Low Background Counting At SNOLAB

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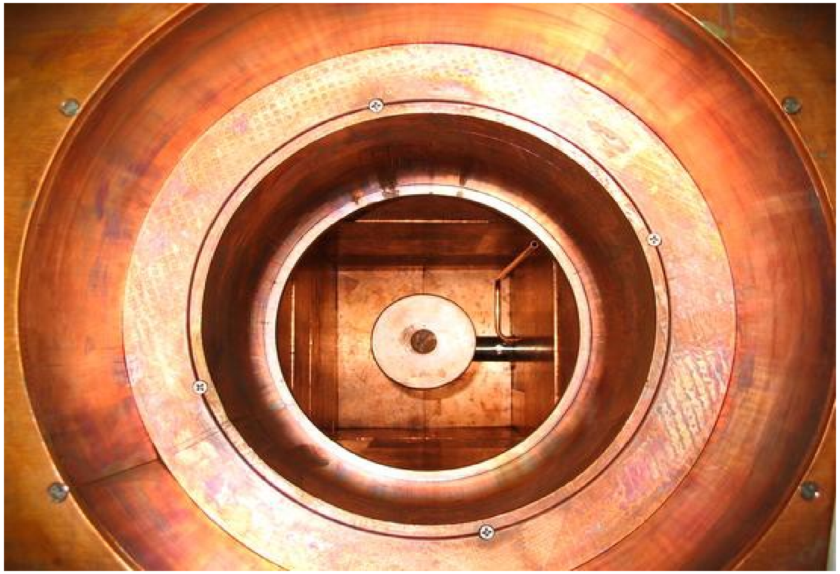
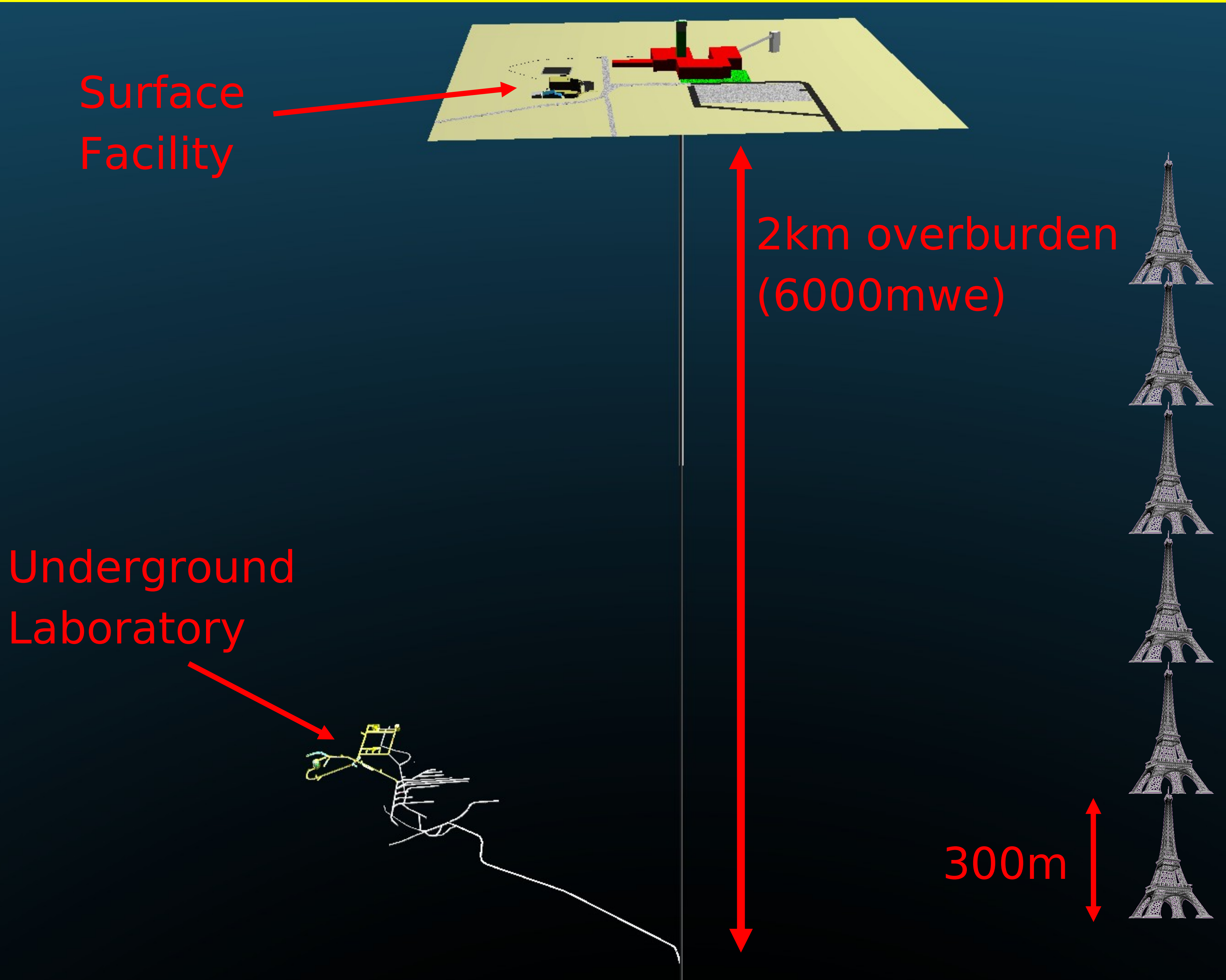
AARM S4 Collaboration Meeting
Minneapolis, Minnesota, June 22-23, 2012



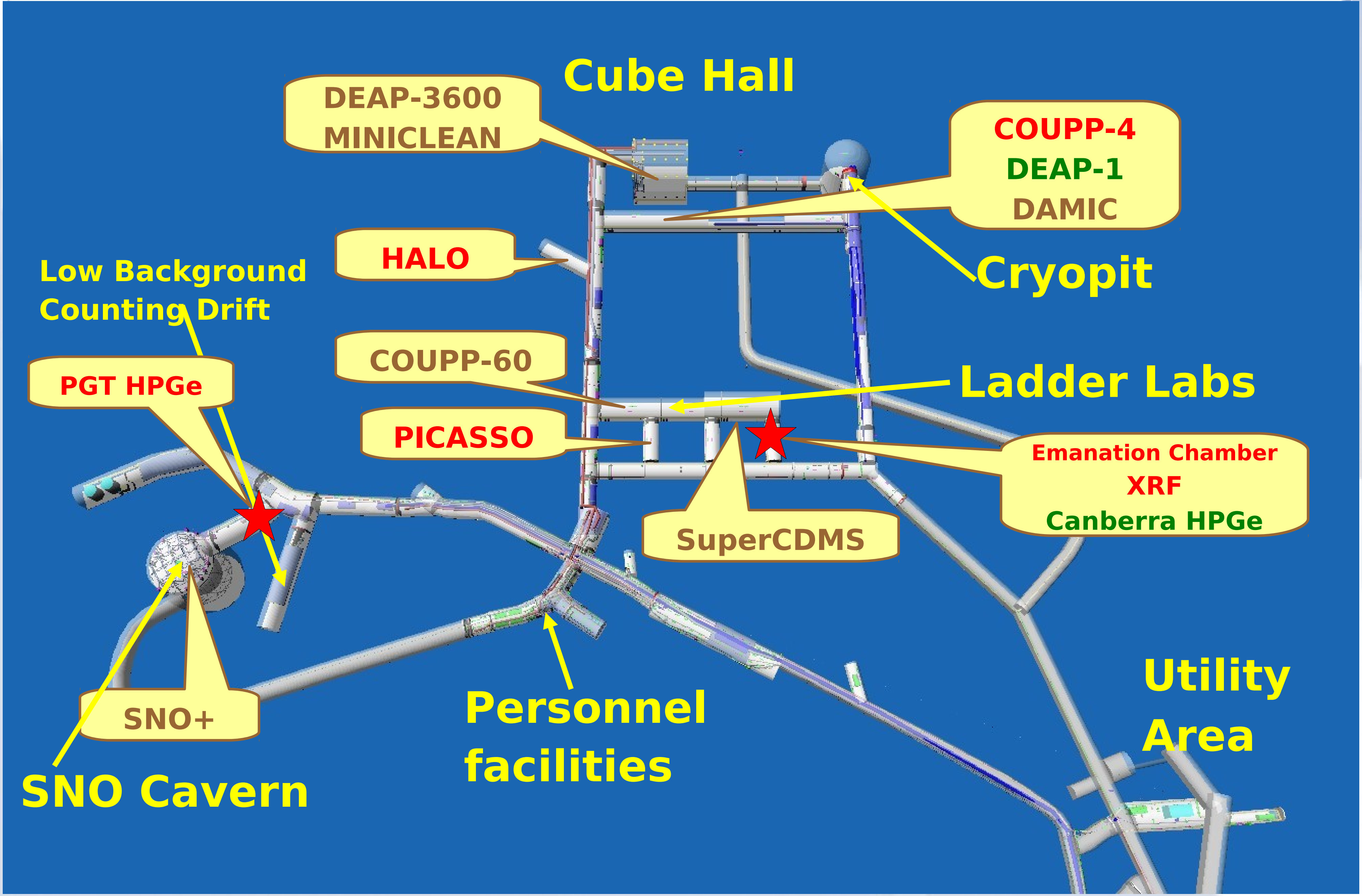
Outline

- 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

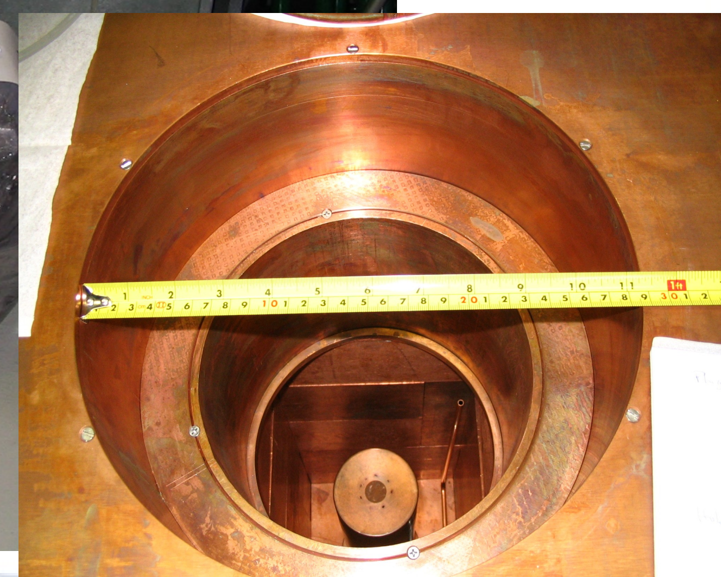
SNOLAB


Cube Hall
DEAP-3600
MINICLEAN
COUPP-4
DEAP-1
DAMIC
HALO
Cryopit
Low Background
Counting Drift
COUPP-60
Ladder Labs
PGT HPGe
PICASSO
Emanation Chamber
XRF
Canberra HPGe
SuperCDMS
SNO+
Personnel
facilities
Utility
Area
SNO Cavern

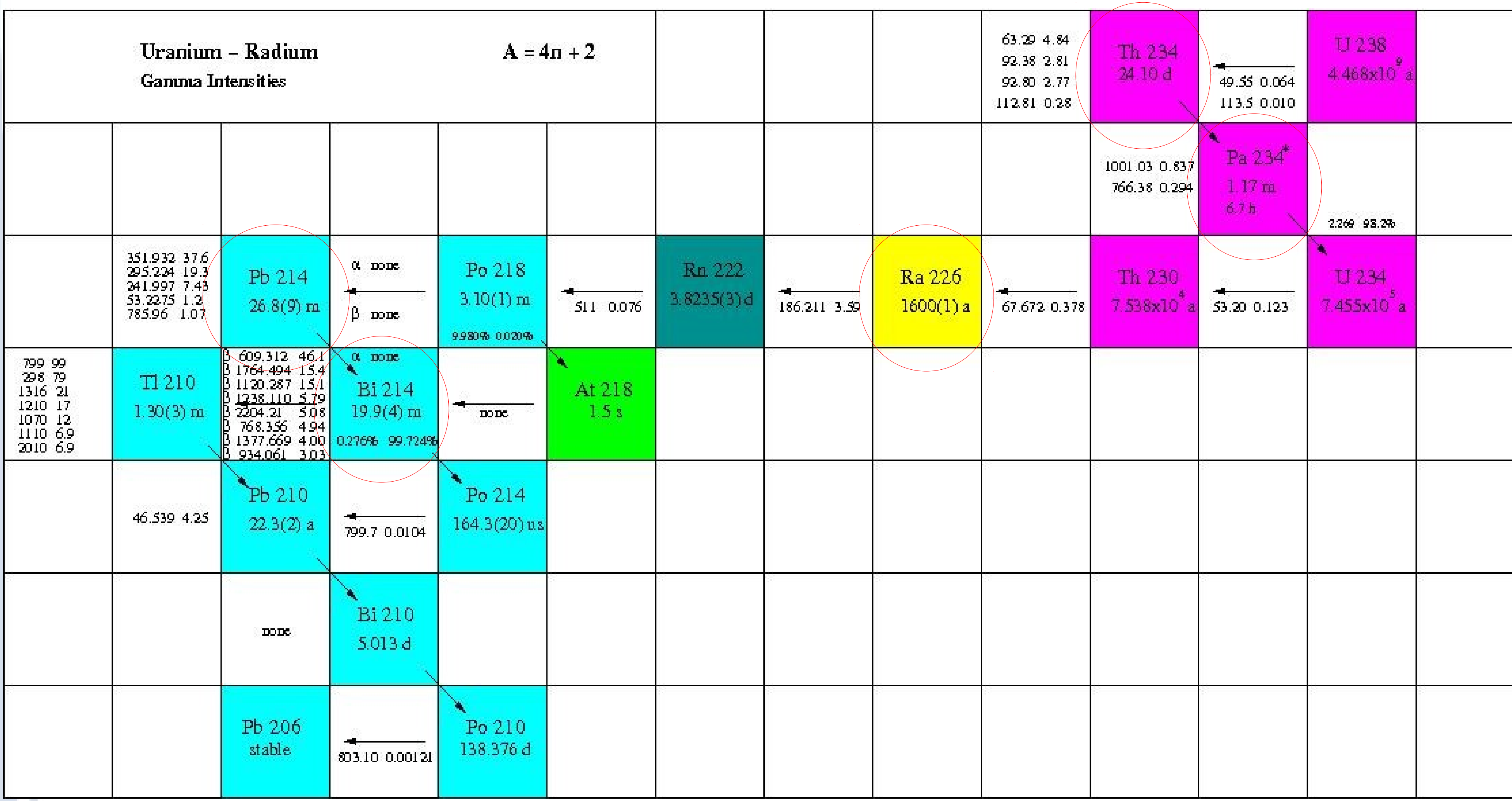
SNOLAB Low Background Counting System

- 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



Thorium Decay Chain

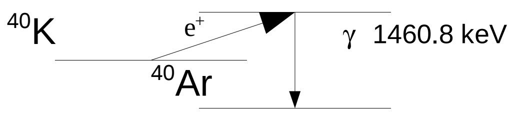
Thorium Gamma Intensities				A = 4n			13.52 1.600 16.2 0.72 12.75 0.304 15.5 0.16	Ra 228 5.75 a	63.823 0.264 204.68 0.021	Th 232 1.405×10^{10} a			
								911.204 25.8 968.971 15.8 338.320 11.27 964.766 4.99 463.004 4.40 794.947 4.25 338.320 3.89	Ac 228 6.15 h				
	238.632 43.3 300.087 3.28 115.183 0.592	Pb 212 10.64(1) h	804.9 0.0019	Po 216 145(2) ms	549.76 0.114	Rn 220 55.6(1) s	240.986 4.10	Ra 224 3.66(4) d	84.373 1.220 215.983 0.254 131.613 0.131 166.410 0.104	Th 228 1.9116(16) a			
2614.533 99.0 583.191 84.5 510.77 22.6 860.564 12.42 277.351 6.31 763.13 1.81	Tl 208 3.053(4) m	α 39.858 1.091	Bi 212 60.55(6) m 35.94% 64.06%	β 727.330 6.58 1620.50 1.49 785.37 1.102									
		Pb 208 stable		Po 212 299(2) ns									

Other Interesting Isotopes

Usually Present:

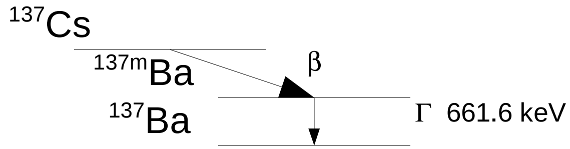
- ^{40}K

  1460.83 keV

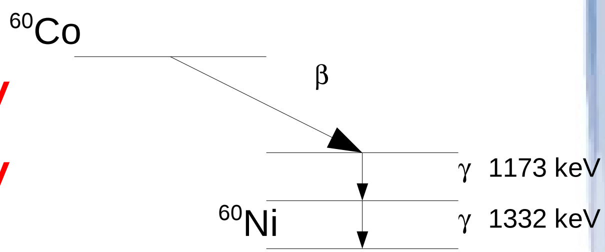


- ^{137}Cs

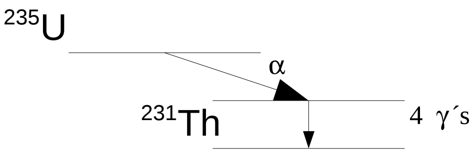
  661.66 keV



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



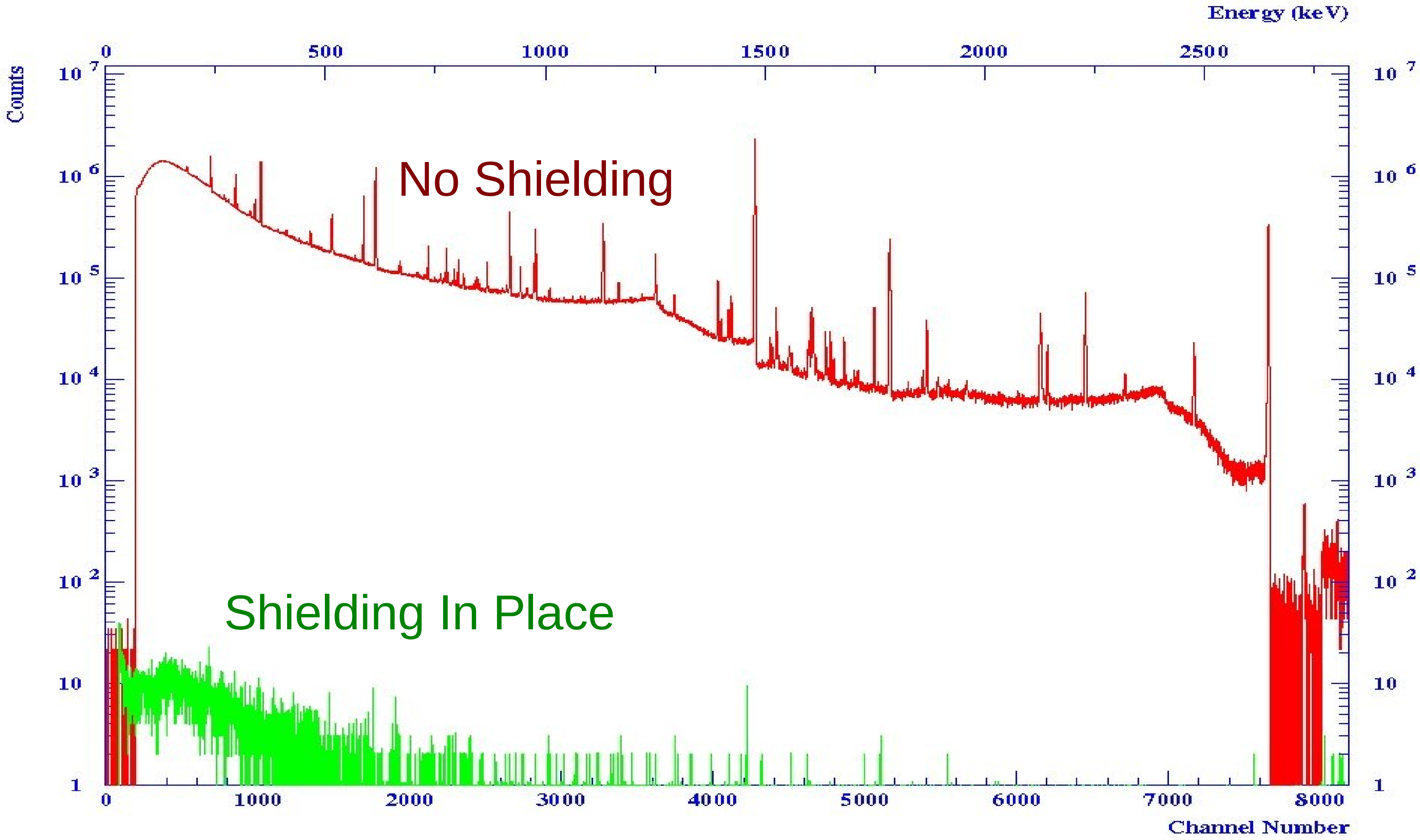
- ^{235}U
  - 143.76 keV
  - 163.33 keV
  - 185.22 keV
  - 205.31 keV



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.

Unshielded and Shielded Spectra



Background Comparison

Unshielded Versus Shielded Activity

Isotope	Activity Unshielded Crystal(Bq)	Activity Shielded Crystal (Bq)
^{238}U	70.11 ± 1.64	0.00128 ± 0.00016
^{232}Th	36.99 ± 1.21	0.00141 ± 0.00016
^{40}K	1723.33 ± 88.02	0.0189 ± 0.0017
^{137}Cs	1.00 ± 0.15	0.0020 ± 0.0002
^{60}Co	0.023 ± 0.052	0.00036 ± 0.00005

Unshielded Measurements done by Yoram Nir-EL

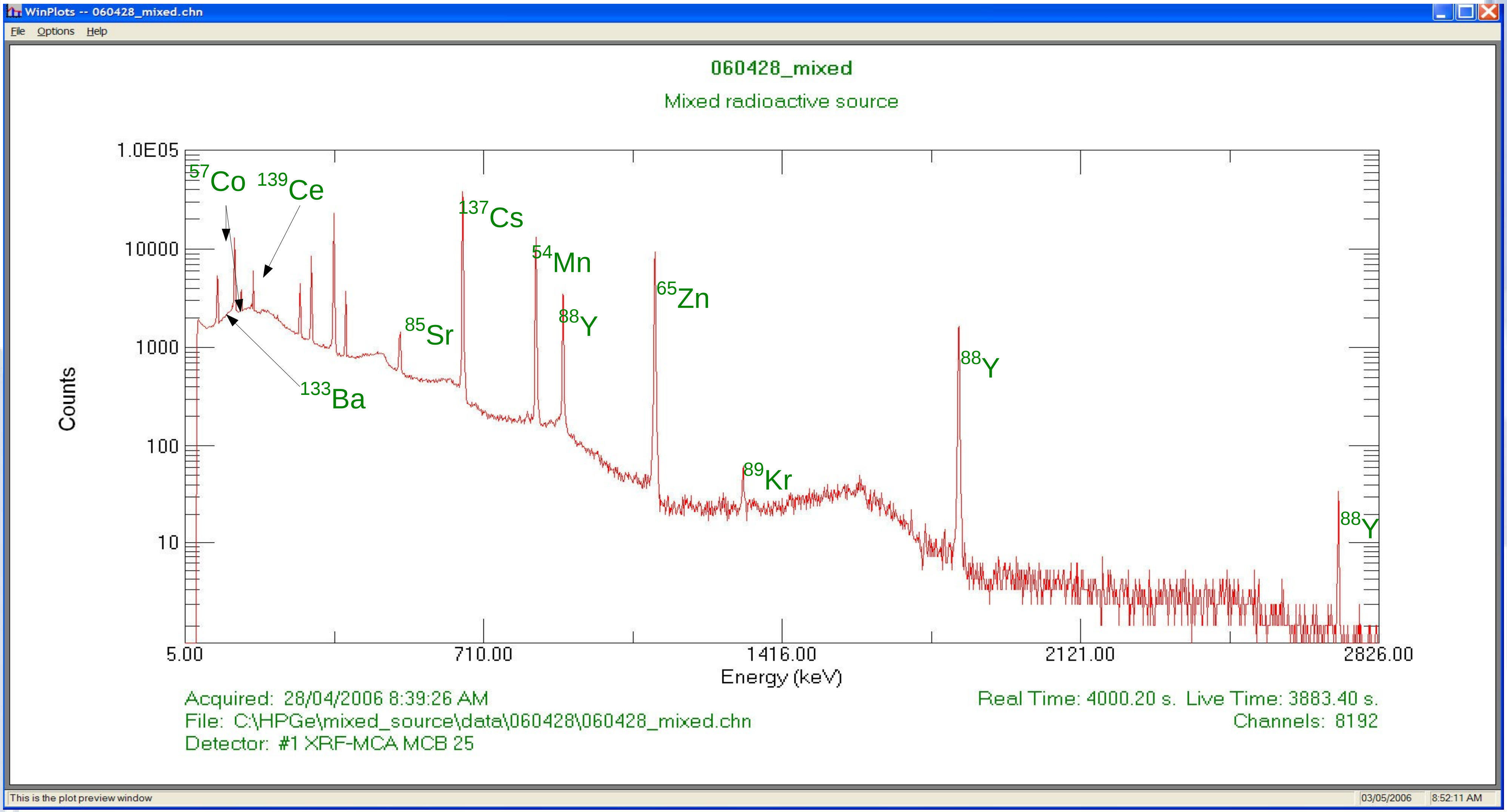
PGT HPGe Detector Sensitivity

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

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

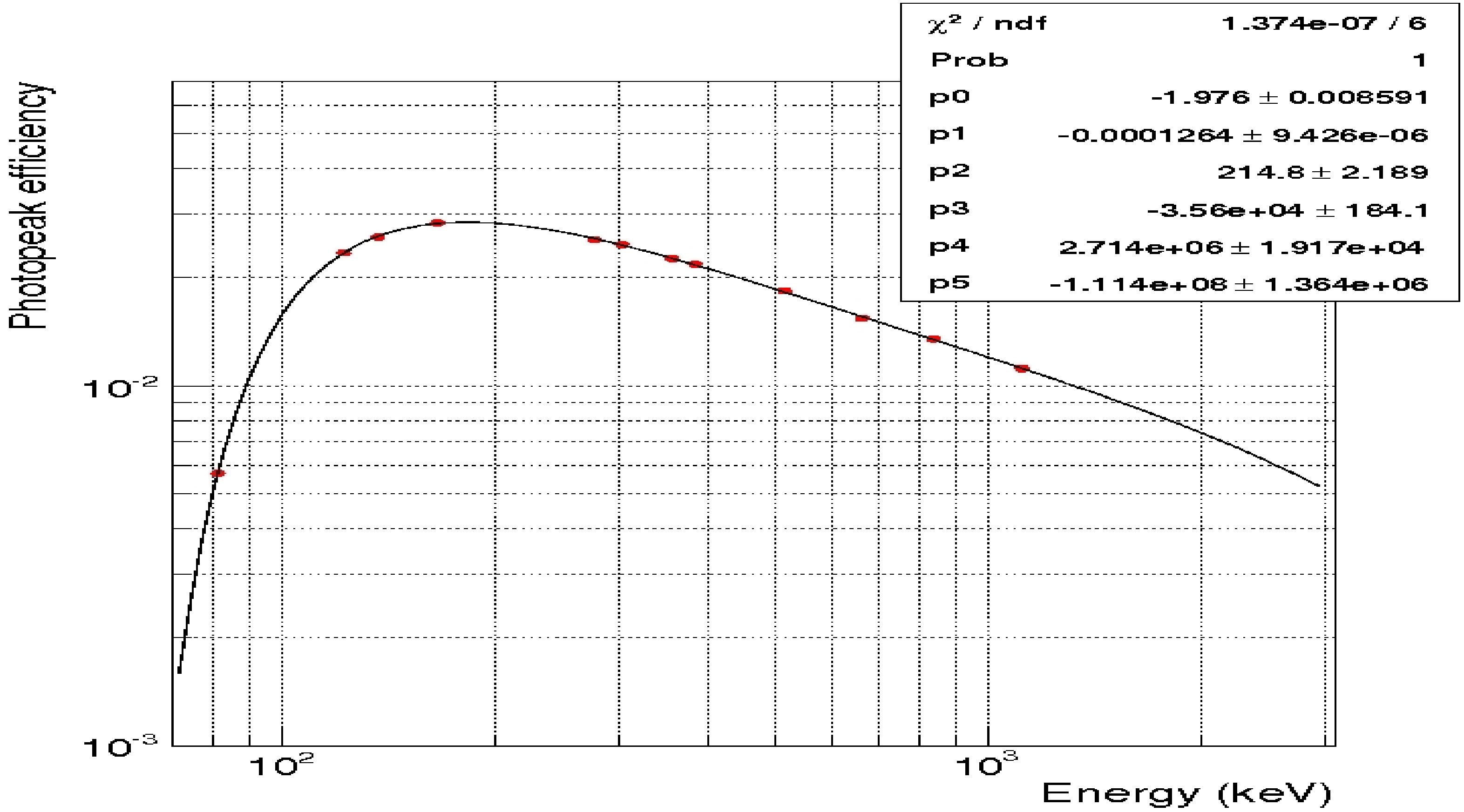
^{238}U: 0.009 ppb,
^{232}Th: 0.02 ppb,
^{40}K: 87 ppb

Calibration Spectrum



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.

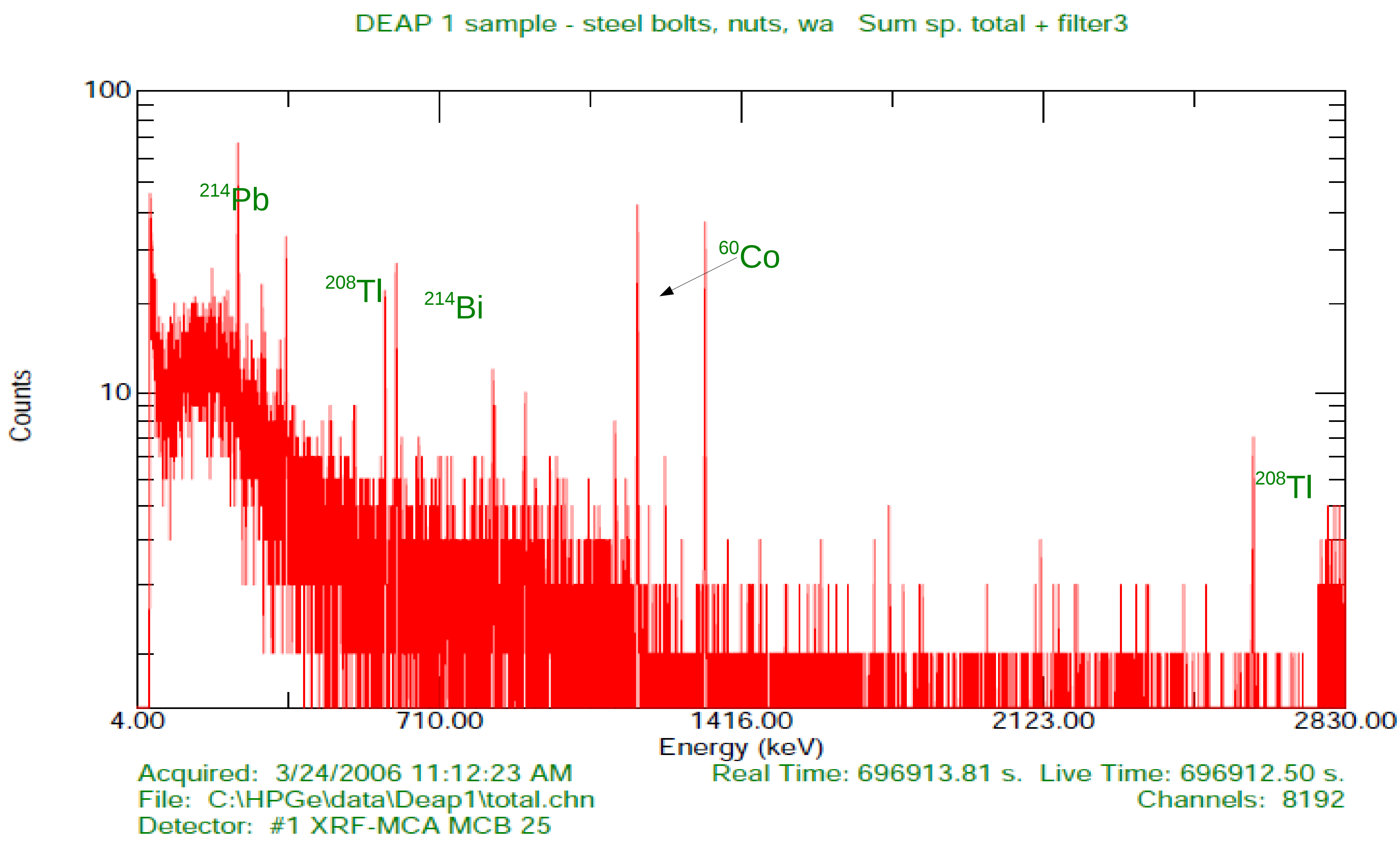
Detector Efficiency From Mixed Calibration Sample



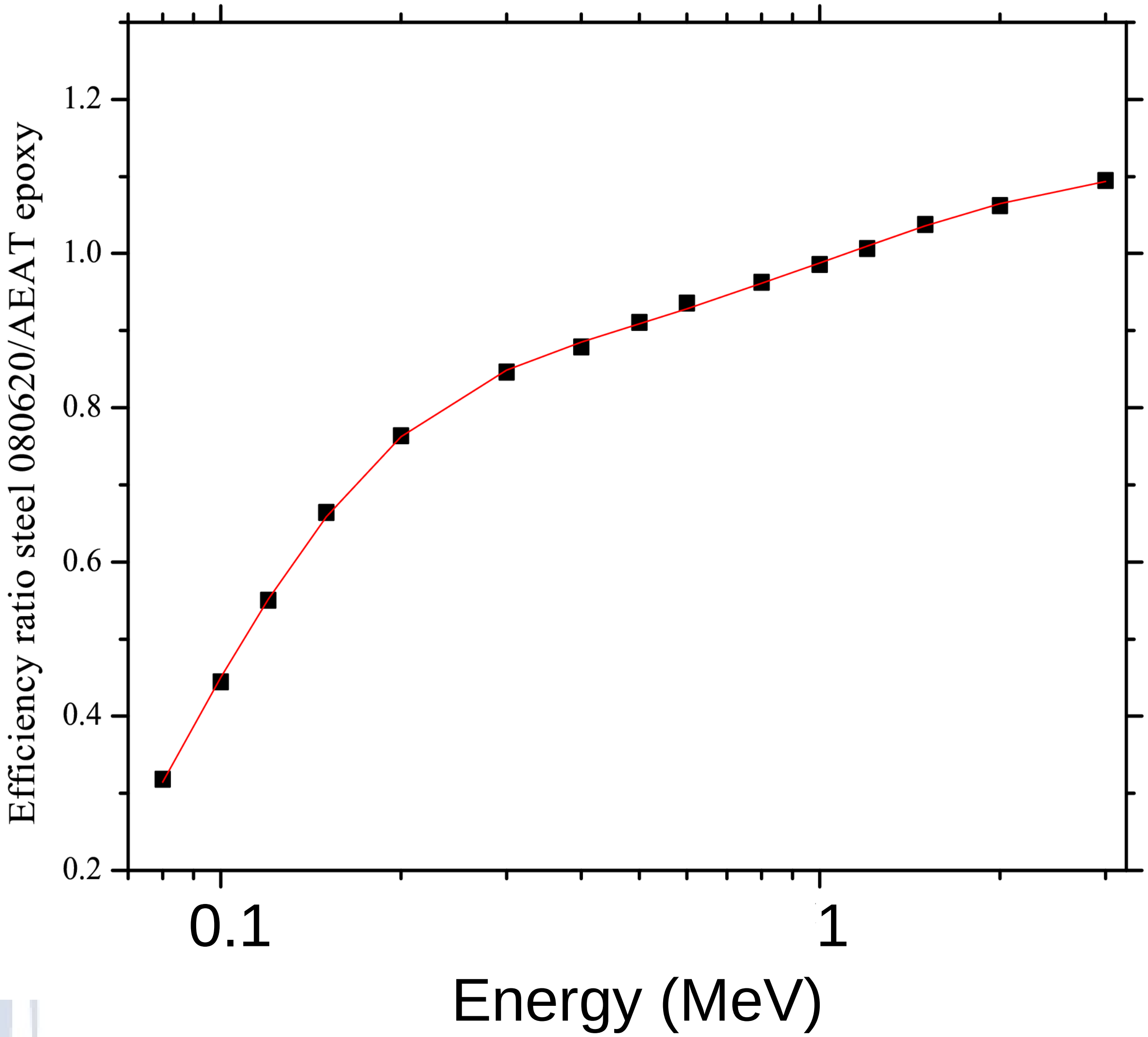
Plot by James Loach

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



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

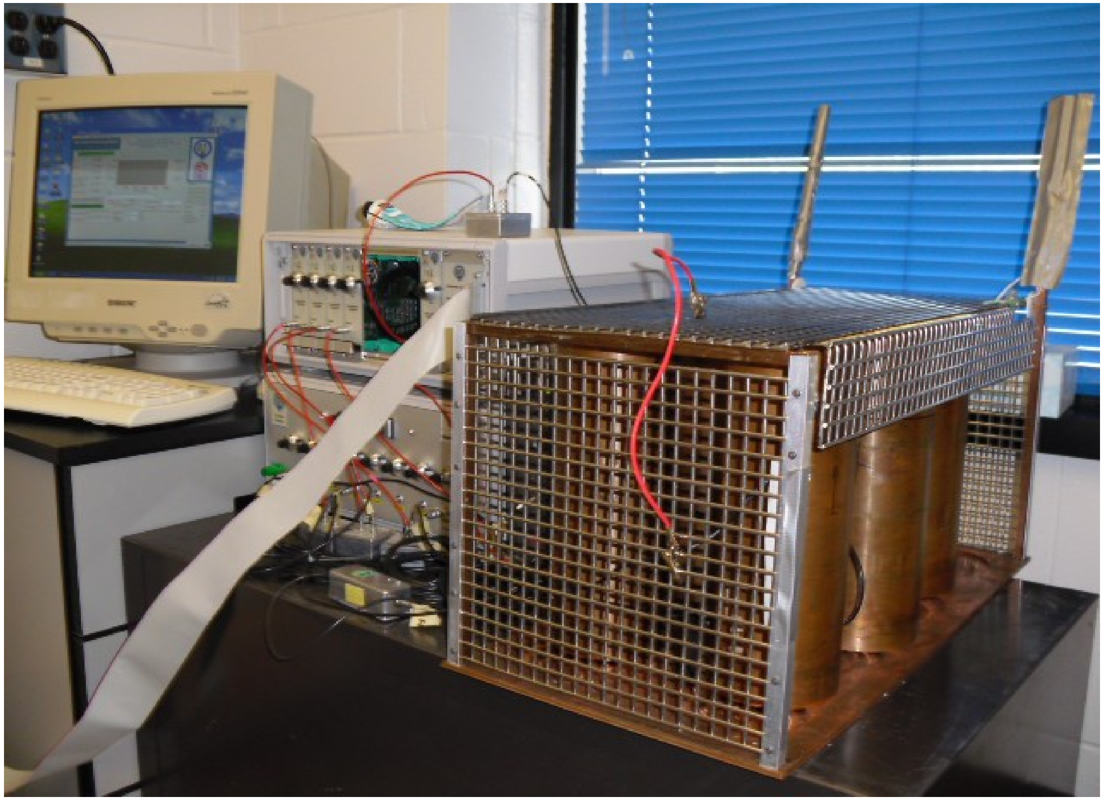
Sensitivity Levels are:

- ^{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.

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

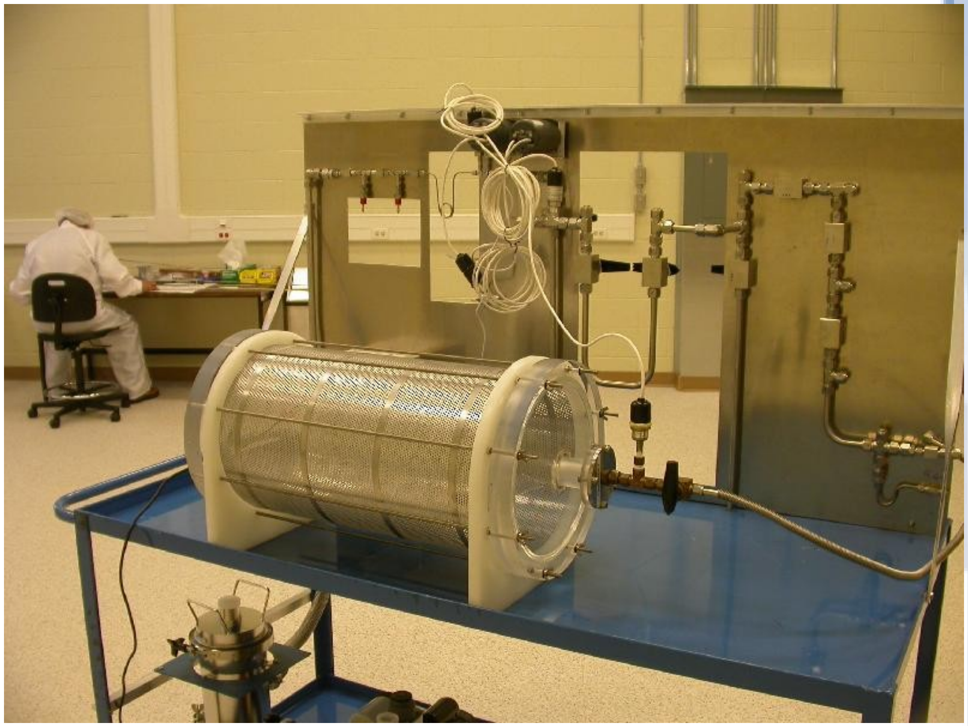


Currently located at the SNOLAB hot lab at LU so that spike sources can be measured.

Sensitivity for ^{238}U and ^{232}Th is ~ 1 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

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

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

Some Useful Information Concerning the results

The Conversion factors for the primordial nuclides are given by:	1 Bq 238U/kg = 81 ppb U (81 x 10^{-9} gU/g)	The 238U decay chain gammas used are:	226Ra: 186.2 keV 214Pb: 295.22 and 351.93 keV 214Bi: 609.32, 1120.29, 1764.49 and 2204.21 keV
	1 Bq 232Th/kg = 246 ppb Th (246 x 10^{-9} gTh/g)	The 232Th decay chain gammas used are:	212Pb: 238.63 and 300.09 keV 208Tl: 583.19 and 2614.53 keV 228Ac: 911.21 keV
The relationships are valid for any daughters in the 238U, 235U or 232Th chain only if the chain is in equilibrium.	1 Bq 40K/kg = 32300 ppb K (32300 x 10^{-9} gK/g)	The 40K decay chain gammas used is:	40K: 1460.83 keV
	1 Bq 235U/kg = 1.79 ppm U (1.79 x 10^{-6} gU/g)	The 235U decay chain gammas used are:	235U: 143.76, 163.33 and 205.31 keV

Sample Description	Manufacturer	Mass (g)	Live Time (days)	Counting Dates (if applicable)		238U from 226Ra	238U from 234Th	235U	232Th	40K	137Cs	60Co	Comments
Background 1			61.794		(mBq)	2.31 ± 0.21		0.10 ± 0.30	1.47 ± 0.18	13.70 ± 1.60	1.00 ± 0.20	0.45 ± 0.07	
Empty Marinelli Beaker													
Background 2			4.244	Aug 23, 2006	(mBq)	2.60 ± 1.04		0.71 ± 10.07	2.60 ± 1.05	30.20 ± 6.20	1.50 ± 0.70	0.21 ± 0.28	
Empty Marinelli Beaker				Sep 6, 2006									
Background 3			14.737	Oct 12, 2007	(mBq)	1.36 ± 0.44		0.797 ± 0.502	1.47 ± 0.48	18.40 ± 4.00	1.70 ± 0.45	0.30 ± 0.14	
Completely Empty Detector				Oct 30, 2007									
Background 4			20.794	Dec 23, 2010	(mBq)	1.275 ± 0.203		0.103 ± 0.400	1.220 ± 0.268	15.20 ± 3.10	1.000 ± 0.300	0.240 ± 0.080	Tl4 Signal
Completely Empty Detector				Jan 11, 2010									1.70 mBq ± 1.60 mBq
Combined Background	Combined Backgrounds of runs 1, 3 and 4		97.304		(mBq)	1.264 ± 0.162		0.173 ± 0.243	1.312 ± 0.151	16.02 ± 1.60	1.056 ± 0.166	0.418 ± 0.066	
					Additional backgrounds:	210Pb	7Be	54Mn					
						11.54 Bq ± 3.68 Bq	1.28 mBq ± 0.80 mBq	0.110 mBq ± 0.054 mBq					

The measurements of the samples below take into account the background measurement shown above. If a measurement is below the background then the upper bound shown is the 90% confidence limit.

SNOLAB Measurements:

Sample Description	Manufacturer	Mass (g)	Live Time (days)	Counting Dates (if applicable)		238U from 226Ra	238U from 234Th	235U	232Th	40K	137Cs	60Co	Comments
SNOLAB 1	[illegible] Epoxy Products, Inc	1156.7	2.266	Apr 22, 2008	(mBq/kg)	326.48 ± 24.78	305.43 ± 235.27		232.78 ± 22.73	77440.78 ± 3004.00	<3.33	4.66 ± 0.87	
Canadian Coatings EP100 Epoxy	2150 Thompson Drive, Toronto			Apr 25, 2008	(ppb)	26.28 ppb ± 2.20 ppb	24.74 ppb ± 19.05 ppb		57.62 ppb ± 5.14 ppb	2501.34 ppm ± 120.04 ppm			
SNOLAB 2	International Paint Inc.	1477.5	1.820	Apr 25, 2008	(mBq/kg)	1066.4 ± 31.35	800.35 ± 200.48	83.15 ± 42.30	322.2 ± 13.83	6278.48 ± 471.07	N/A	N/A	
Intergard 254 Yellow	6001 Antoine Drive, Houston, Texas 77091			Apr 28, 2008	(ppb)	86.24 ppb ± 2.53 ppb	64.84 ppb ± 16.18 ppb	148.34 ppb ± 74.51 ppb	78.80 ppb ± 3.43 ppb	197.33 ppm ± 15.22 ppm			
SNOLAB 3	International Paint Inc.	1450.0	2.254	Apr 28, 2008	(mBq/kg)	1187.40 ± 32.00	750.57 ± 275.8	31.01 ± 36.34	254.14 ± 21.33	8842.78 ± 480.88	N/A	N/A	
Intergard 251 Tile Tint	6001 Antoine Drive, Houston, Texas 77091			May 1, 2008	(ppb)	96.20 ppb ± 2.50 ppb	56.02 ppb ± 24.08 ppb	56.18 ppb ± 63.07 ppb	61.32 ppb ± 3.64 ppb	285.62 ppm ± 15.62 ppm			
SNOLAB 4	International Paint Inc.	1550.0	1.075	May 1, 2008	(mBq/kg)	1048.40 ± 33.02	1788.00 ± 340.4		320.02 ± 27.47	13516.48 ± 842.07	N/A	N/A	

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

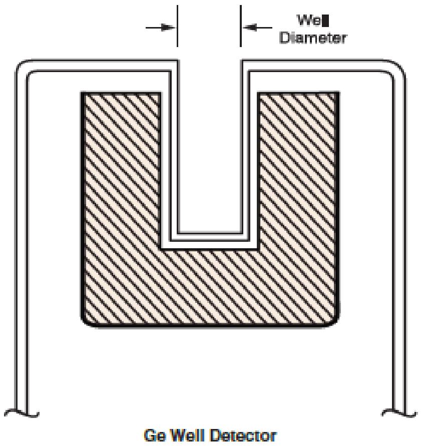
- Two new low background high purity Ge Counters were ordered from Canberra

  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.

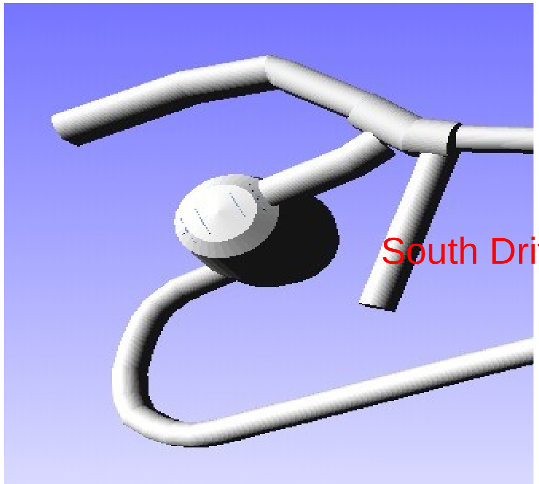
The activities present are:

- ^{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.