Low Background Counting At SNOLAB

Ian Lawson

AARM S4 Collaboration Meeting
Minneapolis, Minnesota, June 22-23, 2012
Outline

• SNOLAB and description of the SNOLAB Low Background Gamma Counting System
• Other material screening and counting systems
• Existing SNOLAB low background data repository
• Status of new Canberra gamma counting systems
• New low background underground lab
• Summary
SNOLAB

Surface Facility

2km overburden (6000mwe)

Underground Laboratory

300m
SNOLAB Low Background Counting System

• Establishment of the Low Background Gamma Facility @ SNOLAB in 2005. The counter has run continuously since then.

• Motivation
  • Survey materials for new, existing and proposed experiments (to be) located @ SNOLAB, such as SNO, SNO+, DEAP1, miniCLEAN, PICASSO, EXO, ... Have also assayed materials for DM-ICE and DRIFT.
  
• Constructed @ SNOLAB from an HPGe detector and its associated shielding located underground at 4600 ft level since 1997.

  • Counter manufactured by PGT.
  • Endcap diameter 83 mm.
  • 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.
SNOLAB PGT HPGe Counter
# Uranium Decay Chain

## Uranium - Radium

<table>
<thead>
<tr>
<th>Gamma Intensities</th>
<th>$A = 4n + 2$</th>
<th>Th $234$</th>
<th>Pa $234$</th>
<th>U $238$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{218}$Po</td>
<td>$26.8(9)$ m</td>
<td>$5.10(1)$ m</td>
<td>$3.823(5)$ d</td>
<td>$4.468 \times 10^5$ a</td>
</tr>
<tr>
<td>$^{222}$Rn</td>
<td>$5.11$ 0.00%</td>
<td>$165.211$ 3.5 s</td>
<td>$67.672$ 0.37%</td>
<td>$3.20$ 0.123</td>
</tr>
<tr>
<td>$^{226}$Ra</td>
<td>$1600(1)$ a</td>
<td>$7.538 \times 10^4$ a</td>
<td>$7.455 \times 10^4$ a</td>
<td></td>
</tr>
</tbody>
</table>

## June 22 & 23, 2012

AARM S4
# Thorium Decay Chain

<table>
<thead>
<tr>
<th>Thorium</th>
<th>$A = 4n$</th>
<th>$^{139}La$</th>
<th>$^{228}Ra$</th>
<th>$^{228}Ac$</th>
<th>$^{228}Th$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma Intensities</td>
<td>238.5 ± 4.3</td>
<td>10.64 ± 0.09</td>
<td>604.9 ± 0.019</td>
<td>60.55 ± 0.006</td>
<td>55.6 ± 1.1</td>
</tr>
<tr>
<td>$^{212}Pb$</td>
<td>238.5 ± 4.3</td>
<td>10.64 ± 0.09</td>
<td>604.9 ± 0.019</td>
<td>60.55 ± 0.006</td>
<td>55.6 ± 1.1</td>
</tr>
<tr>
<td>$^{212}Po$</td>
<td>10.64 ± 0.09</td>
<td>604.9 ± 0.019</td>
<td>59.85 ± 1.09</td>
<td>55.6 ± 1.1</td>
<td></td>
</tr>
<tr>
<td>$^{208}Tl$</td>
<td>305.3 ± 4.08</td>
<td>605.55 ± 0.006</td>
<td>55.6 ± 1.1</td>
<td>55.6 ± 1.1</td>
<td></td>
</tr>
<tr>
<td>$^{208}Pb$</td>
<td>stable</td>
<td>605.55 ± 0.006</td>
<td>55.6 ± 1.1</td>
<td>55.6 ± 1.1</td>
<td></td>
</tr>
<tr>
<td>$^{208}Bi$</td>
<td>605.55 ± 0.006</td>
<td>55.6 ± 1.1</td>
<td>55.6 ± 1.1</td>
<td>55.6 ± 1.1</td>
<td></td>
</tr>
</tbody>
</table>

June 22 & 23, 2012  AARM S4
Other Interesting Isotopes

Usually Present:

- $^{40}\text{K}$
  - $1460.83\text{ keV}$

- $^{137}\text{Cs}$
  - $661.66\text{ keV}$

- $^{60}\text{Co}$
  - $1173.2\text{ keV}$
  - $1332.5\text{ keV}$

- $^{235}\text{U}$
  - $143.76\text{ keV}$
  - $163.33\text{ keV}$
  - $185.22\text{ keV}$
  - $205.31\text{ keV}$

Occasionally Present:

- $^{54}\text{Mn}$ at $834.85\text{ keV}$
  - Observed in Stainless Steel

- $^7\text{Be}$ at $477.60\text{ keV}$
  - Observed in Carbon based materials, due to neutron activation, samples are particularly affected after long flights.

- $^{138}\text{La}$ and $^{176}\text{Lu}$
  - Observed in rare earth samples such as Nd or Gd.
Unshielded and Shielded Spectra

No Shielding

Shielding In Place
# Background Comparison

Unshielded Versus Shielded Activity

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Activity Unshielded Crystal (Bq)</th>
<th>Activity Shielded Crystal (Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}$U</td>
<td>$70.11 \pm 1.64$</td>
<td>$0.00128 \pm 0.00016$</td>
</tr>
<tr>
<td>$^{232}$Th</td>
<td>$36.99 \pm 1.21$</td>
<td>$0.00141 \pm 0.00016$</td>
</tr>
<tr>
<td>$^{40}$K</td>
<td>$1723.33 \pm 88.02$</td>
<td>$0.0189 \pm 0.0017$</td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>$1.00 \pm 0.15$</td>
<td>$0.0020 \pm 0.0002$</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>$0.023 \pm 0.052$</td>
<td>$0.00036 \pm 0.00005$</td>
</tr>
</tbody>
</table>

Unshielded Measurements done by Yoram Nir-EL
PGT HPGe Detector Sensitivity

<table>
<thead>
<tr>
<th>Isotope</th>
<th>1 Bq/kg</th>
<th>1 ppb</th>
<th>Sensitivity for Standard Size Samples</th>
<th>Typical for Earth's Crust</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}$U</td>
<td>81 ppb</td>
<td>12 mBq/kg</td>
<td>~ 1 mBq/kg ~ 0.1 ppb</td>
<td>37 Bq/kg 3 ppm</td>
</tr>
<tr>
<td>$^{232}$Th</td>
<td>246 ppb</td>
<td>4.1 mBq/kg</td>
<td>~ 1.5 mBq/kg ~ 0.3 ppb</td>
<td>45 Bq/kg 11 ppm</td>
</tr>
<tr>
<td>$^{40}$K</td>
<td>32 ppm</td>
<td>0.031 mBq/kg</td>
<td>~ 21 mBq/kg ~ 0.7 ppm</td>
<td>800 Bq/kg 2.5 %</td>
</tr>
</tbody>
</table>

Better sensitivities have been achieved for specialized very large samples combined with an extremely long counting period:

$^{238}$U: 0.009 ppb,
$^{232}$Th: 0.02 ppb,
$^{40}$K: 87 ppb
New calibration standards are being proposed which have much longer half-lives to allow the calibration sample to be used for several years unlike most commercial multigamma calibration samples. Would be used to cross-calibrate PGT and Canberra detectors.
Detector Efficiency From Mixed Calibration Sample

The efficiency is scaled to individual samples using GEANT 4.9.4 which takes into account the sample components, to account for the density difference between the calibration source and the sample, and the sample geometry.
Typical Stainless Steel Spectrum

DEAP 1 sample: stool bolts, nuts, wa Sum sp. total + filtor3

Counts

Energy (keV)

Acquired: 3/24/2006 11:12:23 AM
File: C:\HPGe\data\Deap1\total.chn
Detector: #1 XRF-MCA MCB 25

Real Time: 696913.81 s. Live Time: 696912.50 s.
Channels: 8192
Typical Efficiency Correction

Efficiency correction for steel sample.

Use GEANT4.9.4, simulate detector with 5 million events at each energy.

Extrapolate between energy bins with a polynomial fit.
Electrostatic Counting System

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

Sensitivity Levels are:

- $^{222}\text{Rn}: 10^{-14} \text{ gU/g}$
- $^{224}\text{Ra}: 10^{-15} \text{ gTh/g}$
- $^{226}\text{Ra}: 10^{-16} \text{ gU/g}$

Work is ongoing to improve sensitivity even further.

9 counters located at SNOLAB,
1 on loan to LBL,
1 on loan to U of A,
1 remains at U. of Guelph
Alpha Beta (Bi-Po) Counting System

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

Sensitivity for $^{238}\text{U}$ and $^{232}\text{Th}$ is $\sim 1 \text{ mBq}$ assuming that the chains are in equilibrium.
Material Screening

- **Radon Emanation Chambers**
  - Used extensively for counting materials used in the SNO experiment.
  - Sensitivity ~50 decays per day.

- **ICP-MS**
  - Association with facility at NRC (National Research Council) ICP-MS facility in Ottawa and with GeoLabs in Sudbury.
  - NRC facility can be tuned to maximize sensitivity to U and Th at sub ppt levels. K limits to < 100 ppb.
# Measurements To Date For Each Experiment

<table>
<thead>
<tr>
<th>Experiment</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012 (-Jun 17)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNO</td>
<td>2</td>
<td>7</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>SNO+</td>
<td>0</td>
<td>2</td>
<td>18</td>
<td>14</td>
<td>15</td>
<td>35</td>
<td>1</td>
<td>85</td>
</tr>
<tr>
<td>SNOLAB</td>
<td>7</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>6</td>
<td>10</td>
<td>35</td>
</tr>
<tr>
<td>EXO</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>MiniCLEAN</td>
<td>5</td>
<td>1</td>
<td>9</td>
<td>18</td>
<td>8</td>
<td>3</td>
<td>2</td>
<td>46</td>
</tr>
<tr>
<td>DEAP</td>
<td>8</td>
<td>8</td>
<td>12</td>
<td>10</td>
<td>8</td>
<td>15</td>
<td>2</td>
<td>63</td>
</tr>
<tr>
<td>HALO</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>PICASSO</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>DM-ICE / DRIFT</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>9</td>
<td>9</td>
<td>4</td>
<td>22</td>
</tr>
<tr>
<td>COUPP</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>1</td>
<td>15</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
<td>23</td>
<td>43</td>
<td>49</td>
<td>34</td>
<td>85</td>
<td>28</td>
<td>296</td>
</tr>
<tr>
<td>Calibrations &amp;Tests</td>
<td>30</td>
<td>34</td>
<td>14</td>
<td>9</td>
<td>4</td>
<td>3</td>
<td>6</td>
<td>100</td>
</tr>
</tbody>
</table>

Samples in Detector Queue: - 19, which means up to 19 weeks or more of counting time!  
- the queue keeps getting longer, so the new counters are very important.
SNOLAB Data Repository

### SNOLAB Measurements

<table>
<thead>
<tr>
<th>Sample Description</th>
<th>Manufacturer</th>
<th>Mass (g)</th>
<th>Late Time Stage</th>
<th>Counting Time</th>
<th>203Hg</th>
<th>205Hg</th>
<th>207Pb</th>
<th>208Pb</th>
<th>210Pb</th>
<th>210Po</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Background

<table>
<thead>
<tr>
<th>Background 1</th>
<th>Manufacturer</th>
<th>Mass (g)</th>
<th>Late Time Stage</th>
<th>Counting Time</th>
<th>203Hg</th>
<th>205Hg</th>
<th>207Pb</th>
<th>208Pb</th>
<th>210Pb</th>
<th>210Po</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Background 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Background 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The measurements of the samples below take into account the background measurement shown above. If a measurement is below the background then the apparent value is in the 50% confidence limit.

---

**June 22 & 23, 2012**

**AARM S4**
SNOLAB Data Repository

SNOLAB maintains a database in a spreadsheet format for each experiment.

The data is shown in units of mBq/kg or pp(b or m).

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. These are also included in the spreadsheet for each sample.

The database is available to all SNOLAB users and can be made available to others upon request as it is password protected, contact Ian.Lawson@snolab.ca or Bruce.Cleveland@snolab.ca.
Future Low Background Counting At SNOLAB

- Two new low background high purity Ge Counters were ordered from Canberra

  One counter is a p-type coaxial detector and the other is a well detector. Canberra also supplied a specially built shield for the well detector.

  However, the well detector would not fit in the supplied shielding setup as the base of the well detector was too large for the copper disks and the vacuum tube connecting the dewar with the detector was too short for the shielding thickness.

  The well detector was sent back to Canberra to be rebuilt to fit the shielding, it has not been returned to SNOLAB yet.

  The shielding was slightly modified to allow the coax detector to fit so that the coax detector could be tested.
Future Low Background Counting At SNOLAB

The well detector shielding was slightly modified to allow the coax detector to fit so that the coax detector could be tested.

The coax detector was then run inside the well detector shielding to characterize the backgrounds in the hope the detector has backgrounds less than the PGT detector, which we used as the basis for maximum background requirements.

However, it was determined that the coax detector is anything but low in backgrounds. It has substantial amounts of $^{232}$Th and $^{235}$U, the other backgrounds are similar to those observed from the PGT counter.
Future Low Background Counting At SNOLAB

The background levels for a true ultra-low background detector should be no more than 100 counts/year from U and Th chain events.

The activities present are:

- $^{228}$Th progeny at 30 counts/day
- $^{228}$Ra progeny at 30 counts/day
- $^{238}$U progeny at 500-600 counts/day, although below $^{226}$Ra the rate is only about 5 counts/day.
- $^{40}$K at 18 counts/day

Canberra has sent SNOLAB many components to determine where this background is coming from, but so far there is no smoking gun.
SNOLAB Low Background Laboratory (under construction)

A new dedicated space is being constructed at SNOLAB for a low background lab located in the South Drift (former refuge station).

This drift is somewhat isolated from other drifts and is inaccessible to large equipment (fork lift). 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 3-5 Ge detectors, XRF, radon emanation chamber and have room for other types of counters which would benefit from low-cosmic ray background.
Summary

- SNOLAB PGT HPGe low background counting system has run continuously for the past since 2005 and has counted 296 samples so far. Counting queue in unusually long at 19 samples, this sometimes limits when samples can be counted in a timely manner.

The counter(s) is available for all SNOLAB experiments and can be made available to non-SNOLAB experiments upon request.

- Two new Canberra Ge detectors were delivered to SNOLAB, but are now being refurbished since they are not ultra-low background as expected.

The new counters should allow much higher sensitivity, effort underway to ensure all materials are low background. The well detector will be used for very specialized small samples such as vapourized acrylic.

- Specialized counting can be done using the ESC or Alpha-Beta Counters and materials can be emanated for Radon.

- New low background counting lab is being constructed at SNOLAB, final preparations are now underway.