Assay of ultra-low background materials for rare event searches

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UNDERGROUND SCIENCE

The Sanford Underground Research Facility(SURF), see figure 1, is home to the LUX-ZEPLIN(LZ) dark matter experiment, see figure 2. Dark matter makes up approximately 85% of the mass of the universe but has not been detected directly. Ionizing radiation causes background in the LZ detector, which can overwhelm a possible dark matter event. Rare event search detectors are placed deep underground, using the surrounding rock to shield radiation from cosmic rays on the surface. However, the LZ detector itself contains small amounts of radioactive elements, which are also background sources. To minimize these background sources, the Black Hills State University Underground Campus (BHUC), see also figure 1, is tasked with screening materials used in the construction of LZ and other rare event searches.

Figure 1: SURF

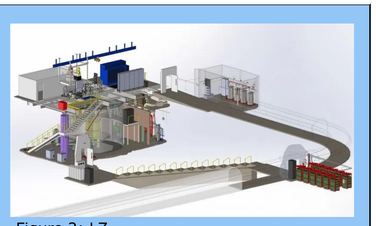
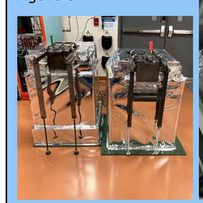


Figure 2: LZ

HIGH-PURITY GERMANIUM DETECTORS

The BHUC is home to four High-Purity Germanium(HPGe) detectors which are used to assay ultra-low background samples, see figures 3a-c. HPGe detectors must be encased in lead to block any background radiation found in the immediate area from entering the chamber to ensure only the sample's radiation is counted. The detectors are wrapped and sealed in Mylar and purged with liquid nitrogen boil-off to keep radioactive radon-containing air from entering the sample chamber.

Figure 3



a. Maeve and Morgan

b. The Twins

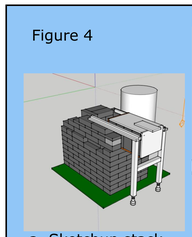
c. Mordred

d. SOLO HPGe crystal

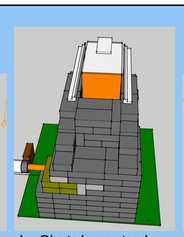
CONSTRUCTING SOLO

Because of construction, the BHUC has been moved from its previous location in the Ross Campus to the machine shop adjacent to the Majorana experiment in the Davis Campus. Due to lack of space in the new location, the SOLO detector, figure 3d, (once located at the Ross Campus) has been moved above-ground to the Black Hills State University campus to pre-screen materials. This other stack, SOLO, needed to be designed in such a way that the inner chamber, figure 4d, and Germanium crystal were protected by at least 4" of lead. A design of the stack pattern for SOLO was created using Sketchup, see figure 4 a-c. The lead castle, figures 4e-g, was built over two days. Upon construction, a few errors were found in the design, but the problems were resolved quickly. We then tested the drawer before fastening it and wrapping the lead castle in Mylar, figure 4h.

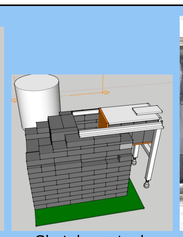
Figure 4



a. Sketchup stack



b. Sketchup stack



c. Sketchup stack

d. Sample chamber

e. Lead castle

f. Lead castle

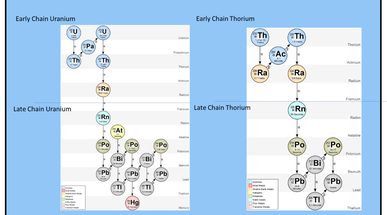
g. Lead castle

h. Completed SOLO

BACKGROUND

When assaying ultra-low radiation, certain Naturally Occurring Radioactive Materials(NORMs) are found in nearly everything. Our major contributors include 238U, 235U, and 232Th, and their daughters, figure 5. It is nearly impossible to remove these impurities, instead, they are measured and counted using Gamma-ray Spectrometry.

Figure 5

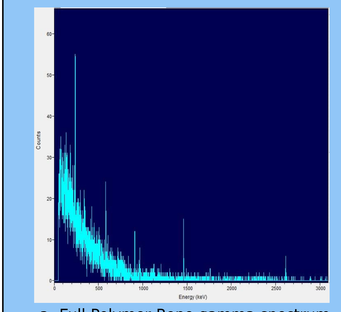


238U, 232Th decay chain

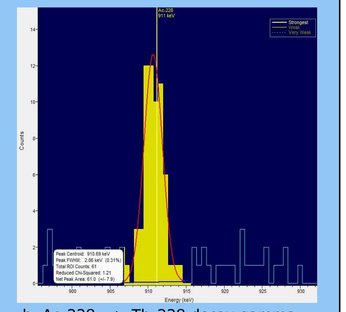
ANALYSIS

As a nuclide decays it releases gamma-rays, each of these gamma-rays have a unique energy signature. Using the program Peakeasy we were able to identify counts of specific gamma rays(peaks), figure 6a, by separating each gamma by the amount of energy(keV) it transfers to the detector.

Figure 6



a. Full Polymer Rope gamma spectrum



b. Ac-228 --> Th-228 decay gamma

The total energy of the peak is given by the area beneath the curve, figure 6b, which is used in the following equation to find the nuclides concentration C:

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

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.[4] The result of these assays will be used to establish background radiation levels in the rare event detectors, against which the collected data can be compared.

REFERENCES

Figure 1
https://www.e-architect.com/wp-content/uploads/2018/01/renovated-cavern-at-sanford-underground-research-facility-l070218.jpg#main
Figure 2 https://www.sdsmt.edu/uploadedImages/Content/Academics/Departments/Physics/_Images/nuclear.jpg
Figure 3 Maeve Morgan and Mordred photos by Jordyn Bass
[4] Gilmore, G.R.. Practical Gamma-Ray Spectrometry. John Wiley & Sons, Ltd, 2008

ACKNOWLEDGEMENTS

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