Data Acquisition Preparation for a Twin HPGe Low Background Counting System at the BHUC

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Gamma-Ray Spectroscopy

Gamma rays occur when radioactive nuclei decay along chains like the Uranium chain shown in Figure 1. In order to find out properties of materials we can look at gamma rays coming from them with detectors like the High-Purity Germanium (HPGe) detector show in Figure 2.

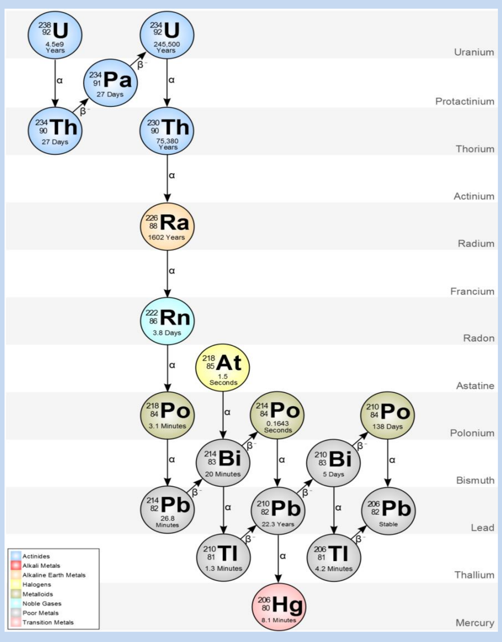

Fig. 1 Uranium Decay Chain

Fig. 2 HPGe gamma ray spectrometer

Why Underground?

Lower backgrounds allow for increased sensitivities for HPGe systems to measure smaller amounts of radioactivity.

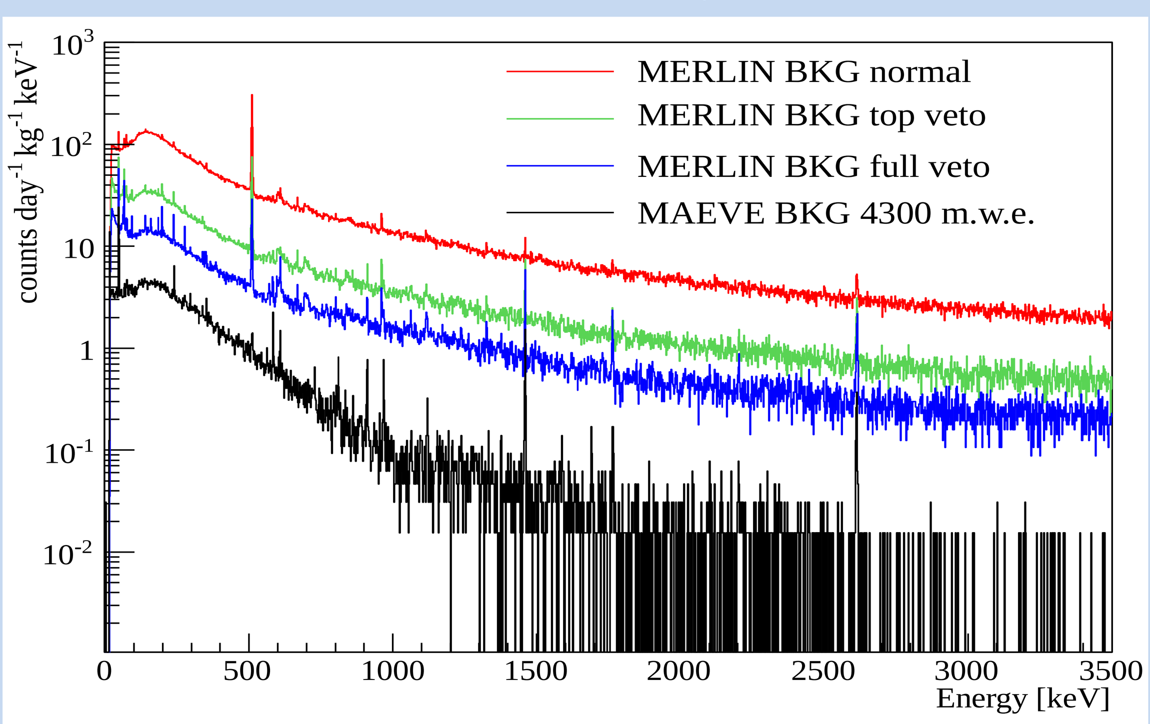

Fig. 3. A comparison of the Berkeley Low Background Facility (BLBF)'s detector signal backgrounds is displayed. Each is taken from an HPGe detector surrounded by a lead shield, an Oxygen-Free High Conductivity copper (OFHC Cu) inner shield, and an inner cavity flushed with boil-off liquid nitrogen to purge the shield of radon. The top spectrum, in ***red****, is* ***a normal background taken at LBNL****. The* ***green*** *and* ***blue*** *spectra are backgrounds from the same detector taken respectively with the* ***single top*** *and* ***full panel*** *arrangement of a muon veto system. Last, in* ***black****, is* ***a background spectrum from the 4850-ft. level of SURF*** *in Lead, SD with a different, but very similar detector which clearly demonstrates the effectiveness of shielding the apparatus from cosmic rays with nearly a mile of rock!*

Need For Low Background

The experiments conducted underground are very sensitive to radiation and the low background counting services provided by the BHUC are absolutely critical to the success of extremely sensitive experiments. All the materials must be screened for their radioactive properties so that the backgrounds generated by the detector itself do not interfere with the extremely weak signals and interactions they expect to see from extremely rare events. Candidate construction materials are screened to determine their trace radioactive content. If the radioactivity of the material is low enough. It can be used in ultra sensitive experiments such as those searching for dark matter, neutrinos, or neutrinoless double beta decay.

The BHUC

The Black Hills State University Underground Campus (BHUC) will eventually hold up to 12 low background detectors for use by many different entities. The facility will act as a screening center, a resource for biologists and chemists as well as an educational center. The BHUC currently holds 4 detectors, which are being used to screen materials for a few projects including the new LUX-ZEPLIN (LZ) project, an experiment searching for evidence of dark matter.

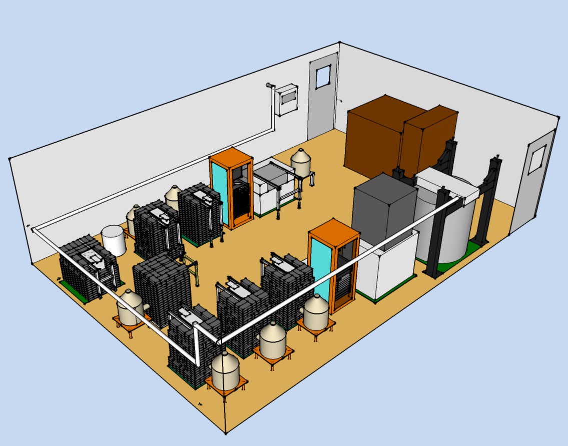

Fig 4. Projected BHUC

Fig 5. The 4 current detectors in the BHUC

Acknowledgements

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Construction of Mordred

Mordred, the fourth detector in the BHUC, was installed in the summer of 2016. It is a 60% n-type HPGe detector co-owned by LBNL and the University of South Dakota. The detector is shielded by 8 inches of Doe Run Pb (naturally lower in Pb-210 concentrations than many other sources of Pb) and 2 inches of OFHC Cu. The copper is more radiopure than the Pb and acts as a graded shield to reduce the effects of x-ray fluorescence from Pb x-rays from interfering with measurements since the copper shields Pb x-rays from the inner cavity while its own characteristic x-rays are lower than the primary regions of interest in the detector's sensitive range.

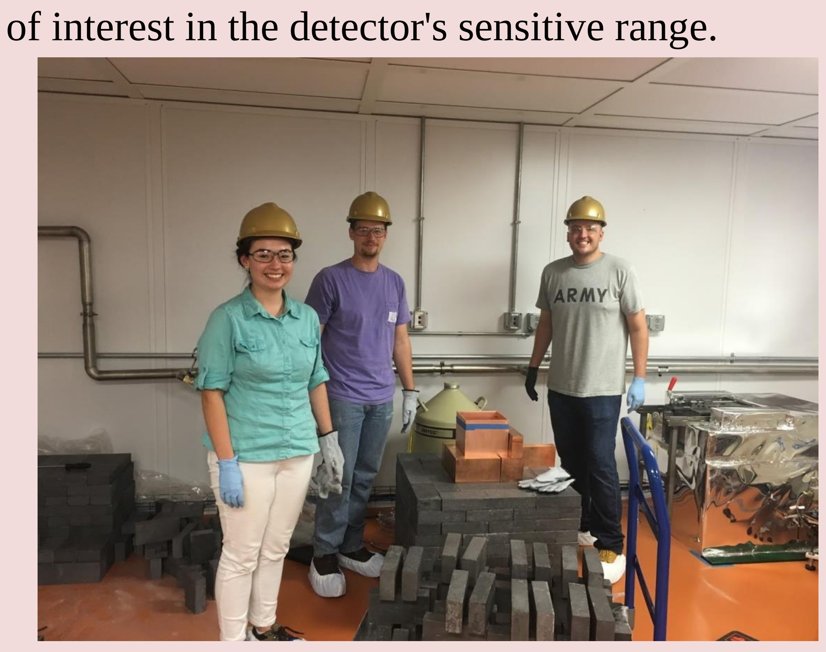

Fig. 6. Construction of Mordred by left, Pauline Dredger, middle, Dana Harvey, right Keenan Thomas

Sample Introduction

This is an example of how a sample is loaded onto a detector for screening. To the left is an image of how it is modeled in Geant4 for Monte Carlo analysis to estimate the detection efficiencies of gamma rays emitted in the sample. The middle shows the actual titanium sample arranged in that same manner. The right shows the sample after being carefully arranged around the crystal.

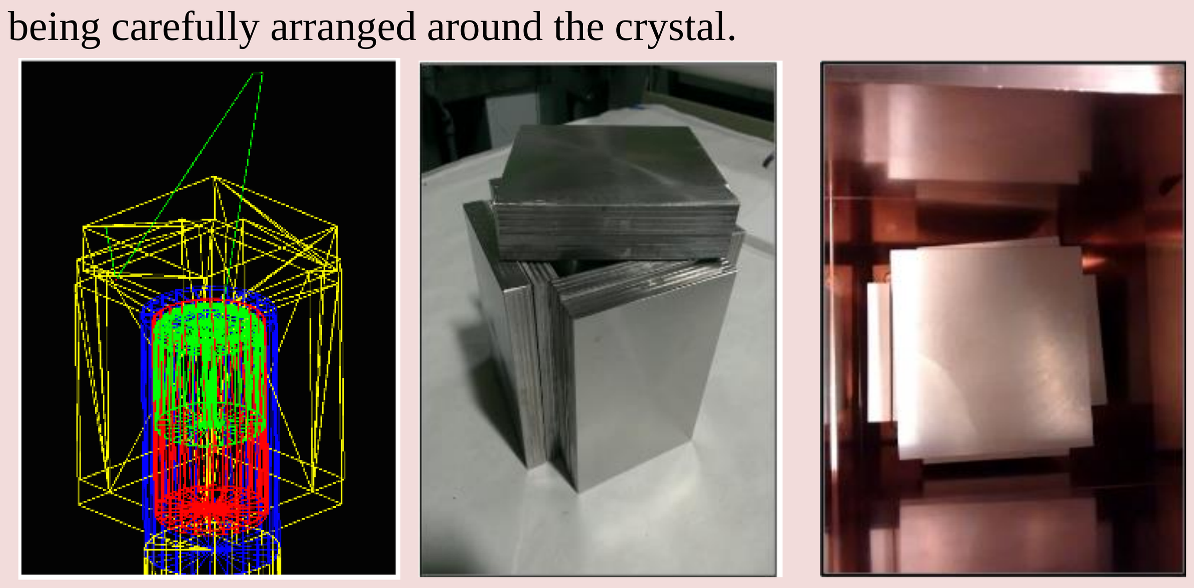

Fig 7. left – Model, middle – Arrangement, right- Arrangement in detector

Data Analysis

The first thing we do is look at the background of the detector that we're using and check for any peaks at energy levels associated with the Uranium and Thorium decay chains. We want to subtract any background that may add to the peaks that we will look at in our sample. Then we look at the net areas of peaks associated with the two decay chains. We note the net counts of the peak and the uncertainty given to us by the program. When we compare the two count rates with reference analysis libraries we can find a fractional contamination of U-238, Th-232, and K-40 that is in the sample. The report made on the sample will usually include a concentration of U-238, Th-232, and K-40 that can be anywhere from the % level, to parts-per-million, parts-per-billion, or parts per trillion (ppm, ppb, ppt). If it is a man made sample the data will be broken up for both the U-238 and Th-232 into a late and early decay chain since production steps can break secular equilibrium. The data is also reported in Bq/kg.

Data Collection

One of the main problems with HPGe detection is that the crystals detect all gamma radiation. When looking at samples you don't necessarily want to see every gamma ray created or partial energy depositions. The main gamma rays you don't want to see are those caused by Compton scattering.

Compton Scattering will show up on the spectrum as fractions of the full energy gamma ray emitted from radioactive decay. When this occurs, it adds counts into the background continuum. Reducing these excess counts in the background can assist with reducing the uncertainty of a peak area measurement, which in turn enhances the sensitivity of the system. In addition, the coincidence/anticoincidence abilities of the DAQ system, Fig. 8, will allow for more sophisticated analysis methods such as utilizing specific decay schemes to target specific energy windows and cascades found in radioactive decays of selected radioisotopes.

Fig. 8 CAEN DAQ box

References

Gilmore, G., & Hemingway, J. D. (1995). *Practical gamma-ray spectroscopy*. Chichester: Wiley.

Thomas, Keenan. Berkeley Low Background Facility

LUX Gravel

The gravel sample (Figure 9) has quite a bit of inherent radiation. Most samples are not nearly as high in radiation as the gravel is. The run time for this sample was 900 minutes and you can clearly decipher peaks from the background

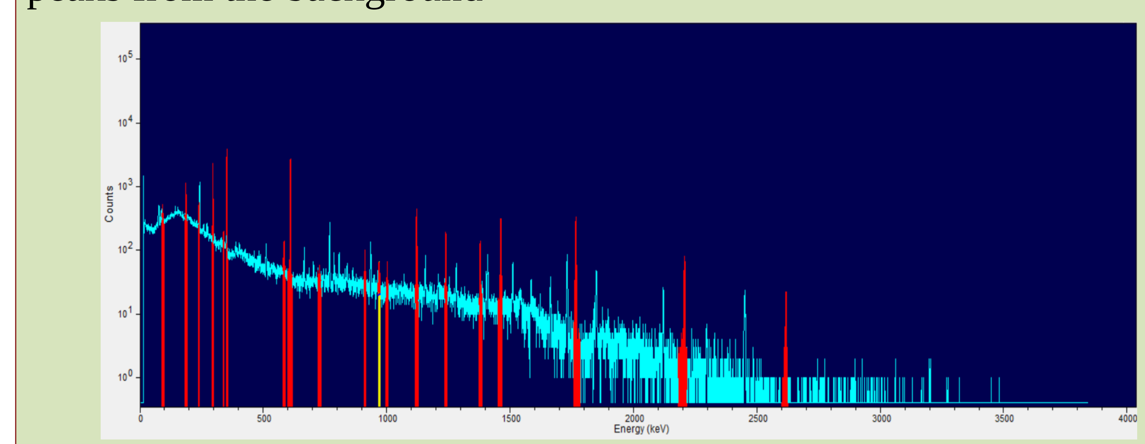

Fig. 9. A spectrum taken of gravel that was below the tank of the LUX experiment.

Titanium

To detect amounts of this magnitude the detectors must run for long live times and carefully manage backgrounds within the detector setup. In the case of the titanium, fig. 10, the runtime was 18 days and as you can see in the spectrum is still very hard to find the peaks not resulting from any background (in this case, internal contamination within the detector and shielding itself). You can notice the difference in the use of ppt instead of ppm a factor of 1 million smaller--- showing the extreme sensitivity of these instruments.

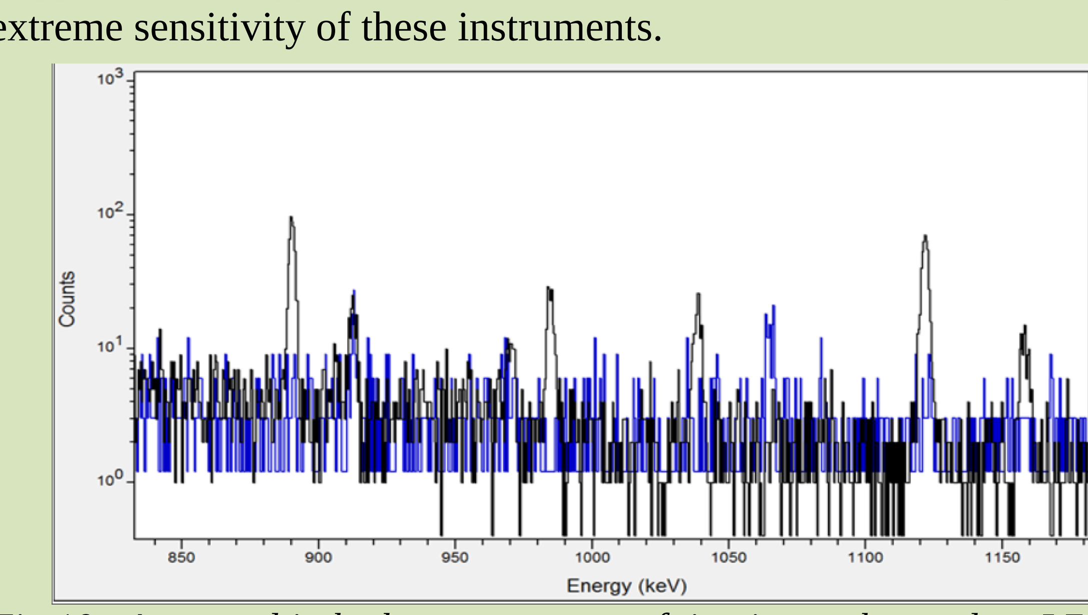

Fig 10. A zoomed in look at a spectrum of titanium to be used on LZ along with a background.

Analysis

Table 1. is an example of how data would be reported. It also shows the difference in sensitivity the HPGe crystals can detect. The concentrations of radioactive isotopes in titanium is reported in ppt instead of ppm, a factor of 1 million smaller than the gravel sample.

Sample Analysis	Concentration		Activity per Mass	
LUX Gravel U-238	1.65(2)	ppm	20.3(2)	Bq/kg
LZ Titanium U238 e	<130	ppt	<1.6	mBq/kg
LZ Titanium U238 l	<7	ppt	<0.09	mBq/kg
LUX Gravel Th-232	0.30(2)	ppm	1.2(1)	Bq/kg
LZ Titanium Th-232 e	69(7)	ppt	0.28(3)	mBq/kg
LZ Titanium Th-232 l	55(5)	ppt	0.23(2)	mBq/kg
LUX Gravel K-40	0.066(2)	%mass	20.4(5)	Bq/kg
LZ Titanium K-40	<17	ppb	<0.54	mBq/kg

The Twins: Morvyyd and Ywain

One of the next detectors to enter the BHUC will build upon the already great sensitivities found there. It will be more sensitive because it will hold 2 germanium crystals in one enclosure. The idea is that with a little coding the data from both crystals can be used to eliminate some of the background noise due to Compton Scattering or target coincident signals from specific decays. If data from both detectors is looked at and events that occur simultaneously are found, the code can selectively identify those events since they were likely caused by Compton Scattering. This data can then be eliminated from the spectrum giving a modified spectrum that has reduced background counts and therefore an increased sensitivity. The other advantage to having two crystals is simply a greater detection of gamma rays being emitted by the sample-- double the crystals, double the efficiency. The crystals will be situated so that the sample goes between them see Figure 11. One detector can move horizontally on one axis, which will allow for reconfiguring the detectors for small or large samples for optimal detection efficiency on a sample per sample basis. The detector is being developed by LBNL, BHSU, and UCSB.

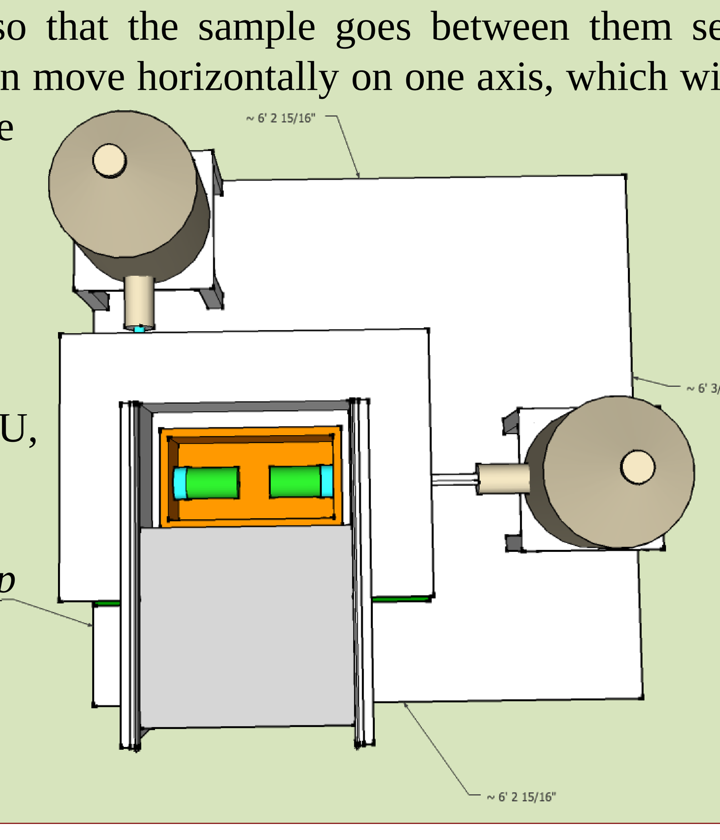

Fig 11. The proposed set up for the twin detectors Morvyyd and Ywain