Studies on the Reduction of Radon Plate-out on Copper Using Electric Fields

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Abstract

As radioactive elements decay, the daughter particles can stick to surfaces, a process called plate-out. Reducing radon plate-out on copper is extremely important to the next generation of ultra-sensitive particle detectors. Background interactions resulting from decaying radon daughter particles can mimic signals seen in direct dark matter searches, neutrinoless double beta decay searches, and other exotic particle searches. ^{222}Rn and its radioactive daughter particles can be a contributor to background when the detector housings and shielding are stored and exposed to ^{222}Rn for long periods of time. Previous studies indicate that electric fields can be used to deflect daughter particles and reduce radon plate-out in copper. As an extension to these studies, I investigated the use of electric fields at a potential difference of 35 kV to further mitigate radon plate-out on copper. To do this, I placed copper samples into a ^{220}Rn rich environment and created an electric field at a potential difference of 35 kV to attempt to deflect radon's daughter particles to prevent plate-out. After exposure, the emissivity of the copper samples were measured using the XIA UltraLo 1800 alpha particle counter.

Introduction

Radon is a naturally occurring radioactive gas that exists everywhere in the environment. Its daughter particles can plate-out onto the surfaces of materials and further decay. Over time, all materials can become contaminated with radon and its daughter particles. If these materials are used in the construction of an ultrasensitive experiment, similar to the ones searching for dark matter or other exotic particles, the decays can embed daughter particles into the detectors and the subsequent decays of those daughter particles can create a false signal. This research focuses on creating new procedures to reduce radon plate-out onto copper. Reducing the plate-out of radioactive elements onto copper is crucial for next generation ultra-sensitive experiments to obtain the clearest signal possible.

^{222}Rn is a large contributor to background interactions that can mimic desired signals in dark matter, neutrinoless double beta decay and other exotic particle searches. A majority of these daughter particles are positively charged, meaning they can be deflected using a strong enough electric field. As a result of this deflection, there should be a reduction in radon plate out on copper. To test this, copper samples are placed in an exposure chamber and exposed to ^{220}Rn sources. The sources are camping mantles manufactured before the mid 1990s which contain thorium. In Figure 1, the ^{232}Th decay chain shows that ^{232}Th decays down to ^{220}Rn, and eventually to a stable lead-210 atom. Radon is a gas, so

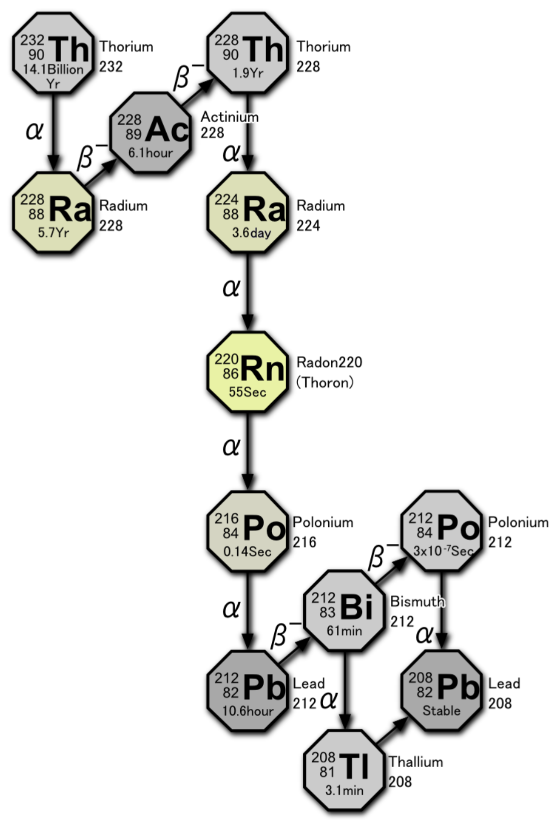


Fig. 1 - The ^{232}Th decay chain

eventually the atmosphere within the exposure chamber will be have a high concentration of radon particles. One would expect all the radon on earth, with its short half-life of four days, to have decayed away by now, but that isn't the case. All radioactive elements have decay chains to a stable particle. The thorium decay chain in Fig. 1 has a series of decays above thorium that originate from Uranium-238 which has a half-life over 4 billion years. Since these elements are embedded in the soil and dirt and are continuously decaying, there will always be a concentration of radon infused in the atmosphere.

A previous study [1] showed that copper samples stored within an electric field have a lower rate of plate-out, but that experiment was limited to 6,000 V when producing the electric fields due to the dielectric breakdown of air that occurred within the exposure chamber. The minimum distance required to prevent this arcing was 6 inches, but the exposure chamber was much smaller. ^{220}Rn was used as a substitute for ^{222}Rn because ^{222}Rn requires special licensing and training to handle safely. ^{220}Rn sources are easily obtained and require no licensing to use. In addition, ^{220}Rn decays to its stable daughter particle with a couple of days compared to ^{222}Rn which takes many years.

An electric potential difference will create an electric field, and a charged particle will follow the electric field lines. Most radon daughter particles are positively charged. Thus, a potential difference can be applied to create an electric field can push these radon daughters away from the copper samples.

Motivation

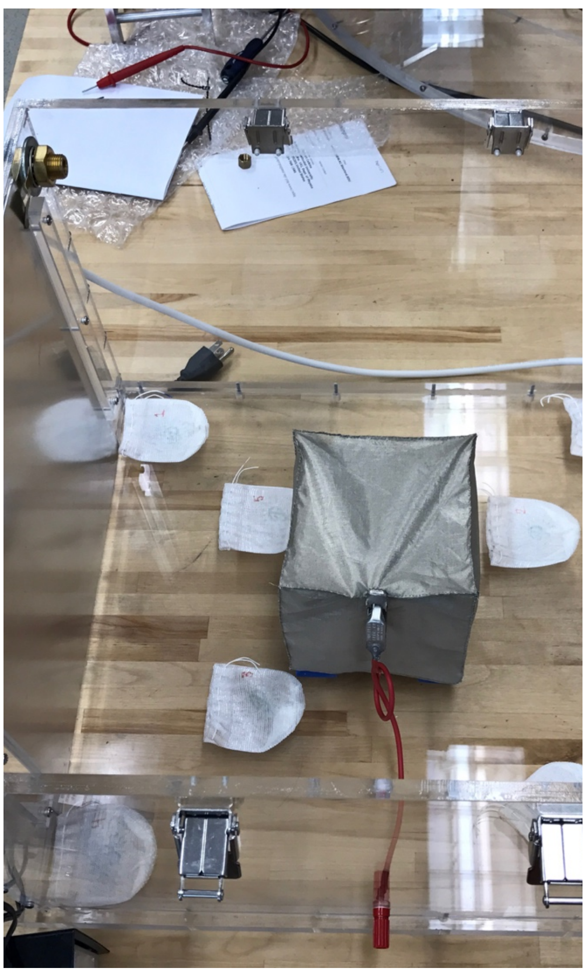
The Super Cryogenic Dark Matter Search (SuperCDMS) uses copper in the construction of its detector housings. In order to maximize the sensitivity of the experiment, we must find a way to ensure that the copper used in the construction is clean and remains clean throughout the process of storage and data collection. If contaminated copper is used in the construction of the housings, the subsequent decays of radon and its daughter particles can cause recoil that pushes the nuclei into the detector causing a false signal to be created. SNOLAB, the future home of SuperCDMS in Sudbury, Canada, has an average radon environment around 130 Bq/m^3. Since construction and assembly of the experiment takes time, the materials used in the construction must be stored nearby. In the time between fabrication and installation, the copper housings of the detectors will be stored traditionally, using nitrogen filled purge boxes. This research will hopefully provide insight into new procedures for storage to reduce plate out. One of radon's decay products is ^{210}Pb, which has a long half-life of 22.3 years. It is not practical to wait for the ^{210}Pb contamination to decay away since the expected lifetime of the experiment is less than the half-life of the lead atoms.

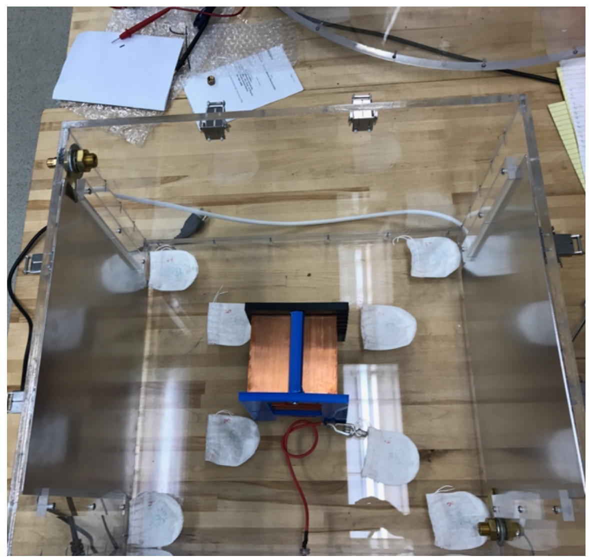
Fig. 2 – SuperCDMS iZIP Detector

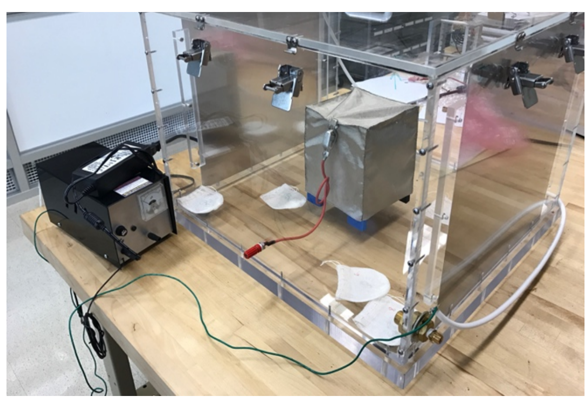
This research will benefit experimenters who work in direct dark matter or neutrinoless double beta decay studies. SuperCDMS is an example of an experiment that will benefit from this research, since the materials studied are the same as the those used in the design of the detector housings used within the collaboration. The results of understanding how ^{220}Rn, and by extension ^{222}Rn, plate-out is affected by electric fields can be used for detectors that use similar materials and construction methods.

Methodology

In previous studies, the exposure chamber was made from a modified pressure cooker. The pressure cooker's geometry prevented the power supply from being used at its full capability of 35,000 volts. Since the chamber was so small, and the housing was made of metal, arcing occurred at any potential above 6,000 V. The minimum separation for the anode and cathode needed to prevent arcing was found to be six inches. With this information, a new exposure chamber was designed and created. It was constructed of acrylic and was much larger to prevent any possibility of arcing, with two metal plates on opposite sides of the chamber to ground the electric field within the chamber. Inside of the chamber, eight camping mantles were placed around a 3D printed sample holder, which was then covered with







Photos of experimental set up

a conductive nickel-copper fabric. To measure plate out, four-inch by four-inch copper samples were used. The samples were cleaned using Radiac wash, isopropyl alcohol, and deionized water. The Radiac wash and isopropyl alcohol helped to remove any surface contamination. Their emissivity was then counted in the XIA UltraLo 1800 alpha particle counter prior to exposure. The three copper samples were then placed in the sample holder and sealed into the exposure chamber for 72 hours with no electric field active as a control.

Once the samples are removed, they are counted again in the XIA UltraLo 1800, and the contamination levels are inferred from the counts. The entire procedure is then repeated using an electric field generated by connecting the power supply's high voltage lead to the nickel-copper fabric using an anode clip.

Results

A total of two runs were completed using the new exposure chamber. In the first run, the anode clip connecting the metal fabric to the high voltage power source disconnected from the fabric and was lying on the floor of the chamber for 60 of the 72 hours of the exposure. This created a point charge with a 35 kV potential in the exposure chamber, and created a field configuration that was drastically different from what was intended. This experiment provided some interesting results. Since the nickel-copper fabric had an induced charge, it deflected particles, causing a reduction in the emissivity of the copper samples of about 35%. In this run of the experiment, the control copper samples were placed into the exposure chamber at the same time as the thorium sources, and resulted in a lower emissivity.

The emissivity calculation is done in the XIA software with the formula:

$$\varepsilon = \frac{\alpha}{A \cdot t}$$

where ε is the final emissivity, α is the number of alphas, A is the electrode size, and t is the elapsed time. [2] This formula assumes that the entire counting area of the tray in the XIA is covered by the

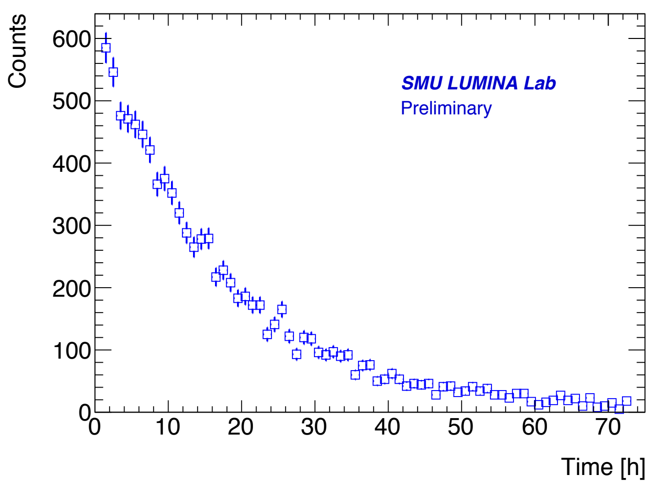


Fig. 3 - Run 1, no electric field applied

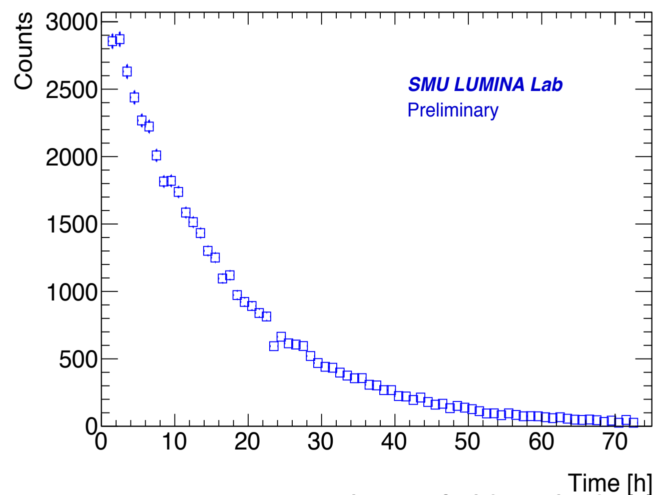


Fig. 4 - Run 2, no electric field applied

samples which is not the case. The anode of the tray is 707 cm^2, but the samples themselves cover about 400 cm^2. The number of background particles resulting from the uncovered portion of the tray is negligible compared to the emissivity of the copper samples.

In the second run, the anode clip remained connected to the fabric, and a similar 35% reduction was seen in the emissivity of the copper samples. In this case, the number of initial counts seen was drastically different. The emissivity was higher compared to the emissivity of the first control run. The spectral differences can be seen in figures 3 and 4 and a comparison of the event counts can be found in table 1.

	After Exposure (alphas /cm^2/hour)
Run 1	0.5501
Run 2	3.121

Table 1 – Comparison of experimental values

The differences in the emissivity prompted a follow up study to learn more about how radon reaches equilibrium within the exposure chamber. A Rad7 Radon Detector was connected to the ports of the exposure chamber in a closed loop and the thorium samples were placed inside. The level of contamination in the chamber was measured as a function of time. The results were inconsistent. However, a notable correlation was found between radon concentration and the time of day. That correlation disappeared when the Rad7 was connected to the pressure cooker exposure chamber, which indicated that the seals of the new exposure chamber may not be completely sealed, exposing the chamber to environmental changes like humidity or temperature.

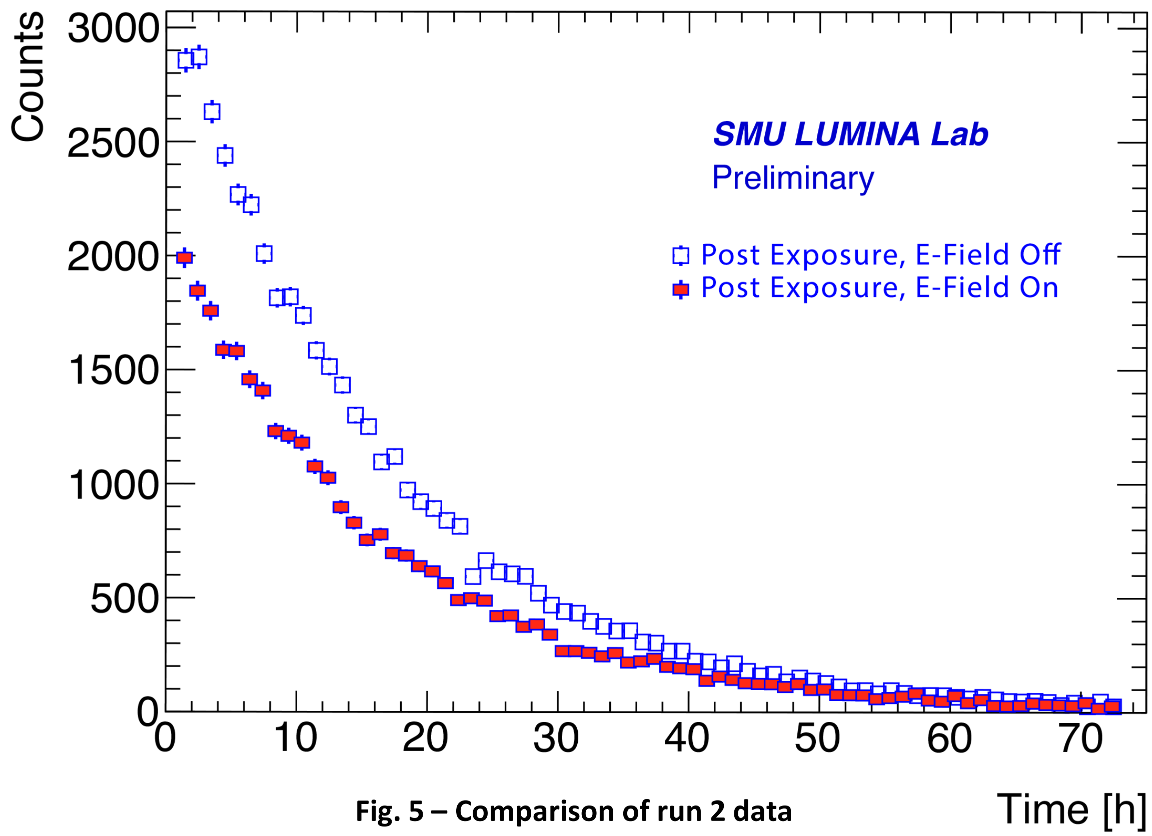


Fig. 5 – Comparison of run 2 data

Conclusion

The results obtained allowed us to learn a great deal about the new exposure chamber and the experimental set up. After two runs of the experiment, a 30% reduction in plate out was observed using the full 35kV power of the high voltage power supply (figure 5). While this is not the same as the 98.1% reduction seen in the first iteration of the study done by a previous student, a great deal was learned about the new exposure chamber. The number of changes in the design and construction of the exposure chamber led to many variables that could have been the cause of the discrepancies in the results. In the experiments, a discrepancy was seen in the emissivity of the control runs both before and after bake in time for the thorium sources to saturate the exposure chamber with radon. Further studies can investigate the consistency of the results by running the experiment again with no changes.

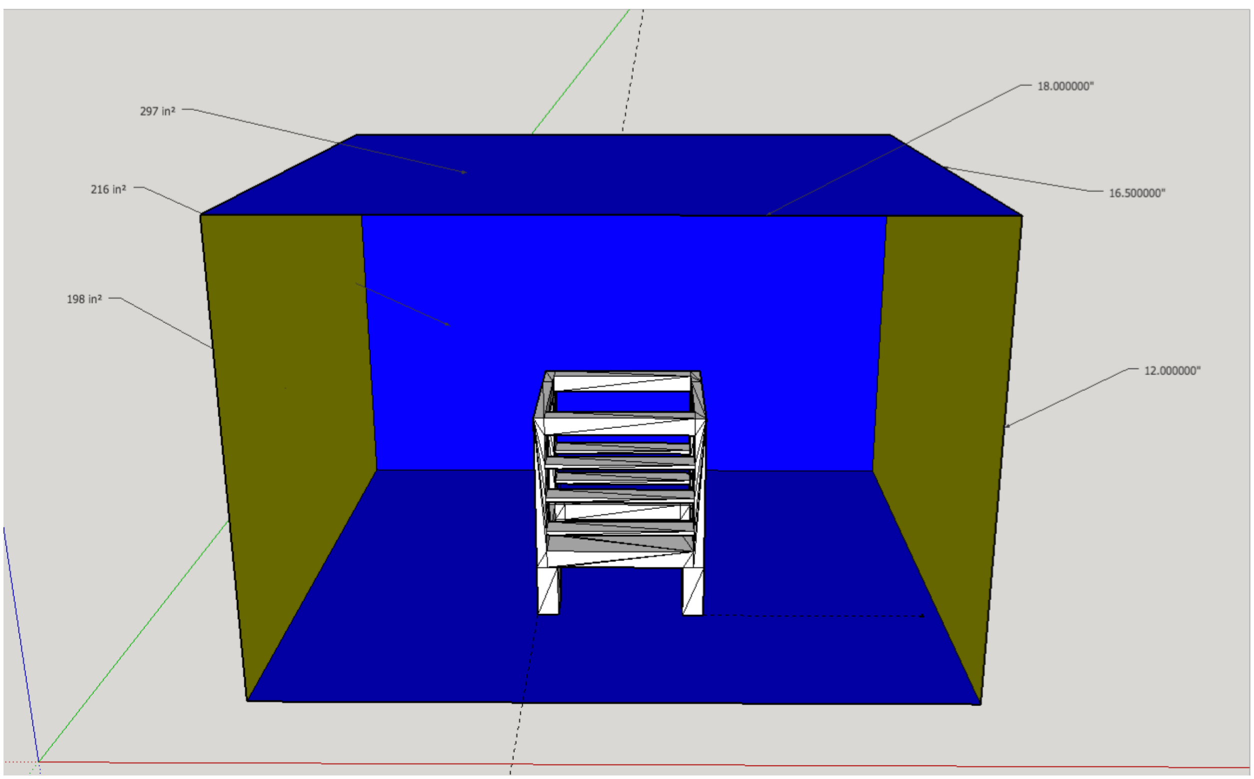


Fig. 6 – Rendering of new exposure chamber, grounding plates are colored gold

The old exposure chamber's electric field was grounded to all sides, but in the new exposure chamber (figure 6), the grounding plates are only on two sides of the chamber. This causes the field to be drastically different from the old exposure chamber. The chamber can be modified to add two more grounding plates so the field is grounded on four sides instead of just two. Grounding to the top and bottom of the field would create arcing within the experiment since the sample holder and nickel-copper fabric cannot be suspended in the chamber with a sufficient separation from the top and bottom grounding plates. Future studies can further improve the design of the exposure chamber to be taller and accommodate grounding plates on the top and bottom.

This information and conclusions on the ability of electric fields to prevent or reduce plate out of radon onto copper will allow further investigation into the field. The problem currently faced using this exposure chamber is the reproducibility and quantification of the reduction. It is known that electric fields will reduce plate out, but narrowing the exact procedures to maximize this reduction will require additional work.

References

[1] “ArXiv.org Physics ArXiv:1506.04050” [1506.04050] Studies on the Reduction of Radon Plate-Out. Web. 13 May 2015. arXiv:1506.04050 [physics.ins-det]

[2] “UltraLo-1800 Alpha Particle Counter User’s Manual” Version 0.2, February 2013.