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Section A

# Large mass, low temperature, low background detectors

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Bolometric detectors can be realized with a wide range of materials, and large mass. Some aspects regarding the energy resolution of large bolometers are analyzed. Preliminary experimental results on neutrinoless ββ decay of tellurium, obtained with this technique, are shown.

## 1. Introduction

The use of cryogenic techniques makes the measurement of the energies of a very wide kind of particles possible [1]. This essential characteristic arises from the fact that at very low temperatures, where the Debye contribution to specific heat dominates, the part of the energy absorbed by a medium which is converted into heat after the impinging of a particle, can be measured by means of a suitable thermal sensor, which can be a low temperature thermistor, a superconducting tunnel junction (STJ), an edge detector (ED), etc. [2].

In order to study rare events like ββ decay, or possible interactions of exotic particles candidate to form the dark matter of the universe, large detector masses have to be used to limit the time necessary to obtain enough statistics. The detector energy resolution worsens when the mass increases. Some aspects of this effect on bolometric detectors used in the very low background environment of the Gran Sasso Laboratory, in an experiment on the measurement of the ββ decay of $^{130}$Te, are analyzed. Interesting background suppression considerations are briefly reviewed.

## 2. Large mass bolometer performances

A large mass bolometric detector is composed of a semiconductor thermistor attached to an absorbing crystal. The model of the detector looks as in fig. 1. The impinging particle causes a steep rise of the crystal temperature which is proportional to the energy released and to the reciprocal of the crystal heat capacity. After this transient, the heat is splitted between the thermal conductance $K_C$, connecting the crystal to the base temperature, and the conductance $K_G$ which represents the thermal contact with the thermistor, generally connected with glue or special vacuum grease. The heat flowing through $K_G$ is again divided in two paths: the conductance between the thermistor lattice and the heat sink, and that between the lattice and the electron gas. This last effect happens at very low temperatures where the electron gas and the lattice of the thermistor behave as two separate systems connected with a thermal conductance $K_e$ [3]. The final temperature rise of the electron gas is converted into an electrical signal by a modification of the electrical resistance of the thermistor.

As seen, at the end of the process the increase of the gas temperature is only a fraction of the initial temperature increase of the absorbing crystal. How the two temperatures are related to each other depends on

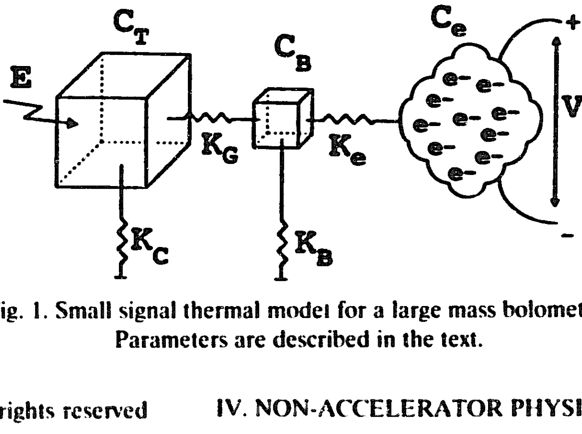

Fig. 1. Small signal thermal model for a large mass bolometer. Parameters are described in the text.

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the ratios of the above heat conductances and capacities.

The signal amplitude is therefore only a fraction of what could be obtained in ideal conditions. Since the noise is quite independent of these parameters, there is a worsening in the signal-to-noise ratio (S/N), that is, in the energy resolution, due to the above mentioned partition of heat. The resolution of the detector can then be written as:

$$\Delta E_{\mathrm{RMS}} \approx \frac{1}{\alpha}\sqrt{k_{\mathrm{B}} T C_{\mathrm{C}}}\,; \qquad (1)$$

where the term under square root is obtained in ref. [4] for small mass bolometers, $k_{\mathrm{B}}$ is the Boltzman constant, $T$ the detector temperature, $C_{\mathrm{C}}$ the crystal heat capacitance at $T$, and $\alpha$ is a correction factor, $\alpha \leq 1$, which take into account the loss of the signal amplitude. Values of $\alpha \approx 1$ are obtained with small mass bolometers [5].

For our detector the signal loss is of the order of $40 \sim 50\%$.

## 3. Construction of low background detector

Another important consideration regarding the detector performance is the crystal holder. The aim of the holder should be to introduce a very weak thermal conductance $K_{\mathrm{C}}$ between the crystal and the heat sink at the base temperature, while keeping steady the detector itself. In this way the heat would be conducted away (hence measured) from the crystal only by means of the thermal contact between the thermometer and the heat sink. Nevertheless, weak thermal contact generally gives also weak mechanical supports. This determines the possibility for the crystal to oscillate around its equilibrium position, due to the characteristic vibrations of the refrigerator.

Three correlated effects appear. First, the vibrations cause an increase of the working temperature of the detector because of the mechanical friction which dissipates power, originating an increase of the detector heat capacity. Second, as the amplitude of the vibrations have a statistical distribution, noise is generated due to this random vibrational heating. Last, the movements of the crystal implies also movements of the thermistor attached to it, hence a random modification of the parasitic electrical capacitance shunting the thermistor, which gives rise to microphonic noise.

The above considerations lead to the conclusion that a compromise between a good mechanical support and a weak thermal contact must be found, to minimize the effects of the loss in the signal amplitude and of the microphonic noise.

The solution we have adopted is shown in fig. 2. The crystal is suspended with brass screws whose extremities have small needles which exert a pressure adjustable with springs. Springs also compensate the different contraction of crystal and support when the temperature decreases. The screws are located into an oxygen free copper frame, connected to the cold plate of our dilution refrigerator especially designed for low background activity [6]. All the materials employed which face directly the detector were chosen for low background activity.

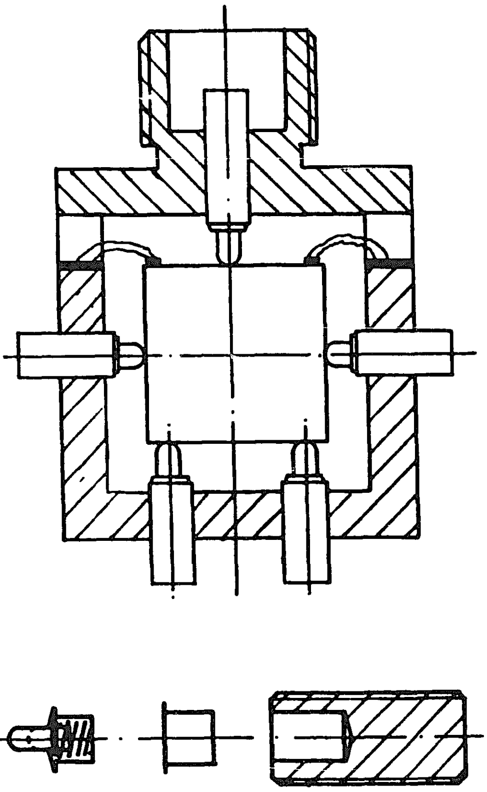

Fig. 2. The detector is supported with a OFHC frame with brass screws exerting pressure with springs, as shown in the expanded view.

## 4. Experimental measurements

Two runs were performed in the Gran Sasso Laboratory in order to investigate the background level of the whole apparatus. A 6 g tellurium oxide ($TeO_2$) ($^{130}Te$ is an interesting good candidate for $\beta\beta$ decay), with a neutron transmutation doped (NTD) thermistor [7], was employed as test detector (the energy resolution was about 50 keV). Fig. 3 shows the normalized spectra of two runs. The first run (continuous plot) has a non-negligible activity into the 3000–11 000 keV interval of energy of 2.92 ± 0.086 c/h (after 370 h of measurements). Searching for a possible source of this contamination, we found that tin was used for soldering the needles (which face directly the detector) in the screws. The quantity of tin employed had an $\alpha$ activity,

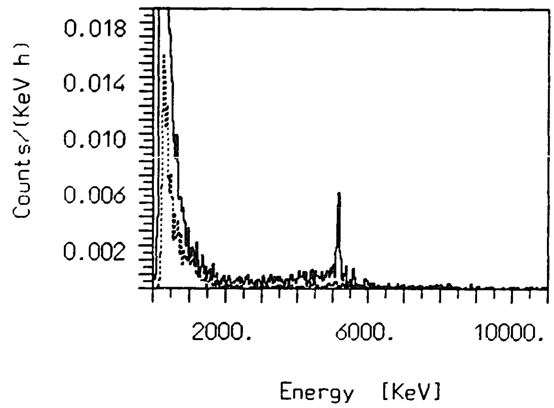

Fig. 3. Background spectra of 6 g $TeO_2$ bolometric detector. In the first run, continuous plot, tin, having non negligible α activity, was used in the supports facing the detector. In the second run, dotted plot, tin was avoided: the background was greatly reduced.

due to the lead contained in it, consistent with that measured with the detector ($5 \pm 0.3$ $m^{-2}$ $s^{-1}$ after 20 h of measurement with a silicon detector). Once tin was eliminated from the needles the new spectrum looked like the dotted plot of fig. 3 (after 260 h of measurement). The activity in the 300–11000 keV region was $0.6 \pm 0.0499$ c/h, confirming that the previous contamination was given by the tin. The background in the neutrinoless ββ decay region (2533 keV for $^{130}Te$) was $8 \times 10^{-5}$ c $h^{-1}$ $keV^{-1}$, from which a preliminary limit of $4 \times 10^{19}$ yr for the halflife time of the process can be computed at 90% confidence level. This result is the best ever obtained with direct measurements of tellurium [8].

Our aim is to carry on a new long time measurement with a larger mass crystal of the same material. For that reason we have developed a new detector of 21 g with a NTD thermistor. It is now installed in the Gran Sasso refrigerator. The detector is operated at 16 mK, the read-out of the signal is obtained with a GaAs MESFETs differential voltage sensitive preamplifier operated at 4.2 K [9]. The first spectrum collected using a thorium source of γ ray with peaks at 911, 969, 1593, and 2614 keV is shown in fig. 4. The energy resolution is about 20 keV FWHM. The resolution obtained is very good if it is considered that the Debye temperature of Te is quite low, about 250 K [10].

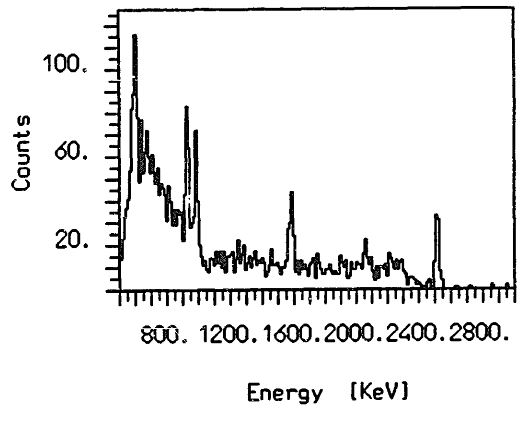

Fig. 4. γ ray spectrum of a Thorium source obtained with a 21 g $TeO_2$ crystal with a NTD thermistor. Peaks are at 911, 969, 1593 keV and 2614 keV.

While writing this paper a measurement has started to study the purity level of the new crystal. If a satisfactory background is obtained, a long run for the measure of ββ decay will be carried on.

## 5. Conclusions

We have shown that it is possible to obtain good energy resolution with large mass bolometric detectors in long-term experiments.

During a background measurement with a 6 g $TeO_2$ bolometric detector, a limit of $4 \times 10^{19}$ yr, with 90% of confidence level, for neutrinoless ββ decay of $^{130}Te$ was obtained after 260 h of run. A new $TeO_2$ detector of 21 g is now installed. Its resolution is 20 keV FWHM. A new measurement will be performed to study the purity level of the new detector, in view of a long time measurement for ββ decay search.

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