A Highly Sensitive Radon Emanation Measurement System at SNOLAB

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Overview

- Motivation
- Radon-222 Emanation Measurement System
- Efficiency and Sensitivity
- Services
- Summary
The SNOLAB Facility

- Hosted at the Vale Creighton Nickel Mine in Sudbury, Ontario, Canada
- Operated as a joint venture of 5 Canadian Universities (Carleton, Queen’s, Montreal, Alberta, and Laurentian)
- Operations funded by the Canada Foundation for Innovation and the Province of Ontario
SNOLAB includes a campus 2km underground

Developed from original SNO detector as part of a competition to develop international facilities within Canada
Why go Deep Underground?

- High energy muons travel deep
- Deep UG facilities provide significant rock overburden-> reduction in cosmic ray flux.

~2km walk from cage to SNOLAB
There is ~50 million times reduction in cosmic rays 2km underground at SNOLAB!
Cleanliness is critical to SNOLAB operations and science.
Why do we care about cleanliness?

Radioactive backgrounds from the environment dominate underground
Many experiments require ultra low level of radioactive backgrounds to achieve required sensitivities for their searches.

Main backgrounds: Naturally occurring radioactivity (238U and 232Th decay chains).

These backgrounds (alphas, betas, gammas) may mimic the expected detector signal.

**GOAL:** To measure these backgrounds and apply techniques to reduce them as low as possible.
How to measure Radioactivity Related Backgrounds

- SNOLAB has several facilities which are used to directly measure these radioactive backgrounds

- Suppress radon in your experiment’s environment (low radon rooms/lab)

- Build a big shield (water as radioactive shield)

- Performing regular assays of detector shield - Water Assay

- Choose radiopure materials for the detector. Different techniques exist (choose the one that works best for material in question)
  - Gamma counting using HPGe counters (identify radionuclides using their gamma energies)
  - Rn emanation
Motivation

- Rn-222 is chemically inert and has a half-life of 3.8 days.
- Rn-222 can be emitted from the surface of materials (containing trace amount of U/Th) & can propagate throughout detector contaminating expt.
- Rn decays via alpha decay with MeV scale Q values & can result in decay products embedding themselves in the surface of materials.
  - Rn and its progeny are one of the dominant backgrounds to low background and rare event searches
  - Ultra low radioactive materials are needed in order to build experiments.
- Disequilibrium may occur between U-238 and Rn-222 (due to emanation of Rn from materials into the detector)
- Knowing U-238 concentration is not enough for material selection.

Measuring Rn-222 emanation rate has become important to enable construction of low background environments.
Radon Emanation Measurement System

• We require low background, high efficiency radon detectors (near 100%) to determine background caused by Rn and its progeny.

• All detector components and construction materials are tested for their radon emanation levels.

• A technique was developed by SNO collaboration and later adapted by SNOLAB to fulfill these conditions.

• SNOLAB Radon emanation measurement system is made of low-radioactivity acrylic emanation chamber, a Rn transferring board and detection device.
New Portable Rn Emanation Measurement Panel
Portable Rn Emanation Measurement Panel

- Orbital welded to avoid ingress of outside air
- Acrylic chamber 20cm dia. x 20cm height. More chambers to be added
- Built on a moving cart

- Two primary traps (bronze wool/Chromosorb)
- Attachment port to connect sources or samples
Primary/Secondary Traps

- Primary traps are U-shaped ½ inch SS tubing.
- Primary trap efficiency is increased by inserting bronze wool/chromosorb
  - Bronze wool generates an increased surface area in the trap
  - Chromosorb also has high effective surface area (300-400 m^2/g).

- Secondary trap custom designed by Swagelok.
- Coiled SS 1/8-inch diameter tube and has steel wire inserted to reduce volume.
- 1/8-inch selected to improve the Rn transfer efficiency by minimizing the dead volumes.
Radon Emanation/Extraction Process

- Radon emanation is the process of removing all existing radon from a sample and letting new radon to be produced.

- Once sample has been refilled with radon intrinsic to the sample, it is harvested.

Clean chamber, sample → Put sample in the vacuum chamber → Pump down chamber, whole system → Perform Rn extraction using Rn gas board & allows most other residual gas to be exhausted from the system → Wait ~2 weeks for Rn to be emanated from the sample. Rn exists as residual gas inside chamber → Collected Rn is transferred into a counter (Lucas cell)
Radon Extraction Process

1. **Pump down Rn Board System**
   - Primary trap (bronze wool/Chromosorb)
   - Secondary trap
   - The whole Board system (not the chamber).
Radon Extraction Process

2. Extraction of Rn from Chamber (Rn pumped out to primary trap using LN2)
   - Radon freezes at ~61°C, LN2 temperature is ~ -196°C
   - Primary trap immersed in LN2. Chamber to trap valve opened.
   - Rn freezes & sticks to bronze wool/chromosorb (other gases like CO2, N2 exhausted from the system)
   - Extraction time: vacuum pull transfer for 1 hour.
Radon Extraction Process

3. Transfer from Primary Trap to Secondary Trap
   • Secondary trap immersed in LN2
   • Primary trap warmed (~100°C) restoring Rn to its gaseous state
   • Inlet of Primary trap closed & valve between Primary and secondary trap opened
   • Collected Rn transferred by cryo-pumping ~15 minutes.
Radon Extraction Process

4. **Transfer from Secondary Trap to Lucas cell**
   - Attach LC to the system and evacuate
   - Secondary trap isolated and valve between LC and secondary trap opened
   - Secondary trap heated using heat gun ~3-4 minutes
   - Collected Rn transferred by volume sharing (volume of LC > trap) ~15 minutes

5. **Counting**
   - LC coupled to PMT to count the number of alphas
   - Alpha particles produced in decay of 218Po, 214Po, 222Rn strike ZnS producing flash of light detected by the PMT.
   - LC counted using CAEN DAQ system using 8 channels
     - More channels will be incorporated to increase counting capabilities
Efficiency of the System

- Total efficiency = \( \text{eff}_{\text{pumping}} \times \text{eff}_{\text{trapping}} \times \text{eff}_{\text{transfer}} \times \text{eff}_{\text{detecting}} \)

- There are 3 alphas from Rn-222 daughters, this term causes the total efficiency to be more than 100%

- Total efficiency: Ratio of measured Rn atoms in LC to the calculated Rn atoms in the initial Rn sample
Total Efficiency of the System

- Rn emanation is a multi-stage process.
- Performed set of independent measurements to obtain the total efficiency of the system.
- Systematic error expected to define uncertainty, since statistical error is small.
- Systematic studies in progress.

<table>
<thead>
<tr>
<th>Test #</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>215.65 +/- 11.36</td>
</tr>
<tr>
<td>Run 2</td>
<td>192.76 +/- 10.34</td>
</tr>
<tr>
<td>Run 3</td>
<td>245.87 +/- 16.07</td>
</tr>
<tr>
<td>Run 4</td>
<td>223.31 +/- 11.59</td>
</tr>
<tr>
<td>Run 5</td>
<td>222.89 +/- 11.70</td>
</tr>
<tr>
<td>X Run 6</td>
<td>157.93 +/- 8.30</td>
</tr>
<tr>
<td>Weighted average</td>
<td>199.23 +/- 4.46</td>
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</table>
Background Level of the System

- Board background is usually negligible if the board is not contaminated.

- Regular board background tests performed. Sensitivity of our system is 2 Rn/day

- Lucas cell background varies over time. Initially background is ~3 counts/day, but it builds up after few years if the Lucas cell continuously used for radon emanation studies
  - Pb-210 buildup (22 years half-life)
  - Need to build new Lucas cells regularly
Services to the community so far…

• Performed Rn emanation studies of DEAP filter – 3 tests, results sent to the collaboration.

• Rn emanation studies of PICO-40L vessel – performed 3 tests, detailed report sent to PICO collaboration.
Services to the community so far…

• Performed Rn emanation studies of SNO+ LAB assay components – Tests still ongoing.

• Rn emanation studies of material from Health Canada – Campaign expected to start February 2023.

• Other Rn emanation studies of samples performed.
Summary

• New surface Rn emanation measurement facility for material selection studies with a sensitivity of 2 Rn/day.

• We have a robust Rn-222 Emanation screening technique which can be used to study different detector construction materials.

• Good handle on Rn-222 emanation studies in vacuum mode. Systematic studies in progress.

• Carrier gas Rn-222 emanation studies in progress.

• Rn-222 emanation request form exist:
  https://www.snolab.ca/users/services/gamma-assay/assay_request_form.html

Please feel free to contact us if you want your samples to be counted:
dchauhan@snolab.ca
SNOLAB Radon Emanation Counting Request Form

Please input the following information as best as you can for requesting Radon Emanation counting services. This form is intended to gather most of the relevant information.

Sample Shipping Address:
Attn: Dimpal Chauhan
SNOLAB
1039 Regional Road 24
Creighton Mine #9,
Lively, ON P3Y 1N2

Sign in to Google to save your progress. Learn more
* Required

Email *
Your email

Name *
Your answer

Date *
MM DD YYYY
Backup Slides