Automation of a Liquid Nitrogen Cooling System for a High Purity Germanium Detector and Radioanalysis of Sharpie Ink

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Dark Matter and the LZ Detector

It is estimated that approximately 85% of the universe's matter exists in the form of 'dark matter' [1]. One of the leading candidates for the particles comprising this dark matter are Weakly Interacting Massive Particles, or WIMPs. By searching for these WIMPs, LZ attempts to either confirm or reject WIMPs as a possible candidate for dark matter [2].

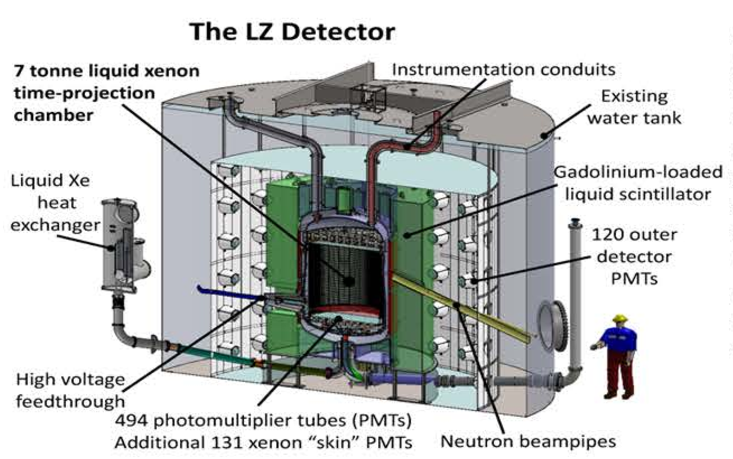

FIG. 1. A diagram showing the internal parts of the LUX-ZEPLIN dark matter detector. Its position 4850ft underground prevents cosmic rays from oversaturating the detector with signals, drowning out the potential signals from WIMPs interacting with the detector. A low background is necessary for the same purpose, and this low background was obtained with the help of the low background counters present at the BHUC. [3]

WIMPs would be detected by the by-products of their interactions with the liquid xenon in the time-projection chamber of the detector, shown in Fig. 1. However, cosmic rays could produce similar signals that would completely drown out the rare interaction researchers are looking for. To avoid this issue, the LZ detector was built under nearly a mile of rock at the Sanford Underground Research Facility (SURF). This provides LZ with a 4300m water equivalent of shielding from cosmic rays and thus significantly lowering the background. [4]

Low Background Counting at the BHUC

The materials used to build the LZ detector had their radionuclides counted in the low background counting facility of the Black Hills Underground Campus (BHUC) [5]. This facility uses several High-Purity Germanium (HPGe) detectors to perform gamma-ray spectroscopy, a process by which the radioactive content of a sample can be precisely determined.

- The unique energies of the gamma rays emitted by a sample can be used to determine what the parent and daughter isotopes are, and this can be traced back to the beginning of a 'decay chain', often beginning with U or Th, as shown in Fig. 2.
- This was necessary because radiation from the detector itself or nearby surroundings could easily overwhelm the relatively faint signals from WIMPs interacting with the detector.
- An aboveground detector known as SOLO (pictured in Fig. 2) is used to prescreen for materials that are high in radiation so that they will not be counted at the low background facility, which generally takes two weeks per sample.

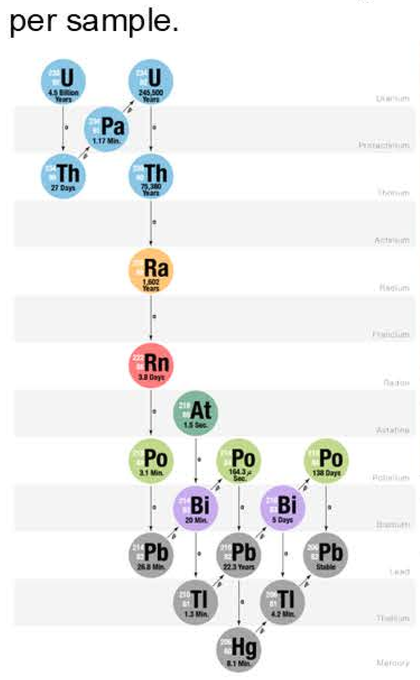

FIG. 2. The SOLO detector and LN_2 dewar (above) and U-238 decay scheme (left) [6]. The SOLO detector is at Black Hills State University to be used as a prescreening detector for the BHUC. The U-238 decay chain shows how the end products of decays can be traced back to their parent isotopes.

- HPGe crystals are kept at liquid nitrogen temperatures to minimize electronic noise, improving their detector resolution.
- Rather than manually filling a small tank with LN_2, an automated fill system would be much more efficient, allowing researchers to save time. It would also help avoid the system running out of LN_2 by sending an alert when it gets low.

Coding the Flow of LN_2

- LabVIEW was chosen to be the coding environment for creating an automatic LN_2 filling system for SOLO [7].
- An AMI 286 was used to detect the liquid level in SOLO's dewar as a percentage [8].
- An SR flip-flop was used to output a signal to open a solenoid valve when the liquid dropped under a variable lower limit .
- An Arlyn scale monitors the weight of the 180L tank used as the source for SOLO's dewar, and this weight would be sent via email through LabVIEW [9]. The code is shown in Fig. 3.

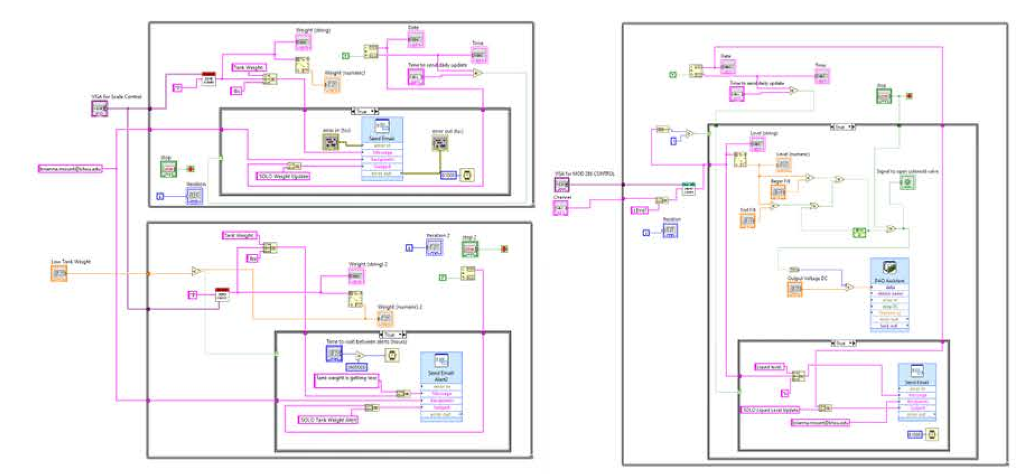

FIG. 3. The block diagrams for the LabVIEW program to read the weight from the Arlyn Scale and send daily updates via email (left) and read the liquid level and control the solenoid valve (right). The program uses an SR flip flop to output a 5V signal from a DAQ when the liquid level drops below a lower limit and a 0V signal when it rises above an upper limit.

Opening Solenoid Valves with LabVIEW

The LabVIEW code for SOLO outputs an on/off signal for opening the solenoid valve, sent through an NI DAQ [10]. A 6036E was originally chosen for this, though this was swapped for a USB-6009 (pictured in Fig. 4) upon finding that the 6036E was made obsolete by NI.

FIG. 4. The NI USB-6009 DAQ (left) and ASCO Red Hat 2 solenoid valve (right). The DAQ was used to output an on/off (0V or 5V) signal to the valve, though a COM-13015 solid state relay was wired between the two in order to swap the DC signal to AC. Another valve of the same kind was wired into the system to be used for precooling, but the code for this was not completed. Adding the precooling system could be the next step in further work on the project

- The valve chosen, the ASCO Red Hat 2 pictured in Fig. 4, is an AC valve, so a relay is necessary to convert the DC on/off into an AC on/off signal [11].
- A COM-13015 solid state relay was chosen for this purpose, and an adjustable circuit breaker was used in case of any shorts. Figure 5 shows the wiring of the circuit.

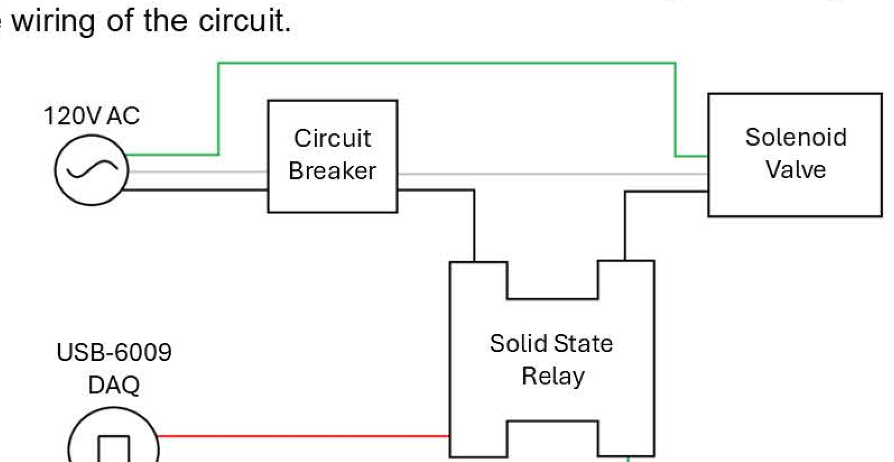

FIG. 5. A wiring diagram representing the circuit used to automate the filling of SOLO's LN_2 dewar. The green lines represent ground, black represents hot AC, gray represents neutral AC, and red represents positive DC. The DAQ changes its output based on the LabVIEW code, and the AC source is a wall socket.

- SOLO's dewar was unfortunately found to have a faulty vacuum, though the code was tested with a separate dewar and was found to work nonetheless and should function just as well for a replacement dewar.

Sharpie Ink as a Confounding Variable

Some of the samples counted at the BHUC had been written on with sharpie as shown in Fig. 6, so the ink of sharpie markers was counted to determine if it was adding radiation to the samples.

- 48 sharpies were drained of their ink, and this ink was placed into a petri dish.
- The dish was weighed before and after the ink was added, allowing the researchers to determine that the sample consisted of 7.4g of sharpie ink.

FIG. 6. Titanium samples counted at BHUC (left) and dried ink from 48 sharpies emptied into a petri dish placed in Mordred (right). The petri dish was covered with a plastic bag to ensure that Mordred would remain clean.

- Mordred, an n-type HPGe detector, was chosen to count the ink, which was placed in a plastic bag to avoid contaminating the detector [4]. Figure 6 includes a picture of the sample in Mordred.
- This sample was originally left in the detector for two weeks to be counted, then remained for an additional week due to errant data.

Gamma Ray Spectroscopy of Sharpie Ink

PeakEasy was the software of choice for analyzing the gamma spectra of the sharpie ink [12]. It was chosen for the ease with which it gives the counts for a certain gamma.

- The concentrations of U-238, Th-232, and K-40 are shown in Tab. I, in both ppb and mBq/kg.
- Early-chain (pre-radon) uranium produced a limit rather than a peak, but this limit is in agreement with the late-chain uranium peak.

Table I. The final results for the concentrations of U, Th, and K in sharpie ink in both ppb and mBq/kg, along with their uncertainties. This data was obtained from Eq. 1, with the counts given by PeakEasy.

Source	ppb	mBq/kg
U (early)	<44(95)	<543(1173)
U (late)	34(11)	420(136)
Th (early)	146(53)	1802(655)
Th(late)	134(49)	1655(445)
K	164(36)	5087(1122)

- These concentrations were calculated using Eq. 1,

$$C = \frac{N}{Mtf}, \qquad (1)$$

where N, M, t, and f represent the gamma counts, sample mass, livetime of the sample, and conversion factor (dependent on the detector, sample geometry, and gamma being counted), respectively [13].
- A weighted sum of the early and late thorium chains gives 1701(368) mBq/kg, and thus sharpie ink adds 7208(1189) mBq/kg overall.
- By weighing a post-it note before and after writing on it with sharpie, a sharpie mark was found to be 80 μg when the ink is wet, and thus less than that when dry.
- Using this as a limiting mass, a typical marking adds <577(95) nBq to a sample. This means that less than 0.70(12) gammas are emitted from the ink in a typical two-week detection period.

Conclusions and Future Work

Automating LN_2 filling with LabVIEW

- SOLO's dewar experienced vacuum failure during this project, preventing the filling program from getting up and running as was intended. However, the LabVIEW code created for the purpose of automating the filling of SOLO's dewar and sending daily weight updates was found to be successful.
- Work that could benefit this program going forward would involve adding a precooling system for the filling. This would involve using another valve to allow the gaseous N_2 to escape entirely when the fill begins, then closing when liquid begins to flow so that only liquid enters the dewar.

Radioanalysis of Sharpie Ink

- The concentrations and activity of radionuclides in sharpie ink are given in Tab. I. The overall activity was found to be 7208(1189) mBq/kg, which results in less than 577(95) nBq for a typical mass marking on a sample, or under 0.70(12) gammas per counting period. This is likely negligible.
- In the future, it may be helpful to test these results by counting a sample before and after writing on it with sharpie.
- If this data is correct, such a test should result in no noticeable difference between the two data sets.

References

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[6] An image from the International Association of Certified Home Inspectors which shows the decay chain of U-238. https://www.nachi.org/gallery/radon/uranium-238-decay-chain

[7] The section of the NI website that deals with LabVIEW, which was used to code the LN_2 filling. https://www.ni.com/en/shop/labview.html

[8] The company that owns the AMI 286 and similar liquid level indicators. https://www.americanmagnetics.com/286.php

[9] The website for Arlyn Scales, which owns the scale model used for weighing the 180L LN_2 dewar. https://www.arlynscales.com/

[10] The NI website, which owns both LabVIEW and the USB-6009 model used to communicate with the solenoid valve. https://www.ni.com/en.html

[11] The website selling the ASCO solenoid valves similar to the one used in the LN_2 filling system. https://www.emerson.com/en-us/automation/asco

[12] The company website for PeakEasy, the software used to determine the gamma counts in the U-238 decay chain https://peakeasy.lanl.gov/

[13] Gilmore, G. (2008). *Practical gamma-ray spectroscopy, second edition*. Wiley.

Acknowledgements

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