock composition, obtained from Secondary Ion Mass Spectrometry (SIMS) (see Table I). Only dominant components with concentration > 0.1% are listed in Table I.

TABLE I: Elemental distributions of BWH rock obtained with TOF-SIMS.

Element	Conc. (%)	Element	Conc. (%)
^{12}C	2	^{39,40,41}K	4
^{23}Na	5	^{40}Ca	9.99
^{24,25,26}Mg	7	^{56}Fe	1
^{27}Al	25	^{63,65}Cu	1.2
^{28,29,30}Si	40	^{120}Sn	0.6

The BWH rock contains 60 ppb of ^{238}U and 224 ppb of ^{232}Th as obtained from Inductively Coupled Plasma Mass Spectrometry (ICPMS). Fig. 1 shows the neutron-energy spectra from spontaneous fission of 60 ppb of ^{238}U obtained with the Watt spectrum [3]. MC studies have been done with a monoenergetic neutron beam of energy $E_n \leq 20$ MeV

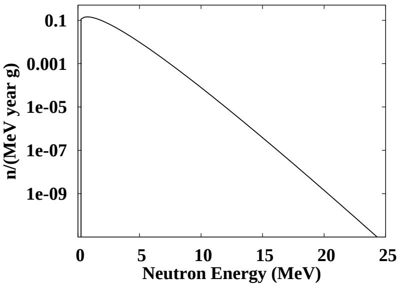

FIG. 1: Neutron-energy spectra from spontaneous fission of 60 ppb of ^{238}U.

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using G4NDL4.0 neutron cross-section library. Shield design for the neutrons and gammas originating from neutron induced reactions is also studied.

Results and Discussions

In the Monte Carlo (MC) simulations, the rock and experimental hall housing the detector setup are separated by a planar boundary. Shield materials are inserted in between the two media (see Fig. 2). The gamma and neutron spectra entering into the hall are studied to understand the propagation of neutron through the rock and shield materials. An effective rock thickness can be calculated by folding of neutron spectra through layers of rocks. This is essential to minimize statistical errors and computation time.

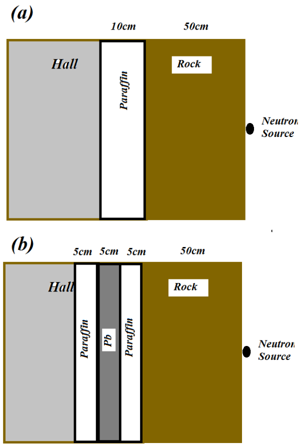

FIG. 2: Neutron shielding using (a) Paraffin (I) and (b) Paraffin+Pb in between the rock and experimental hall (II).

Neutron capture on proton releases a γ-ray of 2224.573(0.002) keV energy (the binding energy of Deuteron) within the region of interest (ROI), near the $Q_{\beta\beta}$ keV of ^{124}Sn (2292.64(0.39) keV). The production of this γ-ray is higher for paraffin due to its high hydrogen content. Hence a Pb shield was inserted in between two blocks of paraffin (see Fig. 2(b)). Table II shows the number of neutrons (N_n) and photons (N_γ) entering the experimental hall for different shielding configurations with 10^6 incident neutrons and 50 cm rock. It can be seen that the composite shielding of Pb and paraffin is suited for both neutron and γ background reduction.

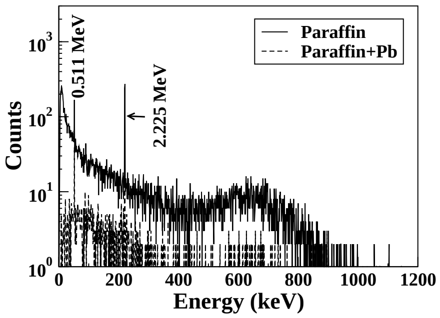

FIG. 3: Gamma-ray spectra at the boundary of the two media for the two shielding configurations.

TABLE II: Number of neutrons (N_n) and photons (N_γ) entering the experimental hall for different shielding configurations.

Shield	N_n	N_γ	2.225 MeV	0.511 MeV
I	2153	13783	535	298
II	1452	1374	36	58

Summary

A composite shielding is required to reduce the neutron-induced background from rock activity in underground locations. For TIN.TIN detector, hydrogen-rich shielding material produces a γ-ray in the ROI for $0\nu\beta\beta$ decay in ^{124}Sn and hence shield design require special consideration for gamma attenuation.

References

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