Pacific Northwest
NATIONAL LABORATORY

Radon Emanation at Cryogenic Temperatures

10/20/26

Chris Jackson,

Aaron Hellinger, Brianne Hackett

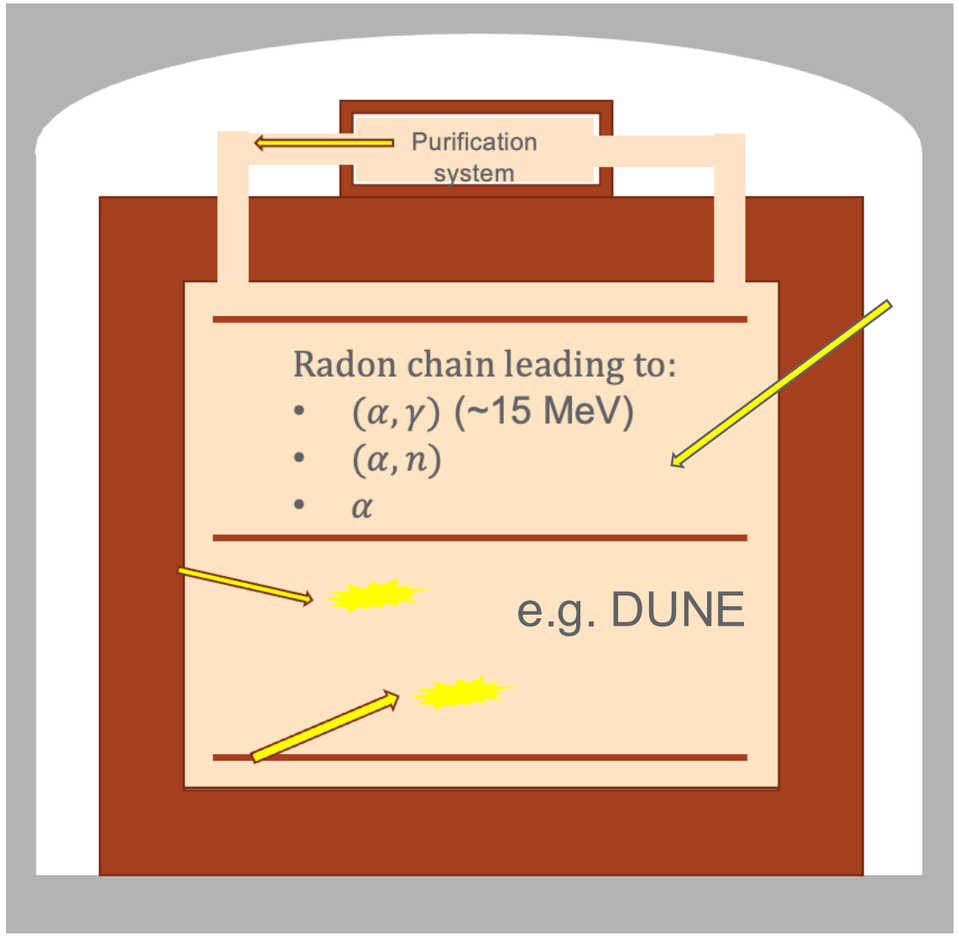
christopher.jackson@pnnl.gov

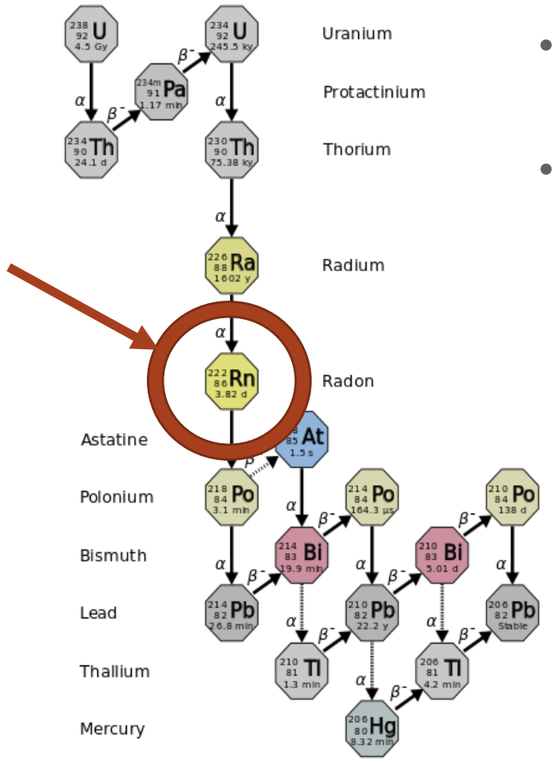


U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

Radon is a problematic background



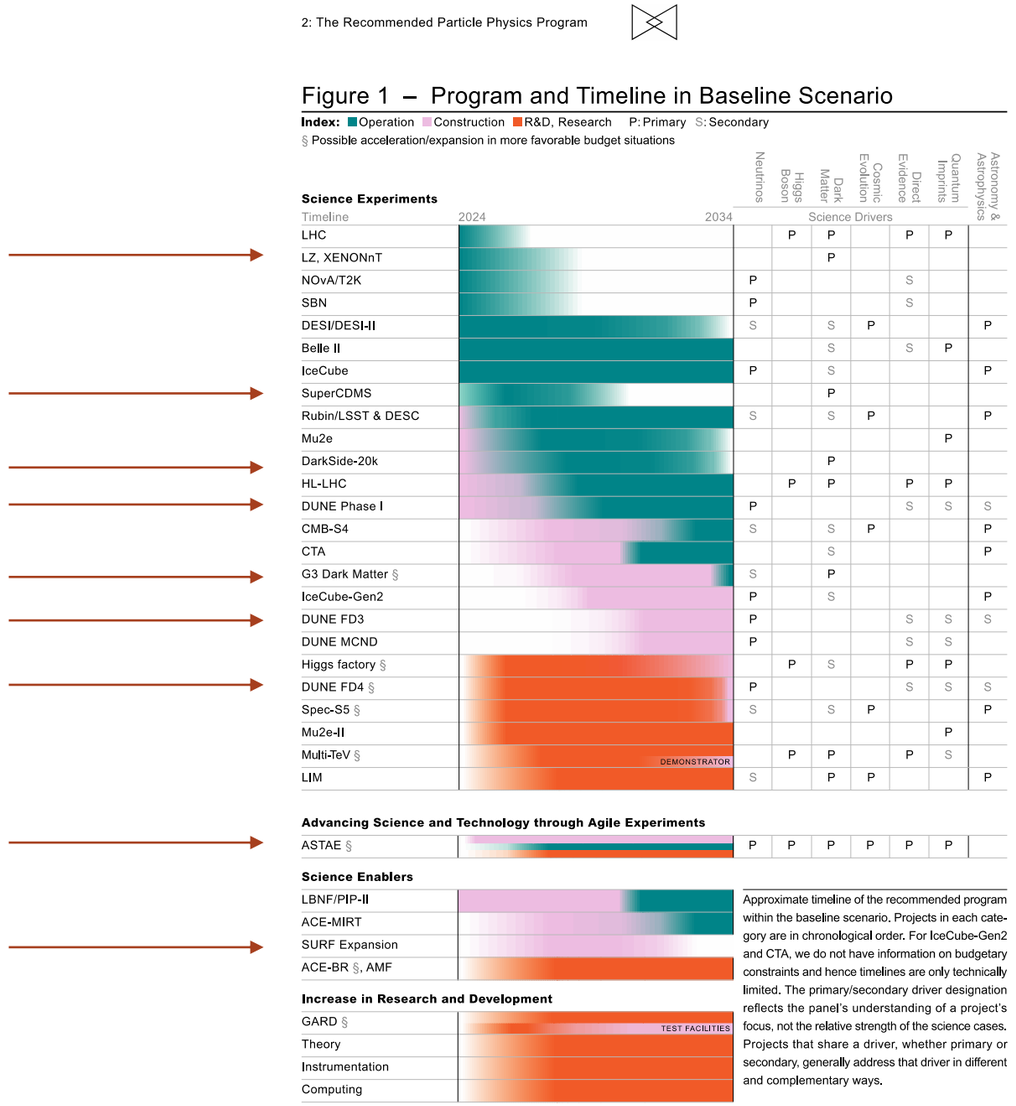


- Ra decay daughter
- Highly mobile, diffuse throughout detector
- Can plate out on surfaces

- An issue for next generation low-energy neutrino, dark matter and neutrinoless double beta decay experiments

P5: Projects where radon could influence

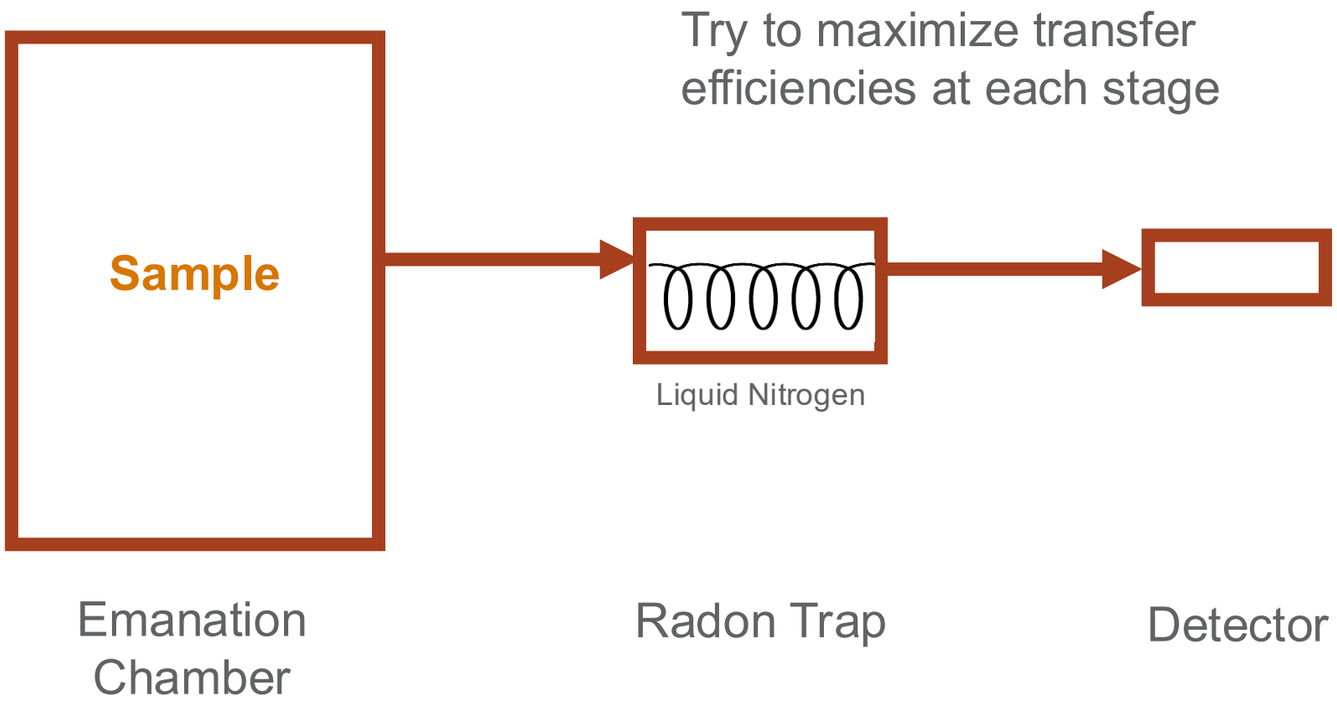
2: The Recommended Particle Physics Program



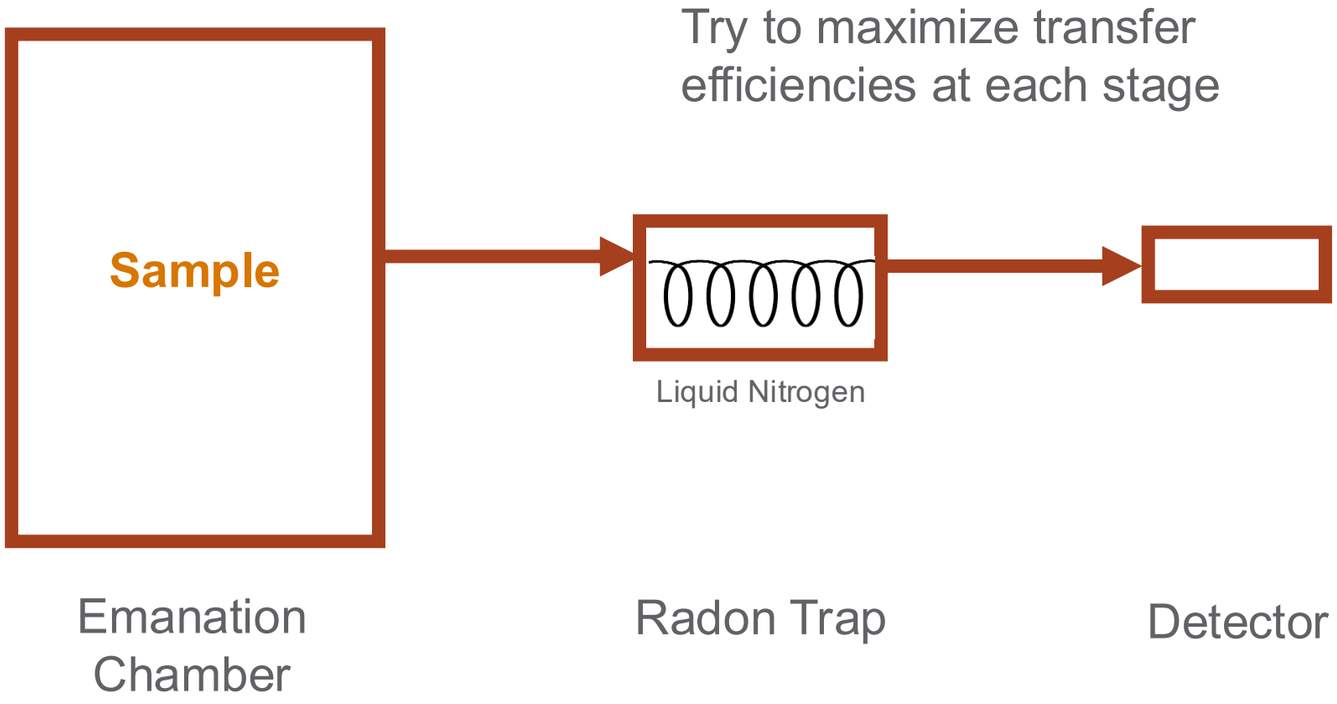
Exploring the Quantum Universe: Pathways to Innovation and Discovery in Particle Physics

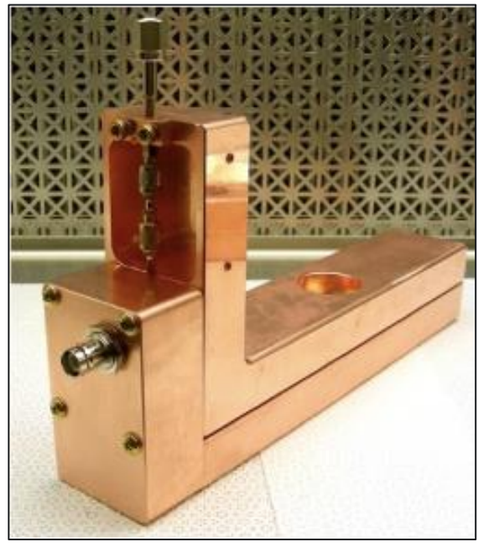
...LEGEND, CUPID, nEXO,…

Radon Emanation Measurements



Radon Emanation Measurements

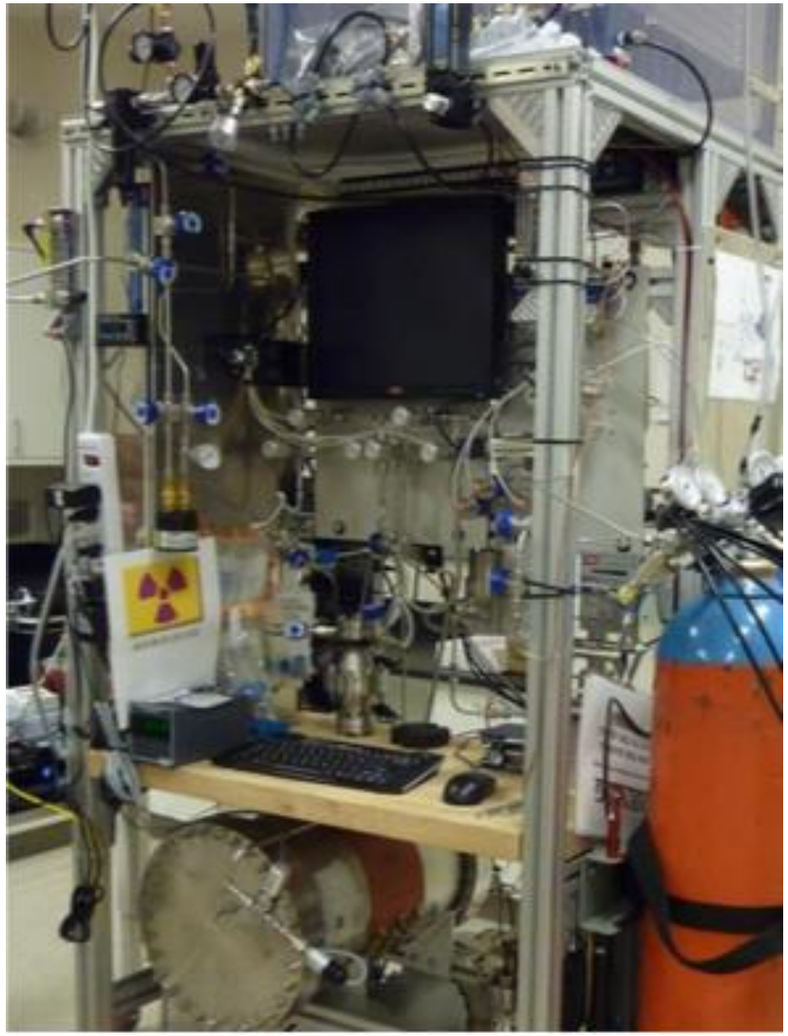




- Take advantage of PNNL ultralow background proportional counters to count radon
- Use ultrapure electroformed copper

Aalseth, C.E., et al., Design and construction of a low-background, internal-source proportional counter. Journal of Radioanalytical and Nuclear Chemistry, 2009. 282(1): p. 233-237

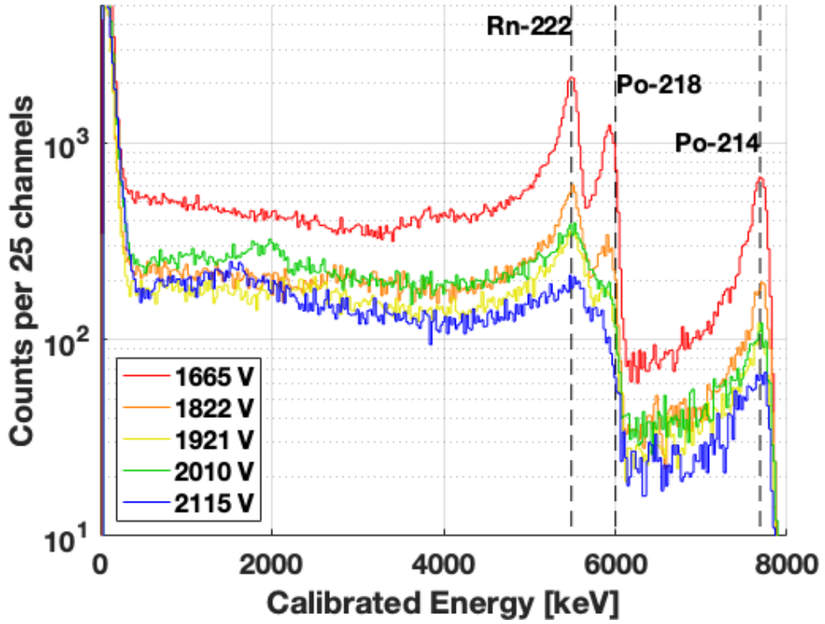
PNNL Emanation Bench

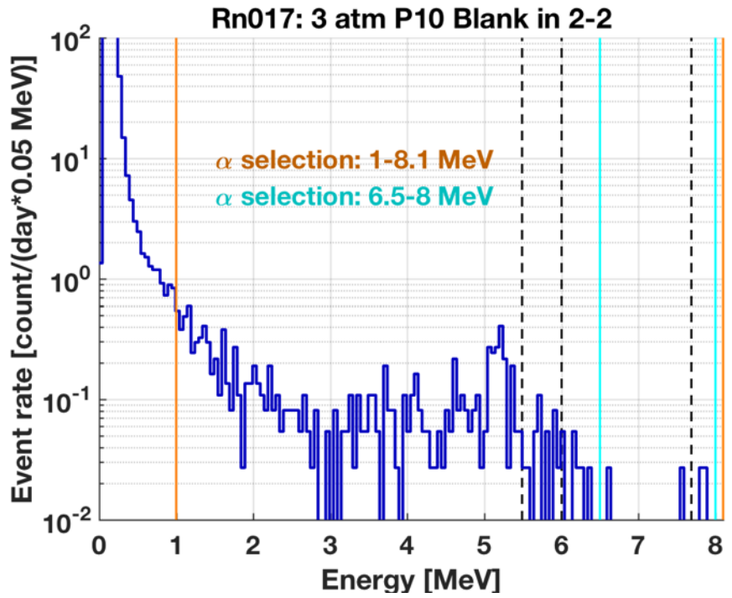


System as constructed at PNNL

Work by Ray Bunker and Dan Jardin (SCGSR)

PNNL Emanation Bench

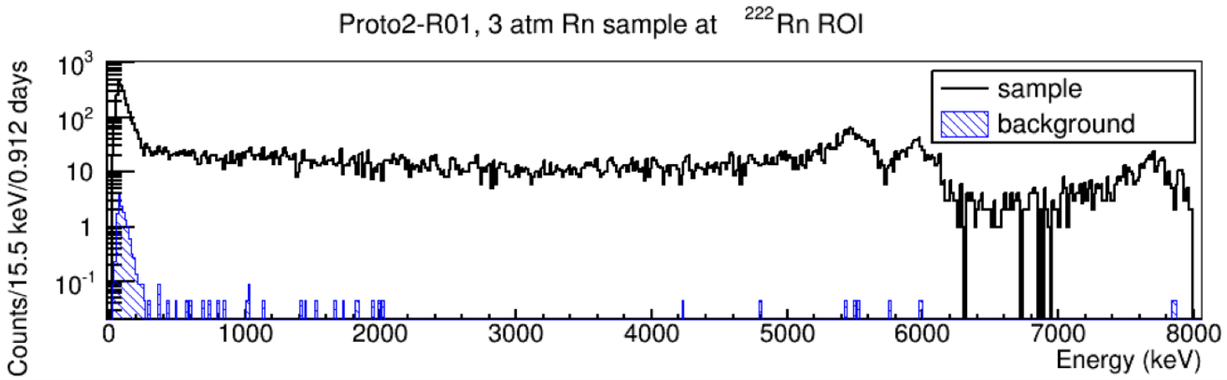


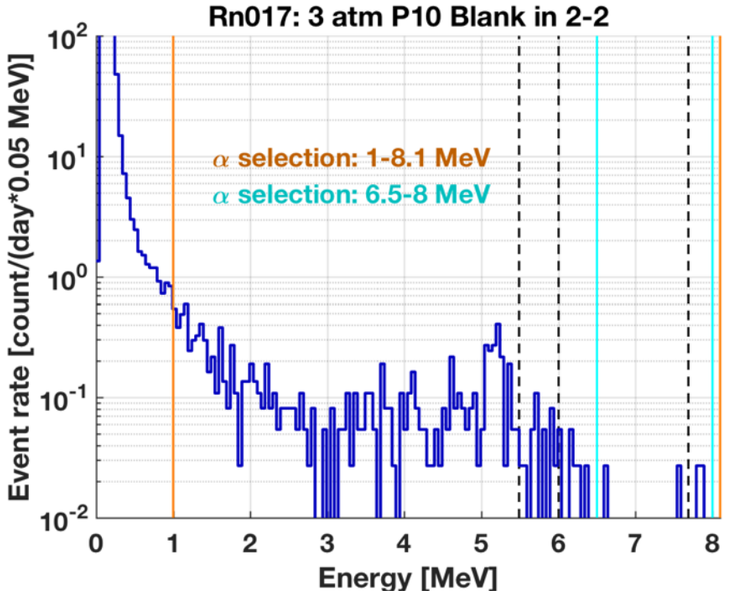


- Calibration with radon source sample using alphas

- Count radon rate using Po-214 alpha peak
  - 0.1 background events/per day in ^{214}Po ROI
  - <100 μBq background rate

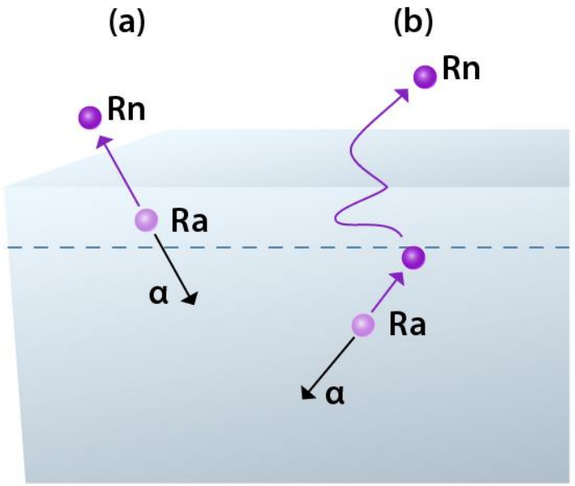
PNNL Emanation Bench





- Calibration and background spectra with new (cleaner) detector operated in shallow underground laboratory
- Count radon rate using Po-214 alpha peak
  - 0.1 background events/per day in ^{214}Po ROI
  - <100 μBq background rate

Emanation in materials and cold



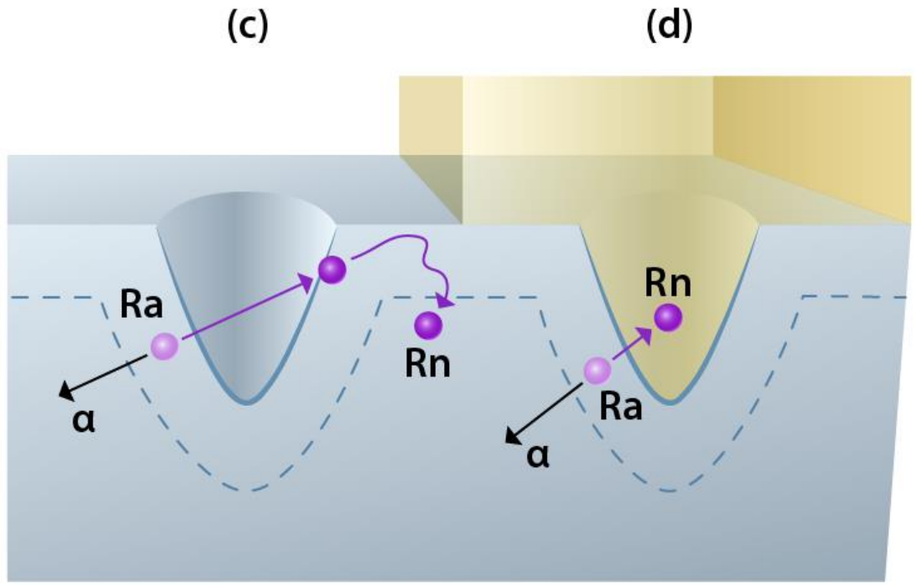
- Total radon emanation is the sum of two distinct components:
  - Recoil induced emanation
  - Bulk diffusion
- Different materials contain varying rates of both processes

- At cold temperatures, the diffusion term is suppressed
- However, in liquids the recoil term is enhanced

  e.g. Sebastian Lindemann; Hardy Simgen; Grzegorz Zuzel, Behaviour of 222Rn/222Rn at cryogenic temperatures *AIP Conf. Proc.* 1338, 156–160 (2011)

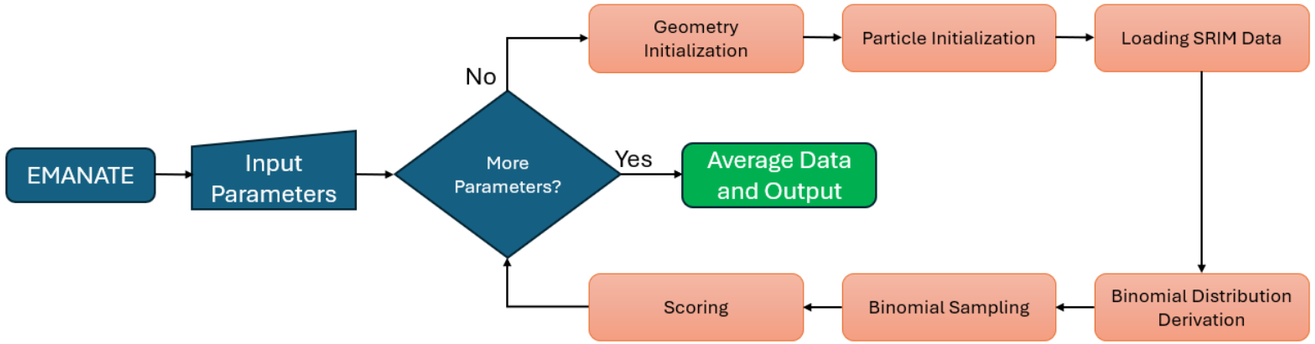
- What are the rates in cryogenic liquids?

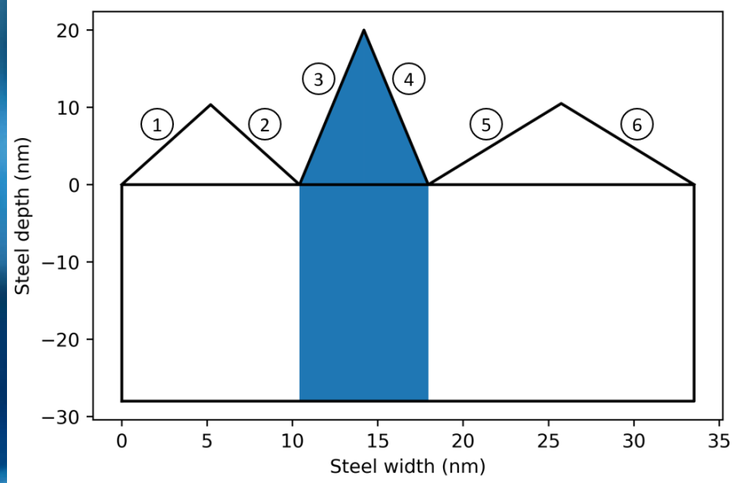
Simulation of Emanation in Cryogenic Liquids

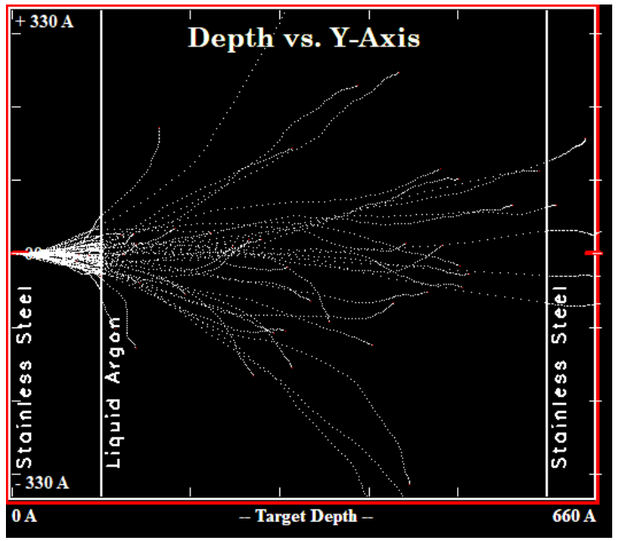


- In vacuum or gases surface effects can lower the radon emanation rates
  - Emitted radon can return to the material it came from
- This effect is suppressed in liquid
  - Denser liquid stops radon more easily before it returns to the material it came from

Emanation Measurement and Numerical Analysis Testing Engine (EMANATE)





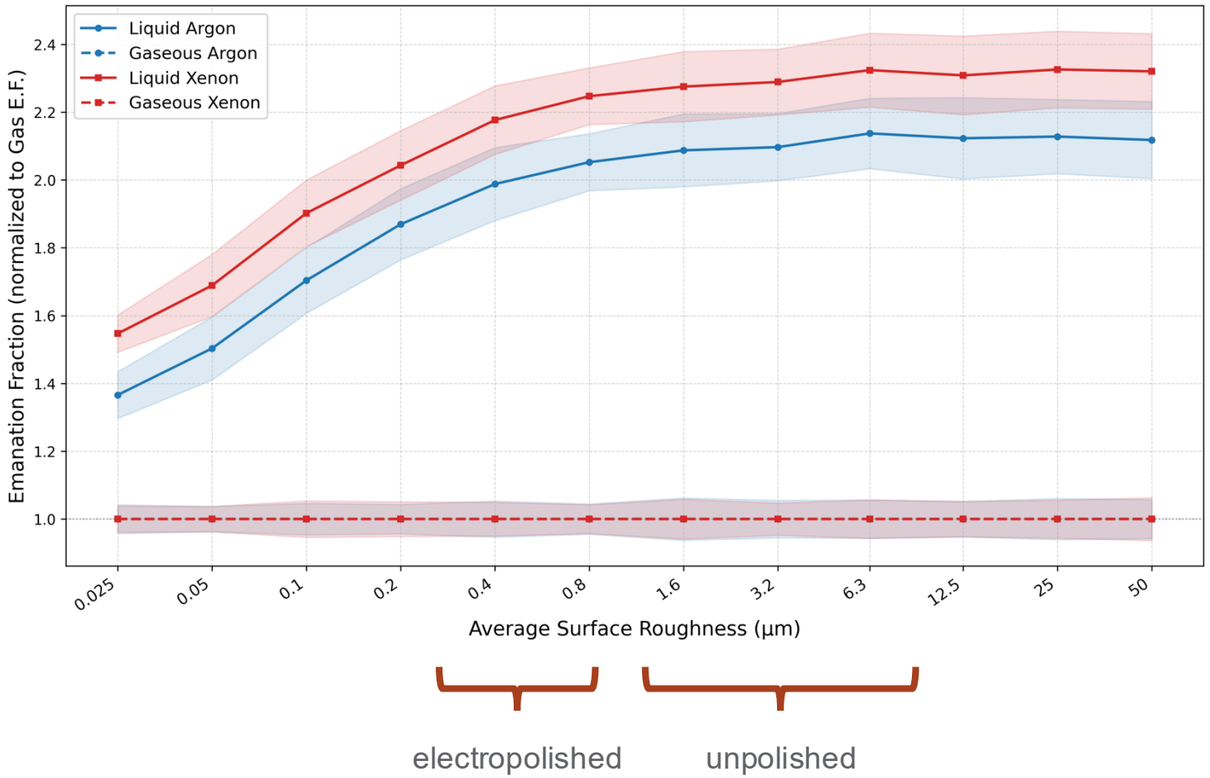


- Monte Carlo model to estimate the surface-shape contribution to emanation
- Consists of:
  - 2D geometric model of surfaces dependent of measured ‘roughness parameters’
  - SRIM based simulation of average propagation depths through materials
- Publication in preparation
  - (Aaron Hellinger, Brianne Hackett, CJ)

Ziegler, J.F., Ziegler, M.D., Biersack, J.P.; SRIM - The stopping and range of ions in matter (2010). Nuclear Instruments and Methods in Physics Research Section B, Volume 268, Issue 11-12, p. 1818-1823.

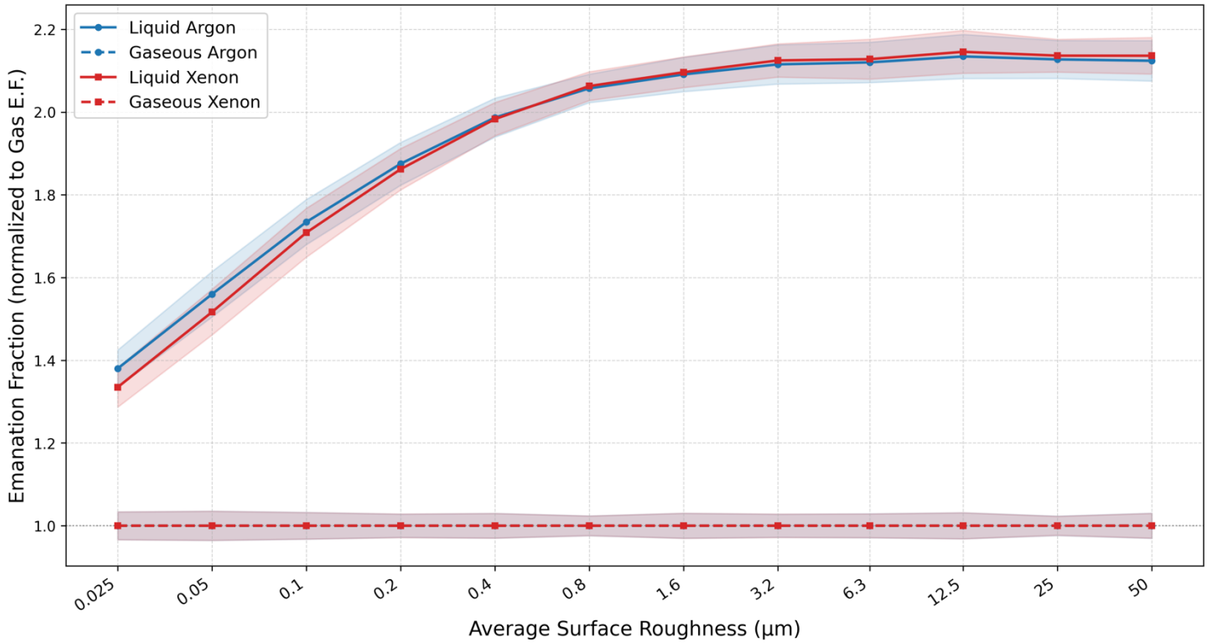
Stainless Steel

- Preliminary simulation results show factor two difference in emanation rates between emanation into liquid and gas at **cryogenic** temperatures
- Uncertainties:
  - Statistical from SRIM and geometric sampling
  - Systematic from modeling of surface roughness distribution

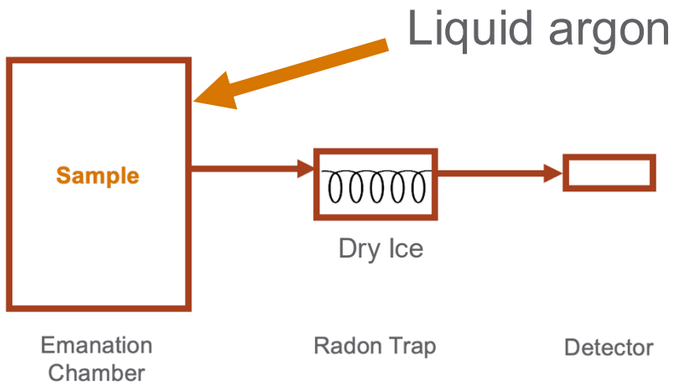


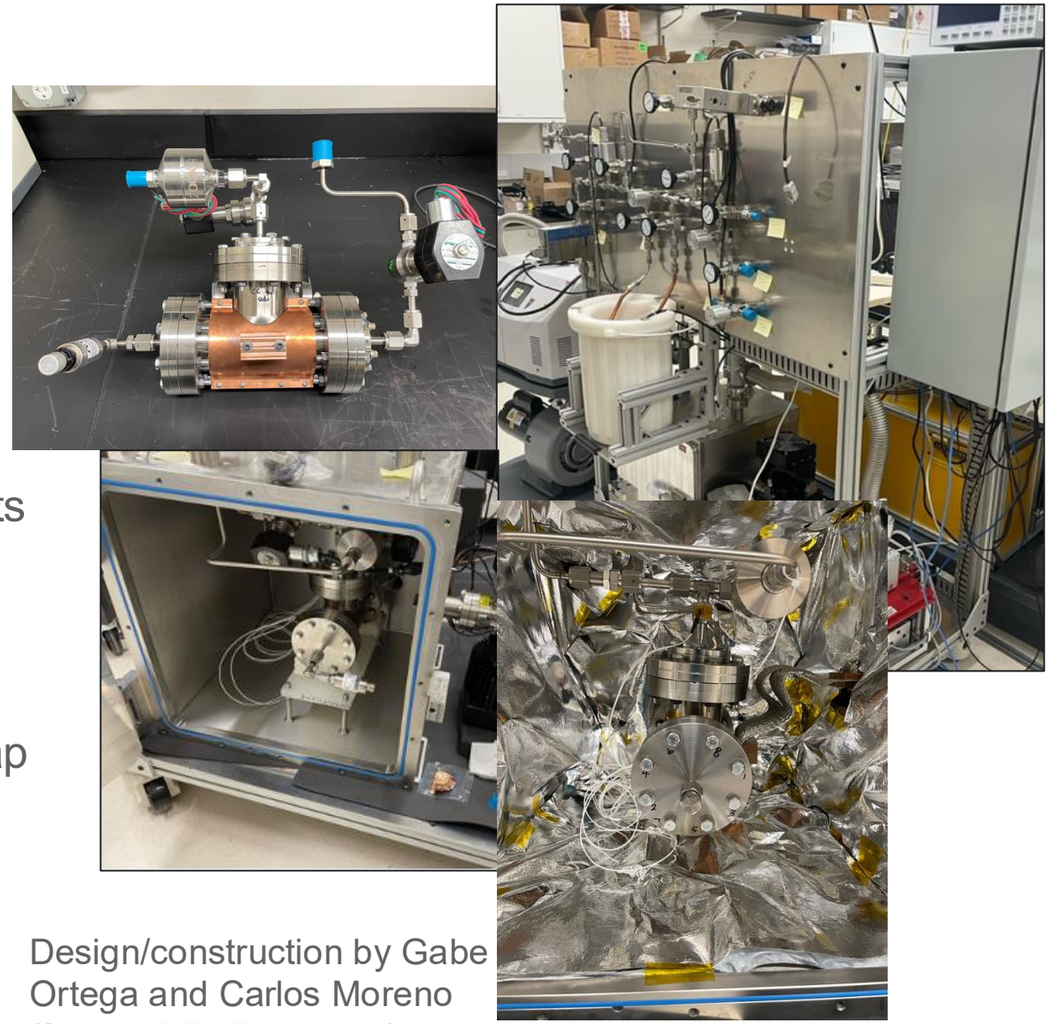
Titanium

- Extending results to additional materials (e.g. Titanium)



Cryogenic Liquid Radon Emanation Measurement Bench





- Installation is underway of system to validate these results
- Designed to maintain stable 1-liter liquid argon radon emanation volume using cold head(1-week timescales)
- Liquid argon then boiled off through dry ice (above argon freezing point, below radon freezing point) filled radon trap
- Control/monitoring system testing completed, leak tests complete, waiting for cryocooler availability
- System can be upgraded for larger emanation chambers

Design/construction by Gabe Ortega and Carlos Moreno (former RENEW intern)

Conclusions

- Radon emanation is a key problem for low background physics experiments for HEP (and NP), such as low-energy neutrino measurements and dark matter searches
- Measurement capability constructed at PNNL:
  - Comparable to best sensitivity in the world
  - Uses ultralow background proportional counter capability
- Temperature and emanation media (gas/liquid) can affect emanation rates
- EMANATE, a SRIM-based simulation developed to evaluate surface roughness effects on emanation has been developed
- Plan to test with cryogenic liquid radon emanation capability being tested to validate this model and evaluate emanation rates for next-generation noble liquid experiments in realistic conditions.

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Thank you

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