The SNOLAB Low Background Measurement Program

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SNOLAB

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The Guildhall, York, UK
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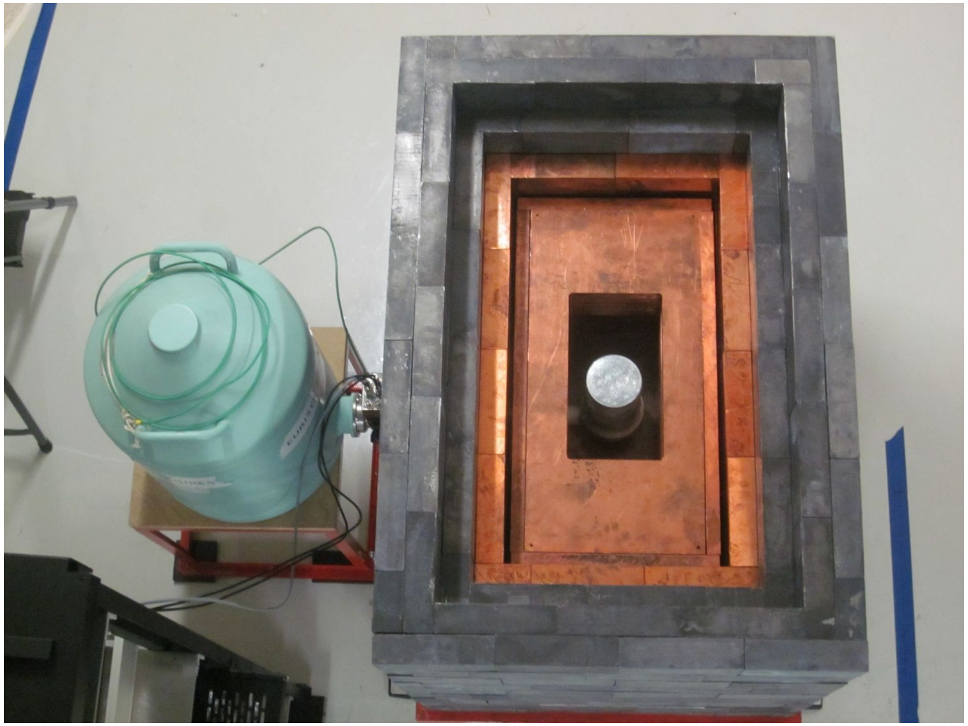
SNOLAB LBL

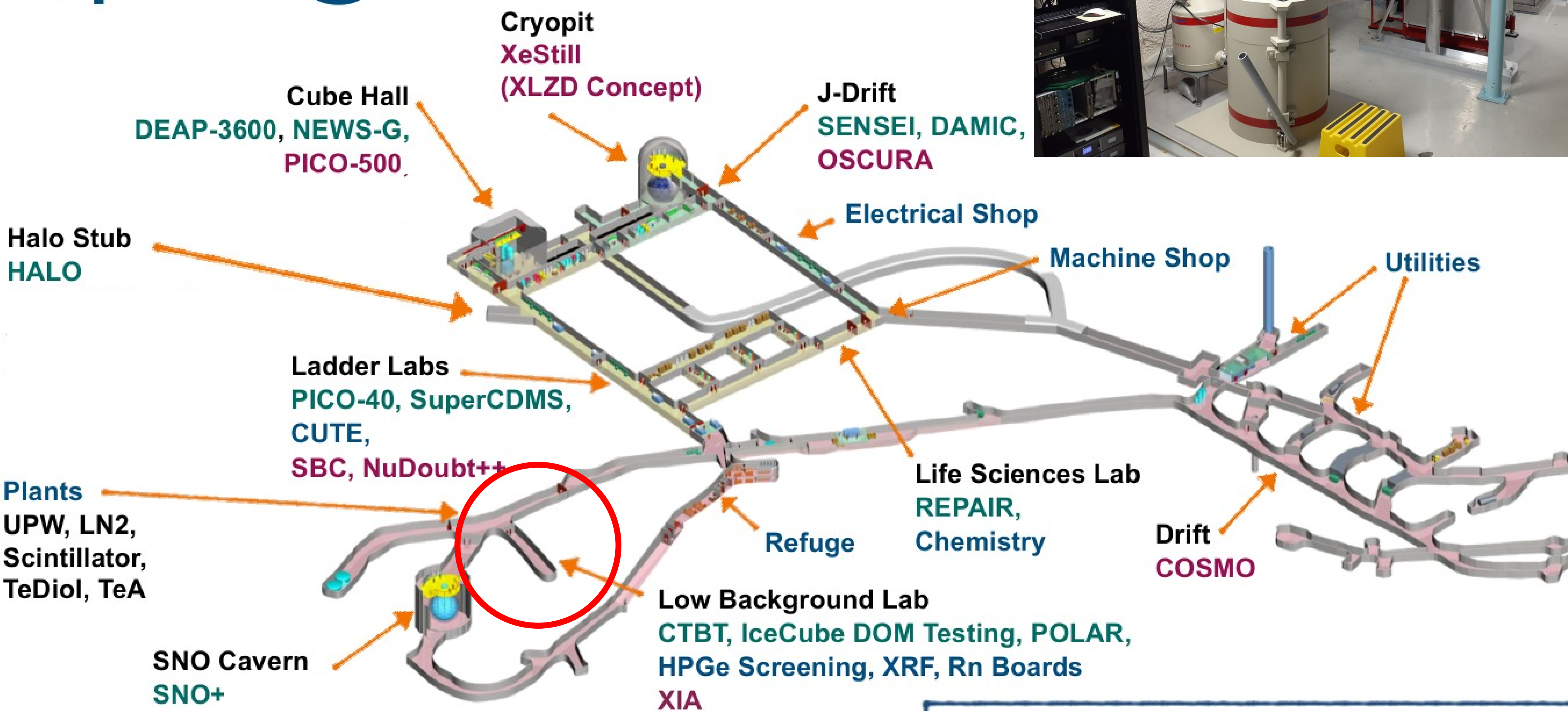

VDA Detector

The SNOLAB Facility

- Hosted at the Vale Creighton Nickel Mine in Greater Sudbury, Ontario, Canada
- Operated as a joint venture of 5 Canadian Universities (Carleton, Queen’s, Montreal, Alberta, and Laurentian) and Vale
- Operations funded by the Canada Foundation for Innovation and the Province of Ontario, with in-kind support from Vale

The SNOLAB Facility

Spaces @ SNOLAB



- 5,000 m^2 of class 2000 cleanroom
- <2000 particles >0.5 μm in diameter per ft^3

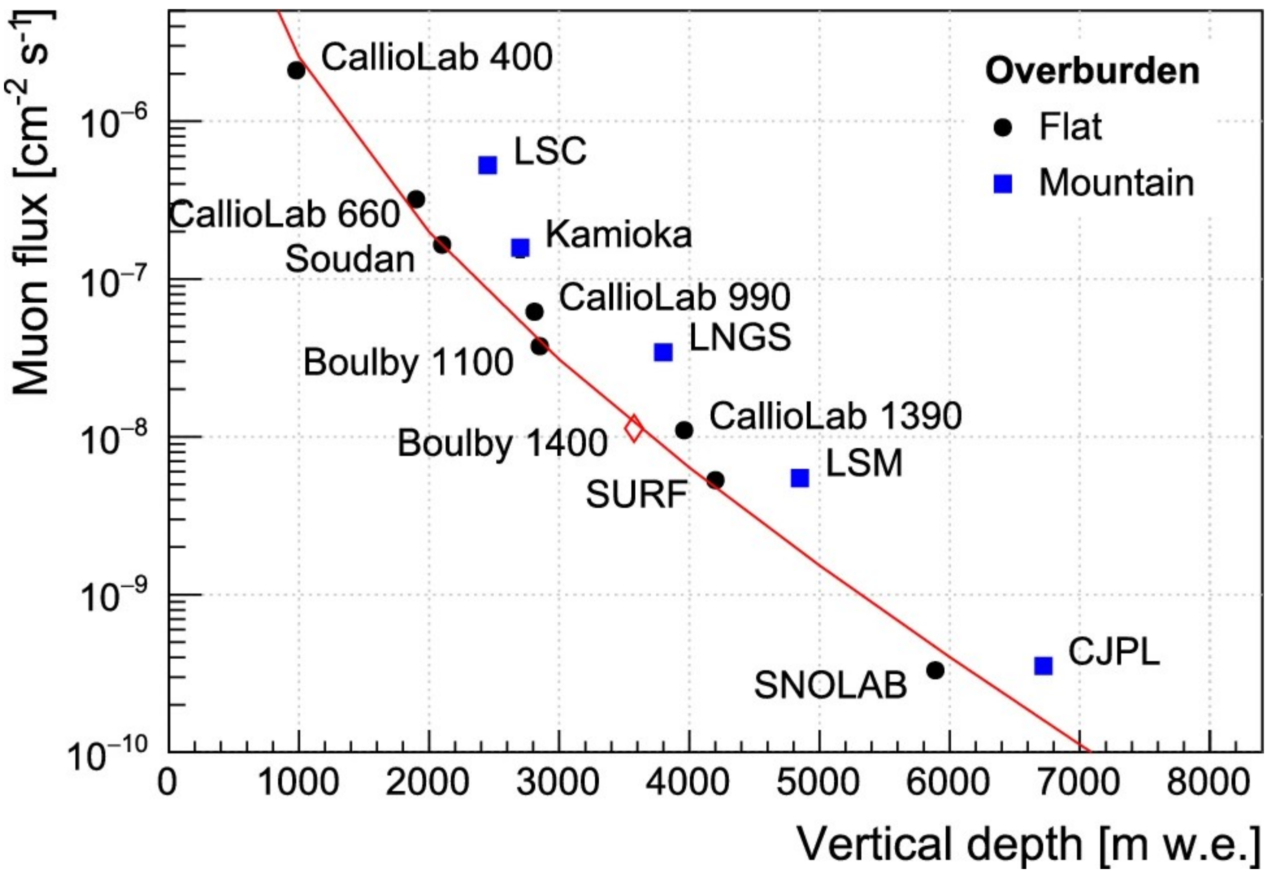
Techniques to Measure These Backgrounds

Measurement Method	Background Detected	Sensitivity (for U/Th)
•Ge spectrometry	γ emitting nuclides	10-100 μBq/kg
•Rn emanation assay	^{226}Ra, ^{228}Th	0.1-10 μBq/kg
•Neutron activation - Proposal in progress to be able to do this at SNOLAB	primordial parents	0.01 μBq/kg
•Liquid scintillation counting - Proposal to buy or build new system	α,β emitting nuclides	1 mBq/kg
•Mass spectrometry (ICP-MS, AMS)	primordial parents	1-100 μBq/kg
•Graphite furnace AAS	primordial parents	1-1000 μBq/kg
•Röntgen Excitation Analysis (XRF)	primordial parents	10 mBq/kg
•α spectrometry (XIA)	^{210}Po, α emitting nuclides	1 mBq/kg

To reach these sensitivities, samples usually have to very large and may have to count for several months.

Muon Suppression

- 2 km overburden
- 6000 mwe
- Muon flux: 0.27 muons/m/day



From Eur Phys J84 (2024) 481

SNOLAB - Rock Properties

- Analysed using ICP-MS, ICP-AES and XRF
- Gamma Counted with HPGe
- Norite: The same as new lab areas
- Shotcrete: New areas slightly higher for Uranium and more than 2x for Thorium

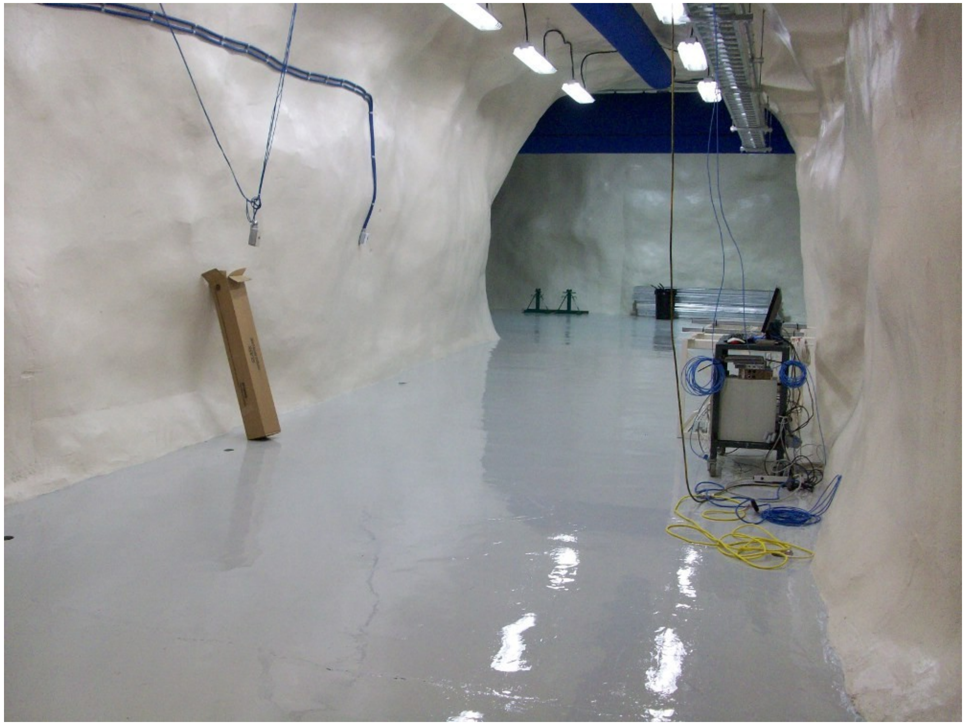
	Norite Rock	Shotcrete/Concrete
O	47 %	48 %
Si	27 %	28 %
Fe	6.5 %	2.5 %
Al	6 %	6 %
Mg	6 %	1 %
Ca	3.5 %	10 %
Na	1.7 %	2 %
K	1 %	1.7 %
Ti	0.3 %	0.2 %

Norite Density: 2.88 g/cm^3

SNOLAB - Rock Properties

Amount of ^{232}Th an ^{238}U which can cause backgrounds in our UG experiments

Isotope	Norite Rock		Shotcrete	
	Concentration	Neutron Production (n/yr/cm^3)	Concentration	Neutron Production (n/yr/cm^3)
^{232}Th	5.10 ppm	8.13	2.4 ppm	0.99
^{238}U	1.10 ppm	3.51	1.2 ppm	1.05
Spontaneous Fission ^{238}U		1.19		1.03
Total		12.83		3.07



SNOLAB - Rock Properties Neutron Production

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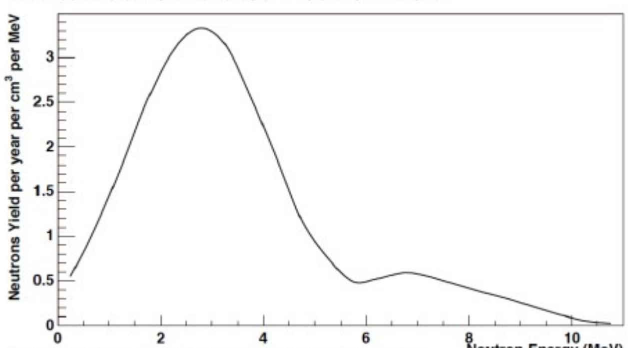
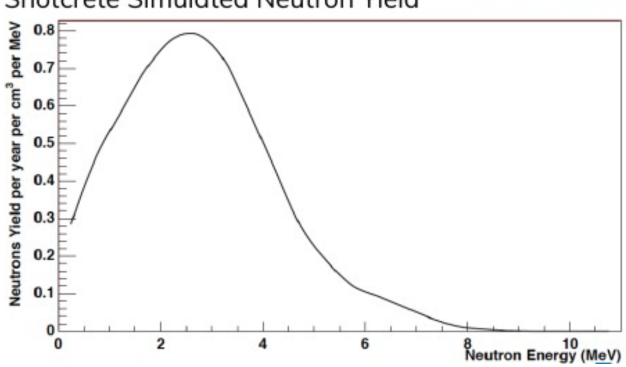
Norite Rock Simulated Neutron Yield



Shotcrete Simulated Neutron Yield



Neutron production estimates were obtained from SOURCES-4C and used as input in GEANT4

- 90%: (α,n) on light elements
- 10%: ^{238}U spontaneous fission
- Measurements from SNO area (1999):
- Thermal Flux: 4144 +- 50 +- 105 neutrons / m² / day
- Estimated Fast Neutron Flux: 4000 neutrons / m² / day

Neutron Flux Measurements at SNOLAB

SNOLAB Underground neutron measurement program began by using neutron bubble detectors from BTI.

However, due to the low flux rate underground at SNO-LAB these detectors will take many years to achieve enough statistics to get a measurement.

SNOLAB's HALO experiment has extra ^3He detectors, which this project is using to make this measurement. These detectors are ~ 2 m and ~ 5 cm in diameter and contain 85% ^3He and 15% CF_4.

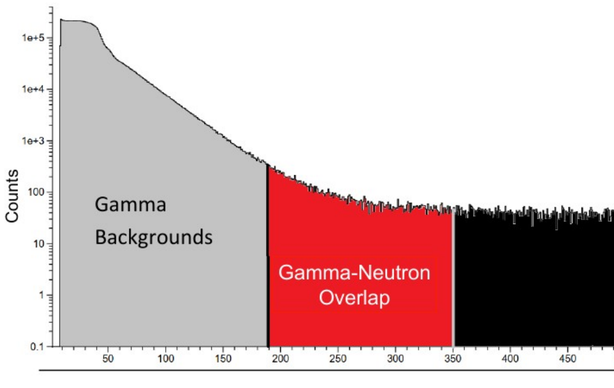
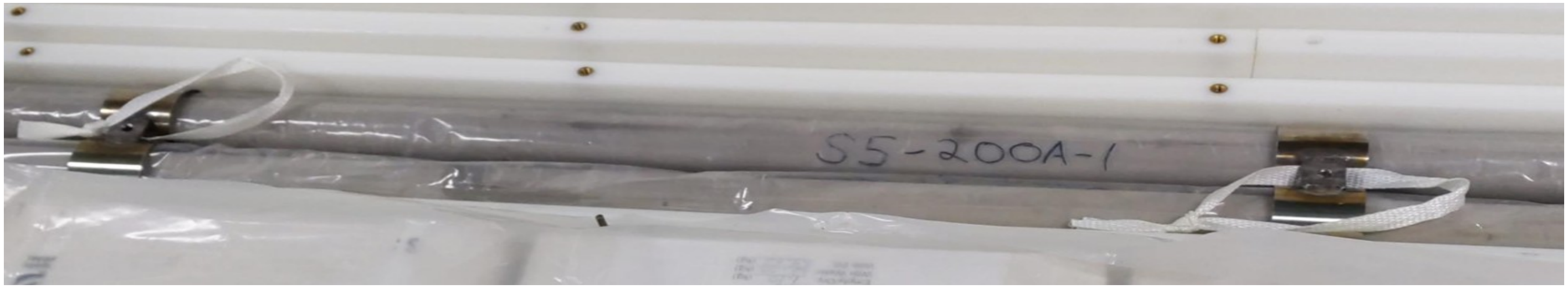


Fig: Experimental AmBe data, background overlap with neutron capture data



Preliminary Neutron Flux Background

Table 1: Configuration R6 Analysis (1", 3", Bare | Prior Weight| κ: 5.65)

Method	Thermal (10E−10 to 10E-7 MeV) $10^{-6} n\ cm^{-2} s^{-1}$	Intermediate (10E-7 to 0.1 MeV) $10^{-6} n\ cm^{-2} s^{-1}$	Fast (0.1 to 11 MeV) $10^{-6} n\ cm^{-2} s^{-1}$	Total Flux (0–11 MeV) $10^{-6} n\ cm^{-2} s^{-1}$
Direct Inversion	2.551	5.896	3.124	**11.571**
LUD ± MC	2.550 ± 0.158	5.899 ± 0.313	3.121 ± 0.153	**11.570 ± 0.383**
SVD ± MC	2.553 ± 0.158	5.890 ± 0.309	3.126 ± 0.152	**11.569 ± 0.378**

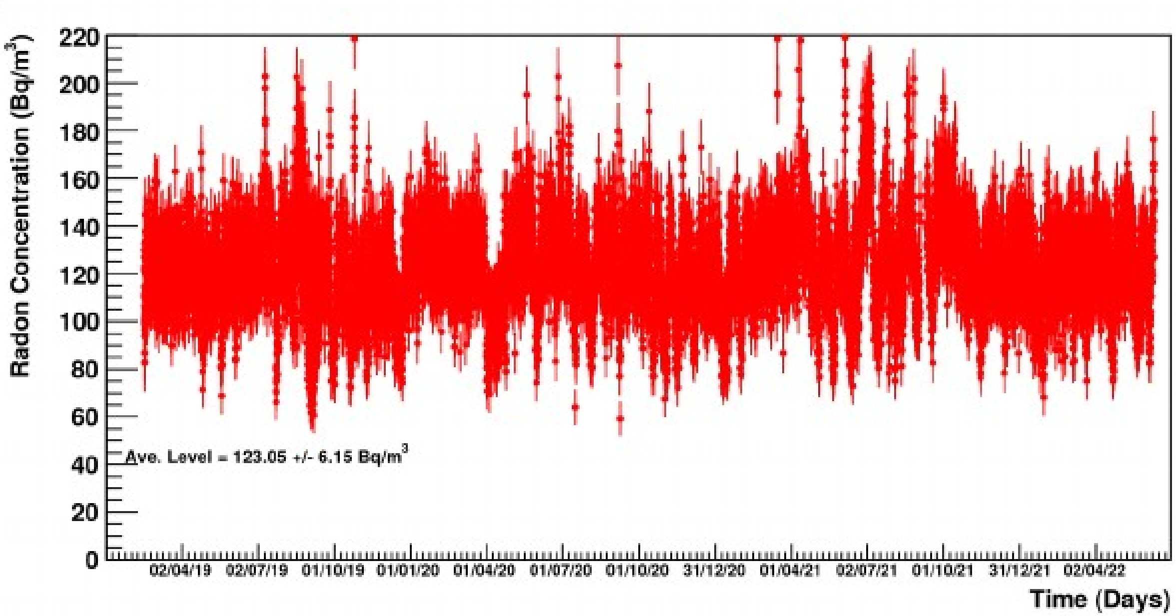
Table 3: Configuration R4 Analysis (1", 3", Bare |Flat Prior| κ: 4.66)

Method	Thermal (10E−10 to 10E-7 MeV) $10^{-6} n\ cm^{-2} s^{-1}$	Intermediate (10E-7 to 0.1 MeV) $10^{-6} n\ cm^{-2} s^{-1}$	Fast (0.1 to 11 MeV) $10^{-6} n\ cm^{-2} s^{-1}$	Total Flux (0–11 MeV) $10^{-6} n\ cm^{-2} s^{-1}$
Direct Inversion	4.132	6.141	2.835	13.108
LUD ± MC	4.134 ± 0.118	6.141 ± 0.280	2.835 ± 0.162	13.110 ± 0.344
SVD ± MC	4.132 ± 0.118	6.142 ± 0.276	2.834 ± 0.163	13.109 ± 0.342

The thermal flux measurement details are to be submitted for publication soon:

“Thermal Neutron Flux Measurement at SNOLAB Using Repurposed ^{3}He Neutral Current Detectors”

Radon Levels

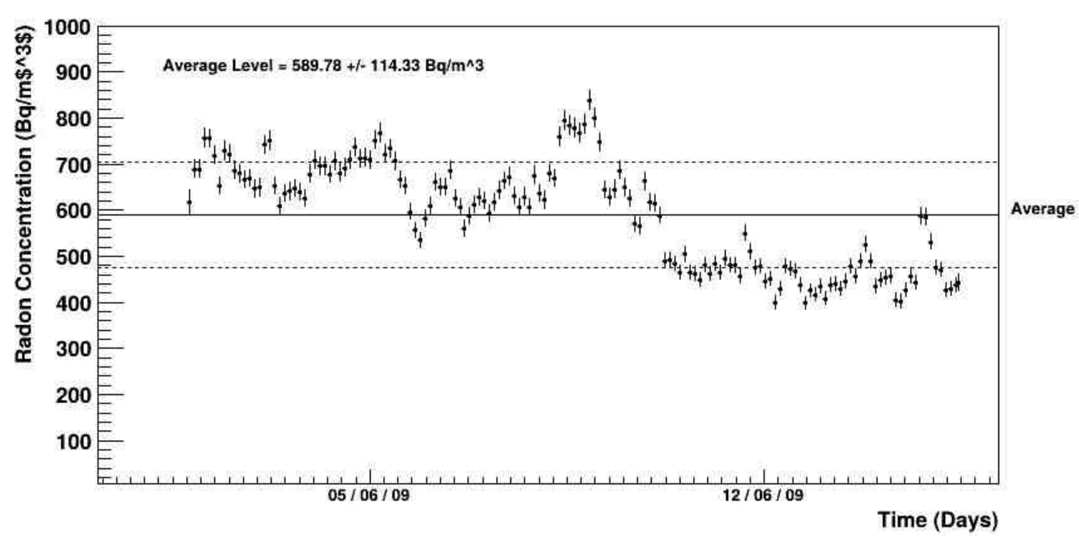


Average radon levels (with air circulation operational:

123.1 +- 6.2 Bq/m^3

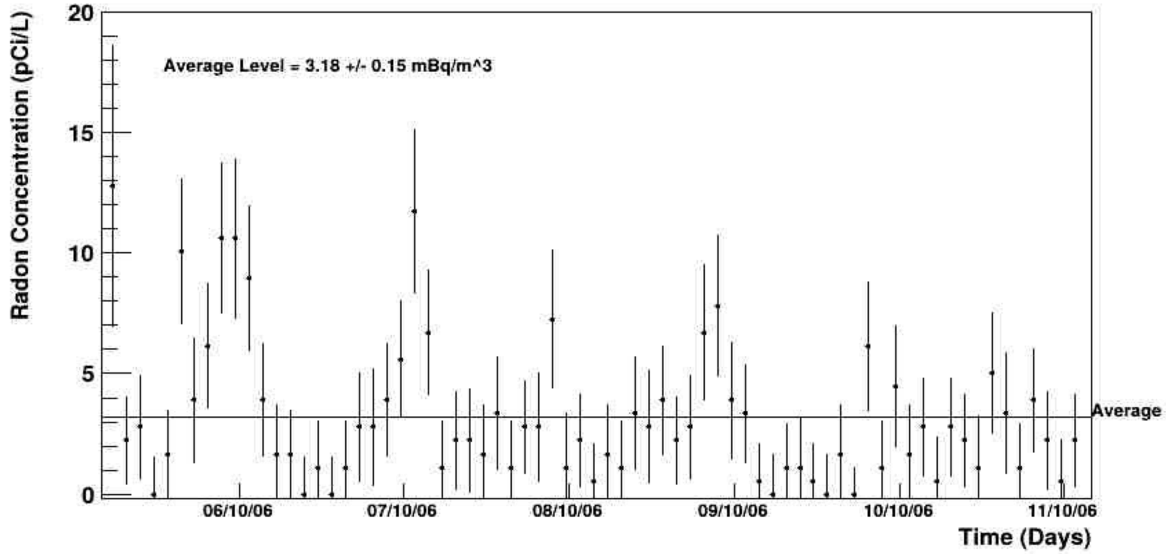
Average radon levels without air circulation:

589.8 +- 114.3 Bq/m^3.



Reducing Radon Levels

Use compressed air supplied from surface



Use liquid nitrogen boil-off gas

Use compressed air supplied from surface: 3.18 +- 0.15 Bq/m^3

One can also use nitrogen gas to purge radon from small/medium volumes: 2.06-4.41 Bq/m^3

Even better results can be achieved using radon scrubbing systems

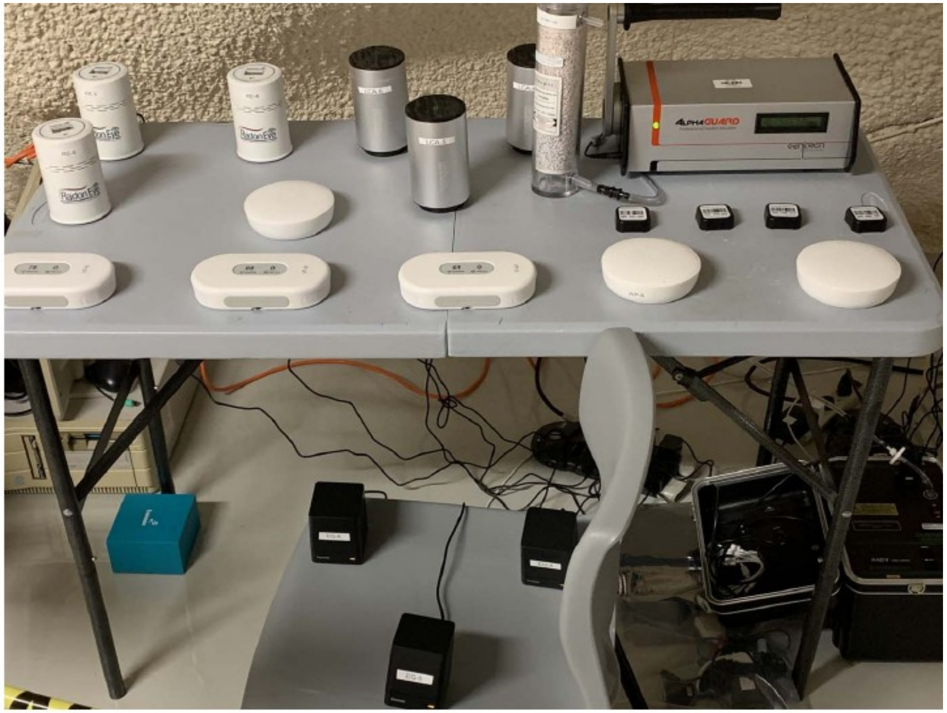
Collaboration with Health Canada

SNOLAB and Health Canada used SNOLAB's unique underground environment to test several commercial grade radon monitors in 2024.

Tests are continuing with additional monitors for long-term stability tests and comparison to calibrated science grade radon monitors from Alphaguard and Durridge Inc. (RAD7 / 8).

The results of the initial set have tests are being published in Health Physics 129 (2025) 374, DOI: 10.1097/HP.0000000000001986

A new test with additional monitors will be starting soon in the mine drift areas to determine the monitors effectiveness in real world mine environments.



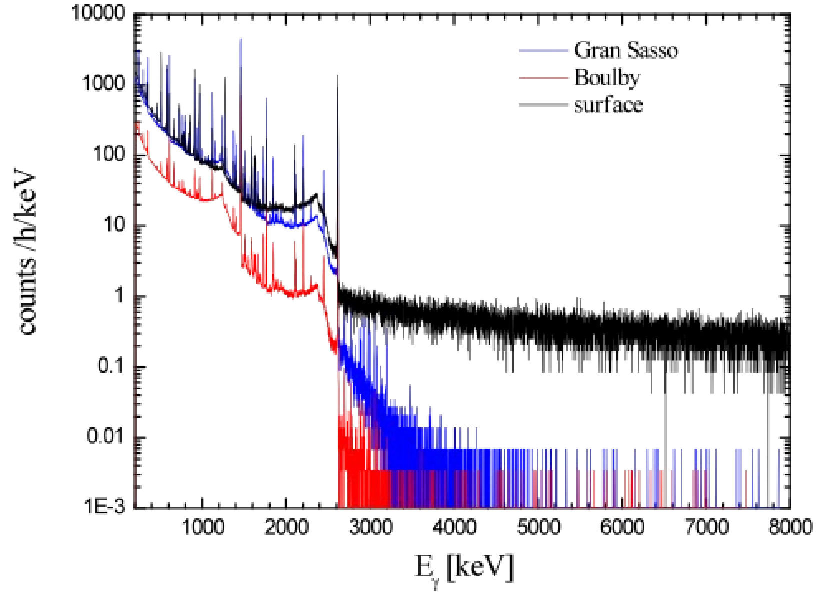
Gamma-ray Backgrounds

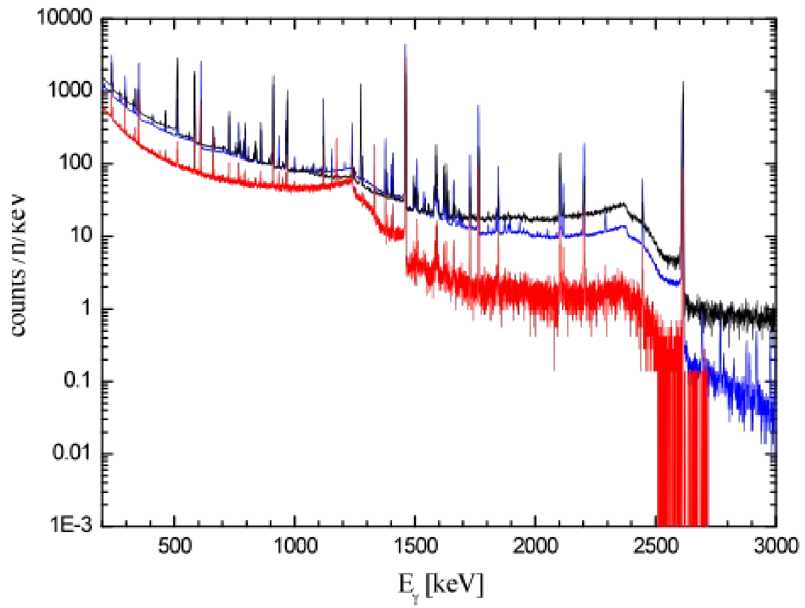
Reduction in γ-ray background at higher energies from c.r. and neutron reduction

- important for nuclear astrophysics dedicated beam experiments, and some $0\nu\beta\beta$ isotopes

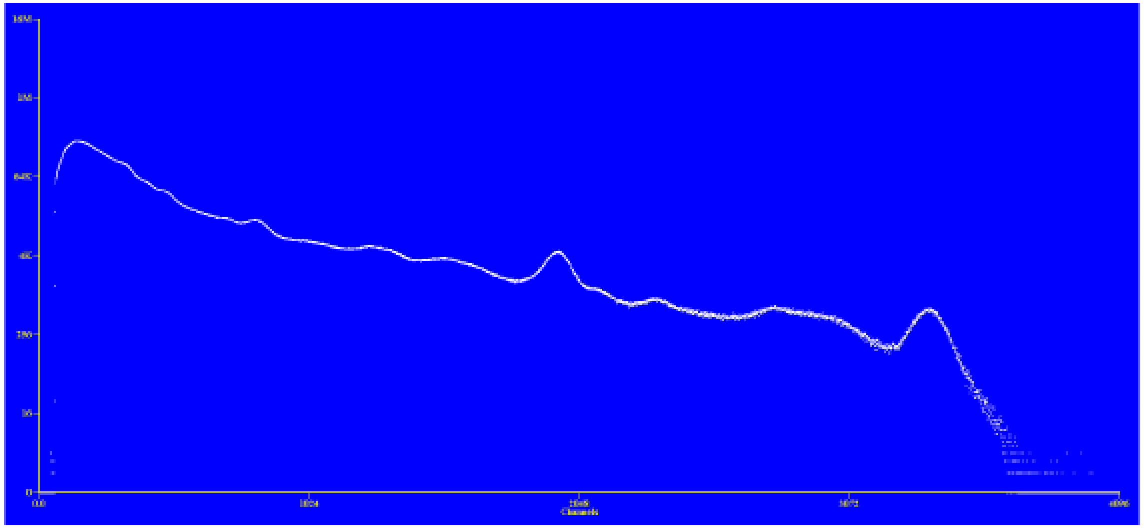
Below 3.5MeV dependent on local geology and rock material

- Boulby (red)
- Gran Sasso (blue)
- surface (black)





Gamma-ray Backgrounds



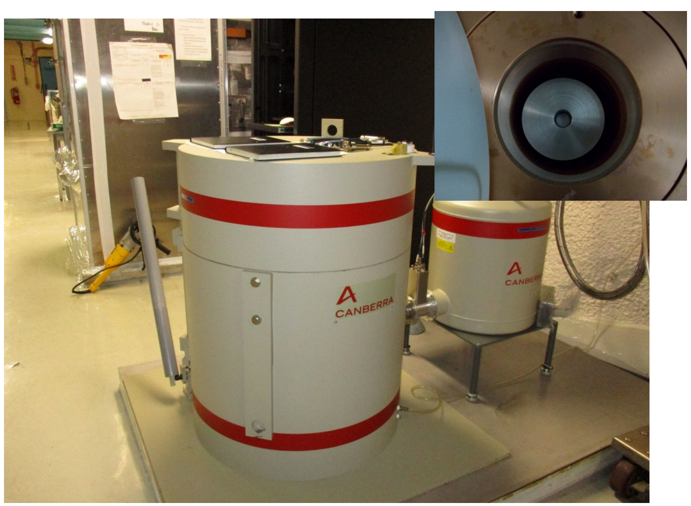
Sample of raw data from one of the small NaI crystal after 7.4 days

- Detailed gamma spectra below 3 MeV in different areas of the laboratory is of interest
- This spectra depends on the rock composition and materials, so it varies within the lab
- We have two 1.5 x 1.5 inch NaI(Tl) crystal and MCAs
- Currently measuring internal backgrounds
- A lab survey will be completed to generate spectra for areas of interest in the lab
- A paper is nearly ready for submission.

Material Characterization with HPGe Spectrometry

PGT

Lively

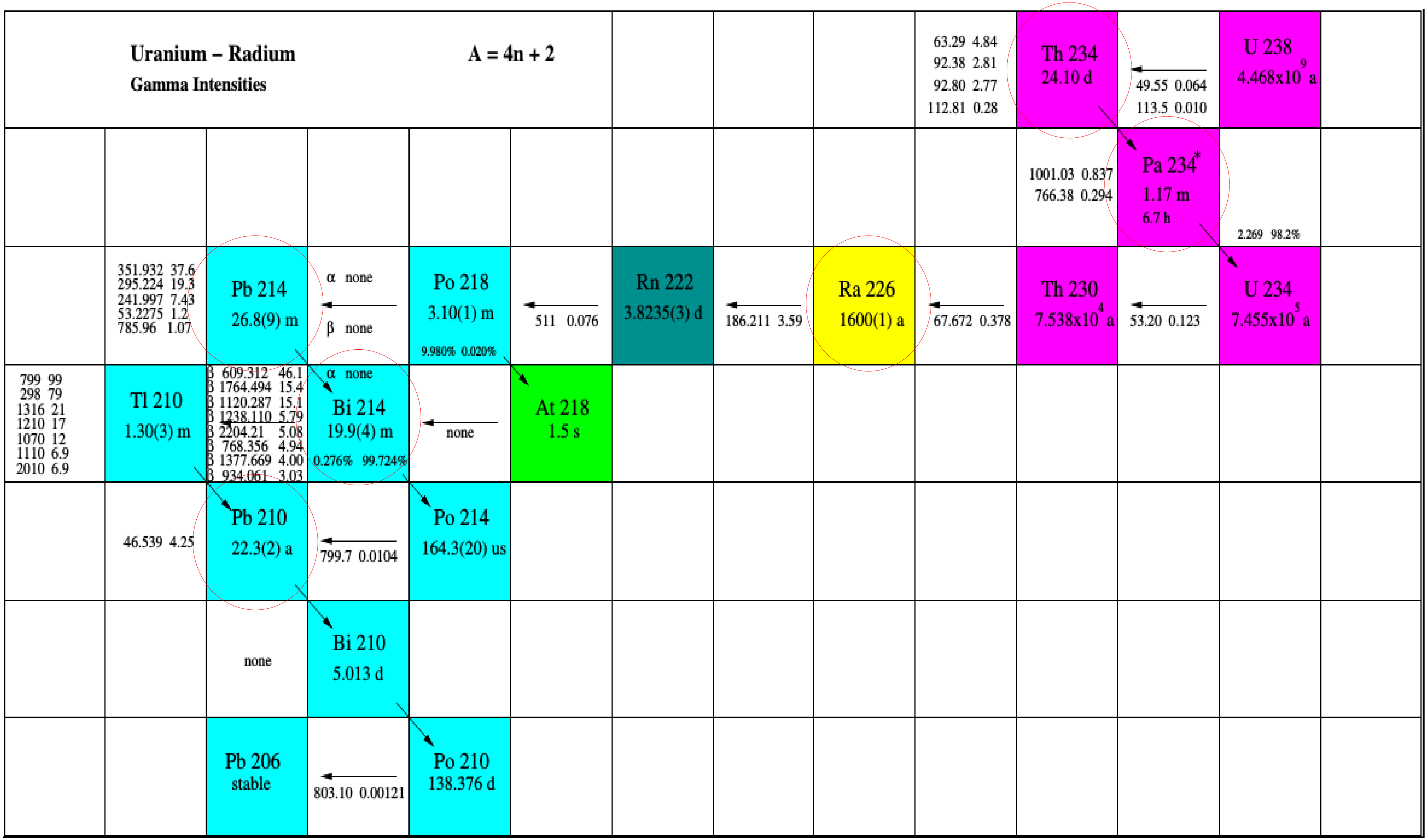


Chelmsford

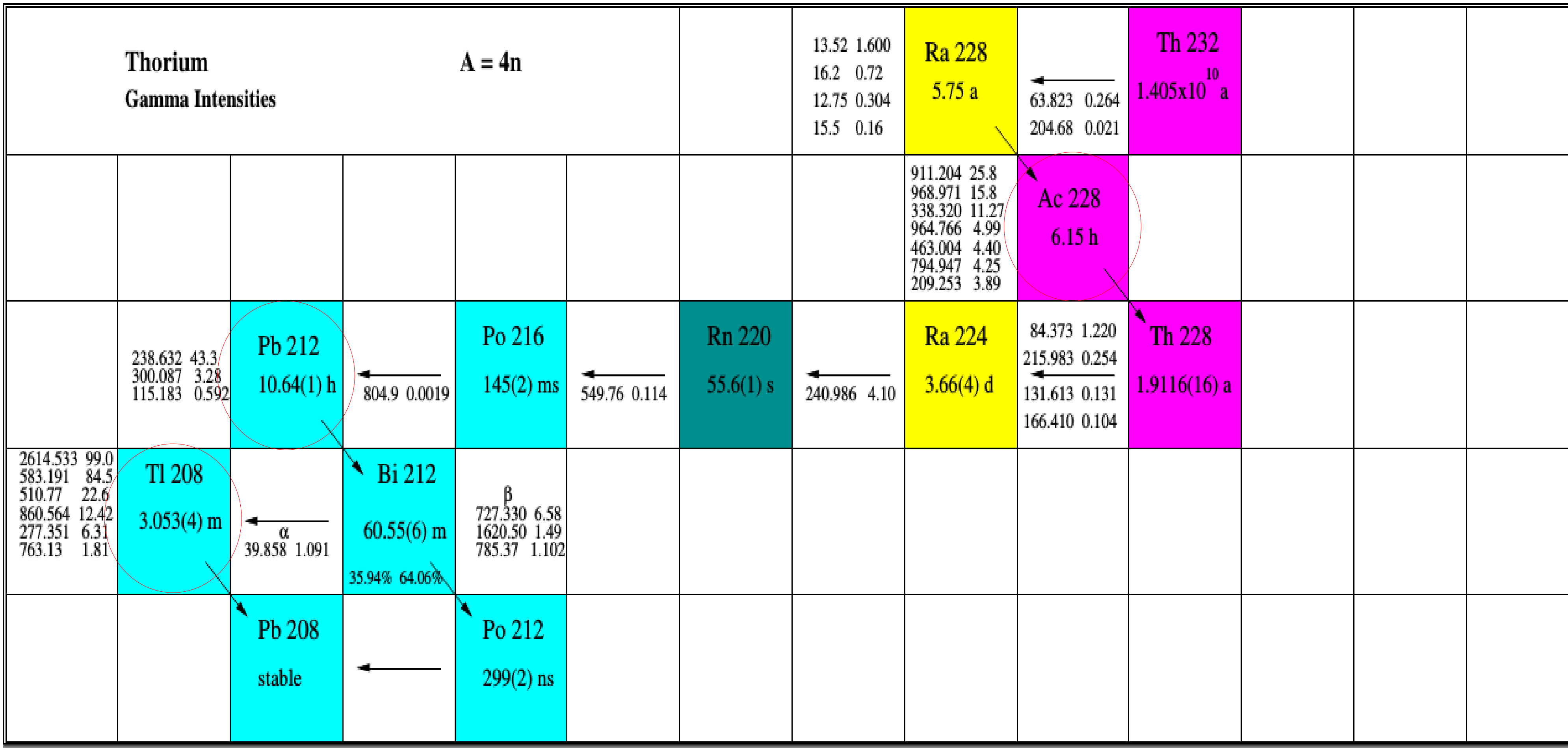
Gopher

VdA

Uranium Decay Chain



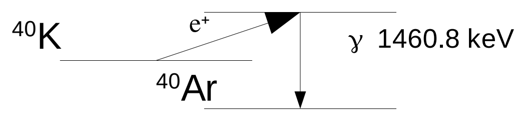
Thorium Decay Chain



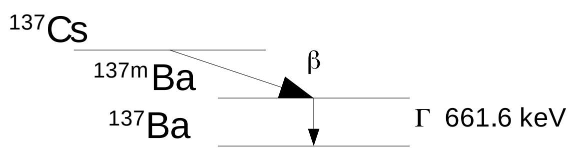
Other Interesting Isotopes

Usually Present:

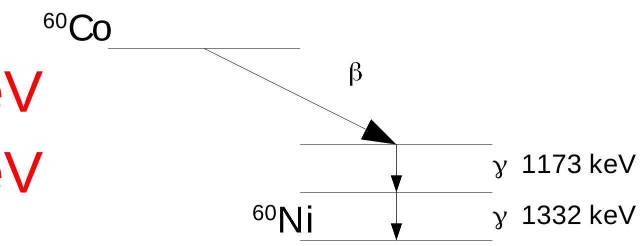
- ^{40}K
  - 1460.83 keV



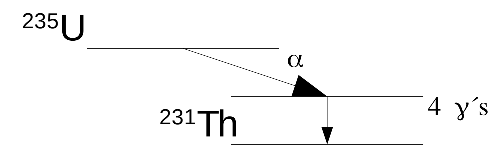
- ^{137}Cs
  - 661.66 keV
  - (from fallout)



- ^{60}Co
  - 1173.2 keV
  - 1332.5 keV



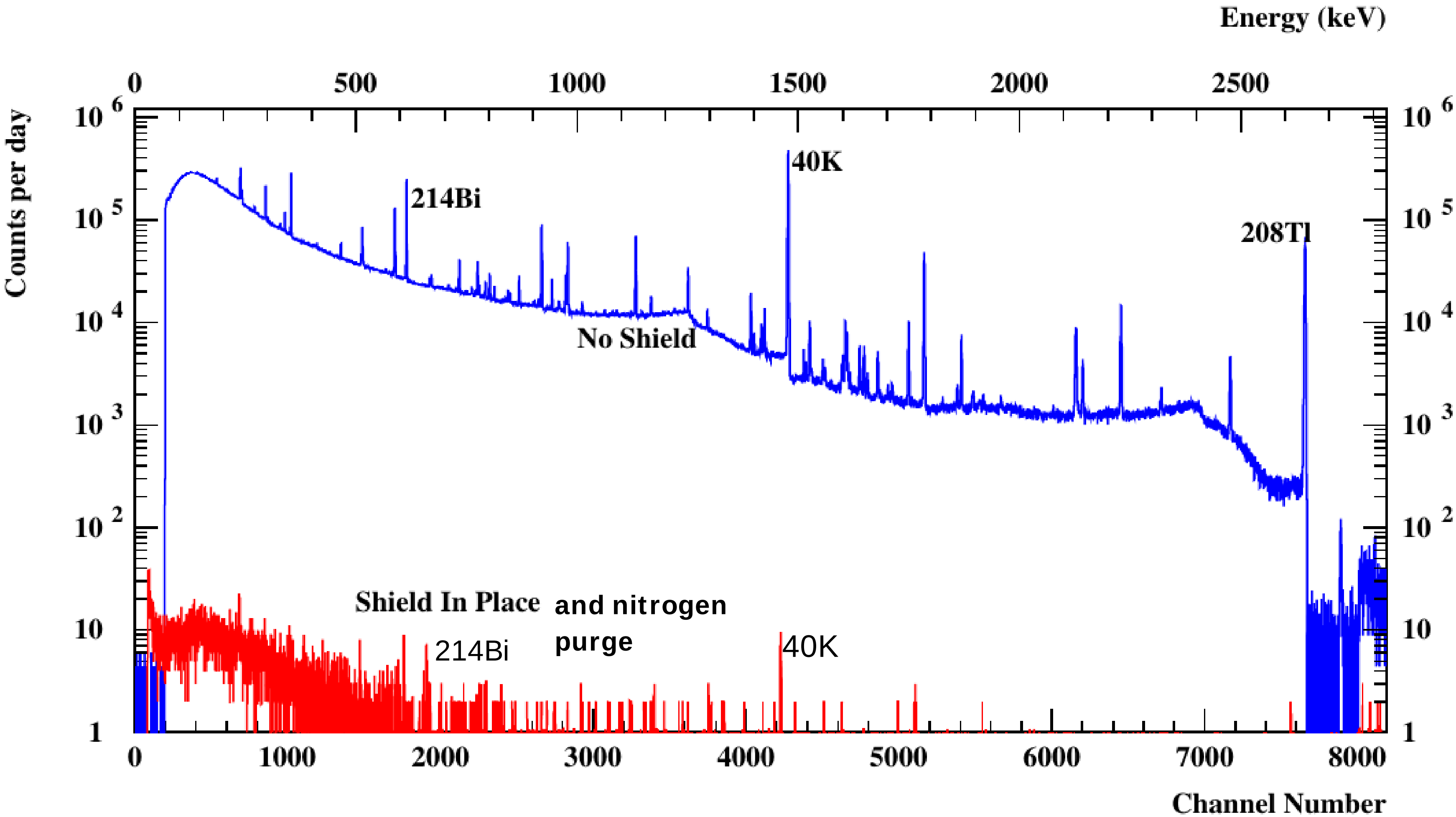
- ^{235}U
  - 143.76 keV
  - 163.33 keV
  - 185.22 keV
  - 205.31 keV



Occasionally Present:

- ^{54}Mn at 834.85 keV — Observed in Stainless Steel
- ^{7}Be at 477.60 keV — Observed in Carbon based materials, due to neutron activation, samples are particularly affected after long flights.

Unshielded and Shielded Spectra (PGT Coax Detector)



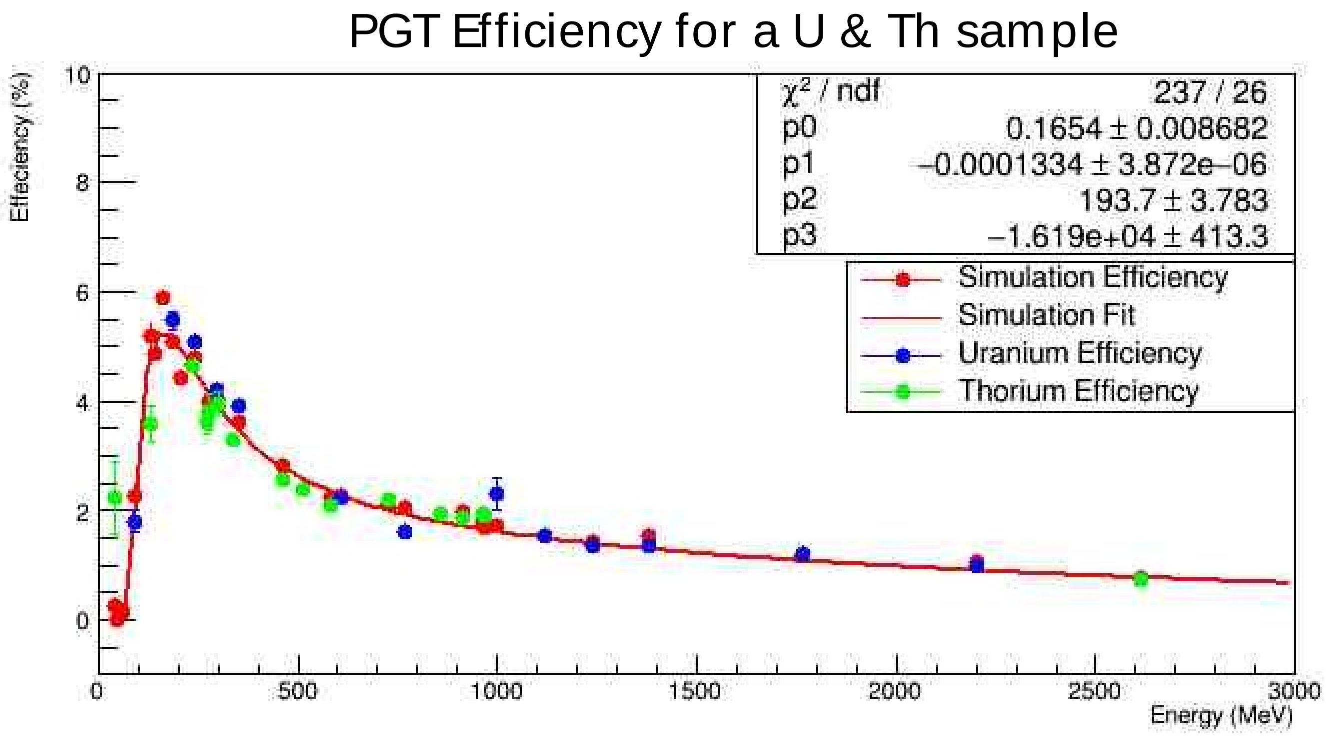
HPGe Continued Analysis Improvements

Upgrading the detector simulations from GEANT 4.10 to 4.11.

GEANT 4.11 now includes better modelling of the gamma decay process including cascade effects which can change the efficiency for some isotopes.

Three SNOLAB student interns have been part of these upgrades, which are now in use for new samples.

SNOLAB's custom analysis code is backwards compatible to allow for processing of the old or new simulations, as needed.

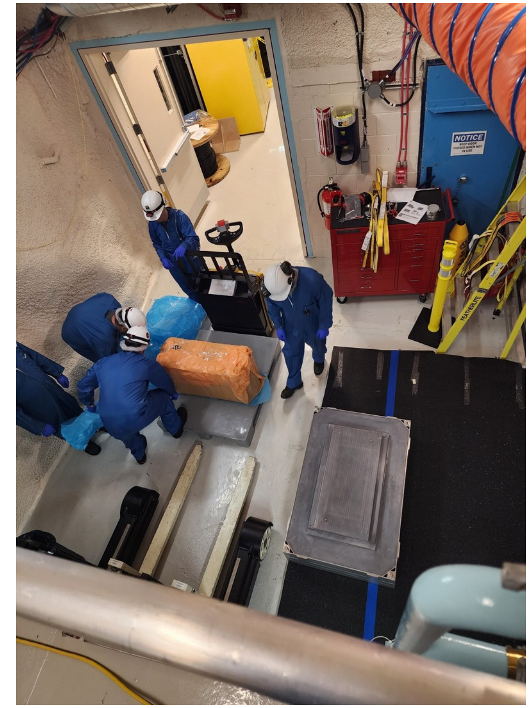


Twin Detector As Originally Assembled

Comprehensive Test Ban Treaty Detector

- Comprehensive Test Ban Treaty Detector
  Health Canada's radionuclide laboratory CAL05
- Two Broad Energy Germanium (BeGe) Detectors
- Coincidence events between the two detectors

Twin Detector Shield Assembly



Shield was designed and built by Lemer-Pax and assembled by SNO-LAB staff.

Used low-background copper and lead.

Copper (CuC1) backgrounds:

^{238}U: < 20 µBq/kg,
^{232}Th: < 84 µBq/kg,
^{210}Pb: < 43 µBq/kg.

Lead (ULB) backgrounds:

^{238}U: < 44 µBq/kg,
^{232}Th: < 470 µBq/kg,
^{210}Pb: < 109 µBq/kg.

Limits use 90% CL

Twin Detector Shield Assembled

The working detector has been used for tests with the RAMPS project.

The Left Detector has been sent to Mirion for repairs, it is expected that the FET will be required to be re-placed.

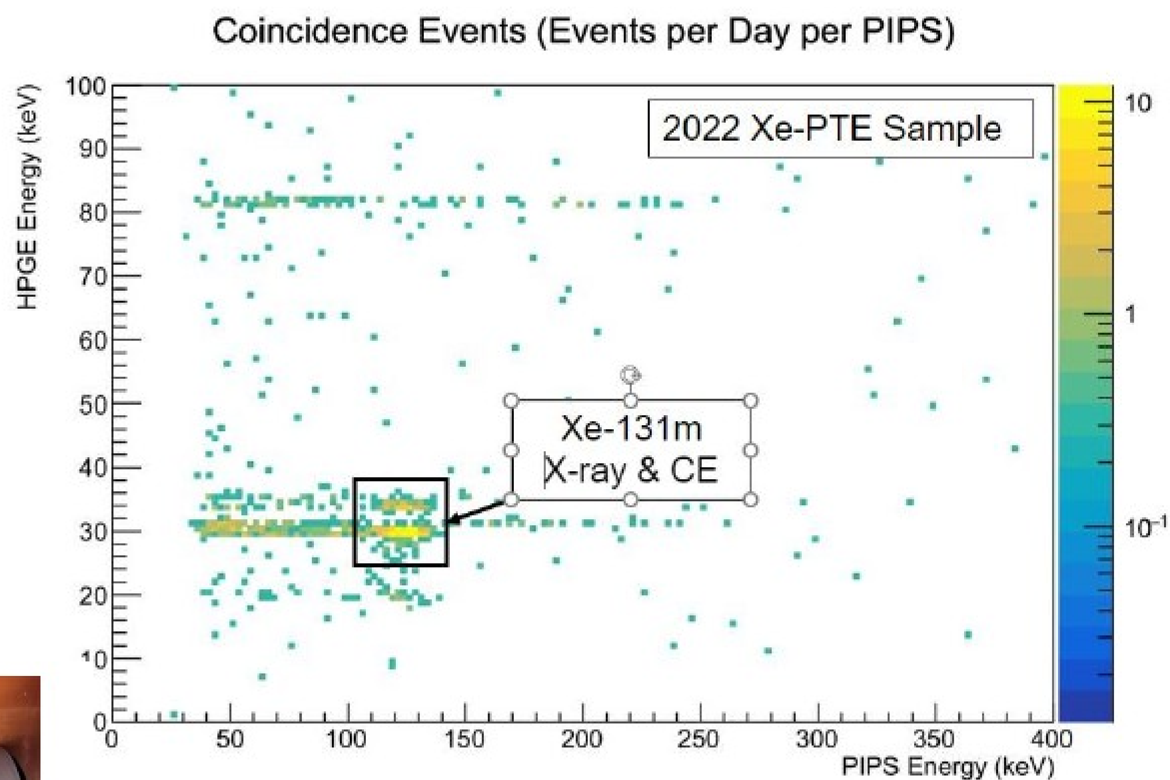
When not used for Health Canada / SNOLAB projects, RAMPS and DarkSide have projects to utilize the coincidence capabilities of the two Ge detectors. In addition, coincidences between Ge detectors and SiPMs will be explored.

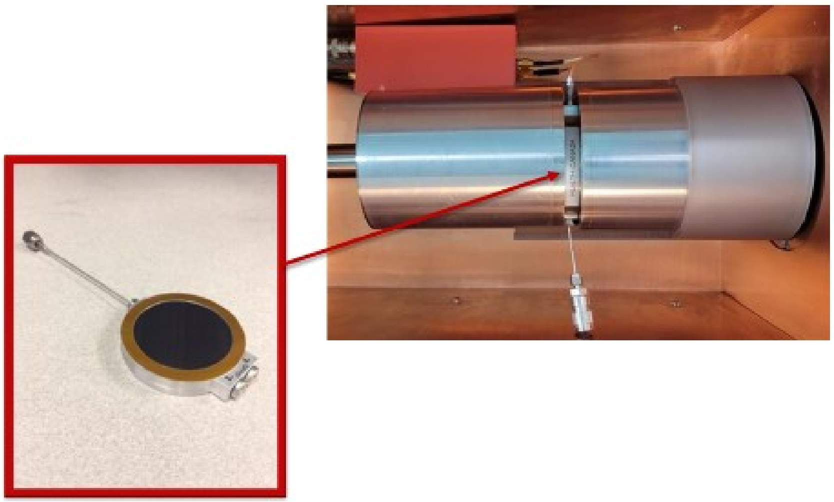
Current plans include extensive background measurements, and calibrations.

Twin Detector Capabilities

Beta-gamma coincidence detection

- Atmospheric radioxenon monitoring
- A PIPSBOX detector was added
- Two thin passivated implanted planar silicon wafers
- Beta Detector
- Gas samples are placed in the detector
- Coincidence of Beta-Gamma





Surface Alpha Counting

SNOLAB XIA Alpha Counter

SNOLAB has two XIA Ultra-Lo 1800

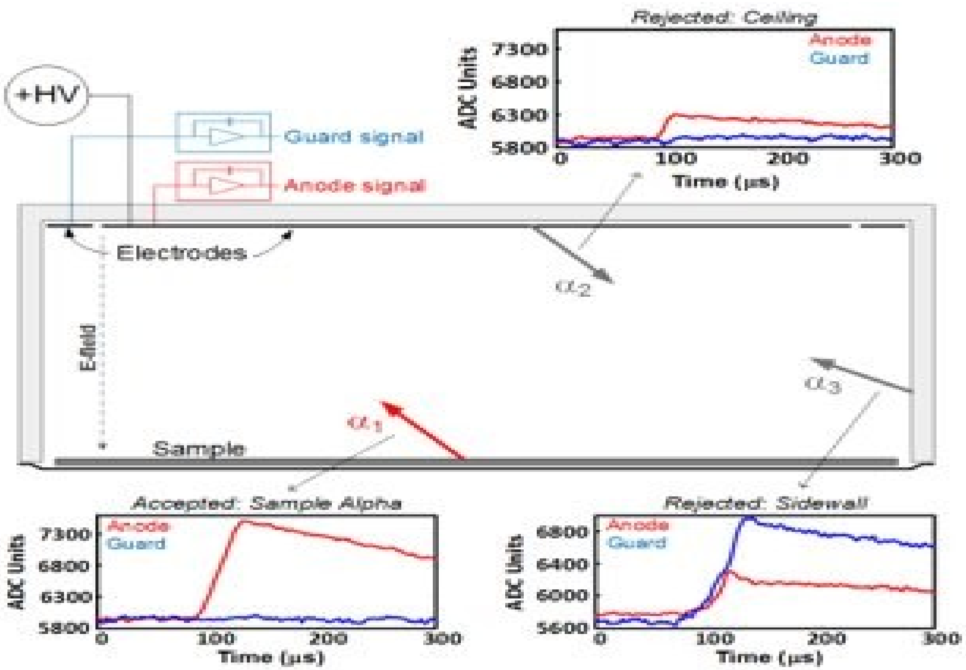
Argon gas drift chamber for Alpha rate measurements

Uses electronic amplification rather than gas amplification to directly measure the movement of ionization products from alpha tracks.

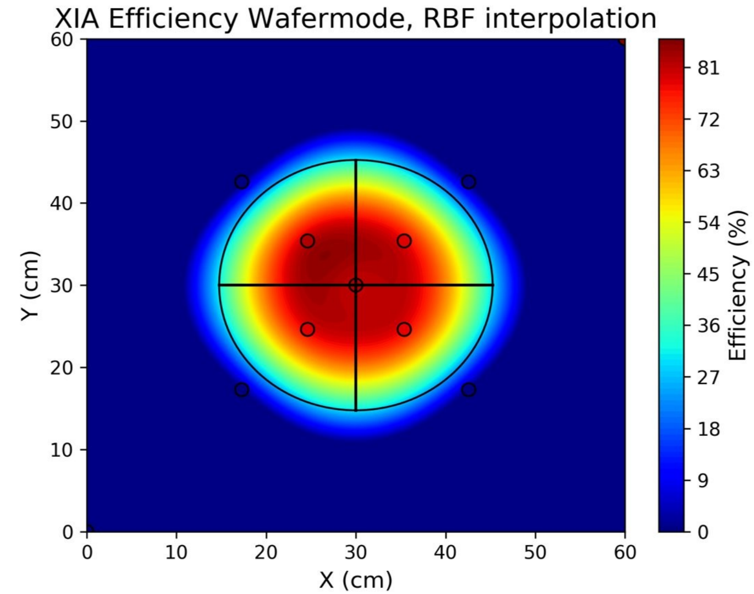
It is able to exclude tracks from both above and outside the surface sample region.

Sample Region of the XIA Alpha Counter

Surface Alpha Counting



Electrode setup and sample readouts for the XIA surface alpha counter. Events are classified based on their risetime, anode charge, and guard charge.



Calibrated efficiency of the XIA surface alpha counter smaller sample region. The calibration was performed with a ^{230}Th source placed in 9 positions. (credit M. Baiocchi)

The UltraLo-1800 has 2 sample regions: a 30 cm diameter circle (707 cm^2) in the center, or the full 1800 cm^2 rectangle. The unit has an 80% collection efficiency for the smaller sample region. Samples are limited to 9 kg in mass and 6.3 mm in thickness.

The tray is covered with a mylar-coated Teflon to mitigate the contribution from the tray itself. The background measurement results in 0.00062 ± 0.00012 alpha/cm^2/hr for the circular read-out in the full energy range (1-10 MeV). The sensitivity is better than 100 nBq/cm^2 in the 1-10 MeV range.

Inductively Coupled Plasma - Mass Spectrometry (ICP-MS)

Agilent 8900 ICP-QQQ advanced application model (triple quadrupole ICP-MS)

A low-Total-Dissolved-Solids 56-element method has been established for use for re-agent quality validations and on-site Ultra-Pure Water quality monitoring at low pg/g levels.

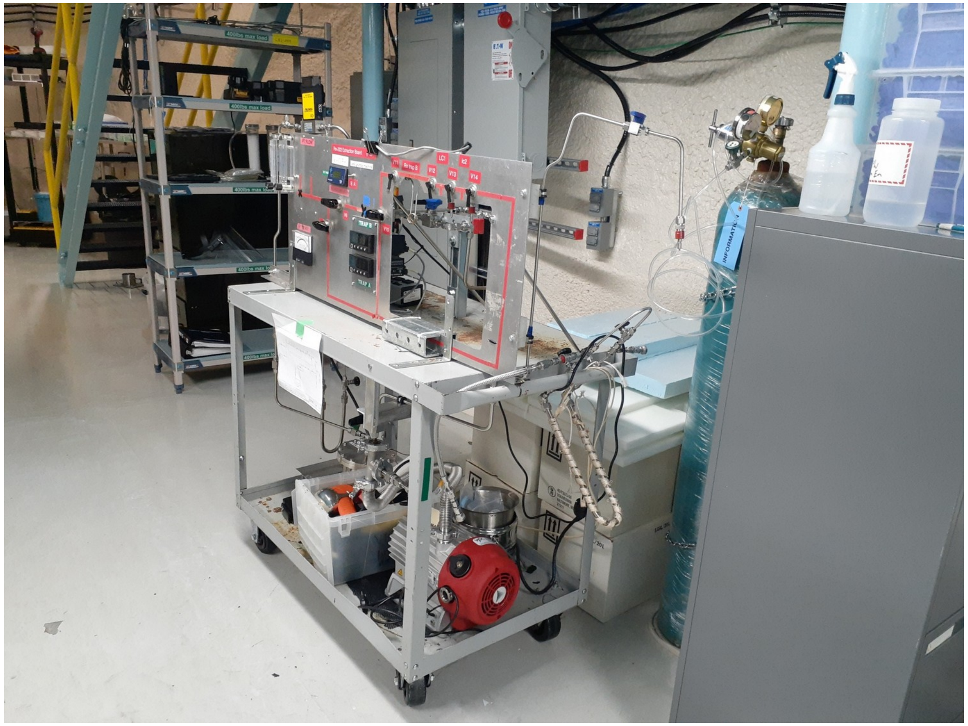
Current development work is focused on iso-topic dilution for ultra trace U-238 and Th-232 measurements, with preliminary blank based instrumental detection limits of ~1 fg/g U-238 and ~2 fg/g Th-232 (IDL = 3 x Std dev of blanks, n=16).

The ICP-MS System at SNOLAB

The program is in the process of expanding into solid copper and nickel analyses, extending the U/Th measurement capabilities to materials relevant in low background detector construction.

Together, these methods will provide both routine contamination monitoring and increasingly sensitive, quantitative radiopurity characterization in-house at SNOLAB.

SNOLAB Radon Emanation Systems



Underground Radon Emanation System

Surface Radon Emanation System

Continued improvement of these techniques with a recent paper:

“Measurement of low 222Rn concentration in N2 using an activated charcoal trap”, lead by N. Fatemighomi and Y. Ahmed , S.M.A. Hussain, J. Lu, A. Pearson, J. Suys,   NIM A 1076 (2025) 170422

See presentation by Nasim Fatemighomi, Session: Rn Detection and Mitigation 2

Neutron Activation

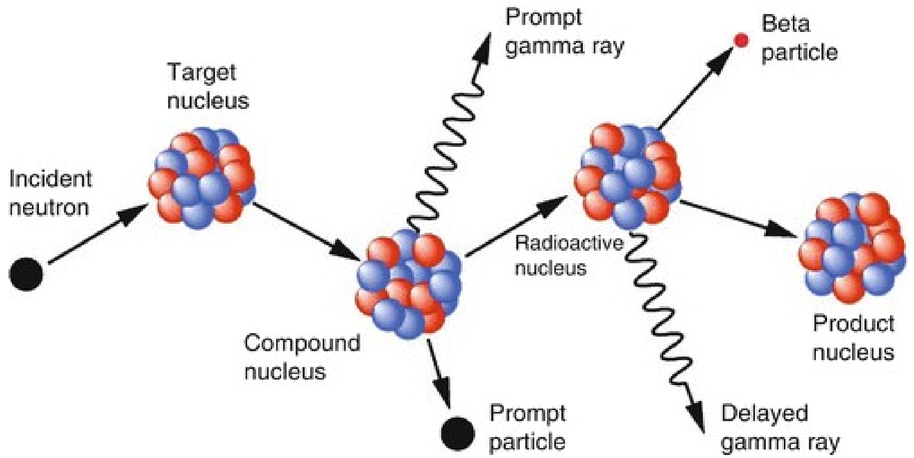
Sample is activated with neutrons causing its components to form radioactive isotopes.

Main advantage is that the sample does not need to be destroyed.

Sample can then be counted using usual methods such as Ge spectrometry.

Main drawback is that the sample may remain radioactive for quite some time and there are limited opportunities to irradiate samples as suitable activation reactors are declining.

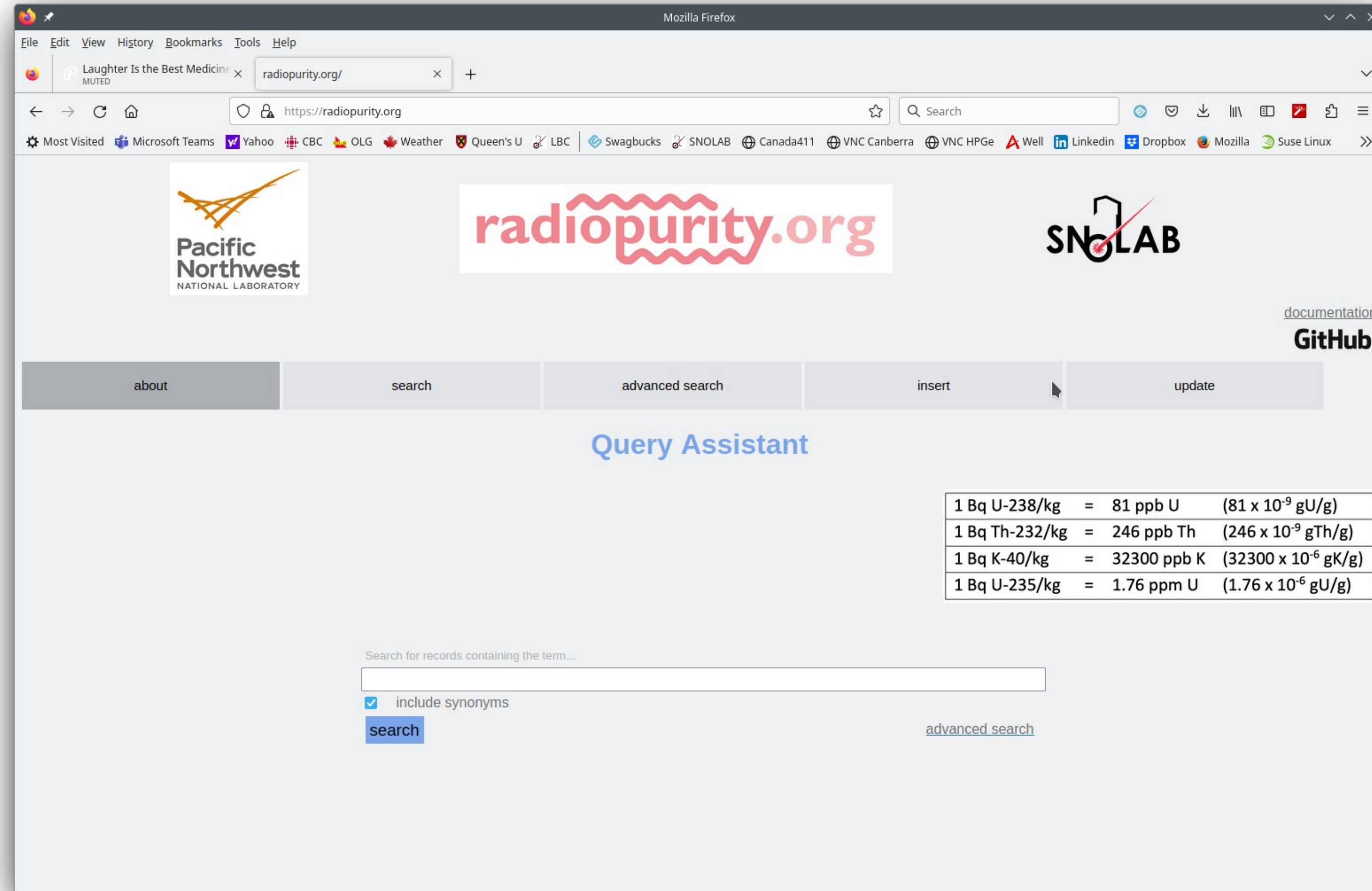
SNOLAB is planning to use its own MF Physics neutron (d-t) accelerator which creates 14 MeV neutrons to activate samples for use by SNOLAB experiments and to enhance screening capabilities by searching for rare decays. The accelerator head was recently replaced and is now being commissioned.



d-t neutron accelerator

^{16}N activation canister

Material Assay Database



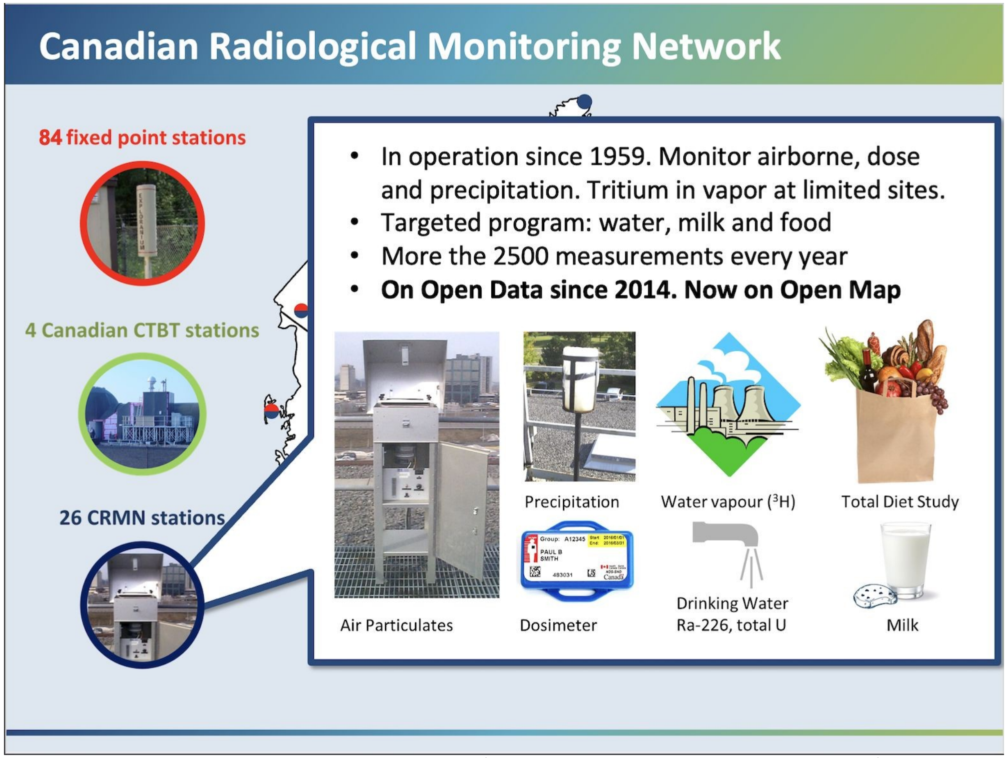
•The Assay and Acquisition of Radiopure Materials (AARM) Collaboration originally developed the Community Material Assay Database radiopurity.org.

•The database is hosted at SNOLAB.

•Contains published results and non-published results with permission of the experiment.

Environmental Monitoring Sampling Station

- Project supported by National Monitoring Section at the Radiation Protection Bureau, HC
- To study and monitor the radionuclide concentration in surface air at SNOLAB.
- To understand the general radiation trend.
- Major motivation: to monitor the accidental release into the atmosphere of radioactive isotopes.
- To train SNOLAB staff and students and produce more HQPs
- Installed in Nov, 2023 and fully operational



Picture from Jean-Francois - HC

Environmental Gamma Counts at SNOLAB

Summary

- There are many different techniques to measure radioactive backgrounds.

- The technique can depend on several factors:
  - upon its size,
  - whether or not the sample itself is to be used in the experiment
  - can the sample be sacrificed, etc…

- Sometimes a sample can be counted using multiple methods
  - Ge spectrometry to measure the sample bulk
  - α spectrometry to measure the sample surface
  - Radon emanation of the sample bulk

- SNOLAB is continuing its program to better understand the underground background environment.

- Background database requires greater involvement with the community to include data from a much larger set of experiments.

- To count samples at SNOLAB visit and follow the instructions at: https://www.sno-lab.ca/users/services/gamma-assay

LBL Group: Ian Lawson (HPGe, N.A., Simulations)
Dimpal Chauhan (R.E., HC Radon & E.M., Database)
Sharayah Read (ICPMS),
Co-op students (All tasks)
Steffon Luoma (XIA, HPGe, N.A),
Tom Sonley (XIA, Simulations),
Nasim Fatemighomi (R.E., ESC),
+Scientific Support & Research Scientists