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Radiation background studies for superconducting Sn-Bi bolometers

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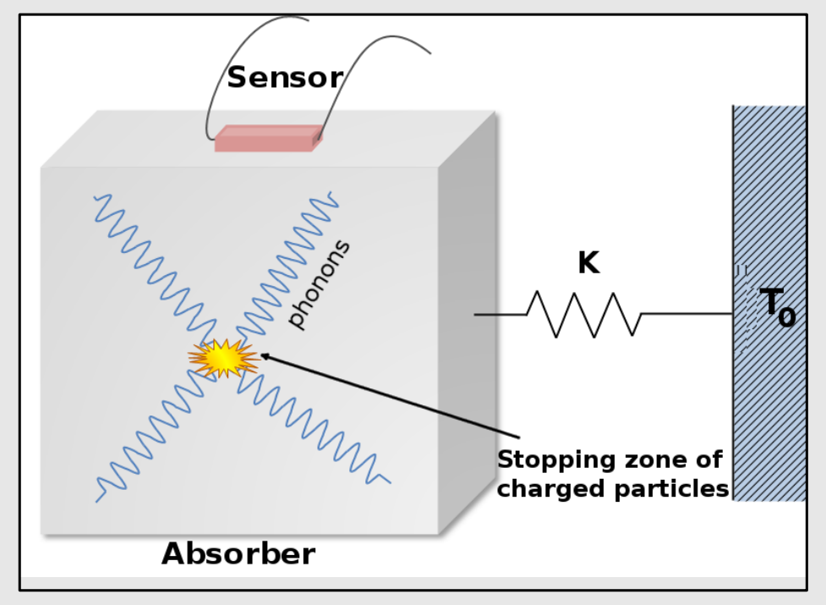
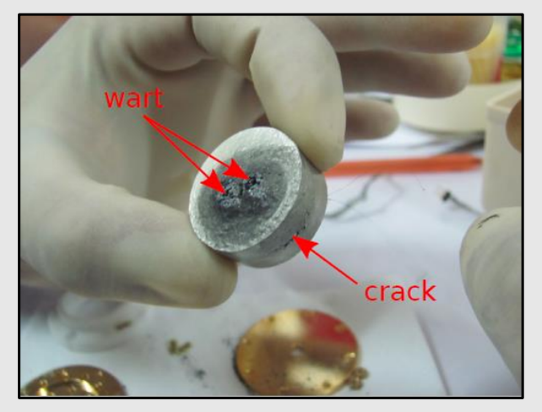
Introduction

- Neutrinoless Double Beta Decay (NDBD) studies can reveal the fundamental nature of neutrinos (Majorana or Dirac).
- Experimental signature – peak at $Q_{\beta\beta}$ in the sum energy spectrum of the electrons.
- Tin-based cryogenic bolometer with Neutron Transmutation Doped Ge sensor is being developed to study NDBD in ^{124}Sn in the upcoming underground facility, INO in India [1].
- ^{124}Sn has moderate isotopic abundance (5.8%) and moderate $Q_{\beta\beta}$ (2291.1 ± 1.8 keV).
- Existing experimental limit for NDBD in ^{124}Sn
  $^{124}Sn \rightarrow {}^{124}Te + 2e^-$: $T^{0\nu}_{1/2} > 2.0 \times 10^{19}\ y$
  measured at Y2L using tin-loaded liquid scintillator detectors [2].





- Pure tin bolometers are susceptible to tin pest, which is a concern for the long term stability of the bolometer array.
- Several tin alloys were synthesized at TIFR Mumbai and tested for resistance to tin pest, in order to find a suitable candidate for a superconducting bolometer [3]. The best performance was seen in 0.22% Sn-Bi (Bi mass %) which has shown no signs of tin pest for more than a year.

- In the absence of an observed signal:

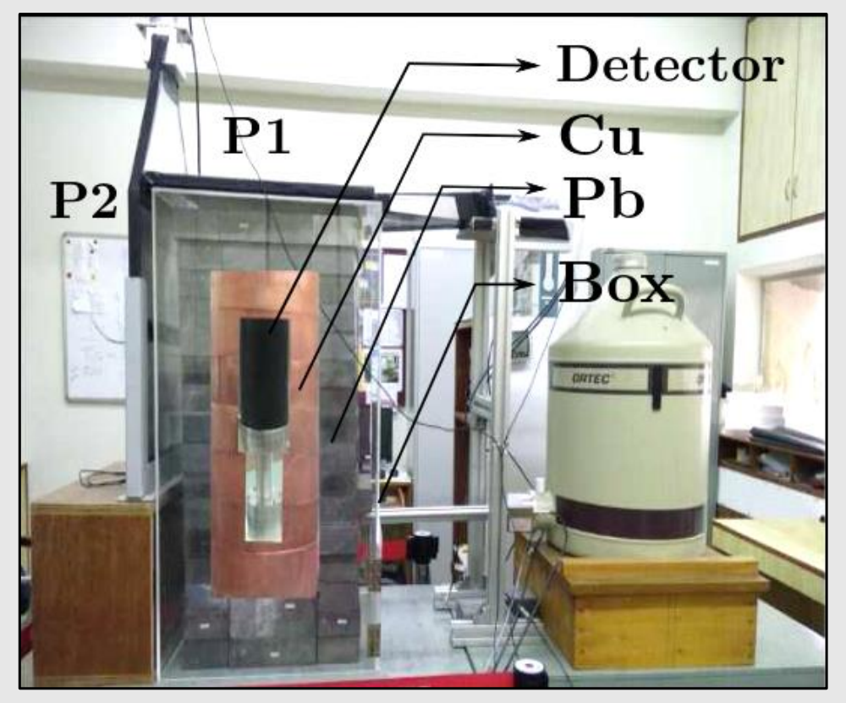
$$T^{0\nu}_{1/2} > \frac{\ln 2\, N_A i \varepsilon}{A f_{CL}} \sqrt{\frac{Mt}{B \Delta E}}$$

Expt	PID?	Bkg (cts/(keV.kg.y)
CUORE	No	1.4×10^{-2}
CUPID-0	Yes	3.6×10^{-3}

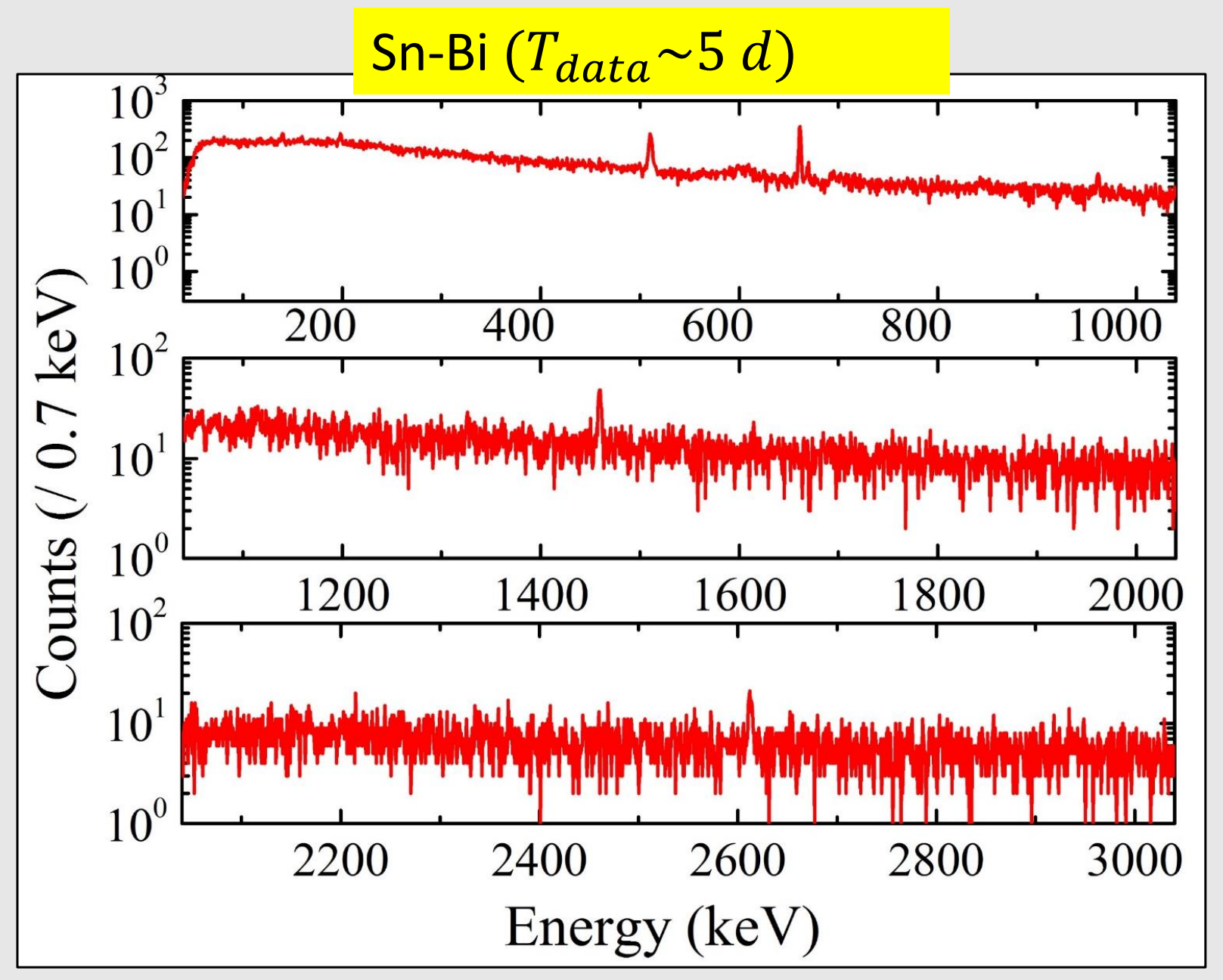
- The sensitivity of NDBD experiments are limited by the background in the region of interest around $Q_{\beta\beta}$ (ROI).
- Primary sources of background for NDBD experiments:
  - Primordial radioactivity from U/Th chains and ^{40}K.
  - Anthropogenic radioisotopes such as ^{137}Cs and ^{90}Sr.
  - Neutron induced reactions in the detector material and surrounding shielding materials.
  - Internal radioactive contamination of the detector.
  - Cosmic ray induced products (neutrons and radioisotopes).

- Internal sources of background are of particular concern as they are often the limiting source of background.
- Introduction of Bi into the Sn matrix can change the background in the ROI and this change needs to be critically evaluated. This poster describes the radiation background studies performed for Sn-Bi bolometers.

Estimation of radioimpurities in $Sn - Bi$



- 99.99999% Sn and 99.999% Bi were used for the Sn-Bi sample synthesis.
- Samples were counted in **TiLES** (Tifr Low background Experimental Setup) [4] in close geometry.
- Background reduction
  - Passive shielding 5 cm Cu + 10 cm low activity Pb.
  - Muon veto using plastic scintillators
  - Radon exclusion box



- Data was acquired using a commercial CAEN N6724 digitizer (14-bit, 100 MS/s).
- Energy spectra were analyzed using LAMPS [5].
- Anticoincidence between the HPGe detector and the plastic scintillators was performed using a C++ based analysis code.

Sample	Mass (g)	Runtime (d)
Background (bkg)	-	4.8
Sn	21.3	2.9
Sn-Bi (9.2% Bi by mass)	4.0	4.9

Energy (keV)	Source	bkg (cts/d)	Sn (cts/d)	Sn-Bi (cts/d)
661.7	^{137}Cs	218 (12)	183 (15)	209 (13)
669.6	^{63*}Cu	18 (5)	28 (9)	24 (7)
962.1	^{63*}Cu	36 (8)	21 (6)	24 (6)
1460.8	^{40}K	31 (6)	30 (7)	36 (6)
2614.5	^{208}Tl	17 (5)	16 (5)	16 (4)

No new γ lines or enhancements observed in the spectra of the samples in comparison to the background or the Sn sample, at the sensitivity level of TiLES.

Fast neutron induced background in $Sn - Bi$

- Neutron activation technique used to study
  - Fast neutron induced background in the absorber material Sn-Bi.
  - impurities present in the bolometer candidate Sn-Bi.
- Methodology followed was similar to ref. [6] in which ^{nat}Sn and some other materials were studied.

$$p + {}^9Be \rightarrow {}^9B + n$$

Neutron energy ranges from 0 to $E_p - Q_{th}$
Q_{th} = 2.057 MeV

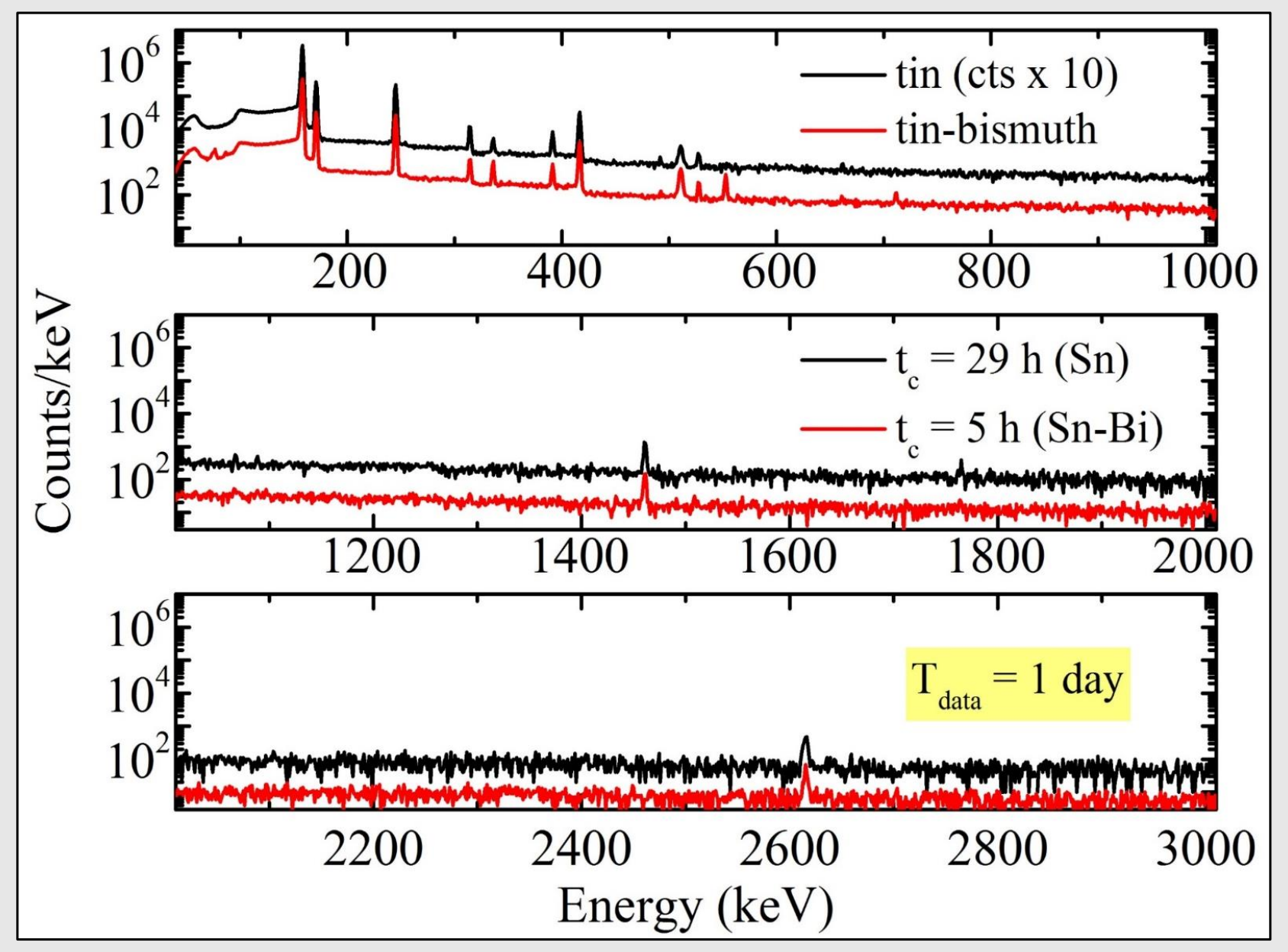
@ 6m irradiation facility, Pelletron Linac Facility, TIFR Mumbai [7].

- The materials studied were 0.09% and 4.53% Sn-Bi (Bi weight%), 99.99999% pure Sn and 99.999% pure Bi.
- Short (30 min - 1 hour) and long irradiation (11 h) times were used to probe short and long-lived activities.

Long irradiation details are described below:

- Samples were stacked in a Teflon cup and irradiated with fast neutrons for 11 h (proton beam energy 21 MeV).
- Samples removed after a short cool-down time and counted offline in TiLES.
- Fe was included in the irradiation set for fast neutron estimation via ^{56}Fe(n,p)^{56}Mn → $\phi_n \sim 10^6\ n\ cm^{-2}\ s^{-1}$.

Half-life tracking for line verification/ coincident summing identification.

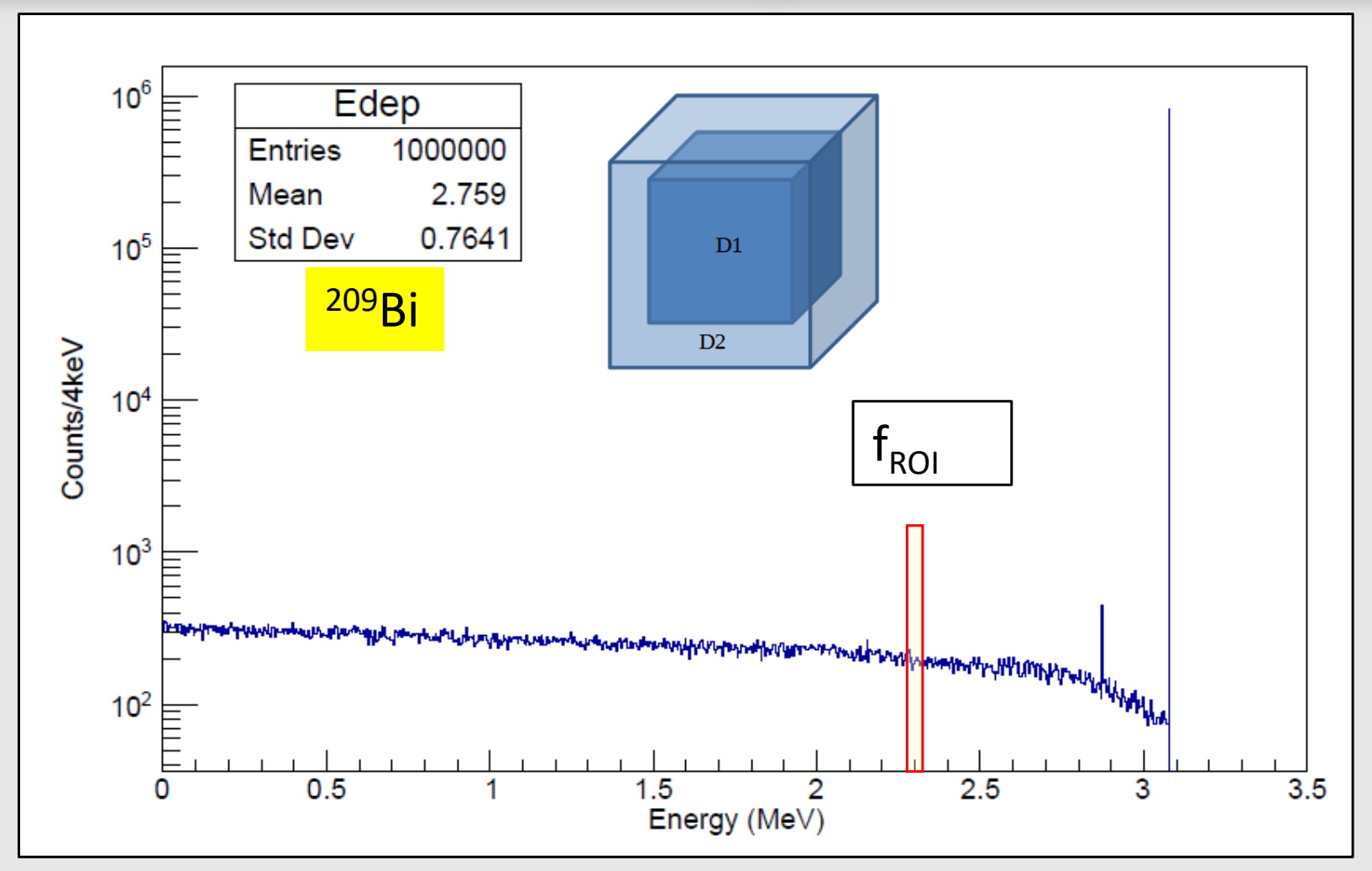


Channel	Eγ (keV)	Half life
^{112}Sn(n,np)^{111}In	171.3, 245.4	2.80 d
^{112}Sn(n,g)^{113}Sn ^{114}Sn(n,2n)^{113}Sn	391.7	115.09 d
^{116}Sn(n,np)^{115m}In ^{115}Sn(n,p)^{115m}In ^{115}In(n,n')^{115m}In	336.2	4.48 h
^{116}Sn(n,p)^{116m}In †	416.9, 1097.3, 1293.6, 1507.6	54.29 m
^{120}Sn(n,α)^{117}Cd †	564.4	3.36 h

Channel	Eγ (keV)	Half life
^{117}Sn(n,p)^{117}In †	158.6, 552.9	43.2 m
^{117}Sn(n,n')^{117m}In ^{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

- Expected Sn activation channels were observed.
- No impurities observed @ measured sensitivity level.
- Bi X-rays were observed but activation channels were not observed due to long $T_{1/2}$ / low cross-sections .

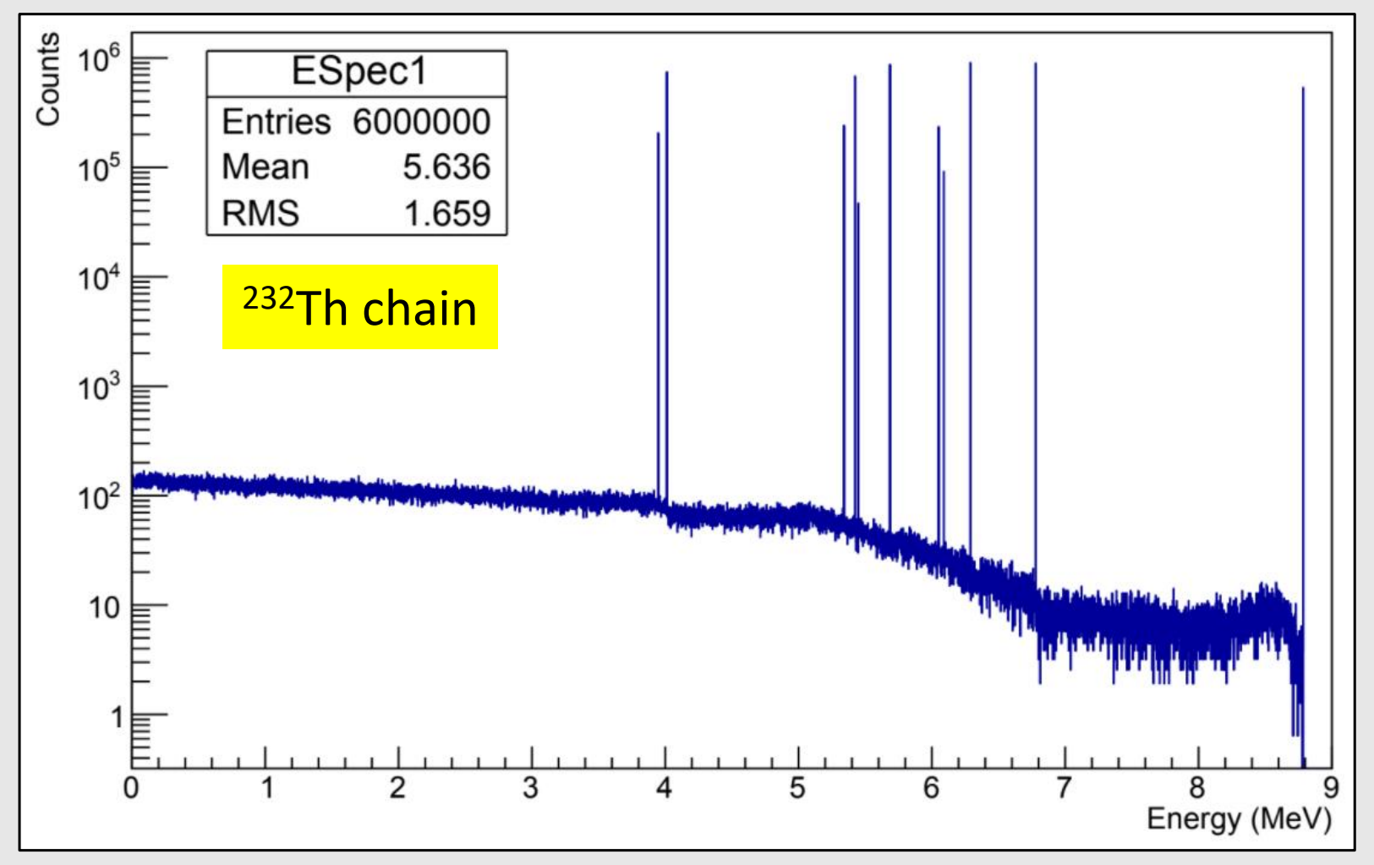
Estimation of the internal background for $Sn - Bi$

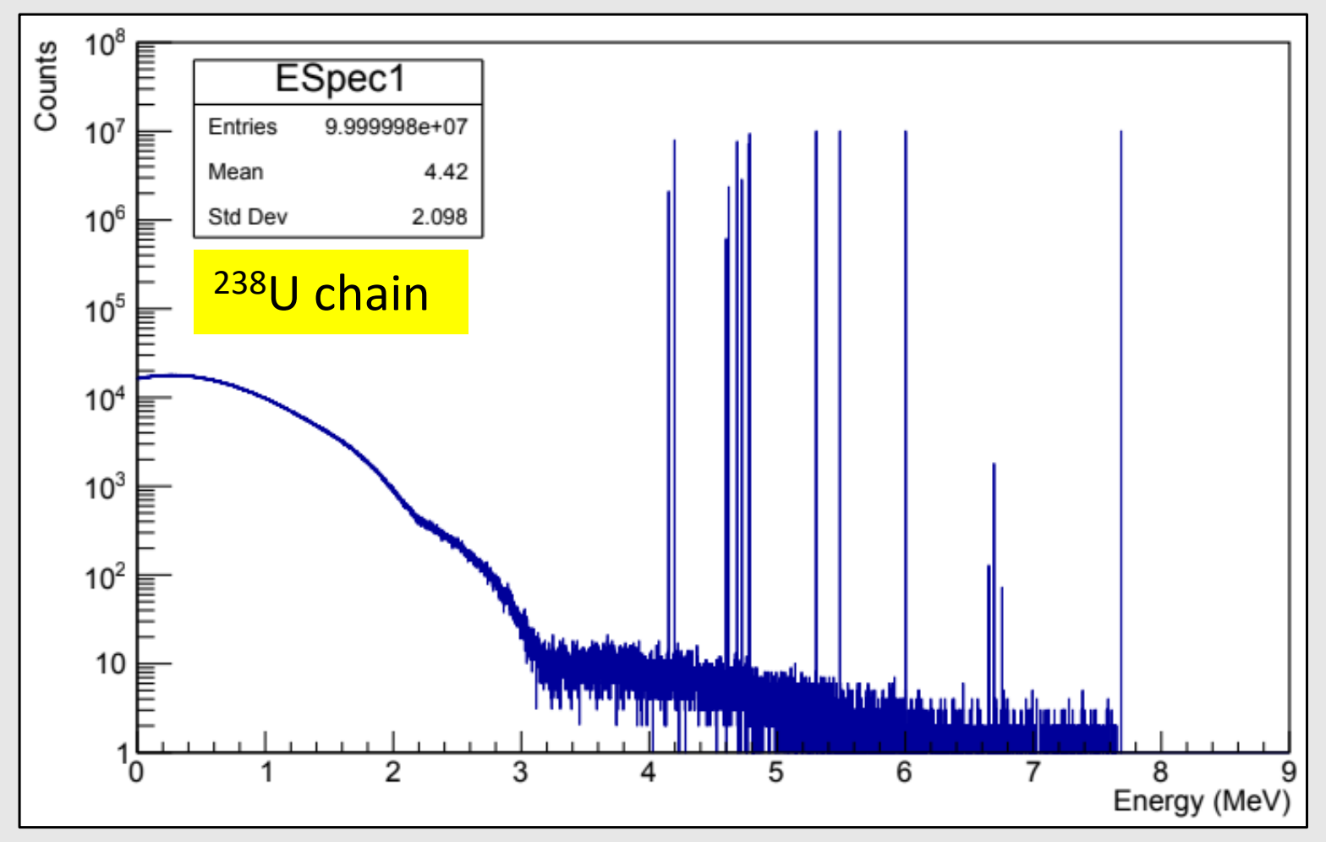


GEANT4 [8] simulation codes were developed to assess the background from sources internal to the bolometer:

- ^{209}Bi α decay: The half-life of the decay is $T_{1/2} = (1.9\ \pm 0.2) \times\ 10^{19}\ y$, which is comparable to that of some 2νββ emitters [9].
- U/Th impurities: Secular equilibrium assumed in the case of the Uranium and Thorium decay chains since the progenitors ^{238}U and ^{232}Th have the longest half-lives.

In the case of α emitters, only surface events contribute to background in the region of interest ($Q_{\beta\beta} \pm 25\ keV$).





- A composition of 0.25% Sn-Bi (Bi mass %) was considered for the comparison, since 0.22% Sn-Bi was found to resist tin pest in cooling tests.
- A radioimpurity level of 0.2 ppt was assumed for U and Th (which is similar to the radiopurity level of the CUORE bolometer [10]).
- The estimated internal background from ^{238}U/^{232}Th chain was compared to that from ^{209}Bi.

27 cc

Impurity level	Source	Bkg (cts/(keV.kg.y)
0.2 ppt	Th chain	5.7×10^{-5}
0.2 ppt	U chain	5.6×10^{-3}
0.25%	^{209}Bi	2.6×10^{-5}
Total		5.7×10^{-3}

64 cc

Impurity level	Source	Bkg (cts/(keV.kg.y)
0.2 ppt	Th chain	3.9×10^{-5}
0.2 ppt	U chain	5.7×10^{-3}
0.25%	^{209}Bi	2.0×10^{-5}
Total		5.8×10^{-3}

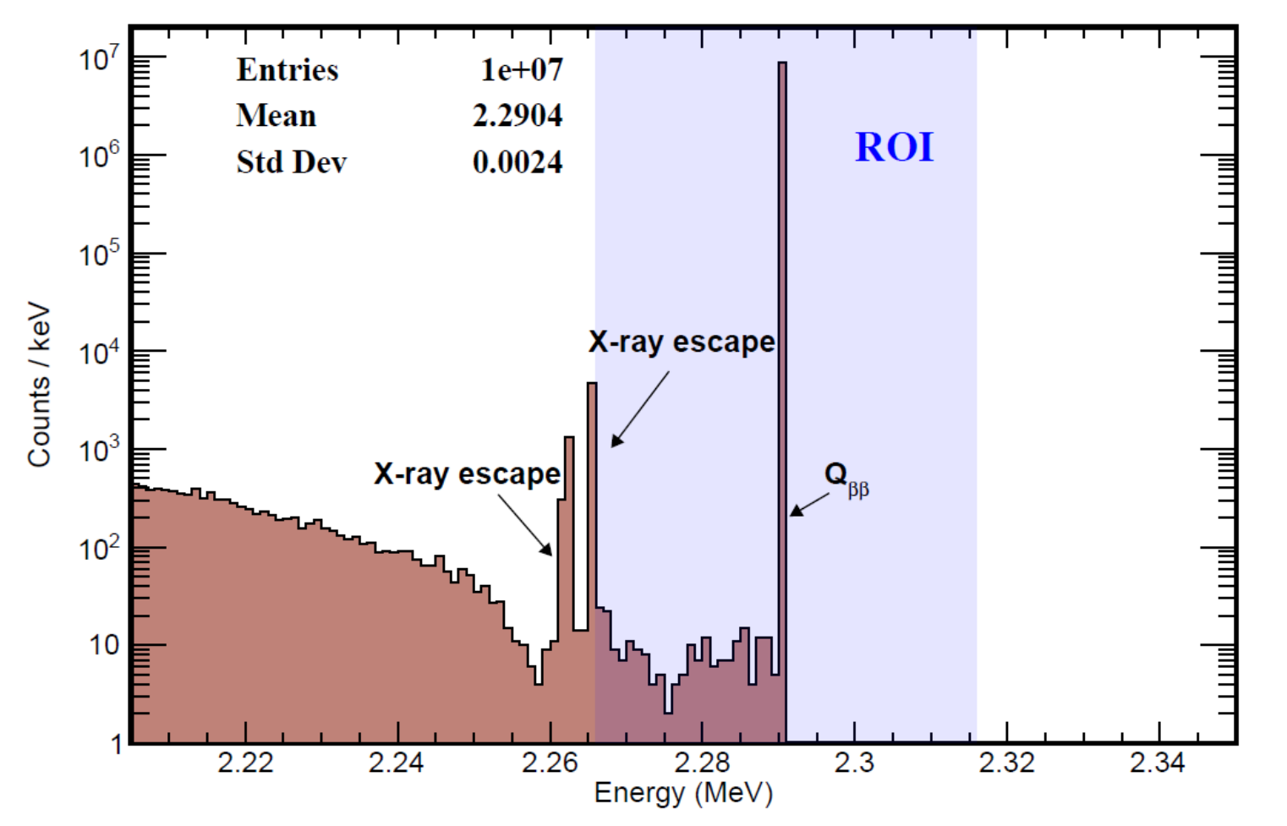
125 cc

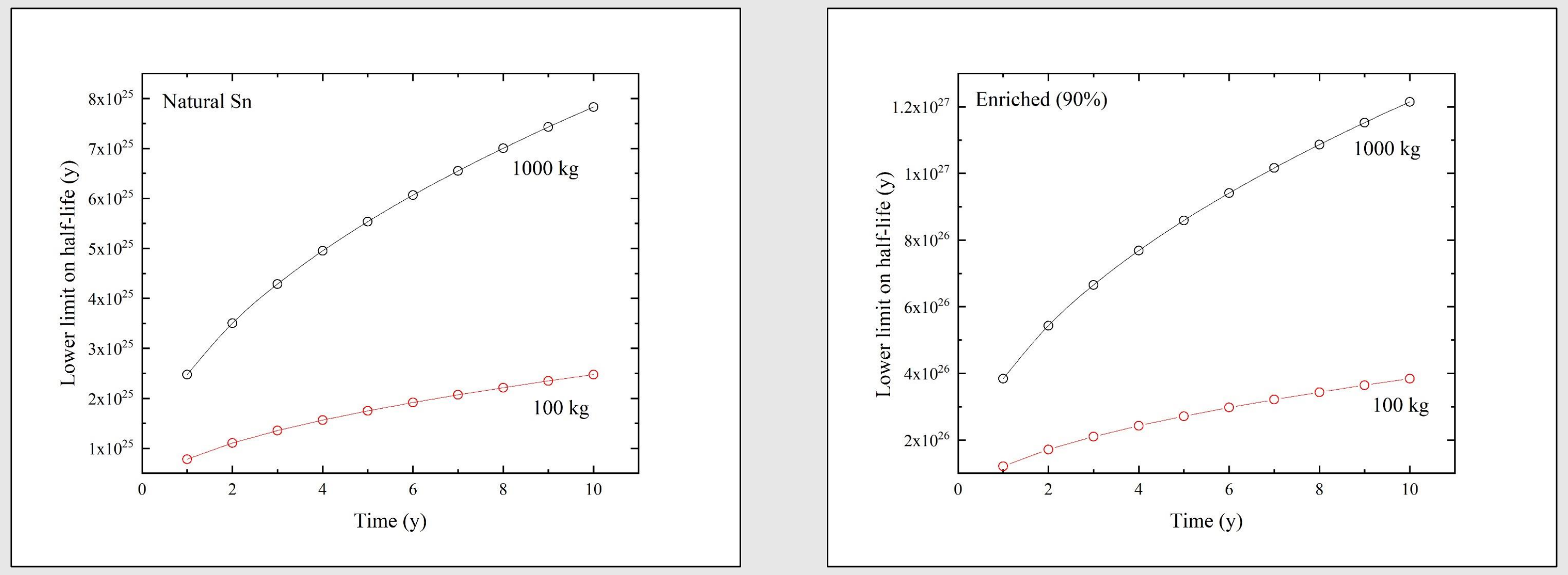
Impurity level	Source	Bkg (cts/(keV.kg.y)
0.2 ppt	Th chain	3.1×10^{-5}
0.2 ppt	U chain	5.8×10^{-3}
0.25%	^{209}Bi	1.6×10^{-5}
Total		5.8×10^{-3}

Sensitivity of $Sn - Bi$ bolometers for $0\nu\beta\beta$

Loss from
- surface events
- Bremsstrahlung events (bulk + surface)

Detector size	Efficiency (%)
27 cc	86.6 %
64 cc	89.0 %
125 cc	90.7 %





Projected sensitivity for $T^{0\nu}_{1/2}$ (1σ)
27 cc bolometer, assuming 5 keV energy resolution (σ_E).

Summary

- The present work reports the radiation background studies for Sn-Bi bolometers and its suitability for NDBD.
- The crystals grown at TIFR Mumbai were counted in the low background setup TiLES. No additional γ lines or enhancements compared to the ambient background were found at the measured sensitivity level.
- Neutron activation of Sn-Bi: All the activity could be attributed to neutron activation channels in Sn.
- GEANT4 simulations to estimate the internal background arising from the rare α decay of ^{209}Bi and from U/Th impurities. The background from ^{238}U decay chain was found to dominate in comparison to the other sources by ~2 orders of magnitude.
- The total background was within 10^{-2} cts/(keV.kg.y), which is the typical background index for the first gen. expt.
- The projected sensitivity of *TIN.TIN* for NDBD was estimated.

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