High Purity Germanium Gamma-Ray Spectrometry for Rare Event Searches

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Low Background Counting at SURF

Rare event searches at the Sanford Underground Research Facility (SURF) [1], see Fig.1, require ultra radiopure materials. High Purity Germanium (HPGe) gamma ray spectroscopy systems, located on the 4850' level of in the Davis Campus at SURF (Figs. 2-4), screen materials for these searches to aid in the selection of materials as well as to inform background analyses [2]. This poster will describe the construction of one of these HPGe systems as well as the analysis of ultra-low background samples.

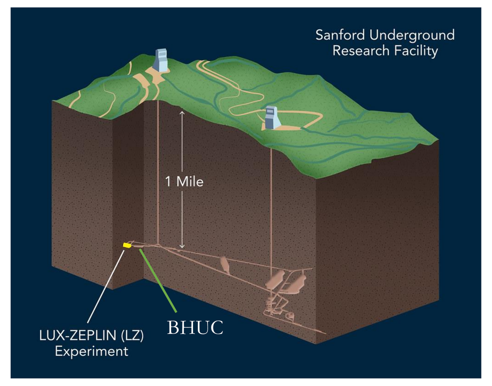

Figure 1: SURF [3]

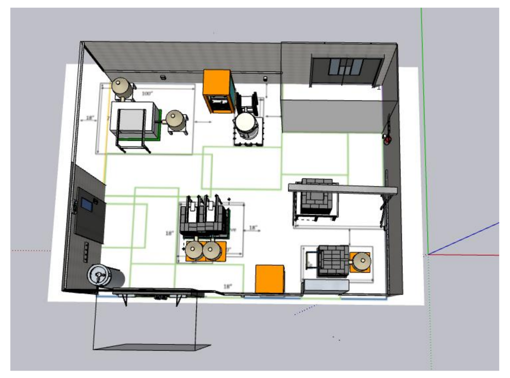
Figure 2: BHUC Layout

The Black Hills State University Underground Campus (BHUC) is a low background counting cleanroom on the 4850' level of the SURF [2]. Figure 2 shows the layout of the BHUC. The four operational detectors located in the BHUC currently are Mordred (Fig. 3), Maeve (Fig. 4), Morgan (Fig. 4), and the Twins. An additional detector, GeIV, is still under construction.


Figure 3: Mordred

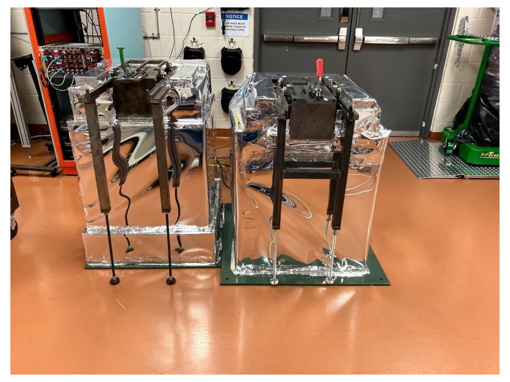
Figure 4: Maeve (left) and Morgan (right)

Building a Low Background Counting System

The BHUC's low background counting (LBC) systems contain high purity germanium crystals [4], see Fig. 5a. To ensure that only the radiation from the samples being counted are detected by the crystal, shields are constructed surrounding the inner detector. The bulk of the shielding material is lead, to block out gamma-rays from the room (Fig. 5b). There is also an inner layer of copper plates and bricks to block out x-rays (Fig 5c). A thin sheet of Mylar surrounds the lead stack and acts as a bubble, working with the nitrogen purge system to keep radon out.

After the initial installation of Mordred at the newBHUC in the Davis Campus in early 2021, it became apparent that its shield had gaps that allowed radon to leak in, so it needed to be rebuilt. The shield was removed and carefully documented and assessed. Gaps were filled in and the copper plates were sealed as best as possible while it was being rebuilt.

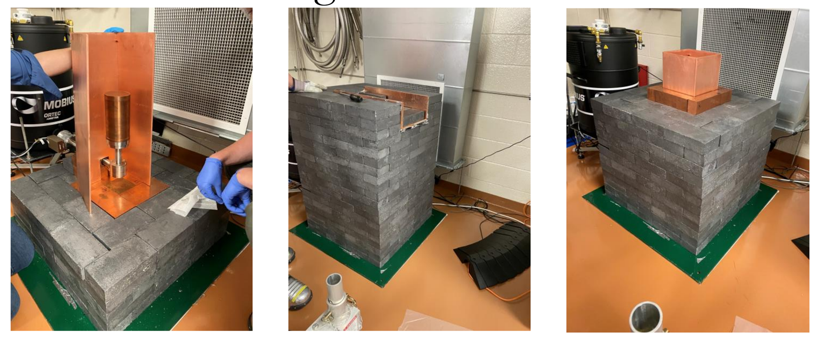
Figure 5: Rebuilding Mordred. a) Germanium Crystal, b) Lead Shield, C) Copper Housing.

Sample Prep and Detector Maintenance

The BHUC is a class 100 cleanroom. Full cleanroom garb (Fig. 6) is donned to maintain cleanliness. To achieve the best sensitivity possible, samples are carefully cleaned before being taken into the room and loaded into the detectors (Fig. 7a,7b).


Figure 6: Me next to Maeve and Morgan


Figure 7: Sample of LZ Screws. a) Top View, b) Zoomed Out View

A 180L dewar (Fig. 8) inside the cleanroom supplies all the detectors with nitrogen gas, which is controlled with flow meters (Fig. 9). This purges the radon in the air from inside the detectors. Each detector also has a smaller dewar, as seen to the left of Mordred in Fig. 3, that uses liquid nitrogen to keep them cool.


Figure 8: 180L Dewar

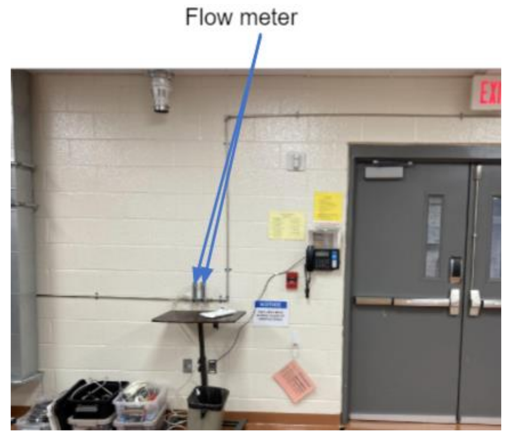

Figure 9: Flow Meters

Gamma-Ray Spectra

Naturally Occurring Radioactive Materials are of interest to rare event searches. Figures 10a and 10b show the decay chains of ^{232}Th and ^{238}U. Each nuclei in these chains emit a unique set of gamma-rays of particular energies when they decay, the strongest of which are listed in Table 1.

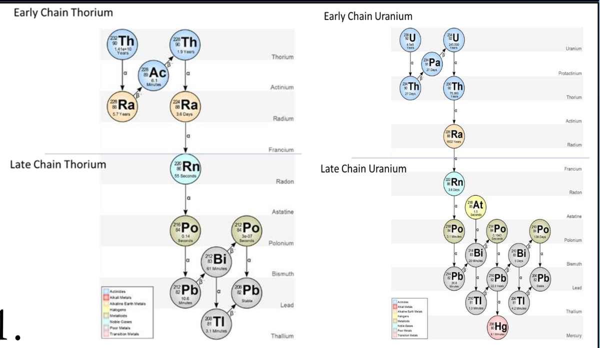

Figure 10: a) Thorium Chain, b) Uranium Chain [5]

Data collection in an LBC consists of counting gamma-rays emitted by a source and collecting their energies into bins. Figure 11 shows a graph with data from the Maeve detector, with the peaks representing counts of gamma-rays from different decays. The concentration of an isotope in a sample is found with this equation:

Table 1: Gamma Energies for NORMs

	Chain and Energy	Decay
U_early	U(e) 63keV	Th-234 --> Pa-234
	U(e) 93keV	Th-234 --> Pa-234
	U(e) 1001keV	Pa-234 --> U-234
U_late	U(l) 295keV	Pb-214 --> Bi-214
	U(l) 352keV	Pb-214 --> Bi-214
	U(l) 609keV	Bi-214 --> Po-214
	U(l) 1120keV	Bi-214 --> Po-214
	U(l) 1764keV	Bi-214 --> Po-214
	U(l) 2204keV	Bi-214 --> Po-214
Th_early	Th(e) 338keV	Ac-228 --> Th-228
	Th(e) 911keV	Ac-228 --> Th-228
	Th(e) 968keV	Ac-228 --> Th-228
Th_late	Th(l) 238keV	Pb-212 --> Po-212
	Th(l) 583keV	Tl-208 --> Pb-208
	Th(l) 727keV	Bi-212 --> Po-212
	Th(l) 860keV	Tl-208 --> Pb-208
	Th(l) 2614keV	Tl-208 --> Pb-208
K-40	K 1460keV	

$$C = \frac{N_{peak}}{\varepsilon_{peak} M_{sample} P_{\gamma} LT}$$

where N_{peak} is the background-adjusted net peak area, ε_{peak} is the full energy peak efficiency, M_{sample} is the mass of the sample in g, P_{γ} is the emission probability, and LT is the livetime of the sample run in minutes [5].

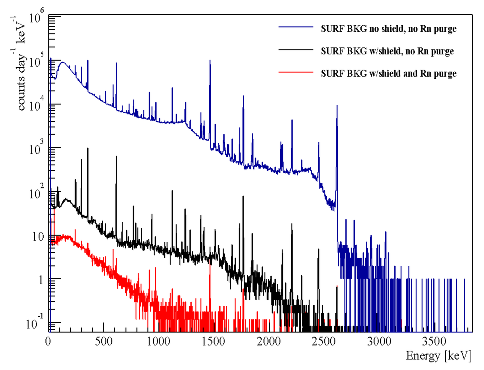

Figure 11: Background Spectra

Analysis

The detectors at the BHUC have been completely subscribed in the past several years counting samples for the LUX-ZEPLIN (LZ) detector. This poster will describe one such sample for LZ, which is a portion of Blackout Curtain for the Outer Detector, see Fig. 13.

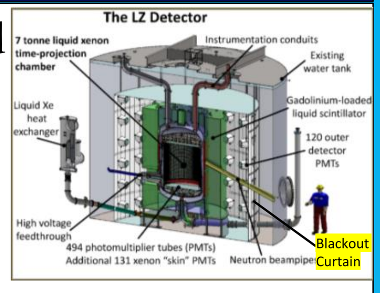

Figure 12: LZ [6]

This plastic material sat underground for some time, so it absorbed radon. Fig. 13 shows the total gamma-ray count per second of the sample before and after the radon data was edited. First, the data from the time the sample was put in the detector to the time the radon decay had faded to background levels was taken out. Then the spikes from the interruption of the purge due to the dewar swaps were taken out. The reason for the removal of this data is so the radioactive isotopes in the material itself could be counted, not remnants of radon from the mine air. Figure 14 shows the final data in the form of counts per energy.

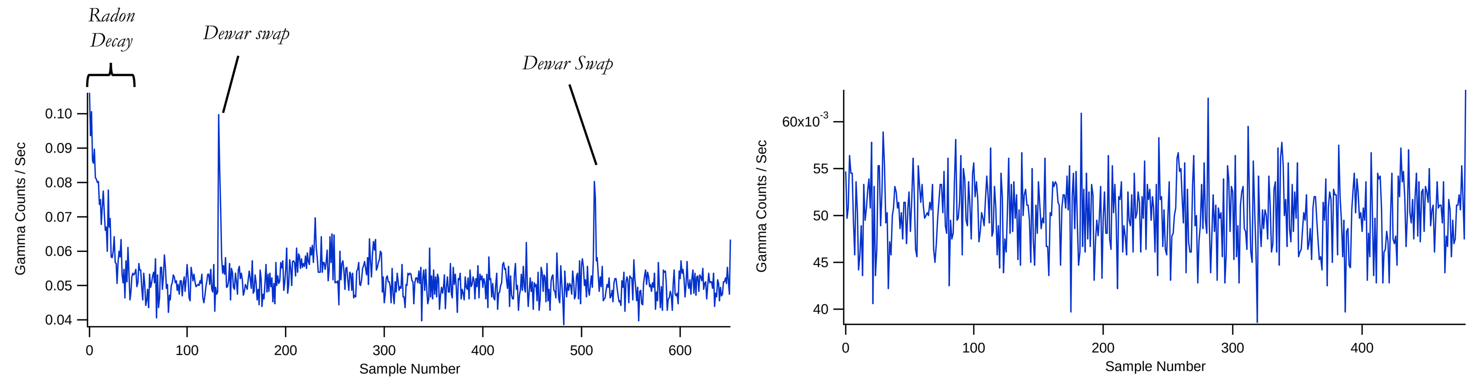

Figure 13: Sample of Blackout Curtain for the Detector. a) Before Radon Taken Out, b) After Radon Taken Out

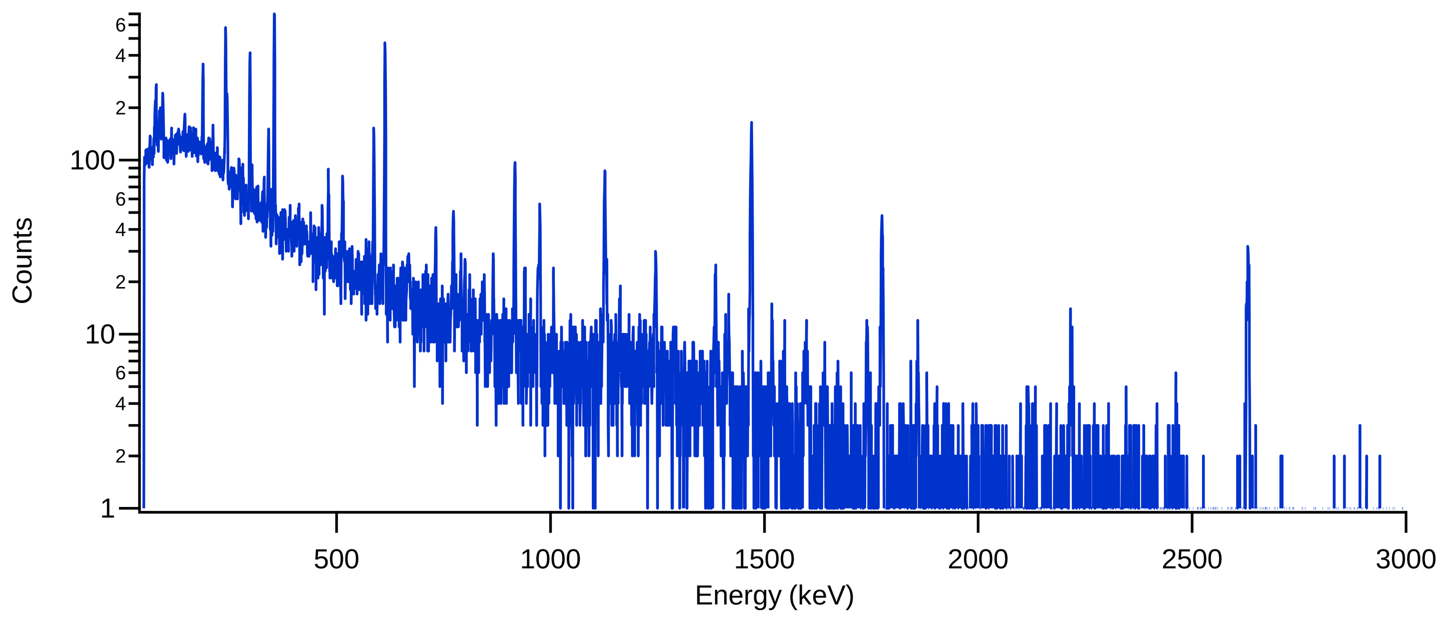

Figure 14: Finished Spectra

References

[1] Heise, J. 2015 J. Phys.: Conf. Ser. 606 012015
[2] Mount, B.J., et al. "Black Hills State University Underground Campus." *Applied Radiation and Isotopes*, Pergamon, 16 Feb. 2017, www.sciencedirect.com/science/article/pii/S0969804316305449?casa_token=ioIyw2o2LSgAAAAA%3A8X3B8ugR5S3cXshsMDBbb_FaOk859ptGlBqCa8n9bae-zsZ5Om_zS3-WG0nFZpSZPz9YZle2jCY.
[3] Laboratory, SLAC National Accelerator. "LZ at the Sanford Underground Research Facility." Flickr, Yahoo!, 24 Oct. 2018, www.flickr.com/photos/slaclab/31667820918.
[4] ORTEC. ORTEC, 2021, ortec.com/en-us.
[5] Gilmore, G.R.. Practical Gamma-Ray Spectrometry. John Wiley & Sons, Ltd, 2008.
[6] Akerib, D.S. "Projected Sensitivity of the LUX-ZEPLIN Experiment to the 0νββ Decay of 136Xe." Arxiv, 27 Apr. 2020, arxiv.org/pdf/1912.04248.pdf.

Acknowledgments

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