Low Background Measurement Program at SNOLAB

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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)

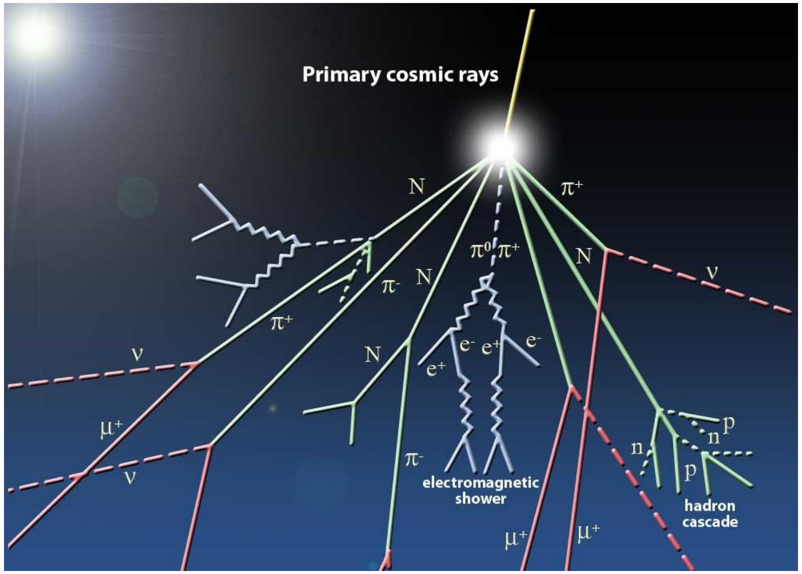
Muons can be veto'd in anti-coincidence shields; however, secondary products may be an issue

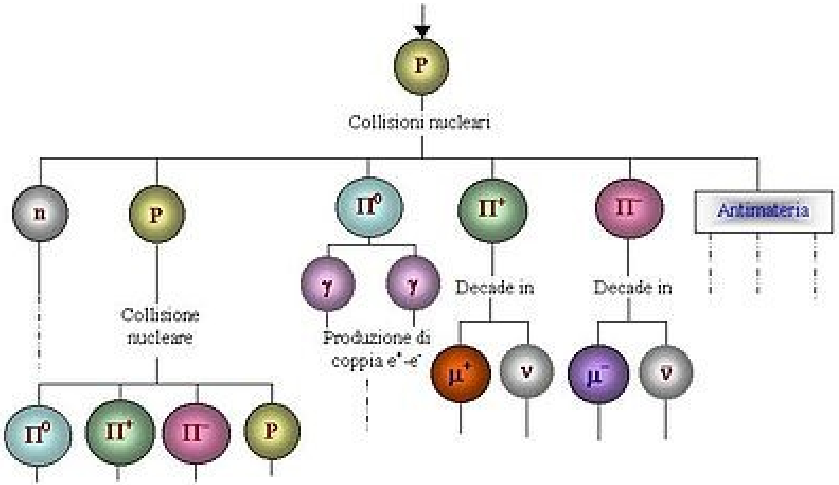
Cosmogenics may require underground material production or purification

- May also contribute to backgrounds (e.g. ^{11}C)

Although being deep reduces backgrounds from cosmic ray products, there can still be backgrounds in the experiment's construction materials and in the surrounding environment, such as the rock.

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





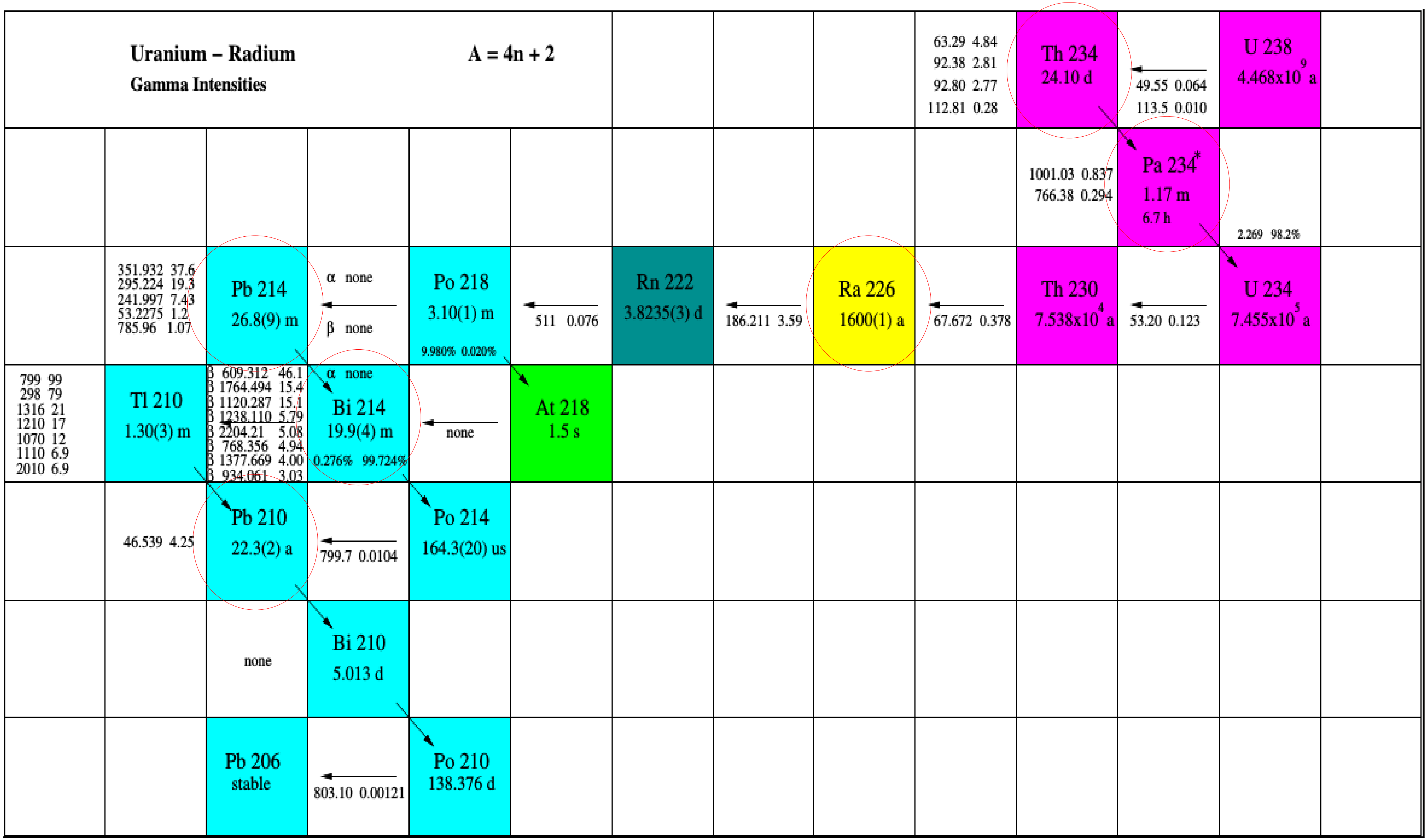
Open Physics Lab

Techniques to Measure These Backgrounds
(Primarily U/Th decay chains and K)

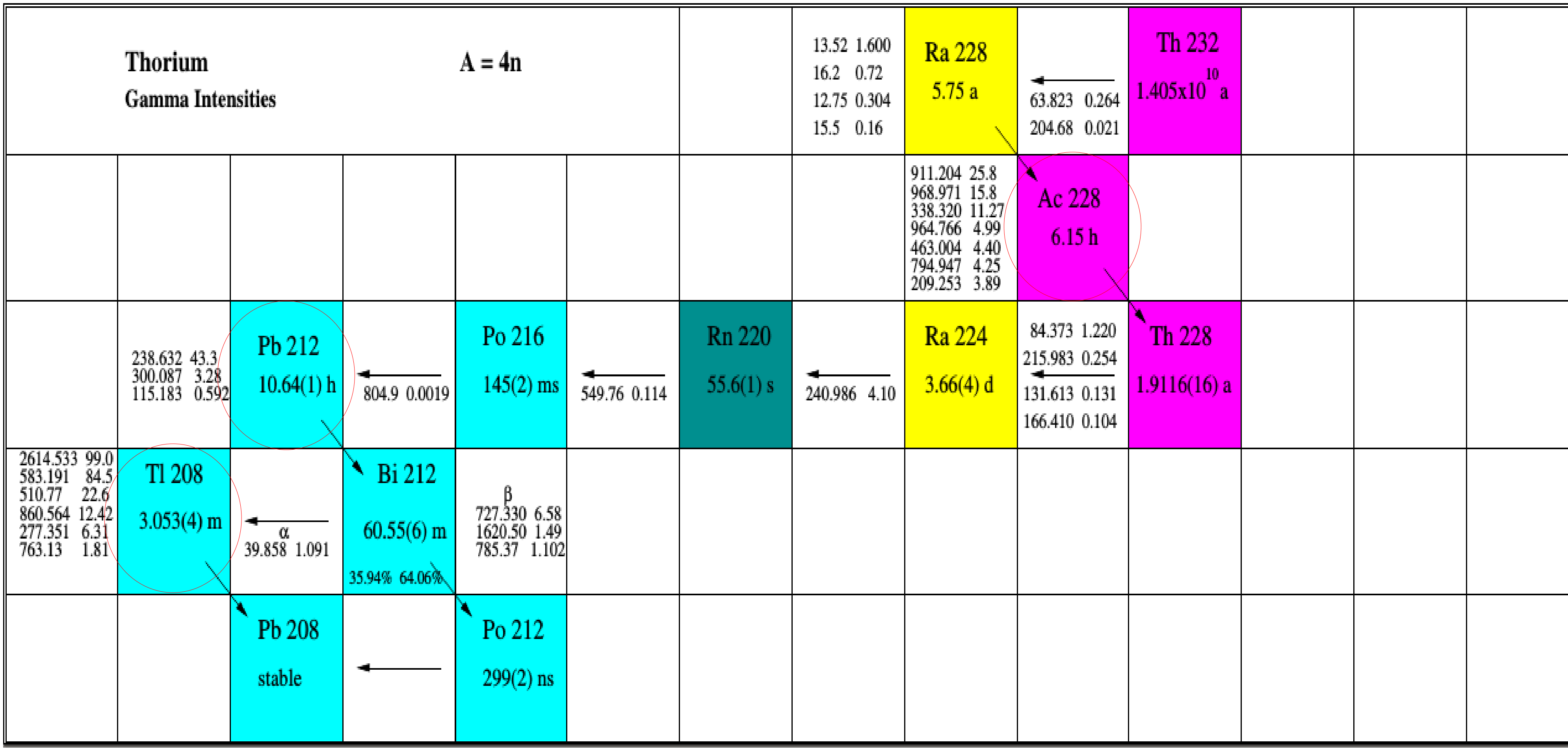
Measurement Method	Background Detected	Sensitivity (for U/Th)
•Ge spectrometry	γ emitting nuclides	10-100 μBq/kg
•Rn emanation assay	^{226}Ra, ^{228}Th	0.1-10 μBq/kg
•Neutron activation	primordial parents	0.01 μBq/kg
•Liquid scintillation counting	α,β emitting nuclides	1 mBq/kg
•Mass spectrometry (ICP-MS; 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	^{210}Po, α emitting nuclides	1 mBq/kg

To reach these sensitivities, samples may have to count for several months

Uranium Decay Chain



Thorium Decay Chain

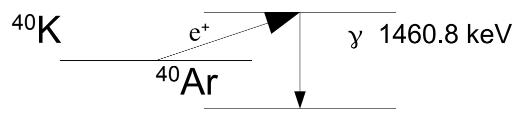


Other Interesting Isotopes

Usually Present:

- ^{40}K

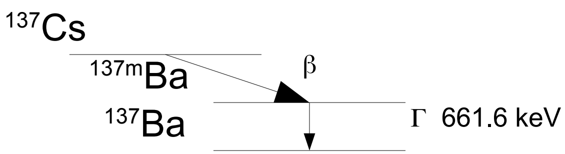
  1460.83 keV



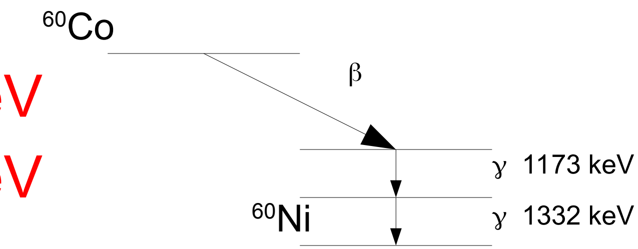
- ^{137}Cs

  661.66 keV

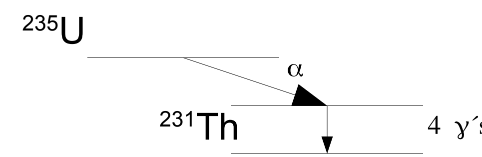
  (from fallout)



- ^{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.
- ^{138}La and ^{176}Lu — Observed in rare earth samples such as Nd or Gd.

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

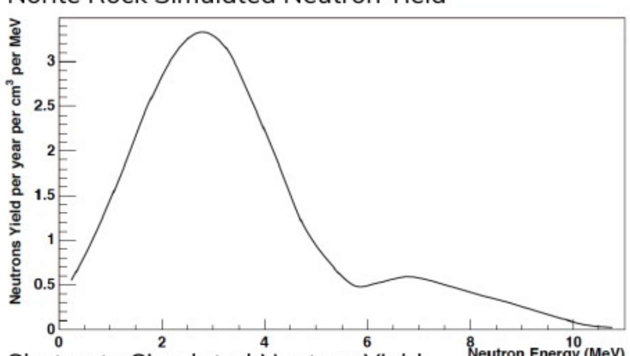
	Norite Rock	Shotcrete/Concrete
O	47 %	48 %
Si	27 %	28 %
Fe	6.5 %	2.5 %
Al	6 %	6 %
Mg	6 %	1 %
Ca	3.5 %	10 %
Na	1.7 %	2 %
K	1 %	1.7 %
Ti	0.3 %	0.2 %

Norite Density: 2.88 g/cm^3

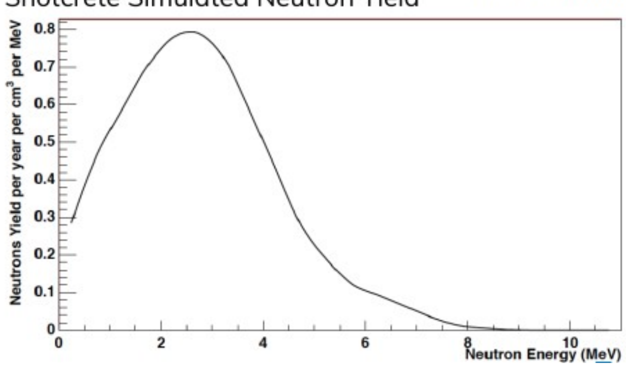
SNOLAB - Rock Properties

Isotope	Norite Rock		Shotcrete	
	Concentration	Neutron Production (n/yr/cm³)	Concentration	Neutron Production (n/yr/cm³)
^{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

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 / m^2 / day
- Estimated Fast Neutron Flux: 4000 neutrons / m^2 / day

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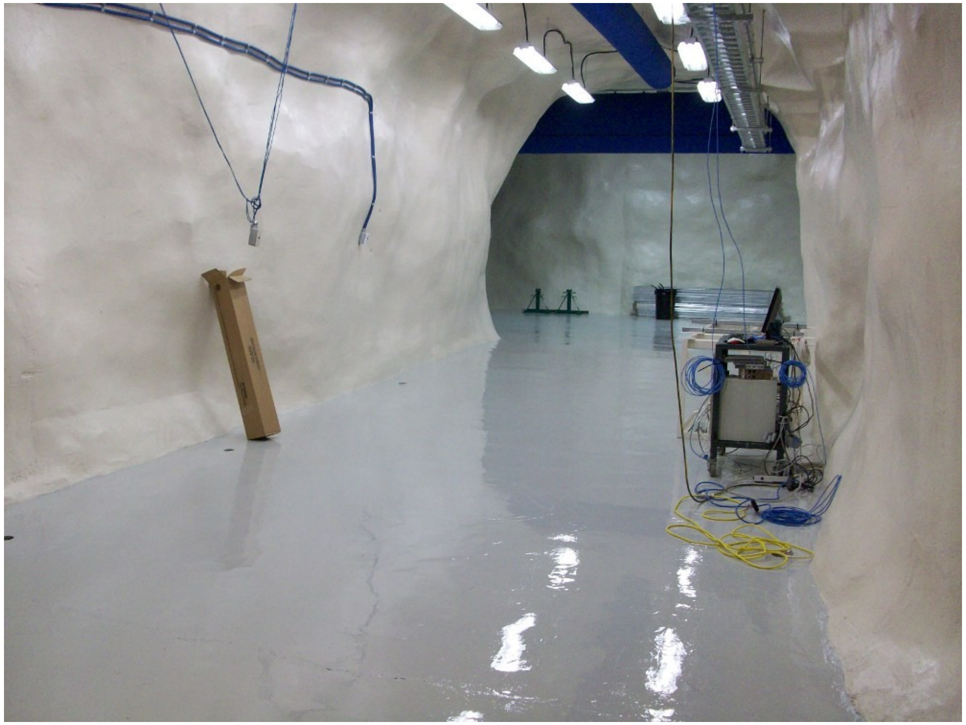
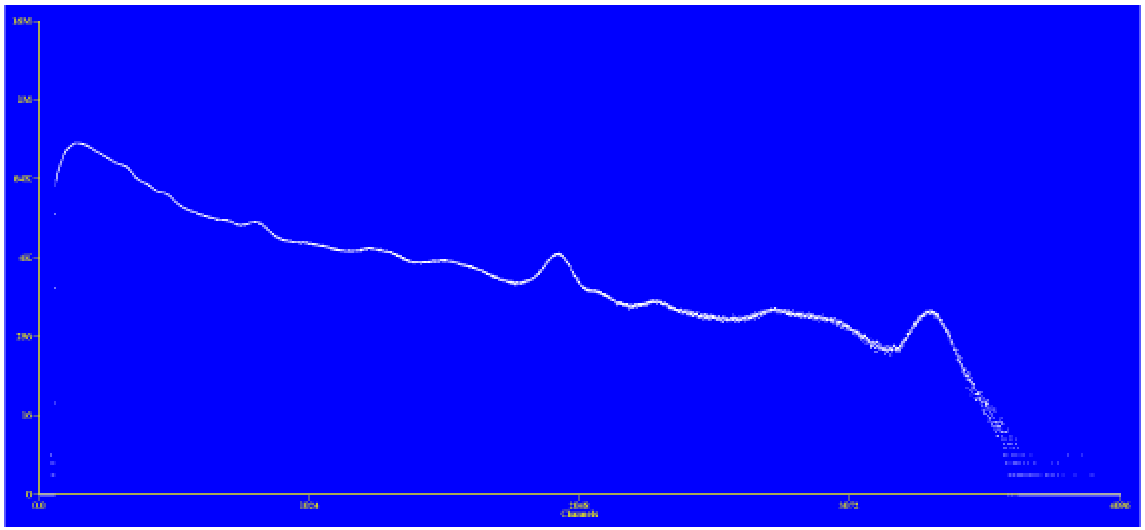


BDS Detectors

144 detectors at 6 thresholds.

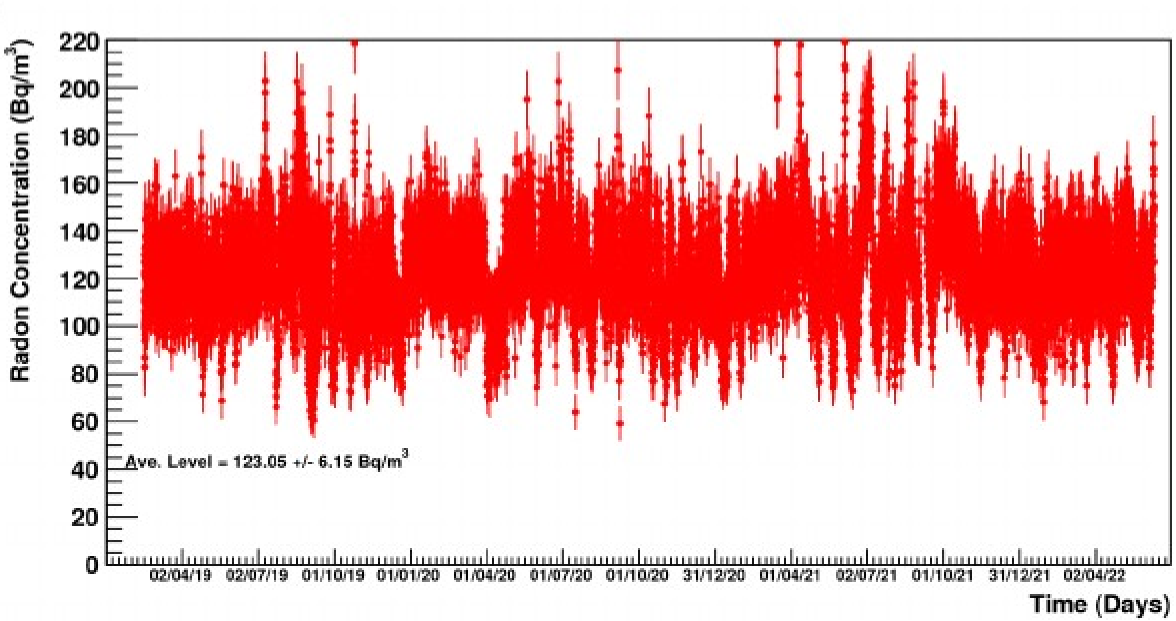
Gamma-ray Backgrounds



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

Radon Levels

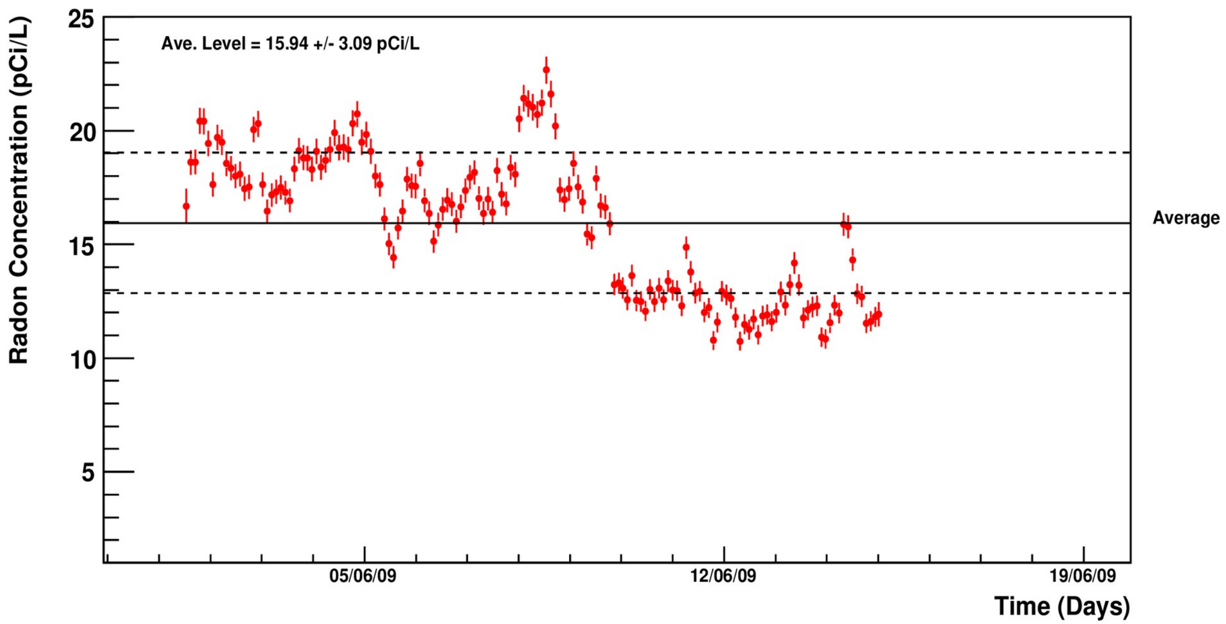


Average radon levels (with air ciruclation operational:

123.1 +- 6.2 Bq/m^3

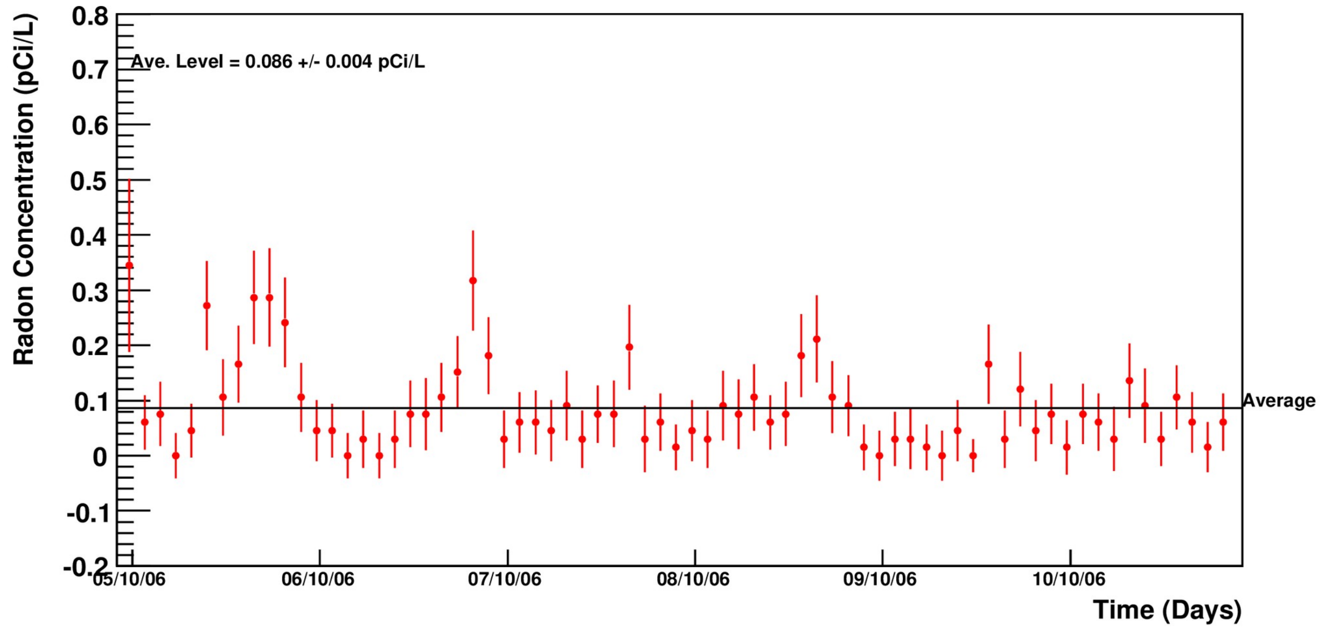
Average radon levels without air circulation:

589.8 +- 114.3 Bq/m^3.



Reducing Radon Levels

Use compressed air supplied from surface



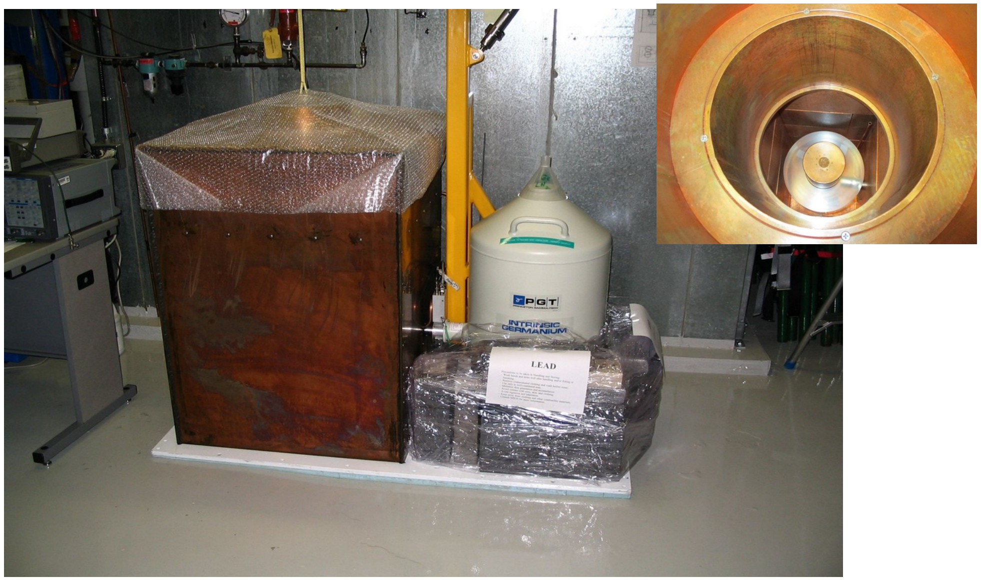
Use compressed air supplied from surface: 3.18 +- 0.15 Bq/m^3

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

Use liquid nitrogen boil-off gas

Gamma-Ray Spectrometry
SNOLAB HPGe Counters



PGT

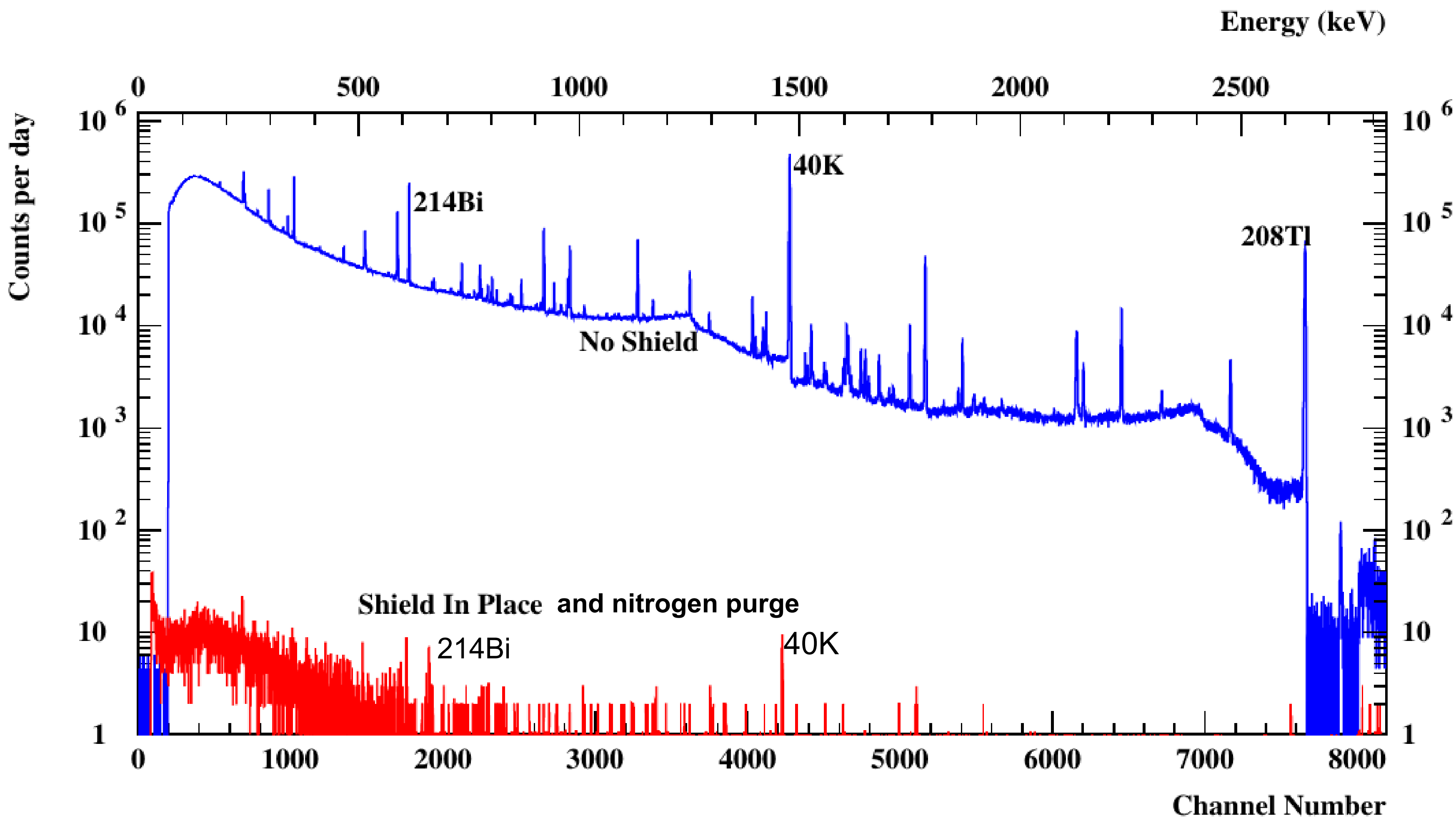
Lively

WELL

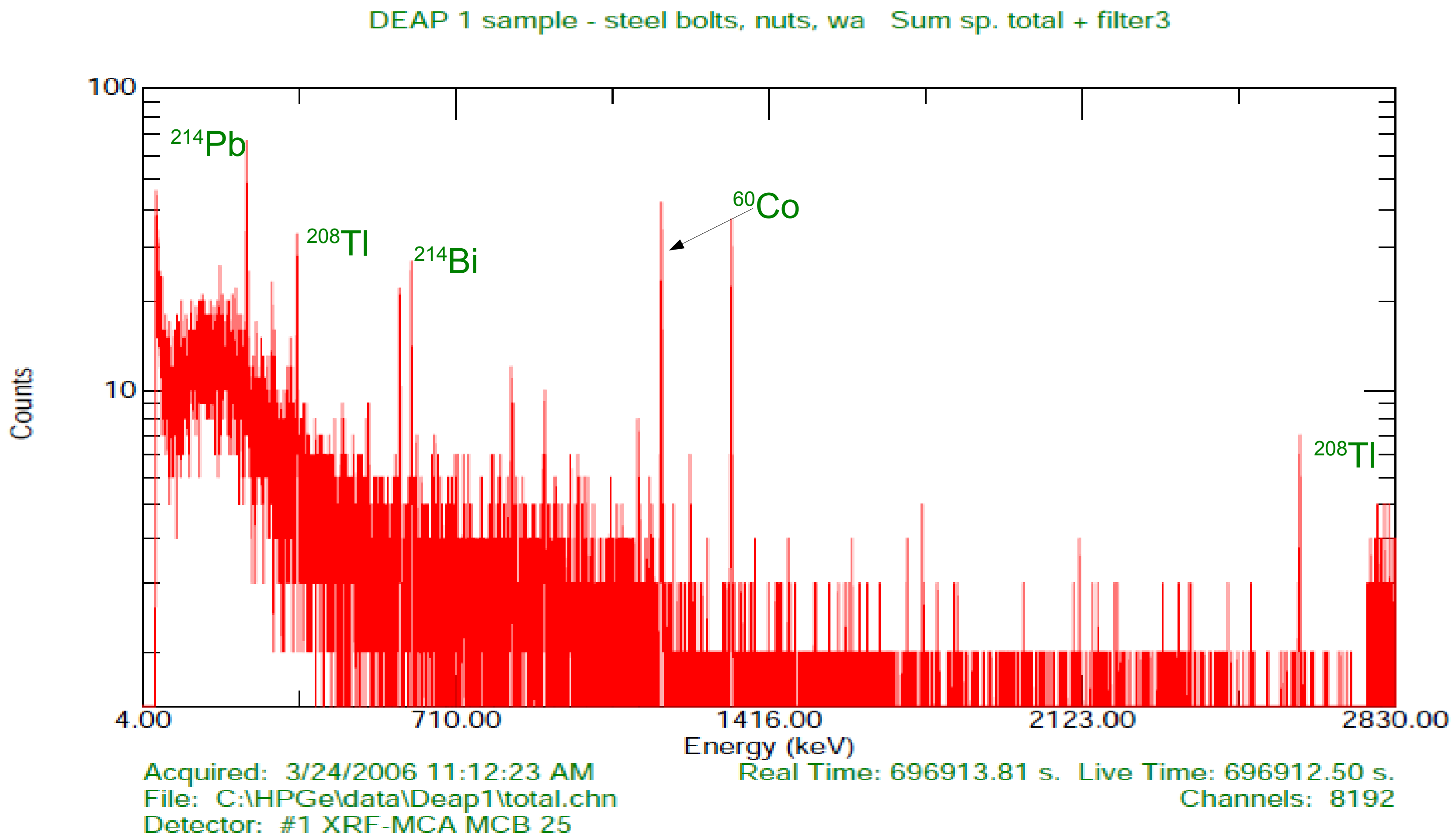
Gopher

VDA

Unshielded and Shielded Spectra
(PGT Coax Detector)



Typical Stainless Steel Spectrum



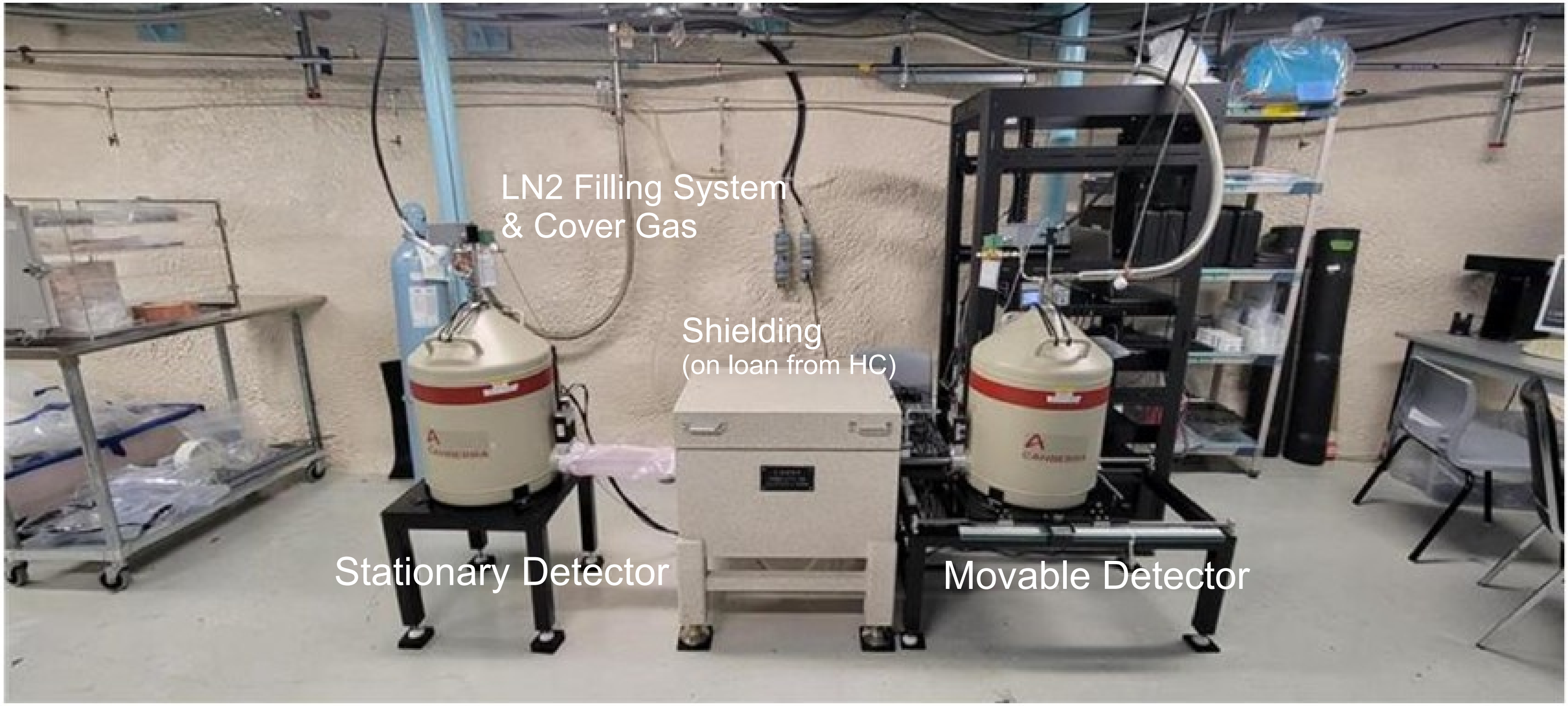
Gamma Counter Sensitivities

(change to counts/kg/day for different gamma lines)

Isotope	SNOLAB Gamma Counter 1 (mBq) PGT	SNOLAB Gamma Counter 2 (mBq) Well	SNOLAB Gamma Counter 3 (mBq) Lively	SNOLAB Gamma Counter 4 (mBq) VdA	SNOLAB Gamma Counter 5 (mBq) Gopher
^{238}U	0.11 mBq	0.02 mBq	0.05 mBq	0.09 mBq	0.17 mBq
^{235}U	0.16 mBq	0.01 mBq	0.02 mBq	0.06 mBq	0.08 mBq
^{232}Th	0.10 mBq	0.02 mBq	0.06 mBq	0.08 mBq	0.21 mBq
^{40}K	1.42 mBq	0.92 mBq	0.45 mBq	1.22 mBq	1.01 mBq
^{60}Co	0.04 mBq	0.03 mBq	0.02 mBq	0.02 mBq	0.04 mBq
^{137}Cs	0.13 mBq	0.02 mBq	0.02 mBq	0.05 mBq	0.08 mBq
^{54}Mn	0.043 mBq	0.033 mBq	0.021 mBq	0.034 mBq	0.044 mBq
^{210}Pb	N/A	0.55 mBq	31.53 mBq	7.71 mBq	16.49 mBq

Dual Detector

Comprehensive Test Ban Treaty Detector

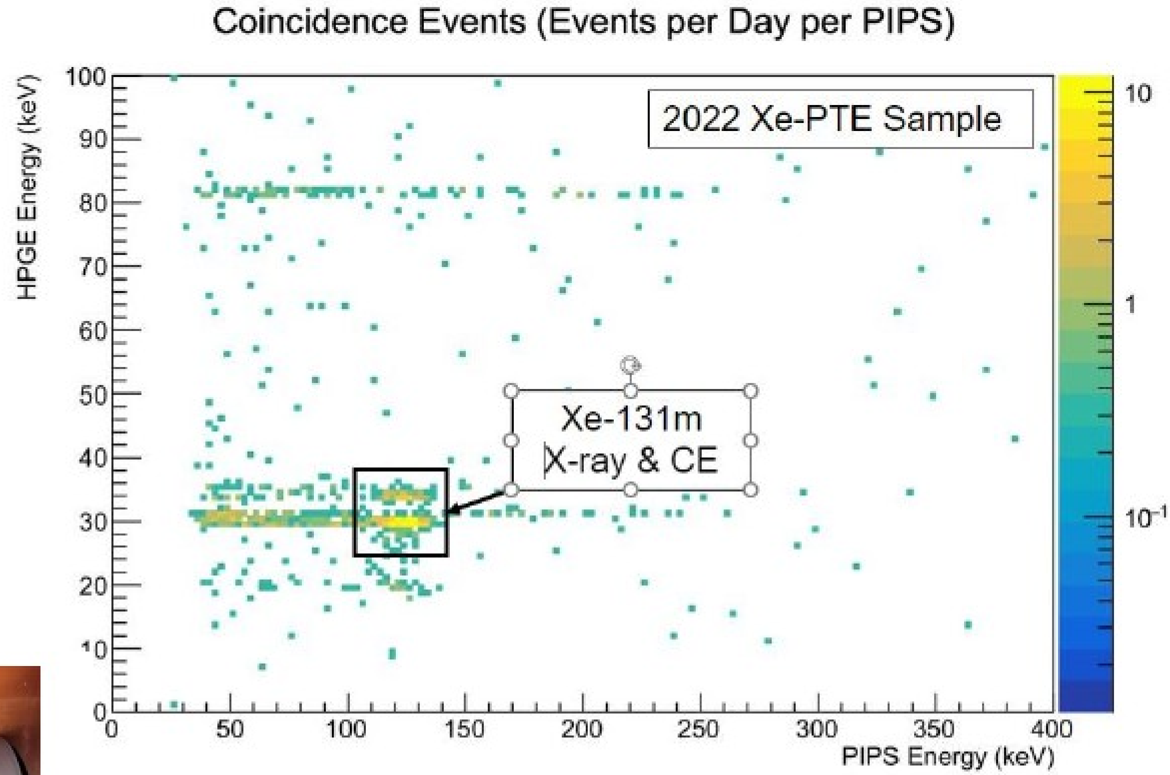


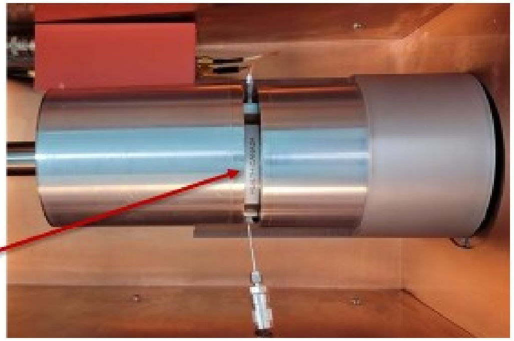
- Comprehensive Test Ban Treaty Detector
  Health Canada's radionuclide laboratory CAL05
- Two Broad Energy Germanium (BeGe) Detectors
- Coincidence events between the two detectors

Dual Detector

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





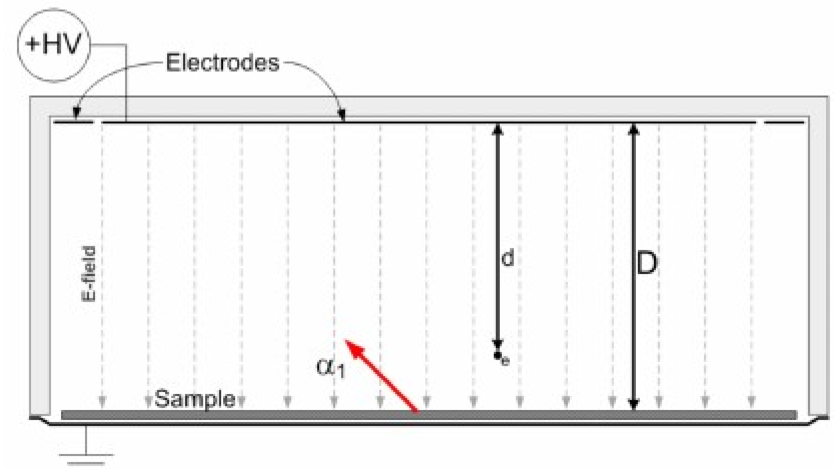
Alpha Counting

Model: XIA Ultra-Lo 1800

Argon gas drift chamber for Alpha rate measurement

Uses electronic amplification rather than gas amplifiication

”Background Free” measurements



Alpha Counting

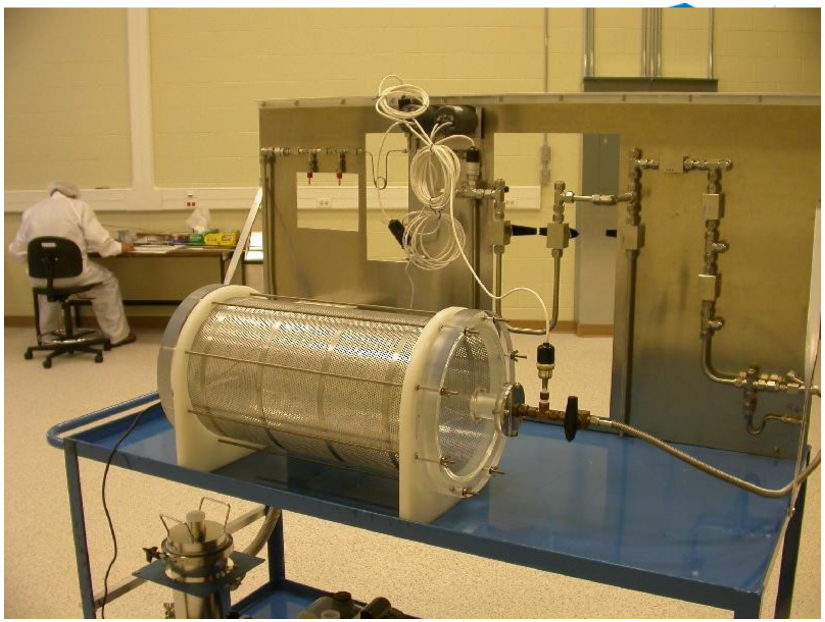
- Activities as low as 6 +/- 1 x 10^{-4} alphas/cm^2/hour = 180 +/- 30 nBq/cm^2 have been measured.
- Small residual background due to radon and cosmic rays slipping through cuts.
- Available for assays.
- Large (30 x 30 cm or more), thin (<1cm), conductive materials are best.
- Count region: 1800 cm^2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

Inductively Coupled Plasma - Mass Spectromety

- 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 Surface Radon Emanation Chamber

- Radon Boards (Surface and Underground)
- Electrostatic Counters (ESC)
- Radon Emanation Studies using Bronze and Xeolite/charcoal traps
- Radon Board on Ultra-Pure Water System
- Add addiitonal emanation chambers

Surface radon emanation system

Catalogue of EMI Signatures

RIGOL Spectrum Analyzer with a 9 kHz - 7.5 GHz frequency range

Survey and catalogue sources of electrical noise in the lab

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
- SNOLAB is embarking on a program to better understand the underground background environment.
- To count samples at SNOLAB visit and follow the instructions at:

  https://www.snolab.ca/users/services/gamma-assay/assay_request_form.html

SNOLAB Low Background Team

- SNOLAB, Sudbury
  - L. Anselmo, D. Chauhan, B. Cleveland, J. Farine, N. Fatemighomi, J. Hall, I. Lawson, S. Luoma, T. Sonley and Students
- CTBT radionuclide laboratory CAL05 - Dual CTBT Detector
  - Health Canada
  - Adrian Botti, Pawel Mekarski, Marc Bean, Colin Vant and Kurt Ungar
- UNAM group
  - Institute of Physics, UNAM, Mexico - Background Gamma and Neutron Measurements
  - Lead: Eric Vázquez-Jáuregui
- University of Michigan – Vibration Studies
  - Bjoern Penning and Sam Venetianer