

Low background techniques for SuperNEMO

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Abstract. The UK contribution to achieving the ultra-low background conditions required inside the detectors of the SuperNEMO experiment are described. A dedicated facility has been established for the screening and selection of materials through gamma ray spectroscopy using germanium detectors. Initial results from two detectors are shown. The radon level inside the SuperNEMO detector must be less than $150 \mu\text{Bq}/\text{m}^3$ in order to achieve the target sensitivity. A Radon Concentration Line (RnCL) has been developed capable of measuring radon levels in large gas volumes down to $5 \mu\text{Bq}/\text{m}^3$, improving on standard state-of-the-art radon detectors by 3 orders of magnitude. The development, commissioning and first measurements of radon content using the RnCL are also presented.

1. Introduction

SuperNEMO [1] is a next generation neutrinoless double beta decay experiment based on the successful NEMO-3 tracker-calorimeter design [2]. The main experimental objective is to achieve a half-life sensitivity of 10^{26} years corresponding to an effective Majorana neutrino mass of $\langle m_{\beta\beta} \rangle < 50 - 100 \text{ meV}$.

One of the main challenges in achieving the desired sensitivity is background from natural radioactivity most importantly coming from ^{238}U and ^{232}Th decay chains. The most critical of these backgrounds comes from the decay daughters of radon, ^{222}Rn and ^{220}Rn , ^{214}Bi ($Q_{\beta} = 3.27 \text{ MeV}$) and ^{208}Tl ($Q_{\beta} = 4.99 \text{ MeV}$) respectively, which have enough energy to mimic a double- β event.

An additional problem comes from the fact that radon can enter the detector either through diffusion, contamination during detector construction or emanation from the detector materials themselves. The main problem comes from the isotope of ^{222}Rn due to its relatively long half-life of 3.8 days. As a result, all construction materials are screened to ensure radiopurity, and materials in direct contact with the tracker gas are measured for ^{222}Rn emanation.

The first SuperNEMO detector module, the Demonstrator, is under construction. The most stringent radiopurity requirements, $A(^{214}\text{Bi}) < 10 \mu\text{Bq}/\text{kg}$, $A(^{208}\text{Tl}) < 2 \mu\text{Bq}/\text{kg}$, apply for the source foil of the $\beta\beta$ isotope of choice, ^{82}Se . This sensitivity is reached with a dedicated detector described in [3]. For the other detector materials the radiopurity requirements are at a level of $0.1 - 10 \text{ mBq}/\text{kg}$ depending on its position inside the detector. These materials are selected using low background Germanium detector gamma-spectroscopy. In addition, radon emanation from detector sub-modules and ^{222}Rn concentration in the tracking detector gas are measured at a level of $< 0.15 \text{ mBq}/\text{m}^3$, the level required to achieve the SuperNEMO design sensitivity.



Here we report on the last two types of radiopurity measurements (Germanium spectroscopy and radon emanation).

2. Boulby Underground laboratory

Boulby is a working potash and rock salt mine, located in the North East of England, the deepest in the UK, at 1070 metres (2805 m w.e.) [4]. The lab is built inside the mined tunnel surrounded by salt which is very low in natural radioactive backgrounds.

2.1. Germanium detectors

So far two detectors have been commissioned for material screening at Boulby. One is an Ortec coaxial low-background high purity germanium (HPGe) detector and the other is a Canberra broad energy germanium (BEGe) detector with sensitive masses of 1.9 kg and 0.5 kg respectively. The detectors are surrounded by passive shielding made of lead and OFHC copper. An anti-radon purging system was constructed for the Ortec HPGe detector which allowed a factor of 4 reduction from radon related backgrounds. The background spectra of the detectors are shown in Fig. 1.

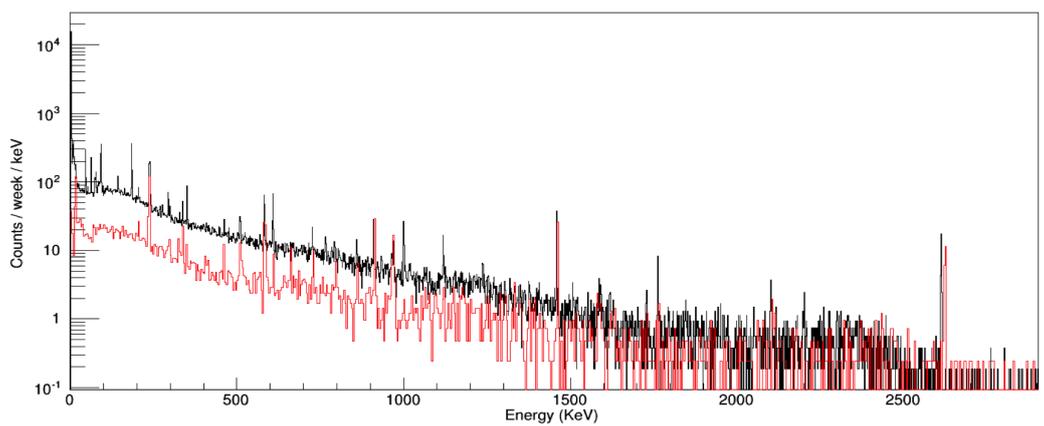


Figure 1. Background spectra of Ortec HPGe (red) and Canberra BEGe (black).

The integral counting rate of the HPGe and BEGe detectors in the 100 - 2700 keV energy region are 0.768 ± 0.001 and 2.381 ± 0.001 respectively. In the case of the BEGe detector the shielding was non-optimised and is currently undergoing a major refurbishment. Nonetheless, both detectors were able to achieve a sensitivity to ^{238}U and ^{232}Th progenies at a level of 1-3 mBq/kg after 3 weeks of measurement, depending on the geometry and composition of the measured sample.

2.2. Detector upgrades

Both the coaxial and the BEGe detector will undergo upgrades to further improve performance. These include conversion of the Ge-crystal cooling system to a J-type configuration to minimise a direct line of sight gamma-ray background and having customised shielding tailored to further suppress backgrounds. In addition, the coaxial detector will have a larger LN_2 dewar and the magnesium endcap will be replaced by one of carbon fibre to improve radiopurity and increase detection efficiency at lower energies. Both detectors will have an upgraded anti-Rn purging system.

3. Low-Level Radon Detector

An electrostatic detector similar to the one described in [5] was used for radon detection. It collects radon progenies on a silicon PIN diode using an electric field. These are then identified by the energy they deposit when undergoing an α -decay. Isotopes of ^{218}Po and ^{214}Po can clearly be seen in an energy spectrum from the detector as shown in Fig. 2.

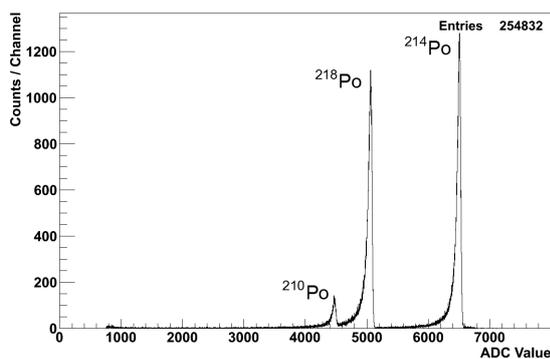


Figure 2. Energy spectrum from a radon source.

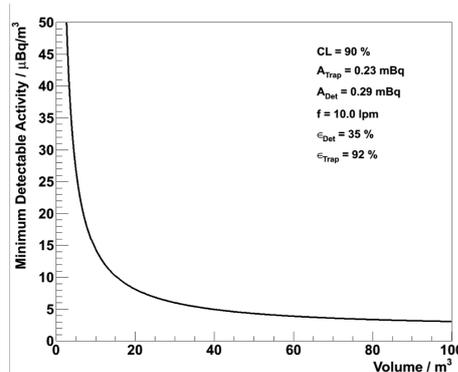


Figure 3. Sensitivity estimates of the RnCL with helium.

The detection efficiency depends on the isotope and the carrier gas. The highest efficiency of 35% was achieved with ^{214}Po in helium. With a background of 7 ± 1 counts per day the detector's sensitivity to radon levels is 1.7 mBq/m^3 (90% CL).

3.1. Radon Concentration Line

Electrostatic detectors are typically sensitive to 1 mBq/m^3 which is higher than the SuperNEMO target radon concentration of 0.15 mBq/m^3 . In order to measure detector sub-modules to this level during construction a Radon Concentration Line (RnCL) has been developed.

The concept behind the RnCL is to “concentrate” Rn by pumping a large volume of gas through a cold ultra-pure activated-carbon trap where Rn is adsorbed. The trap is then heated and this concentrated radon is transferred into an electrostatic detector via helium purge.

3.2. Sensitivity and First Measurements

The trapping and transfer efficiency of the radon concentration line has been calibrated using a dedicated ^{222}Rn source and found to be as high as 92% with helium as a carrier gas. This translates into sensitivity levels for radon concentration down to $O(10) \mu\text{Bq/m}^3$ for large gas volumes as shown in Fig 3. The first measurements of commercially available helium and nitrogen gases have now been made and are shown in table 1.

Table 1. Result from measurement of radon present in helium and nitrogen gas.

Gas	Source	Radon Level ($\mu\text{Bq/m}^3$)
He	Cylinder	70-100
N ₂	Cylinder	400-1000
N ₂	Boil-off	90-140

One interesting observation was that the nitrogen gas in cylinders seems to have a systematically higher content of ^{222}Rn compared to helium although improvement is seen with gas from boil-off from liquid N_2 . Based on these results a dedicated facility has been built to clean the SuperNEMO working gas before it enters the tracking detector.

4. Conclusions

A low background screening facility has been established at the Boulby Underground Laboratory. Two Ge-detectors have been commissioned to carry out material screening campaigns for SuperNEMO and other low background experiments with a sensitivity of 1 mBq/kg and better. In addition, an ultra-sensitive ^{222}Rn detection facility has been commissioned with a sensitivity down to $5 \mu\text{Bq}/\text{m}^3$ when large volumes of gas are sampled. The facility will be also used to measure ^{222}Rn emanation from SuperNEMO detector sub-modules during construction with a sensitivity below $0.15 \text{ mBq}/\text{m}^3$.

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