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# High-purity material selection techniques for Rare-Events Physics experiments

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**Summary.** — In experiments on Rare-Events Physics it is important that the construction materials, in particular those closer to the detectors, have the smallest amount of contaminants that can contribute to background. Copper is a material widely used thanks to its low content in radioactive contaminants, so it is very important to develop tools able to reach high sensitivity in the analysis of Copper radioactivity. A method based on Neutron Activation Analysis (NAA) has been developed to analyze $^{232}$Th contamination in copper samples through the irradiation of 200 g of copper then radiochemical concentrated using nitric acid and actinide resin. Several elutions with various inorganic acids were done to concentrate $^{233}$Pa, activation product of $^{232}$Th, from copper matrix to eliminate radioactive contribution from other activation products. Using gamma spectroscopy with HPGe to evaluate the radioactivity due to gamma rays from $^{233}$Pa decay it was possible to reach a detection limit of $5 \times 10^{-13}$g$^{232}$Th/gCu.

PACS 29.40.-n – Radiation detectors.
PACS 29.30.Kv – X- and $\gamma$-ray spectroscopy.

## 1. – Introduction

The Rare-Events Physics involves low counting rates processes in which the signature is a feeble signal that has to be discriminated from the radioactive background; its reduction is therefore mandatory. University of Milano Bicocca is part of the collaboration of CUORE experiment currently under construction in the Laboratori Nazionali del Gran Sasso of the INFN dealing with the search of double-beta decay without the emission of two neutrinos. This is a rare event in which an even-even nucleus decays into a nucleus with $Z + 2$ with the emission of only two electrons leading to the leptonic number violation by two units. The transition can occur if neutrinos have mass and are their own antiparticles (Majorana particles). The analytical expression that represents experimental sensitivity shows the dependence from some parameters that are crucial to reach the requested sensitivity:

$$S_{0\nu} \propto \varepsilon \frac{\text{i.a.}}{A} \sqrt{\frac{M \cdot T}{\Delta E \cdot b}} \tag{1}$$

 

where $\varepsilon$ is the efficiency, i.a. is the isotopic abundance, $A$ the molecular mass of the isotope, $M$ the detector mass, $T$ the measure time, $\Delta E$ the energy resolution and $b$ the background.

CUORE experiment tried to optimize all of these parameters. The detector is an array of 988 $TeO_2$ crystals containing the parent decay isotope, $^{130}$Te, with an isotopic abundance of 33.8% and a total Te mass of about 741 kg. The transition $Q$-value is 2527 KeV: in this region of the energy spectrum the background it is expected to be $< 10^{-2}$ count/(KeV $\times$ kg $\times$ year).

## 2. – Techniques

Underground facilities are needed to shield experiments from the background induced by cosmic radiation, but the radioactive background due to the experimental apparatus can be reduced only by the selection of the construction materials. In fact the decay products of radio-nuclides such as that presenting $^{232}$Th and $^{238}$U decay chains can have energies near the signature of rare event under study. The most common techniques used to measure the materials radiopurity are complementary: Gamma Spectrometry with High-Purity Germanium (HPGe) providing an indirect measure of chain progenitors and direct detection of long-lived radionuclides with Neutron Activation Analysis (NAA).

**2**˙1. *RNAA*. – Copper, thanks to its low content in radioactive contaminations, is a material widely used for shields, holders and other objects close to the detectors in many experiments on Rare-Events Physics. Radioactivity Laboratory of Milano Bicocca performed Neutron Activation Analysis with Radiochemical Method (RNAA) [1] on copper samples that will be used to realize the support structure of the bolometric detectors of CUORE experiment. A total mass of 199 g of copper was prepared in the form of disks of 5 mm diameter and 1 mm thickness. The samples were strongly cleaned with very pure reagents in order to remove all the possible contaminants on the surfaces. The irradiation was done in the TRIGA Mark II nuclear reactor of the Pavia University (working at 250 kW power with a neutron flux of about $10^{13}$ n/(s$\times$cm$^2$) with cycles of 6 h and 18 h of cooling time for a total exposure time of 30 h. At the same time a standard reference of $^{232}$Th, 100 $\mu$l of 3% $HNO_3$ aqueous solution with 1000 ppm/ml (so that it experienced the same activation as the copper sample), was irradiated. After the extraction the copper sample was dissolved with nitric acid while the standard was dissolved with 200 g of not irradiated copper. This method ensures that the chemical procedures applied on both samples experience the same matrix effect. To determine the presence of $^{232}$Th inside the irradiated sample it is possibile to look at the reaction

$$n + {}^{232}\mathrm{Th} \rightarrow {}^{233}\mathrm{Th} + \gamma,$$

the generated $^{233}$Th is radioactive and decays:

$$\begin{aligned} {}^{233}\mathrm{Th} &\rightarrow {}^{233}\mathrm{Pa} + e^- + \overline{\nu}_e, \qquad t_{1/2} = 22.3\,\mathrm{min},\\ {}^{233}\mathrm{Pa} &\rightarrow {}^{233}\mathrm{U} + e^- + \overline{\nu}_e, \qquad t_{1/2} = 27.0\ \mathrm{days}. \end{aligned}$$

Using an ion-exchange resin, with high affinity for actinide elements, is it possible to extract $^{233}$Pa and measure its activity with HPGe. With this method it was possible to reach a detection limit of $4.9 \times 10^{-13}$ g/g (90% CL) for $^{232}$Th in copper.

**2**˙2. *Gamma spectroscopy*. – An intrinsic low background system with two Ultra-Low Background Germanium Detectors operating in coincidence, a passive background reduction method, has been developed at the Radioactivity Laboratory of Milano Bicocca.

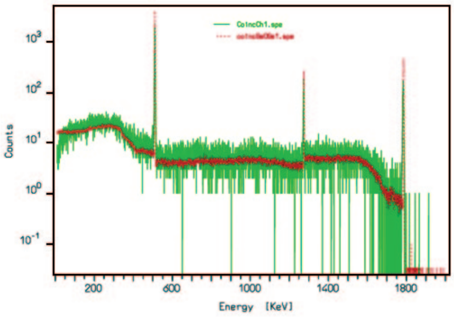


Fig. 1. – Measured and simulated spectrum comparison.

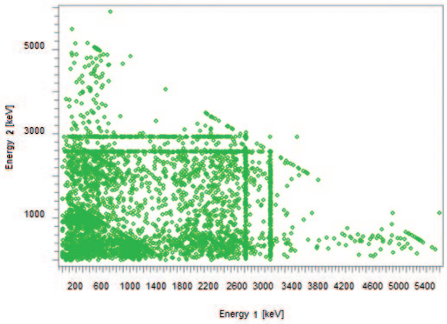


Fig. 2. – Coincidence events of $^{232}$Th in both detectors.

The only available configuration for HPGe (on market) with the possibility of mechanical cooling was the reduced background. The production company provided the materials composing this type of detectors so that it was possible to measure their contaminations in Th, U, K and to choose alternative materials when they were contaminated. The detector geometry was reproduced using a Monte Carlo simulation based on Geant4 and the contribution to the background of all the components was estimated using the measured contaminations of the selected materials. The final configuration is a Ultra-Low Background, with remote electronics, often contaminated in Th, shielded from the detector with Roman Lead. The two detectors are put in a shield with 15 cm of OHFC (Oxygen-free high thermal conductivity) copper and a external layer of 20 cm of lead. The DAQ for the system was dedicated and the trigger is done with an OR so that it is armed every time one of the detectors records a signal while both signals are acquired at the same time. The analysis is made offline having the possibility to consider not only the full peak energy counts but also the continuum to increase the detection efficiency. To test the system a measure of a $^{22}$Na source was done (fig. 1) and the related simulation was performed to calculate the integral and the coincidence efficiency that are 15% and 78% respectively. Using this value it was possible to estimate the detection limit on $^{232}$Th: $< 500\,\mu$Bq/kg (fig. 2).

REFERENCES

[1] Clemenza M., Borio di Tigliole A., Previtali E. and Salvini A., *AIP Conf. Proc.*, **1338** (2011) 37.