Radon Mitigation Strategy and Results for the SuperNEMO Experiment

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Abstract. SuperNEMO is a modern neutrinoless double beta decay ($0\nu\beta\beta$) experiment with a design capability to reach half-life sensitivity of $T_{1/2}(0\nu) > 10^{26}$ years, equivalent to an effective Majorana neutrino mass of $\langle m_{\beta\beta} \rangle < 50 - 100$ meV [1]. To achieve this sensitivity, SuperNEMO aims to become a zero background $0\nu\beta\beta$ experiment in the first Demonstrator phase. This target placed challenging demands on the radiopurity of detector components and the radon activity within the tracker.

To minimise radon levels all internal detector components were screened for radon emanation, which was then confirmed through direct measurement of the gaseous tracker. First measurements of tracker indicated that target radon levels of $<0.15$ mBq/m$^3$ can be achieved.

1. Introduction
The SuperNEMO design is based on the highly successful NEMO-3 detector with improvements to achieve zero background events. The detector, which will be located at LSM, will have improved energy resolution, radiopurity and increased isotope mass. Dedicated screening facilities have been established for the measurement of radiopurity of construction materials in particular radon as it can be emanated from materials as well as enter the detector by diffusion.

2. The Radon Challenge
Radon is a colourless, odourless noble gas which occurs as an indirect decay product of uranium (U) and thorium (Th). Due to its chemical properties radon has a long diffusion length in solids making it difficult to seal against, as well as being difficult to remove chemically, making it a major background to all rare event search experiments. Simulations show that to achieve the designed sensitivity the level of radon must not exceed 0.15 mBq/m$^3$ since its decay daughter $^{214}$Bi, $Q_\beta = 3.270$ MeV can mimic a $0\nu\beta\beta$ event.

3. The Solution
Facilities with a range of complimentary measurement techniques were established in order to meet the challenging radon target. The readily diffusive nature of radon has serious consequences to the design of SuperNEMO detector modules. To determine the radon diffusion length in different materials an experiment was constructed [2] containing two chambers. Each chamber contains a silicon PIN diode capable of measuring radon activity. The two chambers are separated by a modified flange containing a thin foil of the material to be studied. Various
adhesive/sealants have been tested for radon permeability in order to find a candidate for use as a gas seal.

Stainless steel chambers have been constructed to isolate materials in order to measure their radon emanation. This offers a highly sensitive direct measurement of the radon emanation rate of components in their final geometry. All efforts are validated using a custom built apparatus designed to reach the sensitivities required to measure the radon activity inside the fully assembled SuperNEMO quarter-tracker.

4. The Radon Concentration Line
An electrostatic detector was built capable of measuring down to levels of 1-2 mBq/m$^3$, based on the technology described in [3], amongst the best in the world. It has an electro-polished stainless steel central detection volume of 70 litres. The 2 gas valves to the detector were coated with styrene butadiene rubber (SBR) to prevent radon diffusion through the gas seals. However, this still cannot reach the required sensitivity for radon measurements. A new system had to be developed in order to monitor and confirm that the challenging SuperNEMO target of $<0.15$ mBq/m$^3$ has been achieved.

![Diagram](image)

Figure 1. The RnCL in operation in real life.

To do this the electrostatic detector was used in conjunction with a radon trapping system known as the Radon Concentration Line (RnCL). The RnCL system consists of a trap containing activated carbon which is cooled to -50 °C. Large volumes of gas can be flowed through the trap where the radon is adsorbed. The concentrated radon sample can then be heated, releasing the radon, in order to be transferred by a gas purge into the electrostatic detector for measurement. The design of the RnCL is similar to the MoReX line [4] developed in Heidelberg, however the design has been simplified for portability.

The RnCL is calibrated by introducing a known amount of radon into the detector where it is measured to determine the detection efficiency. After a period of measurement the gas in the detector is purged, using helium, through the carbon trap to the exhaust. The trap is then heated and the radon within is once again transferred back into the detector for measurement of the trapping and transfer efficiency, see figure 2. From this the sensitivity of the RnCL can be calculated for a set gas volume of constant activity.

5. Radon in SuperNEMO Tracker
The main purpose of the RnCL is to monitor the radon activity of the SuperNEMO tracker during construction. The tracker is constructed in quarters, called c-sections due to their
shape, each quarter containing over 500 drift cells. Each c-section is fully constructed and then sealed with gas sealing plates which replace the source foil and calorimeter wall of the final configuration. Once sealed, the c-section is then under a constant overpressure via a nitrogen purge for 18 days to allow for any residual radon inside the tracker to decay away. Each measurement uses $\sim 8$ m$^3$ of carrier gas. The results from the first three c-sections are summarised in table 1.

### Table 1. Summary of radon activity inside SuperNEMO quarter trackers.

| Tracker | Activity     |
|---------|--------------|
| C0      | 11.37 ± 1.44 mBq |
| C1      | 15.26 ± 1.44 mBq |
| C2      | 4.36 ± 1.31 mBq  |

After the activity of the first two c-sections were measured a separate measurement showed a tracker component contributed largely to the radon budget. It was immediately replaced for the third c-section and the result was significantly improved. From these results, by taking an average radon level for the final c-section, the activity of the full demonstrator can be estimated at 41.3 ± 4.7 mBq. This level is reduced because the tracker gas is constantly replaced with radon free gas. At a replacement rate of 2 m$^3$/hr the target activity of $<0.15$ mBq/m$^3$ is reached.

### 6. Conclusion

The challenging target of $<0.15$ mBq/m$^3$ inside the SuperNEMO tracker has been overcome through a comprehensive programme of radon R&D. Including, radon diffusion studies to identify radon barrier materials, radon emanation measurements and the development of a RnCL capable of measuring large gas volumes to sensitivities of $5 \mu$Bq/m$^3$. The completed trackers have demonstrated the $<0.15$ mBq/m$^3$ can be reached using a gas circulation flowrate of 2 m$^3$/hr.

### References

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[3] Choi E et al 2001 *Nucl. Instrum. Meth. A* **459** 177-81
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