Low-Background Counting at the Black Hills State University Underground Campus at the Sanford Underground Research Facility

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Abstract & Introduction

The Black Hills State University Underground Campus (BHUC), stationed on the 4850' level at the Sanford Underground Research Facility, is home to a low-background counting facility with four High Purity Germanium (HPGe) detectors in a class 1000 cleanroom (Figure 1). The rock overburden reduces the cosmic-ray flux by a factor of 10^6 relative to the surface, meaning that vastly improved detector sensitivities are achieved. This is critical to rare-event search experiments (for example: LUX, LZ & Majorana), where the materials used in the fabrication of such a detector have to be ultra radio-pure to control background levels.

During my project I have learned how to interpret and analyze gamma-ray spectra to determine the concentration of primordial radionuclides (U, Th & K) in several detector components (see "Gamma Spectroscopy").

I have also been involved in assembly and commissioning of a fifth HPGe detector at the BHUC (See "Twins Installation") which has given me insight into both the practical and theoretical aspects of low-background counting.

Gamma Spectroscopy

During radioactive decay, the daughter nuclide is often left in an "excited state". The excess energy associated with this state is released when the nucleus emits a photon, typically in the gamma-ray energy window of the electrotromagnetic spectrum (~10^2 eV to ~10^7 eV). Its (relatively) high energy means that it can escape the sample and enter the detector, where it may deposit this energy within the crystal volume. The amount of energy deposited is directly proportional to the incident gamma-ray energy and characteristic to a specific nuclide [1, 2]. The following method was used to identify these energies and identify the associated daughters;

- The sample to be assayed is prepared for counting and placed on the detector (Figure 2).
- Because many of the samples are low in intrinsic radioactivity, a counting time of 1 – 2 weeks is typically employed in order to obtain enough statistics for positive identification.
- A pulse-height spectrum of dN/dE against E is produced (Figure 3) using a nuclear instrumentation (NIM) signal processing chain (typically a shaping amplifier – discriminator and Multi-channel analyzer (MCA)).
- Pulse-height analysis is performed using software (reference Los Alamos) to identify key nuclides of interest as well as any other possible contaminants, and compared to natural background levels (see Figure 4).
- Any contamination (activity) above the background level is measured and reported in units of parts per billion (ppb) or specific activity units (mBq/kg)

Figure 1 – BHUC cleanroom. Shown: Mordred (1), SOLO (2), Maeve (3), Morgan (4), the electronics responsible for networking and data acquisition (5), and the particulate counter (6).

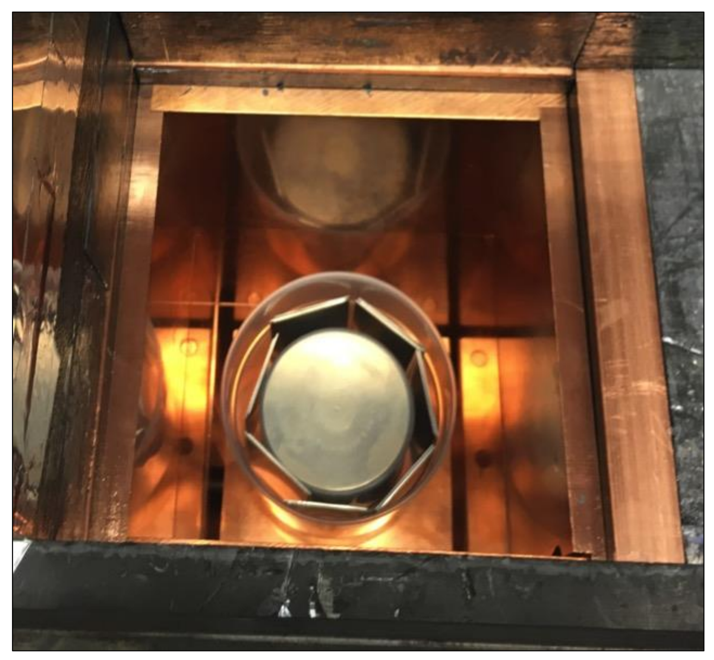


Figure 2 – (left) Detector crystal and aluminum plate sample in a crystal annulus geometry. (right) A sample of titanium wire prepared in a full geometry. In both examples a standard sized "Marinelli beaker" is used to control the counting geometry.

Results

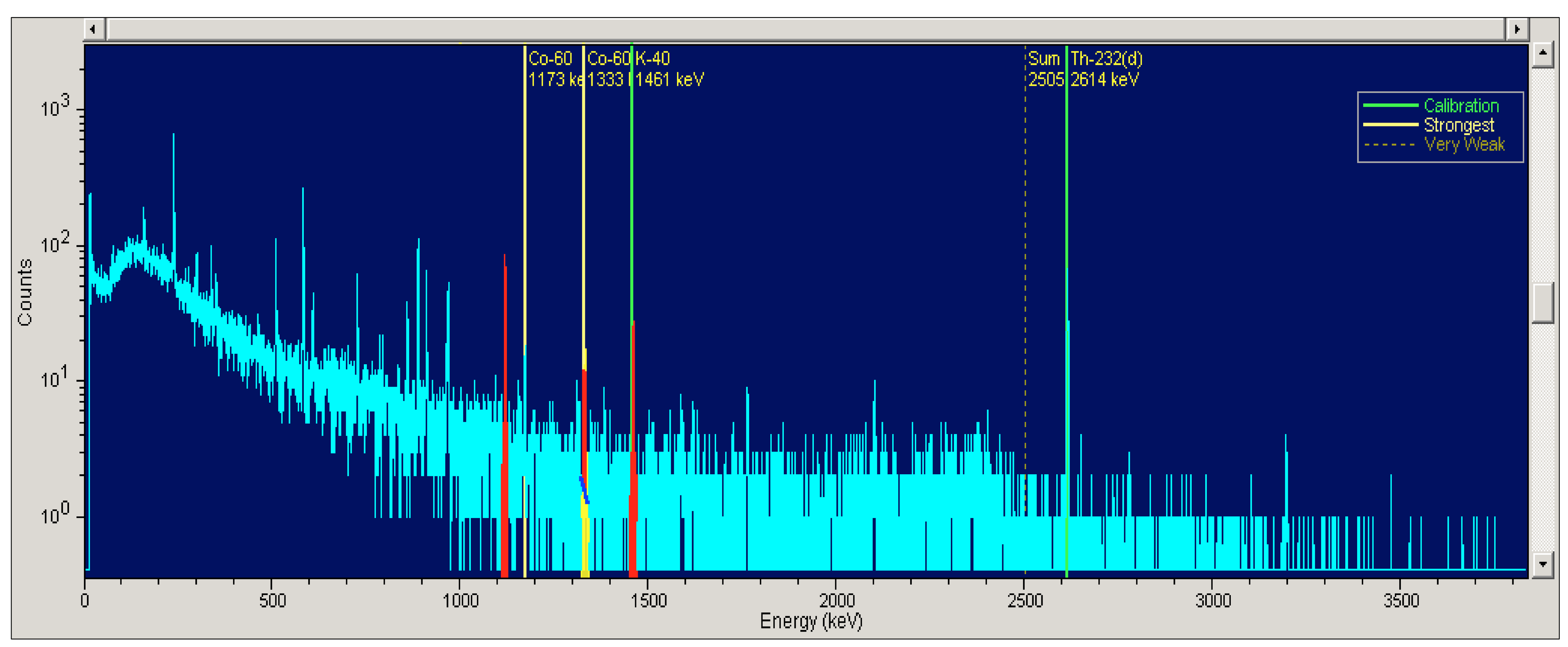
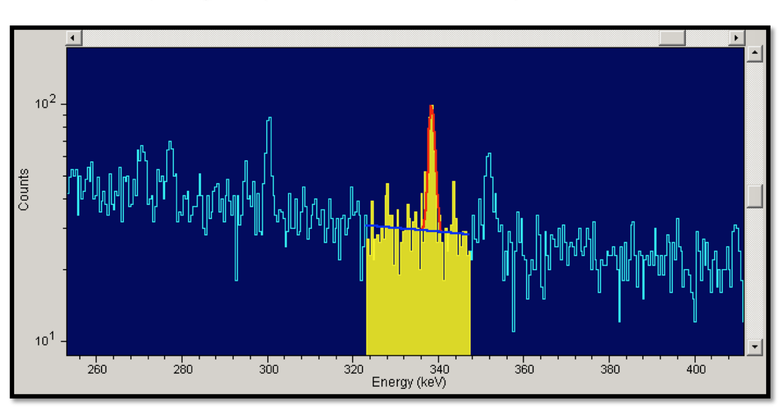


Figure 3 – Typical pulse-height spectrum taken from a BHUC HPGe detector with peaks from Co-60, K-40 and Tl-208 labeled. The red and yellow regions are user-defined regions of interest (ROIs) [3].

Several peaks associated with radionuclides in the decay series of uranium, thorium, and potassium were fitted in order to establish the number of net counts from the sample. This count (and uncertainty) was then combined with the detector efficiency, gamma-ray emission intensity, sample mass and detector live time in order to ascertain the level of contamination in mBq/kg (specific activity).



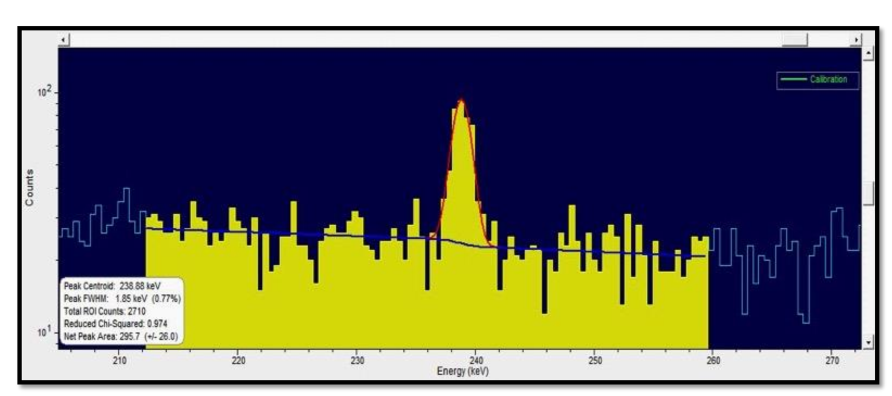


Figure 4 – (above left) Software fit of the 338 keV peak from Actinium-228 which is an indicator of early series Thorium-232. (above right) Fit of the 238 keV photo-peak from Lead-212, which is one of the peaks used to identify late series Uranium-238 [3].

"The Twins" HPGe detector Installation

Twins characteristics [4];

- Large detector mass (4 kg total)
- Well purged (LN boil off) & centralized automated fill system
- Close to 4π counting geometry for small samples
- Very large samples can be accommodated in between and around both detectors

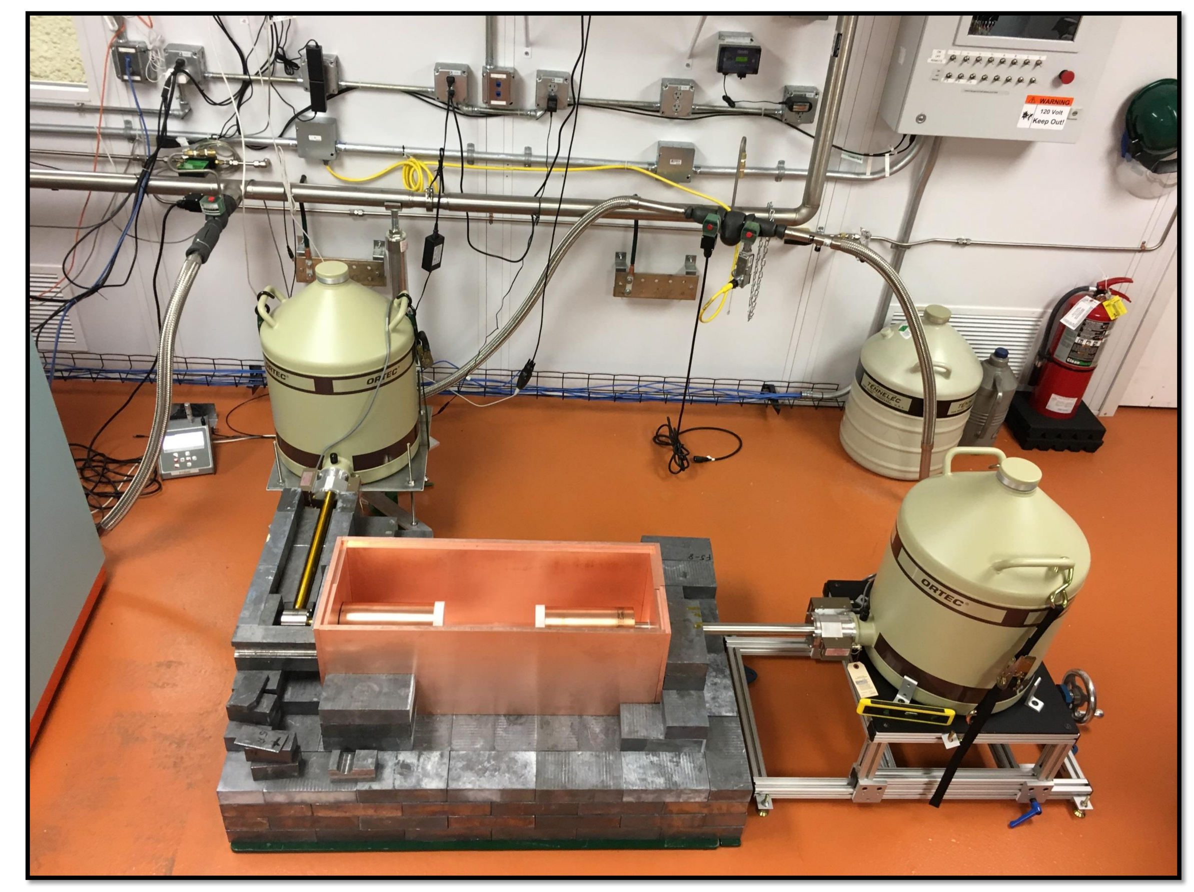


Figure 5 – The Twins as of July 27, 2017.

As of writing this poster, assembly is in the final stages. Figure 5 shows the current set-up with the liquid nitrogen dewars, and the beginning stages of construction of the graded shield with the OFHC copper box and the outer lead. Commencement of the background runs is scheduled for early August and by late August/early September, samples will begin to be assayed for the LZ experiment (and others).

During my time on the REU program I have been lucky enough to be able to help out with all aspects of the Twins installation from the laying of the base plate to the installation of the DAQ.

Conclusion

During my time on the REU program I have learned how important low-background counting is and how critical it is to the success of dark matter and other rare-event search experiments past, present, and future. I have also learned other skills such as detector design, signal processing and spectral analysis, and I have enjoyed every second of the experience.

Acknowledgements & References

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