# EVALUATING THE OFF POSITION FOR E-PERM SENSORS CONFIGURED WITH S CHAMBERS IN A HIGH RADON CAVE ENVIRONMENT

Lawrence E. Welch*,
Abigail R. Van Blarcom,
Christopher P. Andreou,
Mark D. Jones,
and Michael J. Lace

Knox College
Galesburg, Illinois, USA

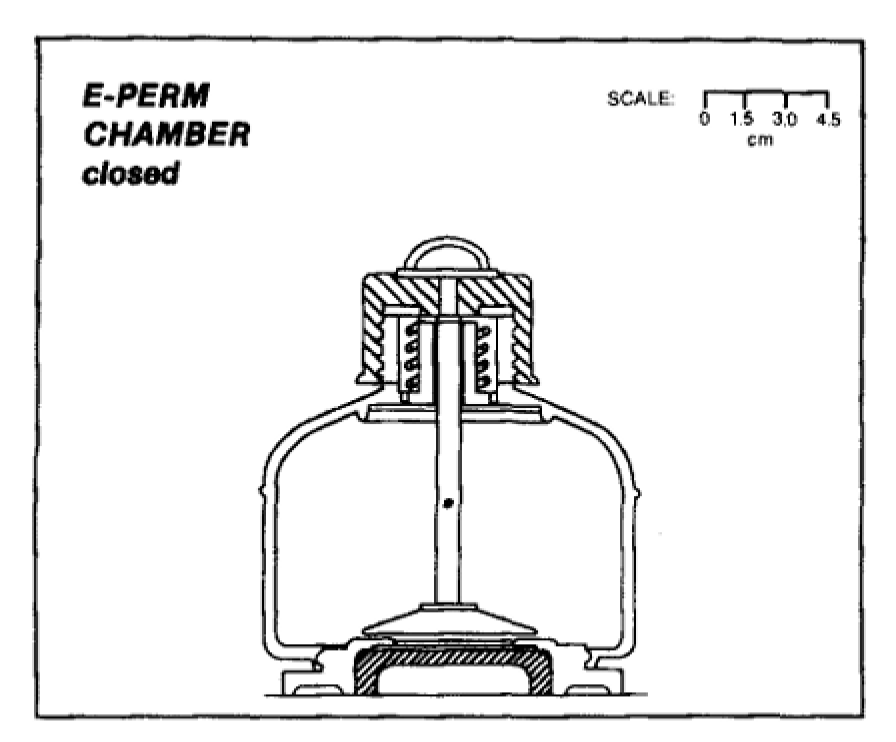
lwelch@knox.edu

# The E-PERM - ON

- An EIC sensor (electret ion chamber)
- Can be used to measure $^{222}Rn$ concentration (RnC)
- Has worked well in the harsh cave environment

# THE E-PERM - OFF

- Cap is screwed down, blocking ingress of gas
- Plunger drops down and covers electret




Kotrappa, P., Dempsey, J.C., Ramsey, R.W., and Stieff, L.R., 1990. A Practical E-PERM™ (Electret Passive Environmental Radon Monitor) System for Indoor $^{222}$Rn Measurement. Health Physics, 58(4), pp. 461-467.

# Removing the electret

- Standard to remove and cap the electret at the end of an experiment

- But, this means exposing the active surface of the electret to the cave environment, which is high in airborne particulates and drippy

https://aarst.org/wp-content/uploads/2024/03/14_10_SR_TUE_Welch_Evaluating_Electret_Radon_Progeny_Integrated_Sampling_Unit-1.pdf

Photo Courtesy of Scott Dankof

# Prior work

- Leave electrets installed in the chambers in the off position for transport out of the cave
- No significant change in voltage compared to removing and capping in the cave
- But, the sensors where the electrets were not removed always seemed to have slightly higher $\Delta V$
- Trip out of the cave was short – what if it wasn't? Could the sensor still be responding to radon in the off position?
- Test experimentally

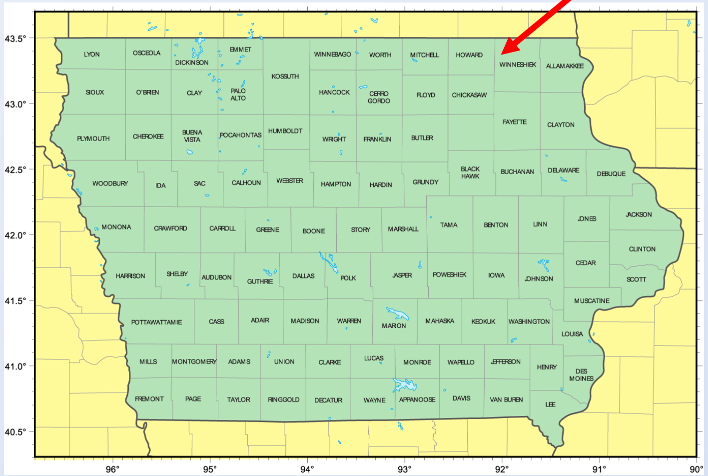
Welch, L.E., Paul, B.E., and Jones, M.D., 2016. Use of Electret Ionization Chambers to Measure Radon in Caves. Proceedings of the 2016 International Radon Symposium, pp. 1-18. http://aarst-nrpp.com/proceedings/2016/Welch_USE_OF_ELECTRET_IONIZATION_CHAMBERS_TO_MEASURE_RADON_IN_CAVES.pdf

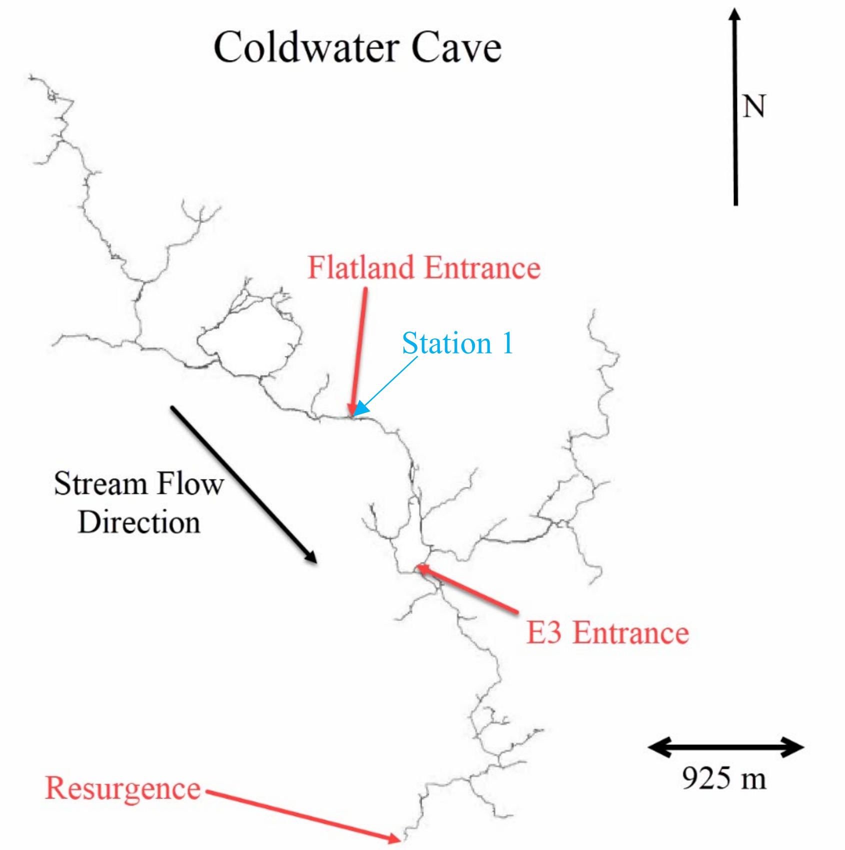
Welch, L.E., Doughty, R.M., Art, E.J., Beck, C.L., Jones, M.D., and Lace, M.J., 2023. Evaluating the Electret Radon Progeny Integrated Sampling Unit for use Measuring Radon and Radon Progeny in a Cave Environment. Awaiting publication in the Proceedings of the 2023 Indoor Environments – Radon and Vapor Intrusion Symposium.

# Sampling Site:  Coldwater Cave, Station 1

- Important Site Information: Radon will be high, but nearly constant within the time frame of the experiments

Coldwater Cave



# CRE – Cumulative Radon Exposure

- CRE = average radon concentration in pCi/L multiplied by the Hours of experimental duration
- Shooting for a value over 30,000 pCi * Hr / L
- Needed a long duration experiment to achieve this

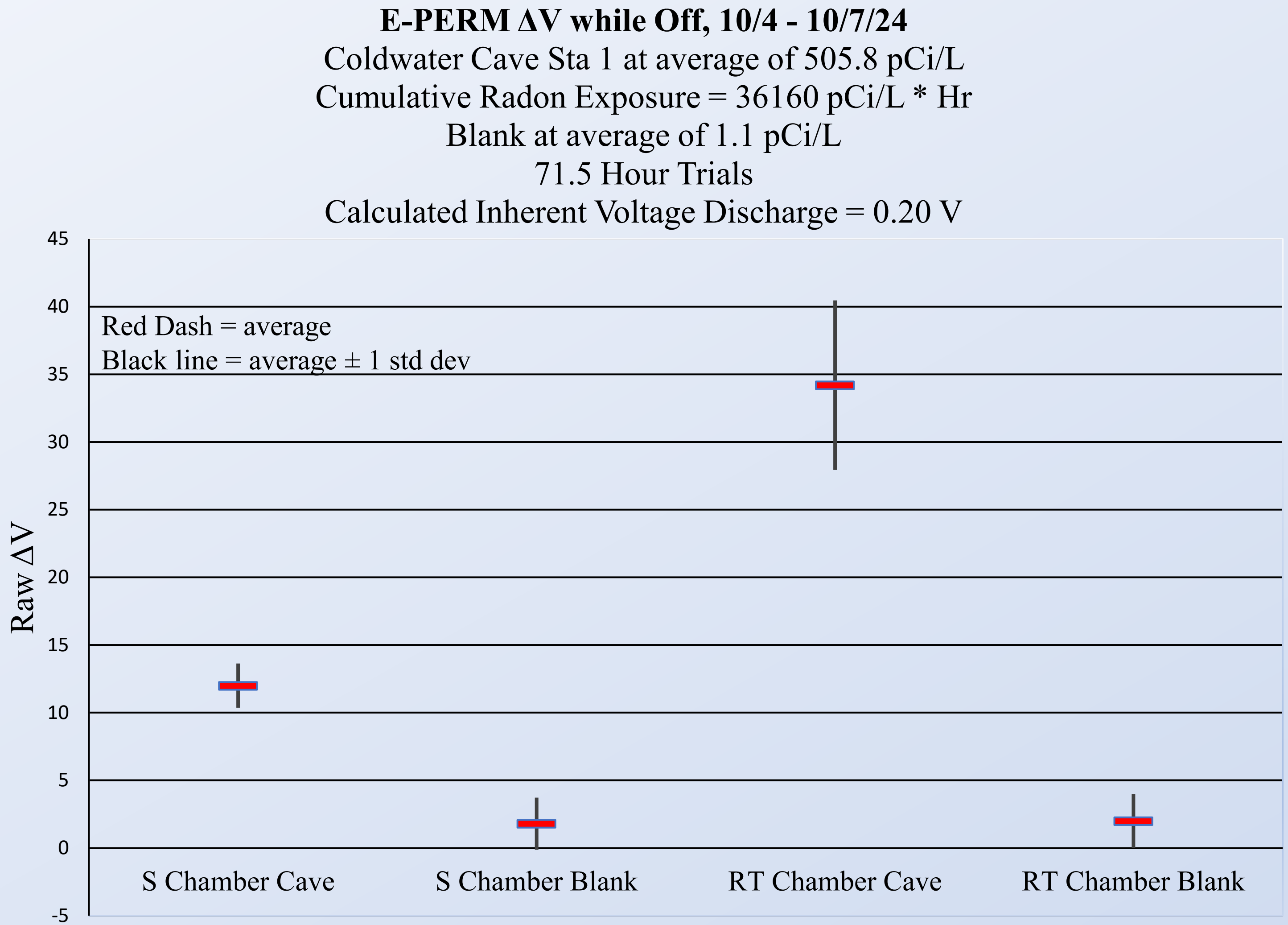
# Other experimental concerns

- Run many replicates to improve precision
  - Range four to eight, most common = six
- Place in Tyvek bags
- Compare vs a blank set run in a shed on the surface
- Using both S and RT chambers, only ST electrets


S chamber
E-PERM

RT chamber
E-PERM

# First Off Position Trial, 10/4 – 10/7/24



# Looks like the Chamber is still running in the off position – but,need to check a couple of things

- Concern 1
  - Could background radiation from the cave be causing the signal difference?
    - Seems unlikely based on past work, but should test

Welch, L.E., Art, E.J., Rau, G.D., Beck, C.L., Frana, M.J., Klausner, E.C., Miller, E.R., Jones, M.D., and Lace, M.J., 2022. Evaluating the E-PERM RT Chamber for use Measuring Rn-220 in a Cave Environment. Proceedings of the 2022 Indoor Environments (AARST) – Radon and Vapor Intrusion Symposium pp. 1-17. https://aarst.org/proceedings/2022/Welch_EVALUATING_THE_E-PERM_RT_CHAMBER_FOR_USE_MEASURING_RN-220_IN_A_CAVE_ENVIRONMENT.pdf.

# Addressing Concern 1: Testing Background Radiation Hypothesis

- Ran a set of sensors in the cave with and without lead shielding
- Lead would be expected to eliminate background alpha, most of beta, and some gamma
- No significant different between the lead shielding set and control set

| Set | Avg MPV | SD MPV | CRE | Avg ΔV | SD ΔV |
|---|---|---|---|---|---|
| | | | | | |
| 6/9 - 6/13/25 With Pb Shielding | 637.8 | 32.5 | 51870 | 17.5 | 3.4 |
| 6/9 - 6/13/25 Without Pb Shielding | 618.9 | 33.8 | 51870 | 20.2 | 2.0 |
| | | | | | |
| 6/21 - 6/27/25 With Pb Shielding | 596.9 | 35.0 | 49300 | 20.2 | 1.7 |
| 6/21 - 6/27/25 Without Pb Shielding | 618.8 | 31.7 | 49300 | 19.5 | 4.1 |

# Concern 2

- Used units of ΔV
  - Could not use normal algorithm to calculate radon concentration, as it assumes chamber being on
  - In previous work, normalized ΔV units since the E-PERM sensitivity varies with electret voltage

Welch, L.E., Doughty, R.M., Art, E.J., Beck, C.L., Jones, M.D., and Lace, M.J., 2023. Evaluating the Electret Radon Progeny Integrated Sampling Unit for use Measuring Radon and Radon Progeny in a Cave Environment. Awaiting publication in the Proceedings of the 2023 Indoor Environments – Radon and Vapor Intrusion Symposium.

Welch, L.E., Paschke, K.A., Doughty, R.M., Klausner, E.C., Jones, M.D., and Lace, M.J., 2024. Characterizing Post-Trial Carryover of Signal When Using E-PERM and Electret Radon Progeny Integrated Sampling Unit Sensors in a High Radon Cave Environment. Awaiting publication in the Proceedings of the 2024 Indoor Environments – Radon and Vapor Intrusion Symposium.

# Cannot Normalize ΔV

- Need to be able to calculate Calibration Factors (CF)
- Requires knowing A and B coefficients
- Know A and B for S chambers in the on position, don't know them for the off position

- CF = A + B * Ln (MPV)
- Where:
  - MPV = midpoint voltage (average of initial and final voltage)
  - CF = calibration factor

Rad-Elec, 2024. *E-PERM® System User's Manual*, Version 4.0.1.

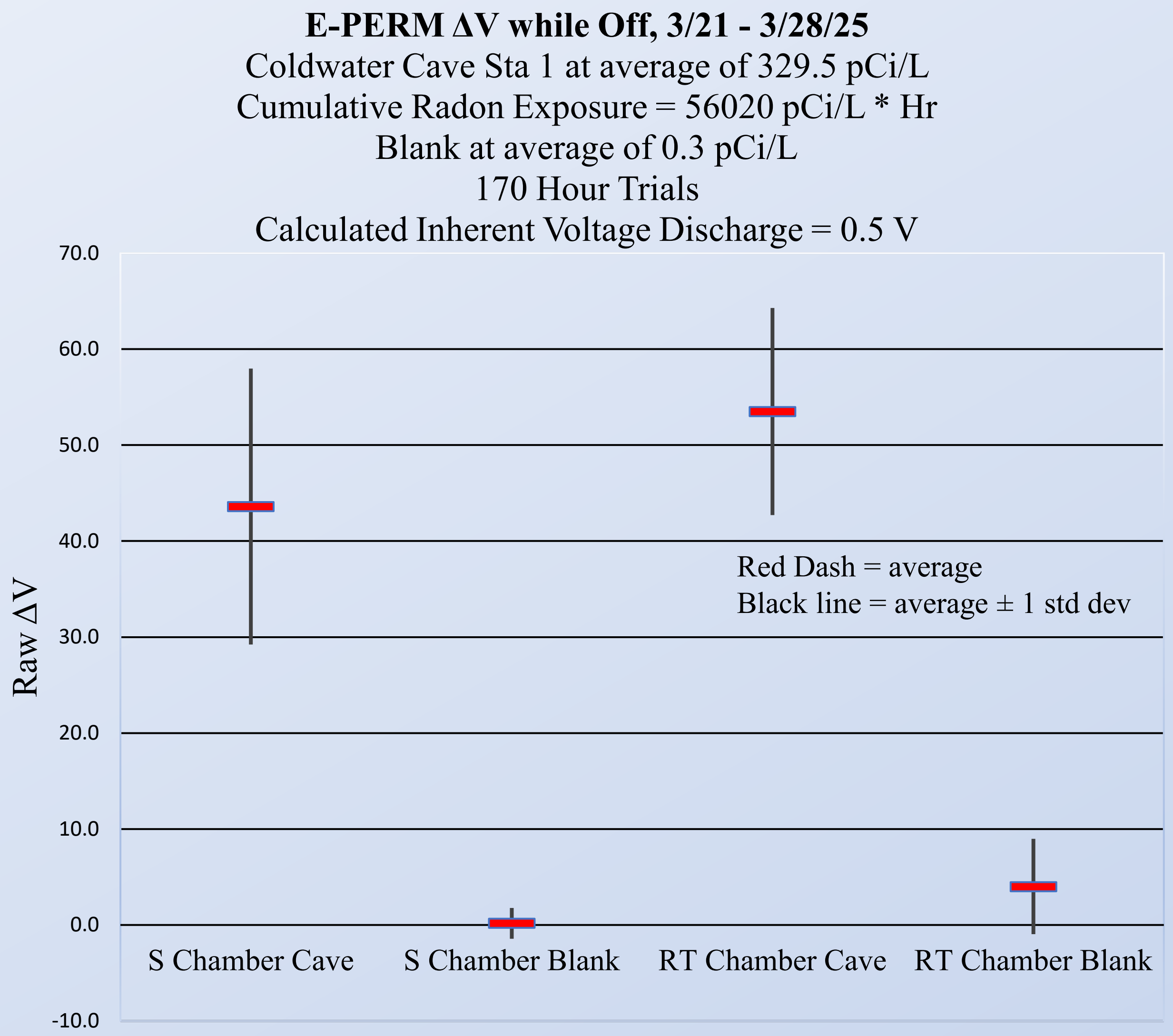
# But, electret sensitivity increases with its voltage

- The first trial used set of sensors with a range of MPV

- Could this be impacting results?

# Addressing Concern 2: Testing Electret Voltage Hypothesis

- Choose electrets such that:
  - Low variation in initial voltage within the set
  - Similar set average initial voltages for the cave set and the control set
- Repeat the earlier experiment



# Looks like the sensor still responds to Radon while the chamber is off

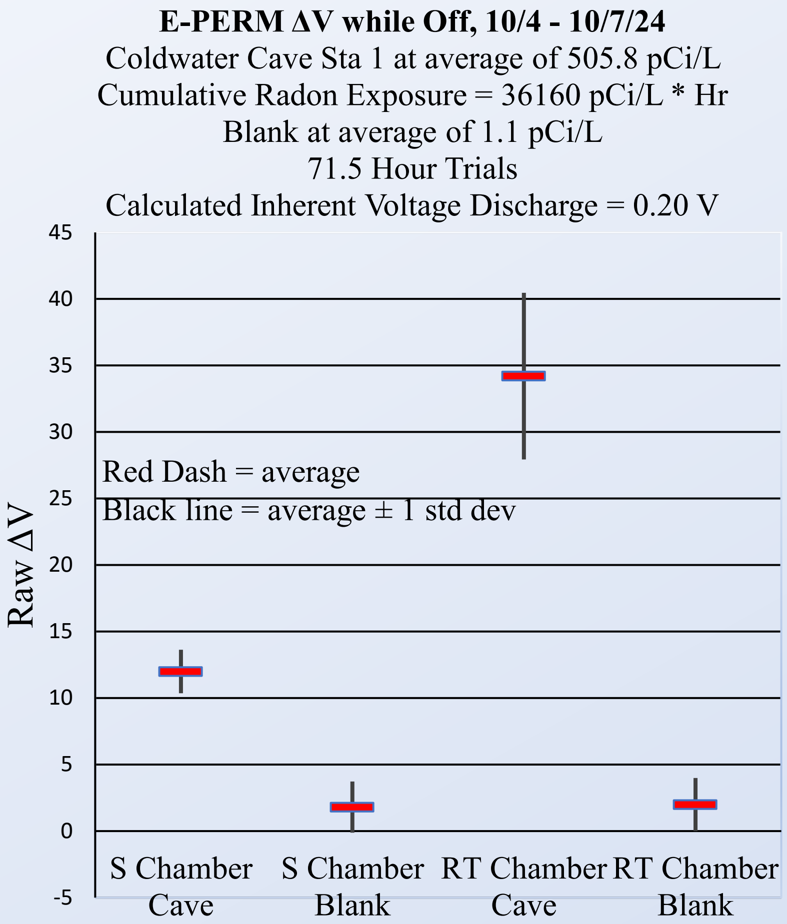
- This means:
  - Radon is getting inside the E-PERM even when the chamber is off
  - There is enough volume between the electret surface and the plunger to permit normal EIC behavior, just on a much smaller scale – referred to as the active chamber

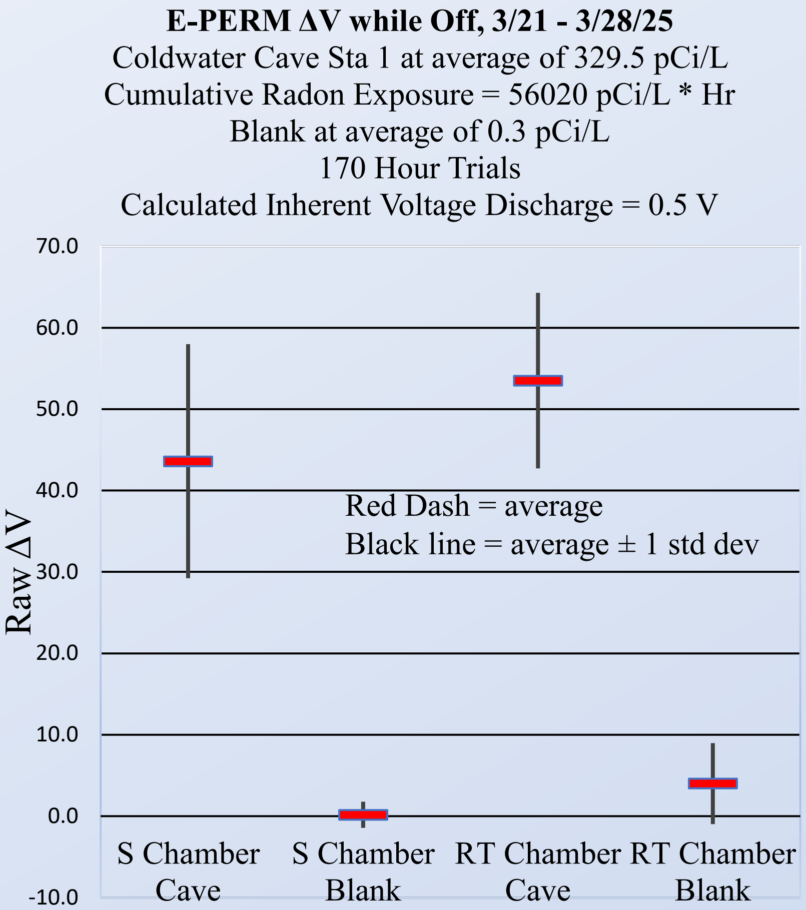
# Probing radon getting into the closed chamber

- Pathways for radon ingress when in the off position
  - A, under the cap
  - B, through the threads at the chamber/electret junction
  - C, for RT chambers only, through the Tyvek-covered pores in the side of the body


Off position E-PERM Sensors and Radon Ingress Pathways. Left E-PERM uses an S chamber, Right E-PERM uses an RT chamber.

# Comparing Trials




- Note that the second trial still had a larger cave signal for the RT chamber than the S chamber
- But, in relative terms, the gap between the two is smaller for the second experiment
- The faster radon ingress of the RT chamber is a larger issue for the shorter (71.5 Hr) first trial compared to the 170 Hr second trial

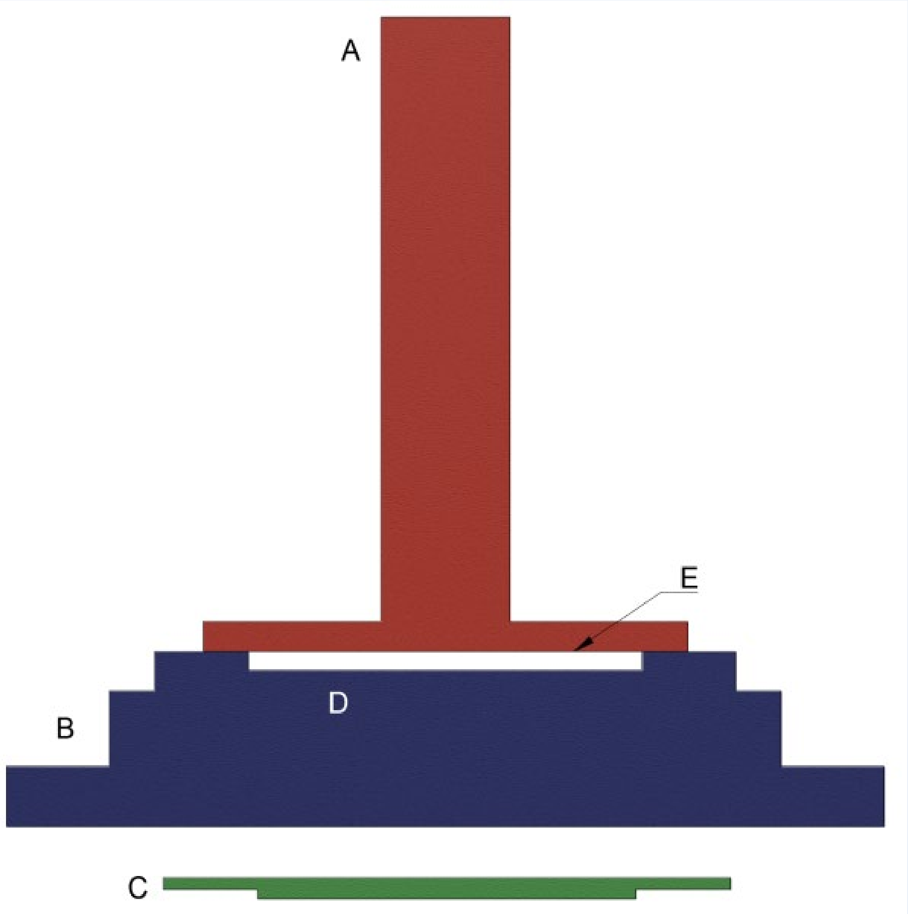
# Adding polyethylene barriers to hinder radon ingress into the off-position S chambers

- Used S chamber due to the slower radon ingress
- 4X nested Ziploc reduced E-PERM off signal to nearly half that seen for in-cave control
- 
- 8x nested Ziploc plus Daren Drum reduces signal to nearly 10% of in-cave control

Daren Drum

| Set | Avg MPV | SD MPV | CRE | Avg ΔV | SD ΔV | % of Control |
|---|---|---|---|---|---|---|
| | | | | | | |
| 6/15 - 6/20/25 E-PERMs in 4X nested Ziploc | 573.4 | 24.3 | 64330 | 12 | 3.5 | 58.3 |
| 6/15 - 6/20/25 Control | 591.3 | 35.1 | 64330 | 20.6 | 4.2 | |
| | | | | | | |
| 6/27 - 7/5/25 E-PERMs in 4X nested Ziploc | 553.1 | 37.7 | 113180 | 20.6 | 3.3 | 57.4 |
| 6/27 - 7/5/25 Control | 563.3 | 38.8 | 113180 | 35.9 | 7.1 | |
| | | | | | | |
| 7/5 - 7/9/25 E-PERMS in 8X nested Ziploc + Daren Drum | 591.1 | 37.1 | 62770 | 2.6 | 1.1 | 12.6 |
| 7/5 - 7/9/25 Control | 598.2 | 31.8 | 62770 | 20.7 | 4.0 | |

# Probe the hypothesis that radon has an active chamber even when off




Scale drawing (side view) of the plunger – electret interface for an E-PERM in the off position

A(red) = plunger
B(blue) = electret
C(green) = spacer
D=positively-charged electret surface
E=active chamber

For scale reference, the plunger bottom width is 1.6 in

- Small space above the electret surface remains when S chamber is closed – 1.3 ml
- Can't reduce this too much or the electret will short upon jostling of the sensor
- Try adding a spacer to reduce the active chamber volume

# Data from Spacer Trials – a mixed bag

| Set | Avg MPV | SD MPV | CRE | Avg ΔV | SD ΔV | RSD (%) ΔV | Stat Sig Diff? |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| 7/9 – 7/13/25 S chamber control, no Spacer | 537.1 | 41.6 | 61220 | 16.4 | 3.5 | 21.4 | No |
| 7/9 - 7/13/25 S chamber with Spacer | 523.4 | 37.1 | 61220 | 15.7 | 14.9 | 95.0 | No |
| | | | | | | | |
| 7/9 – 7/13/25 RT chamber control, no Spacer | 498.8 | 23.8 | 61220 | 38.2 | 9.7 | 25.4 | Yes |
| 7/9 - 7/13/25 RT chamber with Spacer | 487.5 | 42.3 | 61220 | 22.2 | 7.2 | 32.5 | Yes |
| | | | | | | | |
| 8/22 – 8/26/25 S chamber control, no Spacer | 515.1 | 42.6 | 83950 | 20.7 | 2.9 | 14.1 | Yes |
| 8/22 - 8/26/25 S chamber with Spacer | 504.5 | 44.8 | 83950 | 7.9 | 4.7 | 59.4 | Yes |
| | | | | | | | |
| 8/22 – 8/26/25 RT chamber control, no Spacer | 458.8 | 25.9 | 83950 | 38.8 | 5.0 | 12.9 | No |
| 8/22 - 8/26/25 RT chamber with Spacer | 456.4 | 43.5 | 83950 | 28.8 | 22.1 | 76.8 | No |

# Why didn't the spacer trials work better? A look at one of the data sets.

| | 7/9 – 7/13/25 S chamber control, no Spacer | 7/9 - 7/13/25 S chamber with Spacer | 7/9 - 7/13/25 S chamber with Spacer, after Grubbs Test |
|---|---|---|---|
| Sensor 1 ΔV | 15 | 3 | 3 |
| Sensor 2 ΔV | 13 | 36 | 36 |
| Sensor 3 ΔV | 17 | 38 | 38 |
| Sensor 4 ΔV | 15 | 3 | 3 |
| Sensor 5 ΔV | 17 | 10 | 10 |
| Sensor 6 ΔV | 23 | 8 | 8 |
| Sensor 7 ΔV | 12 | 76 | |
| Sensor 8 ΔV | 19 | 12 | 12 |
| | | | |
| Set Avg | 16.4 | 23.3 | 15.7 |
| Set SD | 3.5 | 25.4 | 14.9 |

# A and B Coefficient Determination Theory

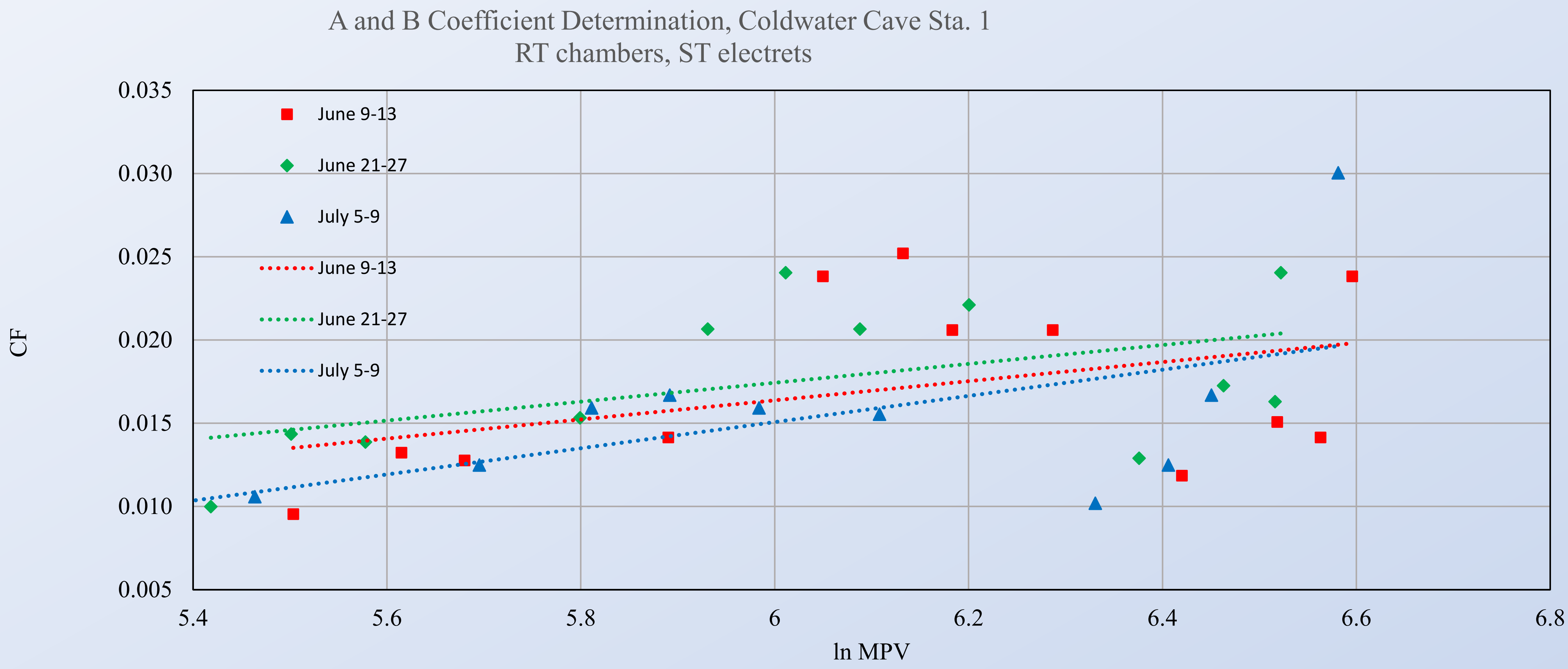
- 
- $RnC = [[\frac{(I-F) - (0.066667*D)}{CF*D}] - BG * G ]$
- Where:
- RnC = radon concentration in pCi/L
- I = initial electret voltage
- F = final electret voltage
- D = experiment duration in days
- CF = calibration factor
- BG = background gamma radiation in µR/Hr
- G = constant converting BG into pCi/L units, 0.087 used here for S chamber (Rad-Elec, 2024).

- Rearrange equation to left to isolate CF
- CF = $\frac{((I-F\ )-(0.066667*D))}{(D*(RnC+BG*G))}$
- Once CF is calculated for each sensor, plot vs Ln MPV
- CF = A + B * Ln (MPV)
- Can find A and B from the slope and intercept of the line fit

# A and B Coefficient Determination Experiment

- Run Trials with 12 off position E-PERMs using RT chambers, run Radon Recon CRM to get RnC value
- Cover a wide range of initial voltages
- Record ΔV values
- Calculate CF and MPV
- Plot CF vs ln MPV

# Graph for A and B coefficient trials



# A and B coefficient experiment conclusions

- Noisy plot, high uncertainty
  - Makes sense, sensor is off, so signal-to-noise is poor
- 3 trials, pretty reproducible outcomes
- Slope is in the right direction – shows that the off E-PERM sensitivity increases with electret voltage, which confirms standard EIC behavior
  - Would not expect this if some background process were causing the ΔV, like background radiation

# Conclusions I

- E-PERM sensors still accumulate ΔV signal at a very low level when the electret is installed but the chamber is off
  - Radon gets in chamber
  - Enough space is available between the plunger and the electret surface to produce a functional active chamber

# Practical Conclusions

- Need to have a very high CRE to observe these changes
- Requires both a high radon concentration and a very long-duration experiment
- Very uncommon circumstances

- Is the presence of active chamber space in the off position a design flaw?
- No, need that space to avoid deterioration of data quality due to contact with the electret surface when the sensor is jarred
- Spacer trials had higher uncertainties as a result
- Space between plunger and electret really is a design feature instead of a design flaw

# Questions?


Contact Info

Lawrence E. Welch

Clara A. Abbott Distinguished

Professor of Chemistry

Knox College

lwelch@knox.edu

309-341-7333


KNOX

PRAIRIE FIRE