Calibration Studies of HPGe Detectors with Differing Source Geometries

Haylee Busch[1], Archer Sagaskie[2], Zachariah Thomas[3], Brianna Mount[4]

Kansas Wesleyan University[1], Grand Valley State University[2], University of Michigan- Dearborn[3], Black Hills State University[4]

Introduction

- Dark matter makes up about 27% of the mass-energy of the universe and differs from regular matter by not interacting with the electromagnetic force [1].
- Scientists infer the presence of dark matter through its gravitational effects on visible matter and its influence on the overall structure of the universe.
- The LUX-ZEPLIN (LZ) experiment, located at the Sanford Underground Research Facility (SURF), uses a highly sensitive detector to detect rare interactions between dark matter particles and regular matter [2].
- Specifically, when a dark matter particle strikes a xenon nucleus in the detector, it produces unique light emissions.
- The LZ detector's sensitivity enables the detection of these elusive particles but requires careful monitoring to distinguish them from background radiation.
- LZ implements rigorous measures to minimize this background radiation from natural sources like uranium, thorium, and potassium, which could overwhelm signals from the desired dark matter particles known as WIMPs (Weakly Interacting Massive Particles) [2].
- Low background counting refers to the practice of minimizing interference from environmental or natural sources of radiation when conducting sensitive experiments.
- It aims to reduce or eliminate signals from background radiation that could overwhelm or mimic signals from the phenomena being studied, such as dark matter interactions.
- Techniques include situating experiments deep underground or in shielded environments to block cosmic rays and radiation from radioactive elements in the Earth's crust.
- Low background counting is crucial for detecting rare events or particles, such as neutrinos or dark matter particles, which may only interact very weakly with ordinary matter

Figure 1 BHSU Underground Campus, 4850L SURF

Figure 2 Myself putting TML sample in Maeve

Gamma Ray Spectroscopy

- As parent isotopes decay into daughter isotopes, gamma rays emit characteristic gamma rays with specific energies. By analyzing gamma ray energies and intensities using the equation below [3], we can identify radioactive isotopes in a sample and determine their concentrations:

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

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 grams, P_{γ} is the emission probability, and LT is the lifetime of the sample run in minutes [3].

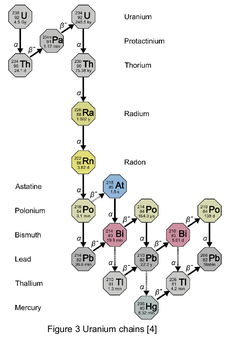

Figure 3 Uranium chains [4]

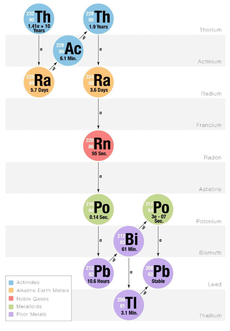

Figure 4 Thorium chains [5]

Radioactive elements such as uranium, thorium, and potassium exist naturally on Earth and can be detected using high-purity germanium detectors. Throughout their decay chains, these elements emit characteristic gamma rays at specific energies during each intermediate beta-decay step, see Figs 3,4. For instance, in Fig. 4, thorium undergoes a series of decay steps culminating in a stable lead isotope. Similarly, uranium and potassium follow their own distinct decay pathways that lead to the formation of stable isotopes.

Process Of 3D Printing

The Prusa Slicer software [6] enables the generation of G-code tailored to the specific design intended for 3D printing. In this case, a Photomultiplier Tube (PMT) model was prepared for initial test prints. Upon successful completion of these test prints, the process was advanced to the development of a series of boxes featuring a sliding lid mechanism Figs 7,8,9,10.

The 3D-printed containers are introduced into the detector by personnel that is following cleanliness protocols, as illustrated in Fig 11, which depicts the insertion of these containers by the author. The arrangement of the containers is such that the crystal is fully encased, as demonstrated in Fig 12.

Figure 5 3D Prusa Printer [2]

Figure 6 PLA Filament

Picture Of The Process

Figure 7 PMT on 3D scanner

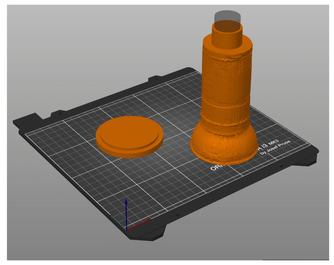

Figure 8 G-code of PMT

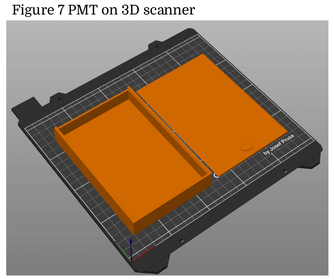

Figure 9G-code of TML Box

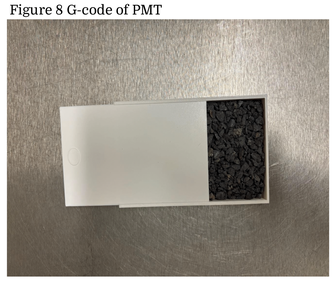

Figure 10 TML in 3D printed box

Figure 11 Myself putting TML sample in Maeve

Figure 12 Box formation in Maeve

Process Of Analyzing Data

- Data taken with the detectors at the BHUC (Fig 1,2,11,12) was analyzed using the Peakeasy software [5]. Spectra files of one hour each are loaded and appended in the software for the entire run. A graph of the counts per each energy is then generated, see Fig 13.

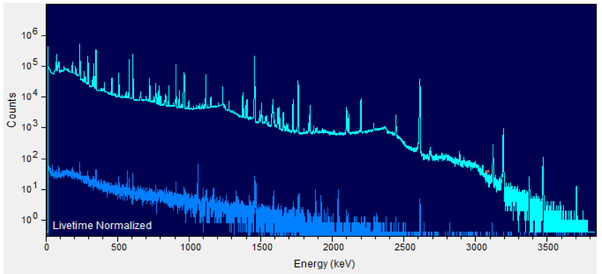

Figure 13 Spectra of TML data in 3D printed boxes

Table 1. Concentration of early and late chain U, Th using calibration from the Marinelli Beaker and the 3D-printed boxes.

	ppb Ti Beaker	ppb Box
U(e)	< 0.15 (0.3)	<0.19 (2.0)
U(l)	0.60 (0.1)	0.93 (0.1)
Th(e)	<0.11 (0.3)	<.16 (0.6)
Th(l)	<0.06 (0.01)	<0.09 (0.02)

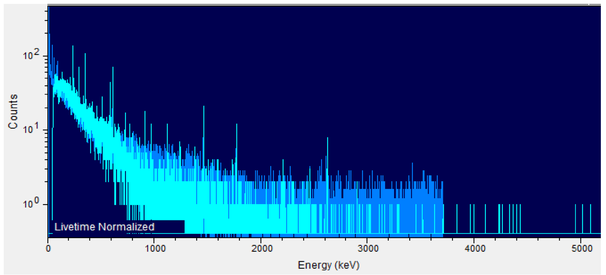

Figure 14 Spectra of PLA filament

Table 2. Concentration limits for PLA filament.

	ppb
U(e)	1.0 (2.0)
U(l)	0.1 (0.04)
Th(e)	0.4 (0.5)
Th(l)	0.4 (0.5)
K-40 ppm	0.2 (0.3)

Calibrations

To calculate the efficiency of a given detector with a given sample geometry, we use a ratio method [6] with a known calibration source, Table Mountain Latite (TML). Calibration spectra are recorded with certain sample geometries, such as the TML gravel within differing sizes of Marinelli beakers, petri dishes, etc. and these are then used to analyze the sample data. However, it is not a perfect calibration tool as the BHUC currently uses, for example, a Marinelli beaker geometry to approximate most samples' configuration around the HPGe crystals. 3-D printing offers an interesting avenue to explore as a 3-D model can be generated, which can then be printed as a container for TML in many different kinds of geometries. To test this, a sample of titanium slabs was selected to replicate. A series of 3D printed boxes made of PLA (Polylactic Acid) filament were printed to house TML.

Results

The calibration data obtained from a Marinelli beaker filled with TML and data obtained from a custom, 3-D-printed replica of the Ti plates filled with TML were separately used to evaluate a sample of titanium slabs.

A PLA filament sample was also analyzed for its U,Th,K content, see Fig 14 and Table 2.

The calibration process involving the Marinelli Beaker and the titanium box constructed from 3D-printed material demonstrates a high degree of concordance, as evidenced by Fig 17, which shows a close alignment between the two datasets.

Only limits were determined for the sample of PLA, so this material is a good candidate for 3D printing of future calibration geometries.

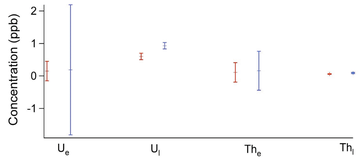

Figure 15. Comparison of Concentration Data using calibration with a beaker (red) and the 3D printed plates (blue).

Future Work

- PVA (Polyvinyl Acid) is another material used as a filament in 3D printing. PVA is known for being more durable and is water soluble. This material is currently being investigated to determine its radionuclide content.
- Now that an "easy" geometry has been tested, other non-standard geometries (like the PMT, Fig 7) would be beneficial to test

References

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Allen.Morris@bhsu.edu