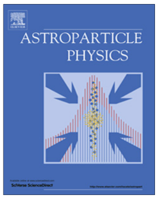
Astroparticle Physics 45 (2013) 13–22

Contents lists available at SciVerse ScienceDirect

Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropart



Validation of techniques to mitigate copper surface contamination in CUORE

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0927-6505/$ - see front matter
http://dx.doi.org/10.1016/j.astropartphys.2013.02.005

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ARTICLE INFO

Article history:
Received 24 October 2012
Received in revised form 17 December 2012
Accepted 28 February 2013
Available online 7 March 2013

Keywords:
Bolometer
Neutrinoless Double Beta Decay
Surface contamination
Radioactive background

ABSTRACT

In this article we describe the background challenges for the CUORE experiment posed by surface contamination of inert detector materials such as copper, and present three techniques explored to mitigate these backgrounds. Using data from a dedicated test apparatus constructed to validate and compare these techniques we demonstrate that copper surface contamination levels better than 10^{-7}- 10^{-8} Bq/cm^2 are achieved for ^{238}U and ^{232}Th. If these levels are reproduced in the final CUORE apparatus the projected 90% C.L. upper limit on the number of background counts in the region of interest is 0.02–0.03 counts/keV/kg/y depending on the adopted mitigation technique.

1. Introduction

Neutrinoless Double Beta Decay ($\beta\beta0\nu$) is an area of vigorous experimental activity with potential for profound impact on modern questions in fundamental physics [1–3]. Observation of this decay would immediately imply lepton number violation and would establish the neutrino as a Majorana fermion. If neutrinos are indeed Majorana fermions, a measurement of the $\beta\beta0\nu$ rate would probe the absolute neutrino mass scale and possibly reveal the neutrino mass hierarchy.

Sensitivity to the non-degenerate inverted hierarchy of neutrino masses is a standard benchmark for next generation $\beta\beta0\nu$ searches which demands that very low background levels – of the order of few counts per ton per year in the region of interest – be achieved. All aspects of the experiment, for example selection of materials, machining and handling of components, and assembly procedures must be scrutinized for background control. Validation of effective control measures and quantifying the residual background is often nearly as challenging as the underlying experiment. This paper focuses on aspects of the background control and validation activities for the CUORE experiment [4–7]. Specifically, we present a study of three techniques explored to mitigate background from residual surface radioactivity on structural materials in the detector, particularly copper.

2. Overview of the CUORE detector

The CUORE experiment, currently under construction underground at Laboratori Nazionali del Gran Sasso (LNGS), will search for $\beta\beta0\nu$ of ^{130}Te. The signature of this decay is a peak in the energy spectrum centered at the Q-value of the transition, at about 2528 keV [8–10]. The experimental goals include a background level of $\leqslant 10^{-2}$ counts/keV/kg/y in an energy window of $\sim$ 100 keV around the Q-value, denoted the region of interest (ROI), and a high-precision measurement of the spectrum in that region.

The apparatus, shown in Fig. 1 will consist of a close-packed array of 988, $5 \times 5 \times 5$ cm^3 cubic TeO$_2$ crystals, amounting to 206 kg of ^{130}Te. These will be cooled inside a cryostat to around 10 mK. At this temperature the crystals function as highly sensitive calorimeters, converting the energy deposited in their volume to a measurable temperature change. The bolometers will be arranged in a compact cylindrical matrix of 19 towers, each tower will contain 13 planes of four crystals. A copper skeleton will provide the mechanical structure to hold the crystals in each tower. The array will hang in vacuum inside a copper cylindrical vessel closed on the top and bottom with copper plates. The copper skeleton, denoted collectively as the *copper holder*, will not touch the crystals directly, instead PTFE standoffs will secure the crystals. Components made of material other than copper or TeO$_2$ make up a small fraction of the detector. These components, denoted collectively as *small parts*, include the thermistors used to read out the bolometric signal, the silicon heaters, used to check for gain variations, the glue used to attach the thermistors to the crystals, the PTFE standoffs, and the readout wires. A complete description of the CUORE detector can be found in [6].

3. Bolometer background from surface and bulk radioactivity

In this Section we discuss aspects of bolometer behaviour that influence their susceptability to background from decays of surface radio-impurities and describe some discriminators to distinguish between surface and bulk contamination. In the context of this paper, bulk contamination represents unwanted impurities distributed uniformly throughout the volume of a material. This contamination arises from impurities present in the raw material, or introduced during manufacturing. On the other hand surface contamination refers to impurities from the environment that

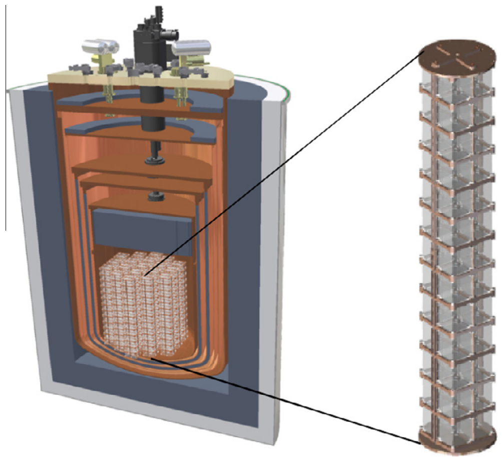

Fig. 1. Set-up of the CUORE experiment: the 988 bolometers arranged in a 19 towers array, hanging in vacuum inside nested copper cylindrical vessels and provided with lead shields. On the right a detail of one CUORE tower.