SuperNEMO - a new generation of underground experiments for double beta-decay investigations: background constrains

Pavel P. Povinec
on behalf of the SuperNEMO Collaboration
Comenius University, Bratislava, Slovakia

The SuperNEMO experiment is dedicated to the search for neutrinoless double beta-decay which would imply, if observed, violation of the lepton number conservation, could give unique information on the neutrino mass hierarchy, and state if neutrinos are Majorana particles, confirming thus the existence of physics beyond the Standard Model. The SuperNEMO experiment builds upon the design and experience from the NEMO-3 experiment. It is based on the tracking and calorimetry techniques, which allow the reconstruction of the final state topology, including timing and kinematics of the double beta-decay transition events, offering a powerful tool for background rejection.

SUPERNEMO EXPERIMENT DESIGN

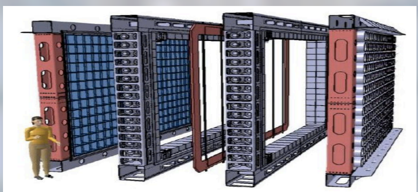

Fig. 1. Construction view of the Demonstrator module. The source foil is situated in the centre, tracking chambers and calorimeters are on both sides of the foil.

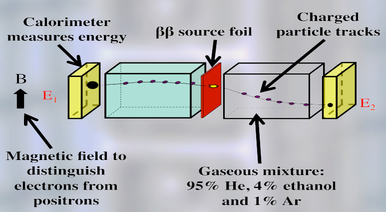

Fig. 2. Description of the SuperNEMO functions.

SuperNEMO represents a unique detector approach combining event topology, isotope flexibility, and background reduction. The system modularity allows building of several detector units which can operate even in different underground laboratories. The SuperNEMO experiment in its full scale will consist of 20 identical planar modules, each being of 4 m height, 6 m length and 2 m width (Fig. 1).

A current carrying coil wrapped around the module produces a magnetic field of 25 G to distinguish electrons and positrons (Fig. 2).

The first module, called Demonstrator, is presently assembled in the Modane underground laboratory, and should be in operation at the end of 2016.

Source foil

The ^{82}Se double beta-decay source will be used in the SuperNEMO experiment because of its higher neutrinoless double beta-decay half-life.

Other sources, such as ^{48}Ca or ^{150}Nd, have also been considered due to their high decay energies, which are well above the expected background of the experiment. The Demonstrator foil will hold 7 kg of ^{82}Se distributed on the foil with surface density of 53 mg/cm^2.

Tracker

The SuperNEMO tracker represents a drift wire chamber consisting of 2 034 cells operating in the Geiger mode. The cells are 3 m long with a nominal diameter of 4.4 cm. Gas filling of a radon-tight chamber is composed of 95 % He, 4 % ethanol and 1 % Ar. Drift cells are assembled by a wiring robot at the Manchester University.

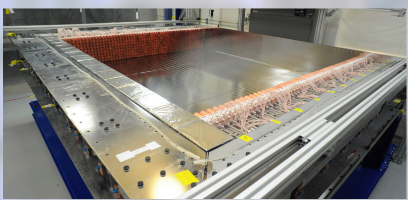

Fig. 3. Fully populated tracker section of the SuperNEMO detector.

Tracker is made of 4 sections and the assembly is taking place in a large clean tent in the Mullard Space Science Laboratory (MSSL) of the University College London (UCL). Two quarters of the tracker are complete. Presently, the first one (Fig. 3) has been shipped to Modane and the second one is undergoing commissioning with cosmic muons. Remaining two quarters should be delivered to Modane in summer 2016.

Calorimeter

A calorimeter energy resolution of 4.5% FWHM for 3 MeV electrons is required to reach sensitivity of the order of 10^{26} years. Large volume plastic scintillator blocks (10 L) were used without compromising other requirements such as the time resolution, radiopurity, reliability and cost effectiveness of the calorimeter. The improvements in the energy resolution have been due to the increase in quantum efficiency of the bi-alkali 8'' PMT photocathodes, optimization of the geometry, and direct coupling of PMTs with scintillator.

Fig. 4. Scintillator blocks (256 mm x 256 mm^2) made from Envinet polystyrene plastic scintillator are *directly coupled to 8'' photomultiplier tubes (R5912-MOD Hamamatsu).*

BACKGROUND CONSTRAINS

Radon (^{222}Rn) and its decay products (^{214}Bi and ^{214}Po), as well as decay product of ^{220}Rn (^{208}Tl) have been identified as the most dangerous contaminants for the SuperNEMO detector. The ^{222}Rn and ^{220}Rn can infiltrate in all parts of the detector, and their decay products due to high energy of emitted beta-electrons and gamma-rays may imitate double beta-decays. The most sensitive parts from the point of view of radioactive contamination are: (i) the isotope source (^{82}Se), (ii) the supporting foil for the source, (iii) and the tracker.

The radiopurity limits are listed in Table 1. The stringent limits were set for ^{222}Rn present in the tracker (<0.15 mBq/m^3), and ^{208}Tl (<2 nBq/g) and ^{214}Bi (<10 nBq/g) in the source, in the foil, wires and walls of the tracker).

Table 1. Comparison of the main NEMO-3 and SuperNEMO parameters.

	NEMO-3	SuperNEMO
Mass (kg)	7	100
Energy resolution @ 3 MeV (%)	8	4
^{222}Rn in tracker (mBq/m^3)	~5	<0.15
^{214}Bi (nBq/g)	60-300	<10
^{208}Tl (nBq/g)	~100	<2
Tracking cells	6180	20x2034
Calorimeter blocks	1940	20x712
Total background (counts/ keV/kg/yr)	$1.3 \cdot 10^{-3}$	$5 \cdot 10^{-5}$
$T_{1/2}^{0\nu\beta\beta}$ @ 90% C.L. (yr)	$>1.1 \cdot 10^{24}$	$>1 \cdot 10^{26}$
$\lvert m_{\beta\beta} \rvert$ (eV)	<0.33-0.87	<0.04-0.10

The selenium powder (^{82}Se source) after enrichment will be chemically purified using extra pure materials at super clean conditions. All the materials entering the source production will be carefully selected and prepared to have ultra-low contamination levels.

The tracker amelioration mainly relies on the reduction of the radon presence inside the tracker volume. After the installation of the tracker modules, the remaining radon concentration activity will be assured to be at the level of 0.15 mBq/m^3, measured by a dedicated radon line.

The counting gases (mostly helium) for the tracking chambers will be continuously purified and analyzed by a radon monitor. Radon adsorption materials have also been tested to improve the purification systems, as well as to build at the LSM a radon-free air factory that will flush the air around the SuperNEMO detectors.

RADIOPURITY MESUREMENTS

The collaboration developed a dedicated BiPo-3 detector (Fig. 5) to measure ultra-low radionuclide levels of isotope sources and materials used in the construction of SuperNEMO parts. To gain in sensitivity, the principle is to detect the delayed beta-alpha coincidences of the ^{214}Bi - ^{214}Po cascades. The high energy gamma-emitter ^{208}Tl is qualified through its parent product, the ^{212}Bi decay.

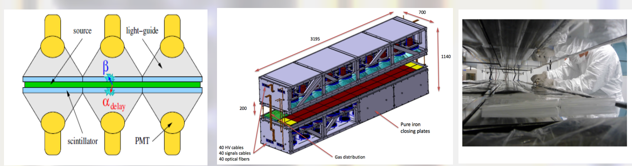

Fig. 5. The BiPo-3 detector for measurement of ultra low-level alpha and beta activities.

The collaboration developed several detectors and techniques to prevent external radon to penetrate inside the detector or to be emanated from inside. Besides the selection of the detector materials for their radiopurity, the most critical materials have been tested in radon emanation chambers coupled to very sensitive radon detectors (Fig. 6).

Fig. 6. Radon emanation chambers in CENBG Bordeaux, UCL London and CU Bratislava.

Table 2. Certified radionuclides in the reference material (glass pellets).

Radionuclide	Mean	Median	Confidence interval
	(Bq/kg)	(Bq/kg)	(Bq/kg)
^{40}K	8.8	9.2	7.8 – 10.6
^{226}Ra	4.5	4.2	4.1 -5.1
^{228}Ra	2.4	2.4	2.1 – 2.6
^{228}Th	2.4	2.4	2.1 – 2.5
^{232}Th	2.4	2.4	2.1-2.5
^{235}U	0.21	0.21	0.19 – 0.25
^{238}U	4.10	4.0	3.4 – 4.8

Table 3. Expected detection limits (Bq).

Method	^{238}U	^{232}Th	^{235}U (^{231}Pa)
Radiometrics	10^{-6}	10^{-6}	10^{-6}
ICPMS	5×10^{-7}	10^{-6}	10^{-6}
AMS	10^{-10}	10^{-10}	10^{-10}
NAA	10^{-10}	5×10^{-10}	10^{-7}

Source, foil materials, source frame, tracker wires and other construction materials are screened using HPGe detectors with a sensitivity of 0.1-10 mB/kg for ^{238}U and ^{232}Th decay chains, and for ^{40}K in underground (LSM in Modane and Boulby in Cleveland) and surface (Bordeaux and Bratislava) gamma-spectrometry facilities.

A reference material has been developed for quality management of laboratories engaged in the high-sensitive analysis of radionuclides in the construction materials of detectors placed in ultra low background underground laboratories (Table 2). .

The HPGe gamma-spectrometry in many cases is not sensitive enough to measure such ultra low ^{208}Tl and ^{214}Bi levels. Therefore new technologies for analysis of their parent radionuclides (^{232}Th and ^{238}U, respectively) are under development (Table 3), comprising accelerator mass spectrometry (AMS) and neutron activation analysis (NAA).

ACKNOWLEDGEMENTS

We acknowledge support by the funding agencies of the CNRS/IN2P3 in France, Ministry of Education of the Czech Republic, RFBR in Russia, VEGA in Slovakia, STFC in UK and NSF in USA.