Assessment of borated rubber for neutron shield

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Introduction

Background reduction is of paramount importance for rare decay experiments like neutrinoless double beta decay ($0\nu\beta\beta$). Given the rarity of the process ($T^{0\nu}_{1/2} > 10^{25}$ years), rigorous qualification and quantification of the background is inevitable. Neutron background is often the limiting background in such cases. The design of the shield for suppressing the ambient neutron/γ-ray background plays an important role in determining the sensitivity of the experiment. We have looked at the possibility of using Boron loaded rubber as passive neutron shield material. Borated rubber was considered a prospect neutron shield material for two reasons : the fast neutrons can be thermalized by hydrogen present in the rubber and the high thermal neutron capture cross section of $^{10}\mathrm{B}(\mathrm{n},\alpha)^{7}\mathrm{Li}$ reaction (3000b) can be exploited to significantly attenuate the neutron flux without the production of any additional γ-rays.

Measurements were carried out to study absorption of neutrons using standard neutron sources. Further background due to dissolved impurities in rubber was assessed using neutron activation setup at Pelletron facility.

Experimental details

Borated rubber with different Boron loading (10,20,30 and 50% by weight) were purchased from Boron Rubbers India. Neutrons from ^{252}Cf source were thermalized with 5 cm thick high density polyethylene (HDPE) and the thermal neutron attenuation in borated rubber for different Boron concentrations was studied with a CLYC detector. It was observed that the thermal neutron counts significantly decreases with 10% Boron loading (∼90% of the thermal neutron flux is attenuated) and saturates (to a value of ∼92%) at around 30% of Boron loading.

To assess the impurities in borated rubber, a sample of 10% Boron loading of dimensions 1cm × 1cm × 1cm was irradiated in the Pelletron facility with fast neutrons from $^{9}\mathrm{Be}(\mathrm{p,n})^{9}\mathrm{B}$ (Q = -1850 keV) reaction[2]. Proton beams of energy $E_p \sim 20$ MeV on a Be target (5 mm thick) were used to obtain neutrons of a broad energy range. After irradiation, the samples were counted offline in HPGe detector for the identification of characteristic γ-rays of reaction products resulting from neutron activation.

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Results and discussions

FIG.1 shows the γ-ray spectrum of the irradiated borated rubber. The list of visible γ-rays, their origin and half lives are listed in Table.1. The half life of the visible γ-rays were tracked and the yields were compared with the expected branching ratios to confirm their origin.

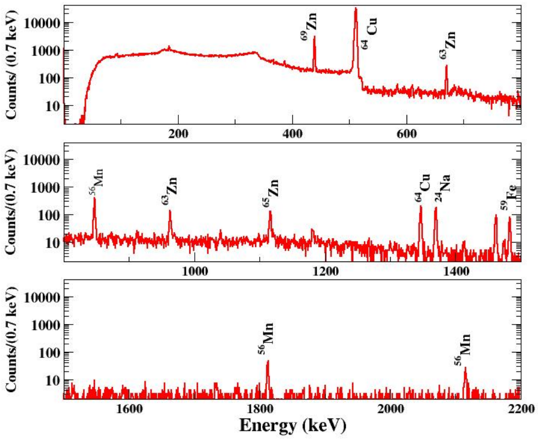

FIG. 1: γ-ray spectrum for neutron irradiated borated rubber taken in TILES HPGe detector [1]. Sample counted on face. $T_{\mathrm{irr}} = 12$ hours, $T_{\mathrm{data}} = 25$min.

The γ-rays from the neutron activation of isotopes of Zn and Fe indicates the presence of these elements in borated rubber. It is expected that the presence of Zn can be the compounds of Boron and Zinc that are used for loading of B in the rubber matrix. However, the origin of neutron activation lines from Fe are unclear.

Although borated rubber is an efficient thermal neutron absorber, the above results have important implications in terms of low background shielding aspects. The observation of high energy γ-rays like 1345.8 from $^{68}\mathrm{Zn}(\mathrm{n},\gamma)^{69}\mathrm{Zn}$ and 2115.9 keV from $^{56}\mathrm{Fe}(\mathrm{n,p})^{56}\mathrm{Mn}$ and the population of long lived isomeric state in $^{65}\mathrm{Zn}(T_{1/2} = 243.9\mathrm{d})$ makes it undesirable for application in rare decay event experiments.

TABLE I: Observed γ-rays in the irradiated borated rubber

E_γ (keV)	Origin	$T_{1/2}$
438.6	$^{68}\mathrm{Zn}(\mathrm{n},\gamma)^{69}\mathrm{Zn}$ $^{70}\mathrm{Zn}(\mathrm{n},2\mathrm{n})^{69}\mathrm{Zn}$	13.7 h
511.0	$^{64}\mathrm{Zn}(\mathrm{n,p})^{64}\mathrm{Cu}$ $^{64}\mathrm{Zn}(\mathrm{n},2\mathrm{n})^{63}\mathrm{Zn}$	12.7 h 38.5 m
669.6	$^{64}\mathrm{Zn}(\mathrm{n},2\mathrm{n})^{63}\mathrm{Zn}$	38.5 m
846.8	$^{56}\mathrm{Fe}(\mathrm{n,p})^{56}\mathrm{Mn}$	2.6 h
962.1	$^{64}\mathrm{Zn}(\mathrm{n},2\mathrm{n})^{63}\mathrm{Zn}$	38.5 m
1115.5	$^{64}\mathrm{Zn}(\mathrm{n},\gamma)^{65}\mathrm{Zn}$ $^{66}\mathrm{Zn}(\mathrm{n},2\mathrm{n})^{65}\mathrm{Zn}$	243.9 d 243.9 d
1345.8	$^{64}\mathrm{Zn}(\mathrm{n,p})^{64}\mathrm{Cu}$	12.7 h
1481.9.8	$^{58}\mathrm{Fe}(\mathrm{n},\gamma)^{59}\mathrm{Fe}$	4.6 s
1810.8	$^{56}\mathrm{Fe}(\mathrm{n,p})^{56}\mathrm{Mn}$	2.6 h
2112.9	$^{56}\mathrm{Fe}(\mathrm{n,p})^{56}\mathrm{Mn}$	2.6 h

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