Study of Neutron-Induced Background in $^{\mathrm{nat},124}$Sn and $^{\mathrm{nat}}$Zr for Double Beta Decay

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Introduction

A tin cryogenic bolometer to search for neutrinoless double beta decay (NDBD) in ^{124}Sn is under development at INO [1]. In a rare decay process like NDBD where $T_{1/2} > 10^{24}$ yrs, background understanding and minimization is critical in improving the sensitivity of the $0\nu\beta\beta$ measurement. A low background counting setup with special lead shielding has been made at TIFR for radiation background studies and material characterisation [2]. This setup can be used to study rare events and measurement of DBD to excited states in ^{94}Zr (E_γ= 871 keV) with $^{\mathrm{nat}}$Zr foil is planned. One of the major sources of background is neutron-induced reactions. The n-capture on ^{124}Sn nuclei produces ^{125}Sn, which undergoes β^- decay ($T_{1/2}$ = 9.64 days, 9.52 mins) and the Q_β = 2357 keV is very close to $Q_{\beta\beta}$ of ^{124}Sn (= 2289 keV). In case of Zr, $T_{1/2}$ for n-capture products ranges from few hours to several days. In addition, any impurities present in target may be the potential sources of background. Hence, study of neutron-induced background becomes very crucial and will be useful to estimate n-induced background from fission in surrounding rocks at INO. With this motivation, n-induced background is investigated in $^{\mathrm{nat},124}$Sn and $^{\mathrm{nat}}$Zr. In addition, n-induced reactions in ETP Cu (used in the cryostat of the dilution refrigerator) are also studied.

Experimental Details & Analysis

The experiment was carried out at the Pelletron Linac Facility, Mumbai using E_p = 12, 20 MeV beam on a ∼5 mm thick Be target in neutron irradiation setup [3]. Fast neutrons with broad energy distribution up to 8 MeV and 16 MeV, respectively, were obtained. Targets for irradiation were mounted in specially designed setup outside the vacuum chamber in forward direction at ∼2.5 cm. Two setups with efficiency calibrated HPGe detectors were used for detection of characteristic gamma rays of reaction products in the irradiated targets. One setup consisted of a low background detector (∼70%) with a 10 cm low activity Pb (<0.3 Bq/kg) shield [2] and the other (∼30%) detector was shielded with 5 cm thick (normal) Pb rings. After irradiation, targets were mounted in a close geometry in these counting setups. Data was recorded and analysed using LAMPS [4]. Fig. 1 & 2 show the spectra of the irradiated Sn and Zr targets in the two counting setups. The characteristic gamma rays are identified by tracking their half-lives and are listed in Table. II. No impurities were found in either of the Sn samples while Nb and Sr elements are seen in Zr. A potential source of background for the study of DBD in ^{94}Zr is the Compton continuum of E_γ = 1713 keV arising from the de-

TABLE I: Details of targets studied

Target	E_p 12MeV	E_p 20 MeV
^{124}Sn	12h	30m, 4h, 13.7h
$^{\mathrm{nat}}$Sn	12h	2h, 13.7h
$^{\mathrm{nat}}$Zr	12h	4h, 13.7h
$^{\mathrm{nat}}$Cu	12h	30m, 13.7h

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cay of ^{89}Zr. In ^{nat}Cu, ^{64}Ni is observed, which leads to ^{65}Ni ($T_{1/2}$ = 2.5 h).

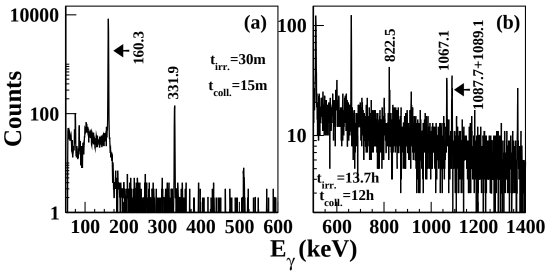

FIG. 1: Gamma ray spectra for ^{124}Sn (a) 15 m, (b) 3 d after irradiation with E_p = 20 MeV.

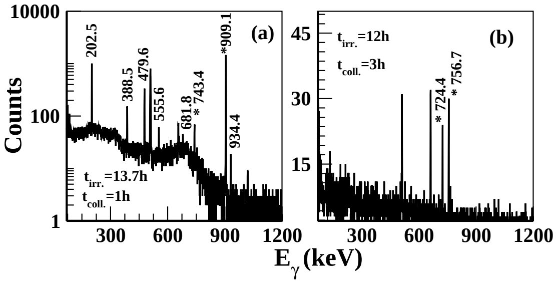

FIG. 2: Gamma ray spectra for ^{nat}Zr (a) 1.5 h, E_p = 20 MeV, (b) 6 d, E_p= 12 MeV, after irradiation.

TABLE II: Gamma lines observed in the irradiated Sn and Zr targets.

Reaction channel	$T_{1/2}$ Refn.[5]	E_γ (keV)
^{124}Sn(n, 2n)^{123m}Sn	40.06m	160.3
^{124}Sn(n, γ)^{125m}Sn	9.52m	331.9
^{124}Sn(n, γ)^{125}Sn	9.64d	822.5, 1067.1, 1089.1
^{90}Zr(n, p)^{90}Y	3.19h	202.5, 479.6, 681.8
^{91}Zr(n, p)^{91m}Y	49.7m	555.6
^{94}Zr(n, γ)^{95}Zr	64.0d	724.2, 756.7
^{96}Zr(n, γ)^{97}Zr	16.7h	743.3
^{90}Zr(n, 2n)^{89}Zr	78.4h	909.1, 1713.0
^{93}Nb(n, 2n)^{92}Nb	10.15d	934.4
^{86}Sr(n, γ)^{87}Sr	2.8h	388.5

The n-capture product concentration N_X is related to measured gamma ray yield (N_γ) in a time interval t_1 to t_2 as,

$$N_\gamma = I_\gamma \times \epsilon_\gamma \times \int_{t_1}^{t_2} \frac{dN_X}{dt}\, dt.$$

where I_γ is the branching ratio and ϵ_γ is the efficiency of the detector for a finite size source in close geometry, which is computed from Geant4-based Monte Carlo simulations. The N_X is related to neutron flux and can be expressed as,

$$N_X = N_i \times N_{t-irr} \times d\Omega \times N_f$$

$$N_f = \int_{E_n} \sigma_c(E_n) N_n(E_n)\, dE_n.$$

where N_i is number of incident protons, N_{t-irr} is number of target atoms per unit area, $d\Omega$ is the solid angle subtended by the irradiation target, $\sigma_c(E_n)$ is the $(n,\gamma), (n,2n)$ cross-section [5] and $N_n(E_n)$ is the thick target neutron yield of energy E_n in ^{9}Be per incident proton per unit solid angle. Table. III shows estimated N_f from the measured yield N_γ.

TABLE III: Estimated N_f for different channels.

Reaction channel	E_γ (keV)	N_f (b×MeV /sr/proton)
^{124}Sn(n, γ)^{125m}Sn	331.9	6.7E-06
^{124}Sn(n, γ)^{125}Sn	1067.0	6.0E-06
^{94}Zr(n, γ)^{95}Zr	724.2, 756.7	1.8E-05
^{90}Zr(n, 2n)^{89}Zr	909.1, 1713.0	8.1E-05

Summary

Fast neutron-induced background is studied in DBD candidates ^{nat,124}Sn, ^{nat}Zr and in ^{nat}Cu which is the surrounding material. No impurities have been found in Sn while ^{93}Nb and ^{86}Sr are observed in ^{nat}Zr. In ^{nat}Cu, ^{64}Ni is present, which has a short lived activity.

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References

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