Radon Backgrounds in LZ & The Cold Radon Emanation Facility

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HEP 1st Year Transfer Talk
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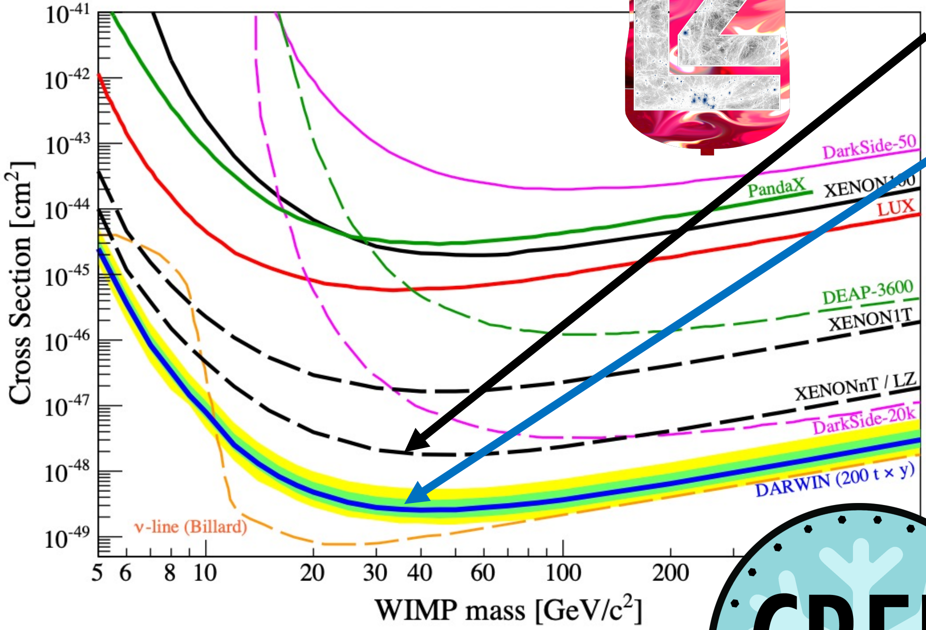
Motivation: Sensitivity depends on Rn levels



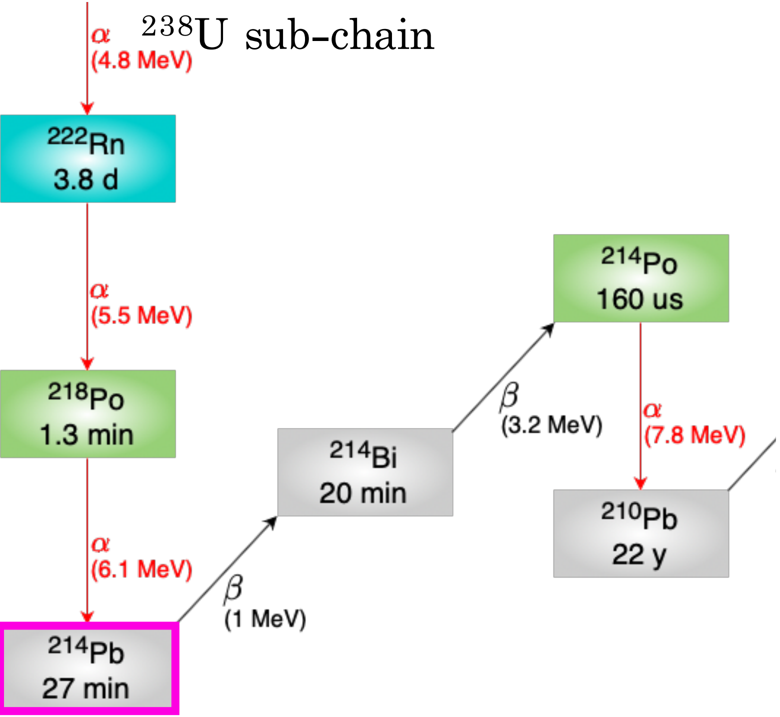
LZ projected Rn specific activity: 2 μBq/kg for the active region. (cleanliness paper)

Next generation (G3)detectors require 0.1 μBq/kg. (DARWIN paper)

This requires an improved level of sensitivity in room temperature assays & knowledge of the temperature dependence of Rn emanation in construction materials.

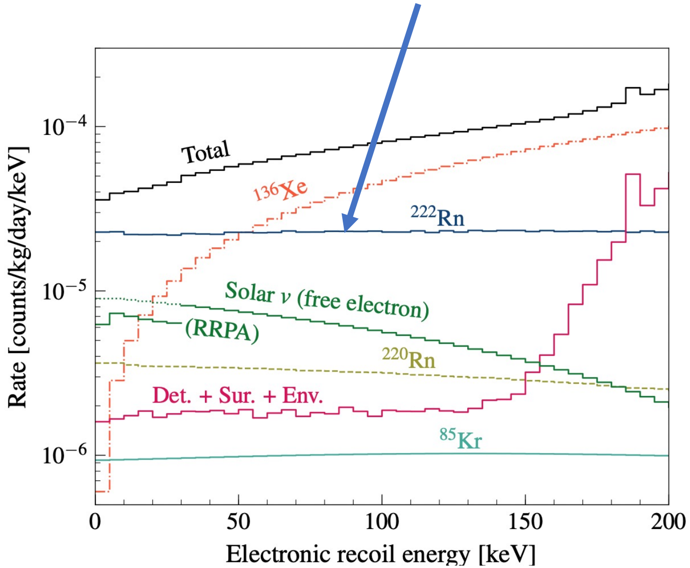
To meet these requirements a dedicated **Cold Radon Emanation Facility** has been built.

Radon Backgrounds in LZ



Background is dominated by the **naked β emission from the ^{214}Pb progeny** of ^{222}Rn (BR 6.3 %).

^{222}Rn emanates from materials, and **decays uniformly providing a constant dominant background to LZ.**



[LZ sensitivity paper]

Cold Suppression of Radon Emanation

The total radon emanation of a material is given by

$$E_{\text{total}} = E_{\text{diffusion}} + E_{\text{recoil}}$$

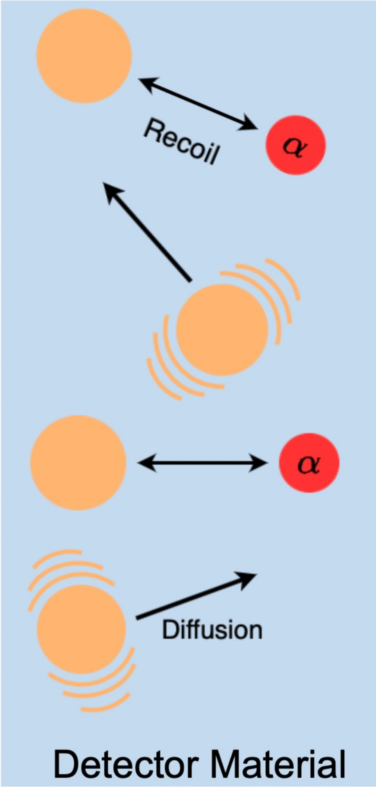
Rn diffusion is suppressed in some materials at cryogenic temperatures.

High sensitivity Rn assay facilities exist, but only operate at room temperature:

- ✅ Informs background model of experiment.
- ❌ Leads to uncertainties due to cold suppression of Rn diffusion.

Limited data available on temperature dependence of Rn emanation.

Rn emanation **must be understood** for next generation searches.



The Cold Radon Emanation Facility (CREF)

<u>Goal:</u> to deliver a world-leading sensitivity <0.1 uBq/kg to ^{222}Rn emanated from materials at temperatures of *relevance to rare-event searches.

*e.g., LXe & LAr temperatures.

Science & Technology Facilities Council
Rutherford Appleton Laboratory

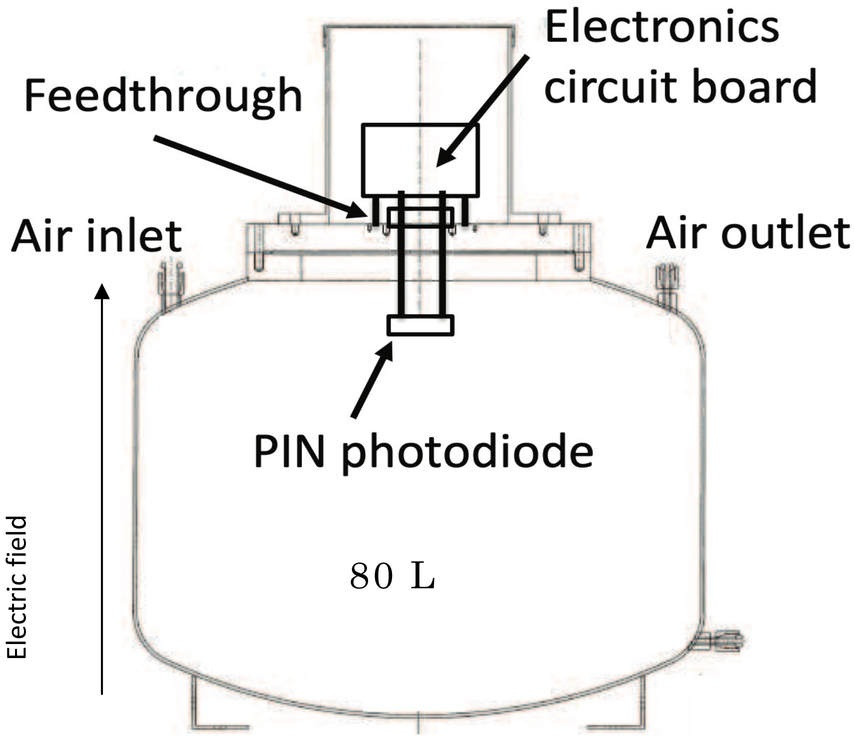
The **worlds first cryogenic radon emanation system**.

2 emanation chambers available:

- A **2.7 L chamber**, operational at several fixed temperatures.
- A **200 L chamber**, which can be cooled and stabilised at temperatures down to ~77 K.
  - Allows measurements of **whole detector components.**
  - Enables studies of **emanation rate as a function of temperature**.

CREF Electrostatic Detector

An electric field (1.8 kV) is applied over the vessel and charged Rn daughters are attracted to the photodiode.



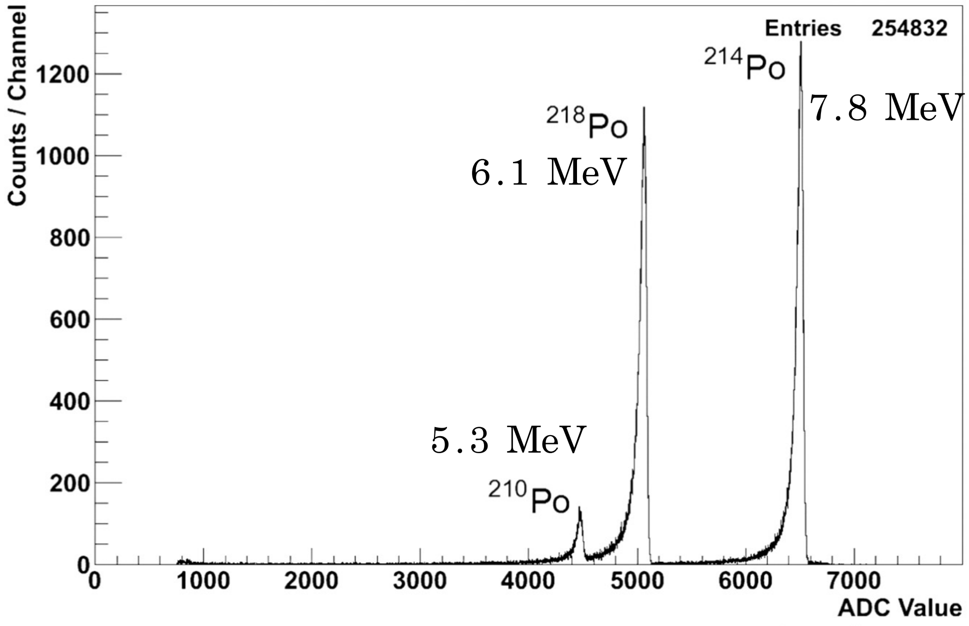
CREF Electrostatic Detector

These isotopes decay and the energies of their ejected alpha-particles are measured to infer the rate of Rn emanation from a sample material.

^{218}Po and ^{214}Po are of interest due to their:

- ✅ clear energy spectrum peak separation
- ✅ collection efficiency.

Spectrum from previous LZ/SuperNEMO detector with 2.5 Bq of a calibration source present.



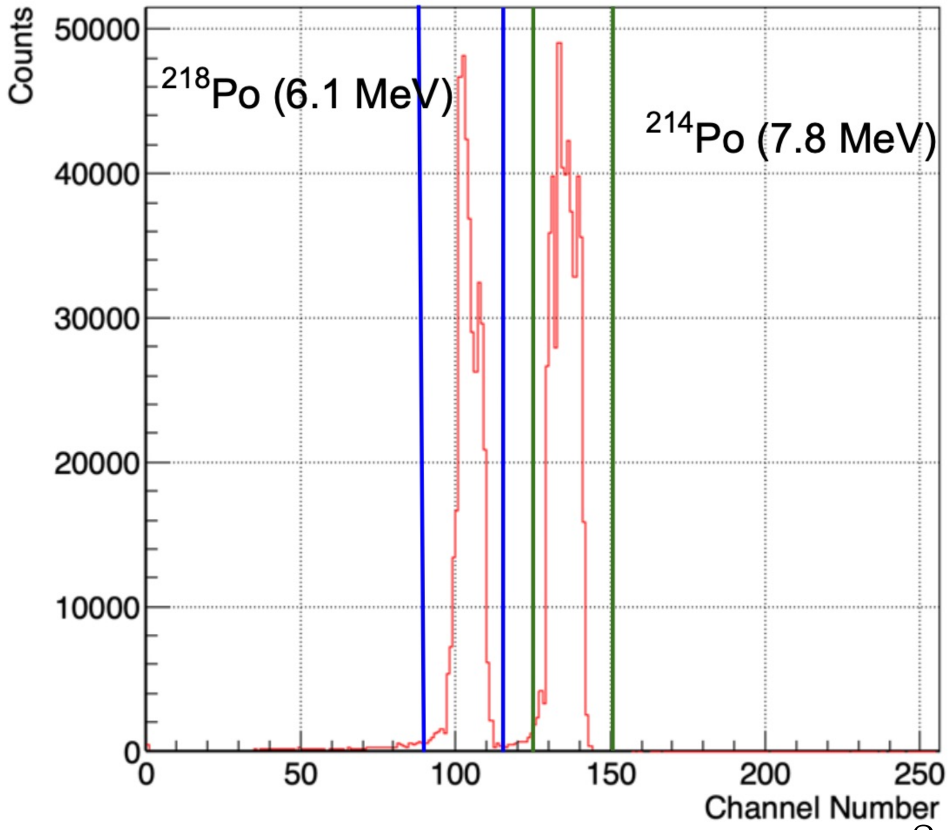
CREF Detector Efficiency Measurement @ UCL

UCL

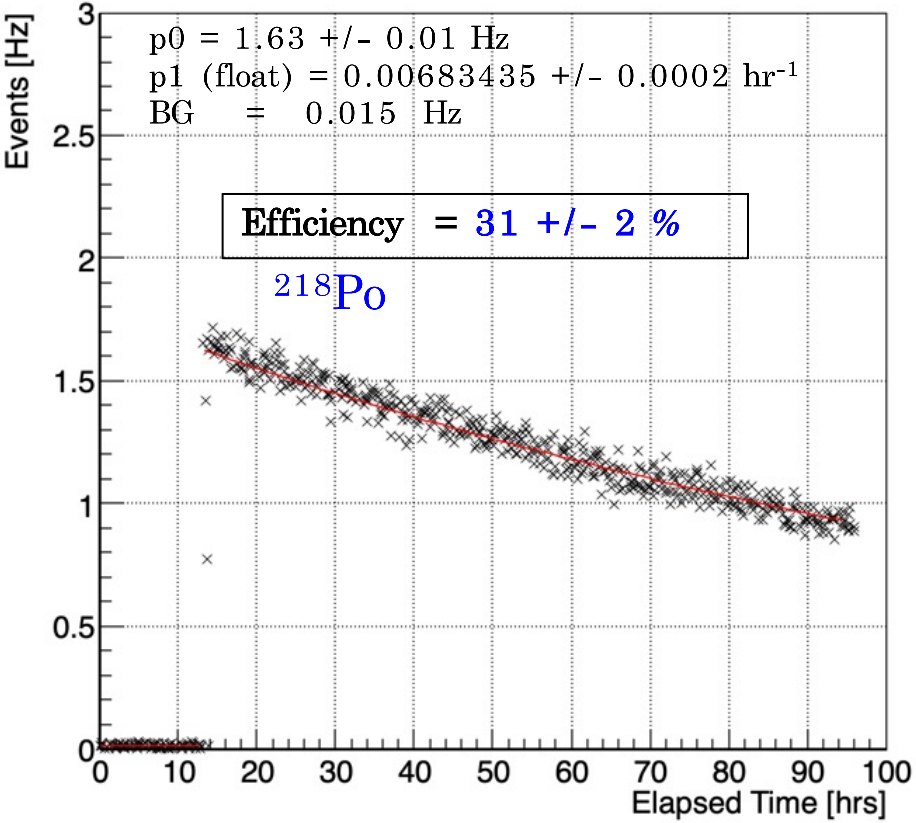
"Spike" Measurement Method

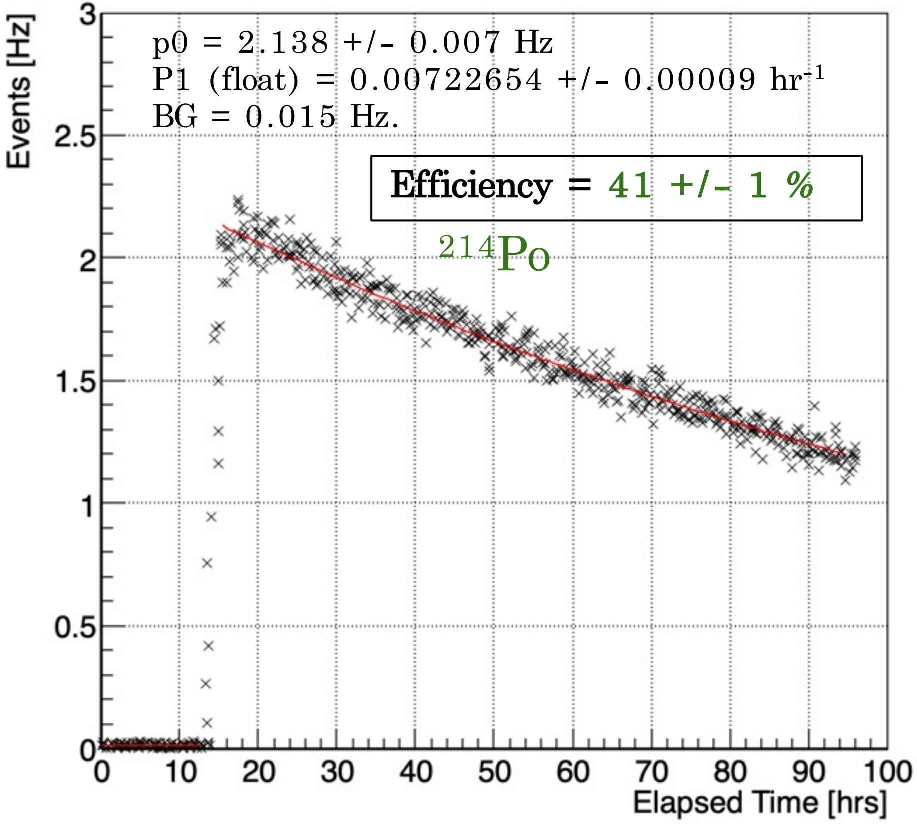
$$A(^{222}\mathrm{Rn}) = A(^{226}\mathrm{Ra})(1 - e^{-t\lambda_{^{222}\mathrm{Rn}}}),$$

Average A(222Rn) = 5.16 +/- 0.16 Hz



CREF Detector Efficiency Measurement @ UCL





Can only be 50% efficient!

CREF Next Steps

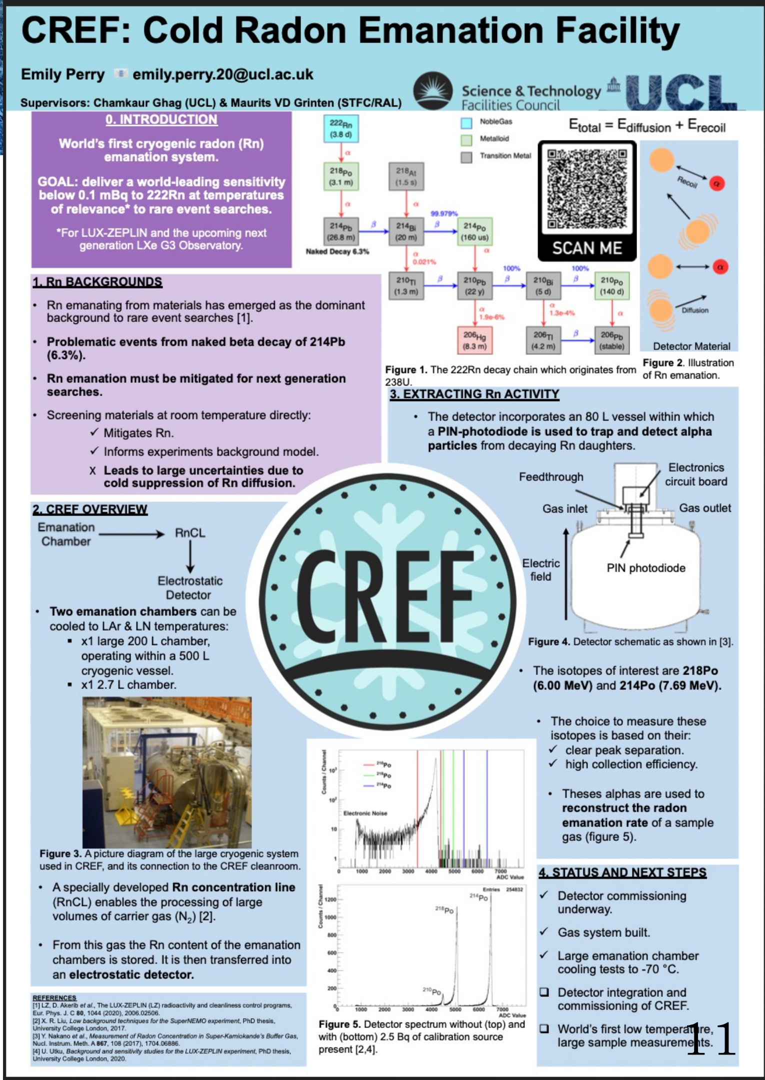
✅ First efficiency measurement conducted.

- Continue to characterize the detector
  - Background measurement.
- Detector integration to CREF and continue commissioning.
- Assay G3 materials and R&D into epoxy barriers.

For More Information

[Video from dark mater day 2020](#)

Helping in the search for Dark Matter | The Cold Radon Emanation Facility



CREF: Cold Radon Emanation Facility

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0. INTRODUCTION

World's first cryogenic radon (Rn) emanation system.

GOAL: deliver a world-leading sensitivity below 0.1 mBq to 222Rn at temperatures of relevance* to rare event searches.

*For LUX-ZEPLIN and the upcoming next generation LXe G3 Observatory.

1. Rn BACKGROUNDS

- Rn emanating from materials has emerged as the dominant background to rare event searches [1].
- **Problematic events from naked beta decay of 214Pb (6.3%).**
- **Rn emanation must be mitigated for next generation searches.**
- Screening materials at room temperature directly:
  - ✓ Mitigates Rn.
  - ✓ Informs experiments background model.
  - X **Leads to large uncertainties due to cold suppression of Rn diffusion.**

Figure 1. The 222Rn decay chain which originates from 238U.

$E_{total} = E_{diffusion} + E_{recoil}$

Figure 2. Illustration of Rn emanation.

2. CREF OVERVIEW

- **Two emanation chambers** can be cooled to LAr & LN temperatures:
  - x1 large 200 L chamber, operating within a 500 L cryogenic vessel.
  - x1 2.7 L chamber.

Figure 3. A picture diagram of the large cryogenic system used in CREF, and its connection to the CREF cleanroom.

- A specially developed **Rn concentration line** (RnCL) enables the processing of large volumes of carrier gas (N_2) [2].
- From this gas the Rn content of the emanation chambers is stored. It is then transferred into an **electrostatic detector.**

REFERENCES

[1] LZ, D. Akerib *et al.*, The LUX-ZEPLIN (LZ) radioactivity and cleanliness control programs, Eur. Phys. J. C **80**, 1044 (2020), 2006.02506.

[2] X. R. Liu, *Low background techniques for the SuperNEMO experiment*, PhD thesis, University College London, 2017.

[3] Y. Nakano *et al.*, *Measurement of Radon Concentration in Super-Kamiokande's Buffer Gas*, Nucl. Instrum. Meth. A **867**, 108 (2017), 1704.06886.

[4] U. Utku, *Background and sensitivity studies for the LUX-ZEPLIN experiment*, PhD thesis, University College London, 2020.

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3. EXTRACTING Rn ACTIVITY

- The detector incorporates an 80 L vessel within which a **PIN-photodiode is used to trap and detect alpha particles** from decaying Rn daughters.

Figure 4. Detector schematic as shown in [3].

- The isotopes of interest are **218Po (6.00 MeV)** and **214Po (7.69 MeV).**
- The choice to measure these isotopes is based on their:
  - ✓ clear peak separation.
  - ✓ high collection efficiency.
- Theses alphas are used to **reconstruct the radon emanation rate** of a sample gas (figure 5).

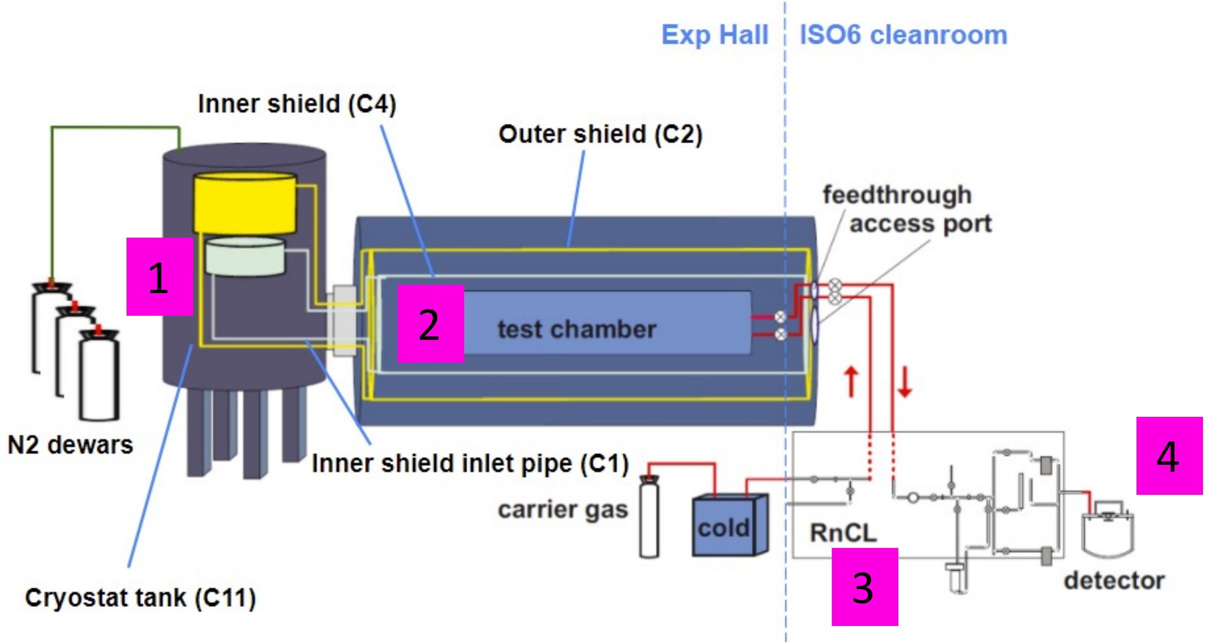
Figure 5. Detector spectrum without (top) and with (bottom) 2.5 Bq of calibration source present [2,4].

4. STATUS AND NEXT STEPS

- ✓ Detector commissioning underway.
- ✓ Gas system built.
- ✓ Large emanation chamber cooling tests to -70 °C.
- ❑ Detector integration and commissioning of CREF.
- ❑ World's first low temperature, large sample measurements.

Back Up Slides

CREF Operational Overview



1. Chamber is cooled by a repurposed Cryo-EDM infrastructure.

2. A sample is introduced into the chamber and allowed to emanate Rn.

3. A carrier gas (N_2) removes this Rn, and a specially developed **Rn concentration line** (RnCL) is used to subsequently trap it.

4. The concentrated Rn sample is then transferred to an electrostatic detector, where its activity is measured.

CREF Detector Efficiency Measurement @ UCL

UCL

"Spike" Measurement Method

A source of known activity is connected to the RnCL.

(1.32 kBq flow-through ^{226}Ra source)

Any built up activity inside the source is first be cleared by flushing the source with carrier gas.

The source valves are then closed to allow activity to build up for time, t.

$$A(^{222}\mathrm{Rn}) = A(^{226}\mathrm{Ra})(1 - e^{-t\lambda_{^{222}\mathrm{Rn}}}),$$

The source is then opened and the radon is transferred to the detector via the carrier gas and measured.

A correction must be applied to account for the increase in activity over the time in which the **radon is transferred from the source to the detector.** **Average A(222Rn) = 5.16 +/- 0.16 Hz**