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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

The bolometers as nuclear recoil detectors

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Abstract

Our group is involved in experiments using bolometric detectors since ten years for rare event searches like double beta decay or Dark Matter interactions. During last year, to check the quenching factor of TeO_2 bolometers, we have measured the nuclear recoils at energy as low as 15 keV in our experimental apparatus at Laboratori Nazionali del Gran Sasso. Two 72*g* TeO_2 detectors were exposed under vacuum to a ^{228}Ra α source that implanted on them ^{224}Ra nuclei. The nuclei emitted by the implanted source were detected in one bolometer in coincidence with the corresponding α particles in the other. The energy spectrum of the 103.4 keV ^{224}Ra nuclei has been obtained with an energy resolution of about 12 keV. Furthermore an α measurement of Roman lead has exploited also the sensitivity of this technique to check for ultralow activity in matter, taking advantage of the source $\equiv$ detector approach. A limit on the ^{210}Pb contamination in roman lead as low as 4 mBq/Kg has been obtained.

1. Introduction

Measurements of the recoiling energy of heavy nuclei are of considerable interest in nuclear physics. Typical examples are experiments on spontaneous fission [1], on the recoil range in nuclear reactions [2], on rare α decays and on radioactivity involving protons, carbon and heavier clusters [1]. In subnuclear and astroparticle physics the interest is related to measurements of nuclear recoils induced by neutrinos or by Weakly Interacting Massive Particles (WIMPs) as candidates for the invisible Dark Matter [2]. For these arguments the ratio between the detected signals of a nuclear recoil and of an electron of the same energy (the so-called Quenching Factor) is a relevant parameter.

Until now "conventional" detectors like semiconductors or scintillators were used in the above experiments. Such devices usually have nuclear recoil QF much lower than unity [2] while the thermal detectors QF is expected to be near unity [2]. In these detectors, in fact, any kind of deposited energy is expected to be converted into heat and they are recorded by a suitable thermometer provided that the heat capacity of the absorber is low enough. Moreover the unique capability to detect

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energy recoil of about 100 keV allows bolometers to distinguish between α particles coming from outside the absorber (α energy only) and from inside (α + nuclear recoil energy). In this way a great sensitivity to the absorber internal radioactive α contamination is reached.

2. Experimental details

We describe here two kind of measurements based on the sensitivity of bolometric detectors to recoiling nuclei energy: the measurements of the quenching factor of heavy nuclei as coming by an α source and the study of the internal ^{210}Pb contamination of various kind of ancient (roman) and modern lead. Both measurements were carried out in our cryogenic facility in hall C of the underground Laboratori Nazionali del Gran Sasso. The experimental set up, described elsewhere [2], were similar both for the cryogenic point of view (cryostat, mounting, shielding, etc.) and for the electronic point of view (bias circuit, front end, etc.).

2.1. The recoiling nuclei Quenching Factor determination

In this case we have used a set of two crystals of $2 \times 2 \times 3$ cm^3 of TeO_2, facing each other. Both detectors worked pretty well at a temperature of about 20 mK (chosen to minimise the pile-up effects by decreasing the thermal decay time of bolometer pulses) and with an energy resolution around 15 keV for the α lines. We have exposed under vacuum both absorbers to a ^{228}Ra α source that implanted on them ^{224}Ra nuclei. In this way the α's and the recoiling nuclei coming from one source can be completely absorbed in one detector, giving the total transition energy; or, if they escape from surface, they can release part of their energy on both detectors [2]. Hence, using the anticoincidence technique, one can isolate the total transition energy lines in one detector; while, using the coincidence technique, one can see the fraction of the total energy deposited in each detector by α's and by recoiling nuclei. Therefore, using a previously done γ calibration, we can determine the QF both of α's and of recoiling nuclei of masses between 210 and 224. We find it definitively slightly more than one (1.02 ± 0.01) for α particles and practically 1 (1.025 ± 0.3) for the recoiling nuclei. We do not observe any significant deviation by this value for recoiling nuclei till energy as low as 15 keV. In Fig. 1 as an example one can see the energy spectrum of the 103.4 keV ^{224}Ra recoiling nuclei determined with a resolution of about 12 keV FWHM.

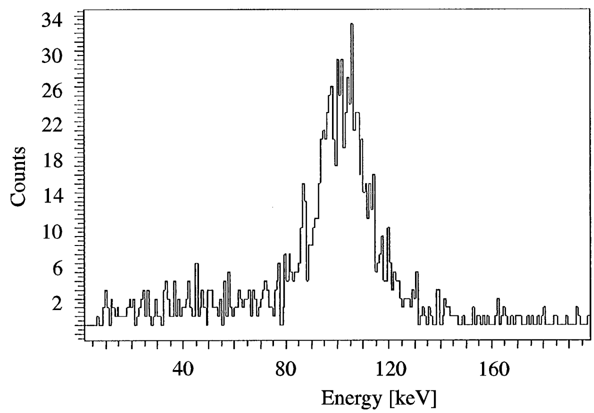

Fig. 1. The recoil spectrum of ^{224}Ra is shown, the 103.4 keV line has a resolution of about 12 keV.

2.2. The determination of the ^{210}Pb contamination in lead

To enhance the sensitivity of our previous measurements of ^{210}Pb contamination in lead [3], we have constructed three lead bolometers of about 11 g, using different lead samples, and we have mounted them in one of our cryostat under Gran Sasso mountain. The measurements carried out on surface found a slight but significant contamination for the best modern lead (coming by Johnson& Mattey) while no indication were found for the ancient roman lead extracted by a ship sunk near Sardinia. The third bolometer is made with another ancient roman lead sample found in a ship sunk near Africa. The bolometers, made with superconductive material like lead, are somewhat more difficult to manage and one has to choose with care the operating temperature to maximise the thermal signal and to avoid the loss due to the energy given by the particles directly to the superconductive system

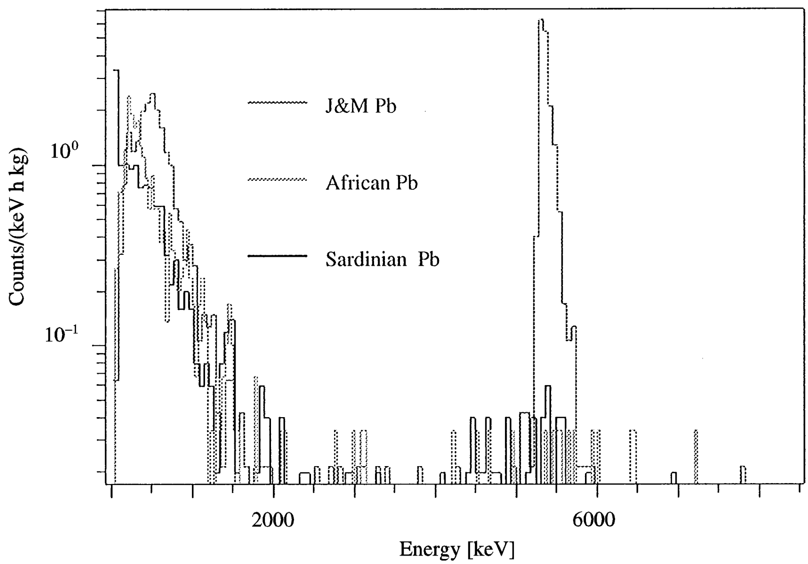

Fig. 2. The spectra of 3 different kinds of leads are shown, the 5.43 MeV line (total transition energy) of the ^{210}Po (daughter of ^{210}Pb) is clearly present only on the J&M modern lead, while the ancient roman lead samples have only few traces of it, leading to a limit on ^{210}Pb contamination in ancient roman lead of less than 7 and 4 mBq/kg, respectively.

[4]. We have worked at a temperature around 25 mK and we have obtained resolution of about 15 keV at 1 MeV, but the distortions of the ^{210}Po (daughter of the ^{210}Pb) α line, not yet completely explained, prevent us from reaching more than 50 keV FWHM of resolution. So it is not possible to separate the contributions to this line coming from internal and external contamination, though a comparison of the three lead spectra (see Fig. 2) clearly indicates that the ^{210}Po α line present in J&M lead is of internal origin, giving a contamination of about 270 mBq/kg, very difficult to see with other techniques. Regarding the roman lead samples we have a limit of less than 4 mBq/kg for the Sardinian one and of less than 7 mBq/kg for the African one, demonstrating the importance of the roman lead as shielding material for ultralow background experiments.

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