

Ultra-low background measurement capabilities at SNOLAB

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Abstract. 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 current generation of experiments can achieve the required sensitivities for their searches. SNOLAB has several facilities which are used to directly measure these radioactive backgrounds. This paper will describe SNOLAB's ultra-low background germanium detectors, describe the data analysis techniques used and present results from these detectors. A description of SNOLAB's alpha-beta and electrostatic counters will be presented and the underground low background counting laboratory currently under construction at SNOLAB will be presented.

1. Introduction

During the construction of the Sudbury Neutrino Experiment (SNO), low background counting facilities were developed to measure materials for its construction and operations. These facilities have been maintained and expanded by SNOLAB and are now being utilized for analyzing materials for new experiments which are being developed at SNOLAB. These experiments require that their fabrication materials have low concentrations of the radioactive chain elements, ^{238}U , ^{232}Th and ^{40}K , often well below ppt levels. These radioactivity levels are below what is generally accessible by chemical analytical techniques, therefore assay methods are often done by radiation counting.

The detector target fluids themselves are often assayed as a quality control requirement, or for diagnostics and purification testing. The backgrounds of interest can include alphas, betas, gammas or neutrons, depending upon the experiment and component in question. The radiation could be direct or via leaching or emanation. Thus, several different detector technologies are used to estimate radioactive contamination levels. In addition, the counting detectors themselves must be very low in background contamination levels, which requires them to be radioactively clean and underground, and fabricated and shielded with low background materials.

2. SNOLAB PGT Germanium Counting Facility

The low background counting facility is located in the underground SNOLAB facility which is 2 km (6000 meters water equivalent) below surface at the Vale Creighton Mine. This germanium detector has been located underground since 1997, first at the 4600 ft level and since 2005 at the 6800 ft level. Between 1999 and 2005, the detector was not operational and it was kept in storage at the 4600 ft level. In 2005, it was decided to restart the counter to measure the radioactivity of the materials for the experiments expected to be located at SNOLAB. Further details of this apparatus have been described elsewhere [1, 2, 3].

The detector was manufactured by PGT in 1991 from low radioactivity components. The crystal volume is approximately 208 cm^3 , its diameter is 67 mm, the relative efficiency is 55%





Figure 1. The SNOLAB PGT germanium counter, the copper box is used to seal the shielding to keep out radon. The right hand photo shows the detector and sample chamber.

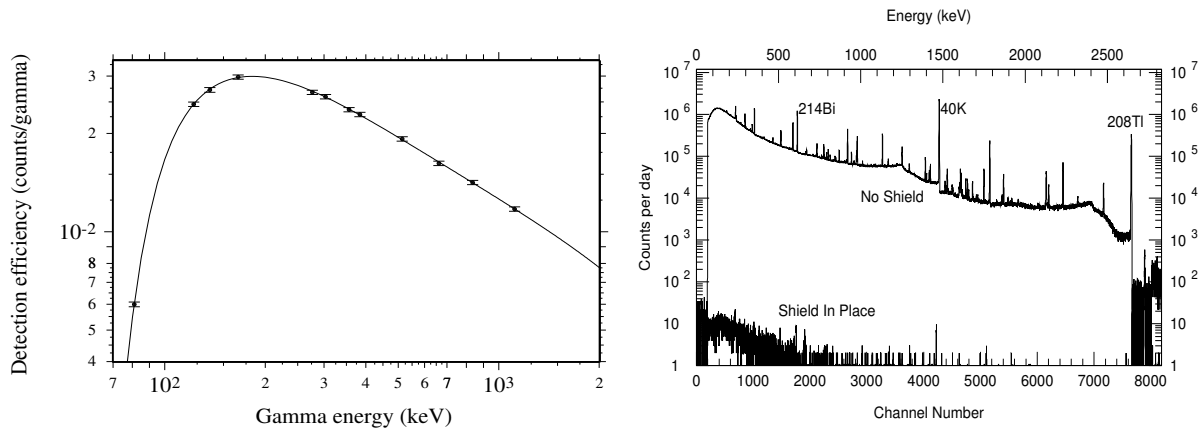


Figure 2. The right hand plot shows the PGT germanium detector efficiency versus energy as measured using a 1 litre mixed radionuclide source and the left hand plot shows the detector spectra from the unshielded and shielded detector, respectively.

relative to a standard $7.62 \text{ cm} \times 7.62 \text{ cm}$ NaI(Tl) detector and the resolution is 1.8 keV full width at half-maximum. The detector is shielded from room backgrounds with 2 inches of copper and 8 inches of lead. In addition, the volume is purged with nitrogen gas at a rate of 2 L/min to purge radon. Figure 1 shows the detector shielding box, and the detector and sample chamber.

The cavity surrounding the germanium detector usually holds one-litre samples in an inverted Marinelli beaker which surrounds the detector end-cap. The detector energy and efficiency calibrations are made periodically with mixed radionuclide samples. Additional checks have also been done using ^{40}K samples, and from a sample composed of flux cored stainless steel wire. The efficiency curve calculated using a 1 litre mixed sample is shown in Figure 2.

Many samples that are measured have either a different geometry or a different chemical composition than the standard source which is in a 1 litre Marinelli beaker. To determine the counting efficiency for such samples, a complete model of the detector and the sample whose activity is under measurement is modeled in GEANT4. The efficiency is then corrected using the calculated results from the model. The energy calibration is verified periodically and recalculated as required due to slight drifts which are usually due to the high voltage power supply drifting slightly with time and changes in the voltage after power outages.

Although most of the cosmic rays are stopped by the 2 km of rock above the underground



Figure 3. The SNOLAB Canberra germanium well counter. The right hand photo shows the detector and sample chamber.

laboratory, there are still ambient backgrounds due to the U and Th daughters from the rock walls. The detector shielding and the radon purge system remove most of this background which can be detected with the germanium counter. The remaining backgrounds come from the shielding and the detector itself. Figure 2 shows a detector spectrum taken with the shielding open with respect to a spectrum with all of the shielding in place. It is observed that the shielding reduces the background by 5 orders of magnitude, this background level then becomes the limit of the detector sensitivity. The detector sensitivity has been measured to be 12 ppt for ^{238}U , 32 ppt for ^{232}Th and 54 ppt for ^{40}K ; the sensitivity can be improved with samples which are much larger than the standard one litre volume.

3. SNOLAB Canberra Germanium Counters

Two new germanium detectors have been acquired by SNOLAB from Canberra, one is p-type well detector and the second is a p-type coaxial detector. Figure 3 shows the detector chamber and shielding setup. The detector volume is 300 cm^3 , and the well diameter is 21 mm. The detector is sensitive to gammas between 10 and 900 keV.

An ultra-low background detector is expected to have less than 100 counts per year from all backgrounds combined. To ensure that the new detector was indeed a low background detector, a combined 3 month background run was completed. It was determined that the combined backgrounds from all detectable gammas was at the level of about 30 counts per year, which is below the limit. The observed backgrounds were 0.029 ± 0.058 and 0.048 ± 0.064 decays per day from ^{238}U and ^{232}Th , respectively. One of the advantages of a well detector is its ability to observe low energy gammas with high efficiency and thus observe gammas from isotopes such as ^{210}Pb , whose energy is 46.54 keV. To determine the efficiency of the well detector, reference samples from IAEA were used. These sources are all made from natural materials, U ore, Th ore, or K_2SO_4 , respectively, and are diluted by the addition of inert chromatographic-grade powdered silica. The spectra from the U and Th ore samples are shown in Figure 4. The detector sensitivity has been measured to be 6 ppt for ^{238}U , 98 ppt for ^{232}Th , 12 ppt for ^{210}Pb , and 35 ppt for ^{235}U .

The Canberra coaxial detector background characteristics were verified using the well detector shield. The coax detector was measured to have backgrounds well above those expected for an ultra-low background detector with rates of 30 counts/day for ^{228}Th and ^{228}Ra and 500-600 counts/day for ^{238}U , the rate below ^{226}Ra was only about 5 counts/day, however still well above the expected limit. The detector was refurbished by Canberra and the backgrounds were subsequently measured to be similar to those from the PGT detector. The detector shielding is

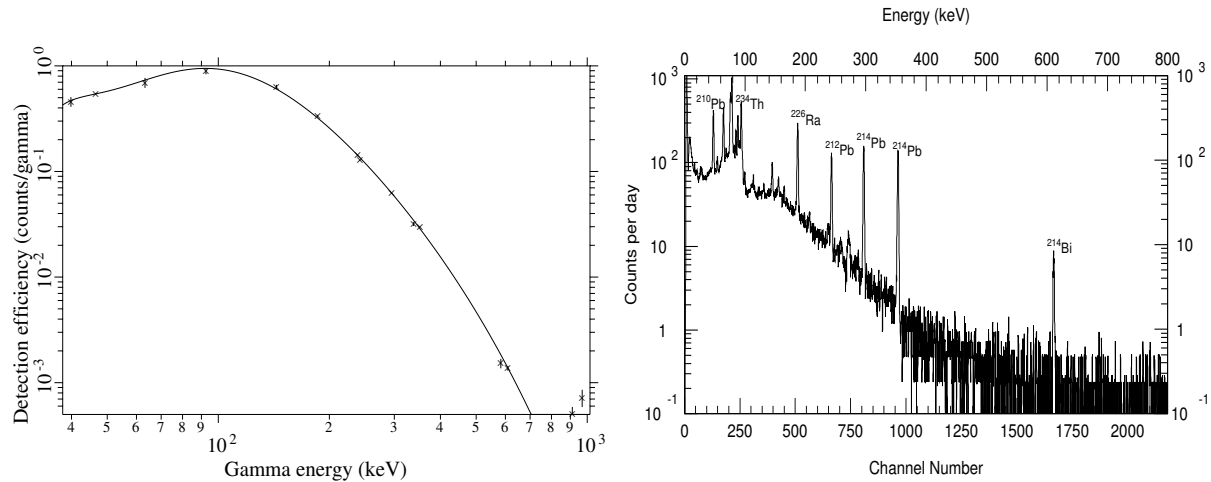


Figure 4. The right hand plot shows the Canberra well detector efficiency versus energy using the IAEA samples and the right plot shows an example spectrum from the IAEA uranium calibration sample.

currently under design and it is expected that the sample chamber will be large enough to hold samples on the order of 20 litres to achieve the maximum sensitivity for future samples.

4. Other Counting Facilities

SNOLAB operates a series of electrostatic counters (ESCs) located in the surface clean labs. The counters were originally built at the University of Guelph for the SNO experiment to assay low backgrounds, but now are available to all experiments at SNOLAB. The ESCs can measure ^{222}Rn , ^{224}Ra and ^{226}Ra levels down to sensitivities of 10^{-14} gU/g, 10^{-15} gTh/g, and 10^{-16} gU/g, respectively for each isotope.

An alpha-beta counting system is available for counting small or concentrated samples. The sensitivity of these counters is about 1 mBq for both ^{232}Th and ^{238}U if the decay chains are in equilibrium. The counting system has been used to measure the radioactivity in the water system for SNO and is currently being used to measure the decay characteristics of specially created spiked sources for the SNO+ experiment.

5. Future Low Background Counting Facilities

SNOLAB is currently developing a low background counting laboratory using the space which was the refuge station for the original SNO experiment. The new laboratory will become the home for the PGT and Canberra germanium detectors, an x-ray fluorescence monitor and a radon emanation chamber which are currently located in the underground laboratory. The area is being designed to allow for additional germanium detectors and other counters which require a low-background environment. The first new detector to be installed in the low background laboratory is the Vue des Alpes detector which will be primarily used by the nEXO experiment. In addition, it is expected that the SOUDAN Gopher HPGe detector will be relocated to SNOLAB as part of the installation of superCDMS at SNOLAB. Figure 5 shows the space as it currently exists and the plans for the future laboratory, which requires the installation of new walls, electrical utilities and air ducting; the Vue des Alpes detector is currently under construction.

6. Summary

The SNOLAB PGT high purity germanium counting system has been operating continuously since 2005 and has counted more than 500 samples. The counting queue remains long which sometimes limits when samples can be counted in a timely manner. SNOLAB has acquired

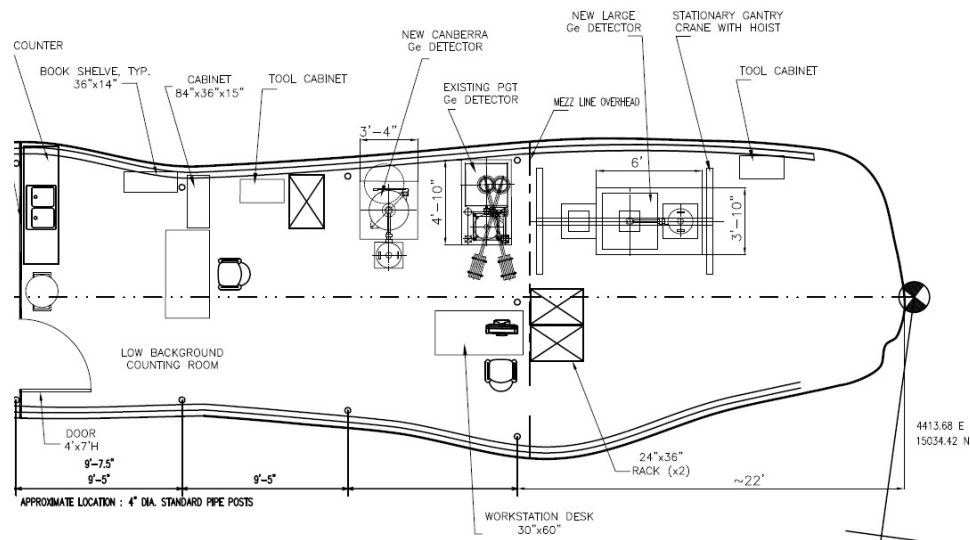


Figure 5. The top schematic shows the SNOLAB low background counting lab layout. The bottom left photo shows the current state of the low background lab and the right photo shows the Vue des Alpes germanium detector with its shielding partially in place

two new p-type germanium detectors, the well detector is operational and the coax detector shielding is under design. Specialized low background electrostatic and alpha-beta counting systems are available at SNOLAB with sensitivities at the 1 mBq level. Finally, a deep low background counting laboratory is under construction and the nEXO Vue des Alpes HPGe detector is currently under construction in the new laboratory and it should be operational soon.

Acknowledgments

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