Abstract. The NEMO-3 experiment is an experiment dedicated to the search for neutrinoless double beta decay ($0\nu\beta\beta$). Detection of $0\nu\beta\beta$ decay would be direct evidence that neutrinos are Majorana particles and lepton number is violated. In NEMO-3, the separation of source isotopes from the active detector region allows for reconstruction of the full event topology, which aids in background suppression and the investigation of $0\nu\beta\beta$ decay underlying mechanisms. NEMO-3 has investigated a total of seven isotopes, $^{100}\text{Mo}$, $^{82}\text{Se}$, $^{116}\text{Cd}$, $^{150}\text{Nd}$, $^{48}\text{Ca}$, $^{96}\text{Zr}$, and $^{130}\text{Te}$, and has produced the world’s best $2\nu\beta\beta$ decay half-life measurements for all of them. No indication of $0\nu\beta\beta$ decay has yet been observed. Presented here is the newly published limit of $T_{1/2}^{0\nu\beta\beta} > 1.1 \times 10^{24}$ y (90% C.L.) for 37 kg·y exposure of $^{100}\text{Mo}$.

1. Introduction
The NEMO-3 experiment searches for neutrino-less double beta decay ($0\nu\beta\beta$). Observation of $0\nu\beta\beta$ would be direct evidence that neutrinos are Majorana particles and lepton number conservation is violated. Therefore, $0\nu\beta\beta$ decay is a process which is beyond the current Standard Model of particle physics [1]. The experimental signature of this decay is the emission of two electrons whose total energy is equal to the kinetic energy available in the decay ($Q_{\beta\beta}$). The largest background to this process is the $2\nu\beta\beta$ decay which is allowed by the Standard. If the $0\nu\beta\beta$ decay process is mediated by a massive Majorana neutrino, then the rate of the decay is related to the effective neutrino mass, $\langle m_\nu \rangle$, by the equation

$$T_{1/2}^{0\nu\beta\beta} = G^{0\nu} |M^{0\nu}|^2 |\langle m_\nu \rangle|^2,$$

where $G^{0\nu}$ and $M^{0\nu}$ are the theoretically calculated phase space and nuclear matrix elements, respectively.

2. The NEMO-3 experiment
The NEMO-3 experiment was located in the Modane Underground Laboratory (LSM), and operated from February 2003 to January 2011. It is unique among $0\nu\beta\beta$ decay experiments due to the separation of the $2\nu\beta\beta$ decay isotopes from the active detector system as shown in Figure 1. It is cylindrical in shape, with the $2\nu\beta\beta$ decay source foils located at a fixed radius. The foils are surrounded by two wire tracking chambers, which provide 3D position measurements of charged particles passing through the detector volume. Surrounding the tracker on all sides...
is the calorimeter system, composed of plastic scintillator blocks coupled to low-radioactivity 3” and 5” photomultiplier tubes (PMT), which provides both timing and energy measurements. More information about the detector can be found in [2]. The separated tracker-calorimeter system allows for direct measurements of internal and external background rates and final state kinematic variables. Seven different isotopes were investigated simultaneously for $0\nu\beta\beta$ and $2\nu\beta\beta$ decay with the NEMO-3 detector. The most massive isotope investigated was $^{100}$Mo with 6.9 kg.

Figure 1. The NEMO-3 detector is shown on the left, and top down view of the layout of the seven different $2\nu\beta\beta$ decay isotopes investigated by NEMO-3 is on the right. $^{100}$Mo (red) was the most massive isotope at 6.9 kg.

3. Measuring backgrounds with NEMO-3
The source foils contain small amounts of radioactive isotopes which were detected with a high-purity Germanium (HPGe) detector before installation in the detector. These isotopes may decay via the emission of one electron or positron, and some gamma rays. These decays can result in a two electron final state through many processes including pair production, Compton and Møller scattering, and emission of a $\beta$ particle together with a conversion electron. Using a number of control regions defined by different final state topologies, the activity of background isotopes, both internal and external to the source foil, can be directly measured with the NEMO-3 detector, compared with the HPGe measurements when possible, and used to estimate the number of expected events in the $2\nu\beta\beta$ and $0\nu\beta\beta$ signal regions. The most significant background to the $^{100}$Mo $0\nu\beta\beta$ decay search is the irreducible $2\nu\beta\beta$ decay spectrum. The half-life for this process as measured by NEMO-3 is $T_{1/2}^{2\nu\beta\beta} = (6.93 \pm 0.04 \text{ (stat)}) \times 10^{18}$ years [3].

4. Results of the $0\nu\beta\beta$ search for $^{100}$Mo
The full NEMO-3 data set is used to search for the $0\nu\beta\beta$ decay of $^{100}$Mo to the ground state of $^{100}$Ru. Events are selected which have two final state electrons with a summed energy in the region 2.8-3.2 MeV. More details on the selection criteria applied to the data set can be found in Reference [3]. The signal efficiency in the region of interest is 4.7%. The number of expected background events are shown in Table 1.

No events above background are observed. Therefore, using an exposure of 34.7 kg·y of $^{100}$Mo, a 90% CL limit is set at $T_{1/2}^{0\nu\beta\beta} > 1.1 \times 10^{24}$ years using the summed electron energy spectrum shown in Figure 2. This limit is obtained using the CLs method, where both statistical and systematic errors have been taken into account. Assuming the exchange of a massive Majorana neutrino, this corresponds to a limit on the effective neutrino mass of $\langle m_\nu \rangle < 0.3-0.9$ eV when the $M^{0\nu}$ and $G^{0\nu}$ are taken into account [3].
Background Expected events

| External | Expected events |
|----------|-----------------|
| Externals | <0.2 |
| Radon | 5.2 ± 0.5 |
| $^{214}$Bi internal | 1.0 ± 0.1 |
| $^{208}$Tl internal | 3.3 ± 0.3 |
| $^{100}$Mo $2\nu\beta\beta$ | 8.45 ± 0.05 |

Total background 18.0 ± 0.6

Data 15

Table 1. Number of expected background and data events in the search window of 2.8-3.2 MeV.

5. Conclusion

The NEMO-3 detector has been used to search for $0\nu\beta\beta$ of seven different isotopes simultaneously. No signal has been observed, and the best NEMO-3 limit using 34.7 kg·y of $^{100}$Mo has been set at $T_{1/2}^{0\nu\beta\beta} > 1.1 \times 10^{24}$ years (90% C.L.). Updated half-life values for $2\nu\beta\beta$ decay and limits for $0\nu\beta\beta$ decay as well as other rare and exotic decays, such as $2\nu\beta\beta$ to excited states of daughter isotopes, using the full data set from NEMO-3 for $^{82}$Se, $^{116}$Cd, $^{150}$Nd, $^{48}$Ca, and $^{96}$Zr are currently under way and nearing completion. Future results hope to improve upon the current published half-life measurements and limits for these processes by utilizing many final state observables from both signal and background channels.

References
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