Background constrains of the SuperNEMO experiment for neutrinoless double beta-decay searches

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ABSTRACT

The SuperNEMO experiment is a new generation of experiments dedicated to the search for neutrinoless double beta-decay, which if observed, would confirm the existence of physics beyond the Standard Model. 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. While the basic detection strategy of the SuperNEMO detector remains the same as of the NEMO-3 detector, a number of improvements were accomplished for each of detector main components. Upgrades of the detector technologies and development of low-level counting techniques ensure radiopurity control of construction parts of the SuperNEMO detector. A reference material made of glass pellets has been developed to assure quality management and quality control of radiopurity measurements. The first module of the SuperNEMO detector (Demonstrator) is currently under construction in the Modane underground laboratory. No background event is expected in the neutrinoless double beta-decay region in 2.5 years of its operation using 7 kg of ^{82}Se . The half-life sensitivity of the Demonstrator is expected to be $> 6.5 \cdot 10^{24}$ y, corresponding to an effective Majorana neutrino mass sensitivity of $|0.2 - 0.4|$ eV (90 % C.L.). The full SuperNEMO experiment comprising of 20 modules with 100 kg of ^{82}Se source should reach an effective Majorana neutrino mass sensitivity of $|0.04 - 0.1|$ eV, and a half-life limit $1 \cdot 10^{26}$ y.

Keywords: SuperNEMO, Double beta-decay, Radiopurity of materials, Reference material, Laboratoire Souterrain du Modane

1. Introduction

Background is playing an essential role in underground experiments investigating rare nuclear processes and decays such as double beta-decay experiments, searches for dark matter, neutrino experiments, etc. (e.g., [1-6]). We shall focus in this paper on neutrinoless double beta-decay experiments. The two neutrino double beta-decay process has been observed for several isotopes (e.g. ^{48}Ca , ^{96}Zr , ^{100}Mo , etc.). It is a second order process, allowed by the Standard Model, and half-lives of the order of 10^{20} y have been observed (e.g., [1-3, 7, 8]). On the other hand the existence of the neutrinoless double beta-decay process would violate the lepton number conservation, requiring a Majorana neutrino (identical neutrino with antineutrino), and giving unique information on the neutrino mass hierarchy, which represents new physics behind the Standard Model. Although more than ten experiments have been going on in several underground laboratories no positive result has been obtained till now, only upper half-life limits of the order of 10^{24} y have been reported, (e.g., [9, 10]).

Underground installations require detectors made of radioactivity free materials with minimum contamination by natural radionuclides. The accurate and precise determination of radionuclide concentrations in construction materials of large underground detector assemblies is essential for reaching background levels prescribed for investigation of rare nuclear processes. Except of U and Th (and their decay products), which can be found in almost all construction materials, other possible

radionuclide contaminants could include ^{40}K , which is frequently found in construction materials made of glass, e.g. in photomultipliers. Anthropogenic radionuclides, e.g. ^{137}Cs of the Chernobyl and atmospheric atomic bomb tests origin, could be found in some materials exposed to the air, similarly as ^{60}Co which is often found in steel samples. Radon isotopes (^{222}Rn and ^{220}Rn), represent a specific case of radionuclide contamination, which is usually the most dangerous for the operation of underground detectors because radon can diffuse through different parts of the detector structure. Therefore it is important to know radon emanation characteristics of construction materials, as well as diffusion patterns of radon inside underground detection systems. Radiopurity of construction materials is thus a must if planned detection limits should be achievable. The acceptable contamination levels differ between various experiments. In some cases they should reach levels down to 1 nBq/g of material [1] when “zero” background detection systems have to be used for investigation of rare nuclear processes and decays.

The aim of the present paper has been to discuss background constraints of the SuperNEMO experiment, as well as radiopurity measurements of the construction materials and development of a reference material for quality management and quality control. The SuperNEMO experiment will search for zero neutrino double beta-decay, and its first part (called Demonstrator) is presently under construction in the Modane underground laboratory (LSM - Laboratoire Souterrain du Modane, France) [7].

2. Design of the SuperNEMO experiment

The SuperNEMO experiment [1, 8-10] is further developing an underground physics technology used by its predecessor, the NEMO-3 experiment [7]. This detector technology is combining tracking and calorimetry techniques for 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. The SuperNEMO experiment in its full scale will consist of 20 identical planar modules, each being of 4 m high, 6 m long and 2 m wide. Each module will consist of the source foil situated in the centre of the module, tracking chambers at each side and finally followed by calorimeters at each side for energy and time of flight measurements, as shown in Figs. 1 and 2.

A current carrying coil wrapped around the module produces a magnetic field of 25 G to distinguish electrons and positrons. Water shielding against neutrons, and iron shielding against gamma rays surround the detector to decrease the related backgrounds. The first module, called Demonstrator, is presently assembled in the LSM. It is expected that it will be operational at the first half of 2017.

2.1. Source foil

The ^{82}Se double beta-decay source will be used in the SuperNEMO experiment because of its expected higher neutrinoless double beta-decay half-life compared to the e.g. ^{100}Mo , which has also been under consideration. 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 . The selenium powder (^{82}Se enriched source) after enrichment has been chemically purified using extra pure materials at super clean conditions. All the materials entering the source production have been carefully selected and prepared to have ultra-low radionuclide contamination levels.

2.2. Trackers

The SuperNEMO tracker represents a drift wire chamber consisting of 2 034 cells operating in the Geiger mode surrounded by optical modules for a cosmic veto and an x-wall. 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 semi automated wiring robot. Tracker itself is made of 4 sections and the assembly is taking place in a clean tent.

2.3. Calorimeters

The main requirements of the SuperNEMO calorimeter are to provide a good energy and time resolution for low energy (1 MeV) electron detection, as well as an efficient γ -ray tagging ($> 50\%$ at 1 MeV) for background suppression. The calorimeter is optimized to detect incoming electrons simultaneously originating from the same vertex in the ^{82}Se source foil. The chosen optical module is a scintillator block ($256 \text{ mm} \times 256 \text{ mm}^2$), directly coupled to an 8" photomultiplier tube (PMT, R5912-MOD Hamamatsu). The calorimeter will consist at each side of 520 optical modules for energy and time of flight measurements. The largest improvements in the energy resolution when compared with the NEMO-3 design have been due to the increase in quantum efficiency of the bi-alkali photocathodes of the 8" PMTs, due to optimization of the geometry of the hemispherical cutout in the scintillator block, and its direct coupling to the 8" PMT without the use of a light guide. The better light-yield and transparency of scintillators, an optimized wrapping and surface finishing of plastic scintillators, and improved high-voltage divider and digitization systems (optimization of the voltage divider, gain and linearity) helped to improve the parameters of the calorimeters.

3. Background constrains

The background constrains of the SuperNEMO detector are determined by external and internal radiation sources. The external ones are mainly due to cosmic rays (muons, neutrons and gamma-rays), neutrons from the underground laboratory walls, gamma-rays from the construction parts of the detector, and radon contamination of the laboratory air, which can also infiltrate inside the detector. The background from internal sources will be mostly composed of: (i) Double beta-decay events, which may imitate neutrinoless beta-decay events; (ii) Radioactive contamination from the internal construction parts, mainly in the tracker; (iii) Radon inside the tracker.

While the first constrain can only diminish by high quality spatial, timing and energy resolution capabilities of the SuperNEMO detection system, the last two constrains require to use as clean as

possible radioactivity free construction materials. The internal contamination is dangerous especially from beta-emitters with energy of beta-electrons above the double beta-decay energy of about 3 MeV, i.e. 3.3 MeV and 4.9 MeV in the ^{214}Bi of the ^{238}U , and ^{208}Tl of the ^{232}Th chains, respectively. The most sensitive parts of the SuperNEMO detector from the point of view of radioactive contamination are: (i) isotope source (^{82}Se); (ii) supporting foil for the isotope source, and (iii) tracker (mainly the components which are inside the tracker, i.e. anode wires, cathodes, front/end insulators).

Radon (^{222}Rn) and thoron (^{220}Rn) inside the tracker will decay to ^{214}Bi and ^{208}Tl , respectively, and their decay products will deposit on source/foil surfaces and on anode wires, imitating thus double beta-decays. The tracker amelioration mainly relies on the reduction of the radon presence inside the tracker volume. To achieve this reduction it is necessary an exhaustive control of the radon-tightness and radon-emanation of the different materials conforming the tracker. After the installation of the tracker modules, the remaining radon concentration activity inside the tracker should be below 0.15 mBq/m³ (measured by a dedicated radon monitor). The counting gas (95 % He, 4 % ethanol and 1 % Ar) for the tracking chambers will be continuously purified to extract radon. 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 detector.

Although ^{40}K also emits high-energy gamma-rays (1.46 MeV), and it is frequently present mainly in glass of photomultipliers, however, it is usually outside of the sensitive volume of the tracker, and therefore radiopurity limits for ^{40}K are not so strict (<100 mBq/kg) as in the case of radon and its progenies.

Figure 3 illustrates typical background contributions observed with NEMO-3 detector as determined during the search for neutrinoless double beta-decay in ^{100}Mo [10]. It can be seen that the main contribution to the background has been from internal and external background sources of ^{214}Bi and ^{208}Tl . With an exposure of 6.914 kg of ^{100}Mo using the entire NEMO-3 data set with a detector live time of 4.96 yr (which corresponds to an exposure of 34.3 kg · yr), no evidence for the neutrinoless double beta-decay of ^{100}Mo has been found. Taking into account statistical and systematic uncertainties, the half-life limit for the light Majorana neutrino mass mechanism is $T_{2\beta}^{0\nu} > 1.1 \cdot 10^{24}$ y (90 % C.L.) which corresponds to a limit on the effective Majorana neutrino mass $[0.33 - 0.62]$ eV. The absence of events in the high-energy part of the spectrum is an encouraging result for future experiments based on the tracking and calorimetric technique. It is necessary to stress, however, that during the NEMO-3 experiments antiRadon facility has been in operation cleaning the counting gas inside the tracker down to 5 Bq/m³ [7].

Following the experience from the NEMO-3 experiment [7], the radiopurity limits defined for the SuperNEMO experiment are based on the goal to reach for the neutrinoless double beta-decay the half-life of $1 \cdot 10^{26}$ y (Table 1). The stringent limits were set for ^{222}Rn present in the tracker (<0.15 mBq/m³). The limits set for the radioactive contamination of the internal parts of the detector (the isotope source, supporting foil, wires and walls of the tracker) were for ^{208}Tl below 2 nBq/g and for ^{214}Bi below 10 nBq/g. When compared with the NEMO-3 detector, the radiopurity limits for the SuperNEMO are lower by about a factor of 30, 50 and 30 for ^{222}Rn , ^{208}Tl and ^{214}Bi contamination, respectively. The selenium powder (^{82}Se source) after enrichment has been chemically purified from radium using extra

pure materials at super clean conditions. All the materials entering the source production have been carefully selected and prepared to have low contamination levels.

4. Radiopurity measurements

4.1. Low-level gamma-spectrometry

Low-level HPGe gamma-spectrometry facilities were developed underground in LSM (Modane, France) and in Boulby (Cleveland, UK), and surface ones in Bordeaux and Bratislava laboratories (Table 2). All source and constructing materials (^{82}Se source, supporting foil materials, source frame, tracker wires and other construction materials) have been 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 (Table 3). It can be seen that the sensitivity of gamma-spectrometers (even those operating underground) sometimes are not good enough to get final results, and therefore only detection limits could be reported. This is mainly due to the fact that the same radionuclides (^{238}U and ^{232}Th decay products, ^{40}K), which should be analyzed in the SuperNEMO detector parts, are also present in construction materials of gamma-spectrometers. Although Ge crystals are free of such contamination, surrounding materials (cryostat, front electronics, cables, shielding materials, etc.) have always been contaminated with radionuclides.

Monte Carlo simulations [11] have shown that the cosmic-ray background of a high volume HPGe detector operating in the Modane underground laboratory (4 800 m w.e.) is by about three orders of magnitude below the measured background spectrum. Therefore materials surrounding the Ge crystal (e.g. cryostat) with lower radionuclide contamination should be selected in future installations, and the Ge crystal should be protected against radon and thoron in the air (e.g. during the exchange of samples in the measuring chamber). Recent investigations showed, however, that it should be rather difficult to decrease detection limits below 1 $\mu\text{Bq/kg}$ for HPGe detectors operating in deep underground laboratories (e.g. Gran Sasso), even if special antiradon arrangements have been made [12].

4.2. BiPo-3 detector

The SuperNEMO collaboration developed a dedicated BiPo-3 detector (a third generation of the BiPo detectors [13]) to measure ultra-low levels of alpha and beta-emitters on large surface materials (e.g. supporting foils, ^{82}Se isotope source on the foil) used in the SuperNEMO detector [7]. To gain in sensitivity, the principle is to detect the delayed beta-alpha coincidences of the ^{214}Bi - ^{214}Po cascades (^{214}Bi is the main contributor to the SuperNEMO detector background from the ^{238}U chain). The high-energy gamma-emitter ^{208}Tl (the representative of the ^{232}Th chain) is qualified through its mother product, the ^{212}Bi . The detector consists of 2 face-to-face planar calorimeters made of pure aluminized polystyrene scintillators coupled to 5" low radioactivity PMTs to detect the beta and alpha-particles, and measure the time delay to distinguish the two isotopes [13]. The total surface area of the detector is 3.6 m². The BiPo-3 detector is operating since 2013 in the Canfranc Underground Laboratory (LSC) in Spain, and it has been used for radiopurity measurements of plastic scintillators, supporting source foils

and the ^{82}Se source sample. The rate of random coincidences is $6 \cdot 10^{-4}$ counts/day/m² of surface area of scintillator for the ^{208}Tl measurement, and 0.13 counts/day/m² for the ^{214}Bi measurement. The results listed in Table 3 document that the BiPo-3 detector represents at present the most sensitive detector for measurement of surface alpha and beta-contamination of thin materials [14].

4.3. New developments in radiopurity measurements

Further requirements for radiopurity of construction materials of underground detectors for rare nuclear and particle physics are so constraining that the high-purity germanium (HPGe) gamma-spectrometry is not sensitive enough to measure ^{208}Tl and ^{214}Bi levels below 1 nBq/g. Therefore new technologies for analysis of their parent radionuclides (^{232}Th and ^{238}U , respectively) are under development, comprising of an accelerator mass spectrometry (AMS) for single atom counting, which hopefully will push the detection limits below the present levels. A Centre for Nuclear and Accelerator Technologies (CENTA) has recently been established at the Comenius University in Bratislava, comprising of ion sources for gas and solid targets, a low-energy analyzing and injection system, a Pelletron accelerator with 3 MV nominal voltage, and a high-energy analyzing system [15]. One of the goals of the CENTA laboratory is the development of the AMS technique for radiopurity measurements at levels below 1 nBq/g, and searching for radioactivity free construction materials [16].

Another promising technology is based on neutron activation analysis (NAA) of long-lived primordial radionuclides (e.g. neutron irradiation in a nuclear reactor: $^{232}\text{Th} (n, \gamma) ^{233}\text{Pa}$ ($T_{1/2} = 27$ days), and $^{238}\text{U} (n, \gamma) ^{239}\text{U}$ ($T_{1/2} = 23.5$ min) $\Rightarrow ^{239}\text{Np}$ ($T_{1/2} = 2.4$ days). This technique may be especially advantageous as no pre-irradiation chemistry is required (which can cause a radioactive contamination of analyzed samples), and on the other hand, a post-irradiation chemistry is possible, which can improve detection limits. The preliminary results obtained with both the AMS and NAA techniques are encouraging further research on radioactive contamination issues below 1 nBq/g levels.

4.4. Radon emanation measurements

Besides the selection of the detector materials for their radiopurity, the most critical materials (e.g. PMTs) have been tested in radon emanation chambers coupled to alpha-detectors. The tracker amelioration mainly relies on the reduction of the radon presence inside the tracker volume. To achieve this reduction it is necessary an exhaustive control of the radon-tightness and radon-emanation of the different materials conforming the tracker. 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. Typical radon sensitivities of Bordeaux, London, Prague and Bratislava laboratories are listed in Table 2.

4.5. Reference material of glass pellets

A reference material based on glass pellets, designed for the determination of natural radionuclides, which could be used in laboratories participating in radiopurity analyses of construction materials has been developed. A trigger for this work has been requirements for quality control and interlaboratory comparisons of the laboratories responsible for radiopurity analyses of all materials used for the construction of the SuperNEMO detector. As usually several laboratories are engaged in radiopurity measurements of construction materials, harmonization of measurements and validation of results is an important pre-requisite for producing data acceptable for further development of the detector systems. Reference materials, regularly analyzed by participating laboratories may thus help to reach these goals. To address the problem of data quality, and to assist collaboration laboratories in verifying their performance, the reference materials are important benchmarks in the quality management of laboratories.

Glass pellets (lead-free glass) of (2.1 ± 0.1) mm in diameter were analyzed by 6 SuperNEMO laboratories, as well as by 7 external expert laboratories. Detail information on the intercomparison exercise and on the certification process is described elsewhere [17]. Median values and confidence intervals were calculated as estimations of true massic activities representing the best estimator of the property values. Seven natural radionuclides (^{40}K , ^{226}Ra , ^{228}Ra , ^{228}Th , ^{232}Th , ^{235}U and ^{238}U) were certified and ^{210}Pb and ^{222}Rn were classified with information values (Table 4). All results (except for ^{222}Rn where emanation chambers were coupled to alpha-detectors) were obtained by nondestructive low-level gamma-spectrometry. The data indicated that both decay series have been within statistical uncertainties in equilibrium. The measured activity ratio of $(^{238}\text{U}/^{235}\text{U}) \sim 19.0$, is close to its nominal value (21.5) observed in materials with natural isotopic abundance [18].

Radon (^{222}Rn) emanation experiments were performed by 5 SuperNEMO laboratories and one external expert laboratory [17]. Radon emanation chambers with transfer of radon by a carrier gas to a calibrated volume and then to a detector, and finally radon counting either by a solid-state detector, an ionization chamber or a scintillation detector were used in the experiments. Radon emanation from glass pellets was estimated to be (1.30 ± 0.14) nBq/kg/s. The weighted mean of saturated ^{222}Rn activity (in equilibrium with the ^{226}Ra source) in glass pellets is 0.62 ± 0.08 mBq/kg. The fraction of ^{222}Rn emanated from ^{226}Ra present in glass pellets is about 25 %.

This reference material may be used for quality management of analytical laboratories, assessing the validity of analytical methods and identifying weaknesses in methodologies. The reference material may be of special interest to laboratories engaged in the high-sensitive analysis of radionuclides in the construction materials of detectors placed in ultra low background underground laboratories. The amount available for applications in external laboratories is about 10 kg. In the case of interest to get a sample of the reference material please contact (pavel.povinec@uniba.sk).

5. Conclusions

While the basic detection strategy of the SuperNEMO detector remains the same as of the NEMO-3 detector, a number of improvements were accomplished for each of detector main components in the

R&D program. Upgrades to the detector technologies, improved radiopurity of construction materials, development of an antiradon system, and a significant increase in source mass (100 kg) will allow SuperNEMO to improve half-life sensitivities for the neutrinoless double beta-decay by two orders of magnitude.

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 (up to 3.3 MeV and 4.9 MeV for ^{214}Bi and ^{208}Tl , respectively) and gamma-rays (up to 2.2 and 2.6 MeV for ^{214}Bi and ^{208}Tl , respectively) may imitate double beta-decays. The remaining radon activity concentration in the tracker should be below 0.15 mBq/m^3 , which will be reached by a continuous radon cleaning and monitoring of the counting gas (95 % He, 4 % ethanol and 1 % Ar).

The limits set for the radioactive contamination of the internal parts of the detector (the isotope source, supporting foil, wires and walls of the tracker) were for ^{208}Tl below 2 nBq/g and for ^{214}Bi below 10 nBq/g. When compared with the NEMO-3 detector, the radio-contamination limits for the SuperNEMO are lower by about a factor of 30, 50 and 30 for ^{222}Rn , ^{208}Tl and ^{214}Bi contamination, respectively.

Several low-level counting facilities (including BiPo-3 detector for surface alpha and beta-activity measurements, radon emanation detectors and HPGe gamma-spectrometers) have been developed to ensure radiopurity control of construction parts of the SuperNEMO detector. A reference material made of glass pellets has been developed to assure quality management and quality control of radiopurity measurements carried out by the SuperNEMO laboratories. Further developments are in progress, including accelerator mass spectrometry and neutron activation analysis, for determination of ultra low-levels of ^{238}U and ^{232}Th in construction materials. The SuperNEMO experiment is the new generation of tracking-calorimetry neutrinoless double beta-decay experiments. The double beta-decay events can be fully reconstructed and the backgrounds strongly reduced by the two electrons topology events selection. These backgrounds can also be accurately measured through other dedicated analysis channels. The first module of the SuperNEMO detector (Demonstrator) is currently under construction in the Modane underground laboratory and should be operational at the first half of 2017. No background event is expected in the neutrinoless double beta-decay region in 2.5 years of its operation using 7 kg of ^{82}Se . The half-life sensitivity of the Demonstrator is expected to be $T_{\beta\beta}^{0\nu} > 6.5 \cdot 10^{24} \text{ y}$, corresponding to an effective neutrino mass sensitivity of $|0.2 - 0.4 \text{ eV}|$ (90 % C.L.). The full SuperNEMO experiment comprising of 20 modules with 100 kg of ^{82}Se source should reach a neutrino mass sensitivity of $|0.04 - 0.1 \text{ eV}|$ (90 % C.L.), and a half-life limit of $(1 \cdot 10^{26} \text{ y})$.

Acknowledgements

We acknowledge support by the funding agencies of the CNRS/IN2P3 in France, Ministry of Education of the Czech Republic, RFBR in Russia, APVV (15-0576) in Slovakia, STFC in UK and NSF in USA.

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

Mass of the target/source (kg)	NEMO-3 7	SuperNEMO 100
Energy resolution @ 3 MeV (%)	8	4
^{222}Rn in tracker (mBq/m ³)	5	<0.15
Radiopurity limits		
^{214}Bi (nBq/g)	60-300	<10
^{208}Tl (nBq/g)	100	<2
Tracking cells	6180	20 · 2034
Calorimeter blocks	1940	20 · 712
Total background (counts/keV/kg/y)	$1.3 \cdot 10^{-3}$	$5 \cdot 10^{-5}$
$T_{1/2}^{0\nu\beta\beta}$ @ 90% C.L. (y)	$>1.1 \cdot 10^{24}$	$>1 \cdot 10^{26}$
$ m_{\beta\beta} $ (eV)	0.33-0.87	<0.04-0.10

Table 2
SuperNEMO gamma-spectrometry and radon facilities.

Laboratory	HPGe detectors	Ge detector mass (kg)	Background in (0.1-2.3) MeV (cpm)	Detection limit ^{214}Bi ^{208}Tl (mBq/kg)	Detection limit ^{222}Rn (nBq/kg/s)
LSM (Modane) @ 4800 m w.e.*	3 coaxial 1 planar	3.19	0.125±0.002	0.2 0.16	
Boulby (Cleveland/UCL London) @ 2100 m w.e.	2 coaxial 1 BEGe	0.8	1.96±0.01	2 1.5	
Radon facility					1.5
PRISNA (Bordeaux) @ 1 m w.e.	2 coaxial 2 well	0.53	2.80±0.01	13 6	
Radon facility					1.5
UNIBA (Bratislava) @ 5 m w.e. with antic cosmic veto	2 coaxial 1 planar	1.44	2.2±0.1	9 4	
Radon facility TechUniv (Prague)					2.5
Radon facility					1.5

*water equivalent

Table 3
Radiopurity results for some of the SuperNEMO construction materials (BiPo-3 and gamma-spectrometry measurements).

Material	^{214}Bi	^{208}Tl	^{40}K
Plastic scintillator – surface (BiPo-3 measurement) (μBq/m ²)	1.0 ± 0.3	1.0 ± 0.2	
PVA foil with ^{82}Se source (BiPo measurement) (μBq/kg)	25±18	20±15	
Plastic scintillator (mBq/kg)	< 0.3	< 0.1	2.2 ± 1.0
PMT glass (mBq/kg)	65±7	4.0±0.5	150±11
Tracker wires (mBq/kg)	0.85±0.18	0.41±0.09	5.6±2.7
HV cables (mBq/kg)	1.1±0.3	<0.80	23±4
Signal cables (mBq/kg)	< 1	< 1	25±4
Tracker screws (mBq/kg)	3.09 ± 0.37	0.86 ± 0.38	13.04±3.6 3

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Table 4
Certified and recommended values for radionuclides in the reference material of glass pellets (the reference date: 1 August 2010).

Radionuclide	Mean	Median	Confidence interval
	(Bq/kg)	(Bq/kg)	($\alpha = 0.05$) (Bq/kg)
Certified values			
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
Recommended Values			
²¹⁰ Pb	3.8	3.9	2.4 – 5.2
²²² Rn	0.62	0.62	0.46 – 0.78

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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.

Fig. 3. Typical background observations during the NEMO-3 experiments – search for neutrinoless double beta-decay in ^{100}Mo .