Evaluation of Consumer Digital Radon Measurement Devices: A Comparative Analysis

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Purpose

- Kansas State University (KSU) Radon Programs, via the cooperative partnership with the U.S. EPA to provide national radon technical assistance, conducted an abridged evaluation of multiple consumer-grade digital radon monitors.

Previous Study

- Published in the Journal of Radiological Protection
  - "A comparison of consumer-grade electronic radon monitors" (Pam Warkentin et al 2020 *J. Radiol. Prot.* 40 1258)
  - Looked at 6 different models (5 of each type)
  - Performed 4 different exposures
    - Winter and Summer at action level
    - Winter at twice action level
    - Winter at 5 times action level
  - Looked at measurement error for each exposure
  - Used an A to E ranking scale
    - performance grade of A having a measurement error ≤ 10 %
    - Performance grade of E having a measurement error > 40%

Overview

- Models to be reviewed include:
  - Detector A (brand name withheld by request)
  - EcoQube
  - EcoBlu
  - RadonEye
  - Lüft
  - View Radon
  - Wave Radon
  - Corentium Home

Device Output- EID/CRM

- Single Data Point (Daily, 7 day, long term)
  - Detector A
  - Corentium Home
  - EcoBlu
- Online Interface with Hourly Data
  - Airthings View Radon
  - Airthings Wave Radon
  - SunRadon Lüft
  - Ecosense Radon Eye
  - Ecosense EcoQube

What do these devices look like?

EcoQube

EcoBlu

RadonEye

Lüft

View Radon

Wave Radon

Corentium Home

KSU Radon Chamber

- AARST NRPP approved secondary test chamber

- Uses RN-1025 flowthrough radioactive gas source that contains Ra-226 that provides calibrated quantities of radon for use in the chamber

- Uses a small fan that distributes the gas throughout the chamber

- Measure average radon concentration using two AB-5 portable radiation monitors
  - One records number of counts over a 5-hour period
  - One records hourly radon concentration
  - Grab sample taken at least once during exposure to ensure accurate results

Procedure

- Five copies of each device model were exposed to:
    - 12.8 pCi/L to 15.5 pCi/L
        - Ecosense (10 pCi/L), Lüft (4 pCi/L), Airthings (5.4 pCi/L)
    - 0.6 pCi/L
    - 27.7 pCi/L to 29.4 pCi/L
        - Detector A (25 pCi/L)
- For all three exposures the temperature and relative humidity was set at household ambient levels
- Exposures were 7 days long
- Data analysis used the device evaluation metrics in the ANSI/AARST Performance Specifications for Instrumentation Systems Designed to Measure Radon Gas in Air (MS-PC)

What does the MS-PC evaluate?

- "This standard specifies the minimum performance criteria and testing procedures for instruments and/or systems designed to quantify the concentration of Radon-222 gas in air."

- Testing Criteria
  - Accuracy and Precision
  - Minimum Detectable Concentration or Integrated Concentration
  - Proportionality
  - Temperature
  - Humidity
  - Compliance

What does the MS-PC evaluate?

- Accuracy and Precision
  - MS-PC Criteria
    - Each device shall demonstrate an Individual Percent Error (IPE) within 0 ± 25% when tested at:
      - A radon concentration in the range of 6-15 pCi/L
      - A temperature in the range of 65-75⁰ F; and
      - A relative humidity in the range of 10-55% with radon concentration, temperature, and relative humidity held as constant as practicable
    - The precision of the devices shall be assessed using the Coefficient of Variation (CV) of the set of five devices which shall be less than or equal to 15%

What did we evaluate?

- Individual Percent Error (IPE): The degree from which a single measure value (X) deviate from the conventionally true value (T) and it measures accuracy of the devices.
  - $IPE = [100(X - T)/T]]$
- Coefficient of Variation (CV): The sample standard deviation (s) of a set of measurements expressed as a percentage of the arithmetic mean of the measurements and it measures the precision of the devices.
  - $CV = 100 * \left(\frac{s}{mean}\right)$

Exposure 1

12.8 pCi/L to 15.5 pCi/L

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Exposure 1 Conditions

- Performed three 7 day runs
- Dates:
  - 5/31/23-6/7/23
  - 6/7/23-6/14/23
  - 6/29/23-7/6/23
- Goal: 8-10 pCi/L
- Chamber Radon Values:
  - 12.8 pCi/L
  - 13.7 pCi/L
  - 15.5 pCi/L

- Temperature:
  - 74.0°F
  - 73.9°F
  - 72.7°F
- Humidity:
  - 18.9%
  - 15.8%
  - 17.3%
- Barometric Pressure:
  - 28.69 in Hg
  - 28.59 in Hg
  - 28.60 inHg

Summary of Results for Exposure 1

Device	Individual Percent Error (Should be 0 ± 25% for each of 5 devices)	Average Individual Percent Error Across all 5 devices	Coefficient of Variation (Should be ≤15%)	Average Radon Concentration (pCi/L)	Standard Deviation
Detector A	✓	-2.5%	7.2%	12.5 pCi/L	0.90
EcoQube	✓	2.36%	2.1%	14.0 pCi/L	0.293
EcoBlu	✓	-18.04%	1.8%	10.5 pCi/L	0.19
RadonEye	✓	-9.6%	2.4%	12.4 pCi/L	0.3
Lüft	✓	-20.3%	3.6%	12.4 pCi/L	0.45
View Radon		-28.5%	5.6%	9.16 pCi/L	0.51
Wave Radon	✓	3.64%	4.5%	14.2 pCi/L	0.632
Corentium Home	✓	-8.64%	7.7%	11.7 pCi/L	0.90

EcoQube to Pylon Comparison for Chamber Value of 13.7 pCi/L
Average Radon Concentration: 14 pCi/L
Standard Deviation: 0.293
Average Individual Percent Error: 2.36%
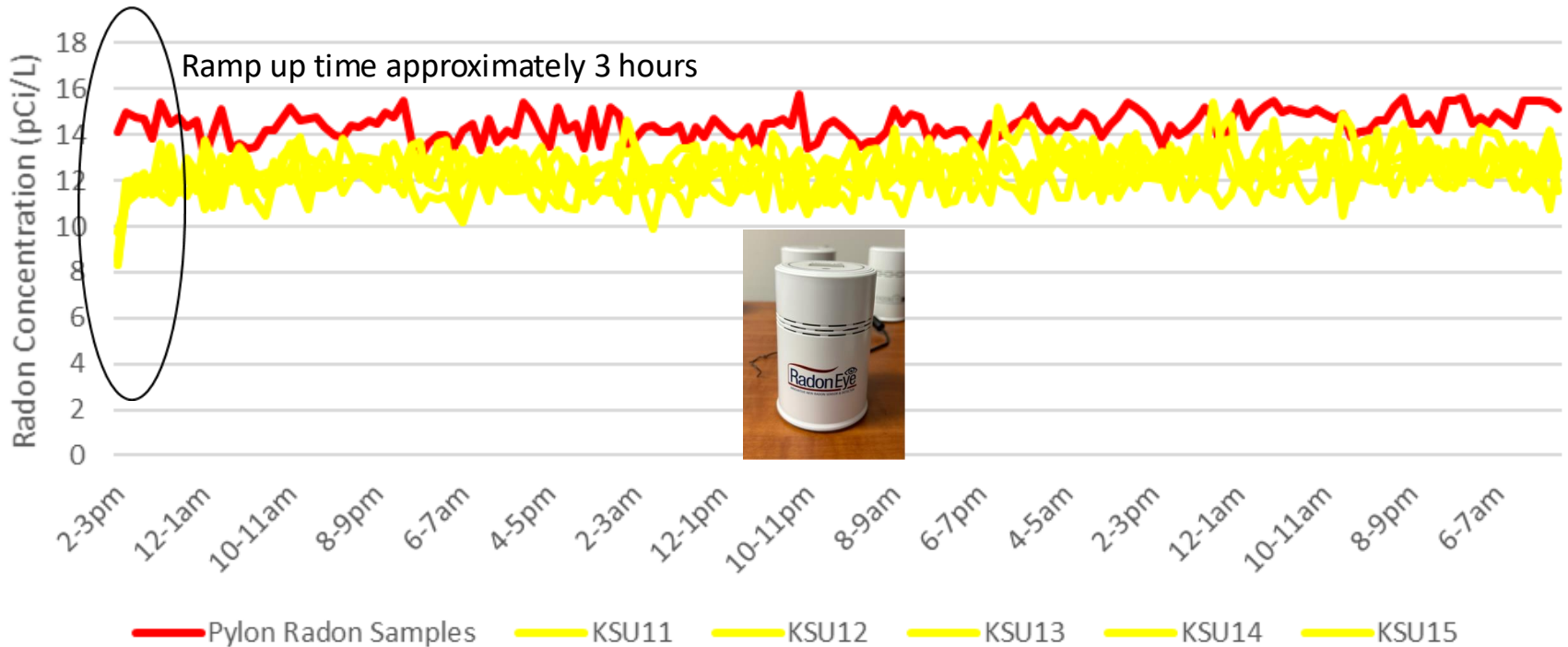
Ramp up time approximately 3 hours
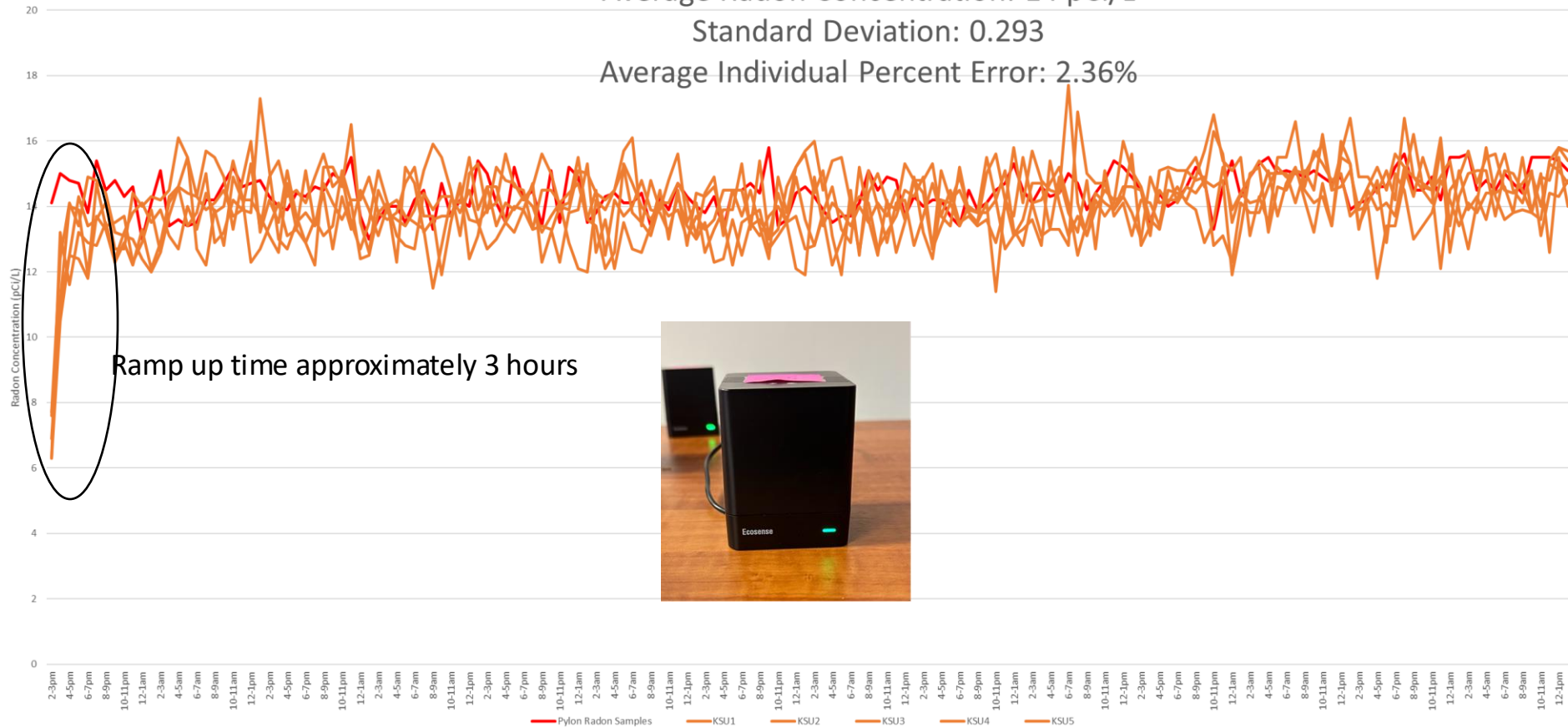
RadonEye to Pylon Comparison for Chamber Value 13.7 pCi/L
Average Radon Concentration: 12.4 pCi/L
Standard Deviation: 0.300
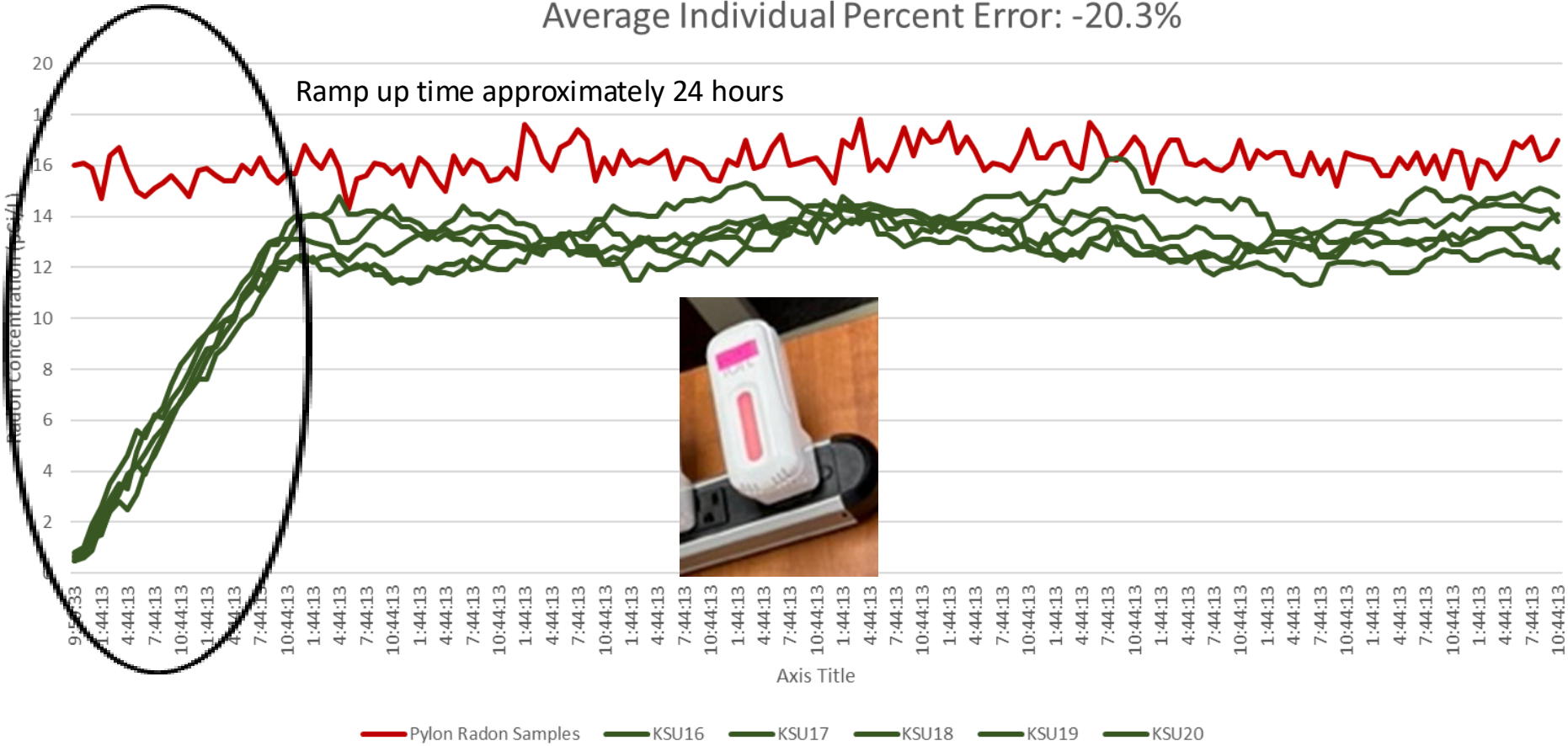Average Individual Percent Error: -9.6%

Ramp up time approximately 3 hours

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Lüft to Pylon Comparison for Chamber Value 15.5 pCi/L
Average Radon Concentration: 12.4 pCi/L
Standard Deviation: 0.45
Average Individual Percent Error: -20.3%
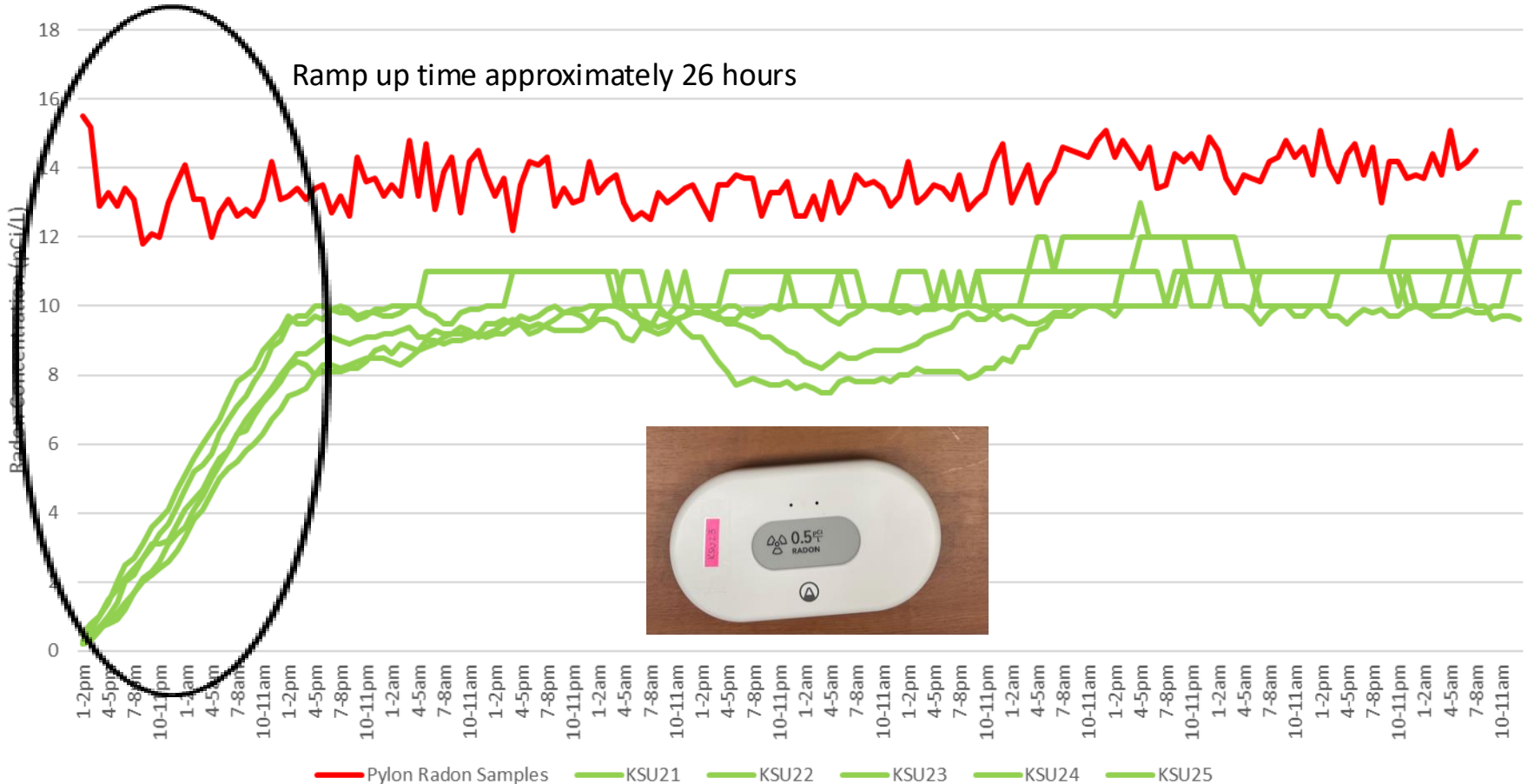
Ramp up time approximately 24 hours

View Radon to Pylon Comparison for Chamber Value 12.8 pCi/L
Average Radon Concentration: 9.16 pCi/L
Standard Deviation: 0.51
Average Individual Percent Error: -28.5%
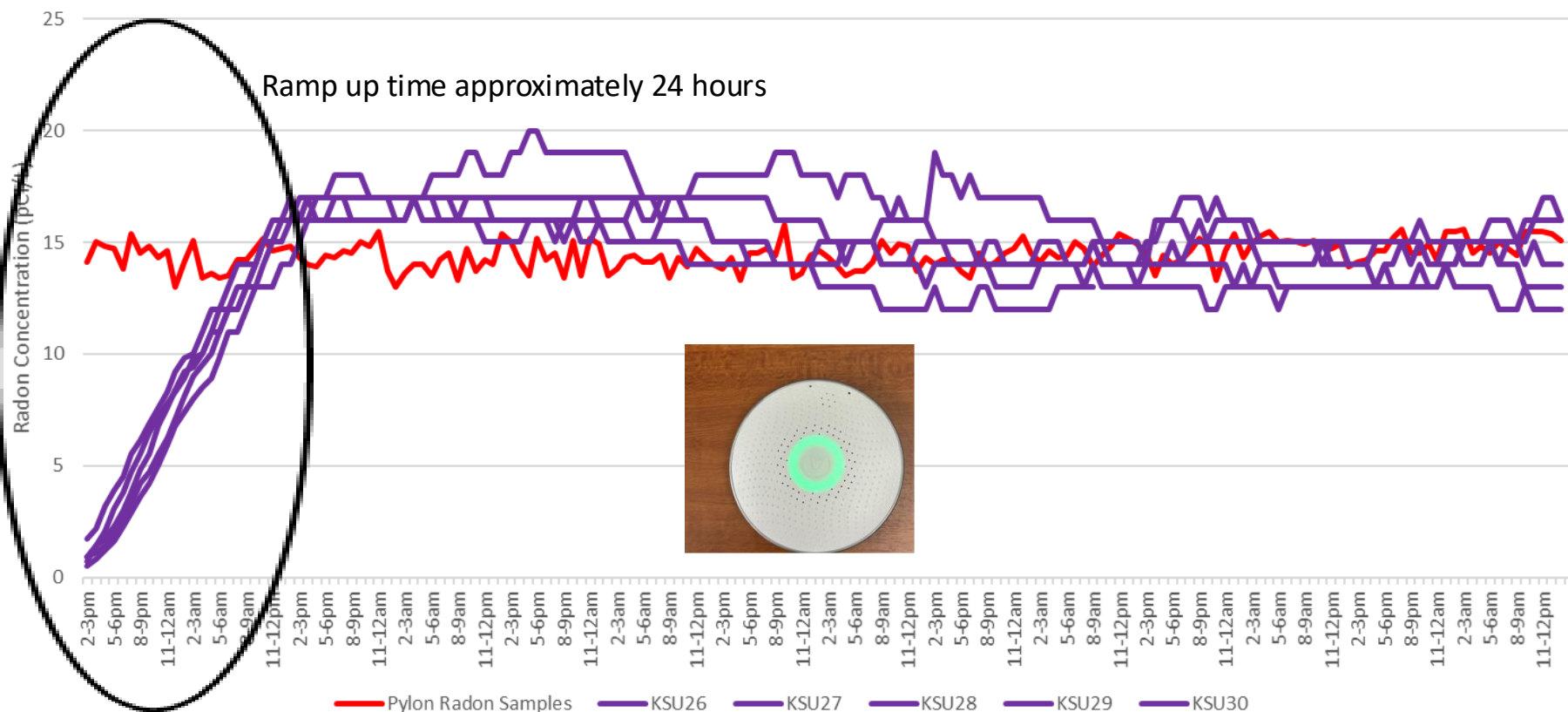
Ramp up time approximately 26 hours

Wave Radon to Pylon Comparison for Chamber Value of 13.7 pCi/L
Average Radon Concentration: 14.2 pCi/L
Standard Deviation: 0.632
Average Individual Percent Error: 3.64%
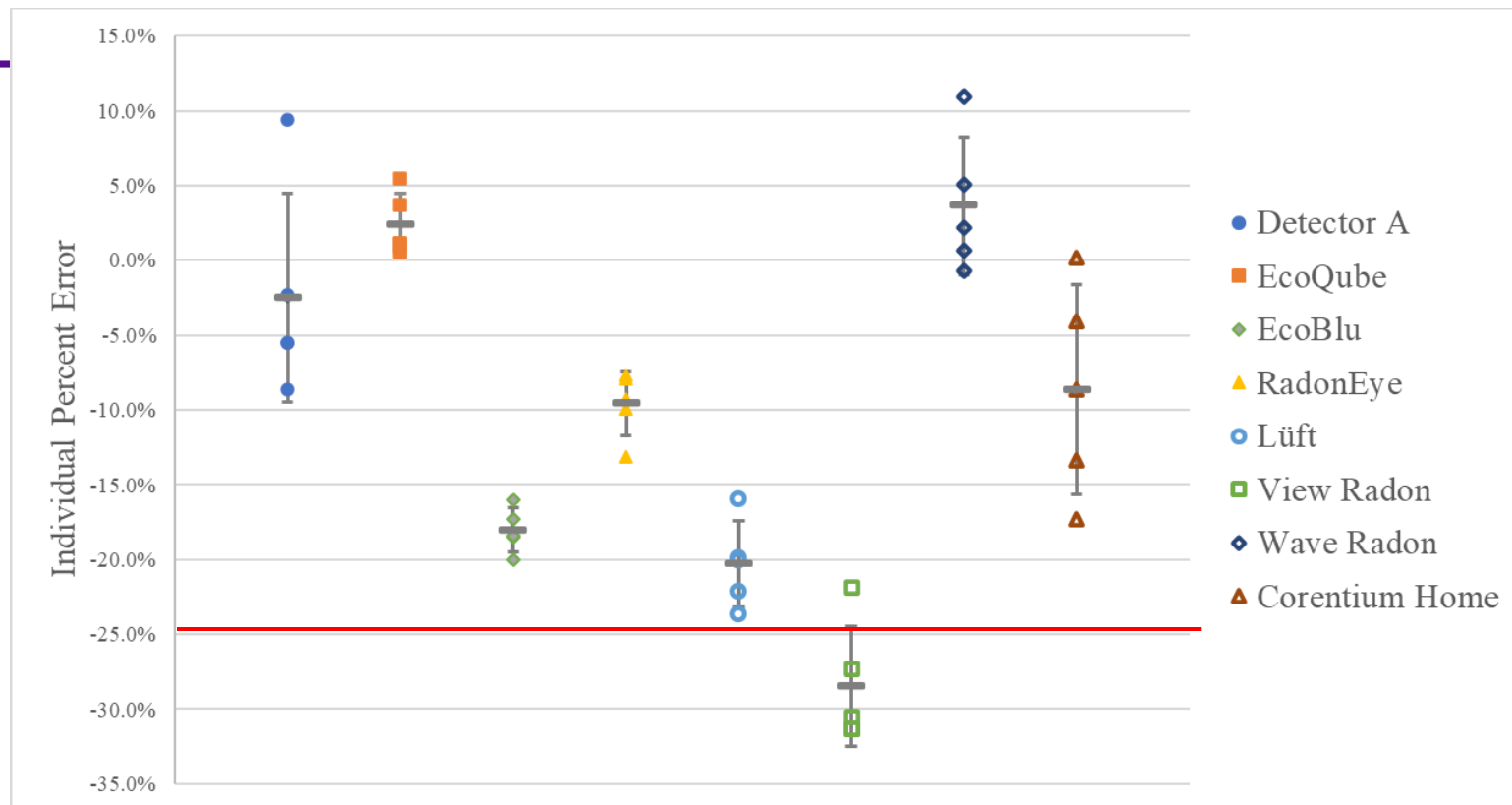
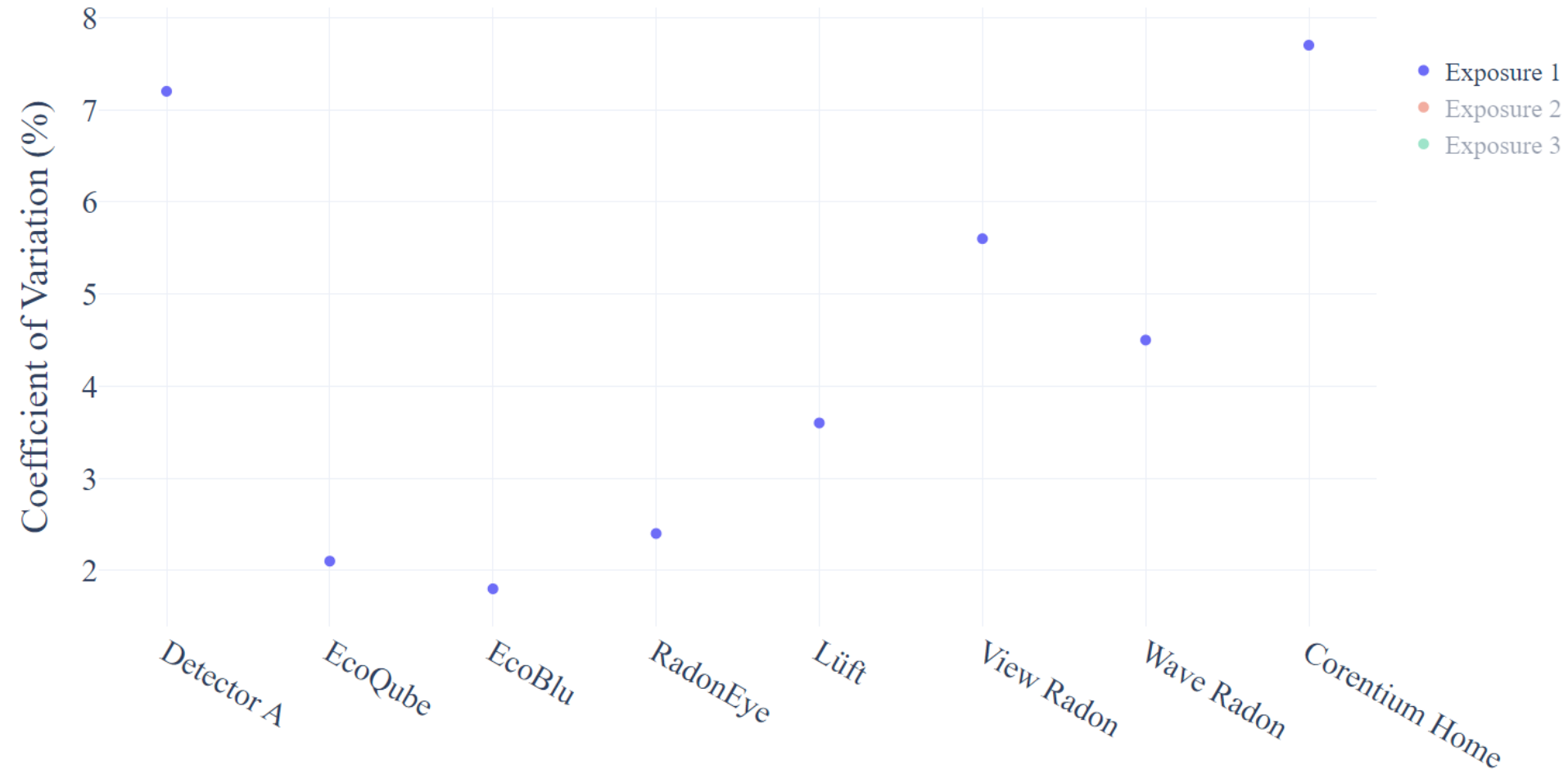Ramp up time approximately 24 hours

Individual Percent Error for Exposure 1

- Individual Percent Error (IPE): The degree from which a single measure value (X) deviates from the conventionally true value (T)
- Average and standard deviation are show for each device model

Coefficient of Variation- Exposure 1

$$CV = 100 * \left(\frac{s}{mean}\right)$$

- Coefficient of Variation measures precision

Exposure 2

Ambient Air: 0.6 pCi/L

Ambient Air Exposure Conditions

- Performed one 7 day run

- Dates: 6/15/23-6/22/23

- Goal: Ambient Air

- Ambient Radon Value Average: 0.63 pCi/L

- Temperature: 70°F

- Humidity: 43.4%

- Barometric Pressure: 28.64 inHg

Summary of Results for Exposure 2

| Device	Average Individual Percent Error Across all 5 devices	Coefficient of Variation (Should be ≤15%)	Average Radon Concentration (pCi/L)	Standard Deviation
Detector A	31%	18.1%	0.8 pCi/L	0.148
EcoQube	16.6%	2.2%	0.7 pCi/L	0.016
EcoBlu	-2.5%	4.5%	0.6 pCi/L	0.027
RadonEye	-2.92%	5.4%	0.6 pCi/L	0.033
Lüft	-8.98%	17.4%	0.6 pCi/L	0.099
View Radon	-6.48%	14.6%	0.6 pCi/L	0.086
Wave Radon	10.8%	21.3%	0.7 pCi/L	0.148
Corentium Home	-14.3%	6.1%	0.6 pCi/L	0.033

Individual Percent Error for Exposure 2
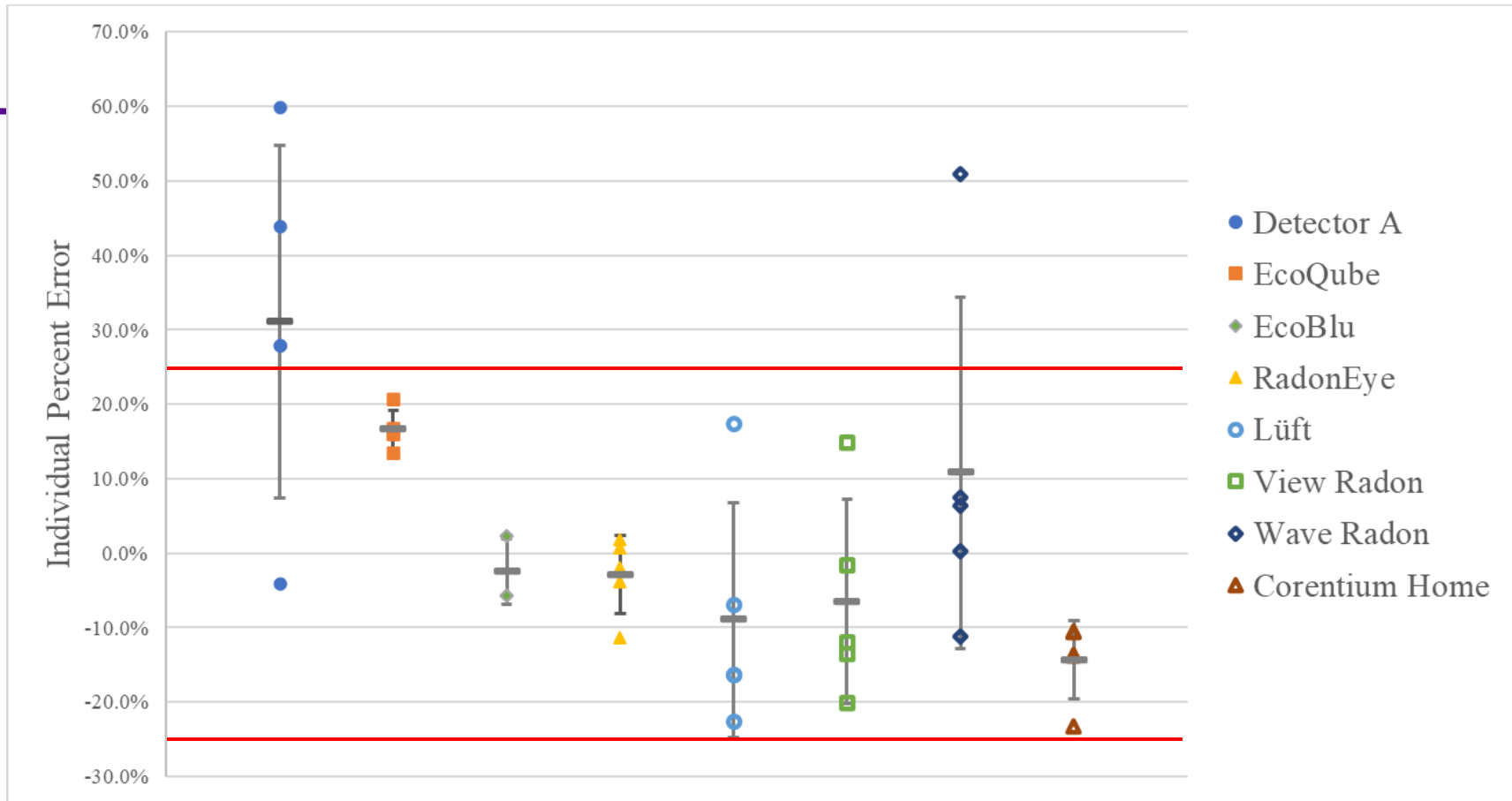
- Individual Percent Error (IPE): The degree from which a single measure value (X) deviates from the conventionally true value (T)
- Average and standard deviation are show for each device model

Understanding IPE Results

- It is anticipated that the absolute value of IPE will decrease as the radon concentration approaches the device model calibration range.
  - Seven of the eight device models have a reported specifications for accuracy and precision near the US EPA action level of 4 pCi/L Seven of the eight device models demonstrated an average IPE within ± 25%.
  - Detector A has reported specifications for accuracy and precision at 25 pCi/L. The ambient air radon concentration average was 0.6 pCi/L, well below the lower limit of the assumed calibration range, and therefore it is anticipated that the accuracy will suffer.

Coefficient of Variation- Exposure 2

$$CV = 100 * \left(\frac{s}{mean}\right)$$
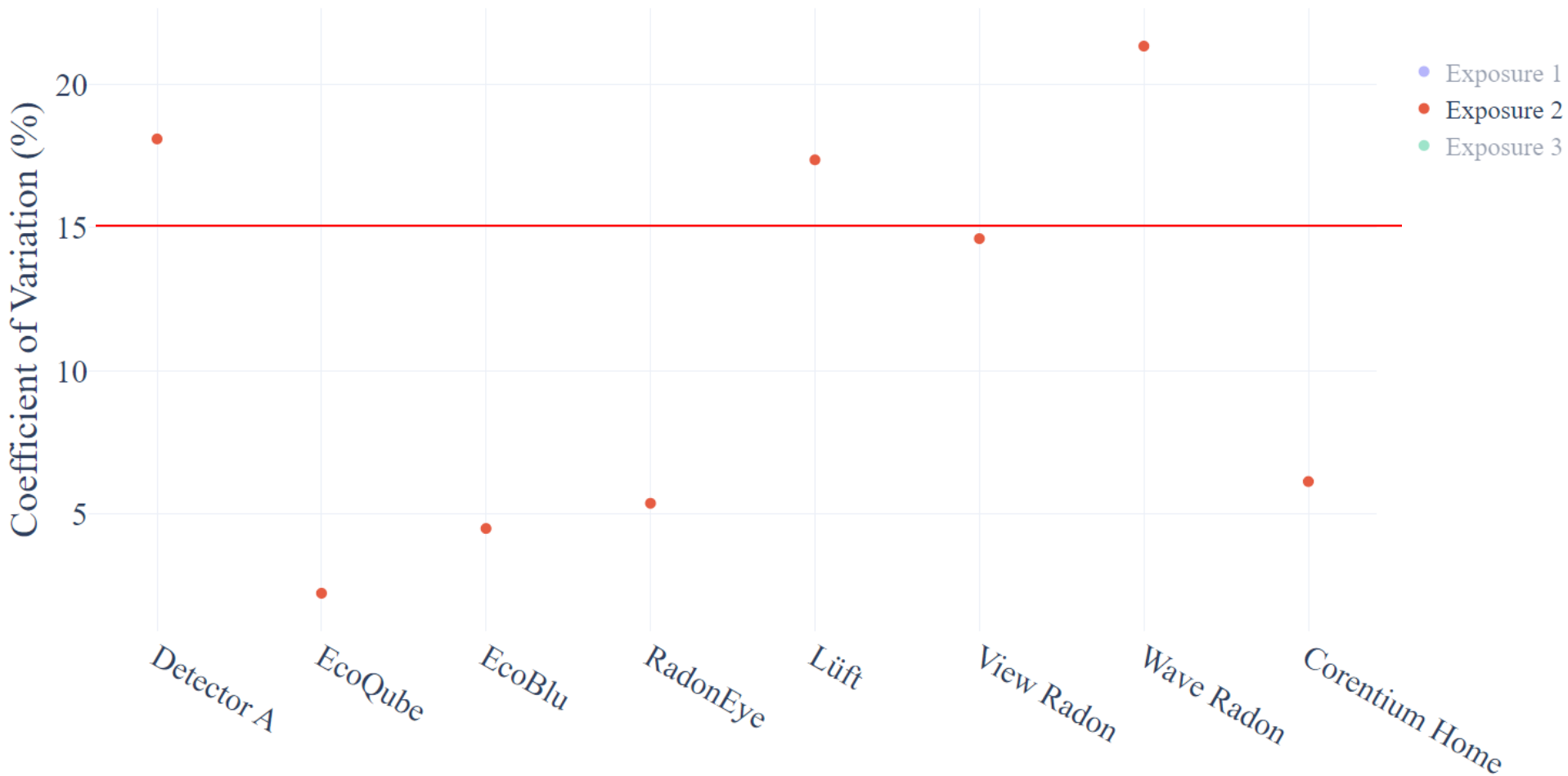
- Coefficient of Variation measures precision. As radon concentration decreases the CV should increase due to statistical nature of radiation counting
- For Exposure 2, the precision worsened for six of the eight device models.

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Exposure 3

27.7 pCi/L to 29.4 pCi/L

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Exposure 3 Conditions

- Performed three 7 day runs
- Dates:
  - 7/24/23-7/31/23
  - 7/31/23-8/7/23
  - 8/7/23-8/14/23
- Goal: 25-30 pCi/L
- Chamber Radon Values:
  - 27.7 pCi/L
  - 28.9 pCi/L
  - 29.4 pCi/L

- Temperature:
  - 73.2^{o}F
  - 73.1^{o}F
  - 72.7^{o}F
- Humidity:
  - 27.1%
  - 21.0%
  - 21.3%
- Barometric Pressure:
  - 27.00 in Hg
  - 28.68 in Hg
  - 28.64 inHg

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Summary of Results for Exposure 3

Device	Average Individual Percent Error Across all 5 devices	Coefficient of Variation (Should be ≤15%)	Average Radon Concentration (pCi/L)	Standard Deviation
Detector A	3.4%	2.69%	29.9 pCi/L	0.804
EcoQube	11.3%	2.91%	32.2 pCi/L	0.935
EcoBlu	-13.3%	1.65%	24 pCi/L	0.396
RadonEye	-4.28%	3.63%	26.5 pCi/L	0.964
Lüft	-12.6%	2.27%	25.7 pCi/L	0.582
View Radon	-0.944%	8.74%	27.4 pCi/L	2.40
Wave Radon	-1.2%	4.78%	28.6 pCi/L	1.37
Corentium Home	-13.1%	5.44%	24.1 pCi/L	1.31
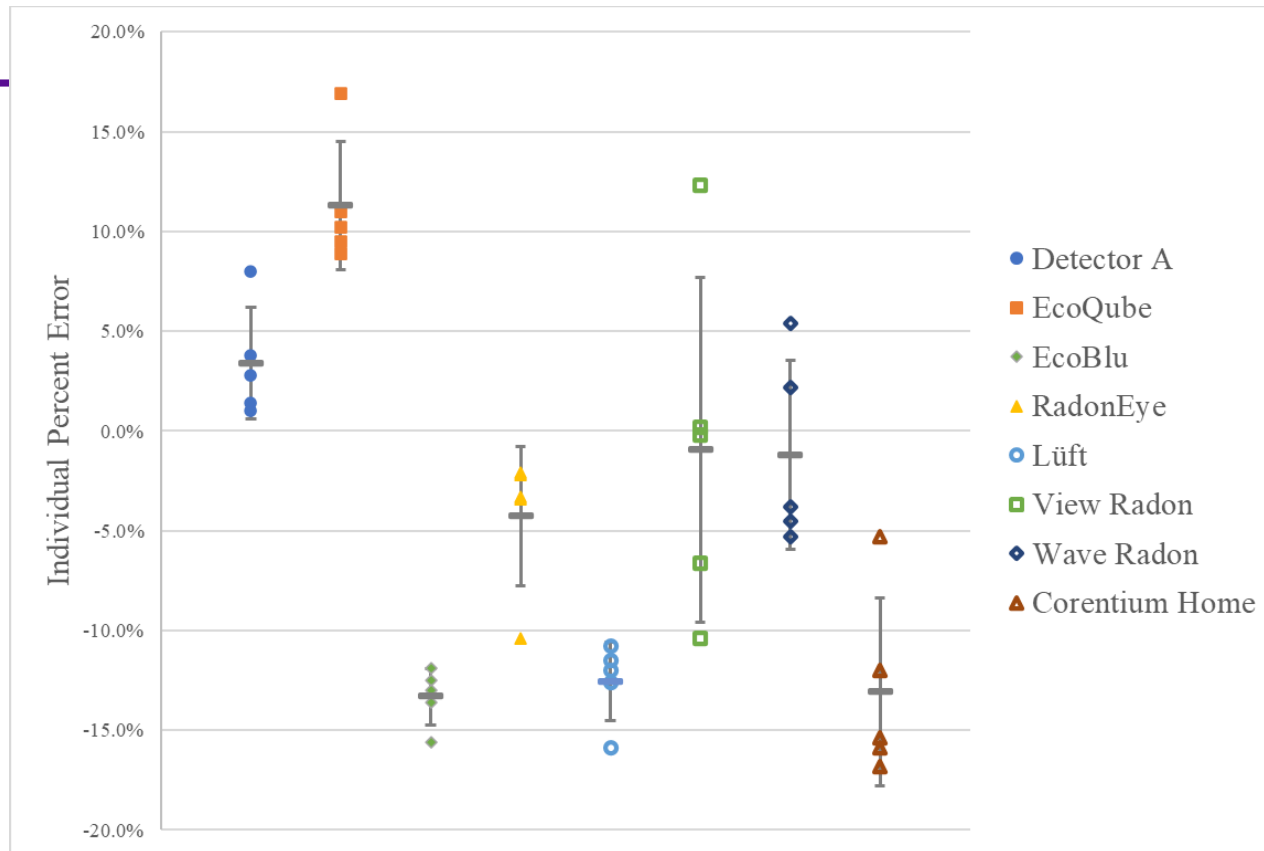
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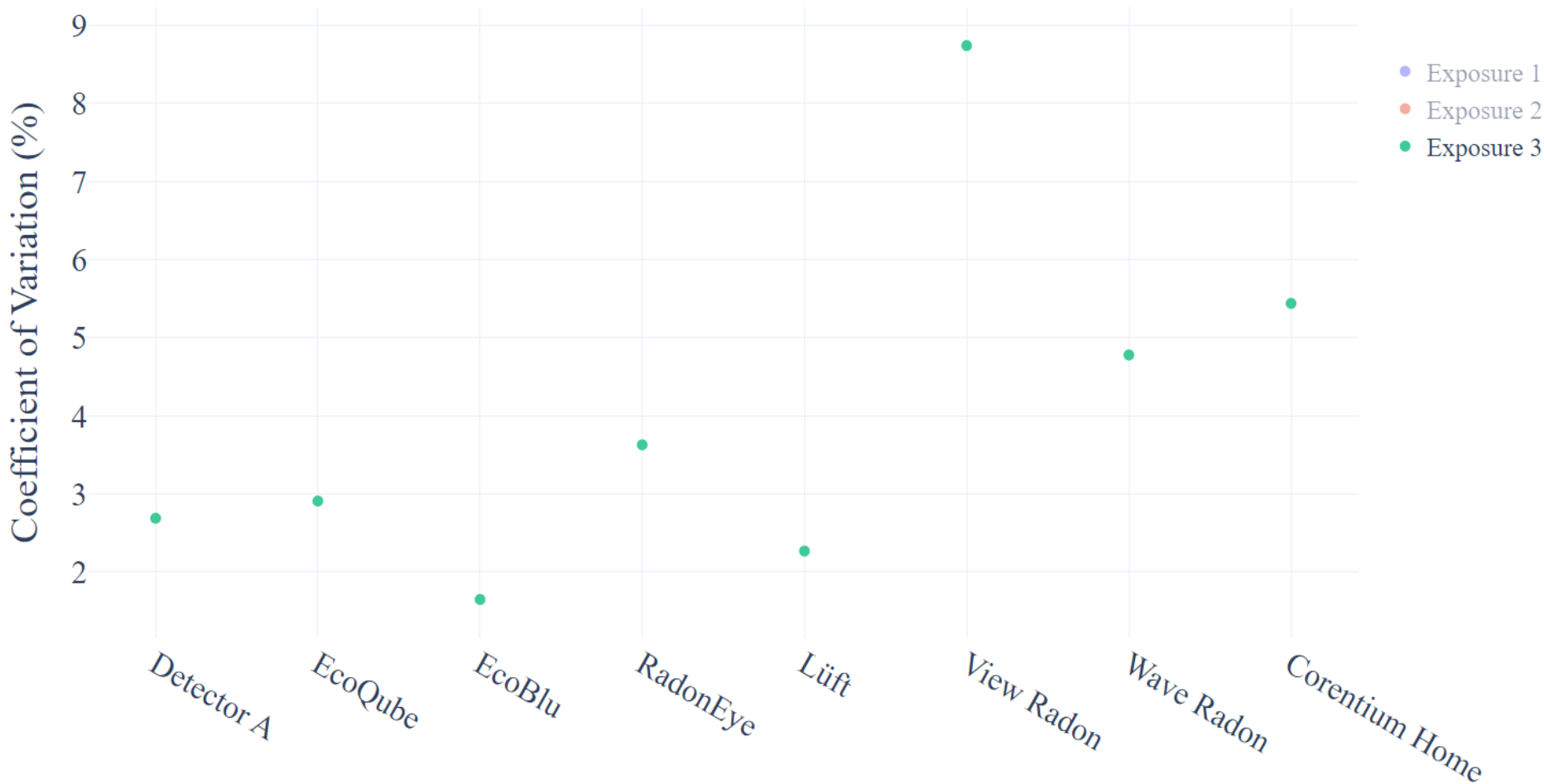
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Individual Percent Error for Exposure 3

- Individual Percent Error (IPE): The degree from which a single measure value (X) deviates from the conventionally true value (T)
- Average and standard deviation are show for each device model

Coefficient of Variation- Exposure 3

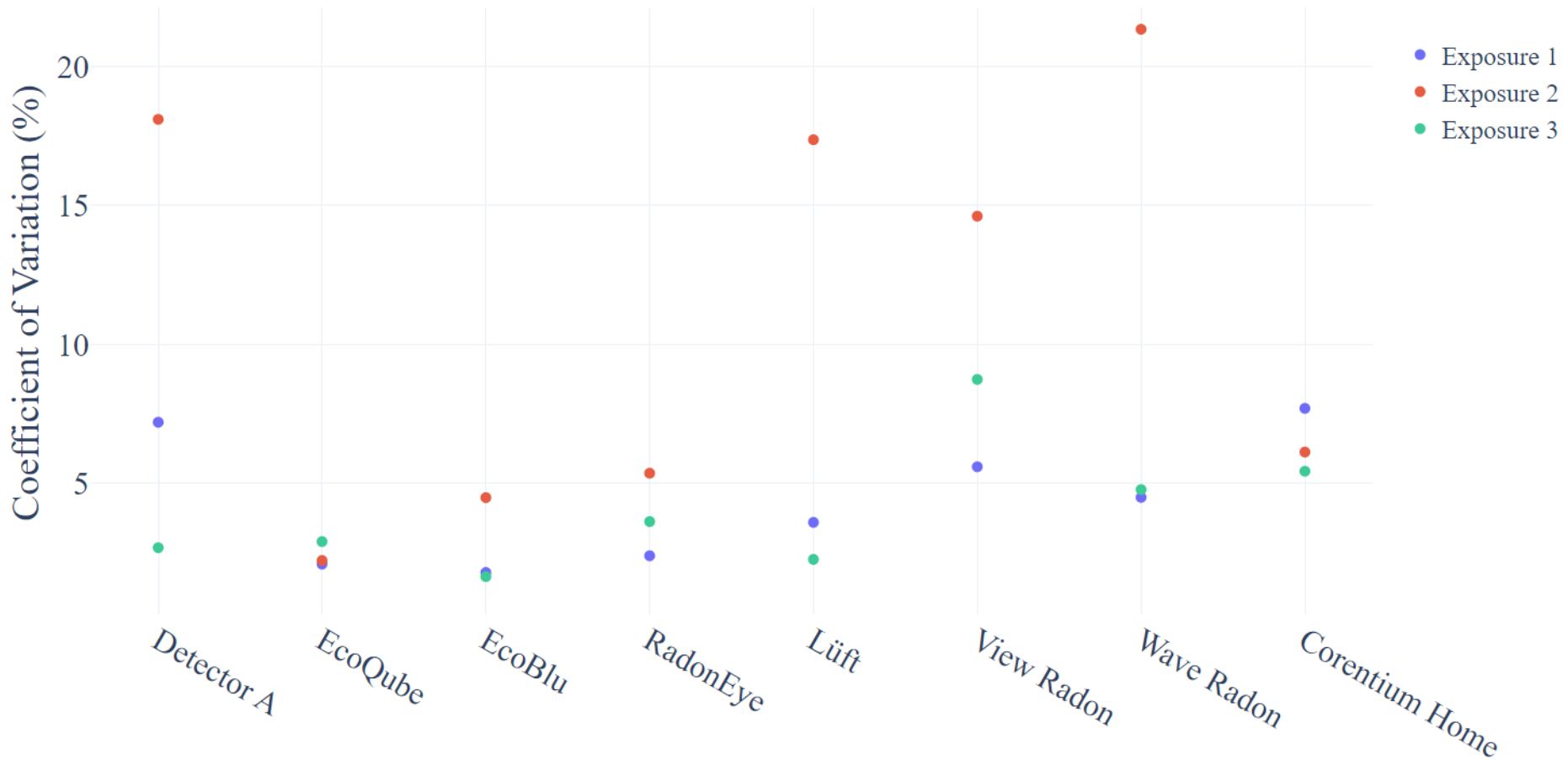$$CV = 100 * \left(\frac{s}{mean}\right)$$

Precision will improve as radon concentration increases. This was observed for four of the eight device models, with two other device models demonstrating precision similar to that observed in Exposures 1 and 2.

Summary Data

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Summary

- Exposure 1
  - Seven of the eight monitors fell within the 0 ± 25% for IPE
    - Airthings View Radon was only device that did not meet the $\pm$ 25% IPE range with four of the five devices falling outside of these limits
  - All eight models fell within the $\pm$ 15% CV range
- Exposure 2
  - Six of the eight monitors fell within the 0 $\pm$ 25% for IPE
    - Detector A and Wave Radon fell outside of the limits
  - Five of the eight monitors fell within the $\pm$ 15% CV range
    - Detector A, Lüft, and Wave Radon fell outside of the limits
- Exposure 3
  - All eight monitors performed within the 0 ± 25% IPE range
  - All eight monitors fell within the ± 15% CV range

Coefficient of Variation

$$CV = 100 * \left(\frac{s}{mean}\right)$$

Anticipated that precision would worsen as the radon concentration decreased

Improvements & Future Work

- Allowing more time between chamber runs for adequate ramp up and ramp down time.
  - Although we allowed for 12 hours between Exposures 1 and 2, there was still a significant amount of ramp down time for a few of the detectors.
  - It took 24 to 36 hours for the detectors readings to come to equilibrium with the air they were being exposed to.
- Exposure for 30 days or more as per the manufacturer recommendations.
- Detector performance over longer periods of time
  - How can homeowners expect these consumer-grade device models to perform during their operational lifetimes?

Contact Information

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