The SNOLAB Ultra-Low Background Material Screening Program

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SNOLAB

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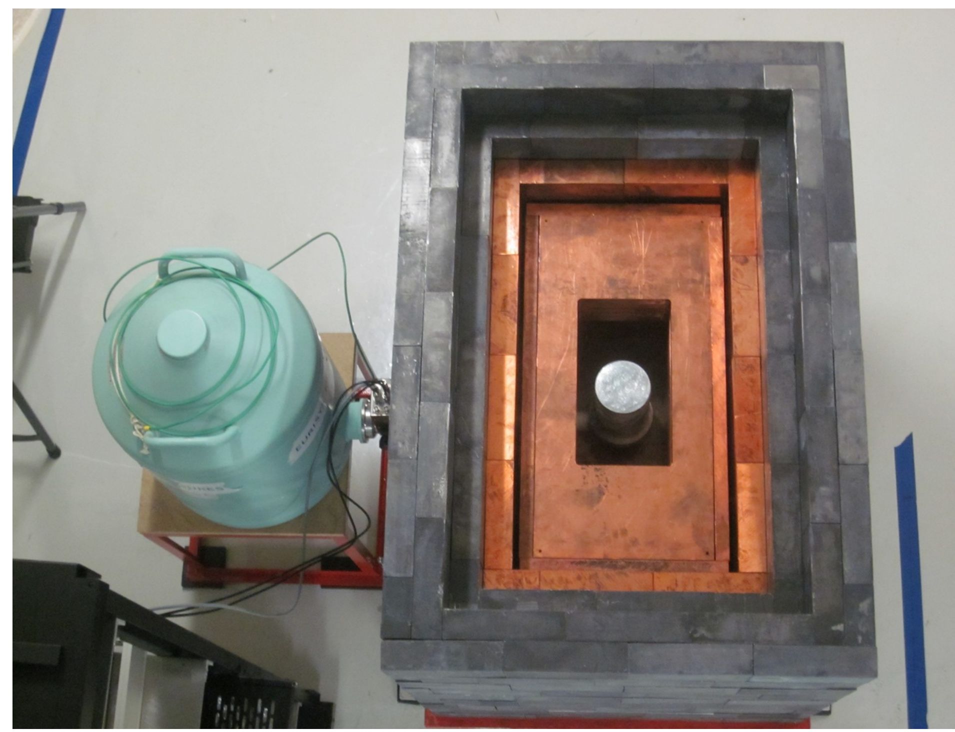
SNOLAB LBL


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

Going Underground For Science

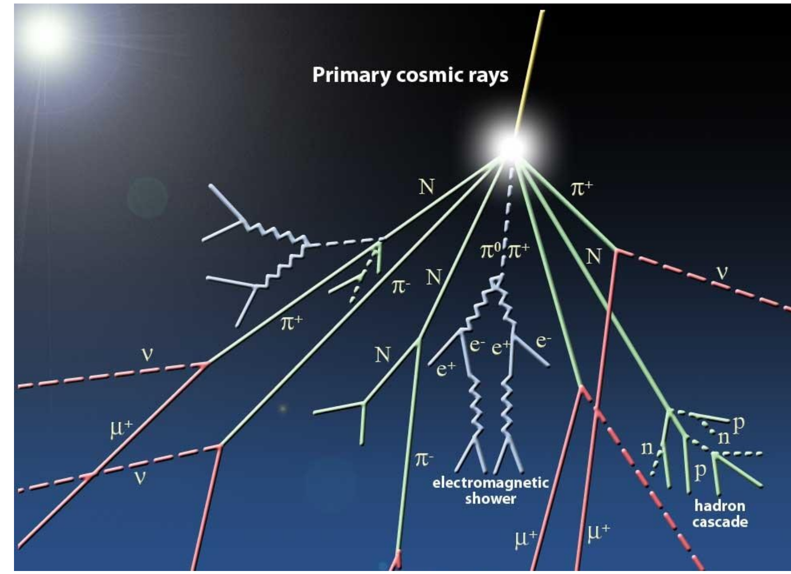
Deep underground facilities provide significant rock overburden and commensurate reduction in cosmic ray flux, and cosmic ray-spallation induced products (neutrons)

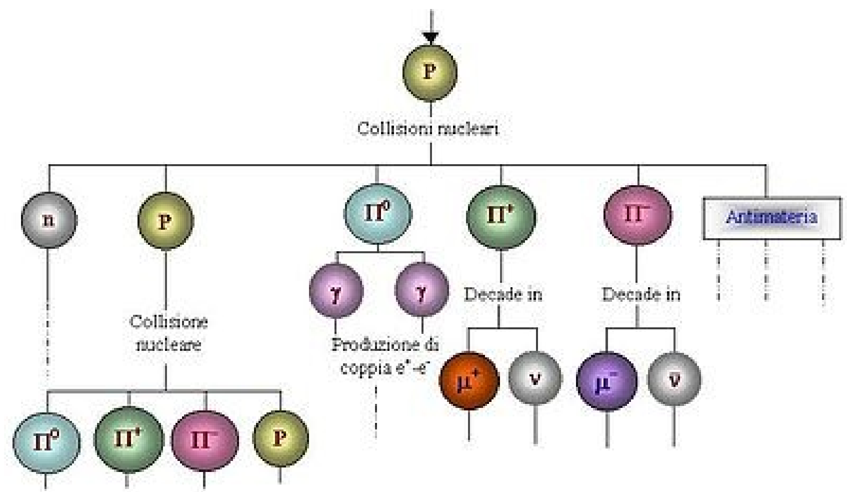
Muons can be vetoed in anti-coincidence shields; however, secondary products may be an issue

Cosmogenics may require underground material production or purification
- May also contribute to backgrounds (e.g. ^{11}C)

Muon flux depends on
- Overburden
- overburden profile
- seasonal effects

With all of these backgrounds present, there are several methods to measure them and these will be described.





Open Physics Lab

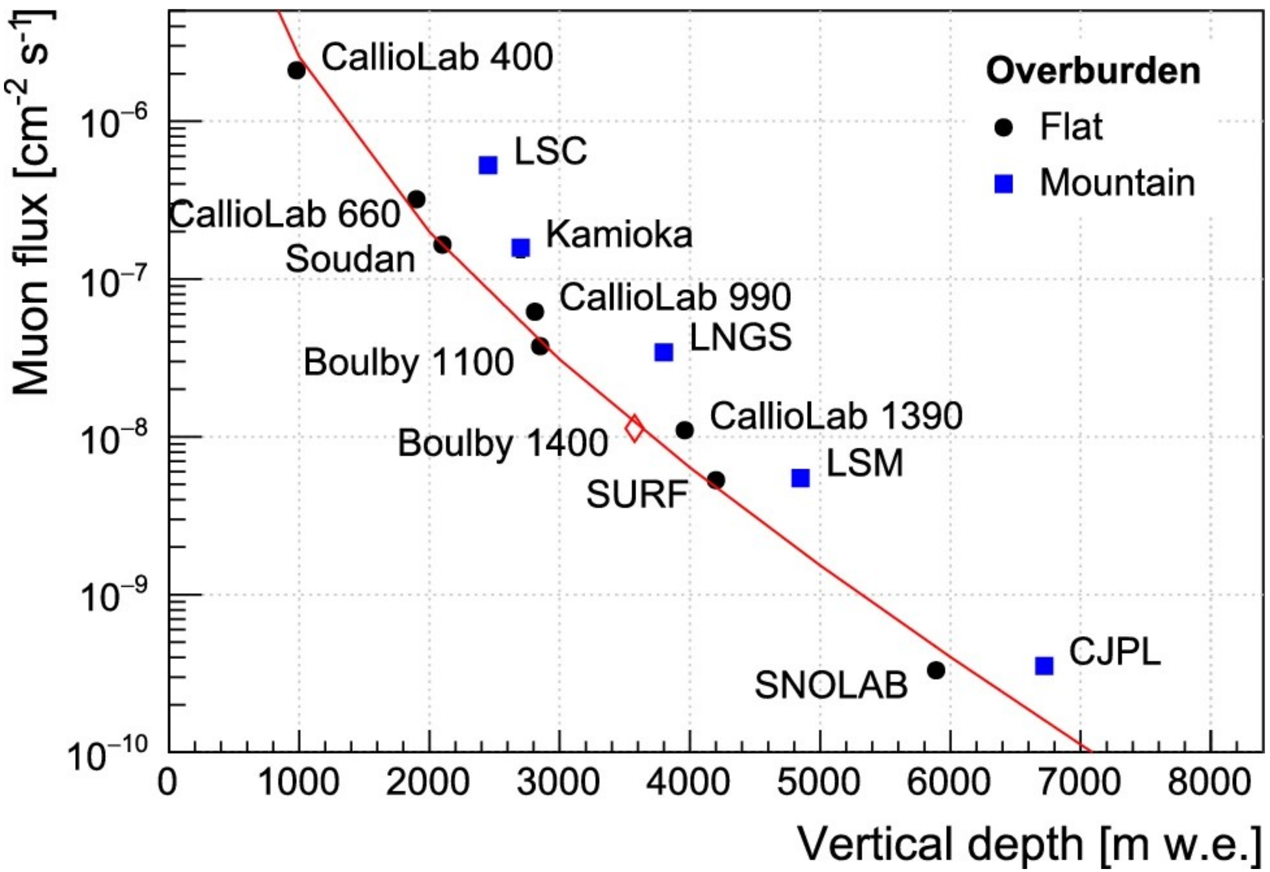
Techniques to Measure These Backgrounds

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	primordial parents	0.01 μBq/kg
•Liquid scintillation counting	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 have to very large and may have to count for several months.

Muon Supression

- 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

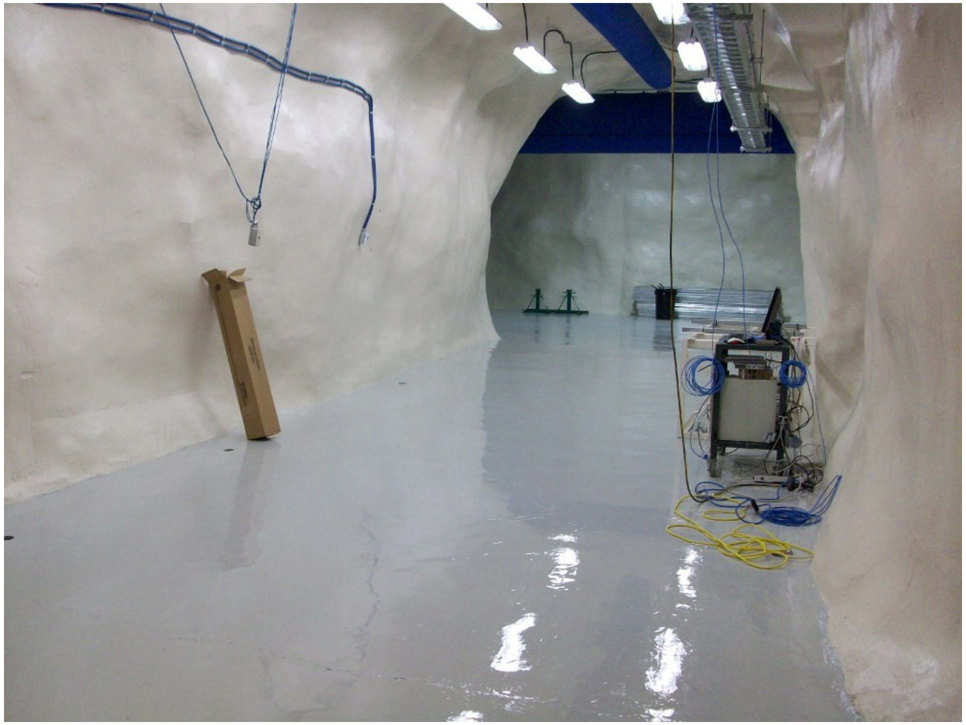
	Norite Rock	Shotcrete/Concrete
O	47 %	48 %
Si	27 %	28 %
Fe	6.5 %	2.5 %
Al	6 %	6 %
Mg	6 %	1 %
Ca	3.5 %	10 %
Na	1.7 %	2 %
K	1 %	1.7 %
Ti	0.3 %	0.2 %

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



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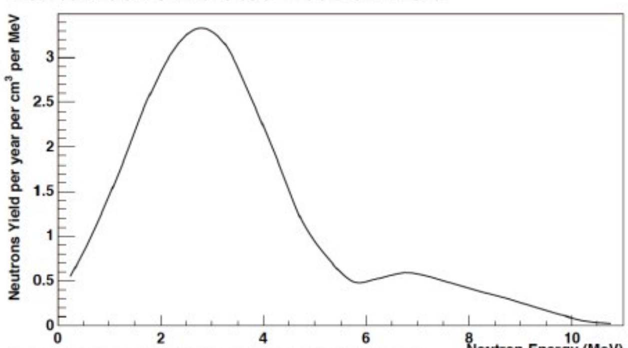
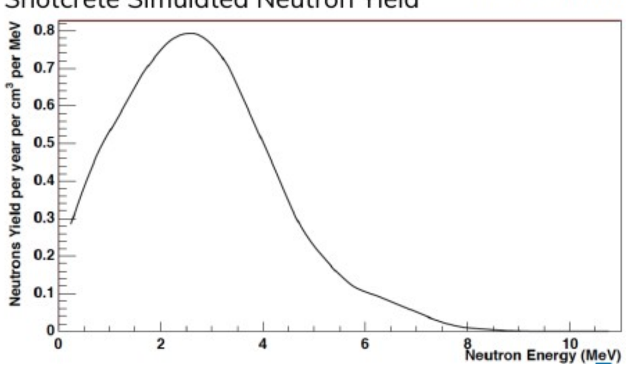
Norite Rock Simulated Neutron Yield



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 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.

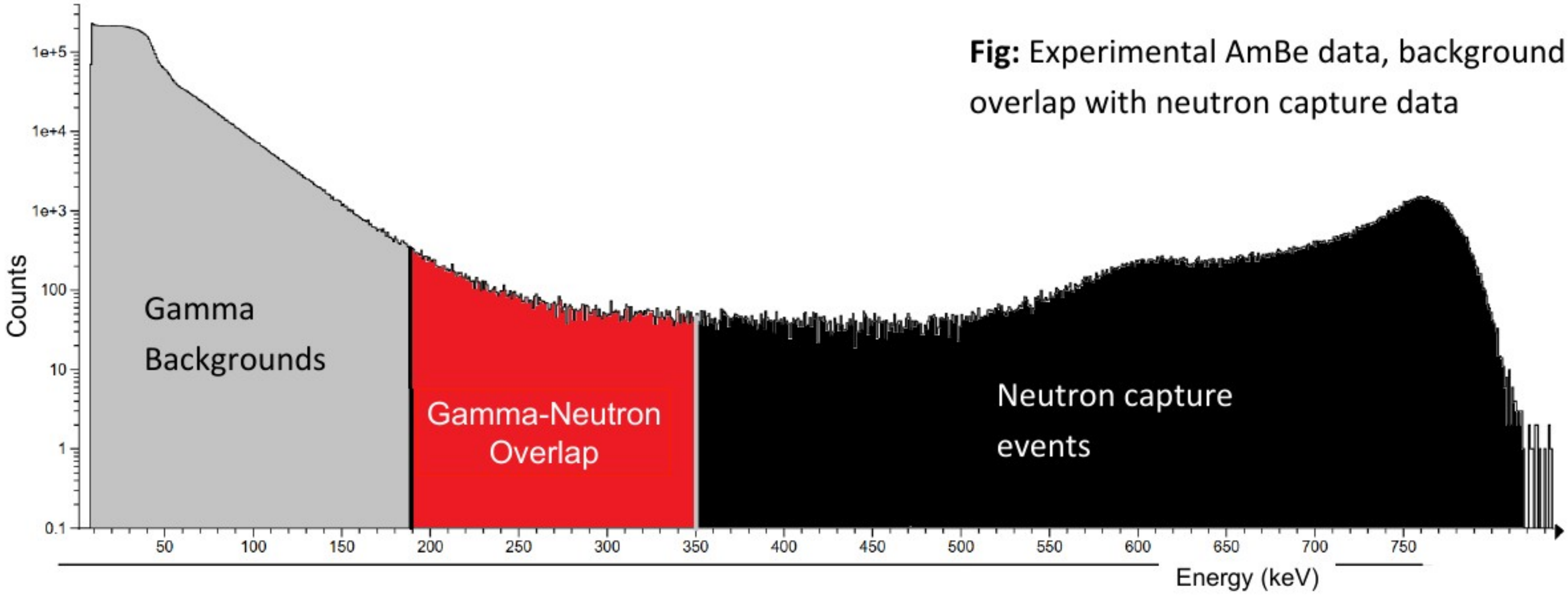


Fig: Experimental AmBe data, background overlap with neutron capture data

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

Mitigating Neutron Backgrounds

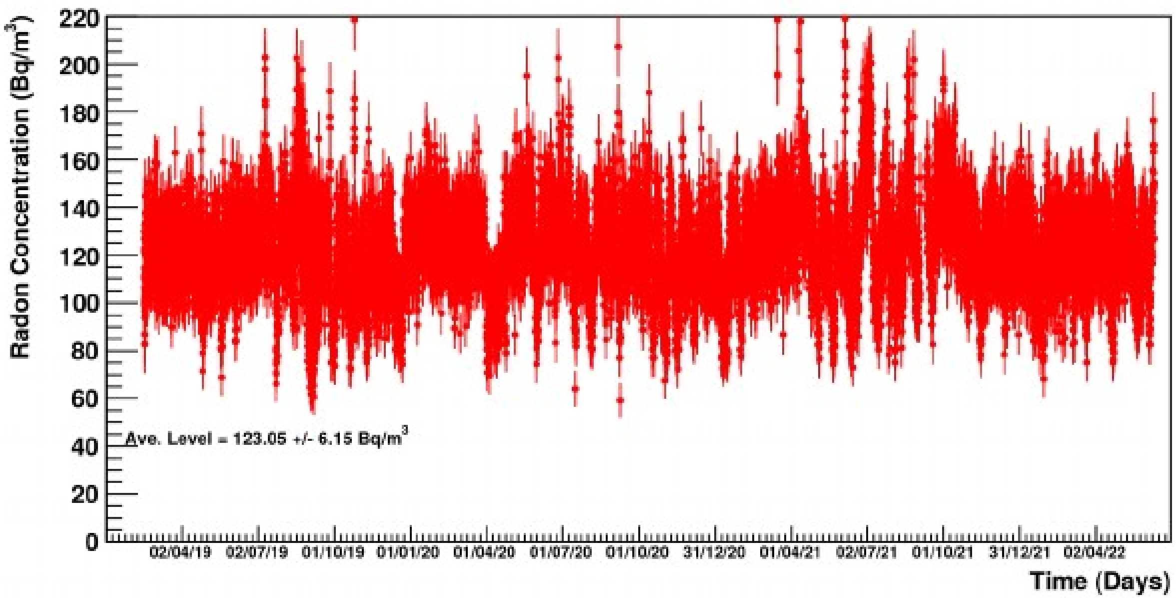
PICO-2L/SENSEI shield, showing water tank shielding stack, pressure carts, DAQ racks.

Tanks are 50 cm thick, combining water and polypropylene.

DAMIC CCD-based dark matter detector, focus on low mass WIMPS.

Shielding consists of 16 inches of polyethylene sheeting

Radon Levels

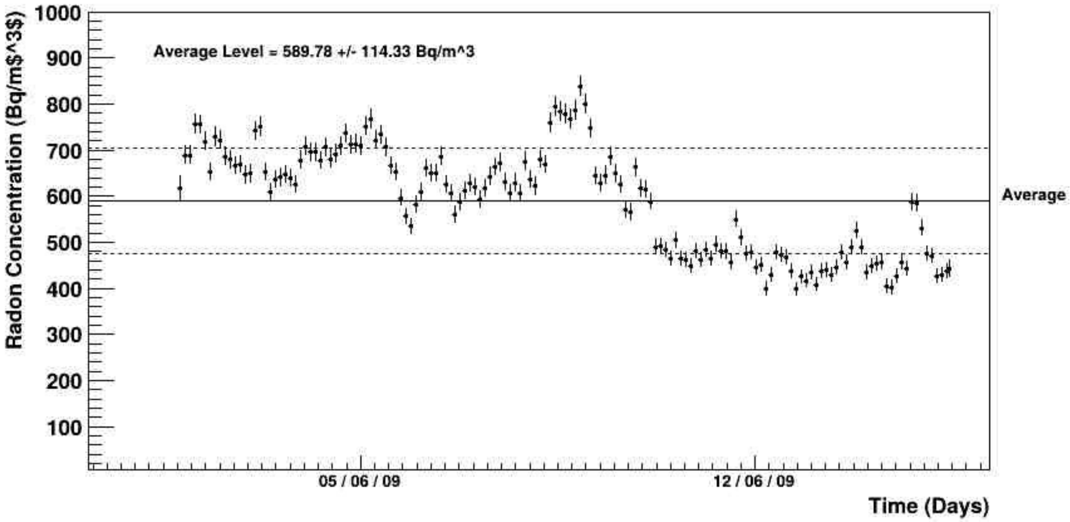


Average radon levels (with air circulation operational:

123.1 +- 6.2 Bq/m^3

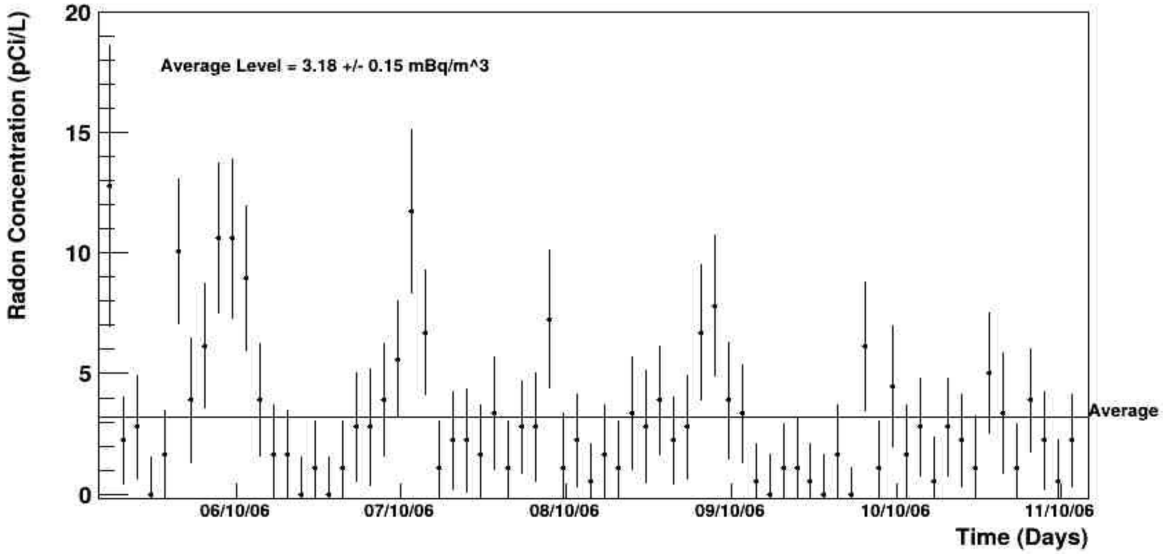
Average radon levels without air circulation:

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

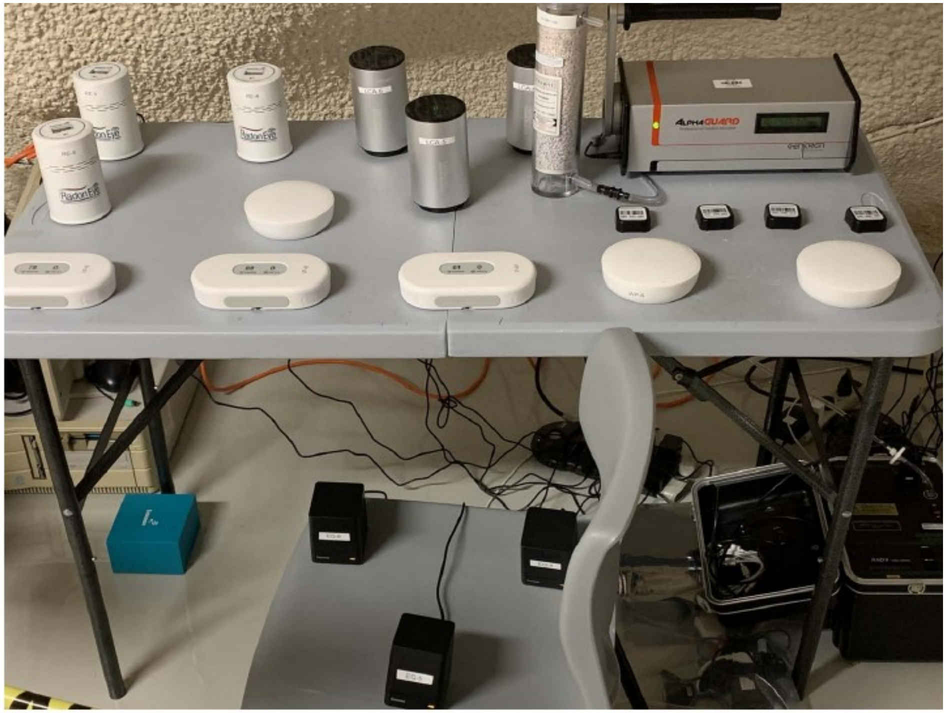
Even better results can be achieved using radon scrubbing systems

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 Durridge Inc. (RAD7).

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



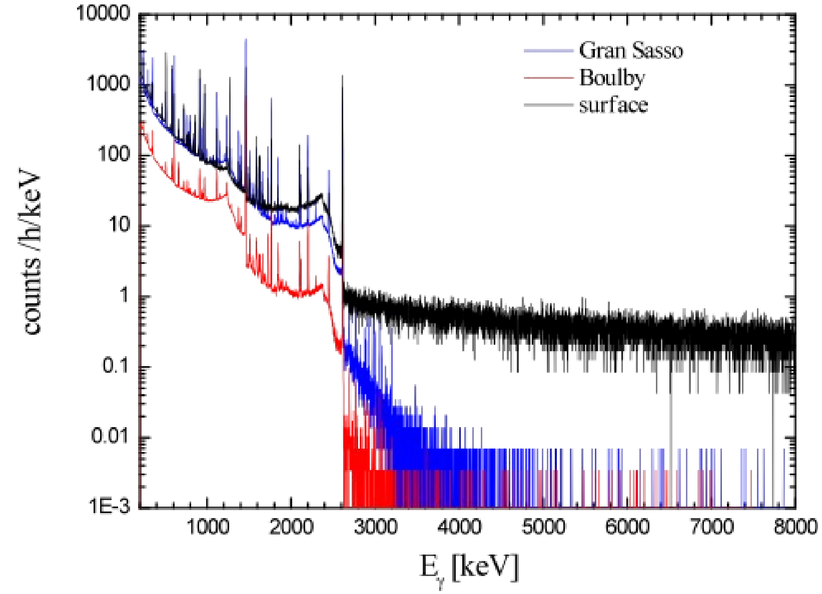
Gamma-ray Backgrounds

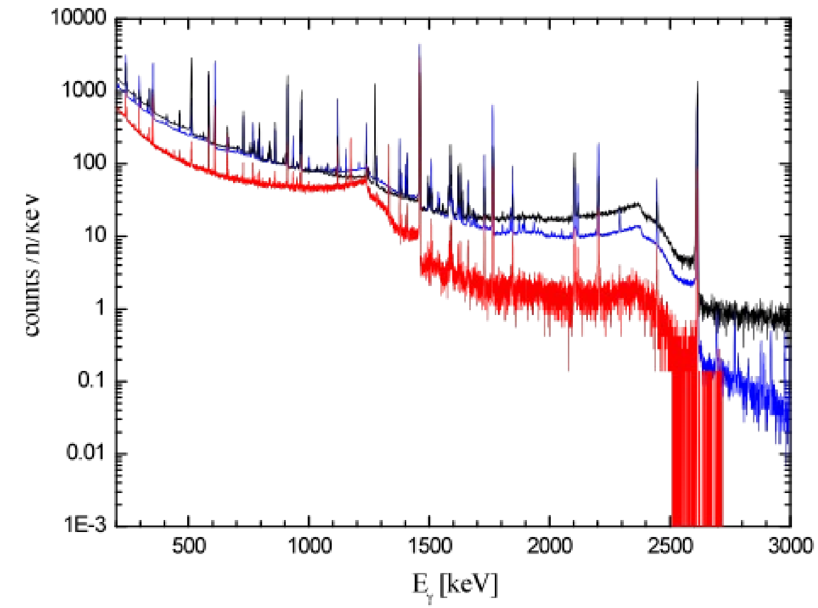
Reduction in γ-ray background at higher energies from c.r. and neutron reduction

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

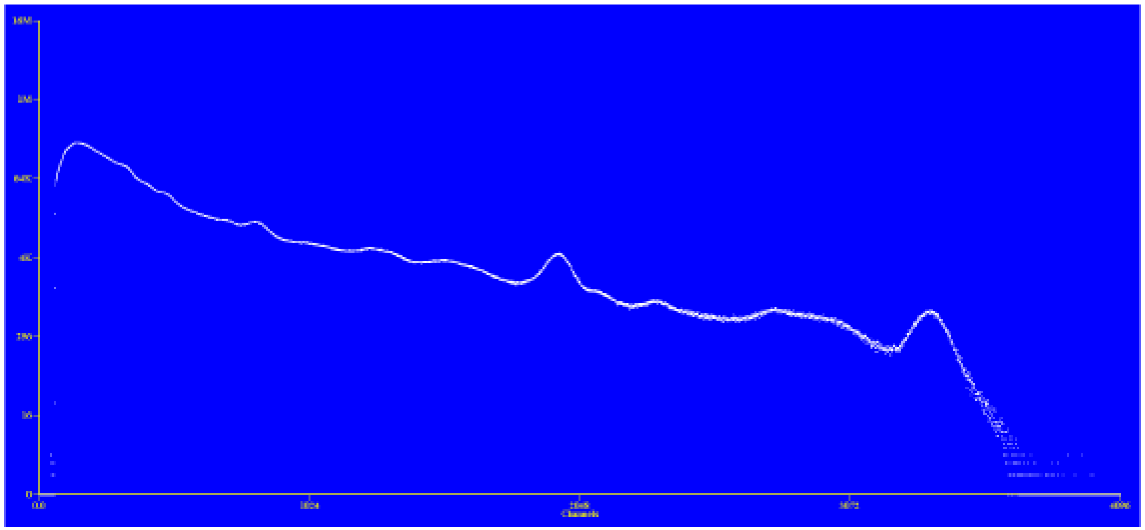
Below 3.5MeV dependent on local geology and rock material

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





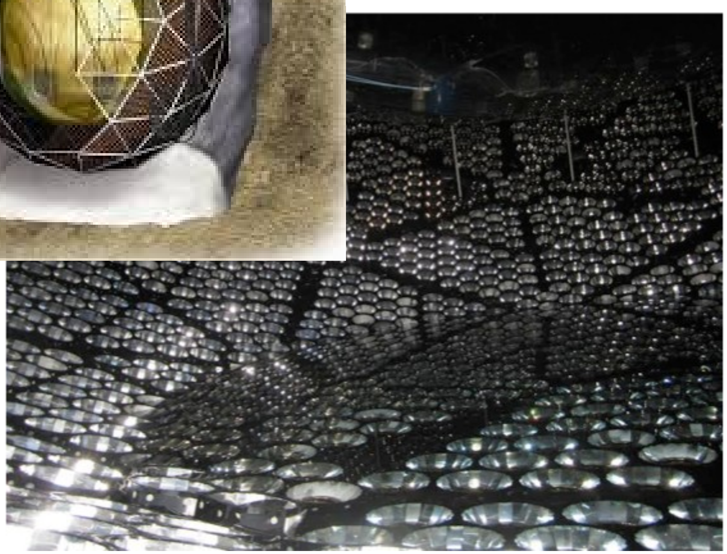
Gamma-ray Backgrounds

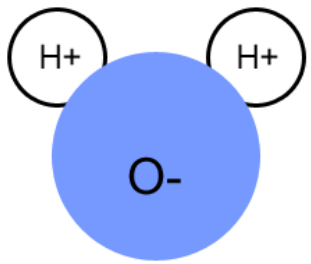


Sample of raw data from one of the small NaI crystal after 7.4 days

- 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

Mitigating γ-ray Backgrounds





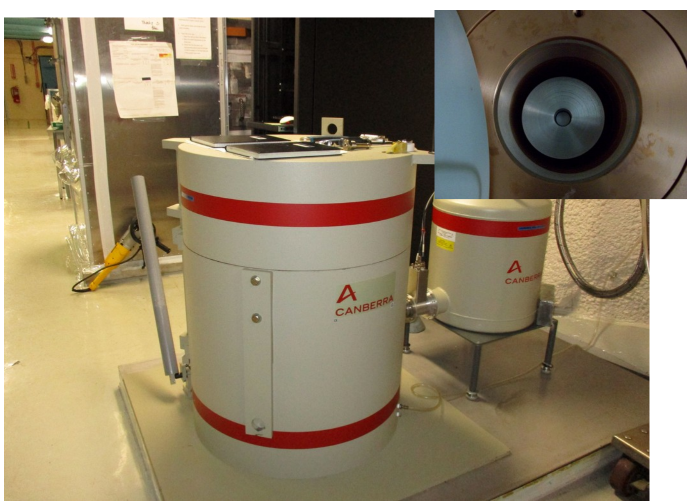
Lead shielding at appropriate thickness

Water shielding at appropriate thickness

Material Characterization with HPGe Spectrometry

PGT

Lively

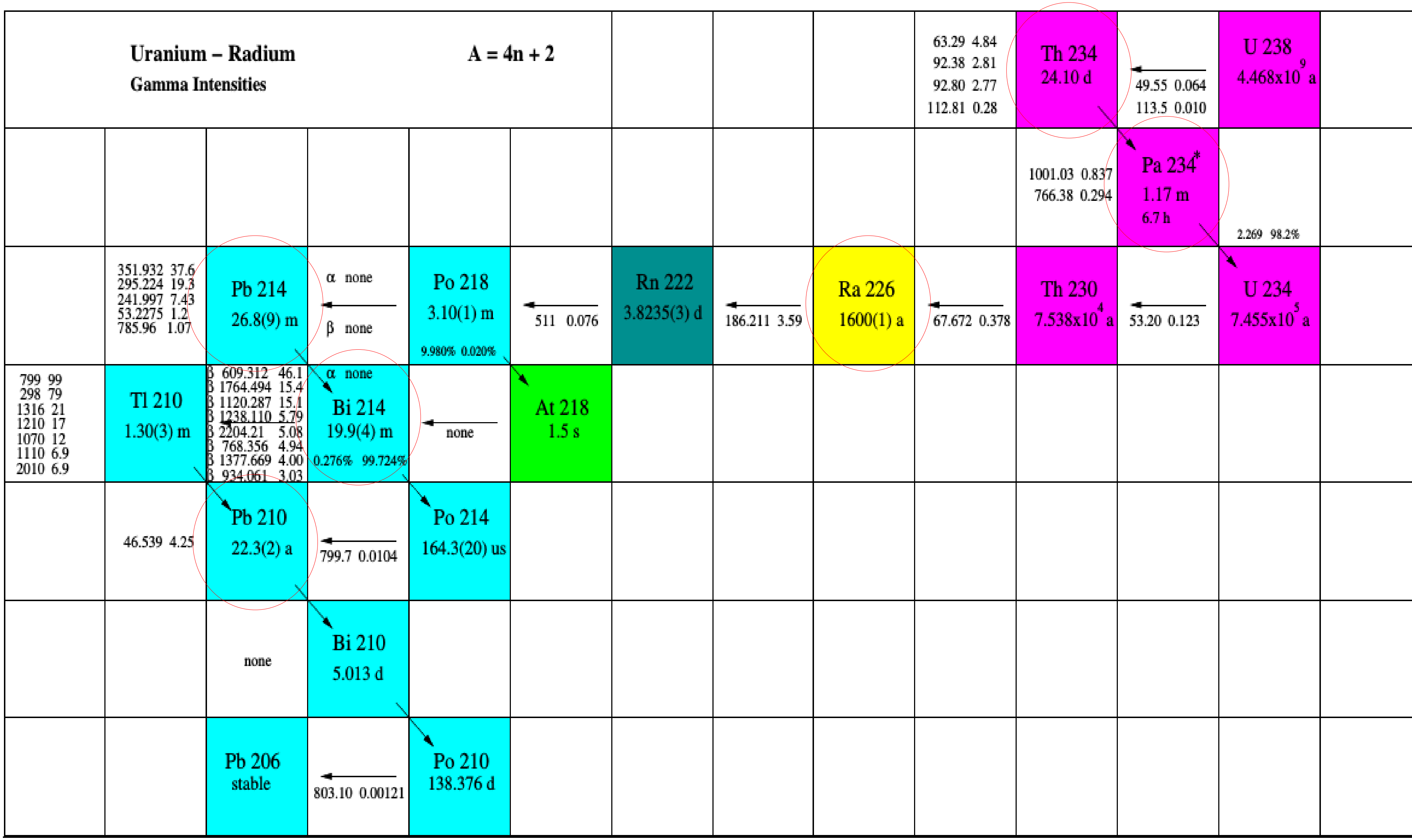


Chelmsford

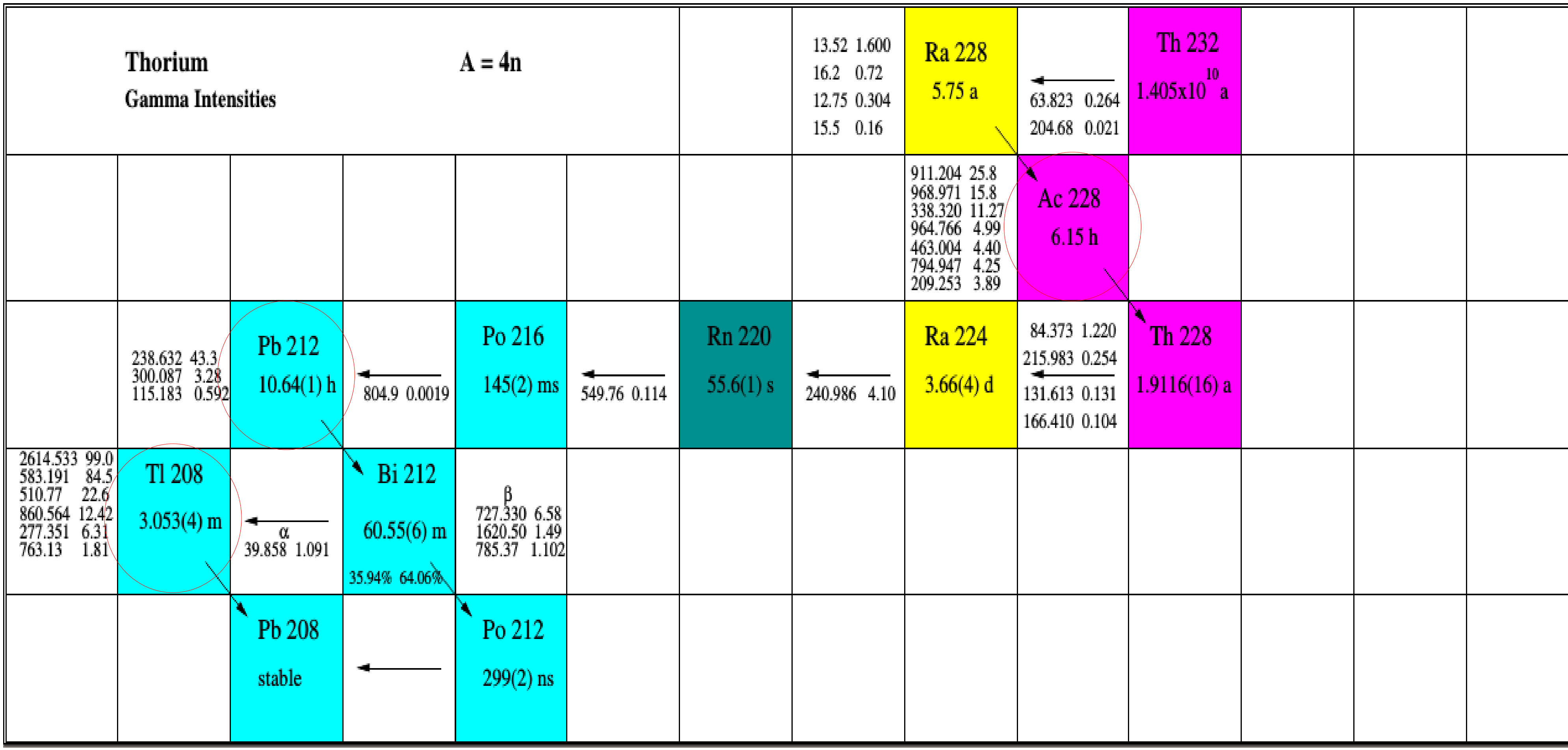
Gopher

VdA

Uranium Decay Chain



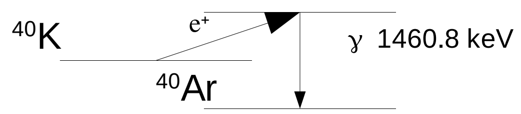
Thorium Decay Chain



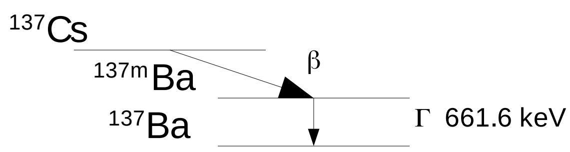
Other Interesting Isotopes

Usually Present:

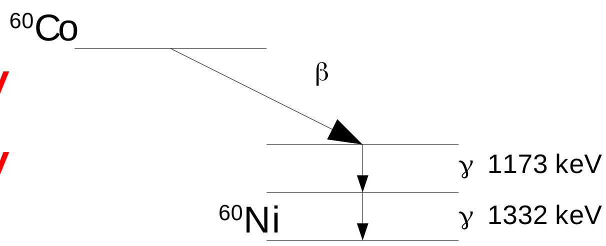
- ^{40}K
  - 1460.83 keV



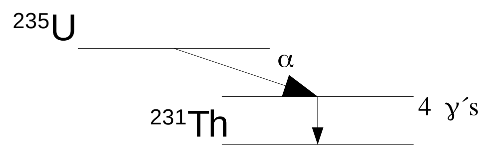
- ^{137}Cs
  - 661.66 keV
  - (from fallout)



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



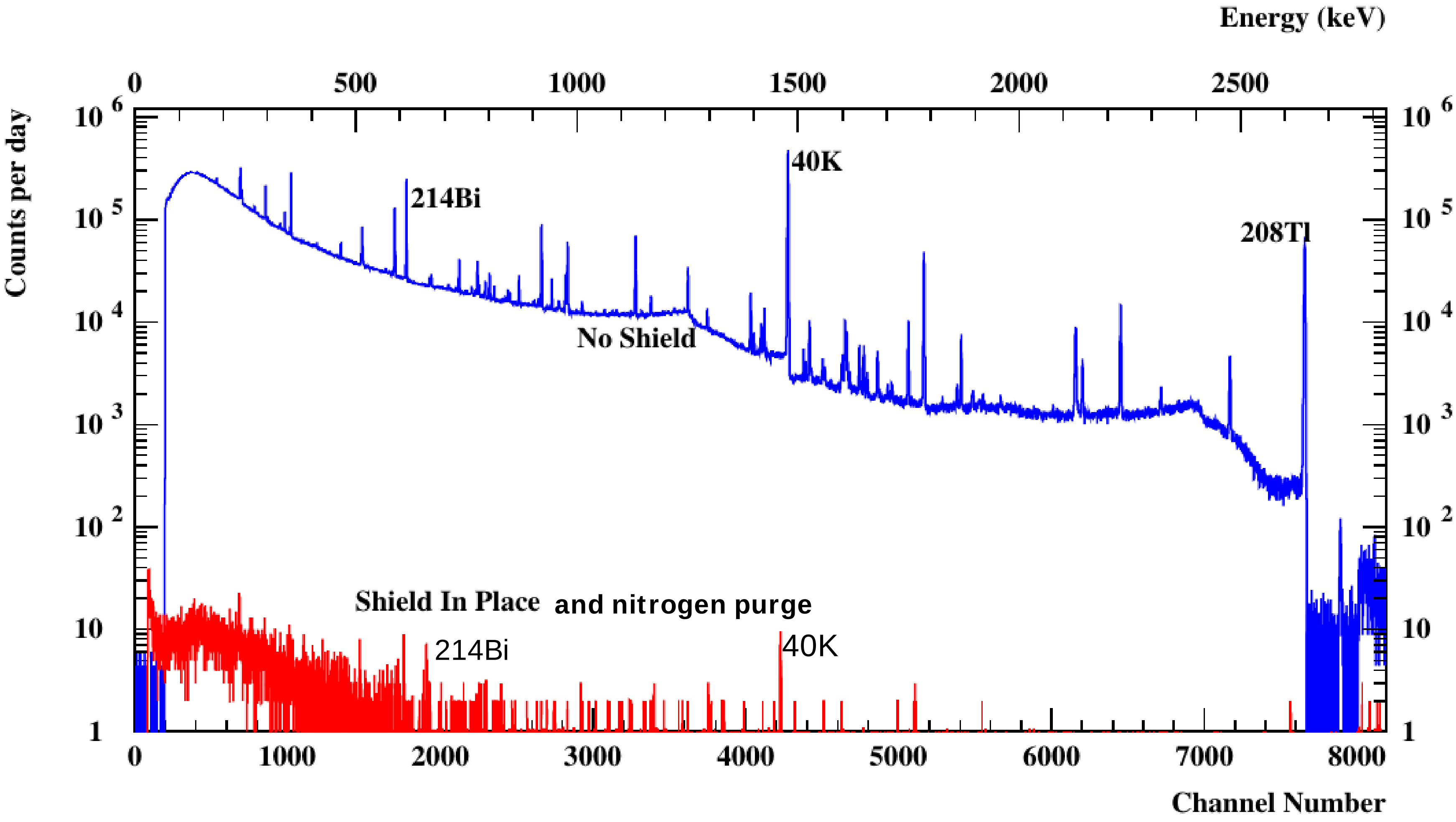
- ^{235}U
  - 143.76 keV
  - 163.33 keV
  - 185.22 keV
  - 205.31 keV



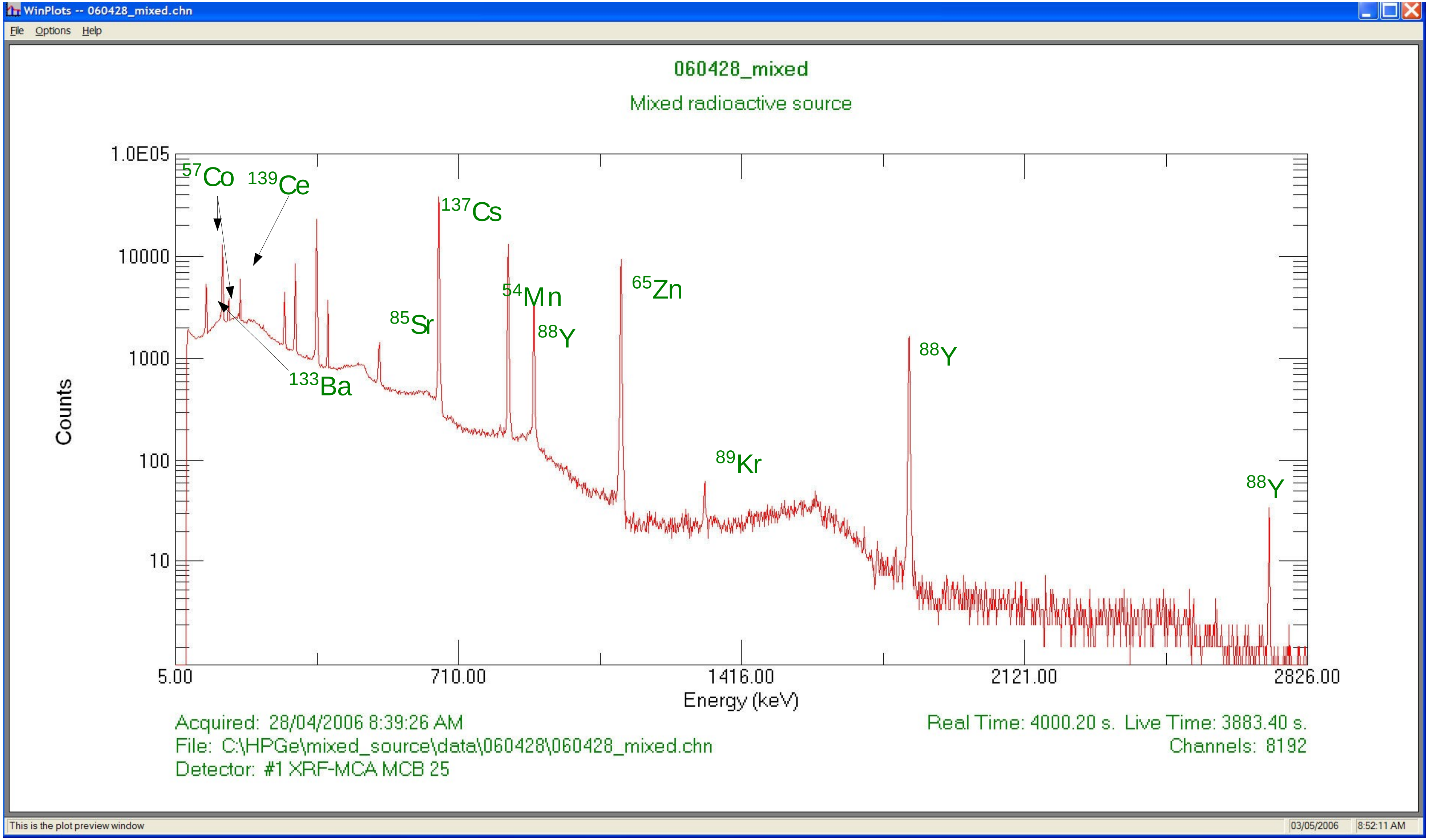
Occasionally Present:

- ^{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.

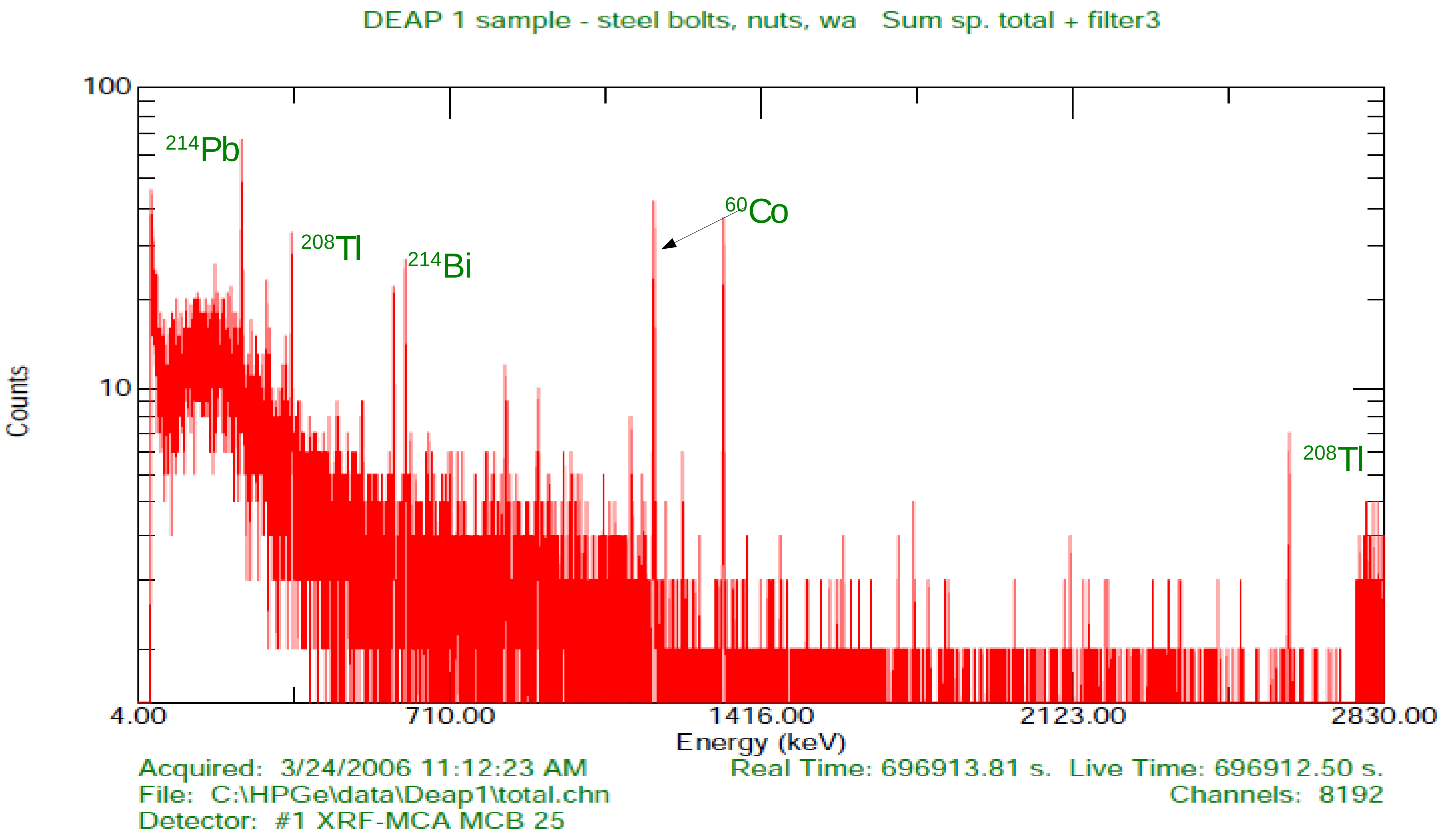
Unshielded and Shielded Spectra
(PGT Coax Detector)



Calibration Spectrum



Typical Stainless Steel Spectrum



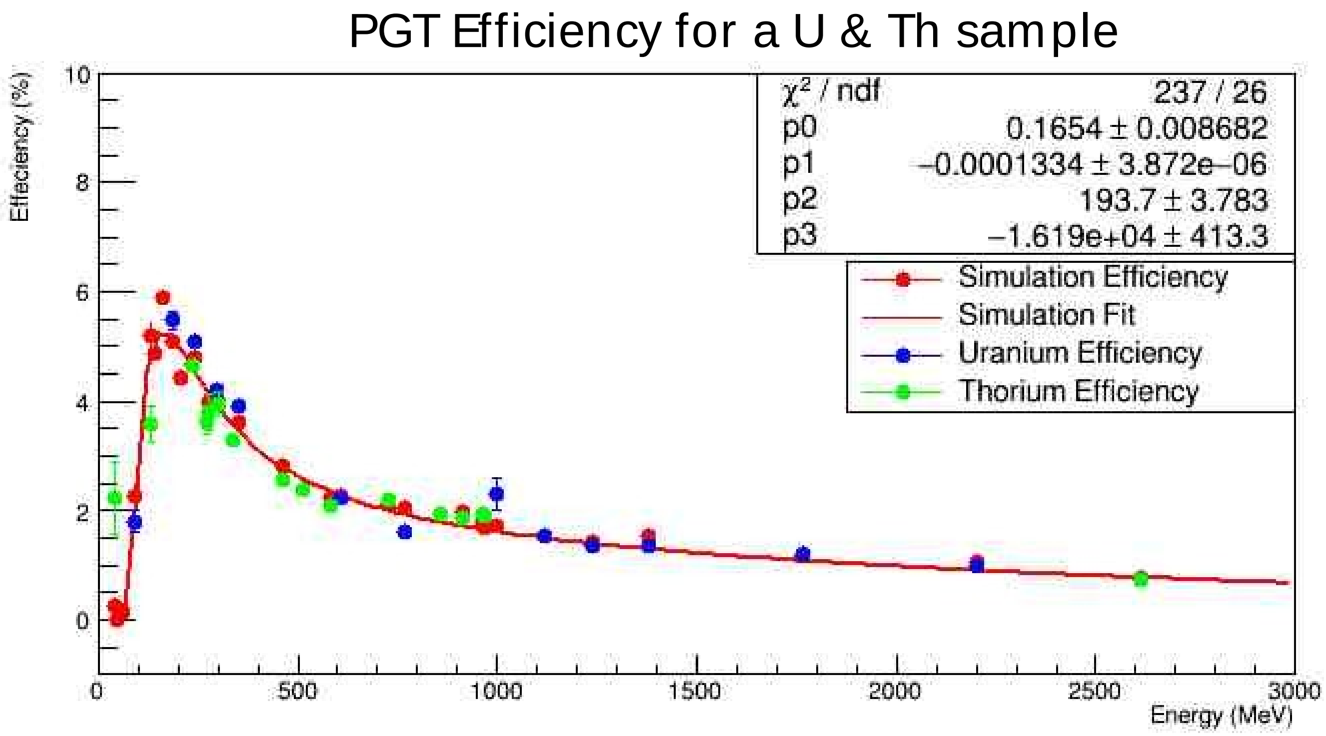
HPGe Continued Analysis Improvements

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.



Dual Detector As Originally Assembled

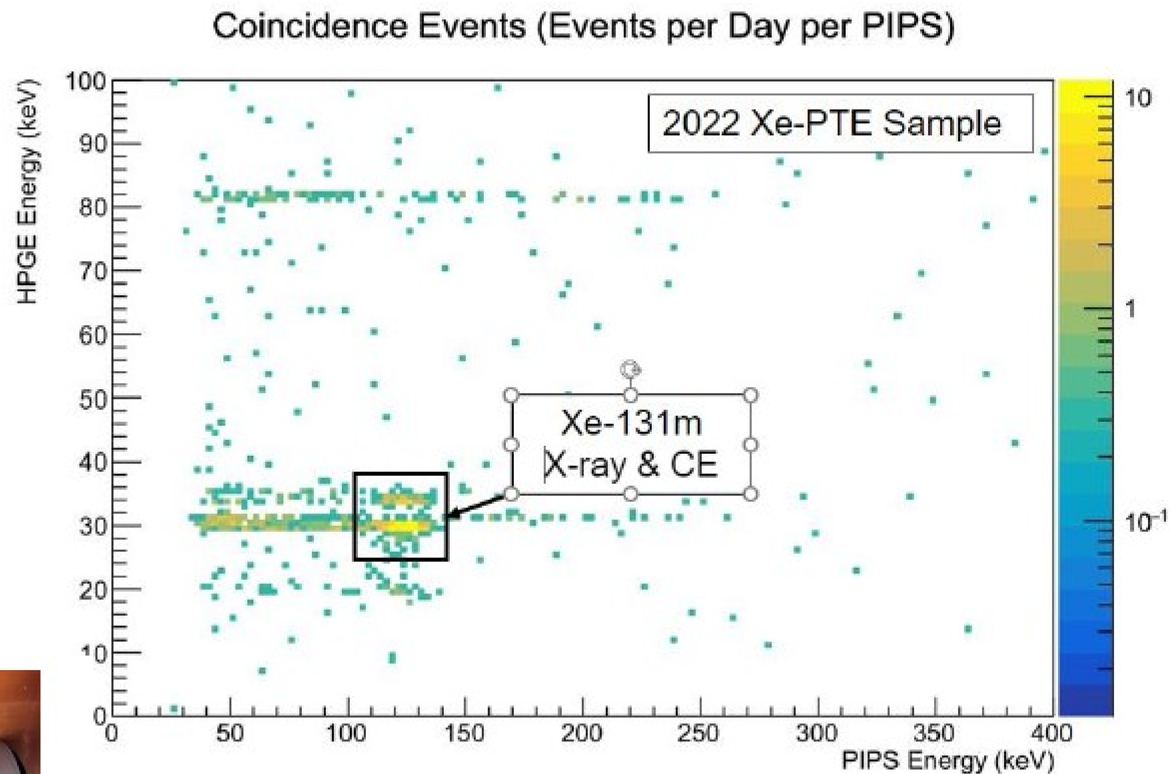
Comprehensive Test Ban Treaty Detector

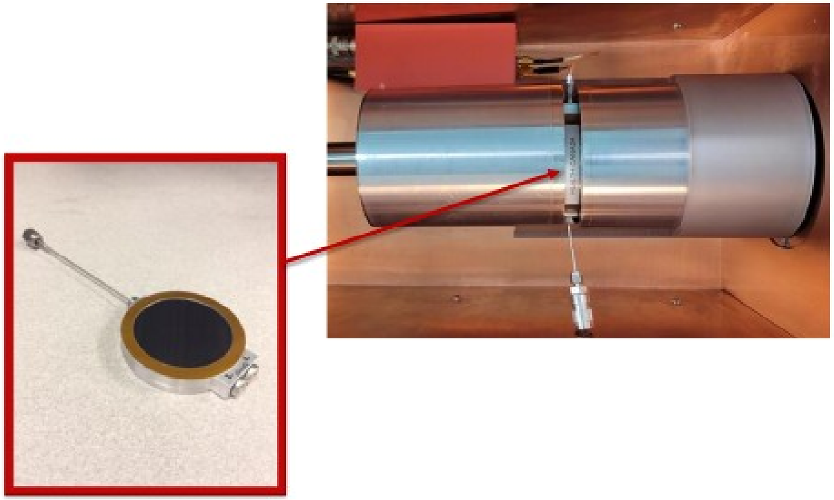
- Comprehensive Test Ban Treaty Detector
  Health Canada's radionuclide laboratory CAL05
- Two Broad Energy Germanium (BeGe) Detectors
- Coincidence events between the two detectors

Dual Detector Capabilities

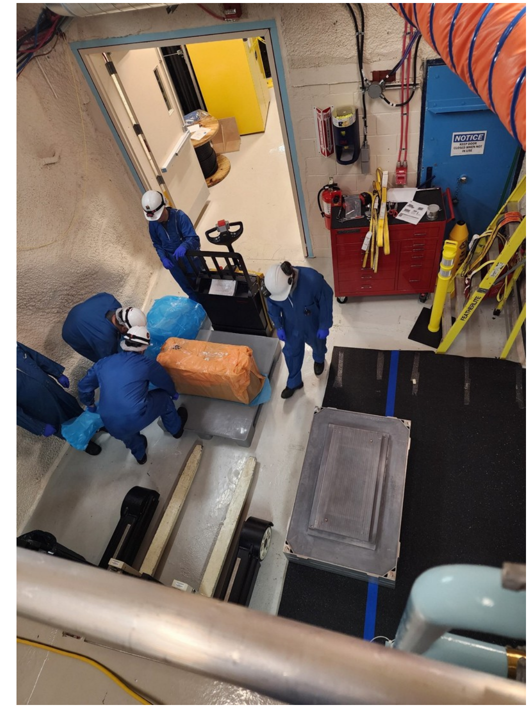
Beta-gamma coincidence detection

- 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





Duel Detector Shield Assembly



Duel Detector Shield Assembled

- The working detector has been used for tests with the RAMPS project
- The Left Detector will be sent to Mirion for repairs, it is expected that the FET will be required to be replaced
- When not used for Health Canada / SNOLAB projects, RAMPS and DarkSide have projects to utilize the co-incidence 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
- Current SNOLAB working group: Ian Lawson, Matt Stukel, Chris Jillings, Steffon Luoma, Tom Sonley, Dimpal Chauhan & Coop/Summer Students
- SNOLAB Leadership team: Ray Bunker, Stephen Sekula & Lina Anselmo
- Project Manager: Darrin Barton

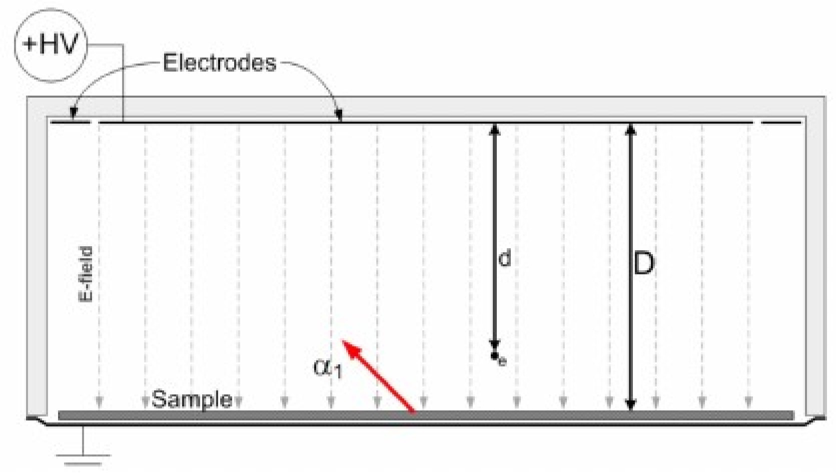
Alpha Counting

Model: XIA Ultra-Lo 1800 (x2)

Argon gas drift chamber for Alpha rate measurement

Uses electronic amplification rather than gas amplification

”Background Free” measurements



Alpha Counting

- Activities as low as 6 +/- 1 x 10^{-4} alphas/cm^2/hour = 180 +/- 30 nBq/cm^2 have been measured.
- Small residual background due to radon and cosmic rays slipping through cuts.
- Available for assays.
- Large (30 x 30 cm or more), thin (<1cm), conductive materials are best.
- Count region: 1800 cm^2 and 707 cm^2 circular Maximum sample weight: 9kg, Maximum sample thickness: 6.3mm

Inductively Coupled Plasma - Mass Spectrometey

- Agilent 8900 ICP-QQQ advanced application model (triple quadrupole ICP-MS)
- System will be run in SNOLAB’s surface clean labs
- Used for elemental analysis at trace detection levels.
- Our aim is to achieve sub-ppt detection of a variety of elemental analytes in samples
- Our first effort will be an ultra-low detection method for UPW monitoring
- Current key analytes of interest for ICP-MS at SNOLAB are currently: U, Th, K, Pb
- We will also be using the instrument to perform isotopic ratio analysis

Agilent 8900 ICP-QQQ
Example of ICP-MS at SNOLAB

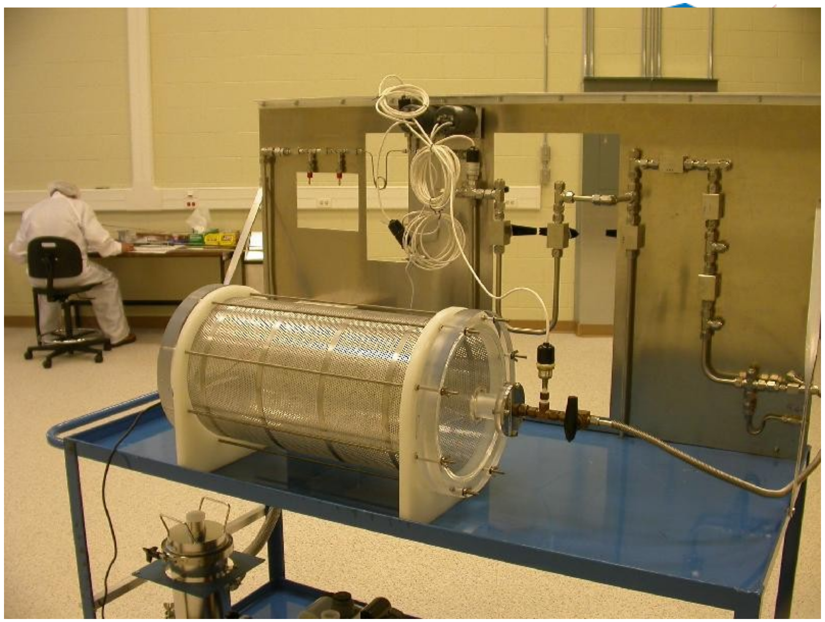
Radon Emanation

Emanation: Radon atoms formed from the decay of radium escape from the decaying isotopes and into the spaces between the isotopes.

Transport: Diffusion and advective flow cause the movement of the radon atoms through the sample to the surface.

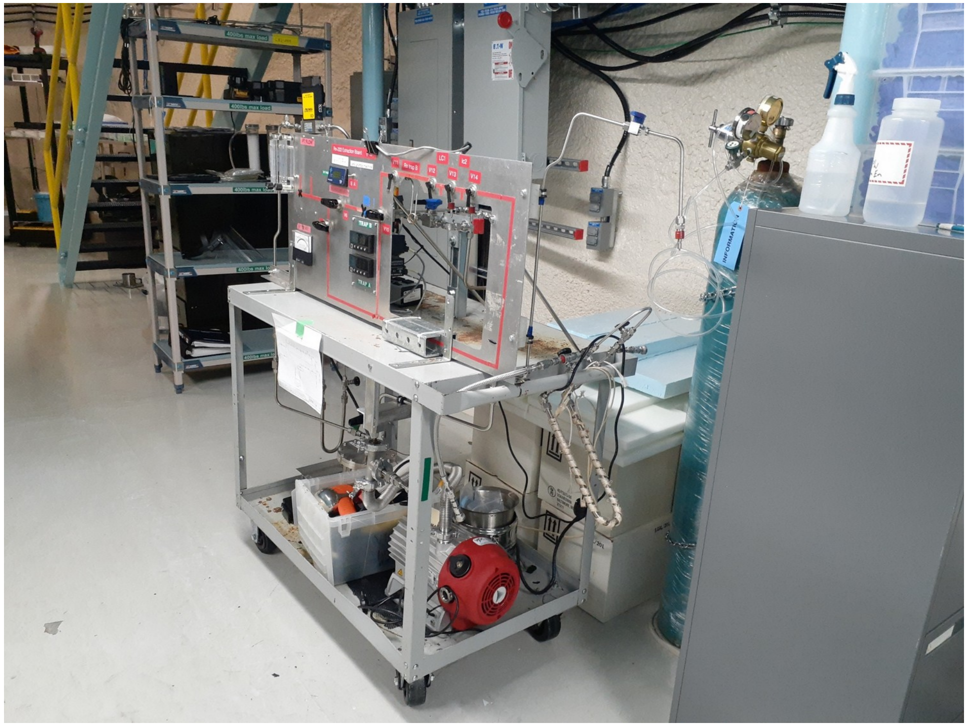
Exhalation: Radon atoms that have been transported to the surface and then exhaled to the surface.

Samples generally placed in a chamber to allow the radium to decay for several half-lives and then radium daughters are accumulated and counted to give the rate in $Bq/m^2/s$ or Bq/kg/s



Sample	Rate ($Bq/m^2/s$)	References
Shotcrete	1.7-4.2 mBq/m^2	J. Bigu and E.D. Hallman SNO-STR-92-064
Copper Foil	1.2-1.7 $\mu Bq/m^2$	G. Zuzel, H. Simgen, Applied Radiation and Isotopes, Volume 67, Issue 5, May 2009, 889.
Stainless Steel	4.6-10.2 $\mu Bq/m^2$	G. Zuzel, H. Simgen, Radon Emanation measurements, GERDA General Meeting, July 11, 2007
Silicon Rubber	196 mBq/m^2	Zuzel, G., AIP Conference Proceedings, Vol. 785, pp. 142-149.

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 presentations by Nasim Fatemighomi, Hantz Nozard and Peter Qin in the DAPI T2-1

Neutron Activation

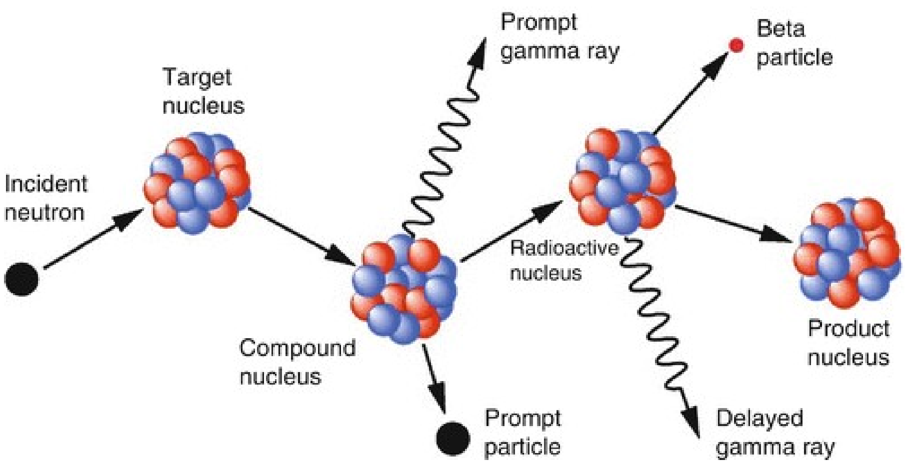
Sample is activated with neutrons causing its components to form radioactive isotopes.

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

Röntgen Excitation Analysis (XRF)

X-ray fluorescence of a sample after being bombarded with high-energy X-rays or gamma rays.

Used for elemental analysis and chemical analysis, used generally for metals, glass, building materials, etc…

For low background experiments, for example, it can be used to measure surface contamination by observing any presence of heavy elements such as iron, calcium and zinc which can be found in mine dust.

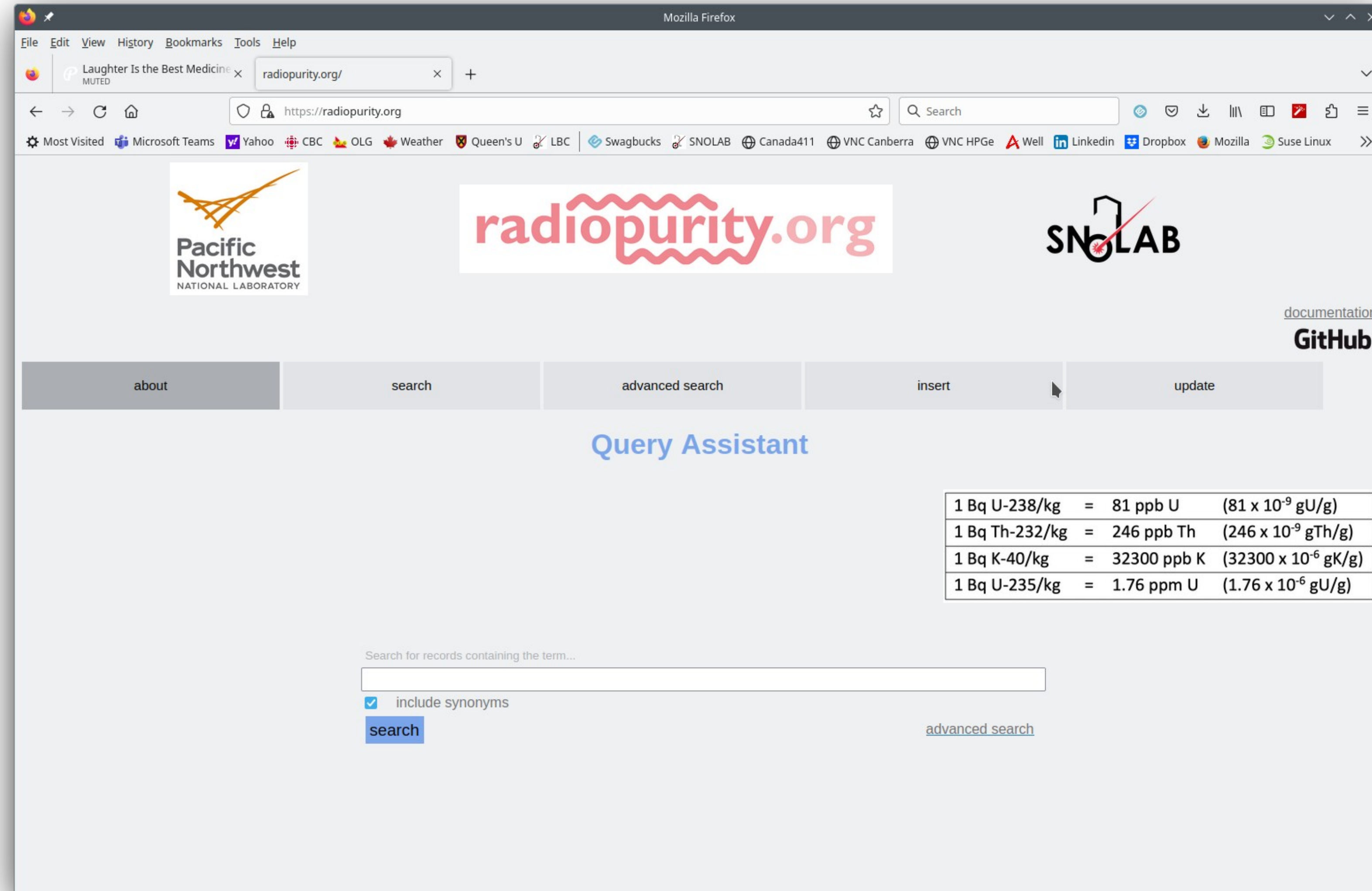
Catalogue of EMI Signatures

Spectrum Analyzer with a 9 kHz - 7.5 GHz frequency range

Survey and catalogue sources of electrical noise in the lab

Devices are available to SNOLAB experiments as needed

Material Assay Database



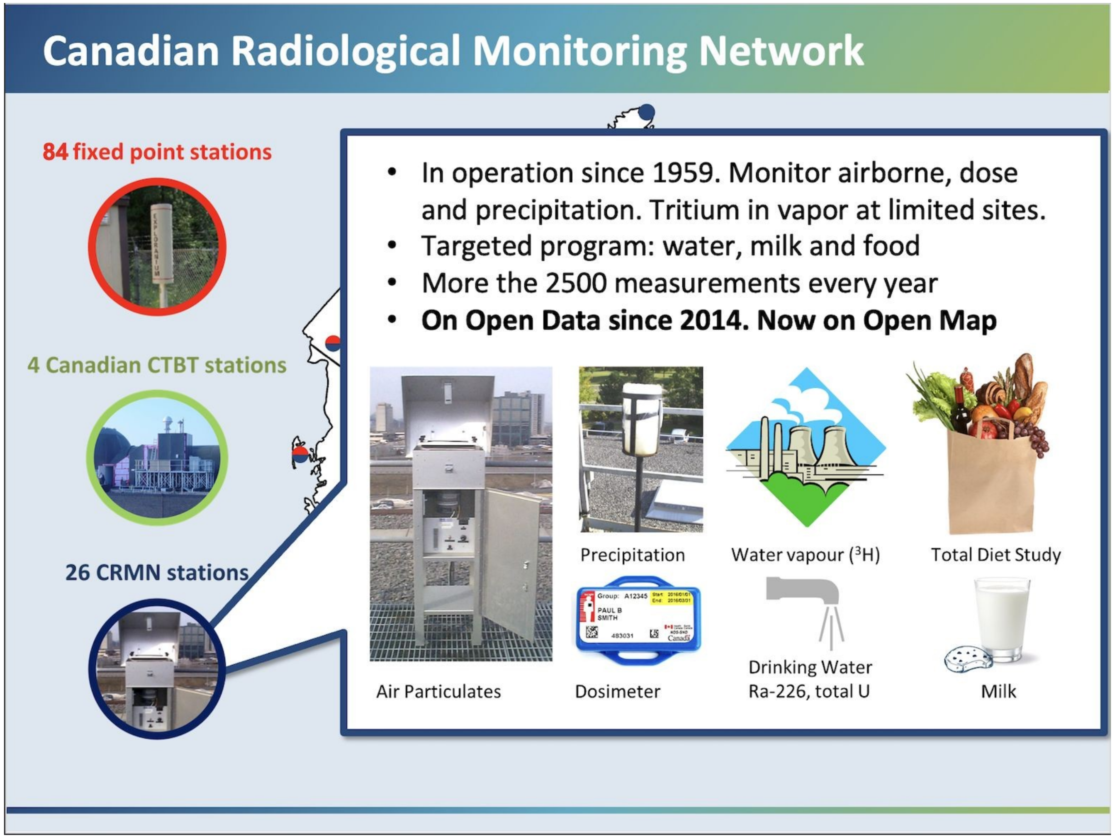
- The Assay and Acquisition of Radiopure Materials (AARM) Collaboration originally developed the Community Material Assay Database radiopurity.org.

- 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

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.snolab.ca/users/services/gamma-assay