SuperNEMO: A next generation double beta decay experiment

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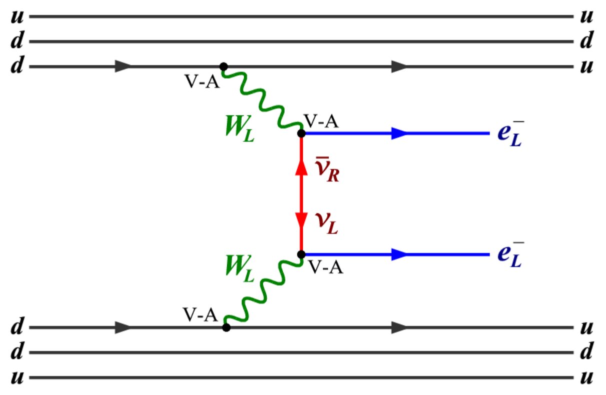
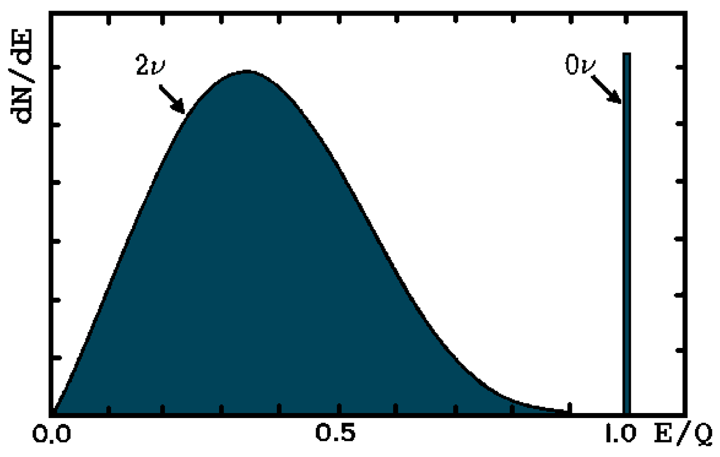
Neutrinoless Double Beta Decay



Neutrinoless double-beta decay (0νββ) is a process beyond the standard model which, if observed, implies that neutrinos are Majorana particles, that they have non-vanishing mass and violates lepton number conservation.

$$\frac{1}{T^{0\nu}_{1/2}} = G^{0\nu}(Q,Z)\left|M^{0\nu}\right|^2 \langle m_\nu \rangle^2$$

The effective Majorana neutrino mass can be extracted from the half-life of the 0νββ decay, which also depends on the nuclear matrix element and a two-body phase-space factor.

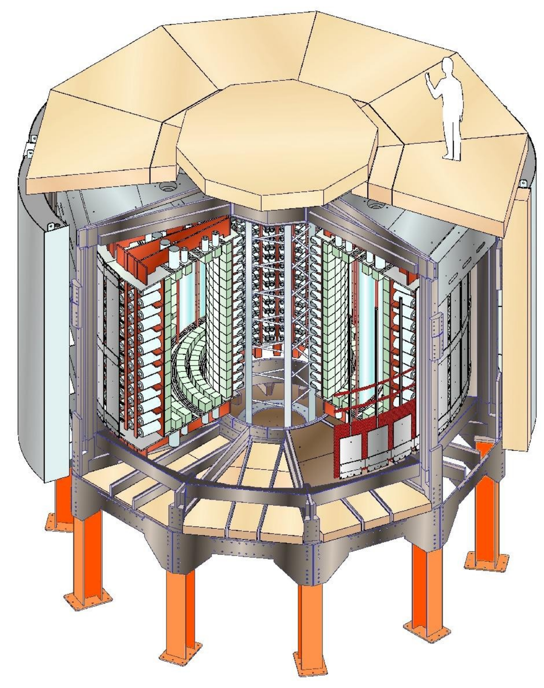


The competing two-neutrino double beta decay (2νββ) is allowed in the Standard Model. The two processes are distinguished by the distribution of the energy-sum of the two electrons: in 0νββ decay, the electron energy sum is a spike at the Q-value of the decay; by contrast, the 2νββ distribution has a continuous spectrum.

The 0νββ decay can take place through several mechanisms, notably the light Majorana neutrino exchange and the existence of right-handed currents. Identifying the specific decay mechanism has deep implications on particle physics and cosmology.

The NEMO-3 Detector

NEMO-3 is the predecessor to SuperNEMO, which stopped data taking in January 2011. It used tracking and calorimetry to study ββ decay in seven different isotopes. Located underground on the French/Italian border, it had a cylindrical design and was divided into 20 equal sectors.



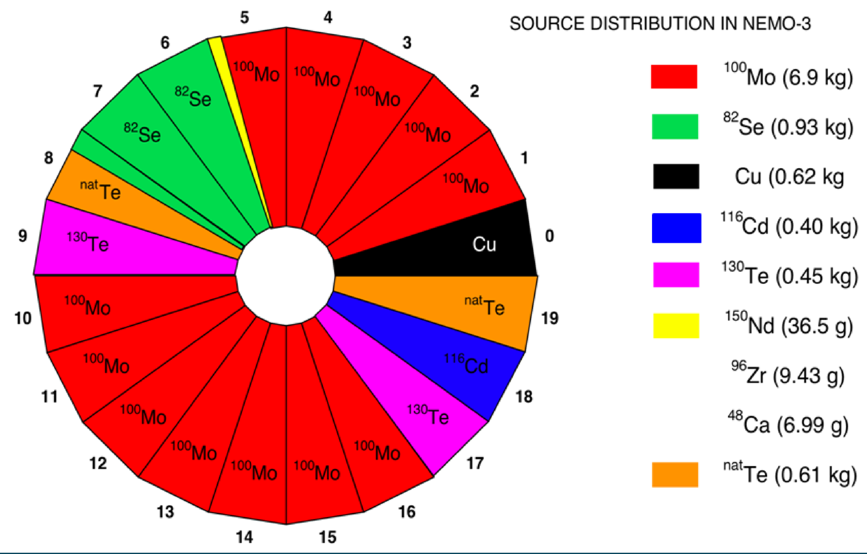
There were four main components of the detector:

- **Tracker**: 6180 vertical Geiger drift cells, filled with a mixture of helium gas, water, argon, and ethyl alcohol.
- **Calorimeter**: 1940 modules made of a block of plastic scintillator, a light guide and a low radioactivity PMT.
- **Source foils**: 10kg of ββ isotopes distributed throughout the detector.
- **Shielding**: Several types surrounded the detector, each layer had a different purpose in reducing external backgrounds.

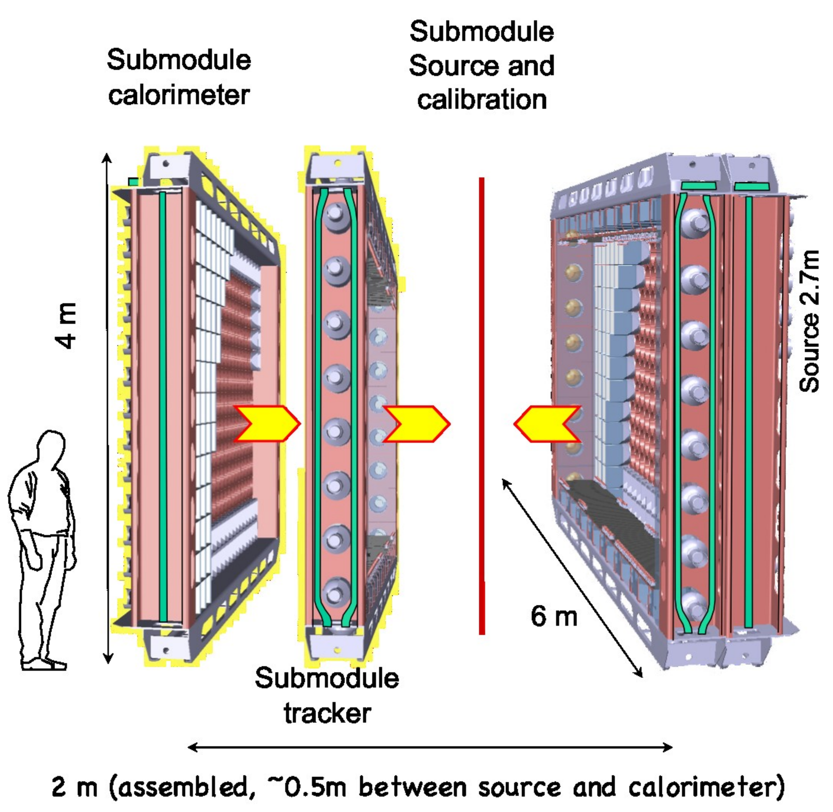
Some key half-life measurements:

^{100}Mo
$T_{1/2}(2\nu)$ = [7.16 ± 0.01(stat) ± 0.54(sys)] x10^{18} y
$T_{1/2}(0\nu)$ > 1.0 x 10^{24} y @ 90% CL

^{82}Se
$T_{1/2}(2\nu)$ = [9.6 ± 0.1(stat) ± 1.0(sys)] x10^{19} y
$T_{1/2}(0\nu)$ > 3.2 x 10^{23} y @ 90% CL



The SuperNEMO Detector



SuperNEMO consists of 20 identical modules, each containing:

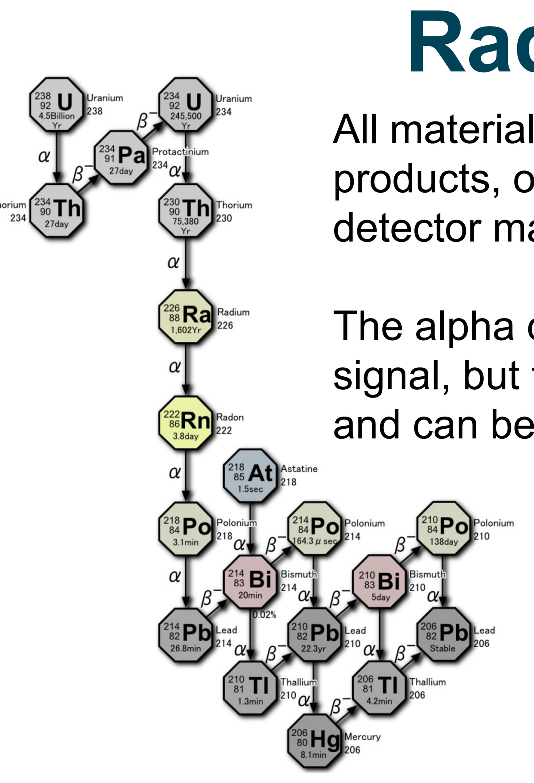
- **Source** : ~ 5 kg of ^{82}Se. High $Q_{\beta\beta}$, Long $T_{1/2}(2\nu)$, proven enrichment technology.
- **Tracker** : Drift chamber with ~ 2000 cells in Geiger mode.
- **Calorimeter** : 500 PMTs & scintillator blocks

Construction of the demonstrator module is about to begin and due to be completed in 2013. It will contain 7kg of ^{82}Se and by 2016 it will be sensitive to $T_{1/2}$ ~ 6.5 x 10^{24} y. This means it could potentially confirm the Klapdor claim to have observed 0νββ.

It will be followed by 19 similar modules, to be built from 2015 and achieving full sensitivity by 2019.

NEMO-3	→	SuperNEMO
^{100}Mo	Isotope	^{82}Se (or ^{150}Nd or ^{48}Ca)
7 kg	Mass	100+ kg
^{208}Tl: < 20 μBq/kg ^{214}Bi: < 300 μBq/kg	Background in foil	^{208}Tl: < 2 μBq/kg ^{214}Bi: < 10 μBq/kg
^{220}Rn: < 5 mBq/m^3	Background in tracker	^{220}Rn: < 0.15 mBq/m^3
18%	Efficiency	~30%
8% @ 3 MeV	Energy Resolution (FWHM)	4% @ 3 MeV
$T_{1/2}$ > 10^{24} y $\langle m_\nu \rangle$ < 0.3 - 0.9 eV	Sensitivity	$T_{1/2}$ > 10^{26} y $\langle m_\nu \rangle$ < 40 - 100 meV

Radon Detection R & D



All materials contain small traces of uranium and thorium and their decay products, one of which is radon. These radon atoms can diffuse out of the detector materials into the tracking volume.

The alpha decay of radon is not easily confused with the double beta decay signal, but the decay of its progeny ^{214}Bi (Q_β = 3.27 MeV) is more problematic and can be a significant background.

Simulations suggest that we need the radon background in the tracker to be < 0.15 mBq/m^3 to achieve our target sensitivity.

Radon detectors that use electrostatic collection are typically sensitive to ~1 mBq/m^3, so we need to use a different technique.

We have therefore built a 'radon concentration line' to concentrate the radon from a gas sample, before passing it into an electrostatic detector.

The gas from the tracker will be pumped through a cold ultra-pure activated carbon trap and the radon in the gas will be adsorbed.

Once collection is complete, the trap will be evacuated and the temperature raised to remove any trapped nitrogen.

Finally, the temperature will be raised further and the radon transferred into the electrostatic detector via helium purge.

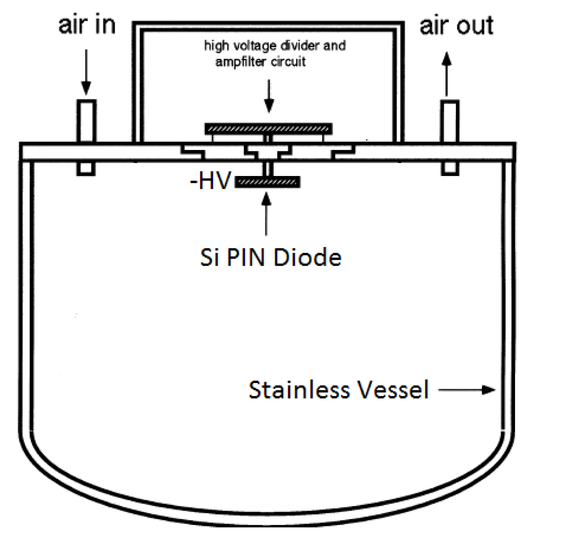
Real life incarnation of the radon concentration line

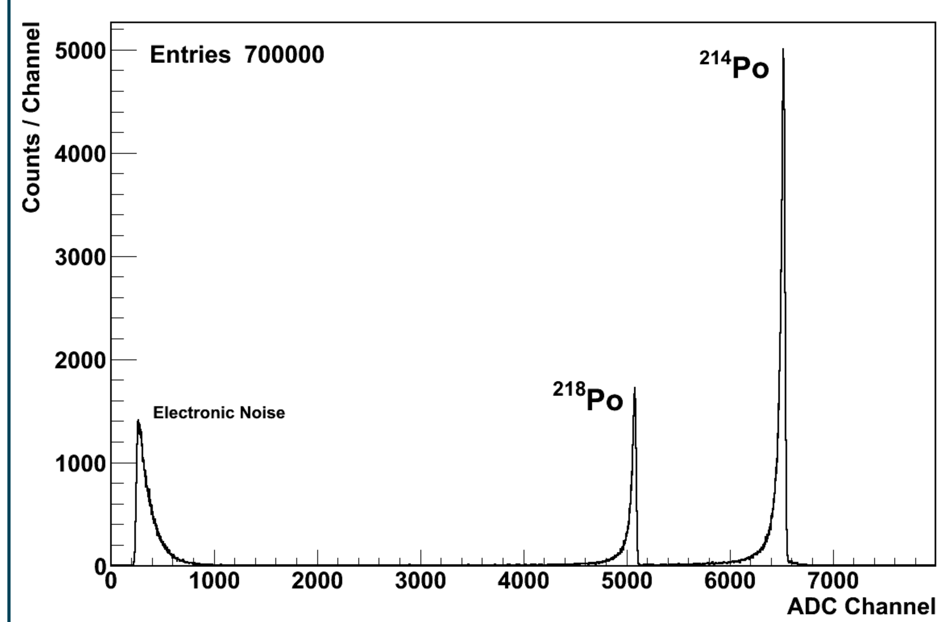
Electrostatic Radon Detector

Principle of Operation

The daughters of Radon decay are predominantly positive ions due to the alpha decay processes. In fact, 87% of the time, ^{222}Rn decays into a positive ^{218}Po ion.

These ions collect on the PIN diode due to the applied negative HV. Once on the photodiode, these daughters decay and their alphas can be seen as distinct peaks in the energy spectrum.





Energy spectrum from a radon source, measured by our detector

The isotopes of ^{218}Po and ^{214}Po can both be seen in the energy spectrum (6.1 MeV and 7.8 MeV respectively) .

^{214}Po is more commonly used to measure radon concentration as it is less susceptible to neutralisation than ^{218}Po and is therefore less affected by slight changes in the composition of the measurement gas.

For 4m^3 of gas, assuming a background of 10cpd and an efficiency of 30%, and a measurement period of 2.5 days, we will have sensitivity to Radon concentration:

$$C_{Rn} \le \frac{1.64\sqrt{B}}{V\tau_{Rn}\varepsilon(1-e^{-t/\tau})} \quad \text{or} \quad C_{Rn} \le 0.04\ \text{mBq/m}^3$$