# Radioactive Background Control for nEXO

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## Intrinsic Radioactivity

Radioactivities of the materials are measured by various techniques, such as Ge counting, Neutron Activation Analysis (NAA), and Inductively coupled plasma mass spectrometry (ICPMS). Combining the measured activities with the hit efficiencies calculated by simulation, its background impact can be estimated. Mitigation strategy:

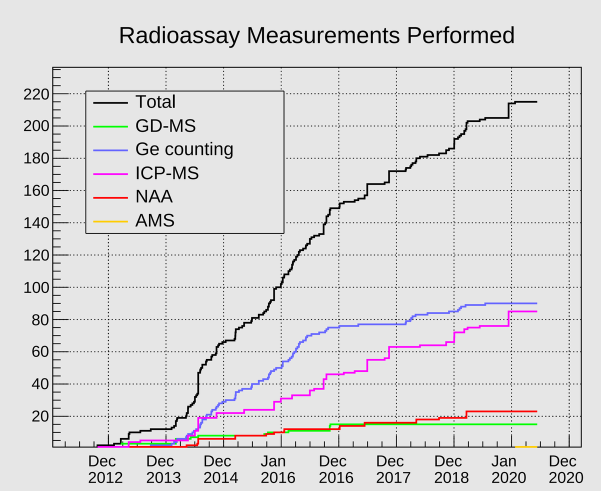
- Repeat measurement with higher sensitivity
- Use alternative design with reduced mass
- Find an alterative material source
- Replace with a different material
- Work with manufacturer to reduce impurities introduced during manufacturing
- Synthesize material in-house
- Adjust budget to accommodate the component

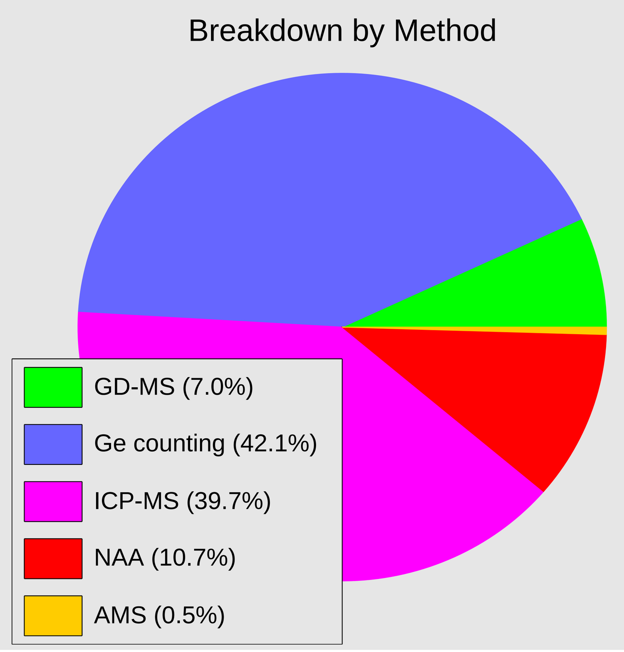
### Radioassay Tools

- Ge counting: nEXO has access to 4 dedicated detectors (2 above ground at UAlabama and 2 deep underground at SURF and SNOLAB), and 5 shared detectors (1 shallow underground at PNNL and 4 deep underground at SNOLAB).
- NAA: In nEXO, samples are irradiated at the MIT research reactor (MITR) and then counted at Alabama. Sub-ppt sensitivities for Th have been achieved for some samples. The sensitivity to U is often limited to a few ppt due to $^{239}$Np decay being masked by side activities.
- ICPMS capability for nEXO is provided by PNNL, CUP (Korea) and IHEP (China)
- AMS is typically used to measure isotopic ratios relative to the stable isotope. with sensitivity down to $10^{-15}$. Using the AMS system at Ottawa, we are exploring ways to measure concentrations of primordial isotopes, possibly using tracers.

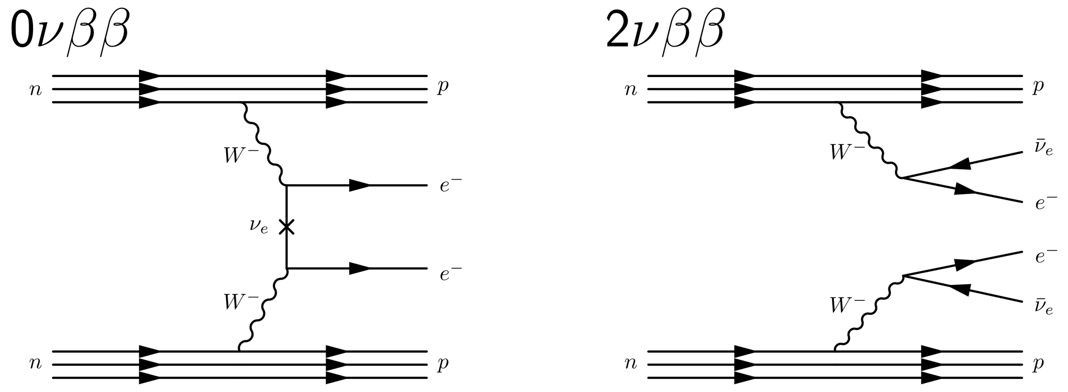
### Materials Database

Database for storing radioassay measurements, and simulation results. It also generates summary spreadsheets for quick background estimates.




Neutrinoless double beta decay ($0\nu\beta\beta$) is a hypothetical nuclear process in which a nucleus undergoes a double beta decay without the associated neutrino emissions as in regular double beta decay ($2\nu\beta\beta$).



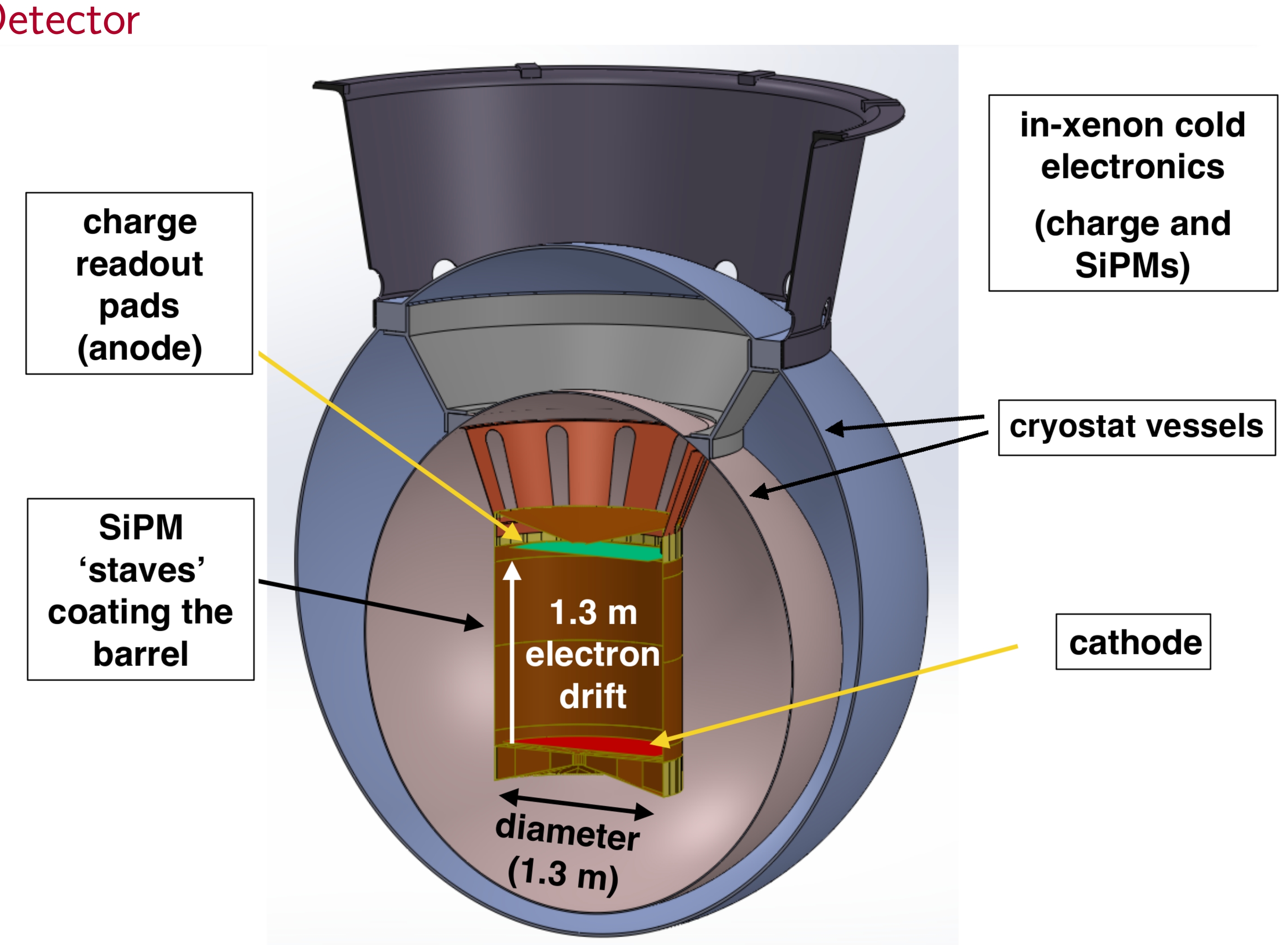

Its observation would imply that neutrinos are Majorana particles and that lepton number is violated. This is direct evidence of physics beyond the Standard Model.

nEXO aims to observe $0\nu\beta\beta$ using a LXe TPC containing 5 tonnes of liquid xenon enriched to 90% in $^{136}$Xe ($Q_{\beta\beta} = 2.458$ MeV). Since $0\nu\beta\beta$ is expected to be a rare process if it exists, to achieve a sufficient sensitivity to $0\nu\beta\beta$, the background rate needs to be suppressed to a low level. For the purpose of background control, background sources are categorized as follows:

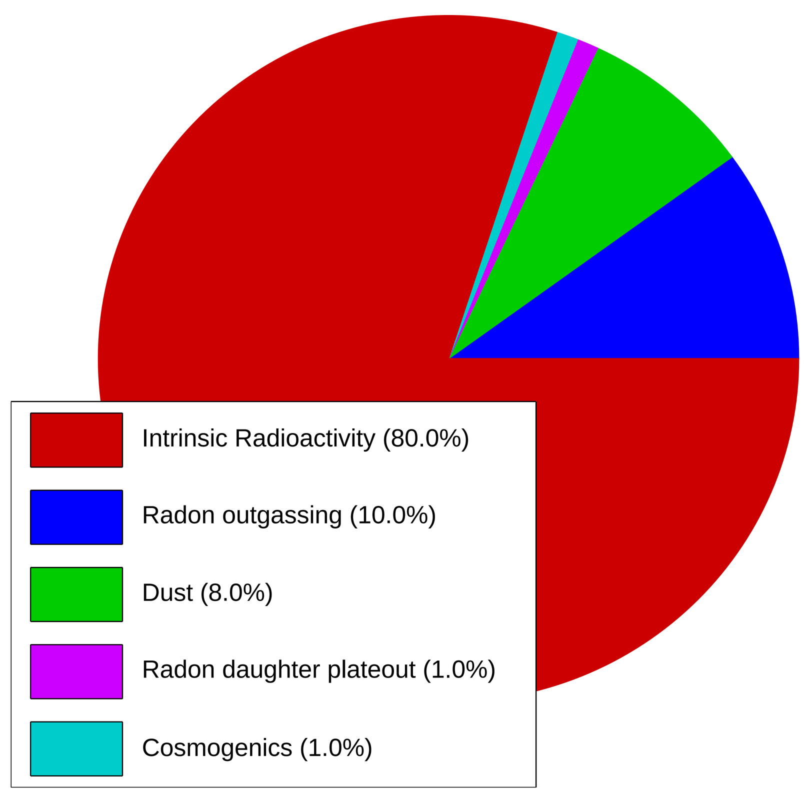
- Intrinsic radioactivity in detector components
- Radon outgassing from detector components
- Dust deposited on surfaces
- Radon daughter plateout on surfaces
- Activation products of cosmic ray particles

The first two are intrinsic to the materials, while the remaining are dependent on handling.

### Detector




### Background Goal

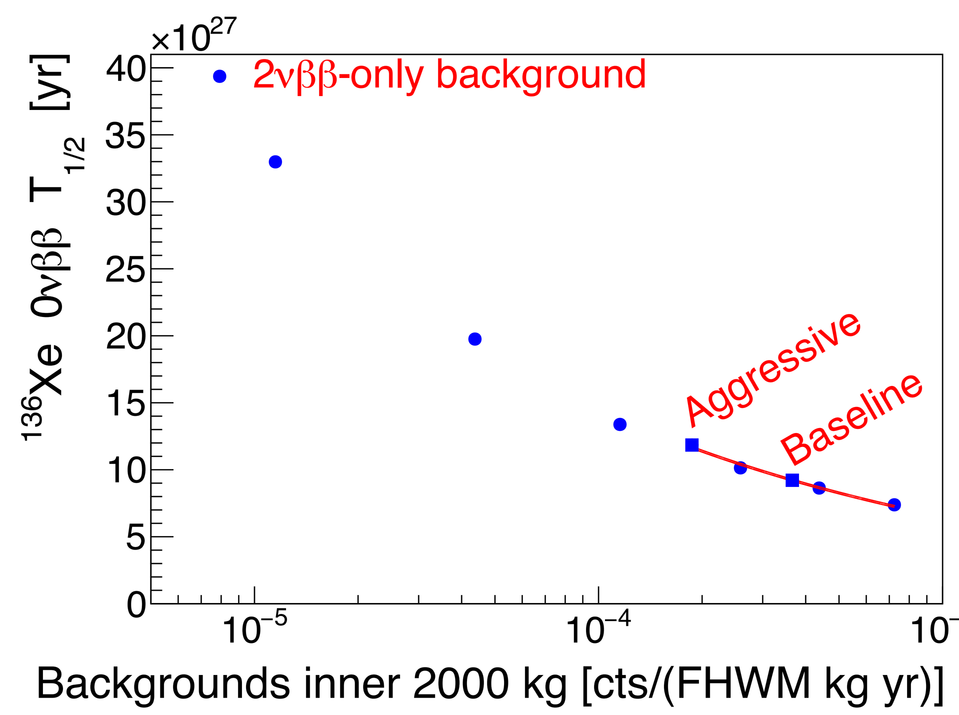



### Radioassay results

| Material | Previously Published [1] | | Latest | |
|---|---|---|---|---|
| | U [ppt] | Th [ppt] | U [ppt] | Th [ppt] |
| Carbon Composite (Resin) | $< 7.66$ | $< 18.9$ | $< 7.66$ | $< 18.9$ |
| Carbon Composite (Fiber) | $39.4 \pm 14$ | $129 \pm 36.8$ | $40.3 \pm 15.4$ | $73.7 \pm 38.6$ |
| HFE-7000 | $< 0.015$ | $< 0.015$ | $< 0.015$ | $< 0.015$ |
| Copper | $0.254 \pm 0.008$ | $0.127 \pm 0.057$ | $0.254 \pm 0.008$ | $0.127 \pm 0.057$ |
| Sapphire | $< 8.86$ | $6.03 \pm 1.05$ | $< 8.86$ | $6.03 \pm 1.05$ |
| Quartz | $< 1.45$ | $< 0.23$ | $< 1.45$ | $< 0.23$ |
| ASICs | $13.2 \pm 0.1$ | $25.7 \pm 0.7$ | $0.67 \pm 0.3$ | $0.97 \pm 0.23$ |
| Epoxy | $< 44$ | $< 23$ | $< 44$ | $< 23$ |
| Kapton | $4.7 \pm 0.7$ pg/cm$^2$ | $< 2.3$ pg/cm$^2$ | $0.71 \pm 0.04$ pg/cm$^2$ | $0.71 \pm 0.20$ pg/cm$^2$ |
| Titanium [2] | $< 11.9$ | $56.5 \pm 4.91$ | $< 11.9$ | $56.5 \pm 4.91$ |
| SiPM | $0.857 \pm 0.046$ | $0.449 \pm 0.118$ | $0.857 \pm 0.046$ | $0.449 \pm 0.118$ |
| HDPE | - | - | $99.6 \pm 18.8$ | $63.6 \pm 2.7$ |
| Teflon | - | - | $< 0.78$ | $< 0.26$ |
| Bump bond wire | - | - | $< 229$ | $26.4 \pm 7.9$ |
| Conductive PE | - | - | $224 \pm 32$ | $10.1 \pm 1.4$ |

For some components, in addition to primordial radioisotopes, such as $^{238}$U and $^{232}$Th, $^{110m}$Ag and $^{26}$Al are also being measured.

### Sensitivity vs. Background [1]




For details on sensitivity see poster #548.

## Exposure-based Backgrounds

Exposure-based backgrounds are induced by exposure of materials to the environment, such as

- Dust
- Air (e.g. radon daughter plateout)
- Cosmogenic activation

This type of background depends on the handling history, storage, and construction process.

To mitigate this, we use the following strategy:

- Monitor environmental conditions of construction and assembly locations.
- Track the exposure history of individual parts.
- Estimate all contributing backgrounds due to environemntal exposure using the collected information.

A tracking database will be developed to track all individual parts through construction process. It stores the location history of every part, and the environmental data vs time such as dust count, radon levels, etc. versus time at various facilities.

To remove surface contamination introduced during manufacturing, handling, and storage, a verifiable cleaning protocol needs to be developed to maintain radiopurity and chemical purity of detector components. Novel cleaning techniques may be required for sensitive components

## Radon Outgassing

$^{222}$Rn decays into $^{214}$Bi which, in turn, beta decays and emits a 2.448 MeV $\gamma$ with an intensity of 1.548%. Due to its proximity to the Q-value, this is potentially an important background source. $^{222}$Rn can be outgassed from detector materials and plumbing into LXe, HFE (the cryogen), and water in the outer detector, causing different levels of background.

Mitigation measures:

- Screening of all LXe-wetted components for radon outgassing
- Periodic monitoring of radon in the LXe purification loop
- Cessation of HFE circulation during operation.
- Lid and cover gas for water tank and periodic monitoring.

### References

[1] nEXO Collaboration, Phys. Rev. C 97, 065503 (2018)
[2] LZ Collaboration, Astropart. Phys., 96, 1-10 (2017)