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Investigation of double beta decay of ^{82}Se and ^{96}Zr with tracking detector NEMO-2

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To investigate double beta decay processes the NEMO collaboration developed an electron tracking detector made of Geiger cells for track reconstruction and plastic scintillators for energy measurements. The prototype, NEMO-2, is described and results on $\beta\beta$ decay of ^{82}Se and ^{96}Zr are given.

1. INTRODUCTION

The NEMO collaboration is building the NEMO-3 [1] detector for double beta decay experiments which will be capable of studying $\beta\beta0\nu$ decays of ^{100}Mo and other nuclei with half-lives up to $\sim 10^{25}$ y corresponding to neutrino masses of 0.1 to 0.3 eV. Two prototype detectors, NEMO-1 [2] and NEMO-2 [3], have been constructed as research and development efforts to establish reliable techniques. NEMO-2 was operated in the Fréjus Underground Laboratory (4800 m.w.e.) from August 1991 to April 1997. Although this detector have been primarily devoted to background studies, it is able to investigate $\beta\beta0\nu$ and $\beta\beta2\nu$ decays of some nuclei with the sensitivity of $\sim 10^{22}$ y and $\sim 10^{21}$ y, respectively. During a period from 1992 to 1995 ^{100}Mo and ^{116}Cd isotopes were investigated by the NEMO-2 detector. Half-life values, energy spectra and angular distributions for $\beta\beta2\nu$ decay of ^{100}Mo and ^{116}Cd were obtained [4,5]. The samples enriched with ^{82}Se and ^{96}Zr were studied from September 1995 to April 1997. Presented here are the preliminary results for ^{82}Se and ^{96}Zr.

2. NEMO-2 detector

NEMO-2 [3] consists of a 1m^3 tracking volume filled with helium gas and 4% ethyl alcohol.Vertically bisecting the detector is the plane of the source foil (1m $\times$ 1m). The tracking portion of the detector is made of open Geiger cells with octagonal cross sections defined by 100μm nickel wires. On each side of the source there are 10 planes of 32 cells which alternate between vertical and horizontal orientations. The cells provide three-dimensional tracking of charged particles by recording the drift time and two plasma

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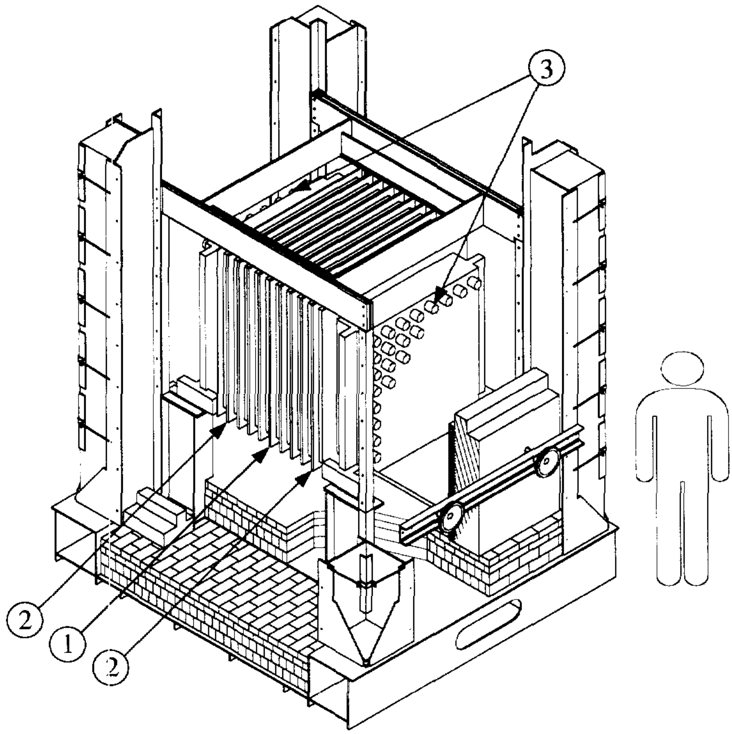

Figure 1. The NEMO-2 detector. (1) Central frame with the metallic foil. (2) Tracking device of 10 frames with 2 × 32 Geiger cells each. (3) Scintillator array. (The shielding is not shown.)

propagation times in each cell.

A calorimeter made of scintillators covers two opposing, vertical sides of the tracking volume. The present configuration includes 2 planes of 25 scintillators (19 cm×19 cm×10 cm) with PMTs made of low radioactive glass. The tracking volume and scintillators are surrounded by a lead (5 cm) and iron (20 cm) shield.

The performance and operating parameters are as follows. The threshold for the scintillators is set at 50 keV, the energy resolution (FWHM) is 18% at 1 MeV and the time resolution is 275 ps for a 1 MeV electron (550 ps at 0.2 MeV). In the 2e event analysis an electron is defined by a track linking the source foil and a scintillator with an energy deposited in the scintillator(s) greater than 200 keV. The maximum scattering angle along the track has to be less than 20° to reject hard scattering situations. Electrons crossing the detector are rejected by time-of-flight analysis. Finally, the NEMO-2 detector is able to measure the internal radioactive contamination of the foils by using the electron-gamma ($e\gamma$) events.

3. ^{82}Se experiment

The source consists of two nearly symmetric halves. The first half contains 156.6 g of enriched selenium (97.02% is ^{82}Se) and the second part contains 133.7 g of natural selenium in which the ^{82}Se isotopic has an abundance of 8.73%. The sources were produced using a special technique to deposit selenium powder on thin films. The thickness of the foils is ~ 50 mg/cm^2 for enriched and ~ 43 mg/cm^2 for the natural ones.

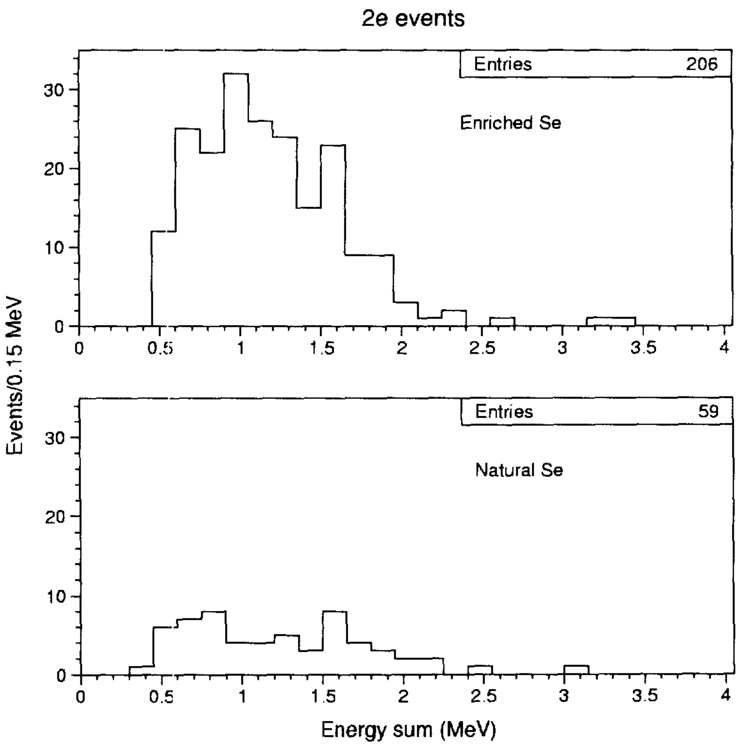

Figure 2. Raw summed electron energy spectra in enriched and in natural selenium.

Radioactive impurities in both foils have again been measured with HPGe detectors in the Fréjus Underground Laboratory before being placed in the NEMO-2 detector. The upper limits on contamination obtained in the enriched selenium for the three isotopes ^{214}Bi, ^{208}Tl and ^{234m}Pa are respectively 4.2, 2.5 and 33 mBq/kg, and in natural selenium these limits are 5, 2 and 16 mBq/kg respectively. Some activity from ^{40}K was found in both samples, specifically (200 ± 30) mBq/kg in the enriched and (117 ± 16) mBq/kg in the natural selenium. The NEMO-2 detector was used by itself for purity control of the foils. A so-called "hot" points were discovered in the selenium foils, using eγ and 2e channels. These "hot" points (~ 4.1% of the natural selenium area and ~ 0.9% of the area in enriched selenium) were excluded from the analysis. The analysis of eγ events showed a small contamination of ^{208}Tl (1.4 mBq/kg) in the natural selenuim foil. Using the single electron energy spectra in the range [1.6 - 2.0] MeV, a limit on the difference of contamination in ^{234m}Pa in both foils of 4.3 mBq/kg is obtained which corresponds to less than 4.8 2e-events.

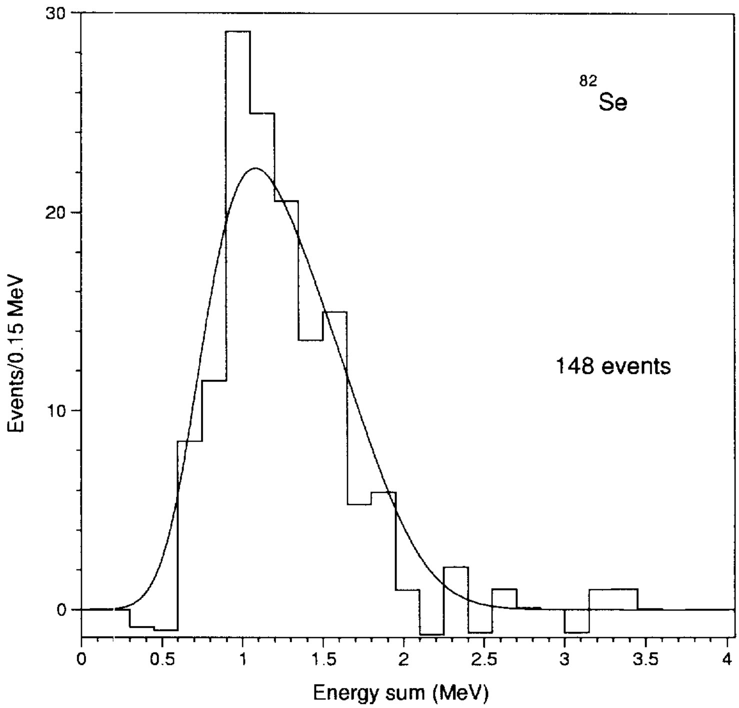

Figure 3. Summed electron electron energy spectrum of $\beta\beta 2\nu$ events in ^{82}Se.

Presented here are preliminary results after 10357.5 h of data collection. Fig. 3 shows the energy spectra of 2e-events in enriched and natural selenium foils (respectively 206 and 59 events). A $cos\alpha < 0.6$ cut is applied. Taking into account mass difference of the natural and enriched foils and the contributions from ^{82}Se, ^{40}K and the chain connected with ^{208}Tl in the natural foil an "external" background in the enriched foil of 41.5 events is calculated. For "internal" backgrounds one can estimate that 16.5 events are contributed by ^{40}K. Consequently, the $\beta\beta$ signal is 148 events (fig. 3). Using the calculated detector efficiency for the $\beta\beta 2\nu$ decay for ^{82}Se ($\varepsilon = 1.28\%$) one gets,

$$T_{1/2}^{2\nu} = [0.8 \pm 0.1(stat) \pm 0.1(syst)] \cdot 10^{20} y.$$

This value is slightly different from the previous geochemical [6-8] and direct [9] experiment results. Half-life limits on the $\beta\beta0\nu$ and $\beta\beta0\nu M^0$ processes in ^{82}Se were found to be $5 \cdot 10^{21}$y and $2 \cdot 10^{21}$y at the 90% CL.

4. ^{96}Zr experiment

The ^{96}Zr double beta decay measurements have been conducted in parallel with the selenium experiment. The source consists of two symmetric halves again and is located in the center of the source plane covering roughly 10% of the available area at the point of greatest geometric acceptance. The mass of the $^{96}ZrO_2$ and $^{nat}ZrO_2$ foils are 20.5 and 18.3 g, respectively. These foils were produced using a technology which binds the zirconium oxide with an organic film. The film thickness with some small variations is 50 mg/cm^2 for enriched and 45 mg/cm^2 for the natural sources. Enrichment of the Zr sample is 57.3% and thus the total mass of ^{96}Zr is 6.8 g.

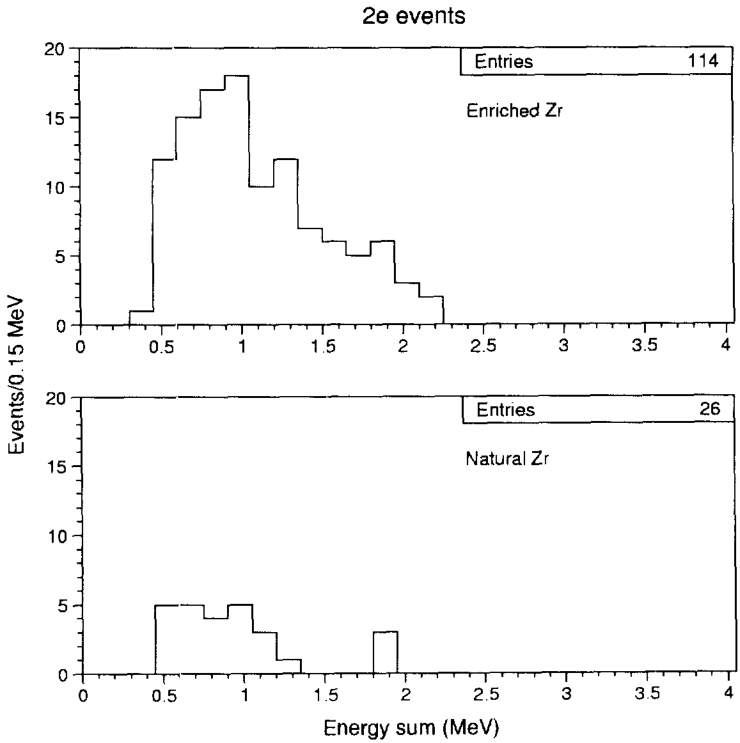

Figure 4. Raw summed electron energy spectra in enriched and in natural zirconium.

Radioactive impurities in both foils have been measured with the HPGe detectors in the Fréjus Underground Laboratory before installation in the NEMO-2 detector and then by the NEMO-2 detector itself. The upper limits on contamination obtained in the enriched Zr for the three isotopes ^{214}Bi, ^{208}Tl and ^{234m}Pa are respectively 12.5, 17 and 280 mBq/kg, and in natural Zr these limits are 13, 8 and 180 mBq/kg. Some activity from ^{40}K, ^{228}Ac, ^{154}Eu and ^{152}Eu was observed in the enriched foil: 1080, 90, 50 and 53 mBq/kg respectively. In the natural foil only limits for these isotopes are observed: 200, 90, 25 and 50 mBq/kg respectively. Using the NEMO-2 purity control (eγ channel) a weak "hot" point in the enriched Zr foil ($\sim$ 6.8% of the area) was discovered and excluded from the analysis. Activities of 14.4 mBq/kg for ^{208}Tl, of 89 mBq/kg for ^{228}Ac and of 48 mBq/kg for ^{154}Eu in the enriched Zr foil and 3.5 mBq/kg for ^{208}Tl in the natural zirconium foil were measured by NEMO-2.

Fig. 4 shows the energy spectra of 2e-events in enriched and natural zirconium, 114 and 26 events after 10357.5 h. A $cos\alpha < 0.6$ cut is applied. A large part of events in enriched Zr is connected with ^{228}Ac, ^{208}Tl, ^{40}K and others pollutions. Using the informations from HPGe and NEMO-2 measurements, the contributions of these isotopes can be estimated. This work is now in progress. In a "simple" analysis one can use the energy region greater than 1.5 MeV, where $\sim$ 34% of $\beta\beta2\nu$ events remain but internal and external backgrounds are strongly suppressed. Then 22 events in enriched and 3 events in natural Zr are obtained. The contribution of the radioactive impurities to the enriched Zr spectrum is estimated to 3.9 events and 0.7 events to the natural Zr spectrum. As a result the positive effect is 15.8 events, that is corresponding to

$$T_{1/2}^{2\nu} = [2.0^{+0.9(stat)}_{-0.5(stat)} \pm 0.5(syst)] \cdot 10^{19} y.$$

Limits (90% CL) are obtained on $\beta\beta0\nu$ and $\beta\beta0\nu M^0$ decays, $8 \cdot 10^{20}$ y and $3 \cdot 10^{20}$ y respectively.

5. Conclusion

Using the NEMO-2 detector the preliminary results for ^{82}Se and ^{96}Zr have been obtained. $\beta\beta2\nu$ decays of these isotopes have been detected and limits on $\beta\beta0\nu$ and $\beta\beta0\nu M^0$ decays have been obtained. Final results will be published soon.

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