Study of long-lived activities from fast neutron-induced reactions in tin-bismuth alloys

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Introduction

The *TIN.TIN* detector will consist of tin-based superconducting bolometers to study neutrinoless double beta decay in ^{124}Sn [1]. As pure tin is susceptible to tin pest failure at low temperatures [2], tin-bismuth alloys are being explored as candidates for the bolometer.

It is crucial to understand the neutron-induced background from the detector and surrounding materials as this limits the background suppression for rare decay searches in an underground lab. The neutron-induced background in ^{nat}Sn and some other materials is reported in [3]. This study will explore the long-lived activity from fast neutron-induced reactions in the bolometer candidate tin-bismuth. Neutron activation can also be used as a sensitive probe to check if the process of growing the tin-bismuth alloys has introduced any impurities.

Experiment and data analysis

The neutron activation experiment was performed at the 6m irradiation facility, Pelletron Linac Facility, Mumbai [4]. A broad range of neutrons upto E_{max}=18.9 MeV was generated using 21 MeV proton beam on ^{9}Be target via the ^{9}Be(p,n)^{9}B channel (Q_{th}=2.057 MeV). Tin-bismuth alloys were grown using 7N pure tin and 6N pure bismuth at TIFR, Mumbai. These samples were rolled into foils of $\sim$ 50 - 60 mg/cm^2. Bismuth was alloyed at 4.53 % by weight and 0.09 % by weight (stoichiometric composition) in the foils. The samples (tin, bismuth, tin-bismuth and iron) were stacked in a teflon holder and mounted in the forward direction with respect to the proton beam. The tin and bismuth samples were included for comparison with the tin-bismuth sample, in order to understand any activity originating from impurities. The samples were irradiated for $\sim$ 11 h. The energy integrated neutron flux was estimated as $\sim 10^6$ n cm^{-2} s^{-1} using ^{56}Fe(n,p)^{56}Mn. All the samples were counted offline. The iron foil was counted in a CeBr$_3$ detector while the other samples were counted in TiLES [5]. All the tin-bismuth foils were counted together. The spectra were analyzed using LAMPS [6] software. Half-life tracking was used to verify/identify the source of the γ-rays, wherever possible.

The bismuth sample did not show any activity after irradiation. Hence, the activity in the tin-bismuth alloys is expected to originate from the activation of tin or additional impurities, which may have been introduced during the growth process. The spectra of the tin and tin-bismuth samples were compared to understand the additional activity arising in the tin-bismuth samples (see Fig. 1). Table I lists the prominent reaction channels that were observed in the samples. Most of the activity observed in the tin-bismuth spectrum can be attributed to the neutron activation of tin. It should be noted that the the cool-down time for the tin sample was $\sim$ 29 h. Hence,

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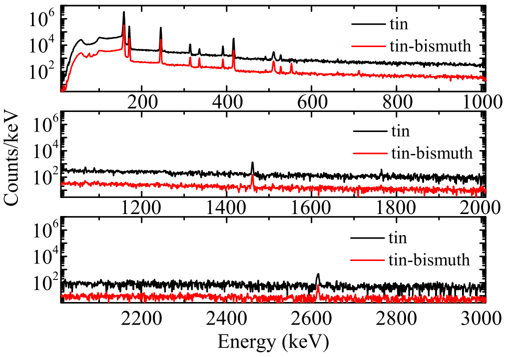

FIG. 1: Spectra of the tin-bismuth and tin samples (1d data) after a cool-down time of ∼ 5 h and ∼ 29 h, respectively. The spectrum of tin has been scaled by a factor of 10 for better visibility.

the short-lived channels ^{116}Sn(n,p)^{116m}In and ^{117}Sn(n,p)^{117}In were not observed in the tin spectrum.

TABLE I: Prominent reaction channels observed in the samples.

Channel	Observed lines	Half life
^{112}Sn(n,np)^{111}In	171.3, 245.4	2.80 d
^{112}Sn(n,γ)^{113}Sn ^{114}Sn(n,2n)^{113}Sn	391.7	115.09 d
^{116}Sn(n,np)^{115m}In ^{115}Sn(n,p)^{115m}In ^{115}In(n,n')^{115m}In	336.2	4.48 h
^{116}Sn(n,p)^{116m}In [a]	416.9[b], 1097.3, 1293.6, 1507.6	54.29 min
^{117}Sn(n,p)^{117}In [a]	158.6, 552.9	43.2 min
^{117}Sn(n,n')^{117m}Sn ^{116}Sn(n,γ)^{117m}Sn ^{118}Sn(n,2n)^{117m}Sn	156.0, 158.6, 314.3	13.76 d
^{124}Sn(n,2n)^{123}Sn ^{122}Sn(n,γ)^{123}Sn	1088.6	129.2 d
^{124}Sn(n,γ)^{125}Sn	822.5, 1067.1, 1089.2	9.64 d

[a] Absent in tin spectrum due to ∼ 29 h cool-down

[b] γ-ray present in tin spectrum: source is coincident summing of 171.3 keV + 245.4 keV

Table II lists the additional γ-rays observed in the tin-bismuth samples. The γ-ray at 564.3 keV is yet to be identified. The half-life is estimated to be < 10 h.

TABLE II: Additional γ-rays observed in the spectrum of the tin-bismuth samples but not the tin sample

Energy (keV)	Source
77.1	Bi K-α
87.3	Bi K-β
564.3	*
711.5	552.9 keV + 158.6 keV coincident summing

Short irradiations for ∼ 45 min were also performed for similar sample sets at proton energies of 18 MeV and 15 MeV. This data is currently being analyzed to understand the short-lived neutron-induced activity in tin-bismuth.

Conclusion

The fast neutron-induced activity was studied for tin-bismuth samples at an energy integrated neutron flux of $\sim 10^6$ n cm^{-2} s^{-1}. An unidentified additional γ-ray at 564.3 keV was observed in the spectrum of the tin-bismuth samples. The source of γ-ray may be a short-lived activity of tin/ activation of an impurity.

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