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Bolometric measurement of the beta spectrum of ^{113}Cd

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A preliminary study of the bolometric characteristics of a $CdWO_4$ crystal, in view of an experiment on ββ decay of ^{116}Cd, has been carried out at Gran Sasso Laboratories. During this test, data have been collected at low energies in order to determinate the end-point (318.8±1.4±5 keV) and the half-life ($(9.3\pm0.5\pm1)\times 10^{15}$ yr) for the β decay of ^{113}Cd, thus showing the good potentials of this technique measurements of internal radioactivities.

1. INTRODUCTION

The use of thermal detectors to search for ββ decay of many different isotopes has been suggested since 1984 [1] and has already been applied successfully [2] for ^{130}Te. An interesting candidate nucleus for this decay is ^{116}Cd, because it has a considerable transition energy (2802 keV), which implies a large phase space factor and low gamma background. A non negligible drawback is the high neutron cross section of Cd for (n, γ) reactions: underground installation and special care in the shielding should be taken into account.

Recently a measurement of the 2ν-decay of ^{116}Cd ($t_{1/2} = 2.7\times10^{19}$ yr) has been claimed [3]; nevertheless the 0ν-decay still has to be looked for. Present best limit ($t_{1/2}>1.5\cdot10^{22}$ yr) is quoted in [4].

Having the opportunity of making an experiment with $CdWO_4$ crystals, enriched in ^{116}Cd at the level of 83% [4], we have decided to test the bolometric characteristics of such kind of crystal. Moreover, its scintillation properties could be used for simultaneous measurement of light and heat, leading to an efficient discrimination of α's [5] (main background contribution in the energy region of interest): a thermal detector could therefore be a competitive device for this study.

The bolometric technique is based on the detection of an interacting particle by means of a temperature rise in the absorbing crystal, which follows the thermalization of the released energy. Working at very low temperatures, the heat capacity of a dielectric diamagnetic crystal can be so small (Debye law) that the temperature rise becomes measurable, even for tiny energy releases. Since the only requirement is a low heat capacity (that is: high Debye temperature), many different compounds in the form of a single crystal can be used, leaving the choice to the requirements of the single application. Moreover, the theoretical energy resolution for this kind of detectors is extremely good, and it has already been proven that for

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massive devices (0.1-1 kg range) energy resolution can be comparable with that of conventional Ge diodes [6].

2. EXPERIMENTAL SETUP

A 58 g natural $CdWO_4$ single cylindrical crystal, of 1.5 cm height and 2.5 cm diameter, has been mounted as a bolometer in one of the dilution refrigerators installed at Gran Sasso Laboratories (see technical details in [7]). The detector shielding consists of 10 cm OFHC copper on top of the crystal inside the cryostat, to shield it from the tiny radioactivity of the refrigerator components (which have all been previously selected, but cannot be avoided completely).

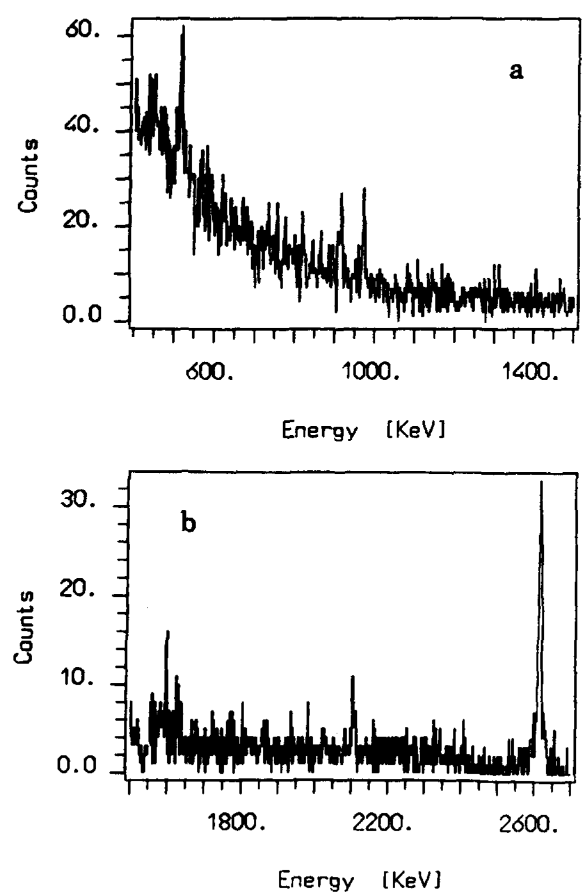

Fig.1 (a) Low energy portion of the ^{232}Th calibration spectrum of the $CdWO_4$ detector; (b) high energy portion of the same spectrum

Outside the cryostat, 5 cm OFHC copper and 10 cm low activity lead at least, in all directions, complete the shielding.

The detector was exposed to γ sources of ^{232}Th and ^{60}Co through a small window in the external shielding. A calibration spectrum with the ^{232}Th source is shown in fig.1. The FWHM energy resolution, after off-line instability correction, is about 5 keV on the average. A residual linear energy dependence, which should not be intrinsic of the detector, could come from residual uncorrected gain fluctuations. The device performs as a very efficient gamma detector, with a good energy resolution and a very high detection efficiency.

3. ANALYSIS AND RESULTS

To test long term stabilities and technical characteristics of the detector, a background measurement of about 340 h of effective running time was then carried out. The low energy part of the spectrum so obtained is dominated by the β decay of ^{113}Cd, which is present in natural cadmium with 12.2% abundance, even if unstable, thanks to its very long lifetime (of the order of 10^{16} yr). This allowed us to study this particular transition (fourth forbidden, non unique): a preliminary fit to the data (fig.2) was obtained assuming a spectrum shape factor C given by [8]:

$$C = p^6 + 7A_1 \cdot p^4q^2 + 7A_2 \cdot p^2q^4 + A_3 \cdot q^6$$

(where p and q are the momenta of the emitted electron and neutrino, respectively) and a continuos component of background represented by the formula:

$$B(E) = B_1 + B_2 \cdot \exp(-E/B_3)$$

The background parameters were extracted from the fit of the region corresponding to energies slightly greater than 350 keV, to avoid influences coming from the beta spectrum. This fit was then extrapolated at lower energies (the

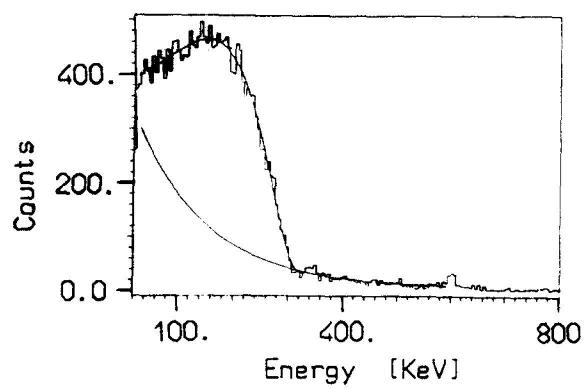

Fig.2 ^{113}Cd β spectrum fitted with theoretical shape plus exponential background (see text).

effectiveness of this method has already been proved with other thermal detectors).

As a result a precise measurement of the transition energy and of the decay half-life has been obtained:

$t_{1/2} = (9.3 \pm 0.5(\text{stat.}) \pm 1(\text{syst.})) \times 10^{15}$ yr

$E_0 = (318.8 \pm 1.4(\text{stat.}) \pm 5(\text{syst.}))$ keV

where the systematic errors come mainly from the uncertainties in the shape factor evaluation and in the background extrapolation procedure.

The coefficients which appear in C were determined to be:

$A_1 = 0.765 \pm 0.095$

$A_2 = 0.589 \pm 0.177$

$A_3 = 2.04 \pm 0.74$

4. CONCLUSIONS

We have thus seen that bolometric technique, thanks to its unique flexibility in the choice of detector materials joined to the accurate energy spectroscopy that it provides, is a powerful method to determine the parameters of intrinsic internal radioactivities (see for comparison the evauation of the half-life of ^{113}Cd in [9] and the Q-value of the transition reported in literature [10]). A first application of these detectors in this direction has been shown for the activities coming from ^{113}Cd in natural cadmium. Other applications in this sense have already been realized (see, for instance, [6] and references therein).

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