Informing dust backgrounds on low-background detector materials using ICP-MS

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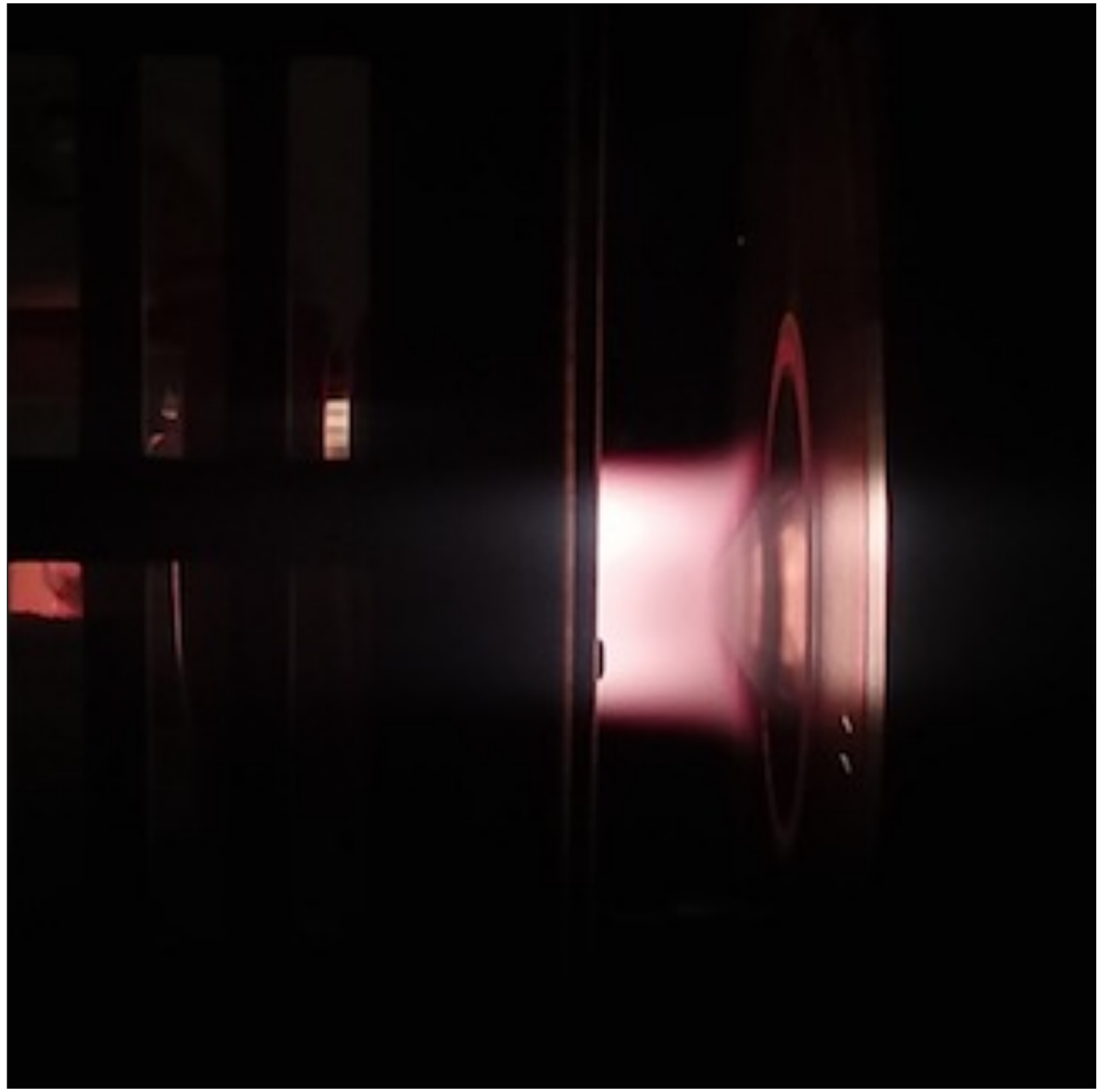

Pacific Northwest
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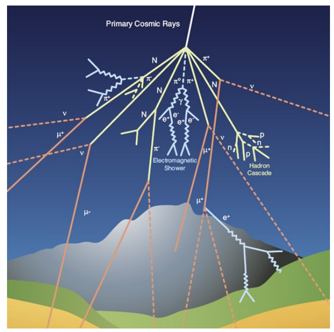
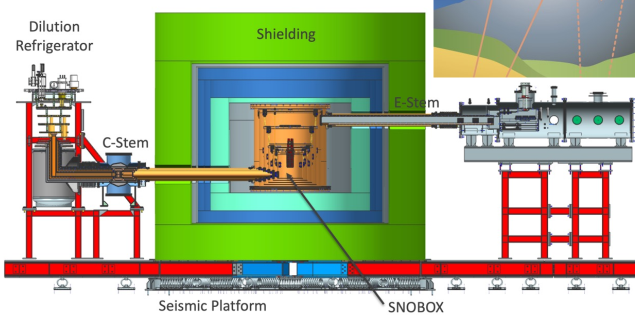
Background mitigation in ultra-sensitive detectors

- Underground facilities and detector shielding

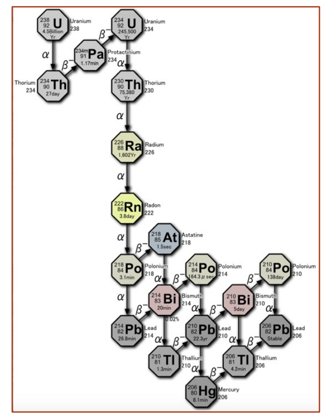




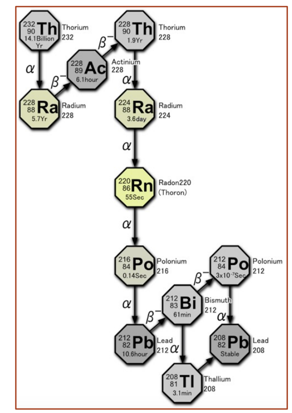
SuperCDMS detector

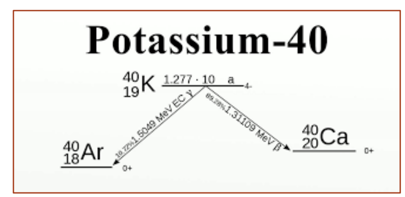
- Sourcing ultra-pure materials

Uranium-238



Thorium-232





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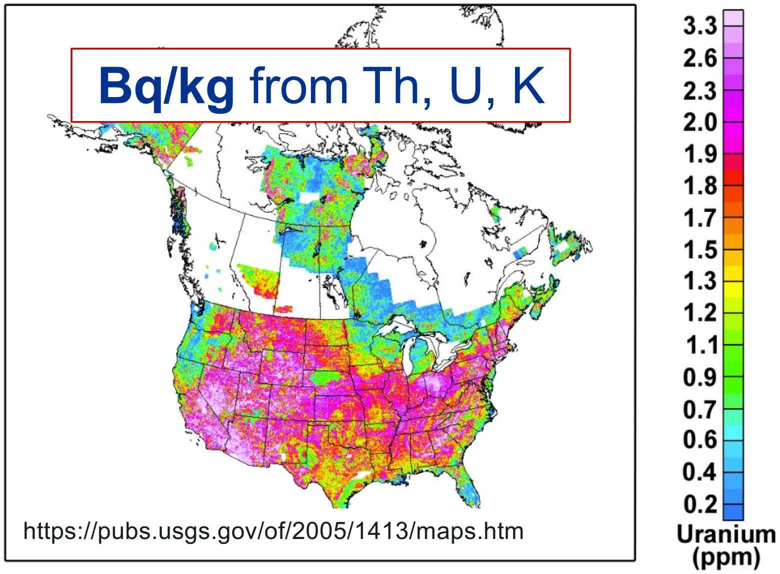
The challenge

- Material radiopurity requirements
  ≈ μBq/kg

- Sourcing
- Screening
  - Ultra-sensitive analytical methods
- Mitigating contamination
  - Exposure: handling and DUST!



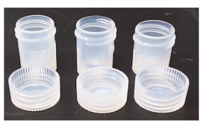
1 ppt Th = 4.1 μBq ^{232}Th/kg
1 ppt U =12.4 μBq ^{238}U/kg
1 ppb ^{nat}K = 30.5 μBq ^{40}K/kg

Dust background monitoring

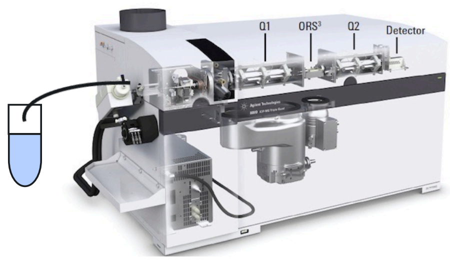
- X-ray fluorescence (XRF) analysis for Th and U **proxy elements** (e.g., Ca and Fe)
- Optical and fluorescence microscopy analysis
- Backgrounds predicted based on **dust fallout models and assumed composition**

- *Boger, Jea, et al. "The Sudbury neutrino observatory." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 449.1-2 (2000): 172-207*
- *Akerib, D. S., et al. "The LUX-ZEPLIN (LZ) radioactivity and cleanliness control programs." The European Physical Journal C 80 (2020): 1-52.*

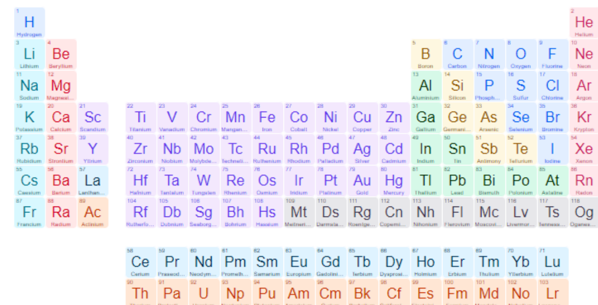
Direct ICP-MS method



1. Dust collection on low-background vials



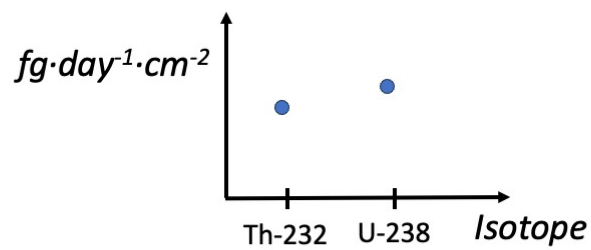
2. Dissolution and analysis on a triple quadrupole inductively coupled plasma mass spectrometer (ICP-MS, Agilent Technologies)



3. Determination of stable elements and long-lived radionuclides

- Sensitivity on ^{232}**Th and** ^{238}**U**
  (30-day collection, class ≈1000 cleanroom)

10^{-3} fg·day^{-1}·cm^{-2}, or 10^{-8} μBq·day^{-1}·cm^{-2}

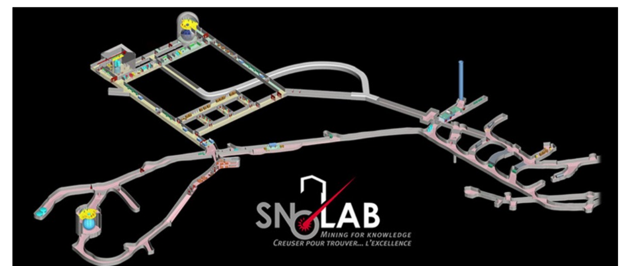


M.L. di Vacri et al., "Direct method for the quantitative analysis of surface contamination on ultra-low background materials from exposure to dust." Nuclear Inst. and Methods in Physics Research, A 449.1-2 (2020) 172-207

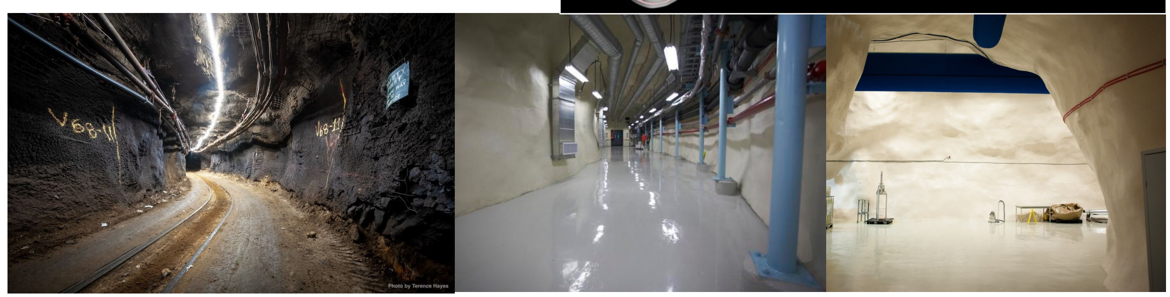
4. Determination of fallout rates
contaminant/surface/time

The SNOLAB facility

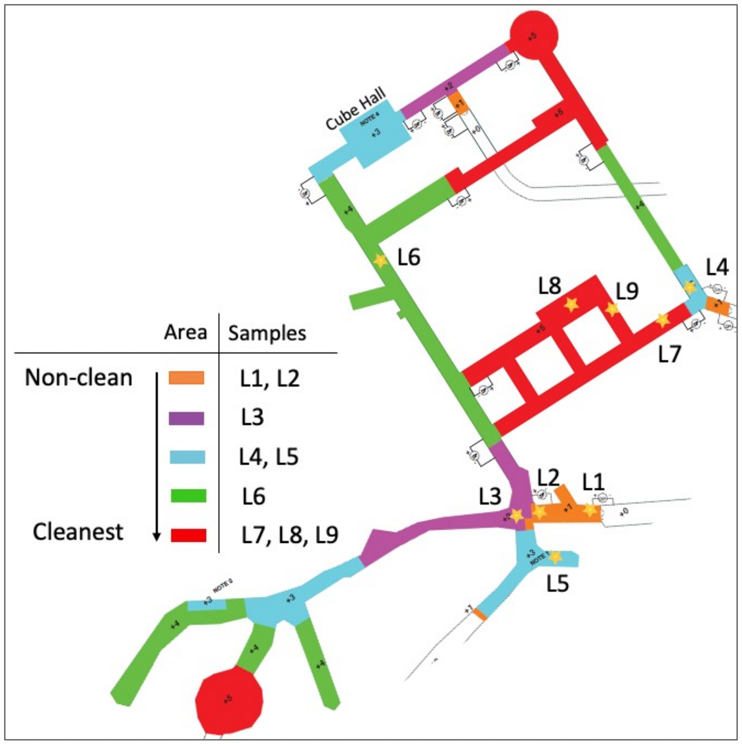
- A ≈ 5000 m^2 class-2000 cleanroom
- **2 km underground, in the working Creighton nickel mine** (operated by Vale Ltd.)



- Hosting neutrino and dark matter experiments
- **Dust control is crucial**



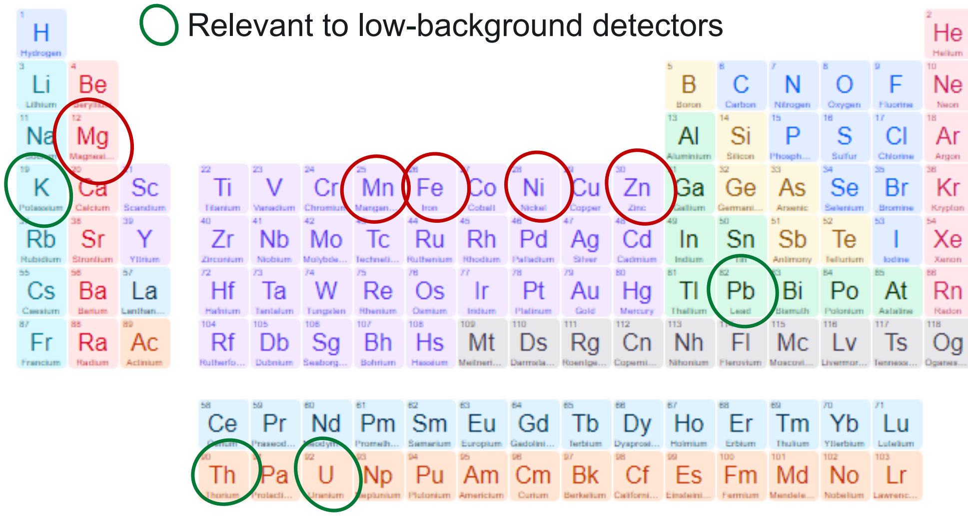
Evaluation of SNOLAB mitigation procedures

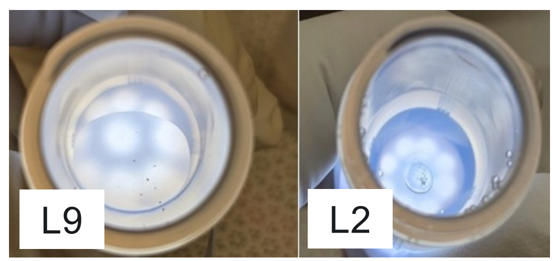


I. Lawson, Analysis of rock samples from the new laboratory, STR-2007-003 SNOLAB technical report (2007)

Tracers for dust from mine and local rock*

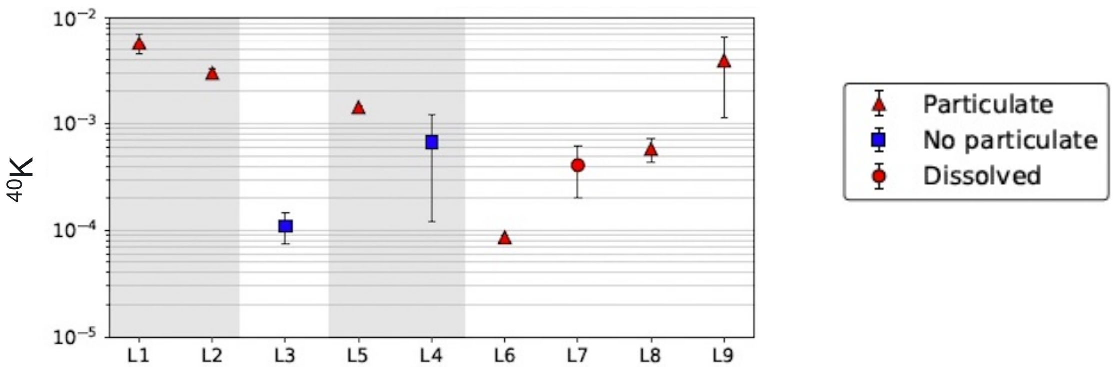
Relevant to low-background detectors

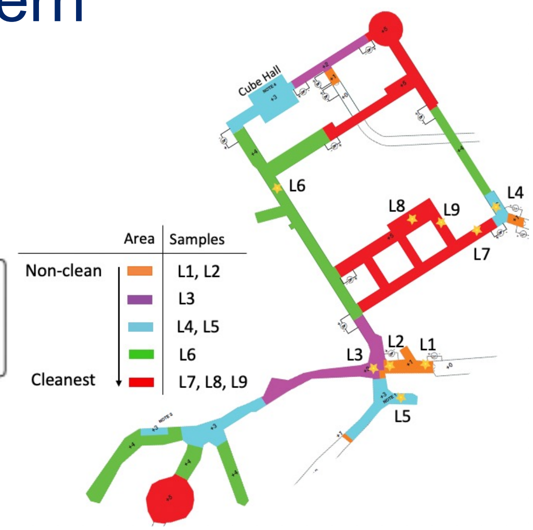


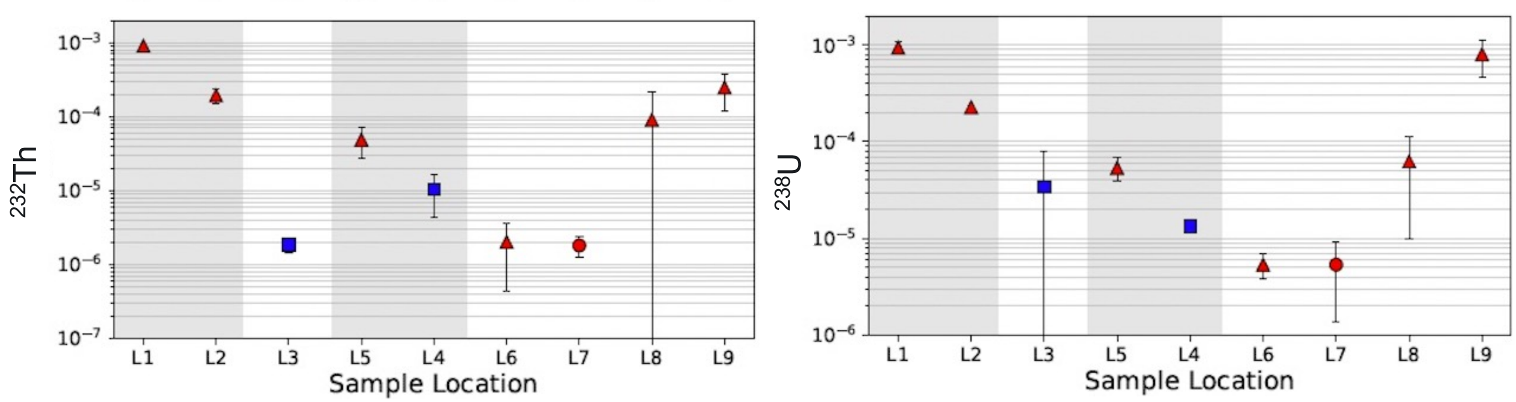


- 2-4 replicates per location
- Visible particulate found in some of the replicates

Results – Radionuclides of concern [µBq·day^{-1}·cm^{-2}]

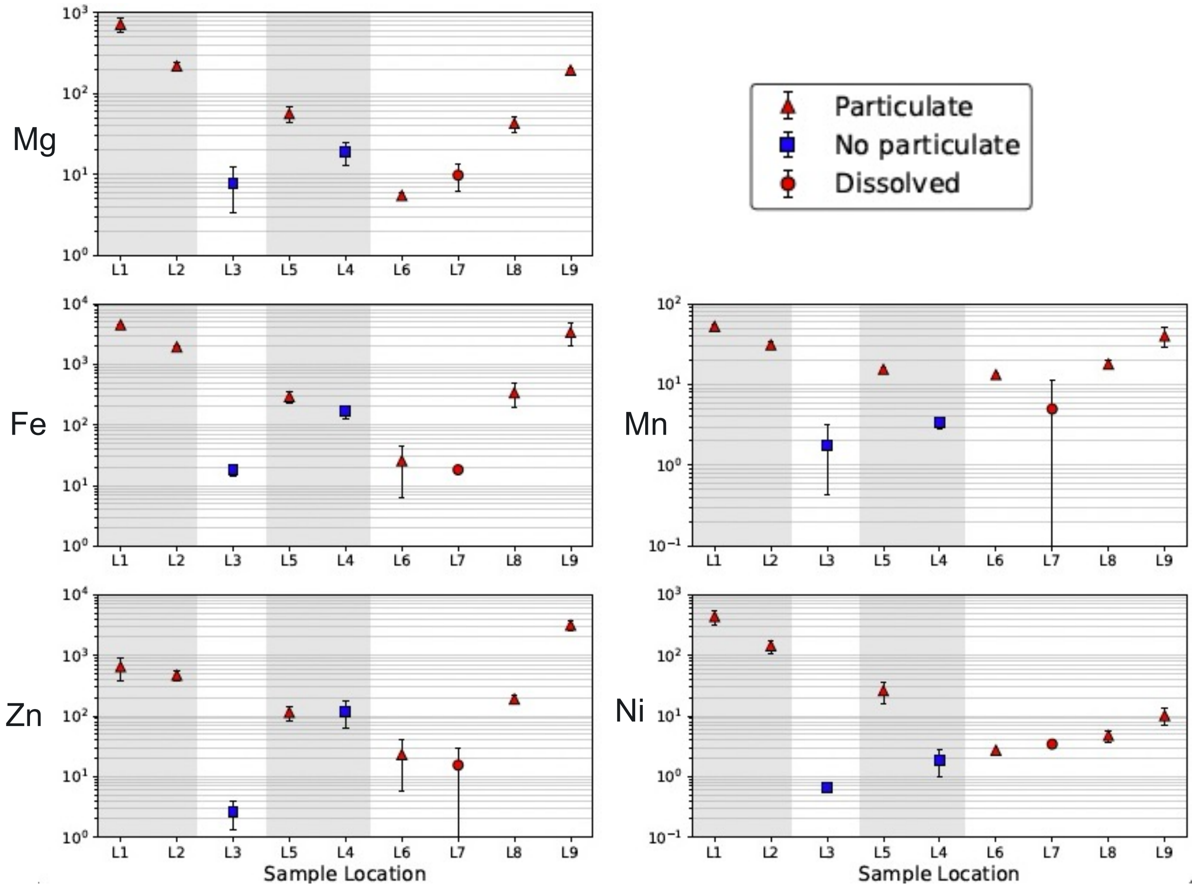


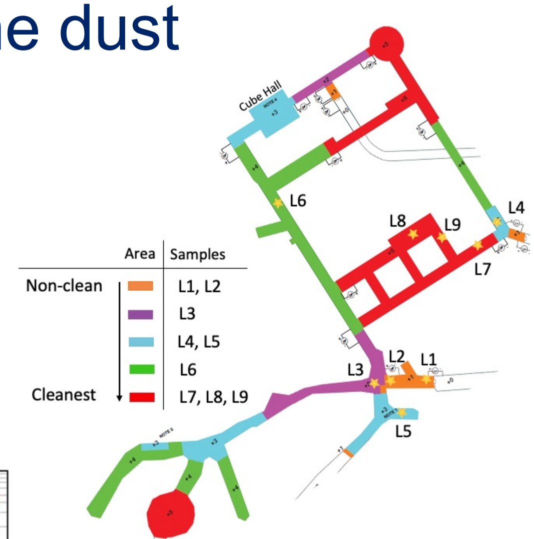




➢ Shaded areas refer to locations that are not maintained at cleanroom levels

Results – Tracers for rock and mine dust [pg·day^{-1}·cm^{-2}]



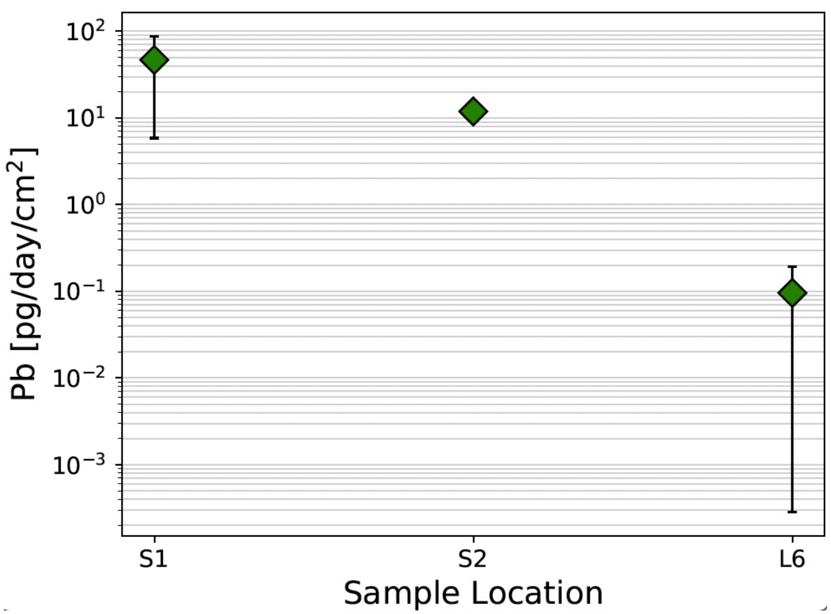


- Shaded areas refer to locations that are not maintained at cleanroom levels

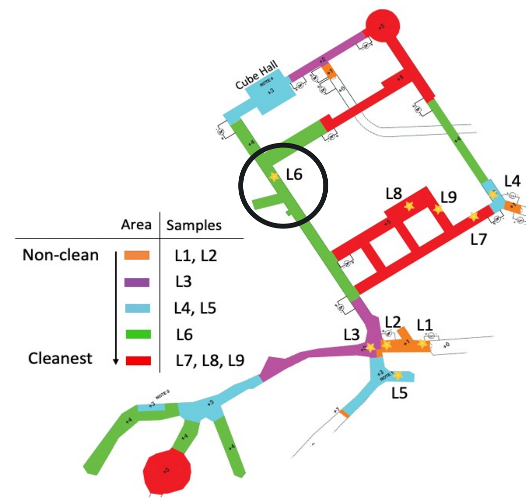
Ni is a mine dust tracer!

Results – Monitoring during construction of a Pb shield (Location 6)

- S1, S2 → Two locations around the Pb shield assembly area
- L6 → Data collected while no Pb was being handled



Pb fallout rate increased by two to three orders of magnitude



➢ Error bar hidden by marker in S2

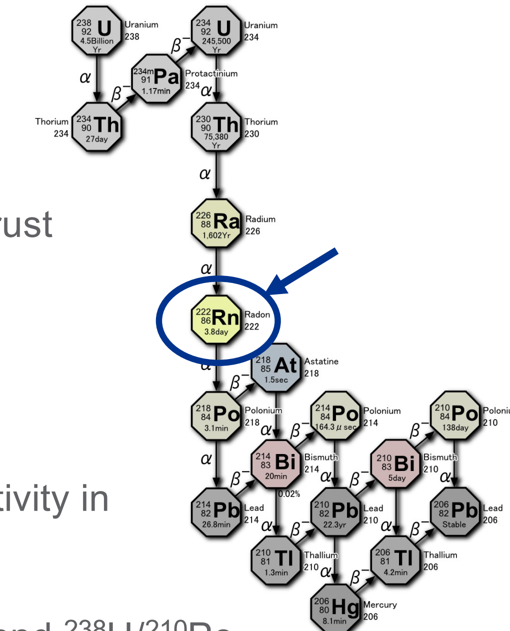
➢ HPGe measured ^{210}Pb in the material: (4.2 ± 1.0) Bq·kg^{-1}*

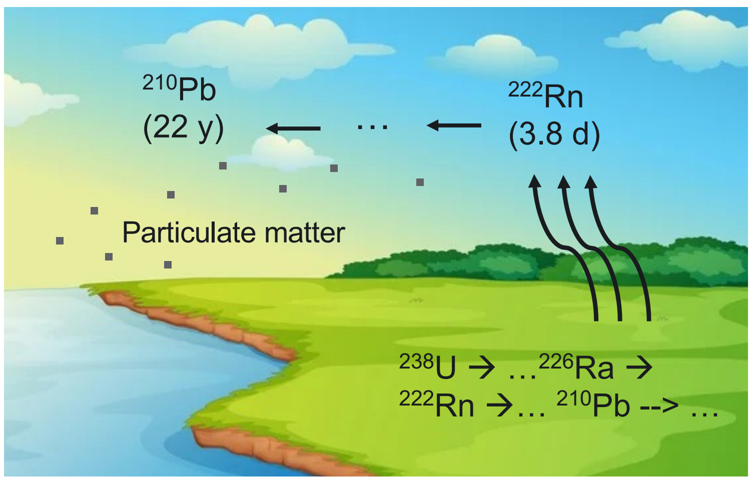
➢ ^{210}Pb fallout rate from the handled material [μBq·day^{-1}·cm^{-2}]:
- S1: (2.0 ± 1.8)x10^{-10}
- S2: (5.0 ± 1.3)x10^{-11}

* p-type Canberra Well Detector, 46 keV line, ≈50g sample

Some considerations

- ^{210}Pb is formed in the atmosphere from ^{222}Rn emanating from the Earth's crust
- Estimated dust activity from ^{238}U **assuming** local dust composition*:
  ≈ 0.02 Bq/g of dust
  - Activity from ^{210}Pb if also **assuming secular equilibrium**





- Reported** ^{210}Pb and ^{210}Po activity in outdoor and household dust:
  ≈ 0.1- 0.9 Bq/g
  - Disequilibrium ^{238}U/^{210}Pb and ^{238}U/^{210}Po

Investigate to what extent ^{210}Pb fractionation in particulate matter affects dust backgrounds in a cleanroom environment

*I. Lawson, Analysis of rock samples from the new laboratory, STR-2007-003 SNOLAB technical report (2007)

**J. Chen, Radiat Environ Biophys 48, 427-432 (2009); M. Behbehani et al., Journal of Environmental Radioactivity, 222 (2020) 106323

Conclusions

- Effective tool to:
  - **Inform** dust backgrounds
  - **Evaluate** mitigation procedures
    - Efficacy of SNOLAB dust mitigation procedures
- Dust backgrounds in clean labs are determined by ongoing **activities** and handled **materials**
- Can be leveraged to develop **quantitative material cleaning** procedures

Note: Adopted within the SCDMS collaboration to monitor backgrounds from dust during installation activities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Full Length Article

Evaluation of SNOLAB background mitigation procedures through the use of an ICP-MS based dust monitoring methodology

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https://doi.org/10.1016/j.nima.2023.168700

If you are interested in monitoring your lab/procedures, please reach out!

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What's next?

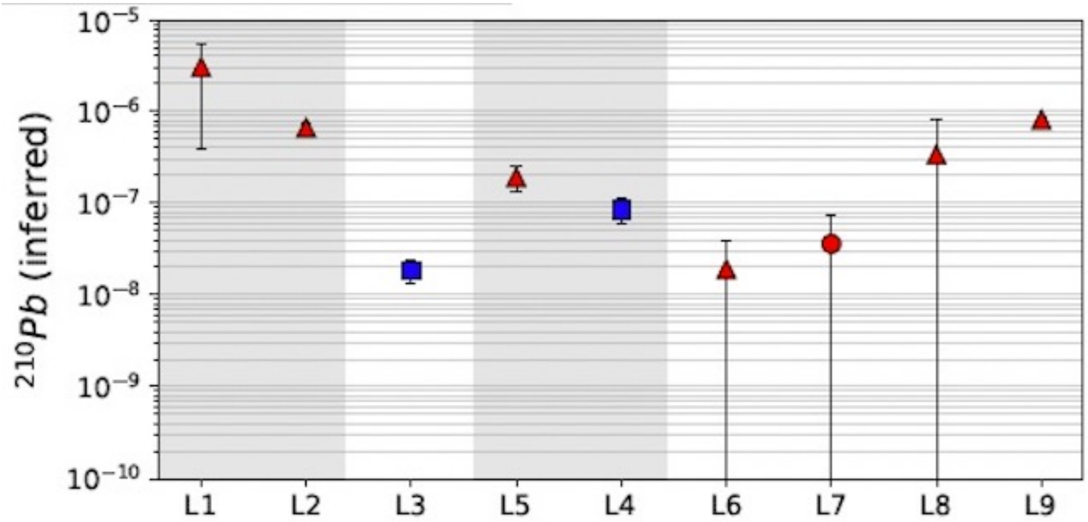
- Develop methods to **investigate** the contribution to cleanroom dust backgrounds from **^{238}U progeny** (e.g., ^{210}Pb)

Thank you!
Questions?

- DOE, USA Office of High Energy Physics Advanced Technology R&D subprogram (KA-25)
- Canada Foundation for Innovation
- Province of Ontario Ministry of Research and Innovation

Back up slides

[μBq·day⁻¹·cm⁻²]



- A reference value for Pb specific activity from ^{210}Pb (200 Bq·kg^{-1}*) was used to infer ^{210}Pb fallout rate

*Alessandrello, A., et al. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* 142.1-2 (1998): 163-172.

I.T. Lawson, Analysis of Rock Samples from the New Laboratory: STR-2007-003
SNOLAB Technical Report (2007)

Table 5. Average concentrations of K, Ca, Fe, Pb, Th and U in rock and concrete samples from the SNOLAB site[30].

Element	Rock	Concrete
K [%]	0.99	1.6
Ca [%]	3.6	10.1
Fe [%]	6.5	2.6
Pb [ppm]	10.4	13.9
Th [ppm]	5.4	13.1
U [ppm]	1.2	2.4

Avg U [ppm]: 1.8