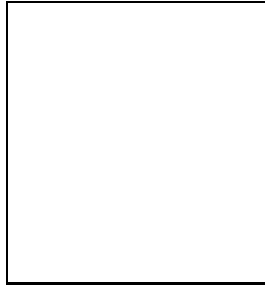


CUORICINO last results and CUORE R&D

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CUORICINO is a bolometric experiment on Neutrinoless Double Beta Decay (DBD0 ν) of ¹³⁰Te. It consists of an array of 62 TeO₂ crystals with a total mass of ~ 40.7 kg. While being a self consistent experiment CUORICINO is also a good test for the feasibility of the next generation experiment CUORE, ~ 750 kg of TeO₂ bolometric mass. In this paper last results from CUORICINO and prospects for the future CUORE experiment will be reported.

1 Introduction

The positive results obtained in the last few years in neutrino oscillation experiments^{1,2,3,4,5} have given convincing and model independent evidences that neutrinos are massive and mixed particles. The obtained data are compatible with two possible mass patterns, or hierarchies, the normal: $m_1 < m_2 \ll m_3$, and the inverted hierarchy: $m_3 \ll m_1 < m_2$. In this scenario there are two general theoretical possibilities for the neutrino with definite mass, depending on the conservation or not of the total lepton charge. In the first case neutrinos are Dirac particles, while in the second case they are Majorana particles. Unfortunately oscillation experiments are only sensitive to neutrino mass eigenvalue differences squared, but cannot give any information with respect to neutrino nature and absolute mass scale^{6,7}.

Experiments looking for the DBD0 ν of even-even nuclei have the highest sensitivity to possible violations of the total lepton number L and to Majorana neutrino masses. A positive signal would therefore give a clear answer with respect to neutrino nature and absolute mass scale.

In this lepton violating process, a nucleus (A, Z) decays into $(A, Z+2)$ with the emission of two electrons and no neutrino. This leads to a peak in the sum energy spectrum of the two electrons at the Q -value of the transition. The decay rate of this process is given by the equation:

$$\left[T_{1/2}^{0\nu}\right]^{-1} = |M^{0\nu}|^2 G^{0\nu} \frac{|\langle m_\nu \rangle|^2}{m_e^2} \quad (1)$$

where $G^{0\nu}$ is the two body phase-space factor including coupling constants and $M^{0\nu}$ is the nuclear matrix element.

The quantity $|\langle m_\nu \rangle|$ is the effective electron neutrino Majorana mass which can be expressed in terms of the elements of the neutrino mixing matrix as follows:

$$|\langle m_\nu \rangle| \equiv ||U_{e1}^L|^2 m_1 + |U_{e2}^L|^2 m_2 e^{i\phi_2} + |U_{e3}^L|^2 m_3 e^{i\phi_3}|, \quad (2)$$

where $e^{i\phi_2}$ and $e^{i\phi_3}$ are the Majorana CP-phases (± 1 for CP conservation), $m_{1,2,3}$ are the Majorana neutrino mass eigenvalues and U_{ej}^L are the coefficients of the Pontecorvo-Maki-Nakagawa-Sakata (PMNS) neutrino mixing matrix, determined from neutrino oscillation data.

Recent global analyses of all oscillation experiments^{8,9,10,11} yield on average:

$$|\langle m_\nu \rangle| = |(0.70 \pm 0.03)m_1 + (0.30 \pm 0.03)m_2 e^{i\phi_2} + (< 0.05)m_3 e^{i\phi_3}| \quad (3)$$

As it can be seen from equation (1) any uncertainty on the nuclear matrix element $M^{0\nu}$ reflects directly on the measurement of $|\langle m_\nu \rangle|$. Many calculations exist in literature^{13,12,14,15} and find rather different nuclear matrix element values. This is one of the regions for which it is fundamental to search for DBD0 ν on several nuclei¹⁶.

No evidence for DBD0 ν has been reported so far, with the exception of the claimed discovery of the decay of ^{76}Ge from which a best fit value for $|\langle m_\nu \rangle|$ of 0.4 eV (99.9973% C.L.) is given^{17,18,19}. Actually the best lower bound on $|\langle m_\nu \rangle|$ is the one obtained by the Heidelberg-Moscow experiment with Ge^{76} and is $|\langle m_\nu \rangle| \leq (0.1-0.9)$ eV (99.73% C.L.)¹⁸.

DBD0 ν can be searched for with different experimental methods. One possible direct approach is based on the bolometric technique²⁰. The energy released in dielectric and diamagnetic crystals gives rise to measurable temperature increases when working at low temperature ($T \sim 10$ mK). The absorber material can be chosen quite freely, the only requirements being, in fact, reasonable thermal and mechanical properties. The absorber can therefore be easily built with materials containing any kind of unstable isotopes as for instance DBD candidates. This method has the same advantages of solid state detectors (high detector mass and good energy resolution) and offers at the same time a wide choice of DBD candidates to be used. The isotope ^{130}Te is

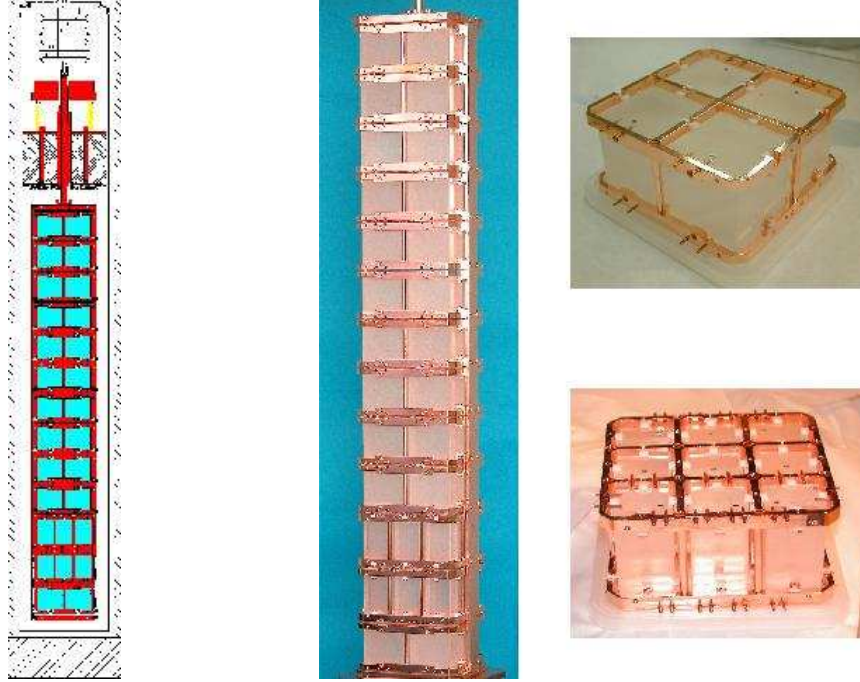


Figure 1: *The CUORICINO detector: scheme of the tower and internal roman lead shields (left), the 13 planes tower (centre), the 4 crystal module (top right) and the 9 crystal module (bottom right).*

and excellent candidate to search for DBD due to its high transition energy (2528.8 ± 1.3 keV) and large isotopic abundance (33.8%) which allows a sensitive experiment to be performed with natural tellurium. Of the various compounds of this element, TeO_2 appears to be the most promising, due to its good thermal and mechanical properties.

Because of the rarity of the searched process, spurious counts due to environmental and cosmic radioactivity, airborne activity (Rn), neutrons, intrinsic contaminations and cosmic ray activation of the detector and of the other experimental setup materials, can obscure the signal counts of interest. A good knowledge of the radioactive sources that mainly contribute to the measured background in the $\text{DBD}0\nu$ energy region, is therefore of fundamental importance in order to study new strategies to reduce such contaminations and consequently improve the sensitivity of the experiment.

The first TeO_2 large mass bolometer (MiDBD experiment) consisted in an array of 20 340 g natural TeO_2 crystals for a total mass of 6.8 kg. It was operated between 1997 and 2001 in the hall A of the National Laboratories of Gran Sasso (LNGS), that constitute a fundamental shield against Cosmic Rays (3200 m.w.e.). MiDBD collected a total statistics of 4.3 kg·y and measured a background in the $\text{DBD}0\nu$ region of 0.3 c/keV/kg/y. The reached limit for the halflife of ^{130}Te as respect to $\text{DBD}0\nu$ is $2.08 \cdot 10^{23}\text{y}$ (90% CL)²¹.

After some tests with larger crystals (~ 750 g each) in 2001 this experiment was dismantled in order to leave the place to the larger mass TeO_2 experiment CUORICINO.

2 CUORICINO set-up

CUORICINO is a tower-like structure made by eleven modules of 4 detector each ($5 \times 5 \times 5$ cm³ 790g TeO_2 crystals) and two modules of 9 detector each ($3 \times 3 \times 6$ cm³ 330g TeO_2 crystals) for a total mass of about 40.7 kg (see fig. 1). The 18 small size crystals were taken from the previous MiDBD experiment. All the crystals are made of natural tellurium but the 4 isotopically enriched crystals previously used in MiDBD.

The experience gained with MiDBD made us aware of the necessity of working with materials with an intrinsic and surface contaminations reduced as much as possible. Particular care was therefore devoted to selection and cleaning of the CUORICINO detector materials. The $5 \times 5 \times 5 \text{ cm}^3$ TeO_2 crystals were grown from pre-tested low activity powders and all the crystals were subject to surface treatments with low activity materials. The mechanical structure of the array was made exclusively in OFHC copper and PTFE, both previously measured in order to make sure of their extremely low radioactive content. All the copper and PTFE parts facing the detectors were separately treated with acids in order to remove any possible surface contamination. All the detector mounting operations were performed in an underground clean room in a N_2 atmosphere to avoid Rn contamination. The tower just after assembly completion and the details of the two different used modules are shown in fig. 1.

The detector tower is surrounded by copper plates and installed in the same ^3He - ^4He dilution refrigerator previously used for MiDBD, at a working temperature of about 10 mK. Roman lead shields are placed all around the detector in order to avoid radioactivity coming from the cryostat. Due to the bigger dimension of the CUORICINO tower with respect to MiDBD, the amount of Roman lead surrounding the CUORICINO tower is less than before: $\sim 1 \text{ cm}$ thick roman lead shield (vs. 3 cm in MiDBD) is placed on the side of the detector tower and two roman lead discs of 7.5 cm (vs. 10 of MiDBD) and 10 cm thickness (vs. 15 of MiDBD) respectively, are positioned just below and above the tower respectively. The tower is mechanically decoupled from the cryostat through a steel spring in order to avoid vibrations from the overall facility to reach the detectors.

The dilution refrigerator is shielded against environmental radioactivity by two layers of lead of 10 cm minimum thickness each. The outer layer is of commercial low radioactivity lead, while the internal one is made with special lead with a ^{210}Pb contamination of $16 \pm 4 \text{ Bq/kg}$. The external lead shields are surrounded by an air-tight box flushed with fresh nitrogen to avoid radon contamination to reach the detector. A borated polyethylene neutron shield (10 cm) is also present. All the structure is housed inside Faraday Cage in order to suppress electromagnetic interferences.

3 CUORICINO performances and results

CUORICINO first measurement started in March 2003. Unfortunately some detector connections broke during the cooling down procedure, so that only $32 \text{ } 5 \times 5 \times 5 \text{ cm}^3$ and $17 \text{ } 3 \times 3 \times 6 \text{ cm}^3$ crystals could be read. Since the active mass was anyway quite large ($\sim 30 \text{ kg}$ of TeO_2) and the detector performances were quite good data collection was continued for a few months. The average pulse height obtained with the working detectors is of $120 \pm 75 \text{ } \mu\text{V/MeV*kg}$ for the $5 \times 5 \times 5 \text{ cm}^3$ crystals and $104 \pm 35 \text{ } \mu\text{V/MeV*kg}$ for the $3 \times 3 \times 6 \text{ cm}^3$ crystals. The average resolution FWHM in the DBD0 ν region was evaluated on the $2615 \text{ keV } ^{208}\text{Tl}$ line measured during calibration with a ^{232}Th source. It is $7.8 \pm 2.8 \text{ keV}$ for the bigger size and of $9.1 \pm 3.1 \text{ keV}$ for the small size crystals.

At the end of October 2003 CUORICINO was stopped to undergo substantial operations of maintenance and to recover the lost electrical connections and hence increase the number of working detectors. At the end of April the second run of CUORICINO started. Unfortunately two of the $5 \times 5 \times 5 \text{ cm}^3$ crystal wire connections had broken during the cooling down procedure. Actually we have 42 big crystals over 44 and all the 18 small crystals working with a TeO_2 active mass of about 39 kg . The average pulse height obtained with the working detectors is of $167 \pm 99 \text{ } \mu\text{V/MeV*kg}$ for the $5 \times 5 \times 5 \text{ cm}^3$ crystals and $147 \pm 60 \text{ } \mu\text{V/MeV*kg}$ for the $3 \times 3 \times 6 \text{ cm}^3$ crystals. The average resolution FWHM is $7.5 \pm 2.9 \text{ keV}$ for the bigger size and of $9.6 \pm 3.5 \text{ keV}$ for the small size crystals.

The results presented here refer to the data acquired with the working TeO_2 crystals up to

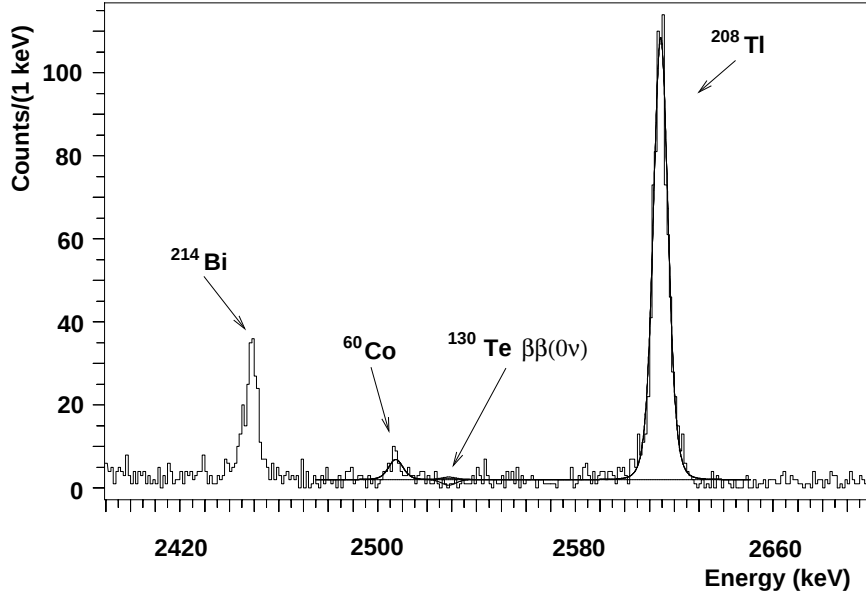


Figure 2: Spectrum of the sum of the two electron energies in the region of neutrinoless DBD

December 2004, with a total statistics of 10.85 kg*y. The sum of the spectra of the $5 \times 5 \times 5 \text{ cm}^3$ and $3 \times 3 \times 6 \text{ cm}^3$ crystals in the DBD0 ν region is shown in fig. 2, where the peaks at 2447, 2505 keV and 2615 keV due to ^{238}U , ^{60}Co and ^{232}Th contaminations respectively are clearly visible.

The background value measured in this region is of $0.18 \pm 0.01 \text{ c/keV/kg/y}$, a factor of about 2 less than the one obtained in the previous experiment MiDBD, thus indicating the effectiveness of the cleaning operation performed in CUORICINO. No evidence is found for a peak at 2528.8 keV, the energy of the DBD0 ν of the isotope ^{130}Te . By applying a maximum likelihood procedure^{22,23} to search for the maximum signal compatible with the measured background, we obtain a 90% C.L. lower limit of $1.8 \times 10^{24} \text{ y}$ on the ^{130}Te lifetime for this decay. This limit leads to a constraint on the electron neutrino effective mass ranging from 0.2 to 1.1 eV, depending on the nuclear matrix elements considered in the computation²⁷. By using the same nuclear matrix element value used by H.V. Klapdor-Kleingrothaus et al.¹⁹ we obtain a value for $|\langle m_\nu \rangle|$ of 0.527 eV. The reported data show that CUORICINO is a competitive experiment in the field of Neutrinoless Double Beta Decay²⁴. It has a 5 year sensitivity (at 68% C.L.) of about $9 \times 10^{24} \text{ year}$ for the $\beta\beta(0\nu)$ of ^{130}Te . This means that CUORICINO will be able to test the Majorana mass in the 100-700 meV range.

4 From CUORICINO to CUORE

The good results and performances obtained with CUORICINO look very promising in view of the future experiment CUORE. It has in fact demonstrated the feasibility of a large bolometric array of TeO_2 crystals in a tower-like structure and at the same time it has shown that detector performances are not affected by the increase in crystal size (from 330 g to 790 g).

CUORE will be a tightly closed structure of 988 TeO_2 $5 \times 5 \times 5 \text{ cm}^3$ crystals arranged in 19 CUORICINO-like towers, for a total mass of $\sim 741 \text{ kg}$. It will be provided with copper shields, internal roman lead shields (2 cm thick all around the detector plus 20 cm thick on the top), external commercial lead shields (20 cm thick) and neutron shield (10 cm thick). The cryostat will be kept in nitrogen overpressure to avoid radon contamination from the air to reach the detector and placed in a Faraday Cage in order to suppress electromagnetic interferences. The goal of this experiment is to reach a background rate in the DBD0 ν energy region in the range

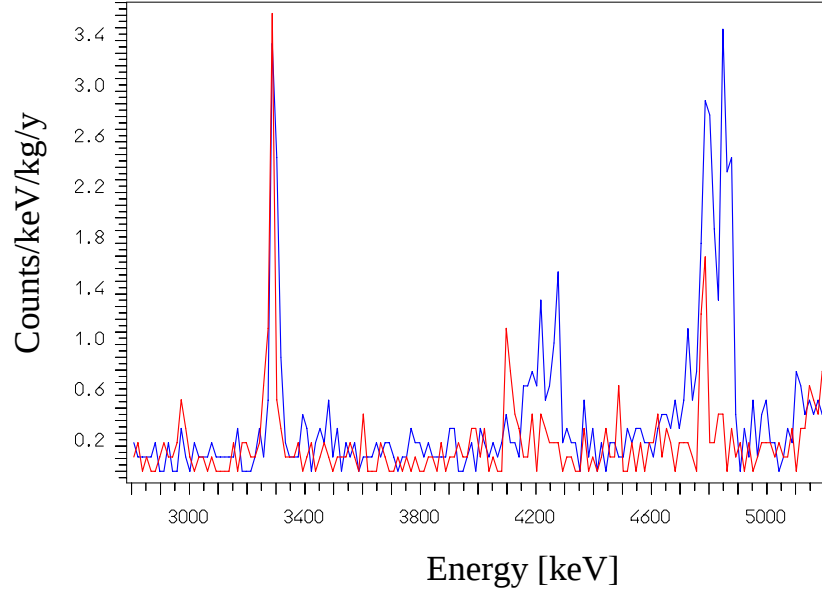


Figure 3: Comparison between the background spectra obtained in Cuoricino (top and bottom planes) (blu) and with the test set-up (red).

0.001 to 0.01 c/keV/kg/y, corresponding to a sensitivity on the effective electron neutrino mass of $0.02\text{--}0.07\text{ t}^{-1/4}\text{ eV}$ and $0.03\text{--}0.13\text{ t}^{-1/4}\text{ eV}$ respectively.

Unfortunately CUORICINO can't be a direct test for what concerns CUORE background, due to the different detector geometry and materials that will be used. Indeed the tightly closed structure of the CUORE detector will allow a strong background suppression working with all the detectors in anticoincidence. Moreover the lead shield designed for CUORE will be optimized in order to practically cancel the background coming from outside. This optimization was not possible in CUORICINO housed in the old cryostat used for MiDBD where the space is limited. The intense R&D activities as respect to surface cleaning and material selection will also give an additional reduction in the background contribution to the DBD0 ν region.

The background results obtained with CUORICINO are very promising. They demonstrate that our knowledge of the main background sources and the efforts made to reduce them are in the good direction.

A dedicated study of the CUORICINO background was performed both with sophisticated analysis procedures and with the aid of Montecarlo simulations of the whole detector set-up. A background model, able to describe the observed measured spectra in terms of environmental radioactivity, radioactive bulk contaminations of the whole detector setup and surface contaminations of the materials directly facing the detector itself, was developed²⁵. The sources identified as possible responsible for the measured background in the DBD0 ν region are β and α decays from the surface of the crystals and of the parts directly facing them (the biggest is due to copper) and multi-Compton events from ^{208}Tl gamma decays, probably due to ^{232}Th contaminations of the materials far away from the detectors. The evaluated surface contamination level for both the crystals and the copper facing them is around 10^{-9} g/g , leading to contributions to the DBD0 ν energy region of the order of $20 \pm 10\%$ and $50 \pm 20\%$ respectively. The evaluated contribution due to ^{232}Th contaminations of distant parts is of $\sim 30 \pm 10\%$.

The results obtained with this analysis have demonstrated to be very useful both in addressing the R&D effort with respect to material selection and surface cleaning and in allowing an

evaluation of the background reachable in CUORE with the contamination levels measured so far for the materials presently at our disposal. With the aid of Montecarlo simulations of the entire CUORE geometry and using the same background model tested on CUORICINO, the contribution expected from bulk and surface contaminations of the crystals and of the copper at the level measured in CUORICINO have been evaluated. For ^{232}Th and ^{238}U bulk contaminations at levels of about 10^{-13}g/g and 10^{-12}g/g for the crystals and the copper respectively, the evaluated contribution to the DBD0 ν energy region in CUORE is less than $2 \times 10^{-2} \text{ c/keV/kg/y}$. The evaluated contribution due to surface contamination levels of about 10^{-9}g/g for both crystals and copper is around $7 \times 10^{-2} \text{ c/keV/kg/y}$. Reductions of factors at least 4 and 10 for surface contamination of crystals and copper respectively are necessary in order to reach the wanted sensitivity with CUORE.

An intense R&D activity with respect to surface cleaning optimization and measurement is under progress. New cleaning procedures for both crystals and copper surfaces have been tested in January 2005 in a second cryostat installed in the hall C of LNGS, provided with copper and lead shields analogous to that used in CUORICINO²⁶. The detector consisted in $8 \times 5 \times 5 \text{ cm}^3$ TeO_2 crystals, arranged in 2 planes of 4 detectors each. The crystal surfaces were treated with a nitric acid solution and successively polished with selected high-purity SiO_2 lapping powders. The copper structure was subject to electro-erosion in an ultra-clean solution of citric acid. All the assembling procedure was performed in clean environment and using materials with measured low radioactive content.

The energy spectrum obtained with the collected data shows a reduction with respect to CUORICINO (fig. 3) in the counting rate in the region above 4 MeV, where the main contribution is due to alpha decays occurring in the crystals bulk and surface and on the surface of material facing them (most likely copper). In particular a reduction of a factor of about 4 is observed in the peaks at the transition energy of ^{238}U and ^{232}Th alpha decays. According to the background model previously described and updated to the actual detector geometry, these peaks can be attributed to contaminations in the first μm depth of the crystal surface. The result obtained in this test fulfills therefore the CUORE requirement with respect to crystal surface contamination level. As regards copper no indication of surface contamination reduction has been observed.

In order to exclude possible contributions to the DBD0 ν energy region arising from small components facing the crystals (i.e. PTFE PTFE parts, silicon heaters and gold bonding wires) a new test has been performed with the same detector used in the previous test measurement. The crystal surfaces have been covered with large amounts of the components to be tested in order to have a high sensitivity. Preliminary results give indications of very small contributions due to these elements, leaving as the most probable background source the copper surface.

New and more effective cleaning procedures for the copper surface are therefore mandatory. Recent measurement performed with laser ablation have given positive indications in favour of the plasma cleaning technique²⁸.

5 Conclusions

CUORICINO ($\sim 41 \text{ kg}$ of TeO_2 crystals) is a sensitive experiment on Neutrinoless Beta Decay able to reach in 5 years a limit on the effective electron neutrino mass ranging from 0.2 to 1.1 eV, depending on the nuclear matrix elements considered in the computation. While being a self consistent experiment CUORICINO is also a fundamental test for the next generation CUORE experiment (~ 740 of TeO_2 crystals) for what concerns detector performances and background value in the DBD0 ν region.

The good results obtained with CUORICINO have shown the feasibility of the tower-like structure and have demonstrated that detector performances are not affected by the mass in-

creasing from 330 g to 790 g. The results obtained with CUORICINO allowed us also to make an evaluation of the background attainable in CUORE with the contamination levels measured for the materials actually at our disposal. Reduction factors of about 4 and 10 of crystals and copper surface contaminations are necessary in order to reach the wanted sensitivity. An intense R%D with respect to material selection and surface cleaning is under progress. Recent test and measurements have given promising results.

For a background value in the $\text{DBD}0\nu$ region of about 0.001 c/keV/kg/y CUORE could reach a sensitivity for $|\langle m_\nu \rangle|$ in the range 30–100 meV in 5 years, just in the region favoured by current oscillation experiments for the inverted hierarchy.

References

1. Super-Kamiokande Collaboration, S. Fukuda *et al.*, *Phys. Lett.* **81**, 2644 (1999) , *Phys. Lett.* **85**, 3999 (2000) ; C. Saji *et al.* (talk given at the Int. Workshop on Neutrino Oscillation and their Origin (NOON2004) 2004, Tokyo, Japan).
2. SNO Collaboration, Q.R. Ahmad *et al.*, *Phys. Rev. Lett.* **87**, 071301 (2001), *Phys. Rev. Lett.* **89**, 011301 (2002), {*PRL* **89**, 011302 (2002).
3. SNO Collaboration, S.N. Ahmad *et al.* (nucl-ex/0309004).
4. Kamland Collaboration, K. Eguchi *et al.* *Phys. Rev. Lett.* **90**, 021802 (2003); J. Detwiler, SLAC Summer Institute, July 2003 (hep-ex/0309004).
5. K2K Collaboration *Phys. Rev. Lett.* **90**, 041801 (2003).
6. S.M. Bilenky, J. Hosek and S.T. Petcov *Phys. Lett. B* **94**, 495 (1980).
7. P. Langacker *et al.* *Nucl. Phys. B* **282**, 589 (1987).
8. F.Feruglio *et al.* *Nucl. Phys. B* **637**, 345 (2002).
9. F.Feruglio *et al.* *Nucl. Phys. B* **659**, 359 (2003).
10. S.Pascoli and S.T.Petkov *Nucl. Phys. B* **544**, 239 (2004).
11. S.Pascoli and S.T.Petkov *Nucl. Phys. B* **580**, 280 (2004).
12. J. Suhonen and O. Civitarese *Phys. Rep.* **300**, 123 (1998).
13. A. Faessler and F. Simkovic *J. Phys. G* **24**, 2139 (1998).
14. S.R. Elliot and P. Vogel *Ann. Rev. Nucl. Part. Sci.* **52**, 115 (2002).
15. O. Civitarese and J. Suhonen *Nucl. Phys. A* **729**, 867 (2003).
16. S.M. Bilenky and S.T. Petcov (hep-ph/0405237).
17. H.V. Klapdor-Kleingrothaus *et al.* *Mod. Phys. Lett. A* **16**, 2409 (2001).
18. H.V. Klapdor-Kleingrothaus *et al.* *Nucl. Phys. B* **586**, 2004 (2004).
19. H.V. Klapdor-Kleingrothaus *et al.* *Nucl. Instrum. Methods* **522**, 367 (2004).
20. D. Twerenbold, *Rep. Prog. Phys.* **59**, 349 (1996).
21. C. Arnaboldi *et al.* *Phys. Lett. B* **557**, 167 (2003).
22. S.Baker and P.D.Cousins *Nucl. Instrum. Methods* **224**, 437 (1984).
23. R.M.Barnett *et al.* *Phys. Rev. D* **54**, 1 (1996).
24. C. Arnaboldi *et al.* *Phys. Lett. B* **584**, 260 (2004).
25. S.Capelli on behalf of CUORE Coll. *Nucl. Phys. B(Proceedings Supplements)* **143C**, 534-534 (2004).
26. S.Pirro *et al.* (Proceeding at Low Radioact. Techniques Conference, Sudbury Canada (2004)).
27. C.Arnaboldi *et al.* (hep-ex/0501034).
28. E.Palmieri (Private Communication).