Estimation of Neutron flux in TIFR Low background Experimental Setup (TiLES)

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Introduction

In rare event studies like neutrinoless double beta decay ($0\nu\beta\beta$), dark matter search etc., minimizing the background is very important. Neutron induced background can be a limiting source of the background in such studies, since neutrons are most difficult to suppress. It is therefore crucial to measure neutron flux in the low background experimental setups.

The ambient neutron background at sea level arises from the spontaneous fission of Uranium and Thorium isotopes as well as from (α, n) nuclear reactions. In addition, the cosmic muon interactions in high Z shielding materials, used for reducing γ background, act as a strong neutron source [1]. They can produce neutrons in many ways like spallation reactions, photonuclear reactions, muon capture etc. Subsequently, these neutrons can interact with the detector and shielding materials, giving rise to enhanced γ-ray background. In this work, we estimate the thermal and fast neutron flux incident upon the TiLES HPGe detector [2] from the intensity of spectral lines arising from ^{74}Ge (n,γ)$^{75\mathrm{m}}$Ge and ^{72}Ge (n,n$'$)^{72}Ge reactions, respectively.

Experimental details

TiLES is a low background, high efficiency counting setup at TIFR (at the sea level). The setup consists of a low background HPGe detector (70%) having an active volume of $\sim$ 230 cm^3 with graded shielding of 5 cm thick low activity OFHC Cu and 10 cm thick low activity Pb (^{210}Pb $<$ 0.3 Bq/kg). The whole system is enclosed in a Radon exclusion box, which is continuously purged with boil-off N$_2$ at an over-pressure of $\sim$ 8 mbar to reduce the Radon (^{222}Rn) contamination. In addition, an active veto system comprising three plastic scintillators (50 cm × 50 cm × 1 cm each) is provided for cosmic muon rejection [3, 5]. The data acquisition system of the TiLES is based on a CAEN N6724 digitizer (14 bit, 100 MHz). Energy calibrations are done with standard sources and the resolution is measured to be 2.2 keV at 1332 keV. The stability of the energy scale is monitored with background gamma rays, and is found to be better than 1% over a period of 12 weeks.

Ambient background data acquired with this setup for a period of about 75 days and is shown in Fig. 1. Several gamma rays resulting from neutron induced reactions from the detector and surrounding materials are clearly visible and are listed in Table 1.

TABLE I: Observed γ-rays due to neutron interactions in detector and surrounding materials.

Energy (keV)	Reaction	Count rate (I$_\gamma$) (s^{-1})
139.9	^{74}Ge (n,γ)^{75m}Ge	4.5(12)$\times10^{-4}$
198.4	^{70}Ge (n,γ)^{71m}Ge	5.3(5)$\times10^{-4}$
594.1-605.2	^{74}Ge (n,n$'\gamma$)^{74}Ge	6.9(21)$\times10^{-4}$
669.8	^{63}Cu (n,n$'\gamma$)^{63}Cu	2.5(2)$\times10^{-4}$
689.1-705.2	^{72}Ge (n,n$'$)^{72}Ge	4.4(14) $\times10^{-4}$
962.1	^{63}Cu (n,n$'\gamma$)^{63}Cu	3.4(3) $\times10^{-4}$

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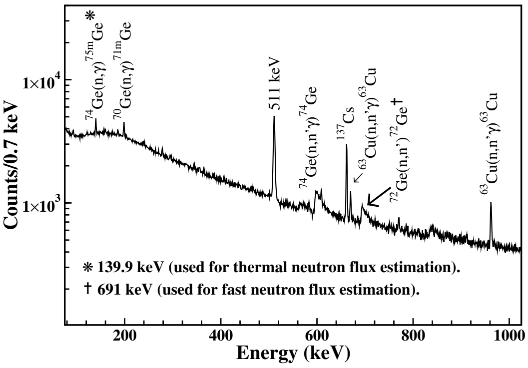

FIG. 1: Ambient background spectrum in TiLES for 75 days.

Analysis

A. Estimation of thermal neutron flux

Thermal neutron flux incident upon the detector is estimated from the intensity of 139.9 keV γ-ray ($I_{139.9}$) as [6]:

$$\Phi_{\rm th} = \frac{I_{139.9}}{N(^{74}{\rm Ge})\frac{\epsilon^{\gamma}_{139.9}+\alpha_{\rm tot}}{1+\alpha_{\rm tot}}\sigma_{\rm th}(^{74}{\rm Ge})}. \quad (1)$$

where $N(^{74}\mathrm{Ge})$ is the number of ^{74}Ge atoms in the detector physical volume (298 cm^3), $\alpha_{\rm tot}$ is the internal conversion coefficient, $\sigma_{\rm th}$ is the thermal neutron capture cross section (0.17 barns [8]) and $\epsilon^{\gamma}_{139.9}$ is the intrinsic photopeak efficiency at E_γ = 139.9 keV). The intrinsic efficiency was calculated using the GEANT4 toolkit (version: geant4 10.1) [7]. A point source of $E_\gamma = 139.9$ keV was placed inside the cylindrical detector volume (covering the physical dimensions of crystal) spanning the range of radius and length in steps of 2 mm. The photopeak efficiency for each grid point was computed for 10^5 events. The average efficiency for this energy, $\epsilon^{\gamma}_{139.9} = 68\%$ was then obtained by numerical integration over the physical volume of the detector.

B. Estimation of fast neutron flux

The inelastic scattering of fast neutrons $^{72}\mathrm{Ge}(\mathrm{n},\mathrm{n}')^{72}\mathrm{Ge}$, populates the 0^+ state at 691 keV. The fast neutron flux $\Phi_{\rm F}$ was obtained from the spectral intensity of 691 keV line (I_{691}), which is a $0^+ - 0^+$ transition [4] and can decay only by electric monopole conversion electrons (E0). Therefore, taking the detection efficiency as 100%, equation (1) can be modified as:

$$\Phi_{\rm F} = \frac{I_{691}}{N(^{72}{\rm Ge}) \times \sigma(^{72}{\rm Ge})} \quad (2)$$

where $N(^{72}\mathrm{Ge})$ is the number of ^{72}Ge atoms in detector active volume and $\sigma(^{72}\mathrm{Ge})$ is the cross section for production of this state ($\sim$ 80 mb for $E_n \sim 1.22$-16.3 MeV [9]). It should be mentioned that since electron range is $\sim$ microns, only the active volume of the detector contributes to the signal in this case. The estimated values of the neutron flux are:

$$\Phi_{\rm th} = 8.4(2) \times 10^{-4}\ {\rm cm^{-2}s^{-1}}$$
$$\Phi_{\rm F} = 2.0(4) \times 10^{-3}\ {\rm cm^{-2}s^{-1}}$$

Further studies on cosmic muon-induced neutron interactions in the shielding materials are in progress.

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References

[1] N. Jovančević et al., NIM A **612** (2010) 303.
[2] N. Dokania et al., NIM A **745** (2014) 119.
[3] PhD thesis, Neha Dokania (2015).
[4] http://www.nndc.bnl.gov/
[5] G. Gupta et al., Submitted to DAE-BRNS symposium (2016).
[6] G.P. Škoro et al., NIM A **316** (1991) 333.
[7] S. Agostinelli et al., NIM A **506** (2003) 250.
[8] Table of Isotopes, eighth edition, Richard B. Firestone, John Wiley & Sons, Inc. (1999)
[9] C. Chasman et al., NIM A **37** (1965).