SuperCDMS & Radon

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Topics in Astroparticle and Underground Physics

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Radon Backgrounds

Non-line-of-sight (penetrating) Backgrounds:

- Inner surface of lead shield
- Cryostat surfaces
- Inner poly surfaces & Interstitial air gaps

SNOLAB Detector Backgrounds

- Radon Decay Chain
  - Radon (Rn)
  - Polonium (Po)
  - Bismuth (Bi)
  - Lead (Pb)

- Photon emissions
- Beta emissions
- Recoil events

Recoil Energy (keV) vs. dR/dE (events/kg-yr-keV)

- Solar neutrinos
- Neutrons
- β-particle recoils
- ³²Si
- ³²P
- ³H
- ²⁰⁶Pb recoils
Radon Backgrounds

Non-line-of-sight (penetrating) Backgrounds:
Electron recoils:
→ $^{210}\text{Bi}$ bremsstrahlung
  (limit exposure of surfaces to radon)
→ $^{214}\text{Pb}$ & $^{214}\text{Bi}$ gamma-rays
  (purge lead shield with low-Rn gas)

SNOLAB Detector Backgrounds

Non-line-of-sight Radon Background
≈1% of Total Electron Recoil Photon Background
Radon Backgrounds

Non-line-of-sight (penetrating) Backgrounds:

Electron recoils:
- $^{210}\text{Bi}$ bremsstrahlung
  (limit exposure of surfaces to radon)
- $^{214}\text{Pb}$ & $^{214}\text{Bi}$ gamma-rays
  (purge lead shield with low-Rn gas)

Nuclear Recoils:
- $^{210}\text{Po}$ ($\alpha,n$) on $^{13}\text{C}$ in poly
  (limit exposure of surfaces to radon)

SNOLAB Detector Backgrounds

Non-line-of-sight Radon Background
<1% of Total Nuclear Recoil
Neutron Background

Radon Decay Chain

$\alpha$ $\alpha$ $\alpha$

Betas

$^{32}\text{Si}$

$^{32}\text{P}$

$^{3}\text{H}$

$^{206}\text{Pb}$ recoils

Photons

Solar neutrinos

Recoil Energy (keV)

d$R$/d$E$ (events/kg-yr-keV)
Radon Backgrounds

Line-of-sight (non-penetrating) Backgrounds:

Detector-surface Backgrounds

copper housing

detector

adjacent detector

SNOLAB Detector Backgrounds

Radon Decay Chain

Radon Backgrounds

Line-of-sight (non-penetrating) Backgrounds:

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SNOLAB Detector Backgrounds
Radon Backgrounds

**Line-of-sight (non-penetrating) Backgrounds:**

Electron recoils:

→ $^{210}\text{Pb}$ & $^{210}\text{Bi}$ betas and x-rays

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**SNOLAB Detector Backgrounds**

Detector-surface Backgrounds

- Copper housing
- Detector
- $^{210}\text{Pb}$
- x-ray
- $^{210}\text{Bi}$
- Adjacent detector

Radon Background

≈100% of Detector-surface Electron Recoils
Radon Backgrounds

Line-of-sight (non-penetrating) Backgrounds:

Electron recoils:
- $^{210}$Pb & $^{210}$Bi betas and x-rays

Nuclear Recoils:
- $^{206}$Pb recoils from $^{210}$Po decays

Detector-surface Backgrounds

Snolab Detector Backgrounds

Line-of-sight Radon Background
$\approx$100% of Detector-surface Nuclear Recoils
Radon Backgrounds

**Line-of-sight (non-penetrating) Backgrounds:**

**Electron recoils:**
\[ \rightarrow {^{210}}\text{Pb} \text{ & } {^{210}}\text{Bi} \text{ betas and x-rays} \]

**Nuclear Recoils:**
\[ \rightarrow {^{206}}\text{Pb} \text{ recoils from } {^{210}}\text{Po} \text{ decays} \]

**Potentially dominant backgrounds unless:**
- Detector/copper surfaces clean at start
- And protected from radon thereafter

**Detector-surface Backgrounds**

**Calls for dedicated background controls:**

I. Limit exposure to radon during payload lifecycle
II. Dedicated low-radon cleanroom at SNOLAB
III. Validate cleanliness of critical processes
Payload Lifecycle & Radon Exposure

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$^{210}\text{Pb}$ from Rn exposure (conservative plate-out tally):

Detector surfaces: 47–80 nBq/cm$^2$
- Assume worst for sidewalls $\rightarrow$ 80 nBq/cm$^2$
- Sensor fab removes surface area on faces $\rightarrow$ 50 nBq/cm$^2$

Copper surfaces: <10 nBq/cm$^2$
Payload Lifecycle & Radon Exposure

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$^{210}\text{Pb}$ from Rn exposure (conservative plate-out tally):

- **Detector surfaces**: 47–80 nBq/cm$^2$
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- **Copper surfaces**: <10 nBq/cm$^2$

Plate-out $\approx$2x larger without low-radon cleanroom
Low-radon Cleanroom @ SNOLAB via Vacuum-Swing Adsorption (VSA)

Class-100 Low-radon Cleanroom

Custom-built Radon Mitigation System

SNOLAB General Lab Air ≈130 Bq/m³

Rn adsorbs to carbon at atmospheric pressure

Rn is purged from carbon at vacuum ≈ 2 Torr

SNOLAB General Lab Air ≈130 Bq/m³

Radon-mitigated Air <0.1 Bq/m³
Demonstration VSA @ SDSM&T
Demonstration VSA @ SDSM&T

Input Air
$\langle \text{Rn} \rangle = 80 \text{ Bq/m}^3$

Cleanroom Radon
Level $<0.07 \text{ Bq/m}^3 \rightarrow >1000x \text{ reduction!}$

Simultaneous RAD7 Readings
Validation of Critical Processes

Bottom-up estimate of $^{210}\text{Pb}$ plate-out from radon exposure in air:

- **Detector surfaces**: $50/80$ nBq/cm$^2$ for faces/sidewalls
- **Tower-copper surfaces**: $<10$ nBq/cm$^2$

But doesn’t include:

- Initial level of surface contamination
  - do surfaces start clean?
- Contamination directly from fabrication processes
  (e.g., chemical contact)

R&D tests to validate critical processes:

- **Detector surfaces** → crystal polishing & sensor fabrication
- **Copper surfaces** → cleaning method

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**Sensor Fabrication Test**

**Goals:**
- Validate starting level of $^{210}$Pb on detector surfaces
- Validate surface contamination from sensor fabrication

**Results:**
- Broad 4–5 MeV peak suggests upper-chain $^{238}$U alphas
- Precedent from DRIFT $\rightarrow$ Battat et al., NIM A794 (2015)
- Background concern $\rightarrow$ $^{234}$Th daughter beta decay
- Follow-up measurements:
  - Backsides of wafers $\rightarrow$ no peak
  - ICP-MS of wafers $\rightarrow$ few Bq/kg of $^{238}$U in aluminum

**Diagram:**
- Process flow: Etch wafers at Stanford fab facility $\rightarrow$ Assay in SMU UltraLo-1800 $\rightarrow$ Fab sensor pattern at Stanford $\rightarrow$ Assay in SMU UltraLo-1800
- Spectra showing $^{210}$Po and uranium alphas.
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Not seen on SuperCDMS Soudan detectors
Working with vendor to pre-screen aluminum
Copper Cleaning Test

**Goal:**
- Validate method for cleaning tower copper parts
  - And thus starting contamination level for detector housings

**Methodology:**
- Fabricate 2 sets of large-area Cu plates: McMaster & Aurubis OFHC (alloy 101)
- Mill off >1 mm from all surfaces to simulate parts fabrication
- Clean w/ PNNL acidified-peroxide etching recipe
- Use SMU UltraLo-1800 to measure surface alphas

**UltraLo-1800 Background not Subtracted** (≈25 nBq/cm\(^2\) in \(^{210}\)Po ROI)
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Anticipate <100 nBq/cm² ²¹⁰Pb (>10x better than Soudan)
Summary

Radon is an important background consideration for SuperCDMS SNOLAB
- $^{210}$Pb within line-of-sight of detectors is a potentially dominant background

Estimate of $^{210}$Pb from plate-out:
- Detector faces/sidewalls: 50/80 nBq/cm$^2$
- Copper housings: <10 nBq/cm$^2$

Low-radon cleanroom for installation at SNOLAB mitigates plate-out by $\approx$2x
- SDSM&T VSA demonstrates >1000x radon reduction

Validation of critical processes:
- Contamination during crystal polishing negligible
- Discovered uranium in detector-sensor aluminum $\rightarrow$ working with vendor to eliminate
- Demonstrated copper surfaces with <100 nBq/cm$^2$ $^{210}$Pb via PNNL acidified-peroxide etch
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Crystal Polishing Test

**Goal:**
- Validate $^{210}$Pb contamination rate during polishing

**Methodology:**
- Seven 100 mm Si wafers as proxy for detector surfaces
- UltraLo-1800 to measure surface alphas
- 10,000x radon w/ SDSM&T source to boost sensitivity

$^{210}$Pb surface contamination during polishing insignificant $\rightarrow <1$ nBq/cm$^2$

XIA UltraLo-1800 Spectra (SMU)

**Pre-Process**
- $<200$ nBq/cm$^2$
  - clean enough for test

**Post-Process**
- $<100$ nBq/cm$^2$
  - Cleaner!
  - Mild etch from slurry solution