Cosmogenic Backgrounds and Mitigation of Radioactive Backgrounds

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SNOLAB

Second DULIA-bio Workshop
LNGS, Assergi, Italy
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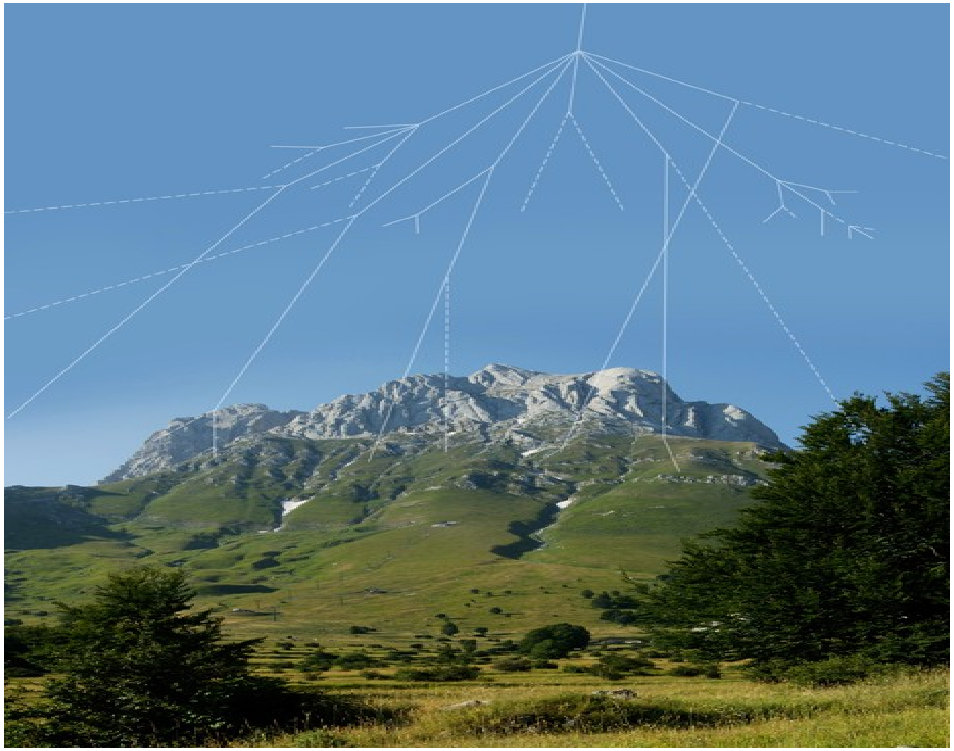
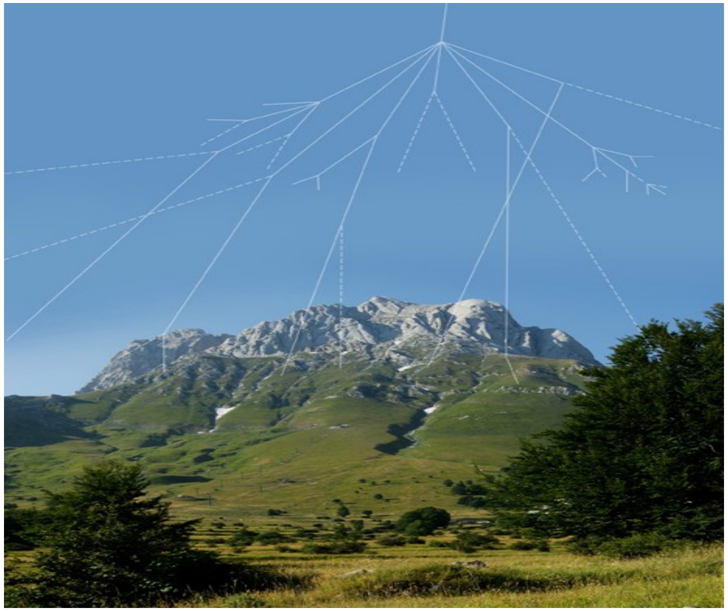


Effect of Overburden
(Why go underground)



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 shield; secondary products may be an issue

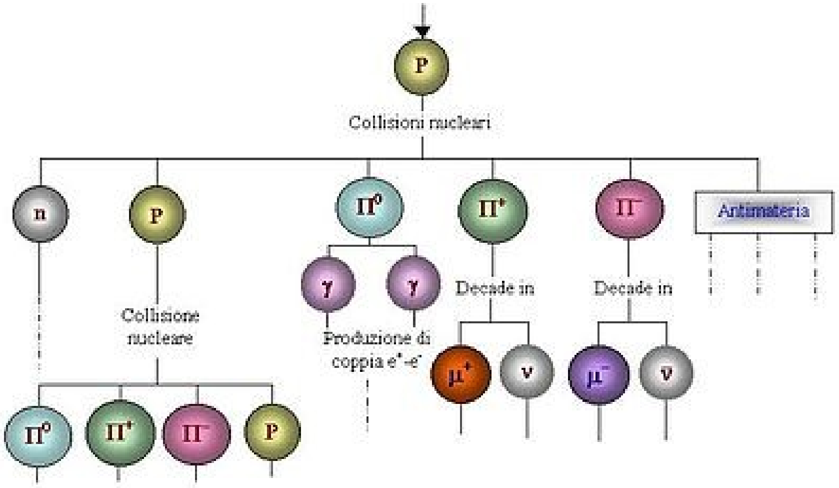
Cosmogenics may require underground material production or purification

- 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.



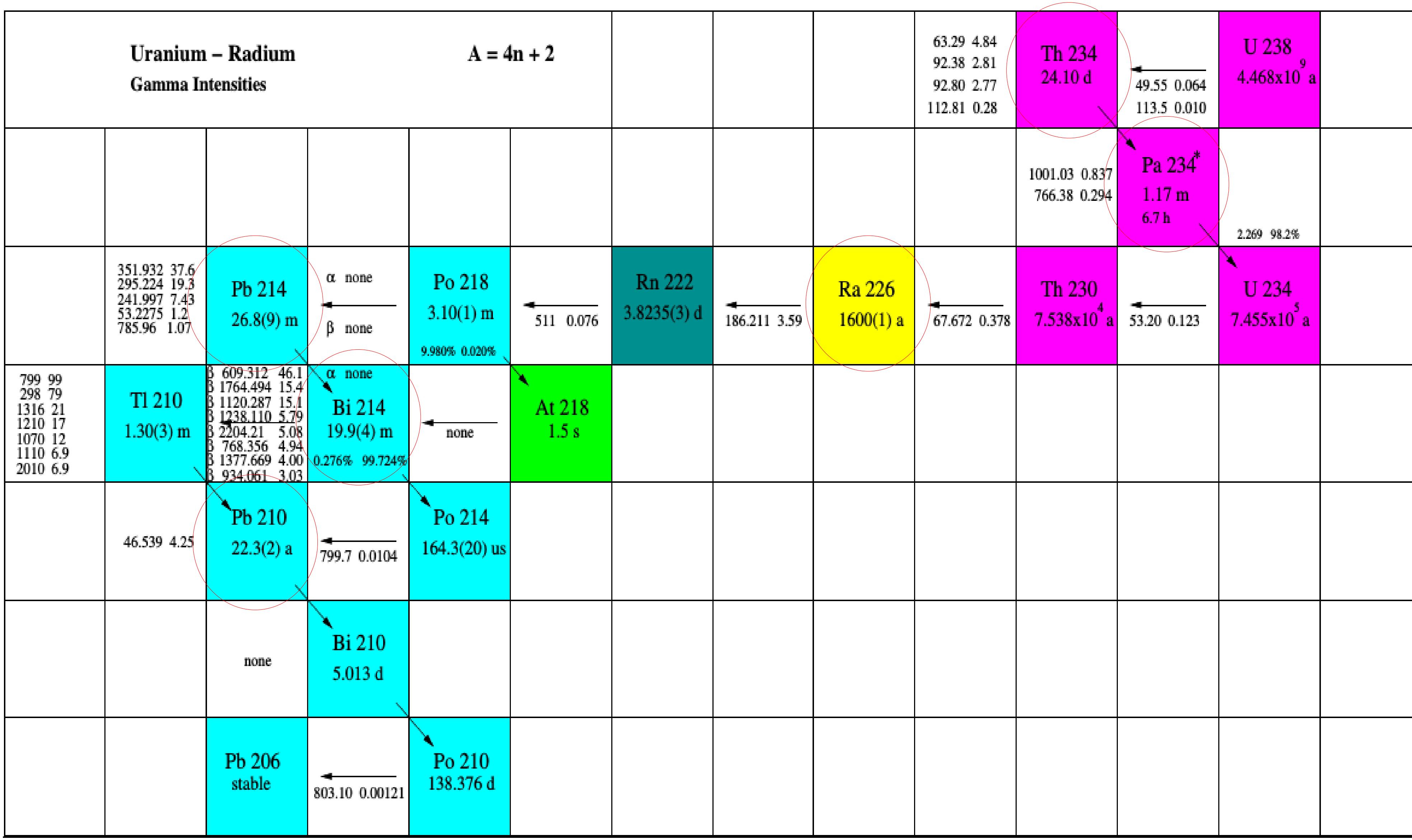
Open Physics Lab

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

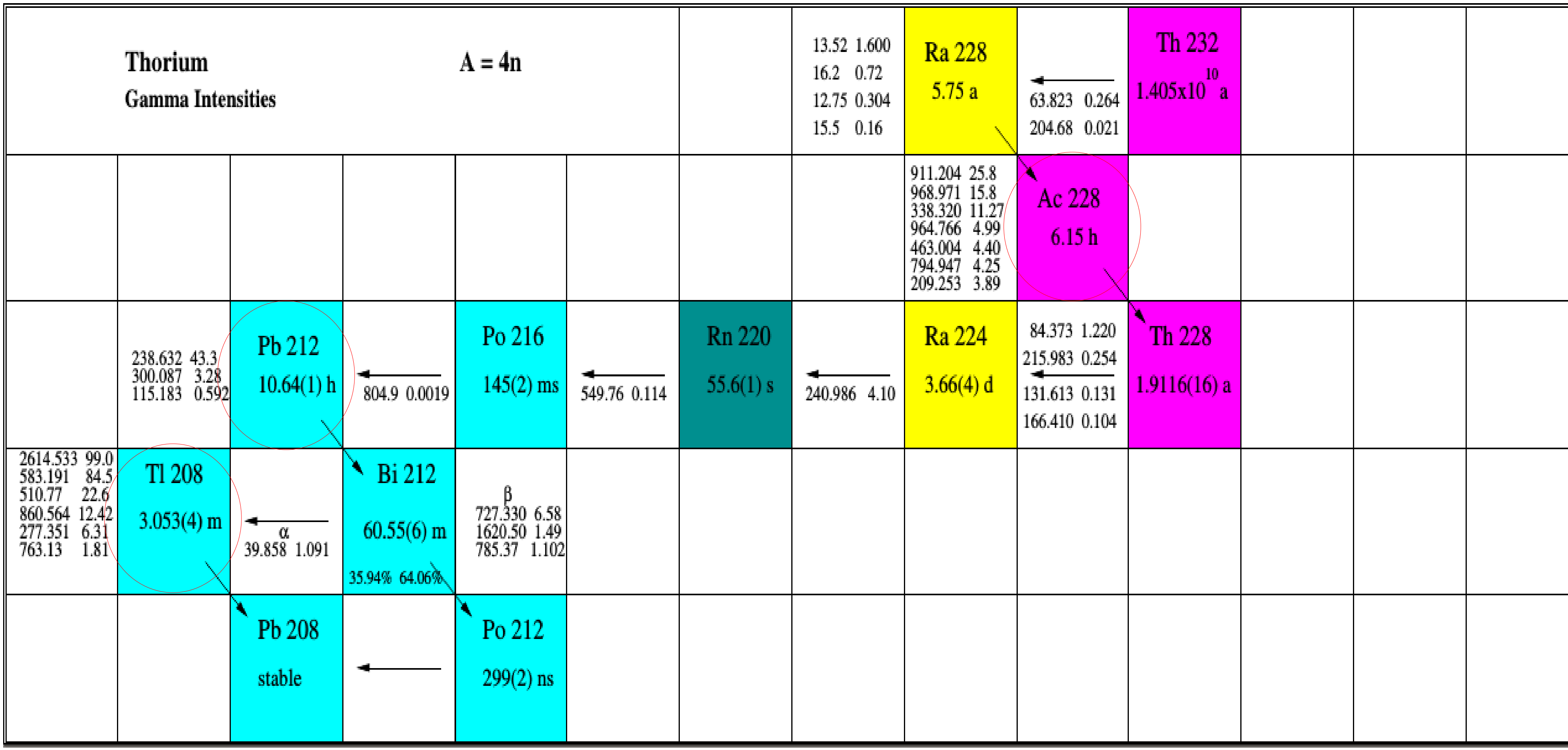
Measurement Method	Background Detected	Sensitivity (for U/Th)
•Ge spectrometry	γ emitting nuclides	10-100 μBq/kg
•Rn emanation assay	^{226}Ra, ^{228}Th	0.1-10 μBq/kg
•Neutron activation	primordial parents	0.01 μBq/kg
•Liquid scintillation counting	α,β emitting nuclides	1 mBq/kg
•Mass spectrometry (ICP-MS; AMS)	primordial parents	1-100 μBq/kg
•Graphite furnace AAS	primordial parents	1-1000 μBq/kg
•Röntgen Excitation Analysis	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

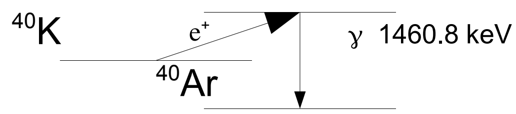


Other Interesting Isotopes

Usually Present:

- ^{40}K

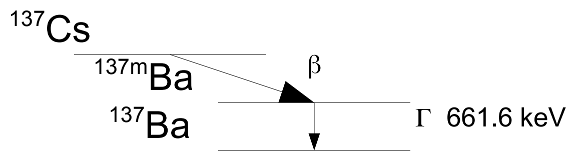
  1460.83 keV



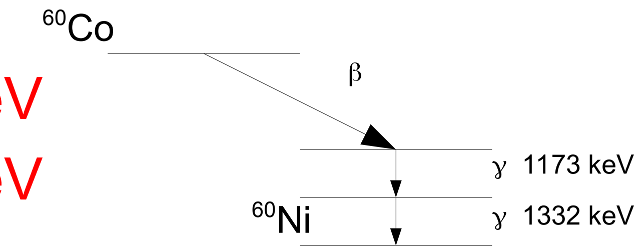
- ^{137}Cs

  661.66 keV

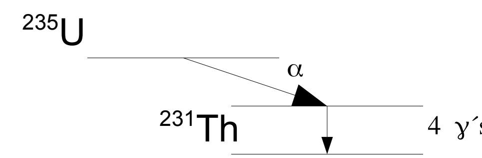
  (from fallout)



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



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



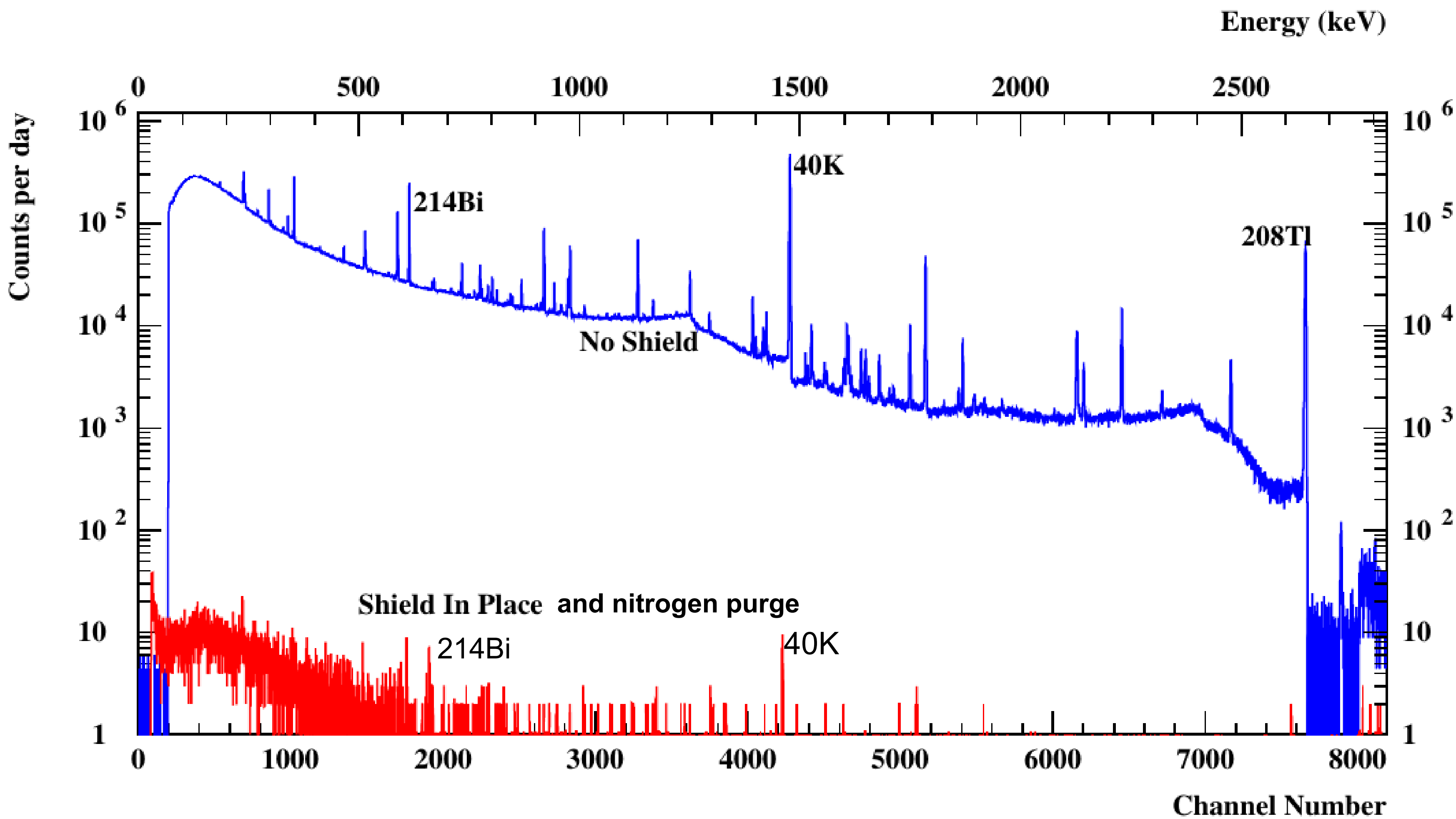
Occasionally Present:

- ^{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.

Ge Spectrometry

SNOLAB PGT HPGe Counter

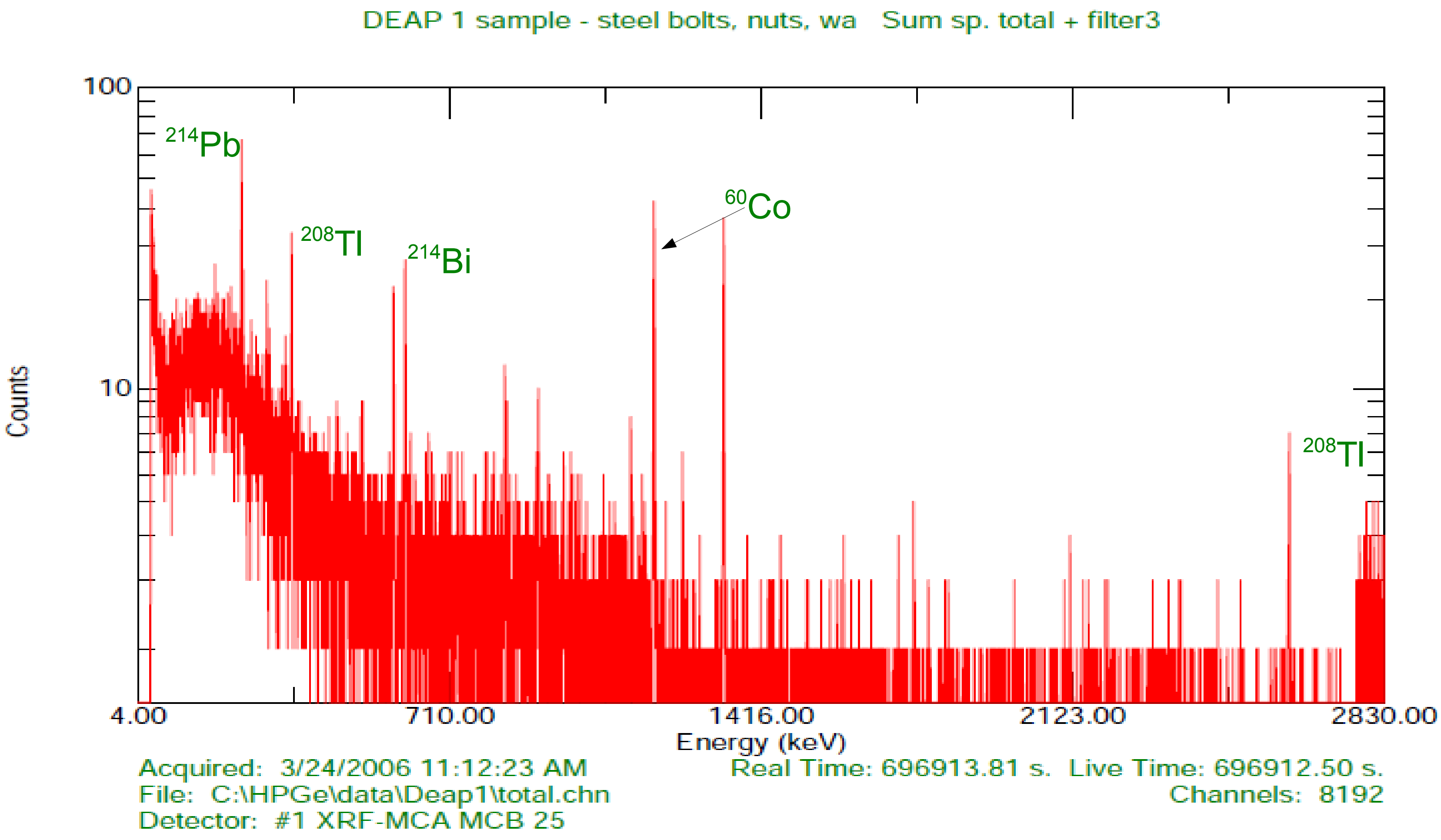
Unshielded and Shielded Spectra
(PGT Coax Detector)



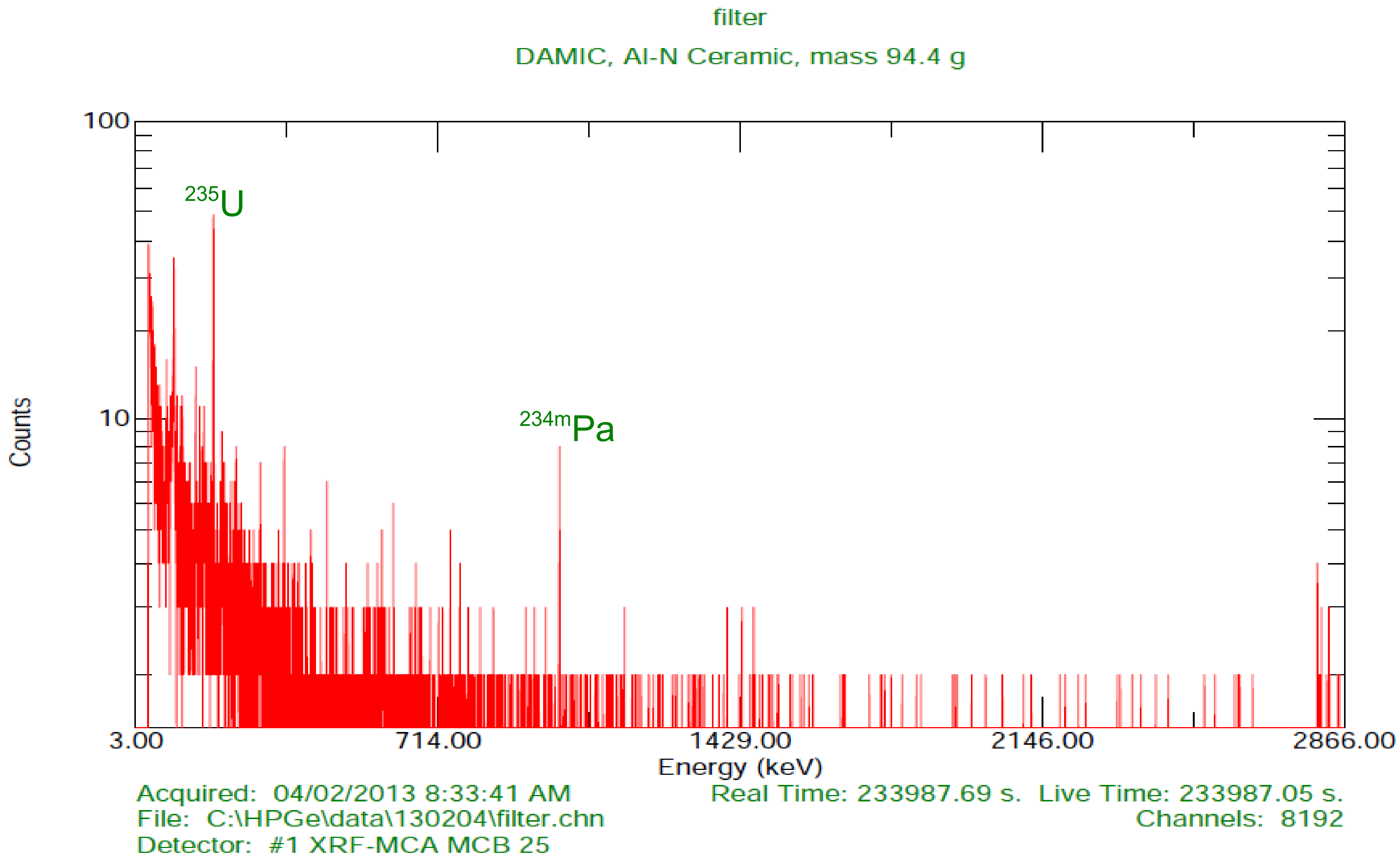
Gamma Counter Sensitivities

Isotope	PGT Detector Sensitivity	Well Detector Sensitivity	Gopher Detector Sensitivity	VdA Detector Sensitivity	Coax Detector Sensitivity
^{238}U	0.11 mBq	0.04 mBq	0.35 mBq	0.06 mBq	
^{235}U	0.15 mBq	0.02 mBq	0.23 mBq	0.04 mBq	
^{232}Th	0.11 mBq	0.23 mBq	0.32 mBq	0.05 mBq	
^{40}K	1.40 mBq	N/A	1.29 mBq	0.70 mBq	Background Run In Progress
^{60}Co	0.04 mBq	N/A	0.04 mBq	0.02 mBq	
^{137}Cs	0.14 mBq	0.02 mBq	0.08 mBq	0.03 mBq	
^{54}Mn	0.04 mBq	0.80 mBq	0.05 MBq	0.02 mBq	
^{210}Pb	N/A	0.08 mBq	N/A	1.65 mBq	

Typical Stainless Steel Spectrum



DAMIC Ceramic Spectrum



DAMIC Data and Simulation Using Results From PGT HPGe Counter

SNOLAB data

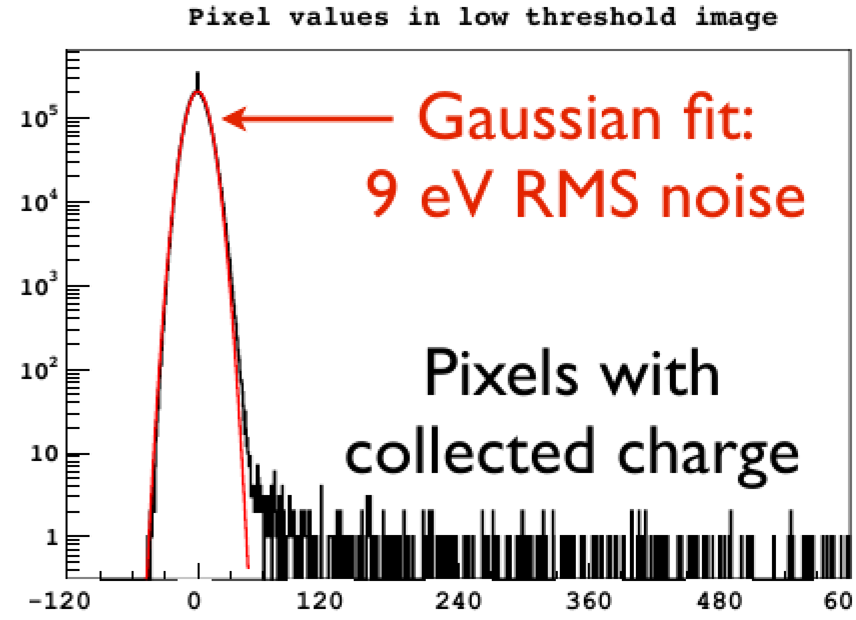
1g, 8 Mpixel CCDs

6 cm x 3 cm x 250 µm

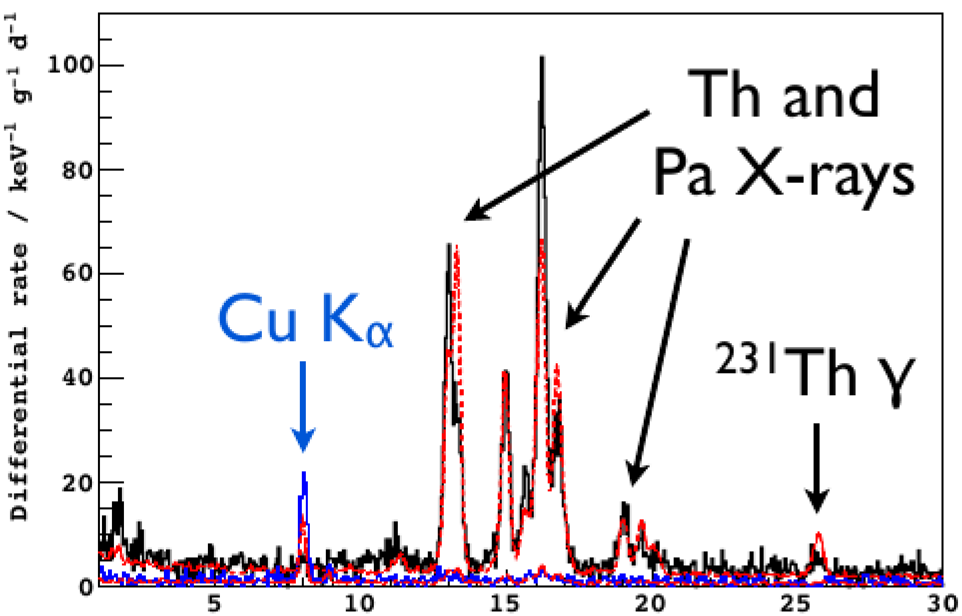
~50 days of data

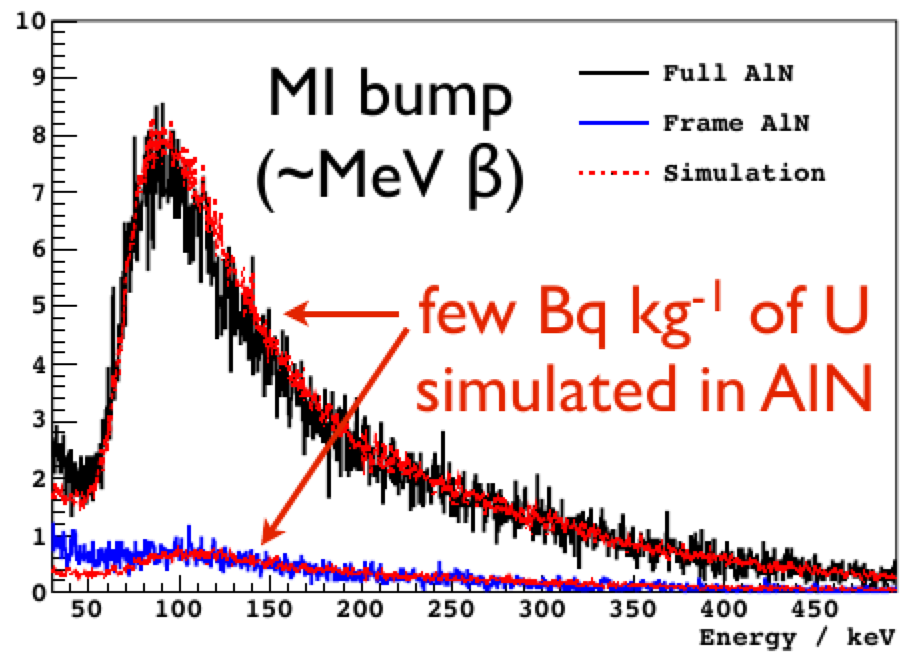
2 CCDs with full AlN

and 2 with frame AlN



Raw spectrum from CCDs at SNOLAB





Gopher Gamma Counter

Gopher HPGE detector, primarily for use by SCDMS, with MOU between U. of Minnesota and SNOLAB.

Currently counting SCDMS and SENSEI samples.

Detector is being re-calibrated to determine a new efficiency equation and to correct the GEANT4 geometry and detector dead layer estimates.

VdA and New Canberra Gamma Counters

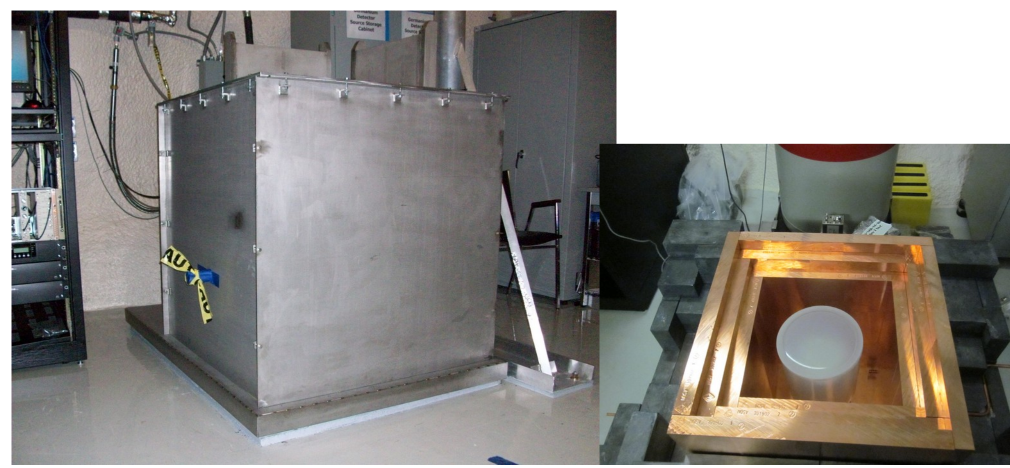
VdA HPGE detector, primarily for use by EXO (nEXO), with MOU between Laurentian U and SNOLAB.

Detector is being calibrated to determine a new efficiency equation.

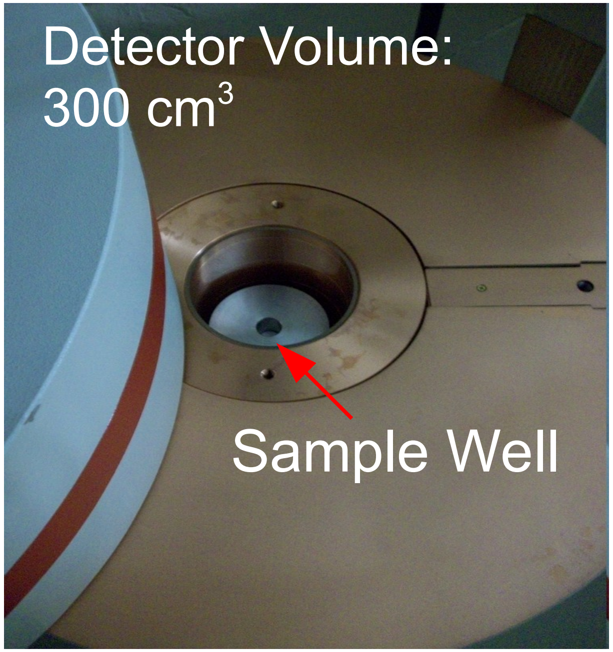
New Canberra Coaxial detector.

Much larger chamber for samples than previous SNOLAB detectors.

General purpose for all experiments. Background runs in progress, efficiency calibration has started.



Canberra Well Detector at SNOLAB



Typical
Sample Bottles
Volume is 3 ml

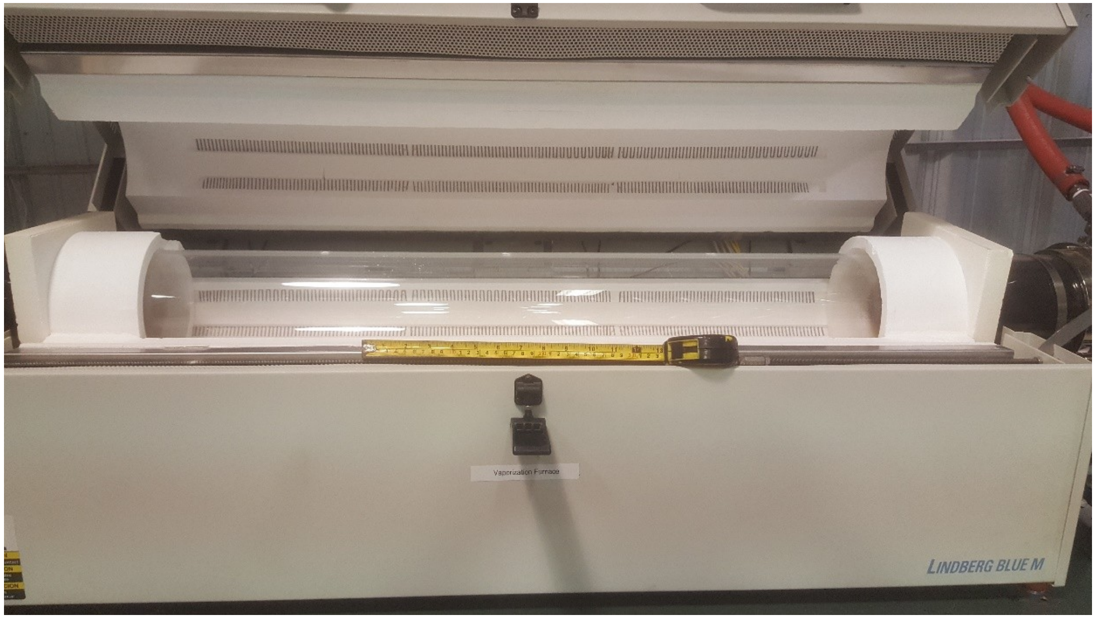
^{210}Pb Detection: Sensitive to 10^{-19} g/g in Plastic

Acrylic vaporized in a furnace and bot - toms collected with acid rinse.

Sample can be several kg.

Gamma count for 46 keV line, OR

Plate out Po-210 from aged effluent on metal discs.



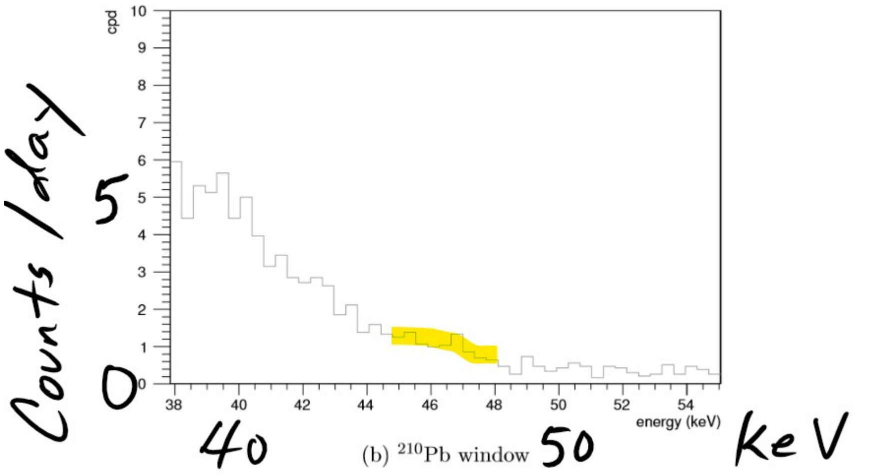
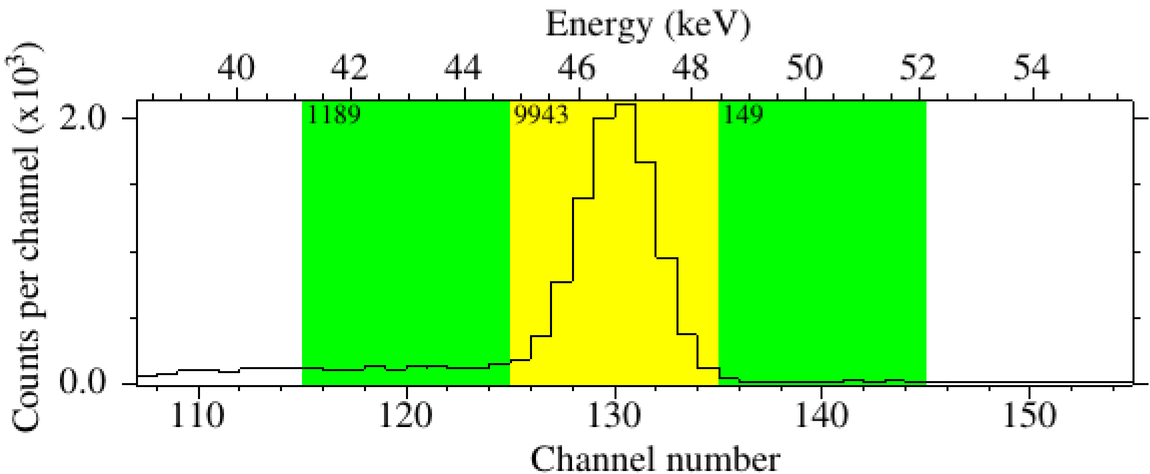


Figure 5.2: The well detector has an acceptable background. (a) The background decreases as energy increases. (b) In the 44.5–48 keV ^{210}Pb window, the background is (10.6 ± 0.7) cpd.



Typical spectrum from acrylic vapourisation sample

Plot from MSc thesis of Corina Nantais, Queen's University at Kingston, 2014

Ge Detectors Calibration Samples

The efficiency of a Ge detector is calculated to minimize systematic uncertainties from the Monte Carlo simulations required for each sample.

Use efficiency derived from measurement of a calibrated source.

Monte Carlo corrections are always done in ratio

$$\epsilon_{sample}(E) = \epsilon_{cal}(E) \times \frac{\epsilon_{MC\ sample}(E)}{\epsilon_{MC\ cal}(E)}$$

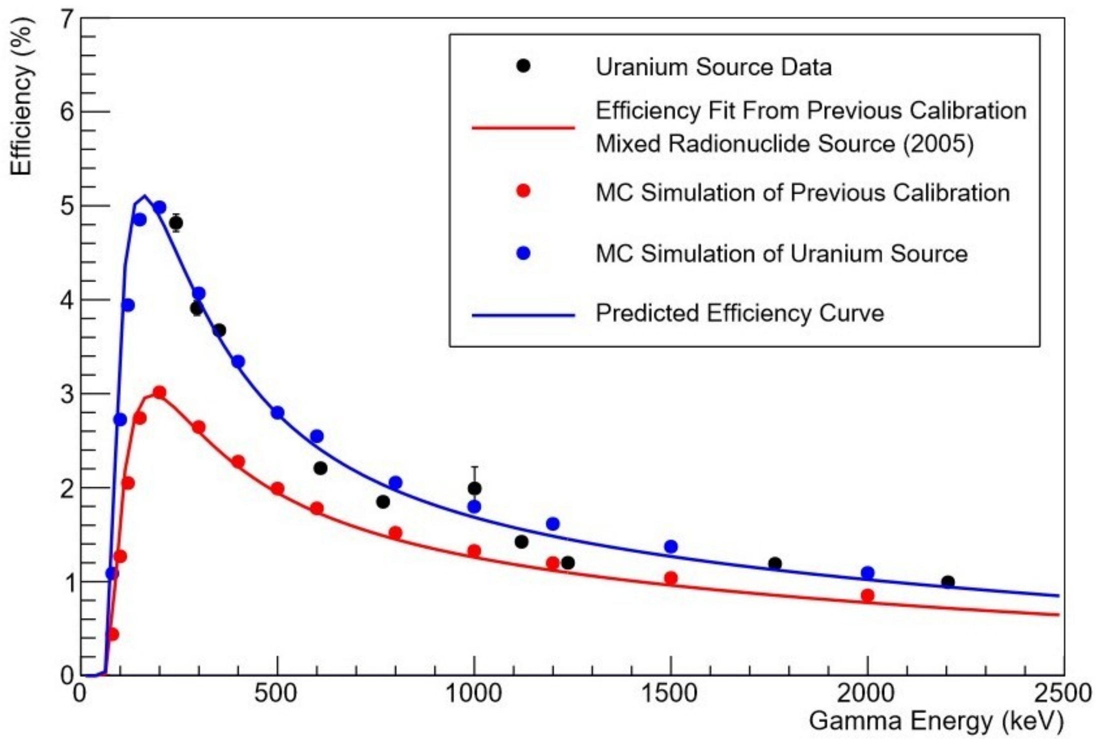
SNOLAB counting has always used this technique. New crystals being brought online required new calibration sources. What is shown today is preliminary results for one calibration for illustration.

Pairs of Sources Made to fit all SNOLAB Ge Detectors

Sample jar designation	Major isotope	Mass of IAEA component (g)	Activity (Bq major isotope)
SRS-18-003-K1	^{40}K	49.998 ± 0.005	699.97 ± 1.0
SRS-18-003-T1	^{232}Th	49.966 ± 0.003	162.39 ± 2.25
SRS-18-004-U1	^{238}U	49.950 ± 0.005	246.75 ± 0.75
SRS-18-003-K2	^{40}K	49.928 ± 0.005	698.99 ± 1.00
SRS-18-003-T2	^{232}Th	50.150 ± 0.005	162.99 ± 2.26
SRS-18-004-U2	^{238}U	49.933 ± 0.005	246.67 ± 0.75

IAEA certificates available

Detector Efficiency - Verification and Updates



All detectors are calibrated with IAEA ^{238}U, ^{232}Th and ^{40}K sources and a ^{152}Eu source from Eckert and Ziegler.

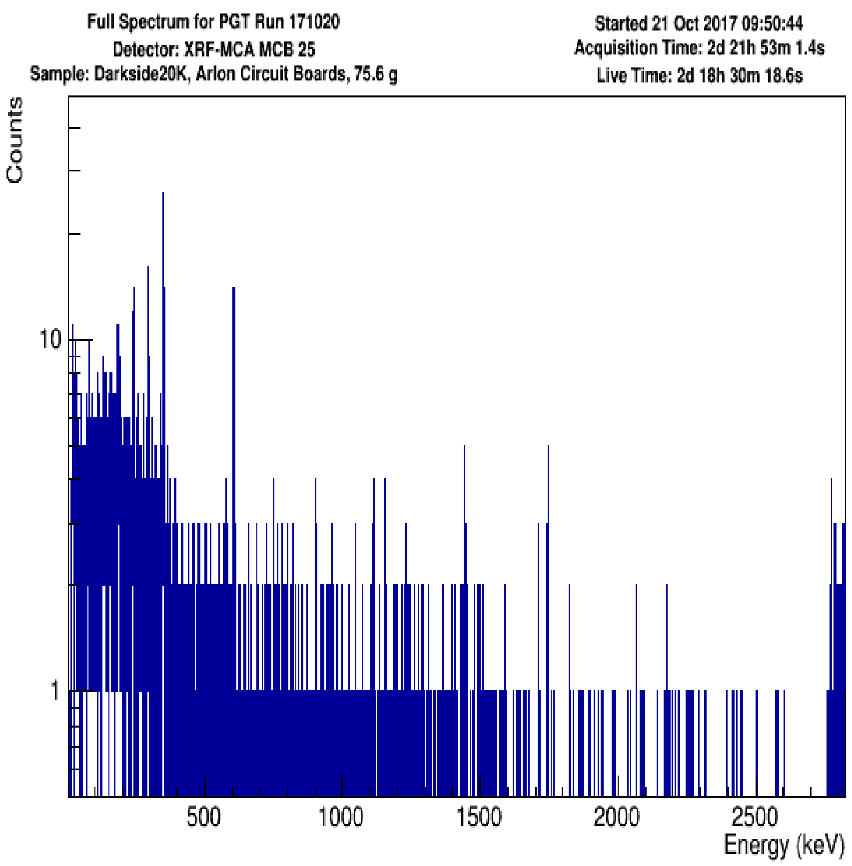
GEANT4 simulations of each detector are completed taking into account the individual detector geometry and sample geometry and location.

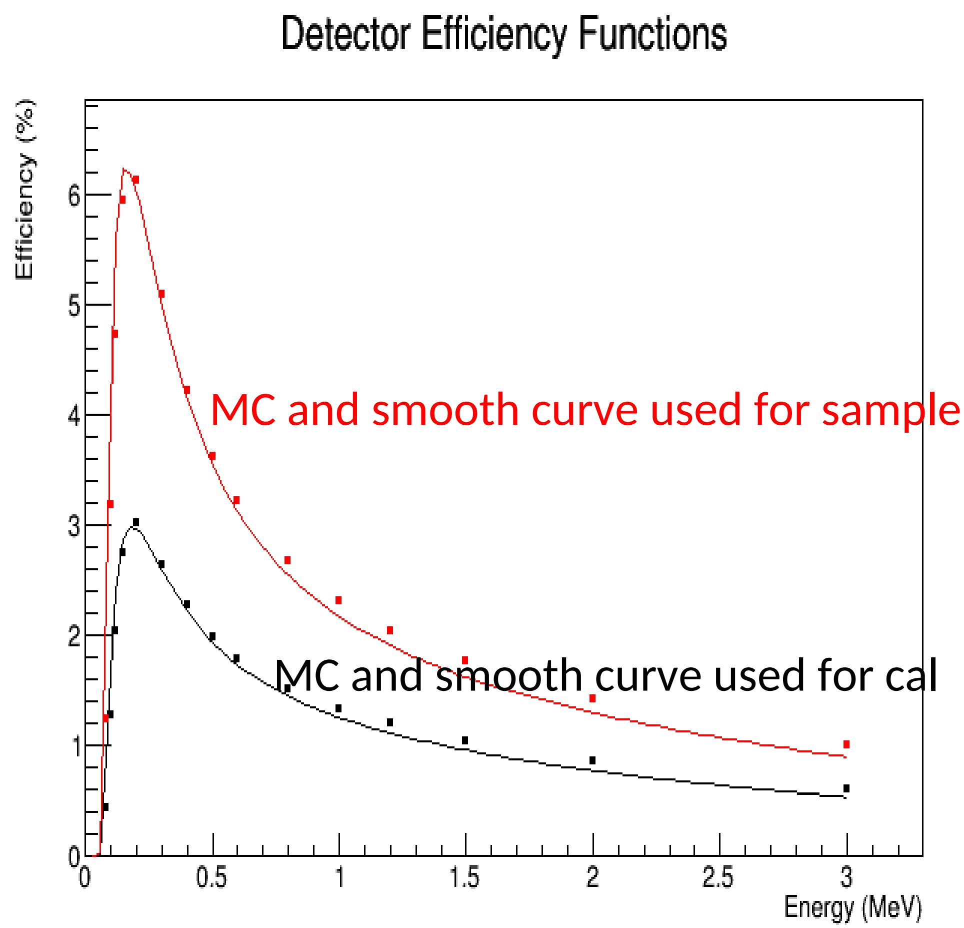
Step 1, verify existing methods using the PGT detector which was calibrated in 2005 using a mixed radionuclide source.

Using this method, all of the high purity germanium detectors will be similarly calibrated.

Example (from using original calibration)

Sample from DarkSide





Next Steps to Ge Detectors Comparison Between Different UG Labs

- Program being lead by DarkSide.
- Create several calibration samples containing known quantities of several isotopes, such as U, Th, K, Co, Cs. Samples will be made by the IAEA and will be low activity samples.
- Samples will be prepared using a sample container which will fit all detectors to simplify comparisons.
- The samples will be counted at detectors located at several underground labs with ties to DarkSide, including SNOLAB, LNGS, LSM and LSC (other labs can be added if they are interested)
- The detector groups will be sent the samples to count without knowing the composition of the sample and then they will report their results to a coordinator. The different labs will keep the results confidential until each lab has counted their samples.
- Once all samples have been counted, then a comparison of the results will occur and we see what happens.
- The goal is to determine how each laboratory's different analyses methods compare and then to determine if there are any fundamental differences once the data is compared, this will also for us to use the same units for the comparison.
- This is in progress, some of the samples have been ordered by SNOLAB via a scientist not directly involved with gamma counting to avoid biases.

ICP-MS Screening

- Good for very small samples or pieces of large samples
- A few drawbacks, sample preparation is destructive and only samples parts of a larger sample.
- Sensitivity down to nBq level can be achieved
- Must ensure all components of the sample preparation process have extremely low backgrounds and work must be performed in a clean room (preferably class 100 or better).
-

Agilent 8800 ICP-MS
Example of ICP-MS at PNNL

Comparison of Ge Counting and ICP-MS

Element	Rock Sample 8		Rock Sample 11	
	Ge	ICP-MS	Ge	ICP-MS
K (%)	1.09 ± 0.01	0.97	1.08 ± 0.03	1.02
U (ppm)	1.24 ±0.16	1.21	1.09 ± 0.03	1.14
Th (ppm)	5.44 ±0.37	5.54	5.72 ± 0.05	5.19

Element	Shotcrete Sample 15		Concrete Sample 14	
	Ge	ICP-MS	Ge	ICP-MS
K (%)	1.78 ± 0.05	1.76	1.75 ± 0.05	1.61
U (ppm)	2.46 ±0.09	2.56	2.41 ± 0.03	2.38
Th (ppm)	15.24 ±0.14	14.90	15.38 ± 0.40	13.10

Alpha Counting

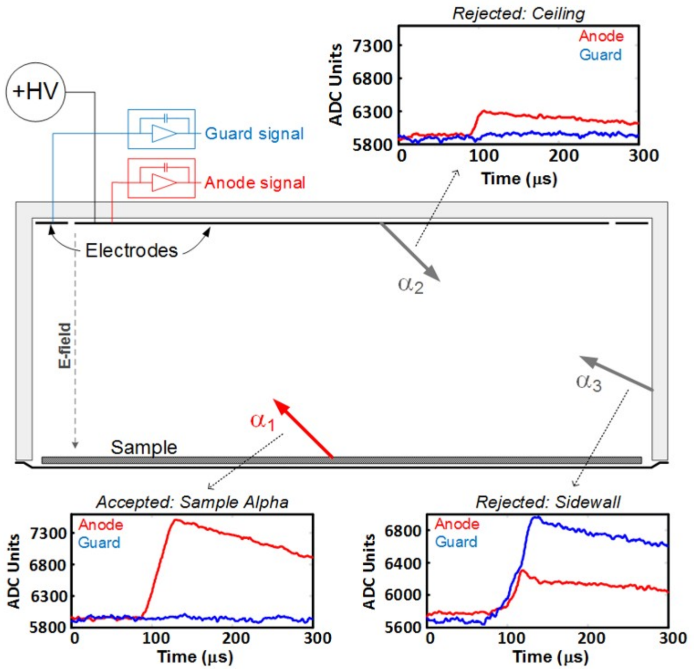
Under commissioning at the SNOLAB surface clean lab

Teflon liner tray background runs show 400 nBq/cm^2 emissivity over full energy range (1-10MeV)

Plan to move it underground by 2019 / 2020

Count region: 1800cm2 square and 707cm2 circular
Maximum sample weight: 9kg
Maximum sample thickness: 6.3mm

Monitor system of environmental parameters (radon, humidity, temperature, particulates ..)



An ionization chamber with no wires.

Alphas ionize Ar gas.

The top of the XIA has a 1100 V anode. Charge drifts from the grounded sample tray. As the charges drift, they induce a current on the anode.

Risetime is the duration of the leading edge of the pulse, the charge drift time.

Risetime is a discriminating variable to reject mid-air decays. (Short rise time because of short drift distance.) 60us nominal cut.

Electrostatic Counting System (ESCs)
(Alpha Counter)

Originally built for SNO, now used primarily by EXO. However, these counters are owned by SNOLAB so samples can be measured for other experiments.

Measures ^{222}Rn, ^{224}Ra and ^{226}Ra levels. The technique involves recirculation of low pressure gas from sample volume to the ESC.

Sensitivity Levels are:

^{222}Rn: 10^{-14} gU/g

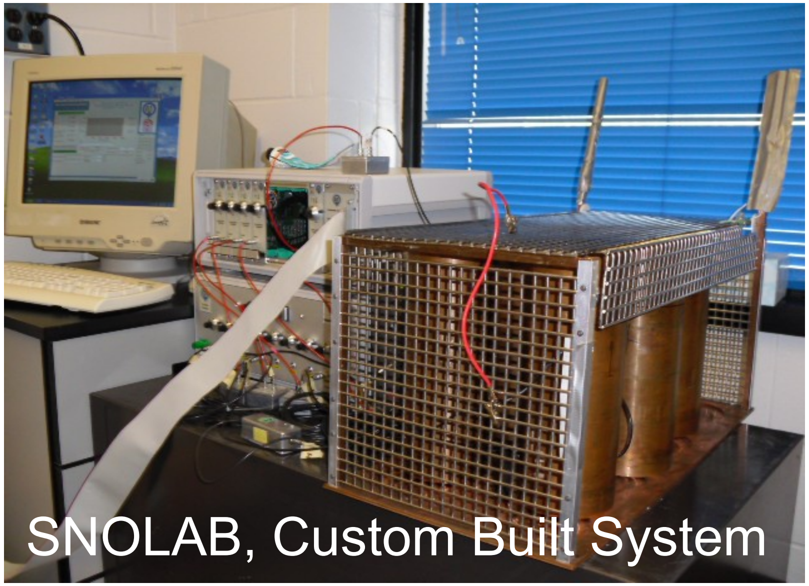
^{224}Ra: 10^{-15} gTh/g

^{226}Ra: 10^{-16} gU/g

Work is ongoing to improve sensitivity even further.

9 counters located at SNOLAB,
1 on loan to LBL (EXO),
1 on loan to U of A (DEAP).

Alpha Beta (BiPo) Counting System



SNOLAB, Custom Built System

Ortec MPC-1000-GFW Commercial System

Transparent liquid scintillator vials optically coupled to 2” PMTs.

The technique is combination of pulse shape discrimination and coincidence counting for identifying BiPo events.

Sensitivity for ^{238}U and ^{232}Th is ~1 mBq assuming that the chains are in equilibrium.

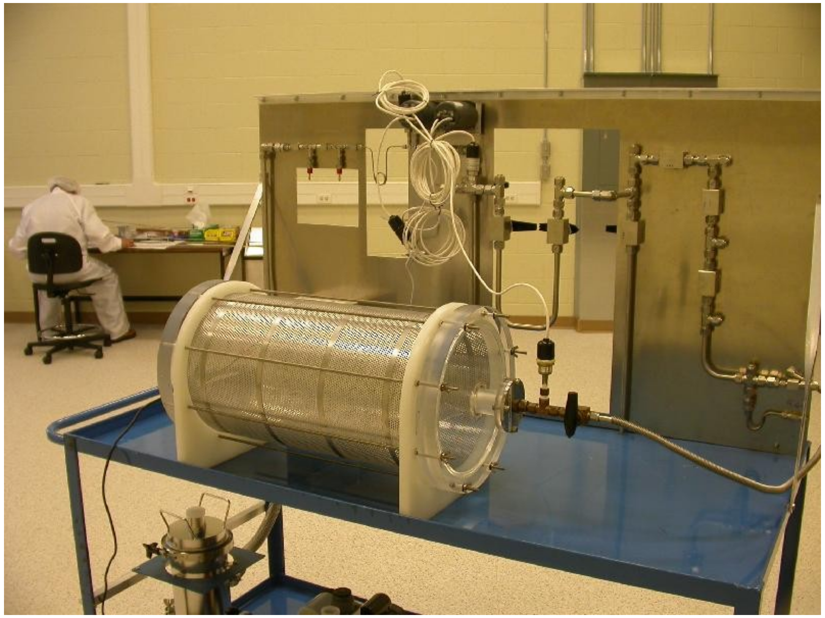
Radon Emanation

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 $Bq/m^2/s$ of 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.

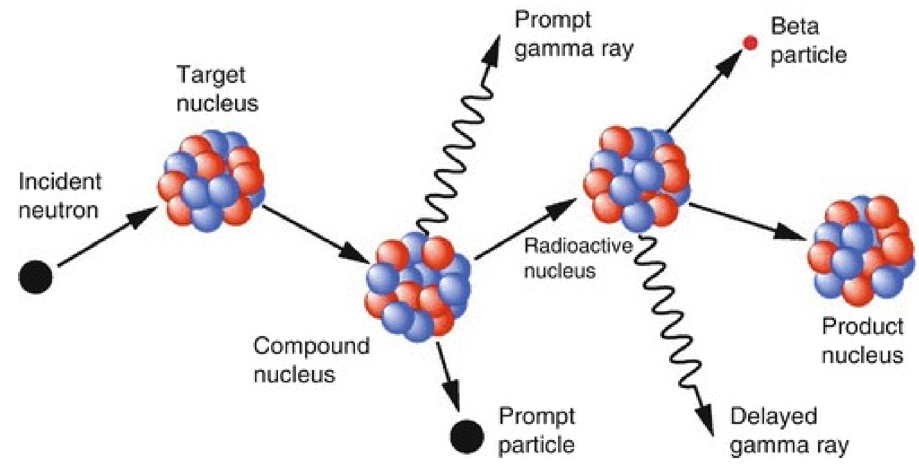
Neutron Activation

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.



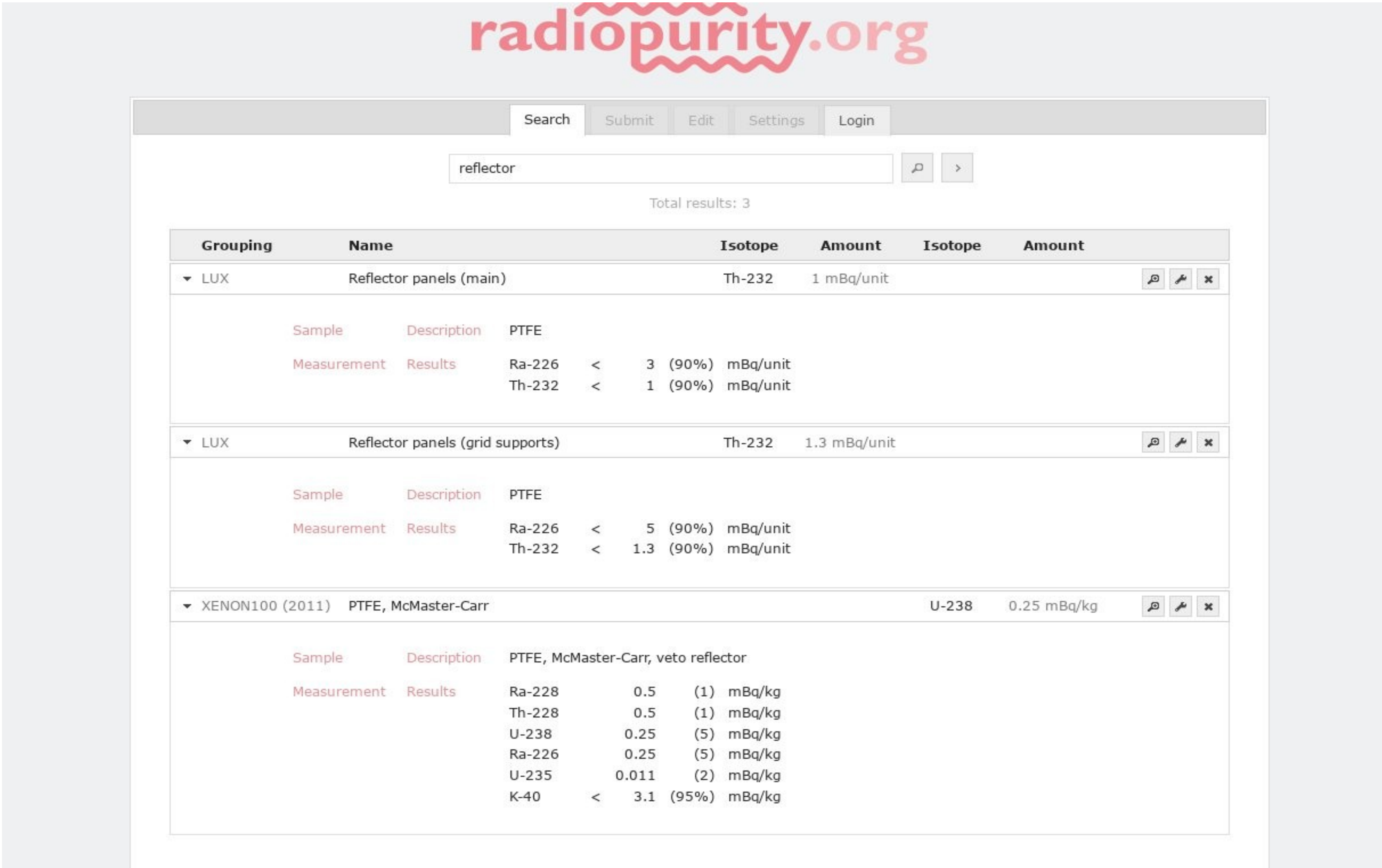
Röntgen Excitation Analysis

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.

Material Assay Database


radiopurity.org

Search | Submit | Edit | Settings | Login

reflector

Total results: 3

Grouping	Name	Isotope	Amount	Isotope	Amount
LUX	Reflector panels (main)	Th-232	1 mBq/unit		
LUX	Reflector panels (grid supports)	Th-232	1.3 mBq/unit		
XENON100 (2011)	PTFE, McMaster-Carr			U-238	0.25 mBq/kg

LUX – Reflector panels (main)

Sample – Description: PTFE

Measurement – Results:

Ra-226	<	3	(90%)	mBq/unit
Th-232	<	1	(90%)	mBq/unit

LUX – Reflector panels (grid supports)

Sample – Description: PTFE

Measurement – Results:

Ra-226	<	5	(90%)	mBq/unit
Th-232	<	1.3	(90%)	mBq/unit

XENON100 (2011) – PTFE, McMaster-Carr

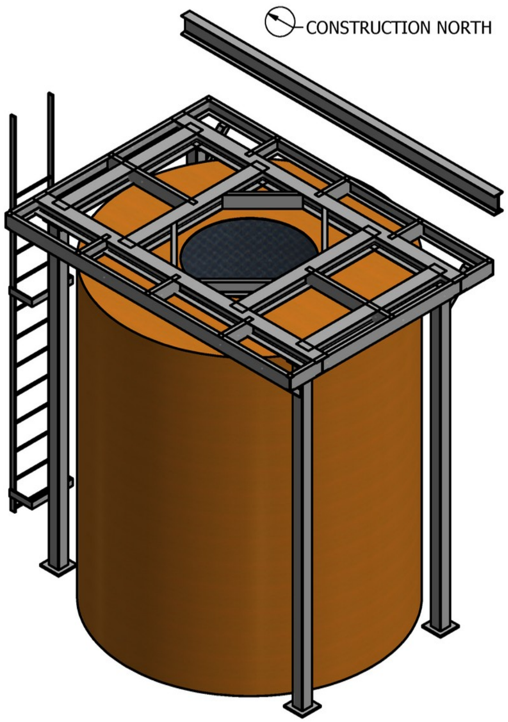
Sample – Description: PTFE, McMaster-Carr, veto reflector

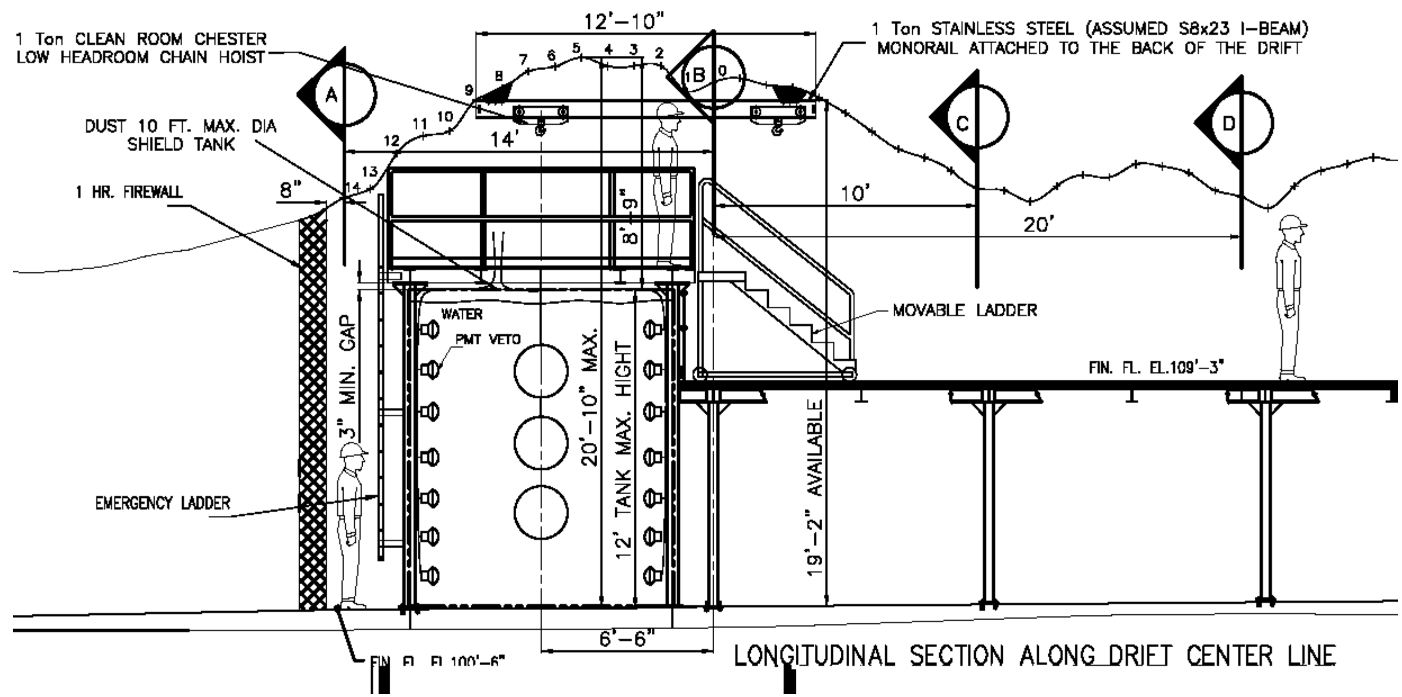
Measurement – Results:

Ra-228		0.5	(1)	mBq/kg
Th-228		0.5	(1)	mBq/kg
U-238		0.25	(5)	mBq/kg
Ra-226		0.25	(5)	mBq/kg
U-235		0.011	(2)	mBq/kg
K-40	<	3.1	(95%)	mBq/kg

- The Assay and Acquisition of Radiopure Materials (AARM) Collaboration originally developed the Community Material Assay Database radiopurity.org.
- The database is now hosted at SNOLAB.
- Several UG labs are now in the early stages of deciding how to improve the database to include future data.

Future Plans at SNOLAB
General Purpose Underground Shielding Tank (GUST)





- General Purpose shielding tank with veto system
- The tank could contain an inner acrylic tank an a PMT array counter
- Walls constructed from bolted, corrugated cylindrical segments of galvanized carbon steel, similar to other SNOLAB water tanks.
- Polyurea lined tank ~ 1 cm thick coats walls, floor, and transition to ss lid, to limit radioactivity from the tank walls.

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

- A program is being established to calibrate Ge detectors at several UG labs using common samples which will be sent to each lab for measurement.

- An improved database is being proposed to allow greater involvement with the community in the goal to include data from a much larger set of experiments.