

Low Background Measurement Capabilities at SNOLAB

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Abstract. Experiments currently searching for dark matter and studying properties of neutrinos 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 and next generation experiments can achieve the required sensitivities for their searches. This presentation will describe the low background measurement facilities currently operating at SNOLAB and will discuss plans and options to expand these facilities to allow for the increased sensitivity required by the next generation of experiments.

1. Introduction

SNOLAB is continuing to develop a low background counting facility to assist in the search for low background materials which can be used in the construction of highly sensitive neutrino and dark matter search experiments located at SNOLAB and other underground laboratories. The origins of the current facilities were developed during the construction and operation of the Sudbury Neutrino Observatory (SNO) experiment, [1] these facilities have been maintained and expanded by SNOLAB with the goal to build a world class low background facility.

The low background counting laboratory is located in the underground SNOLAB facility which is 2 km (6000 meters water equivalent) below surface at the Vale Creighton Mine, located in Greater Sudbury, Ontario Canada. The counting facilities main goal is find materials which 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 and analytical techniques, therefore assay methods are often performed through radiation counting.

Furthermore, 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. In addition to the underground laboratory, there are surface laboratories which also have counting facilities which don't require the low cosmic-ray background environment.

2. Direct Gamma-ray Counting

2.1. SNOLAB PGT Ge Counting Facility

One of the primary methods to measure the radioactivity in a material is to directly count the material using an ultra-low background semiconductor germanium detector. These detectors use the cleanest materials available in order to reduce internal backgrounds to increase the sensitivity to the gamma- and x-rays as much as possible. The PGT germanium detector has





Figure 1. The SNOLAB PGT germanium counter, the copper box is used to prevent the ingress of radon into the detector chamber. The right hand photo shows the detector and sample chamber.

been located underground since 1997, first at the 4600 ft level and since 2005 at the 6800 ft level. Further details of this apparatus have been described elsewhere [2, 3, 4].

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% 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 inner volume is purged with nitrogen boil-off gas at a rate of 2 L/min to prevent radon ingress. 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. 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.

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

The left plot in 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 0.12 mBq for ^{238}U , 0.11 mBq for ^{232}Th , 1.50 mBq for ^{40}K , 0.05 mBq for ^{60}Co and 0.14 mBq for ^{137}Cs ; the sensitivity can be improved with samples which are much larger than the standard one litre volume. The right plot in figure 2 shows a typical spectrum for a sample of stainless steel, the prominent peaks are shown on the plot.

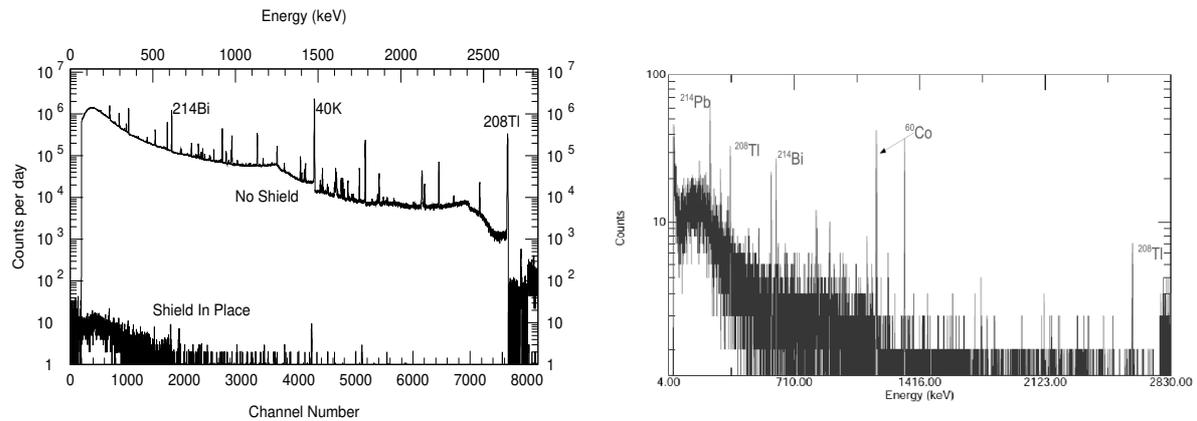


Figure 2. The right hand hand plot shows the detector spectra from the unshielded and shielded detector, and the left plot shows a typical spectrum for a stainless steel sample, respectively.



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

2.2. SNOLAB Canberra Well Germanium Counters

Two new germanium detectors have been acquired by SNOLAB from Canberra, one is a p-type well detector and the second is a p-type coaxial detector. Figure 3 shows the detector chamber and shielding setup for the well detector. 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. The detector is shielded with 8 inches of low background lead and 2 inches of low background copper, the detector chamber is purged with nitrogen boil-off gas at 2 L/min to prevent the ingress of radon.

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. The detector sensitivity has been measured to be 0.03 mBq for ^{238}U , 0.12 mBq for ^{228}Ac , 0.23 mBq for ^{232}Th , 0.08 mBq for ^{210}Pb , and 0.01 mBq for ^{235}U .

The Canberra coaxial detector shielding is currently under construction 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.

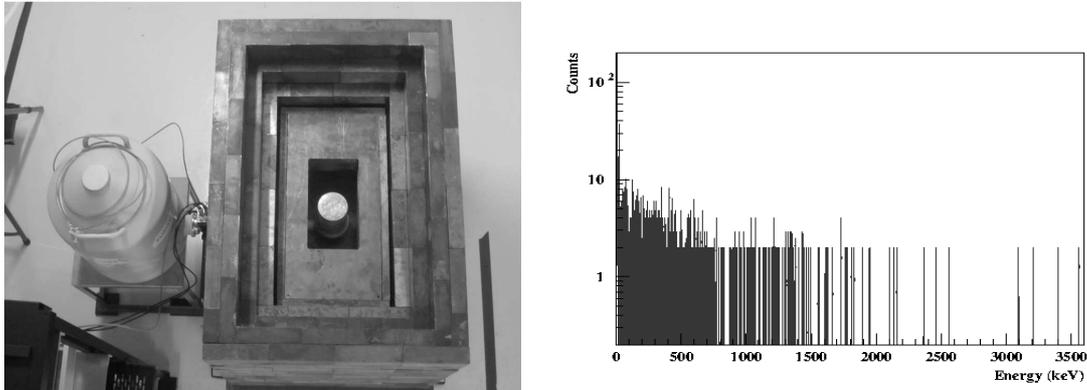


Figure 4. The right photo shows the Vue des Alpes germanium detector with its shielding partially in place and the left plot shows a background spectrum of the detector.

2.3. Vue des Alpes Germanium Counter

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. This detector was relocated from the Vue des Alpes laboratory in Switzerland and is currently collecting background data to characterize the detector background in its new location. Figure 4 shows the Vue des Alpes detector with the shielding lid removed which gives a view of the detector and a typical background spectrum.

3. 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 five low background germanium detectors, an x-ray fluorescence detector, alpha detectors, and a radon emanation chamber. Space is allocated for a radon-reduced clean room to allow for the preparation of samples for the various counters. In addition to the germanium counters described above, the Gopher germanium detector and Tennelec alpha counter previously located at the Soudan underground laboratory are under construction. 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.

4. Material Assay Database

The low background community has an ongoing effort to bring together all relevant low background counting results from around the world to create a central database. The database will be useful in tabulating data from many laboratories into one place so that those searching for new materials have a central repository to search for their materials. The database is hosted at SNOLAB and is maintained by an international collaboration of scientists from North America, Europe and China, who are responsible for developing the database application, defining the material assay data format and helping laboratories contribute their data. The database is located at the following web site: www.radiopurity.org.

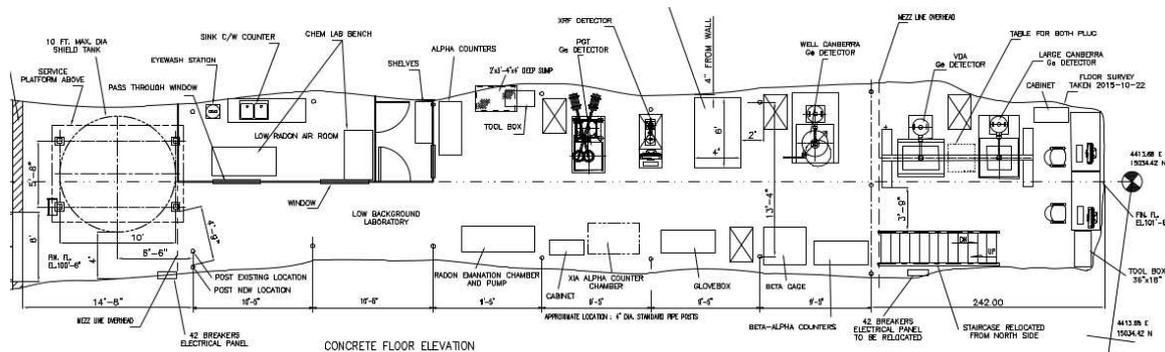


Figure 5. The top schematic shows the SNOLAB low background counting lab layout. The bottom left photo shows the current state of the low background lab and the right photo shows the Gopher germanium detector under construction with its shielding in place.

5. Summary

The SNOLAB underground low background laboratory is under construction and several counting systems are in operation in the new laboratory space while construction is ongoing. The SNOLAB gamma counting program has been in operation since 2005 and is being expanded to meet the growing demand for qualifying materials which are required for low background experiments at SNOLAB and other underground laboratories.

Acknowledgments

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