CHARACTERIZING POST-TRIAL CARRYOVER OF SIGNAL WHEN USING E-PERM AND ELECTRET RADON PROGENY INTEGRATED SAMPLING UNIT SENSORS IN A HIGH RADON CAVE ENVIRONMENT

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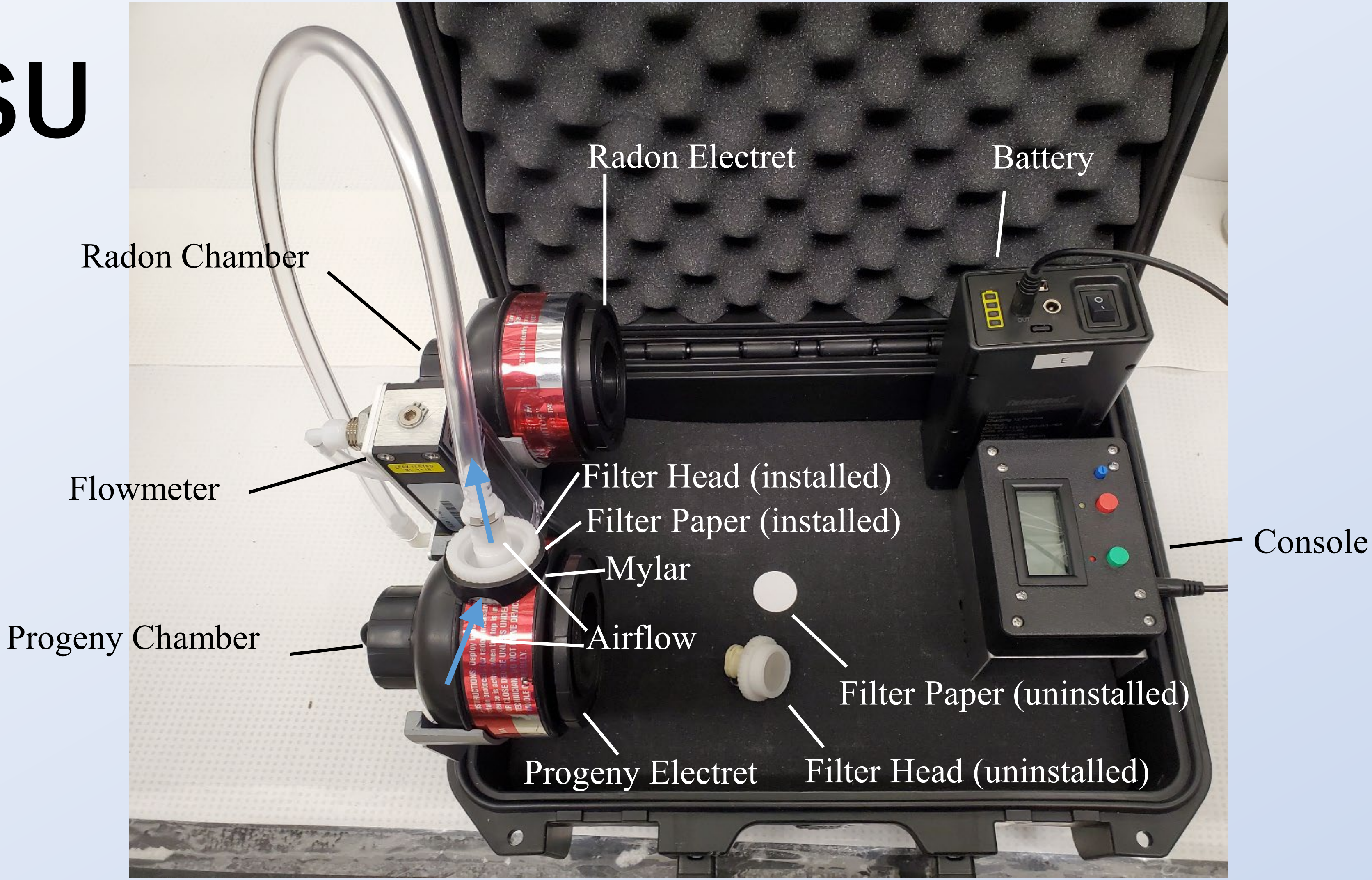
The E-PERM

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

The E-RPISU


Radon Electret
Battery
Radon Chamber
Flowmeter
Filter Head (installed)
Filter Paper (installed)
Mylar
Console
Progeny Chamber
Airflow
Filter Paper (uninstalled)
Progeny Electret
Filter Head (uninstalled)

Results from 2023

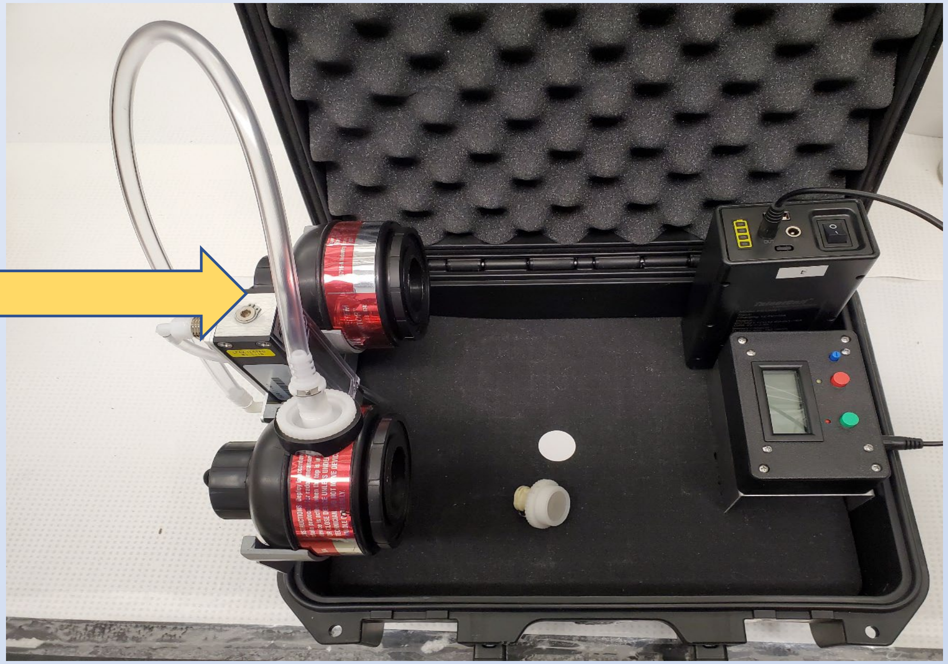
- Both the Radon sensor and the Progeny sensor of the E-RPISU carry over radioactive signal after a trial
- The major source of carryover was the filter paper in the progeny channel
- Less important, but still significant, was carryover related to the chamber itself

Goals for 2024

- 1) Confirm that the E-PERM will feature this same carryover of signal

In theory they should

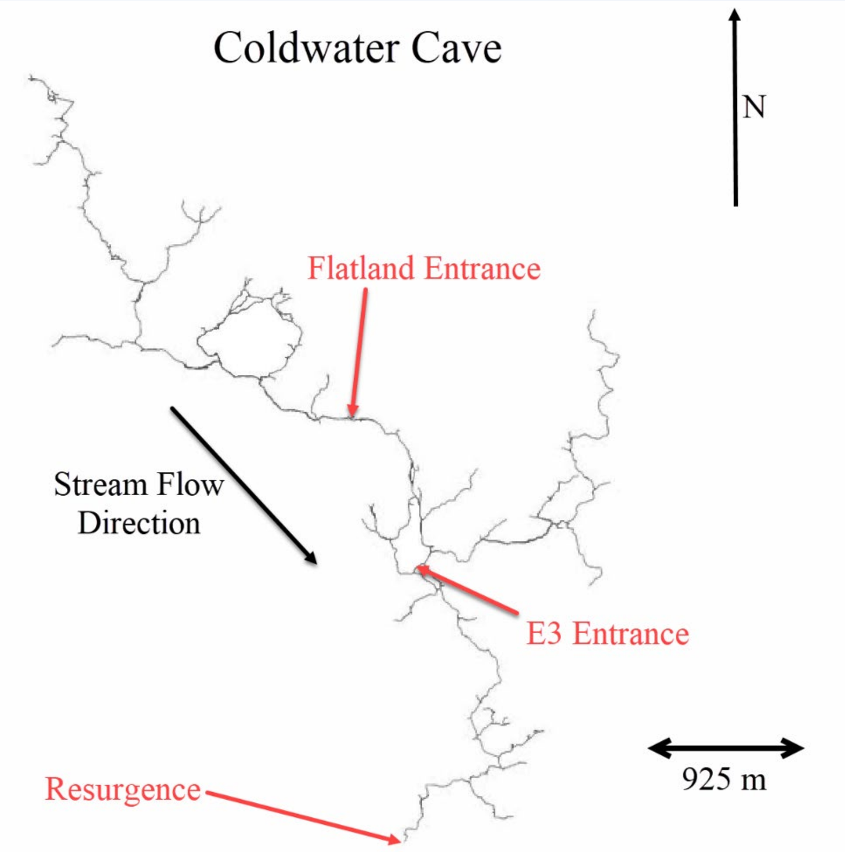
They are essentially the same thing

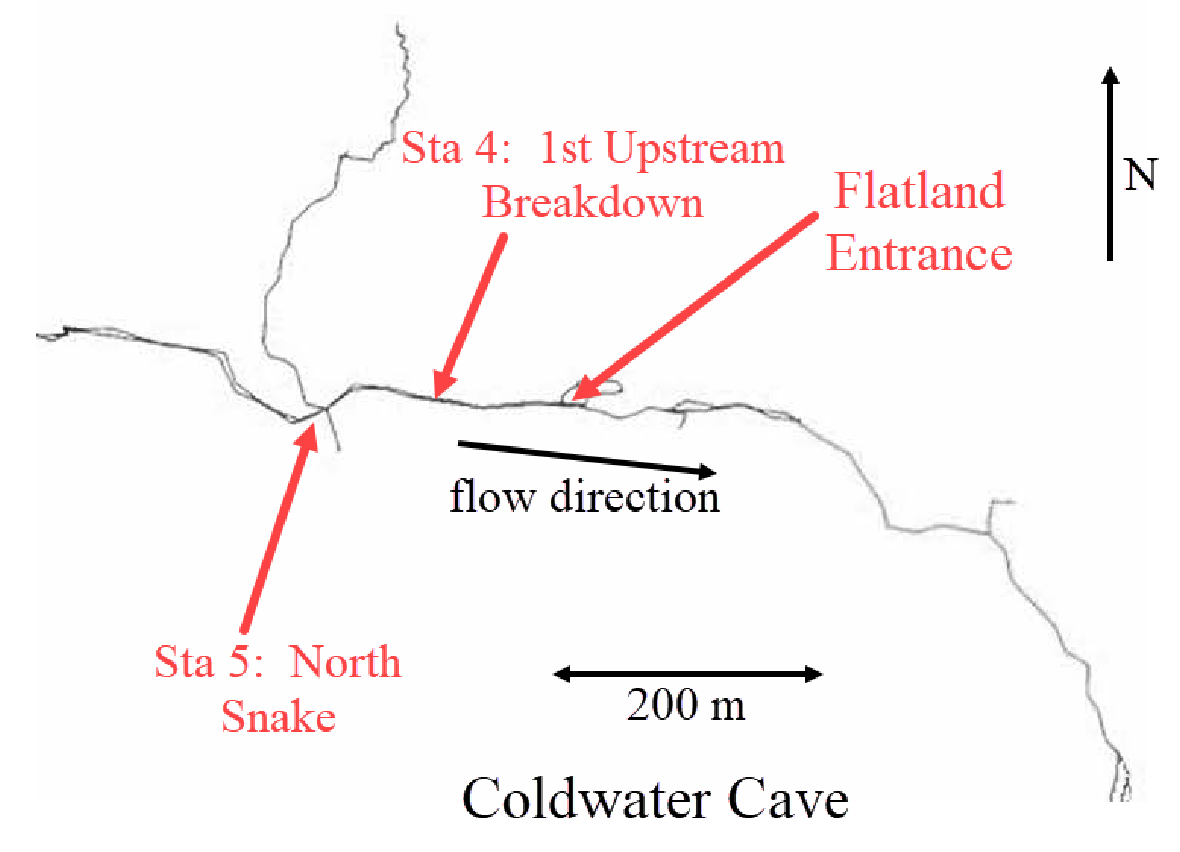


2024 Goals

- 2) Characterize the carryover process further

Sampling Site: Coldwater Cave, Station 4





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

E-PERM Experiment Details

- Run 24 E-PERMs with LT electrets side-by-side at Station 4
- Run 8-12 hours
- Shut all E-PERMs off, remove from the cave, take outdoors
- Vent 30 minutes after shutting off E-PERM (varying procedures)
- Swap LT electrets for ST electrets
- Restart the E-PERMs outside in groups of 6, each started at a different delay time after the sensors were shut off in the cave
- Run all E-PERM carryover trials for 6 hours

E-RPISU Experiment Details

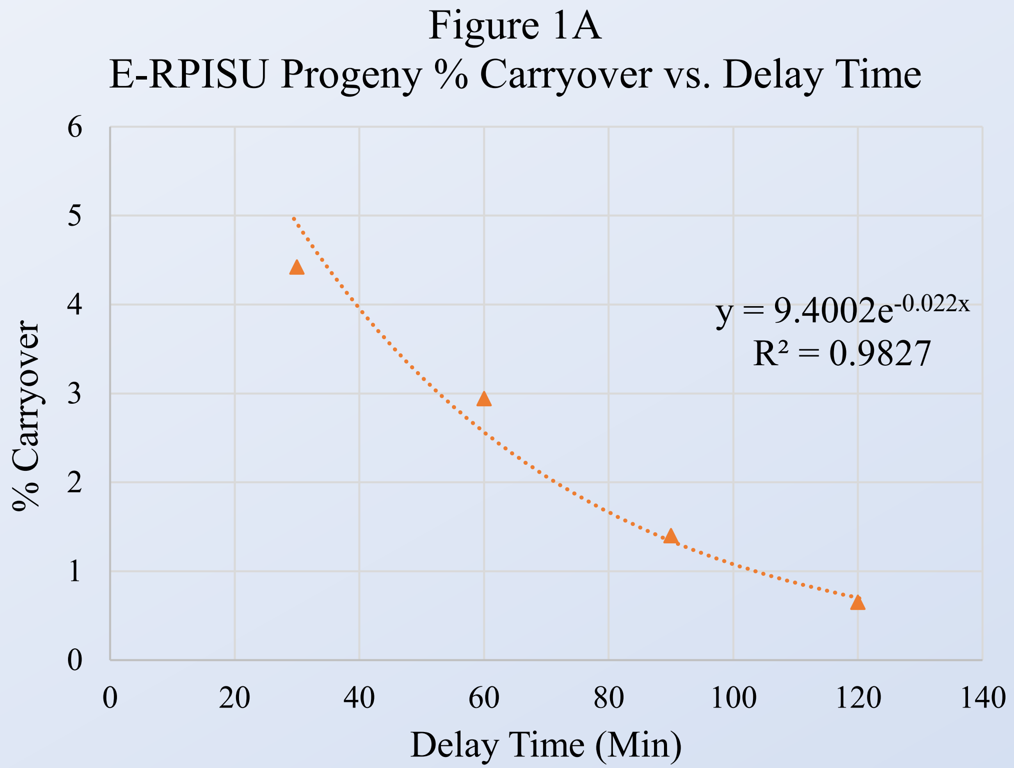
- Run 4 E-RPISUs with LT electrets side-by-side at Station 4
- Run 8-12 hours
- Shut all E-RPISUs off, remove from the cave, take outdoors
- Vent 30 minutes after shutting off E-RPISU (varying procedures)
- Swap LT electrets for ST electrets
- Restart the E-RPISUs outside one by one, each started at a different delay time after the sensors were shut off in the cave
- Run all E-RPISU carryover trials for 6 hours

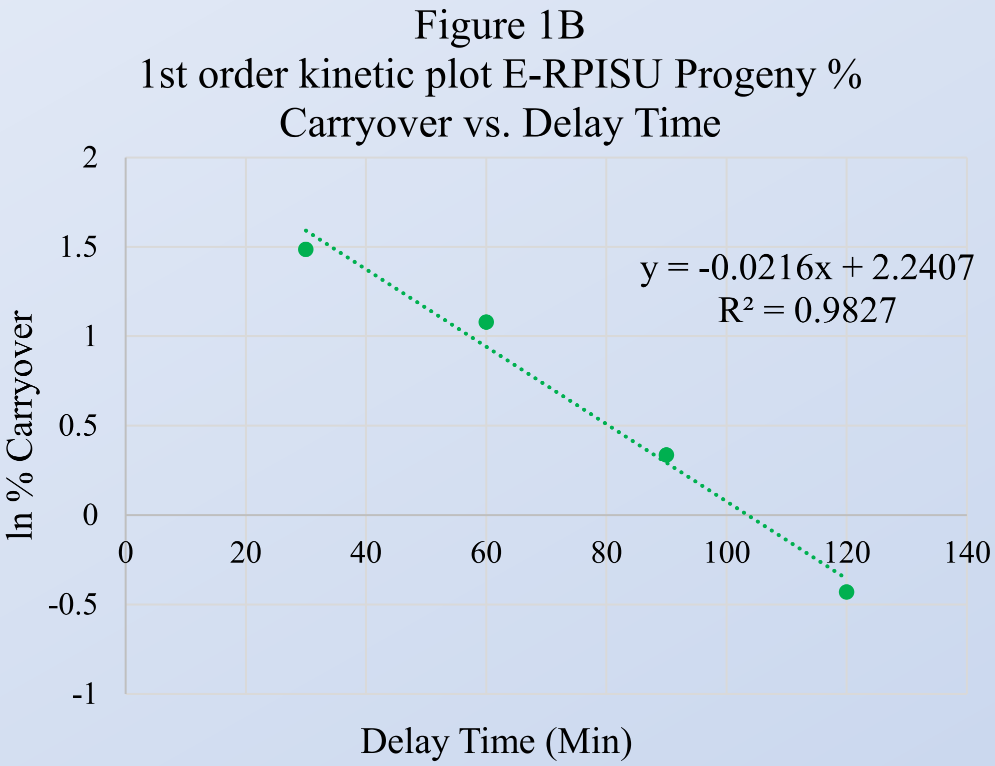
Calculations made from the experiments

- Calculate the % carryover for each
  - % carryover = carryover signal * 100% / in-cave signal
- Plot % carryover vs delay time
  - Expecting an exponential decay – make an exponential fit
- Make a 1st-order kinetic plot – ln % carryover vs delay time
  - Do a linear fit. Rate constant = -slope. Calculate half-life and report R^2.

Set A. Run all 3 sensors December 2023

Plots of data from the E-RPISU progeny sensor





Summary of Set A Data

Set	Date	Sensor Type	Half-life (min)	Exp R^2	E-RPISU Initial flow rate (L/min)	Venting Used
A	**Dec 5-6 2023**	**E-PERM Radon**	**59.4**	**0.9552**		Minimum time needed to switch electrets, <1 min, no agitation
A	**Dec 5-6 2023**	**E-RPISU Radon**	**35.1**	**0.7089**	**0.80**	Minimum time needed to switch electrets, <1 min, no agitation
A	**Dec 5-6 2023**	**E-RPISU Progeny**	**32.0**	**0.9827**	**0.80**	Minimum time needed to switch electrets, <1 min, no agitation

Evaluating the Set A Results 1

- The E-PERM sensors definitely exhibit carryover of signal like the E-RPISU sensors

- All sensors gave an exponential decay

- All calculated half-lives were relatively short
  - Suggestive that the progeny radionuclides were the major players in the carryover, based on known half-lives for the ^{222}Rn decay series.

For reference, the ^{222}Rn Decay Series

Radionuclide	Half-life (min)	Energy of Major Gamma	Radioactive Beta	Emanations (MeV) Alpha
^{222}Rn	5505			5.49
^{218}Po	3.05			6.00
^{214}Pb	26.8	0.295 0.352	0.67 0.73 1.02	
^{214}Bi	19.7	0.609 1.12 1.764	1.0 1.51 3.26	
^{214}Po	$2.73 * 10^{-6}$			7.69
^{210}Pb	$1.17 * 10^{7}$	0.047	0.015 0.061	

Evaluating the Set A Results 2

- Not all of the data was of high quality – the E-RPISU radon gave a poor fit.
- Issue: E-RPISU runs both radon and progeny sensor together, with the progeny sensor producing a much higher signal that the radon sensor
- Low signal at the sensor (low ΔV at the electret) produces poorer precision and high uncertainty
- Carryover ΔV at longer times too small to yield precise data

Adjustments prior to Set B

- Wait until summer when the radon concentration in the cave was higher to improve precision

- To address the disparity between the E-RPISU progeny and the E-RPISU radon sensors, adjust the initial flow rate of the E-RPISU from 0.80 L/min to 0.50 L/min

Summary of Set B Data

Set	Date	Sensor Type	Half-life (min)	Exp R^2	E-RPISU Initial flow rate (L/min)	Venting Used
A	Dec 5-6 2023	E-PERM Radon	59.4	0.9552		Minimum time needed to switch electrets, <1 min, no agitation
A	Dec 5-6 2023	E-RPISU Radon	35.1	0.7089	0.80	Minimum time needed to switch electrets, <1 min, no agitation
A	Dec 5-6 2023	E-RPISU Progeny	32.0	0.9827	0.80	Minimum time needed to switch electrets, <1 min, no agitation
B	Jun 10-11 2024	E-PERM Radon	58.7	0.9751		Minimum time needed to switch electrets, <1 min, no agitation
B	Jul 11-12 2024	E-RPISU Radon	140.0	0.9010	0.50	Minimum time needed to switch electrets, <1 min, no agitation
B	Jul 11-12 2024	E-RPISU Progeny	47.9	0.9711	0.50	Minimum time needed to switch electrets, <1 min, no agitation

Evaluating the Set B Results

- The line fits were much better
- The E-PERM data was similar to that from Set A
  - Helps precision to have 6 side-by-side sensors for each delay time
    - Don’t have this luxury for the E-RPISU
- The E-RPISU radon and progeny sensors still yielded exponential decays with short decay times and better exponential fits, but the values differed quite a bit from Set A.
- What’s going on?
- The system is complicated – the exponential decay is a composite of that from all the different radionuclides present in the sample

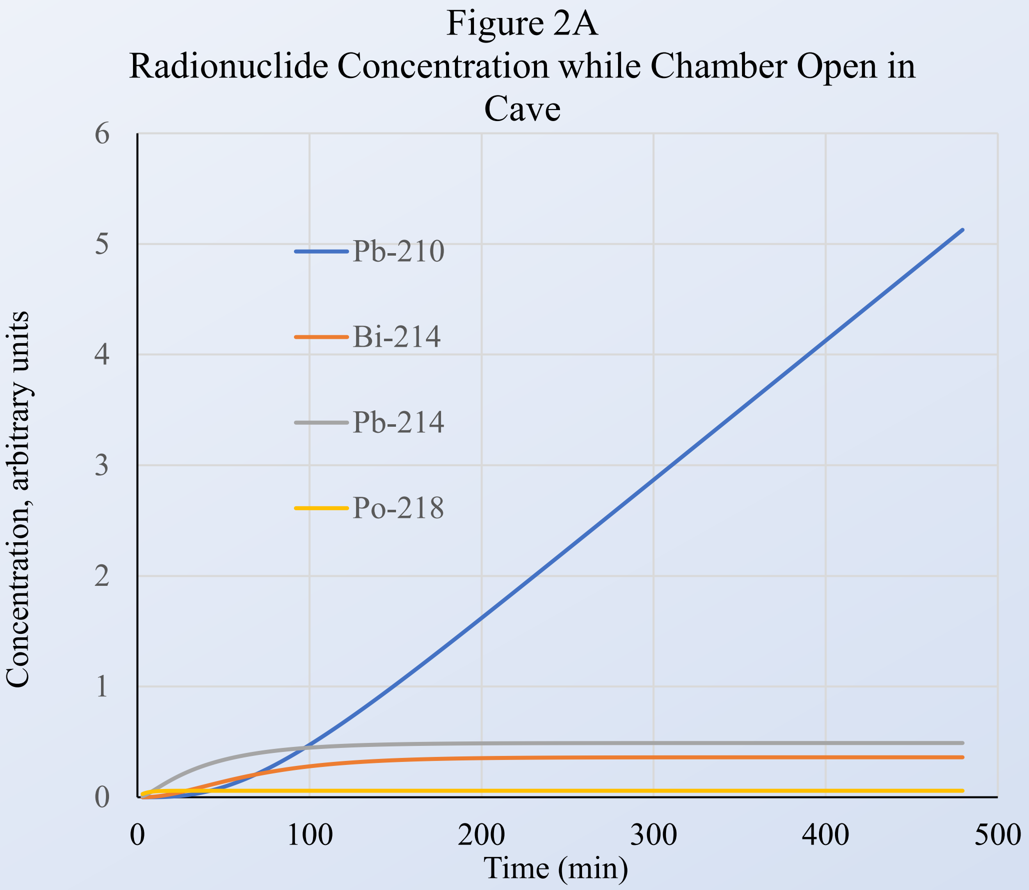
To better understand the composite function, an to evaluate factors that impact it, write an Excel Simulation of the decay

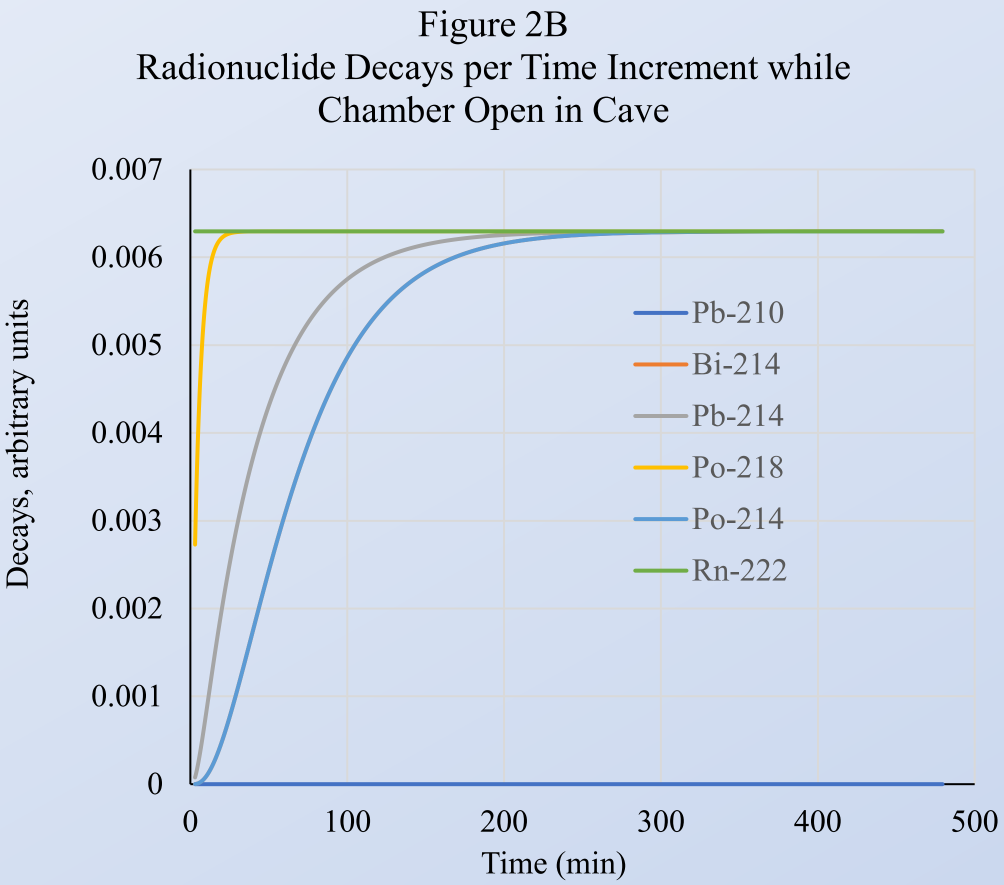
- Tried to match the experimental work as closely as possible
- Assumed only ^{222}Rn was present
- 8 hour in-cave trial. Sensor opened and has constant radon for that period, set to an arbitrary value of 100.
- Progeny concentrations started at zero concentration, and then increased based on their theoretical decay parameters.
- Time increment was chosen to be 0.5 minutes

The simulation 2

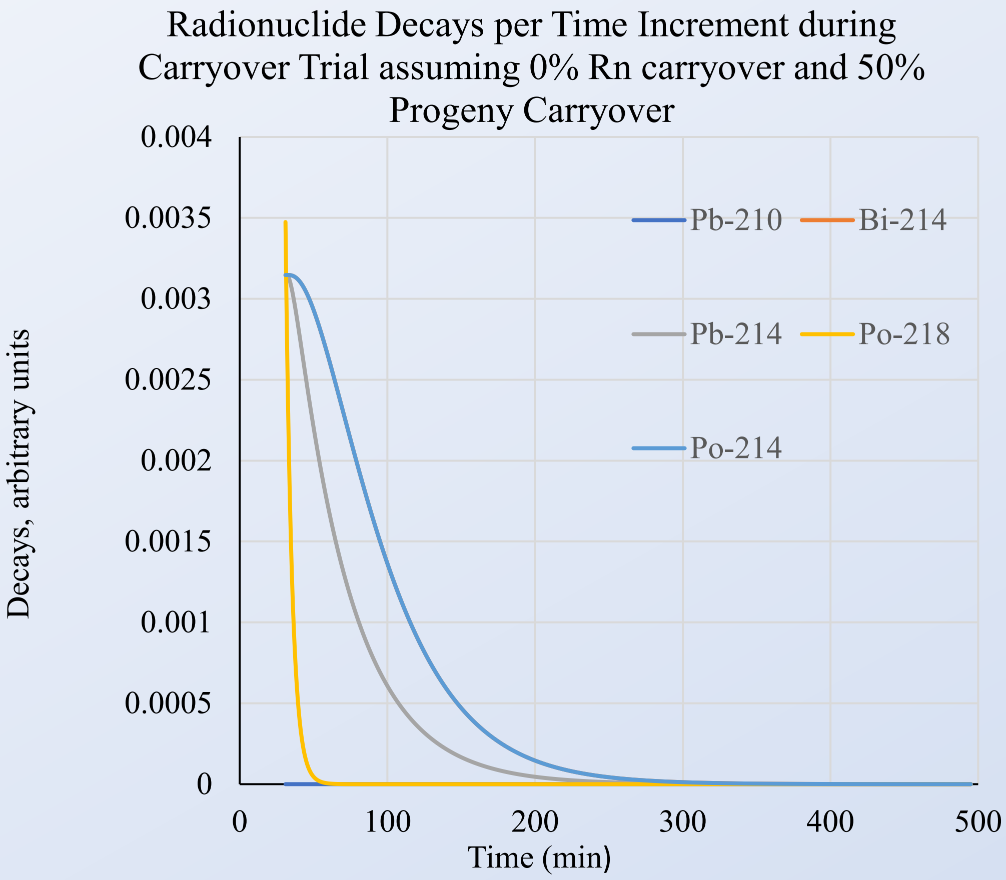
- The chambers were shut off after 8 hours, and kept closed for 30 minutes while removing them from the cave. The radionuclides continue to decay, but no new radon enters the chamber.
- After 30 minutes the chambers were vented. Various venting efficiencies were assumed for different simulation trials.
- The sensors were turned back on for the carryover trial. Since it was run in a blank environment, no new radon enters.
- The carryover trials were all 6 hours in duration.
- The concentrations or decays of radon and the first 5 progeny were integrated over the time frame each sensor was open for the carryover trial

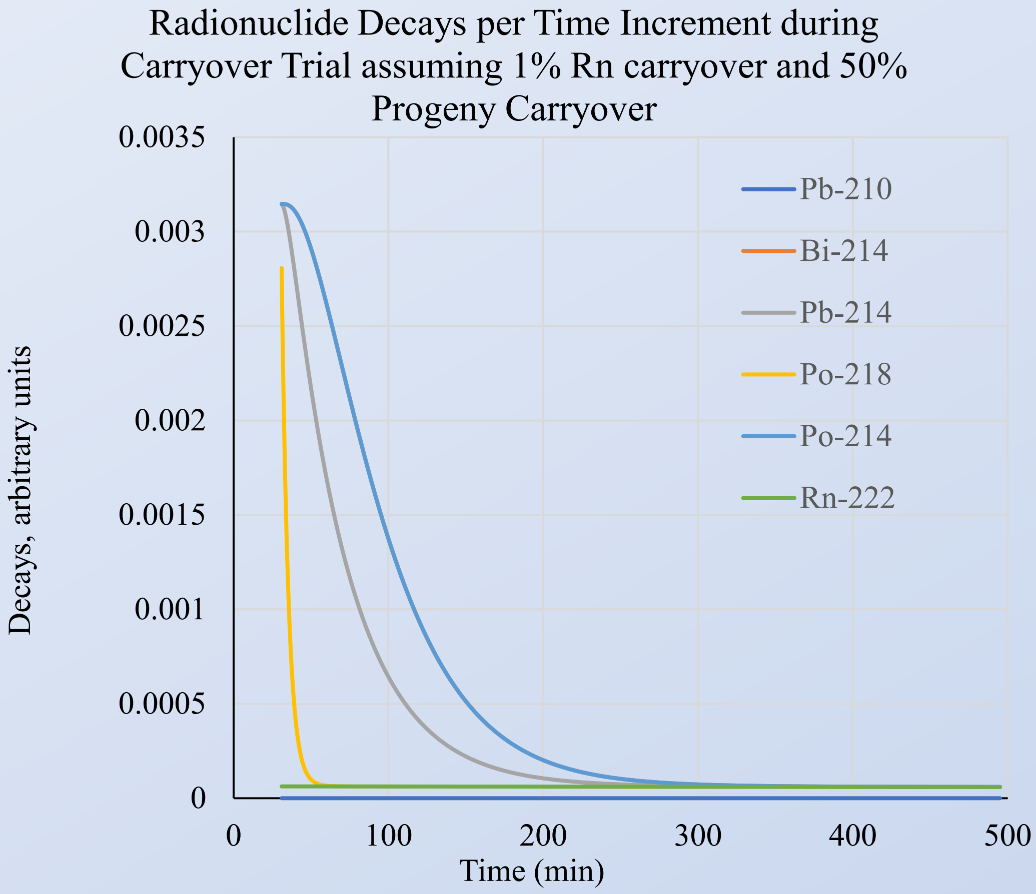
Simulation outcomes: During the in-cave trial





Simulation outcomes: Varying the Assumed % carryover for Radon and Progeny





Compiled Simulation Data

Assumed % Radon Carryover	Assumed % Progeny Carryover	Half-life (min)	R^2
0.0	1	33.8	0.9975
0.0	10	32.2	0.9987
0.0	50	31.9	0.9989
0.0	100	31.8	0.9989
0.5	1	792.9	0.9616
0.5	10	82.4	0.9818
0.5	50	42.6	0.9985
0.5	100	37.4	0.9998
1.0	1	5616	1.000
1.0	10	133.4	0.9704
1.0	50	52.8	0.9940
1.0	100	42.6	0.9985
2.0	1	Signal increases	NA
2.0	10	248.8	0.9615
2.0	50	72.6	0.9853
2.0	100	52.8	0.9940
5.0	1	Signal increases	NA
5.0	10	Signal increases	NA
5.0	50	133.4	0.9704
5.0	100	82.4	0.9818

Lessons Learned from the Simulation

- If no radon is carried over, a variation in the % carryover for the progeny doesn't change the half-life very much
- If even a small amount of radon is carried over, as the assumed % carryover for the progeny goes down, the half life rises sharply
- The progeny grouping was fit well with a single exponential, but this degraded as ^{222}Rn, with its much longer half life, was added
- Chamber venting was not a priority in Sets A and B
  - The haphazard venting technique likely explains the difference in the carryover data and calculated half-lives

Plan for a Set C

- Similar to Set B, run during high in-cave radon levels, but pay much more attention to venting
  - Vent the chamber after 30 minutes in the “off” position by removing the electret
  - Keep the chamber open for 10 minutes
  - Wave the open chamber around for 20 seconds to help flush out carryover gases
  - Install new ST electret after 10 minutes

Set C Data

Set	Date	Sensor Type	Half-life (min)	Exp R^2	E-RPISU Initial flow rate (L/min)	Venting Used
A	Dec 5-6 2023	E-PERM Radon	59.4	0.9552		Minimum time needed to switch electrets, <1 min, no agitation
A	Dec 5-6 2023	E-RPISU Radon	35.1	0.7089	0.80	Minimum time needed to switch electrets, <1 min, no agitation
A	Dec 5-6 2023	E-RPISU Progeny	32.0	0.9827	0.80	Minimum time needed to switch electrets, <1 min, no agitation
B	Jun 10-11 2024	E-PERM Radon	58.7	0.9751		Minimum time needed to switch electrets, <1 min, no agitation
B	Jul 11-12 2024	E-RPISU Radon	140.0	0.9010	0.50	Minimum time needed to switch electrets, <1 min, no agitation
B	Jul 11-12 2024	E-RPISU Progeny	47.9	0.9711	0.50	Minimum time needed to switch electrets, <1 min, no agitation
C	**Jul 24-25 2024**	**E-PERM Radon**	**47.7**	**0.9483**		**Sensor opened for 10 min, chamber waved around for 20 sec**
C	**Jul 24-25 2024**	**E-RPISU Radon**	**51.0**	**0.9757**	**0.50**	**Sensor opened for 10 min, chamber waved around for 20 sec**
C	**Jul 24-25 2024**	**E-RPISU Progeny**	**34.1**	**0.9684**	**0.50**	**Sensor opened for 10 min, chamber waved around for 20 sec**

Evaluating the Set C Results

- High Quality data

- Extrapolated % carryover at time zero gave values between 7-10%

- The E-RPISU progeny sensor gave a lower half-life
  - The E-RPISU progeny sensor has the filter assembly that is known to carry over the largest portion of the signal, as opposed to the radon sensors where the carryover only comes from the chamber walls.
  - As such, the progeny sensor has a higher effective % progeny carryover.
  - The simulation suggests that if any radon is present, the higher % progeny carryover will result in a lower half-life, which is what was observed here.

Conclusions

- The radon doesn't adhere to the sensors, but a small amount will be carried over unless venting procedures are highly efficient
- The progeny will adhere to the sensors, and makes up the major part of the % carryover signal. A 10% carryover might be a good ballpark estimate.
- The decay is exponential with a half-life highly dependent on venting efficiency.

Running back-to-back E-PERM or E-RPISU Experiments without carryover problems

- As noted in the 2023 talk, swap out the components that adsorb the radionuclides: filter paper, filter head, chamber

OR

- Wait
  - In theory, radioactive signal will be reduced to 1% of the original in 6.64 half-lives
  - From the simulation, best to vent really well, as even a small amount of carryover radon greatly increases the half-life, and thus the wait time.

Acknowledgements

- Cave landowner
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Questions?

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