Ultra-Low Background Counting and Assay Studies At SNOLAB

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Outline

- Motivation for Low Background Counters
  - Advantages of being deep

- Current Facilities in Operation at SNOLAB
  - PGT Ge detector
  - Canberra Well detector
  - Electrostatic Counters (ESCs)
  - Alpha/Beta Counters
  - Radon Emanation (see talk by C. Jillings)
  - X-ray Fluorescence

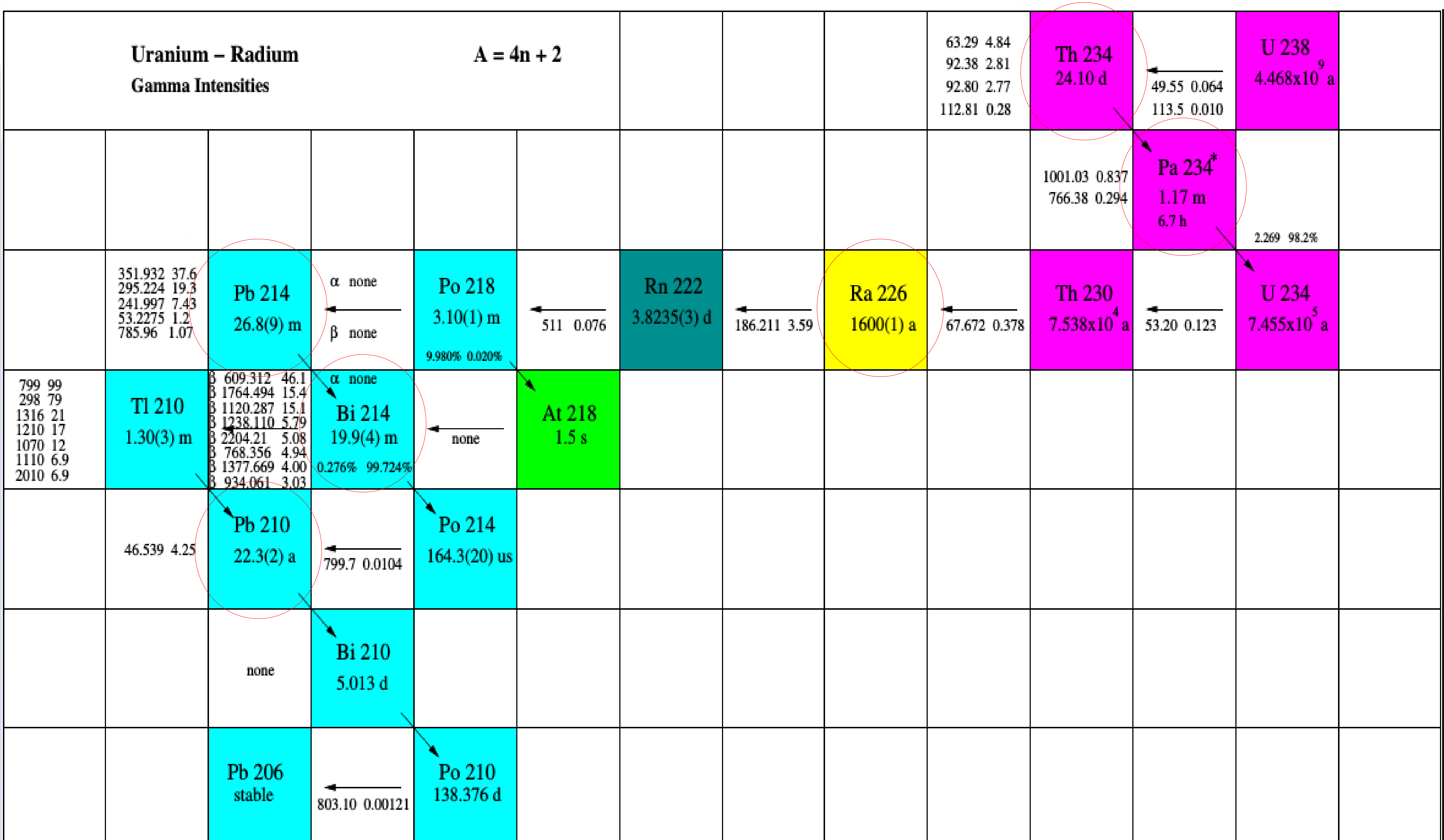
- Low Background Database

- Future Low Background Counters and Facilities

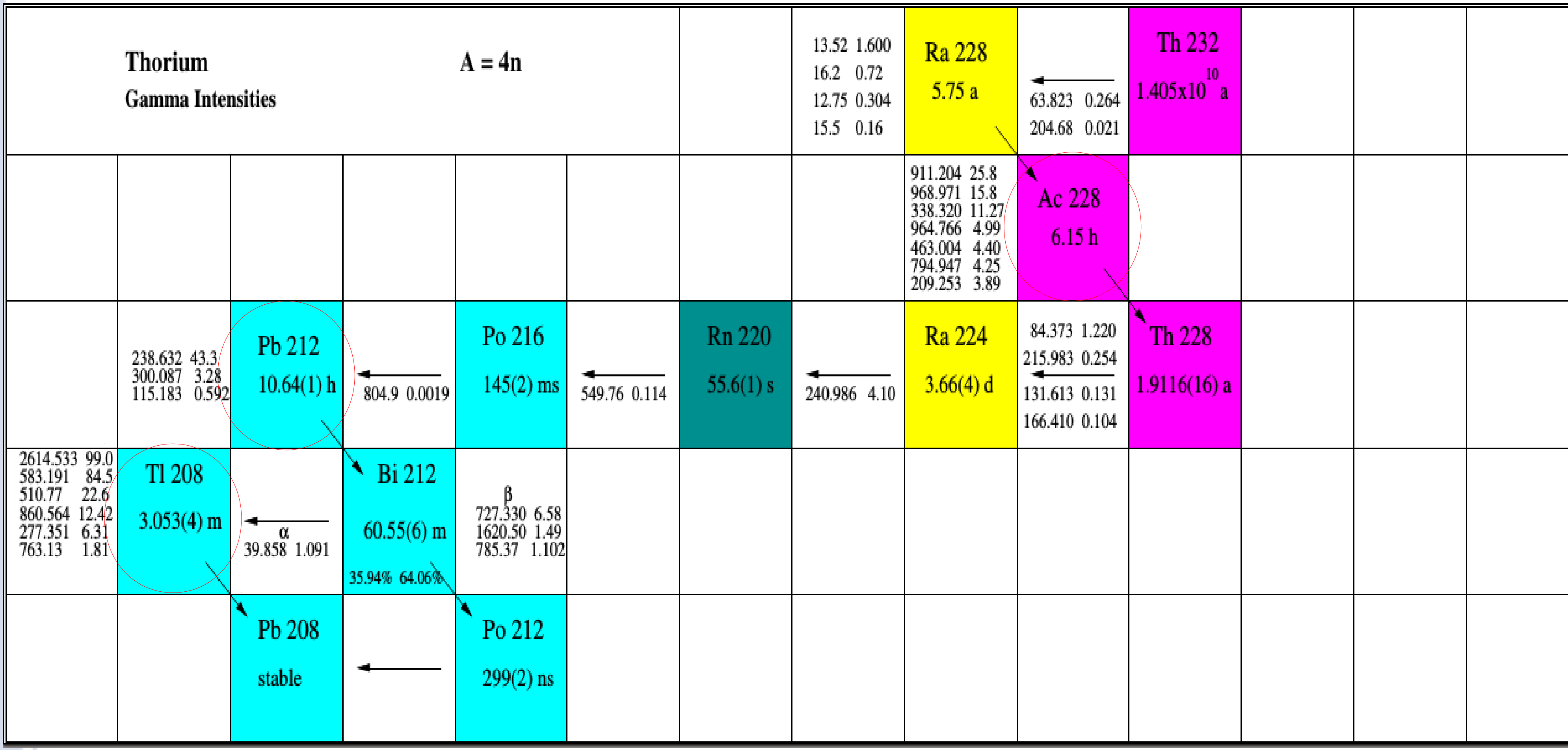
Motivation

- Many of the experiments currently searching for dark matter, studying properties of neutrinos or searching for neutrinoless double-beta decay require very low levels of radioactive backgrounds both in their own construction materials and in the surrounding environment.
- These low background levels are required so that the experiments can achieve the required sensitivities for their searches.
- SNOLAB has several facilities which are used to directly measure these radioactive backgrounds.
- The backgrounds in question are on the order of 1 mBq or 1 ppb for ^{238}U, ^{232}Th and ^{235}U and 1 ppm for ^{40}K, or better, measurements down to 1 ppt are required for many components.
- The problem backgrounds can include gammas, alphas and neutrons or resulting interaction products.
- The goal is to measure these backgrounds and then to reduce them to be as low as reasonably achievable.

Uranium Decay Chain



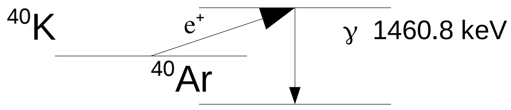
Thorium Decay Chain



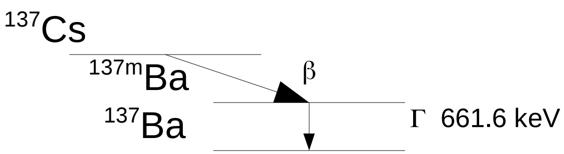
Other Interesting Isotopes

Usually Present:

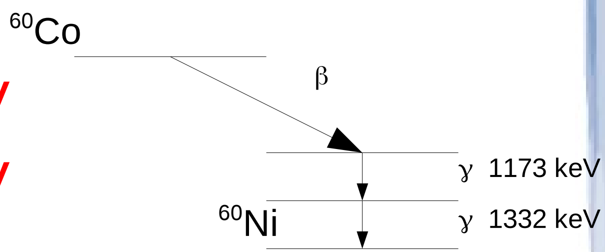
- ^{40}K
  1460.83 keV



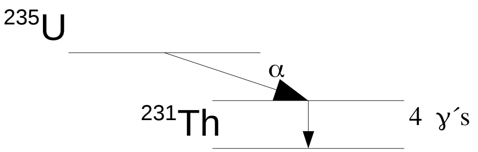
- ^{137}Cs
  661.66 keV



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



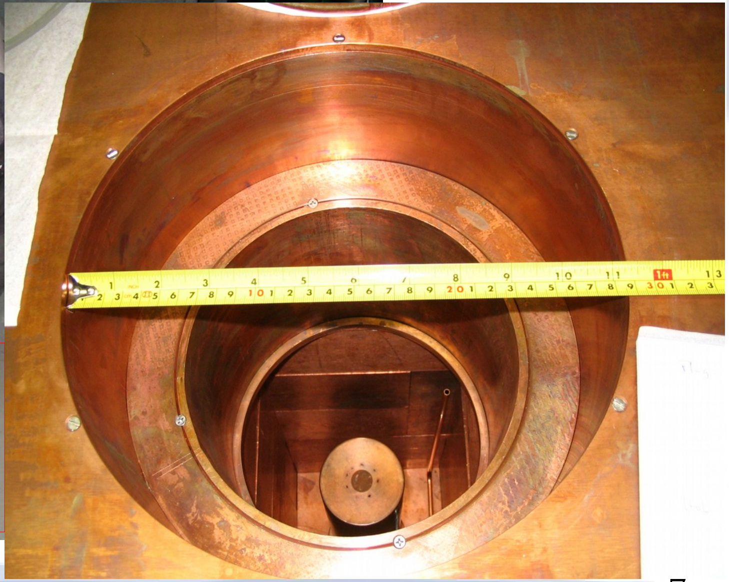
- ^{235}U
  - 143.76 keV
  - 163.33 keV
  - 185.22 keV
  - 205.31 keV



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 PGT HPGe Counter
(The workhorse detector at SNOLAB)

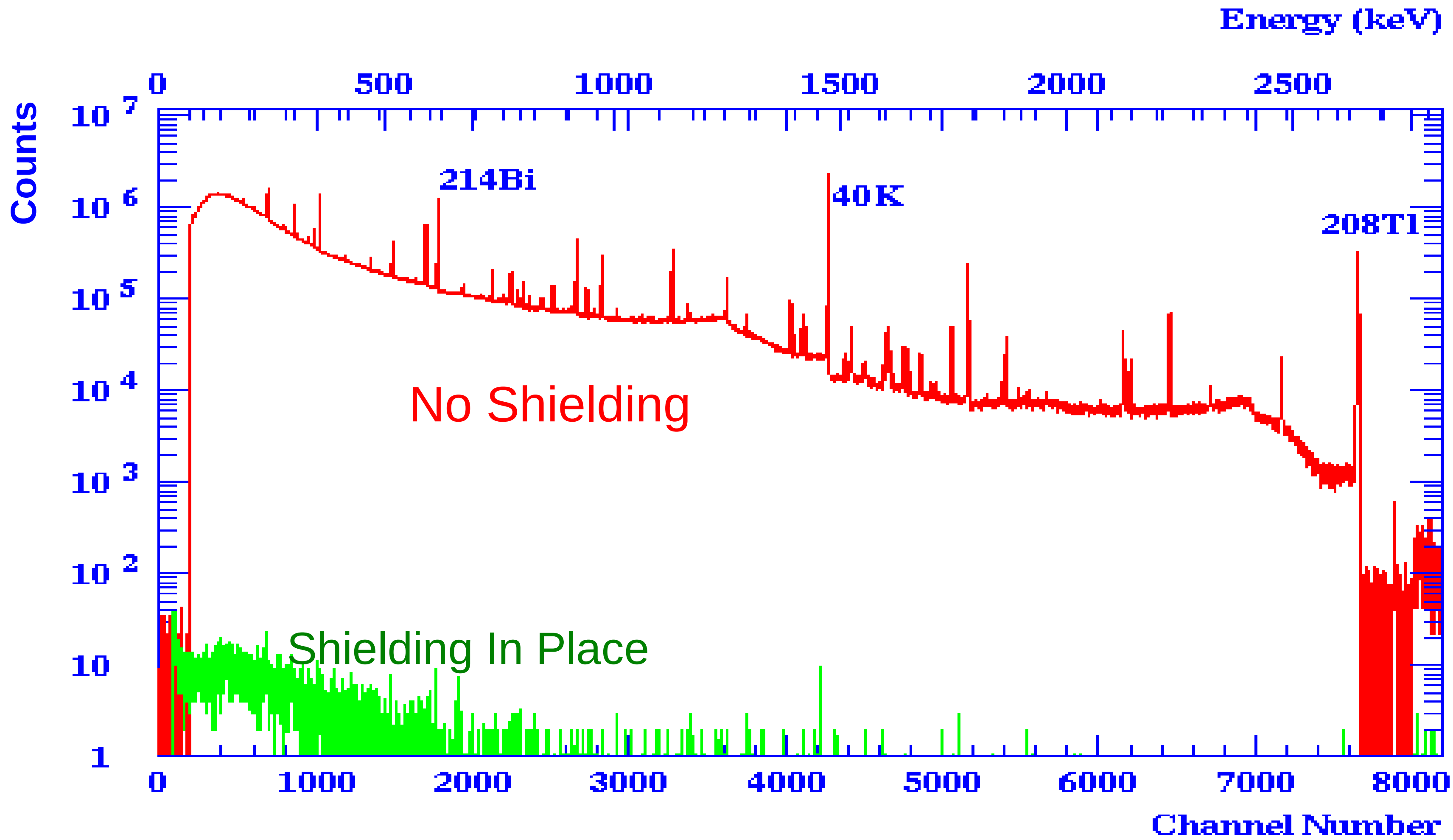


Additional lead used to dampen microseismic activity from blasting and rockbursts

SNOLAB PGT HPGe Detector Specifications

- Motivation
  - Survey materials for new, existing and proposed experiments (to be) located @ SNOLAB, such as SNO/SNO+, DEAP/CLEAN, PICASSO/COUPP/PICO, EXO, ... Also survey materials for the DM-ICE and DRIFT experiments, and Canberra.
- Constructed @ SNOLAB in 2005, detector was in UG storage from 1997, continuous operations since 2005
    - Counter manufactured by PGT in 1992
    - Endcap diameter: 83 mm,
    - Crystal volume: 210 cm^3
    - Relative Efficiency is 55% wrt a 7.62 cm dia x 7.62 cm NaI(Tl) detector,
    - Resolution 1.8 keV FWHM.
- Shielding
  - 2 inches Cu + 8 inches Pb
  - Nitrogen purge at 2L/min to keep radon out, as the lab radon levels are 150 Bq/m^3.
- Detection Region
  - Energy: 90 – 3000 keV

Unshielded and Shielded Spectra
(PGT Coax Detector)



PGT HPGe Typical Detector Sensitivity

(for a standard 1L or 1 kg sample counted for one week)

Isotope	Sensitivity for Standard Size Samples	Sensitivity for Standard Size Samples
^{238}U	0.15 mBq/kg	12 ppt
^{235}U	0.15 mBq/kg	264 ppt
^{232}Th	0.13 mBq/kg	32 ppt
^{40}K	1.70 mBq/kg	54 ppt
^{60}Co	0.06 mBq/kg	
^{137}Cs	0.17 mBq/kg	
^{54}Mn	0.06 mBq/kg	

SNOLAB

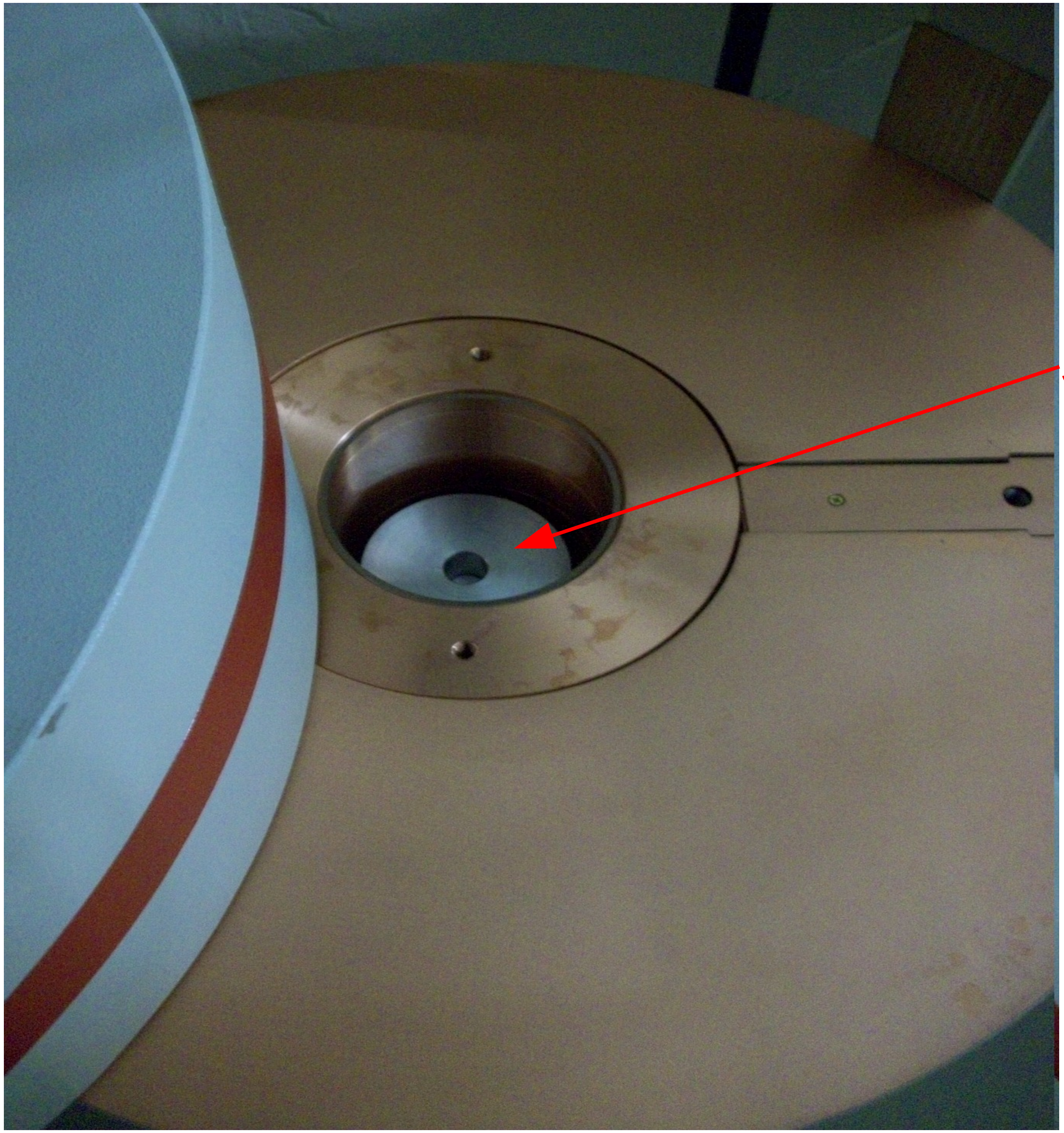
Measurements To Date For Each Experiment

Experiment or Laboratory	Total (2005 - Today)
SNO	11
SNO+	116
SNOLAB	73
EXO	12
MiniCLEAN	56
DEAP	101
HALO	7
PICASSO	9
DM-ICE / DRIFT	23
COUPP / PICO	61
DAMIC	12
Total	481
Calibrations & Tests	118
Counting time per sample averages 6 days.	

Non-experimental measurements include water/snow samples from Fukushima fallout. See publication: Can. J. Phys. 90: 599–603 (2012)

Canberra Well Detector at SNOLAB

Canberra Well Detector at SNOLAB



Detector Volume: 300 cm^3

Sample Well

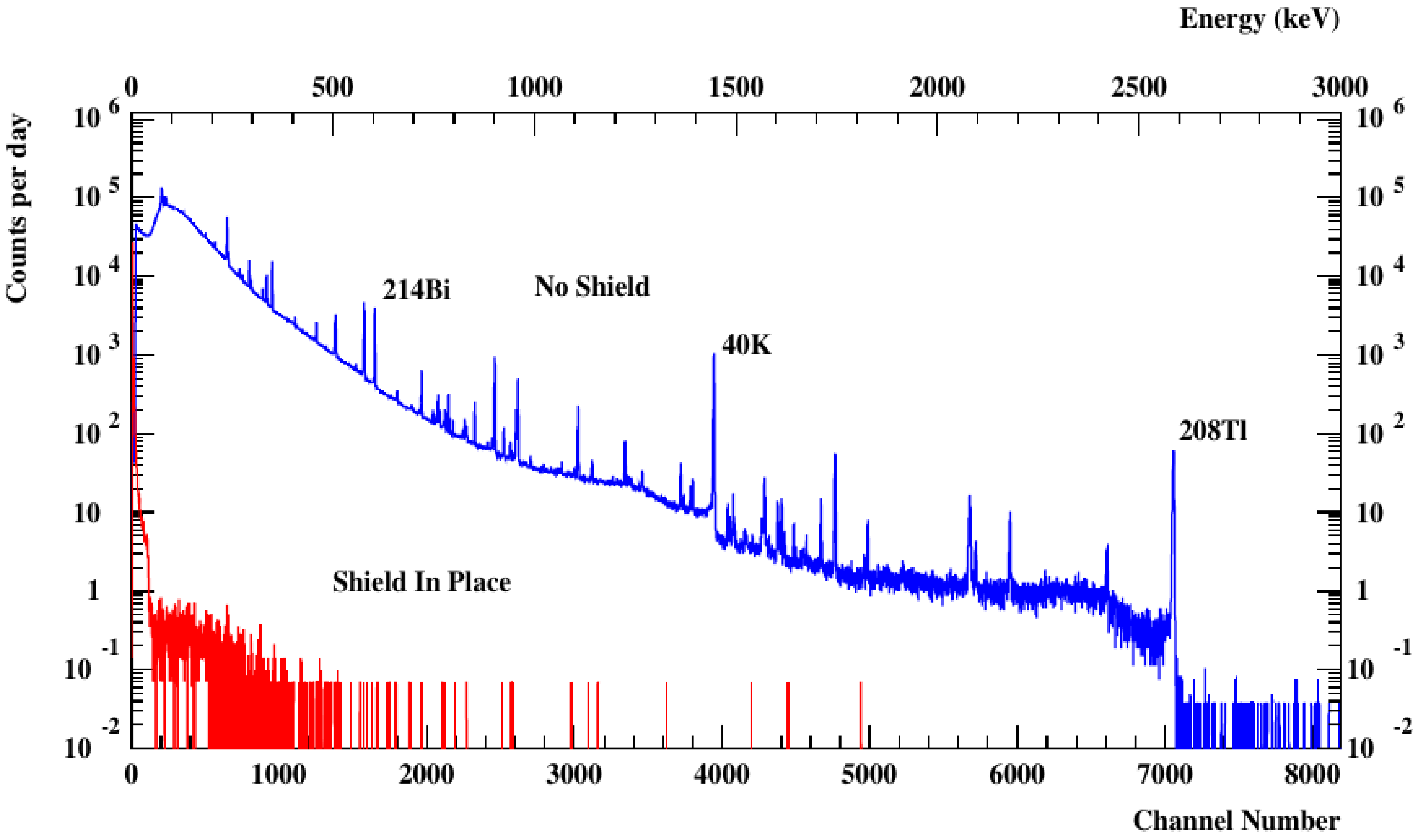
Typical Sample Bottle

Volume is 3 ml

SNOLAB Canberra Well Detector Specifications

- Motivation
  - Survey very small quantities of materials, concentrated samples or very expensive materials. Used by DAMIC, DEAP, PICO & SNO+ so far.
- Constructed by Canberra using low activity materials and shielding.
  - Counter manufactured by Canberra in 2011 and refurbished in 2012, the cold finger was lengthened as it was too short to fit the shielding and the tail end and crystal holder were replaced to reduce radioactivity levels.
  - Crystal volume: 300 cm^3.
- Installed and operational in 2013.
- Shielding
  - Cylindrical shielding of 2 inches Cu + 8 inches Pb
  - Nitrogen purge at 2L/min to keep radon out, as the lab radon levels are 150 Bq/m^3.
- Detection Region
  - Energy: 10 – 900 keV

Unshielded and Shielded Spectra
(Canberra Well Detector)



Canberra Well Detector Background
(is the detector an ultra-low counter)

- Background run completed, ~150 days.

Isotope	Counts per day
^{238}U	1.16
^{232}Th	0.51
^{228}Ac	0.39
^{235}U	0.48
^{40}K	0
^{210}Pb	0

- Total backgrounds at the level of ~2.5 counts / day in regions of interest. An ultra-low detector should have a background no more than 0.3 counts/day per gamma energy.
- Calibration sources approved by SNOLAB and efficiency measurements up to ~900 keV have been completed.
- Samples for DAMIC, DEAP, PICO and SNO+ have been counted or are in progress.

Canberra Well Detector Sensitivity

Isotope	Sensitivity for Standard Size Samples	Sensitivity for Standard Size Samples
^{238}U (↑ ^{226}Ra)	0.05 mBq/kg	4 ppt
^{238}U (↓ ^{226}Ra)	0.08 mBq/kg	6 ppt
^{228}Ac	0.2 mBq/kg	49 ppt
^{232}Th	0.4 mBq/kg	98 ppt
^{235}U	0.02 mBq/kg	35 ppt
^{210}Pb	0.15 mBq/kg	12 ppt

Measurements To Date For Each Experiment

Experiment or Laboratory	Total (2013 - Today)
SNO+	30
SNOLAB	1
DEAP	1
COUPP / PICO	13
DAMIC	1
Total	46
Calibrations & Tests	15
Counting time per sample averages 7 days.	

Electrostatic Counting System

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

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

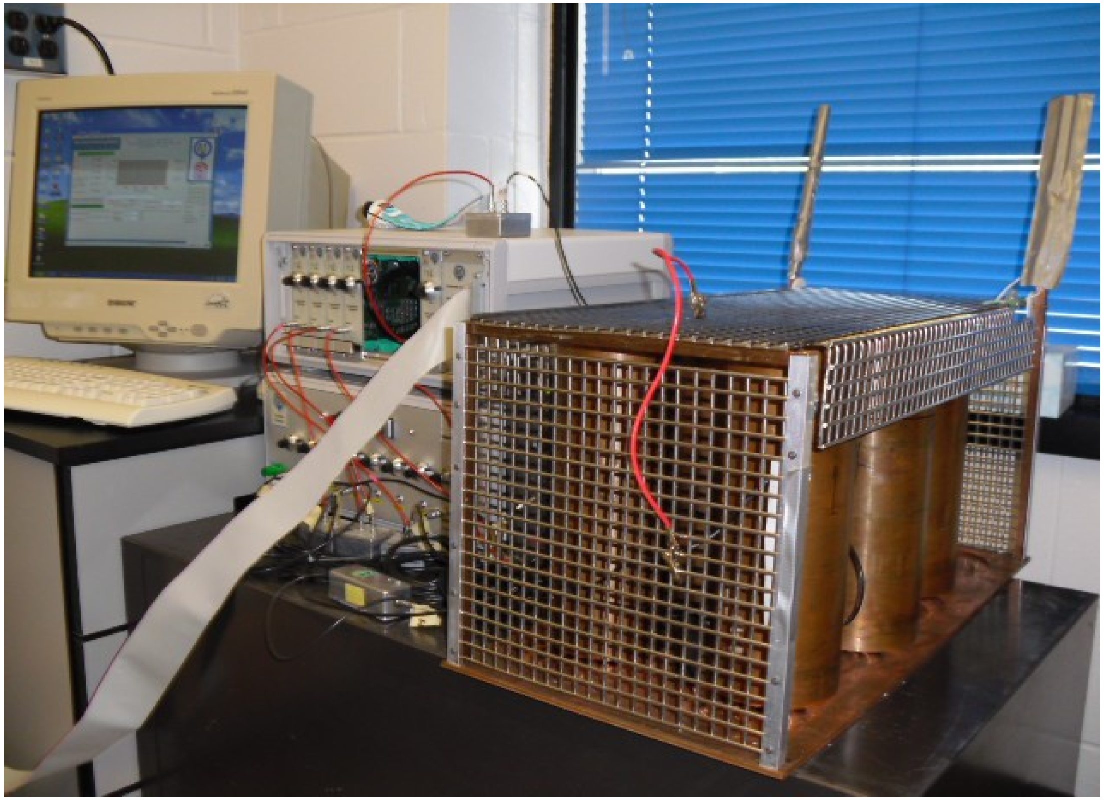
Measures ^{222}Rn, ^{224}Ra and ^{226}Ra levels.

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.

Alpha Beta Counting System



Currently located at the SNOLAB hot lab at LU so that radioactive spike sources can be measured for SNO+.

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

SNOLAB Data Repository

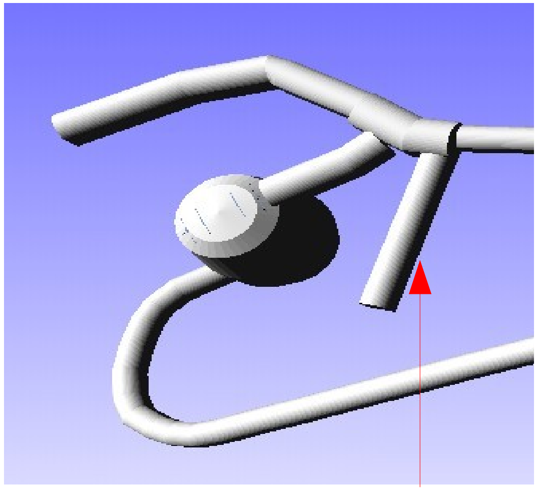
SNOLAB maintains a database in a spreadsheet format for each experiment.
https://www.snolab.ca/users/services/gamma-assay

The table shows data from the standard gamma searches:
^{238}U, ^{235}U, ^{232}Th, ^{40}K ^{137}Cs, ^{60}Co.

While searching for the above gammas, we also search for any other peaks in the spectrum between 100 keV and 2800 keV, For example, ^{54}Mn is usually observed in steel.

SNOLAB is a member of the Assay and Acquisition of Radiopure Materials (AARM) Collaboration, which has developed the Community Material Assay Database radiopurity.org.

Future Low Background Counters and Facilities



A new dedicated space will be constructed at SNOLAB for a low background lab located in the South Drift.

This drift is isolated from other drifts and is inaccessible to large equipment. This will help reduce micro-seismic noise which can effect Ge detectors.

Increased air flow and perhaps other radon reduction techniques will be used. It is known that the compressed air from surface has substantially less radon than the lab air and can be used to reduce radon levels from 135-150 Bq/m^3 to 1-5 Bq/m^3.

Space can accommodate up to 5 Ge detectors, XRF, radon emanation chamber and have room for other types of counters which would benefit from low-cosmic ray background.

Engineering design drawings are now in progress.

Additional Low Background Counters Coming Soon

Two additional high purity germanium detectors will be installed.

1. SNOLAB Canberra 400 cm^3 coaxial detector acquired in 2011 and refurbished into an ultra-low counter in 2013 to be installed, the shielding apparatus is currently being designed.

2. Bern Coax detector, detector is currently at Bern and will be relocated to SNOLAB. This detector has been used extensively by the EXO experiment. It is expected to be shipped to SNOLAB this summer.

Future Improvements and R&D

- Improved neutron shields (detector response, spectrum)
- Improved material selection (more sensitive, better radiopurity e.g. $PbWO_4$ with archaeological lead)
- Active shielding
- Going deeper underground
- Storage of freshly made construction materials underground
- Multisegmented crystals or multiple crystals
- Collaboration with producers (e.g. depleted Ge, crystal growing, Cu electroforming underground)
- Reorganisation and optimisation of existing screening facilities is necessary, because they are costly and measurement times can be rather lengthy.
- Harmonisation of how to report data and intercomparison programs for ultra low-level measurement techniques.

Applications Beyond Particle Physics

- Ultra low-level chemistry
- Particle astrophysics (material and techniques applicable to rare events experiments)
- Space science (e.g. micro meteorites, Mars samples, cosmic activation products, comet tail samples)
- Atmospheric samples (very) short lived isotopes, radionuclide composition, stratospheric samples)
- Ocean samples (e.g. deep ocean water - ^{60}Fe)
- In general application of low background techniques to interdisciplinary fields:
  - Low-level environmental radioactivity measurement and monitoring
  - Radiodating (extension of determined ages towards the past)
  - Geophysics (palaeoseismology, palaeogeology, sedimentation)

Summary

- SNOLAB PGT HPGe low background counting system has run continuously for the past since 2005 and has counted 480 samples so far.

  Counting queue is usually long.

  The counter is available for all SNOLAB experiments and can be made available to non-SNOLAB experiments upon request (eg. DM-ICE, DRIFT).

- Two Canberra Ge detectors were delivered to SNOLAB, but each needed to be refurbished.

  The Canberra Well detector is now in full operation and 45 samples have now been counted.

  The Canberra Coax detector is underground and engineering drawings of the shielding design are in progress.

  The EXO Bern detector will be shipped to SNOLAB within weeks.

- Specialized counting can be done using the Electrostatic Counters, Alpha-Beta Counters and materials can be emanated for Radon.
- New low background counting lab will be constructed at SNOLAB, final design drawings are now underway.