A Review of Multiple Consumer Digital Radon Monitors at Three Radon Exposure Levels

Kansas State University College of Engineering, Engineering Extension

Presented by: Alexandra Bahadori

Research performed by: Alexandra Bahadori and Brian Hanson

Purpose

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.

One 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

Overview

- Models to be reviewed include:
  - Device A (brand name withheld by request)
  - Corentium Home
  - Airthings View Radon
  - Airthings Wave Radon
  - SunRadon Lüft
  - Ecosense Radon Eye
  - Ecosense EcoQube
  - Ecosense EcoBlu

Procedure

- Five copies of each device model were exposed simultaneously at:
  - Approximately twice the national action level
    - Goal was 8-10 pCi/L
  - Room ambient radon levels
  - Approximately 8 times the national action level
    - Goal was 25-30 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 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 65-75^{o} 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)
  - $IPE = [100(X - T)/T]]$
- 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
  - $CV = 100 * \left(\frac{s}{mean}\right)$

Device Output- EID/CRM

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

Exposure 1

Goal: 8-10 pCi/L

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

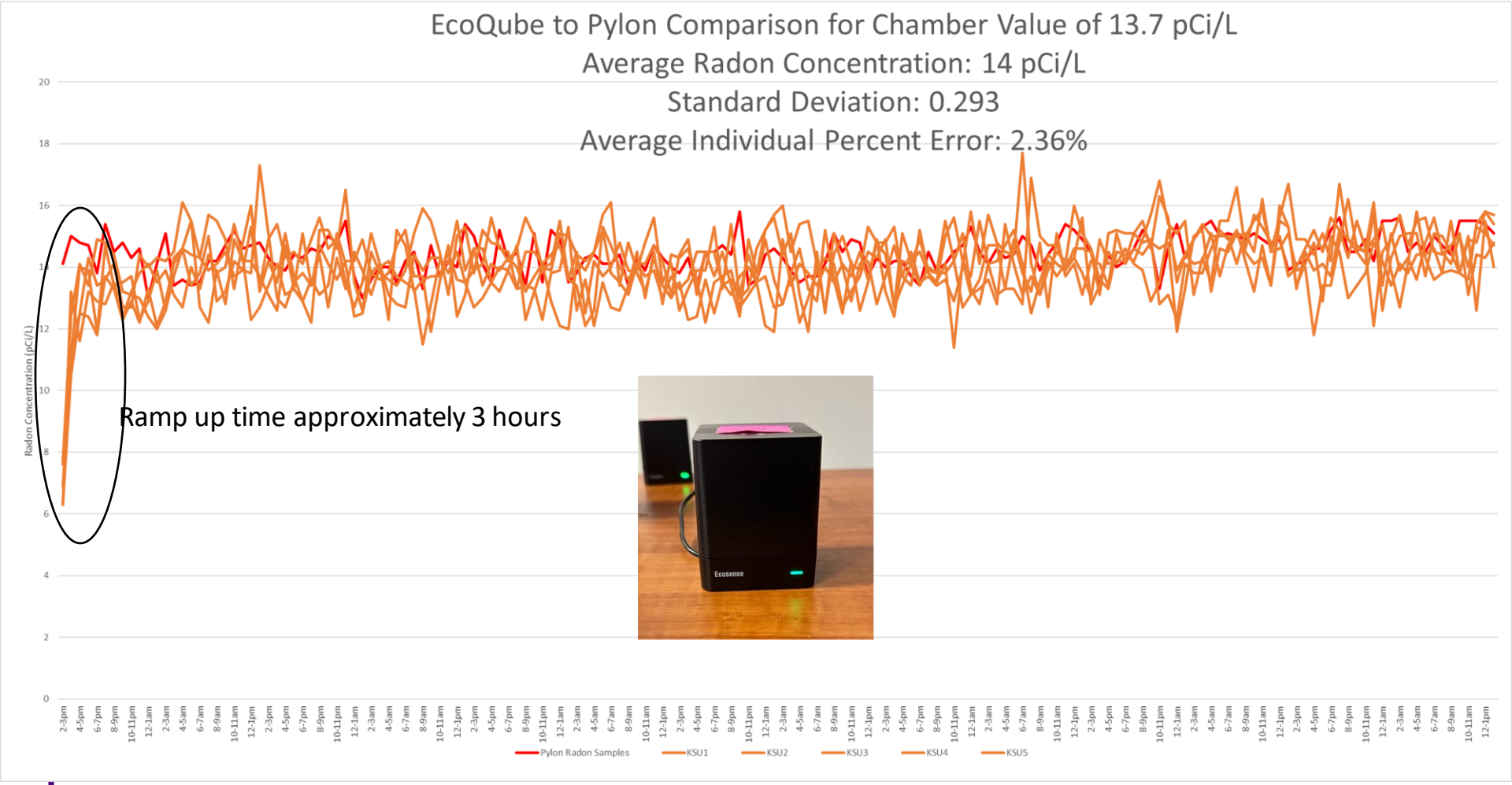
Summary of Results for Exposure 1

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)
Device A	✓	6.3%	7.2%	12.5 pCi/L
EcoQube	✓	2.36%	2.1%	14.0 pCi/L
EcoBlu	✓	18.04%	1.8%	10.5 pCi/L
RadonEye	✓	9.6%	2.4%	12.4 pCi/L
Lüft	✓	20.3%	3.6%	12.4 pCi/L
View Radon		28.4%	5.6%	9.16 pCi/L
Wave Radon	✓	3.9%	4.5%	14.2 pCi/L
Corentium Home	✓	8.7%	7.7%	11.7 pCi/L

Electronic Integrating Devices

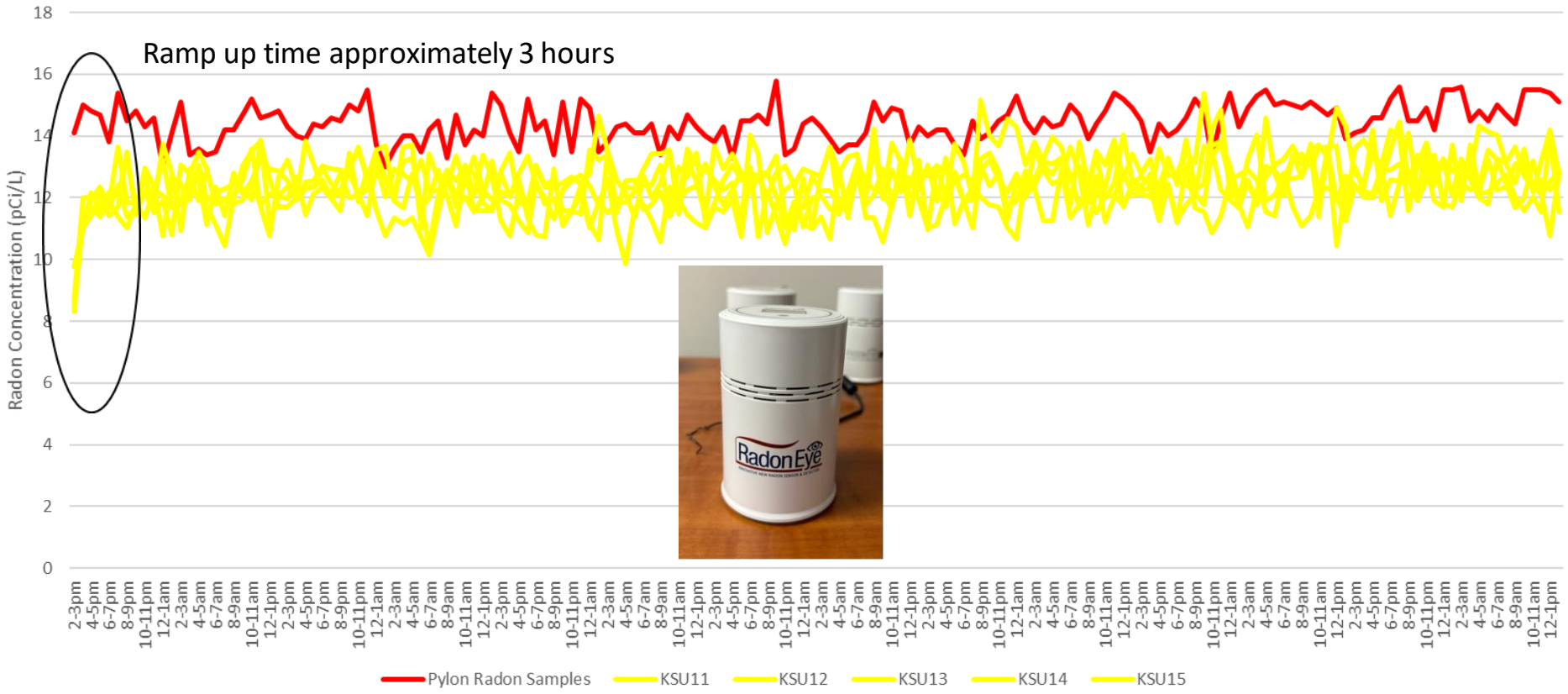
- These do not allow retrievable hourly data

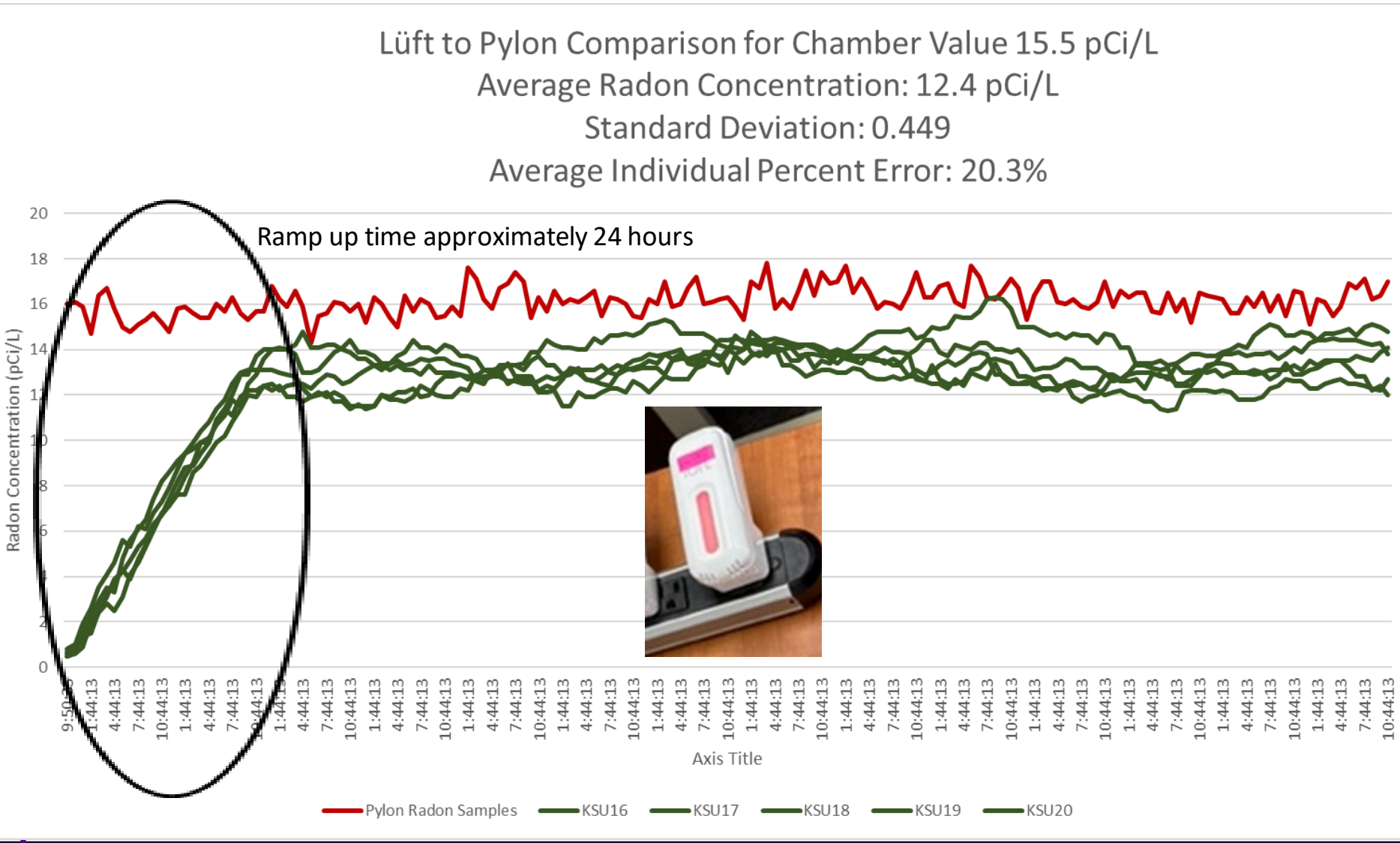
Chamber Value of 12.8 pCi/L	Device A	EcoBlu	Corentium Home
Average Individual Percent Error	6.3%	18%	8.7%
Standard Deviation	0.896	0.191	0.897
Average Radon Concentration	12.5 pCi/L	10.5 pCi/L	11.7 pCi/L


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%
Radon Concentration (pCi/L)
Ramp up time approximately 3 hours
Pylon Radon Samples
KSU1
KSU2
KSU3
KSU4
KSU5

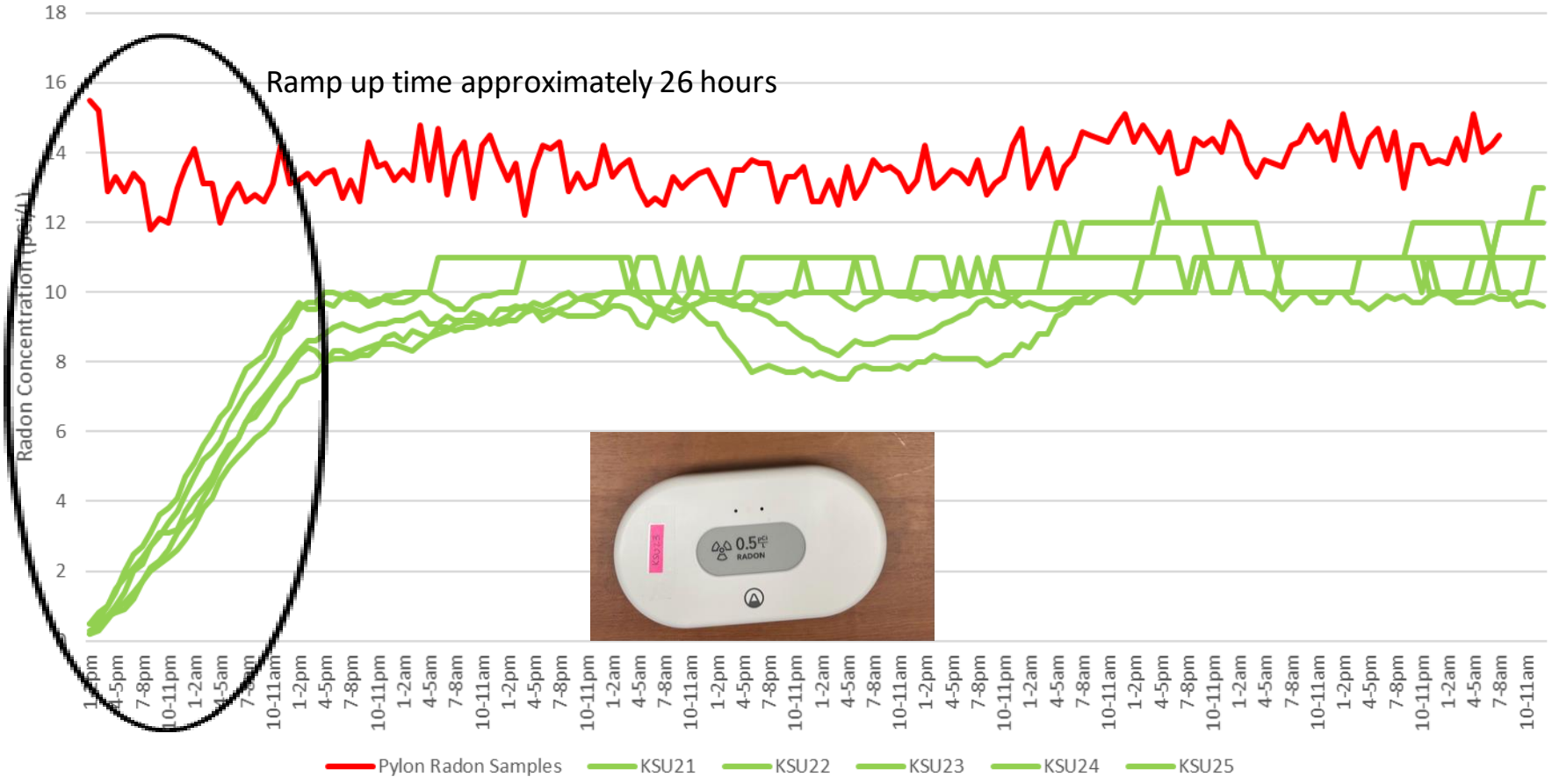
Ecosense

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%

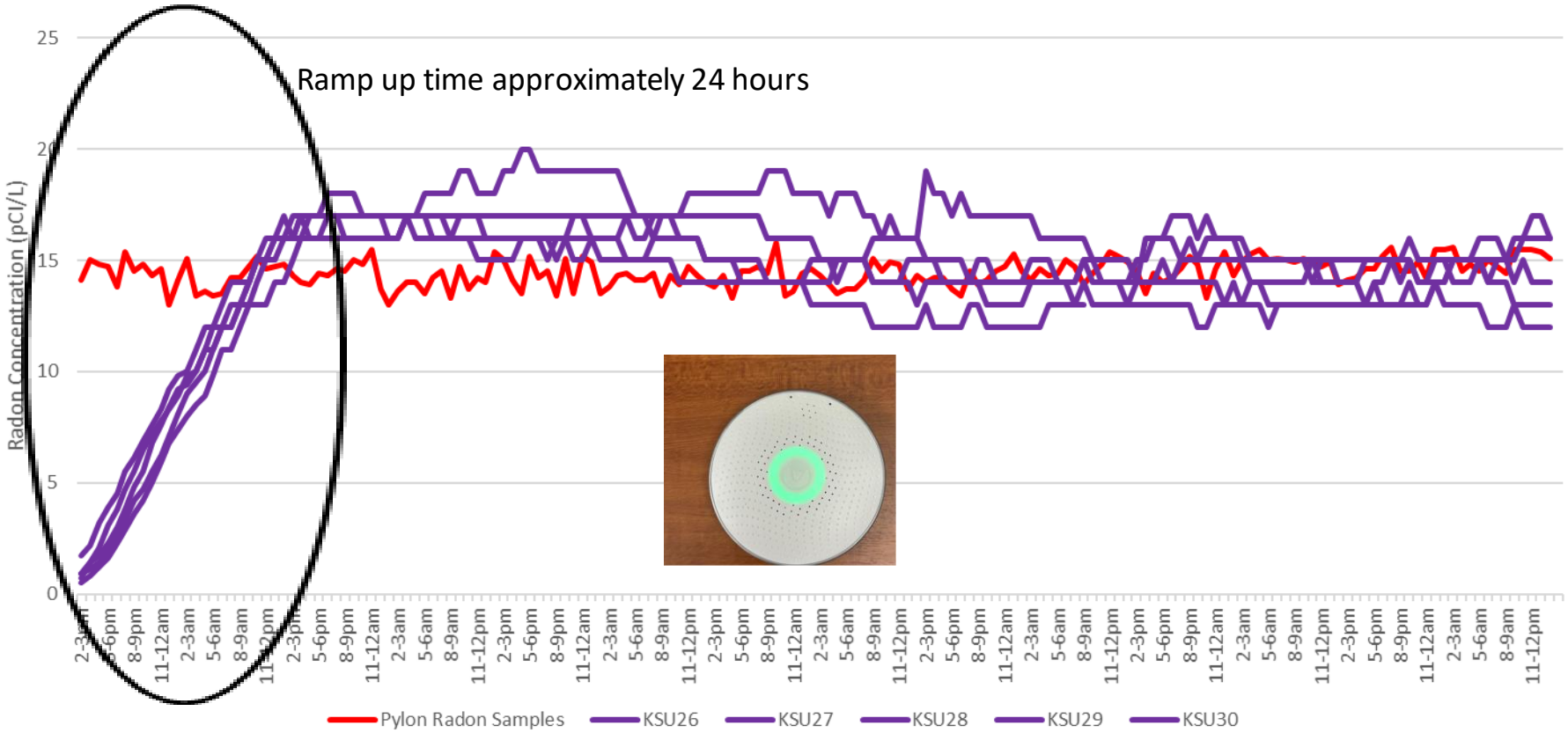


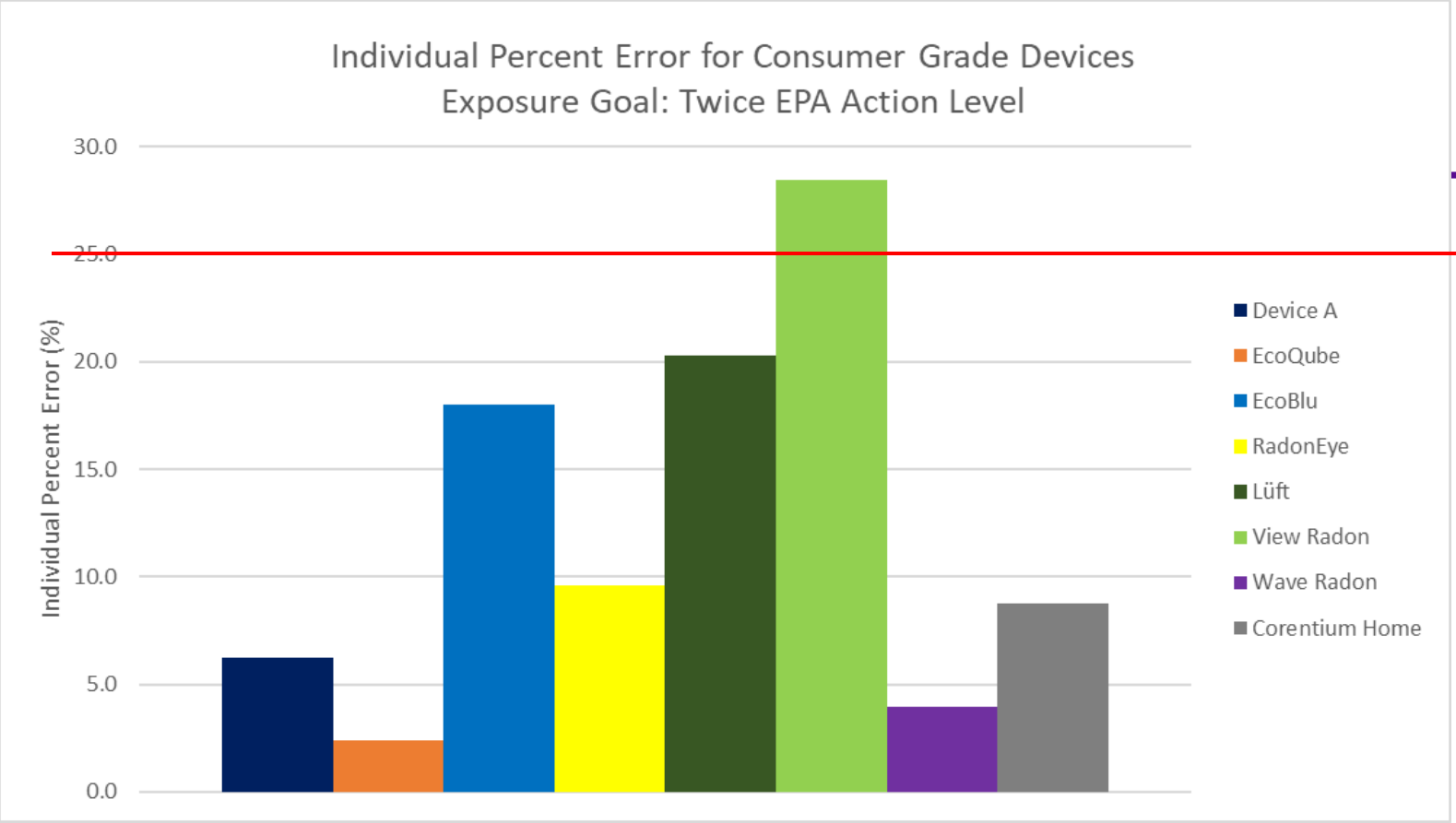

Lüft to Pylon Comparison for Chamber Value 15.5 pCi/L
Average Radon Concentration: 12.4 pCi/L
Standard Deviation: 0.449
Average Individual Percent Error: 20.3%
Ramp up time approximately 24 hours
Radon Concentration (pCi/L)
20
18
16
14
0
Axis Title
Pylon Radon Samples
KSU16
KSU17
KSU18
KSU19
KSU20

View Radon to Pylon Comparison for Chamber Value 12.8 pCi/L
Average Radon Concentration: 9.16 pCi/L
Standard Deviation: 0.513
Average Individual Percent Error: 28.4%

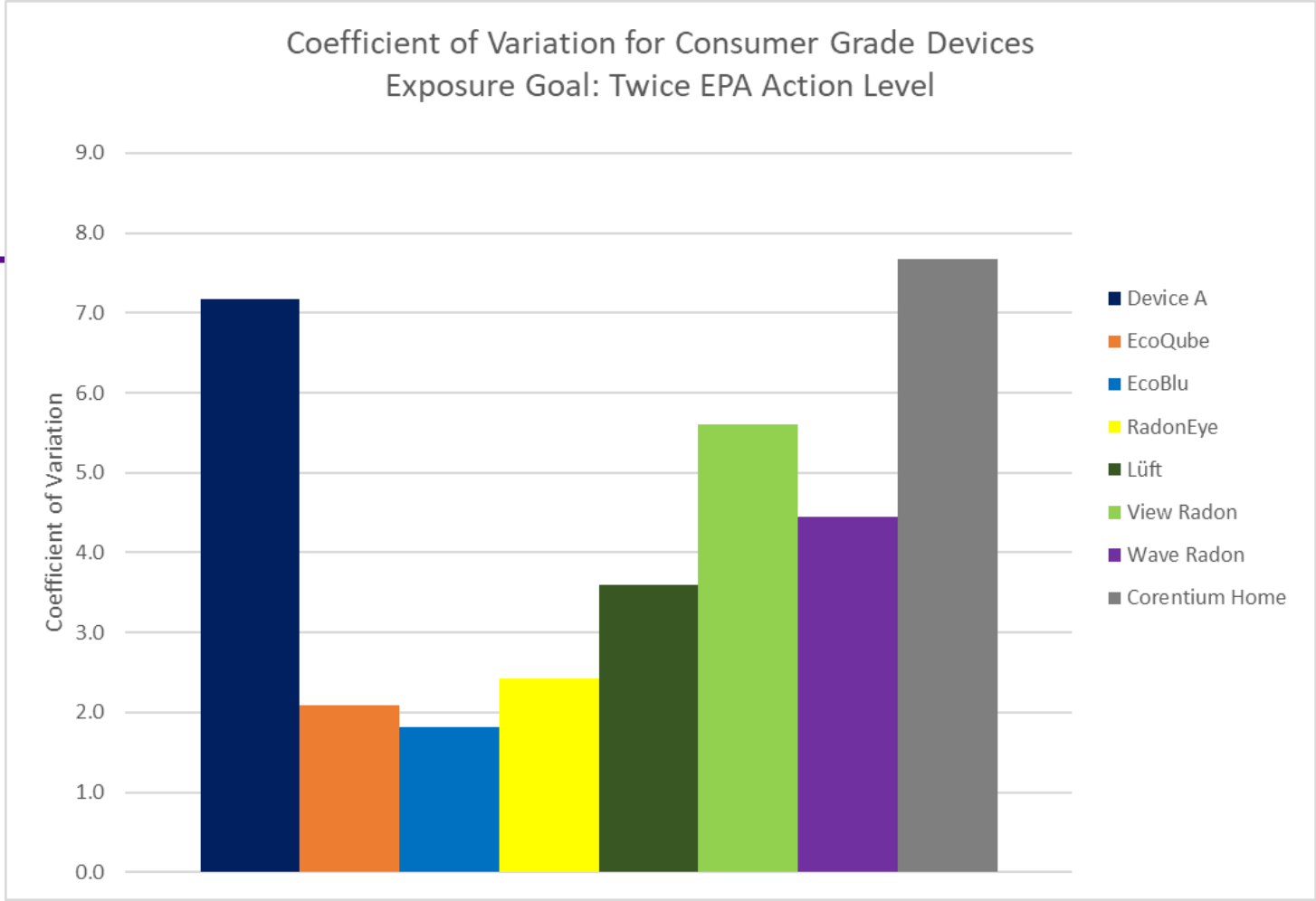


Wave Radon to Pylon Comparison for Chamber Value of 13.7 pCi/L
Average Radon Concentration: 14.2 pCi/L
Standard Deviation: 0.632
Average Individual Percent Error: 3.9%





Individual Percent Error (IPE): The degree from which a single measure value (X) deviates from the conventionally true value (T)



Coefficient of Variation (CV): The ratio of the standard deviation to the mean. The higher the CV, the greater dispersion around the mean.

Goal: CV less than 15%

Exposure 2

Ambient Air

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^{o}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)
Device A	32.7%	18.1%	0.8 pCi/L
EcoQube	16.6%	2.2%	0.7 pCi/L
EcoBlu	4.3%	4.5%	0.6 pCi/L
RadonEye	4.0%	5.4%	0.6 pCi/L
Lüft	16%	17.4%	0.6 pCi/L
View Radon	12.4%	14.6%	0.6 pCi/L
Wave Radon	15.3%	21.3%	0.7 pCi/L
Corentium Home	14.3%	6.1%	0.5 pCi/L

Electronic Integrating Devices

- These do not allow retrievable hourly data

Average Ambient Air 0.6 pCi/L	Device A	EcoBlu	Corentium Home
Average Individual Percent Error	32.7%	4.3%	14.3%
Standard Deviation	0.148	0.027	0.033
Average Radon Concentration	0.8 pCi/L	0.6 pCi/L	0.5 pCi/L

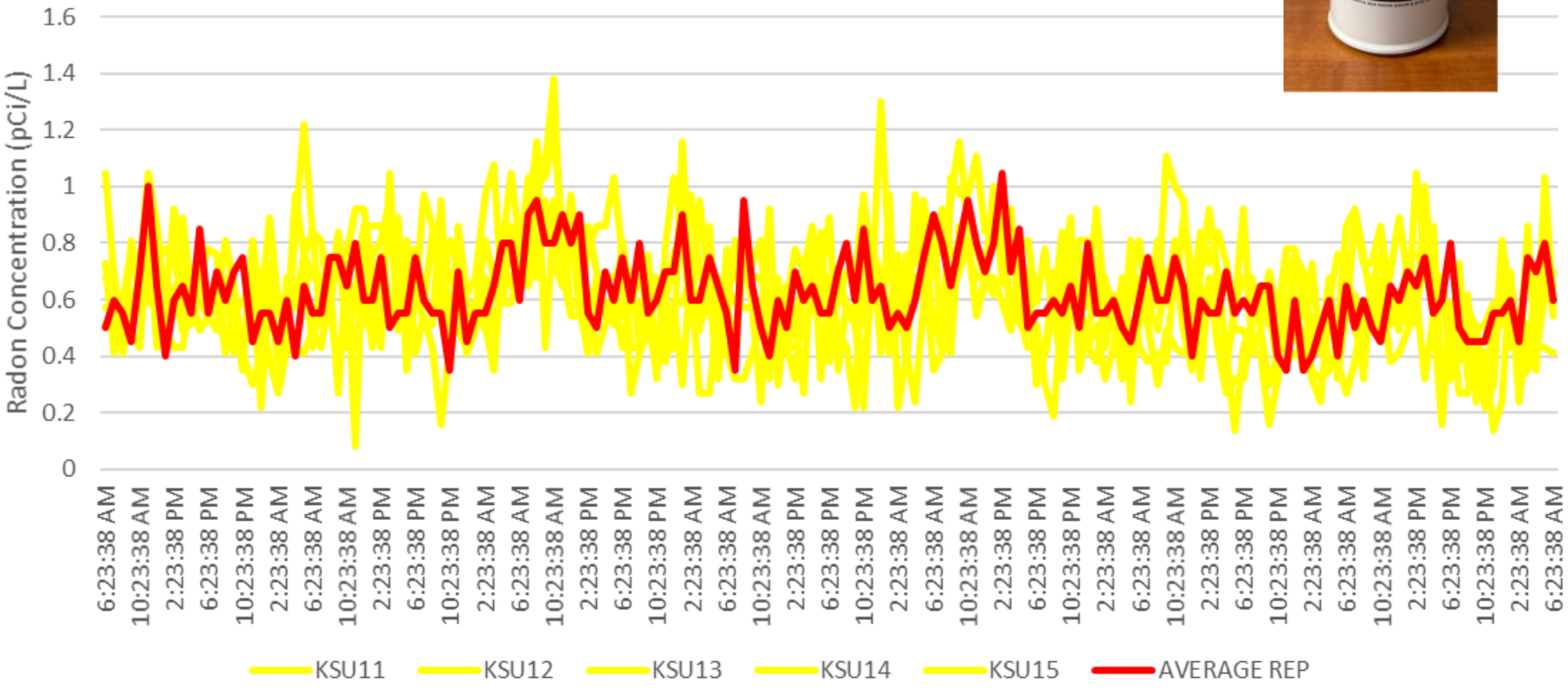
EcoQube to REP Comparison for Ambient Air
Average Radon Concentration: 0.7 pCi/L
Standard Deviation: 0.016
Average Individual Percent Error: 16.6%

RadonEye to REP Comparison for Ambient Air

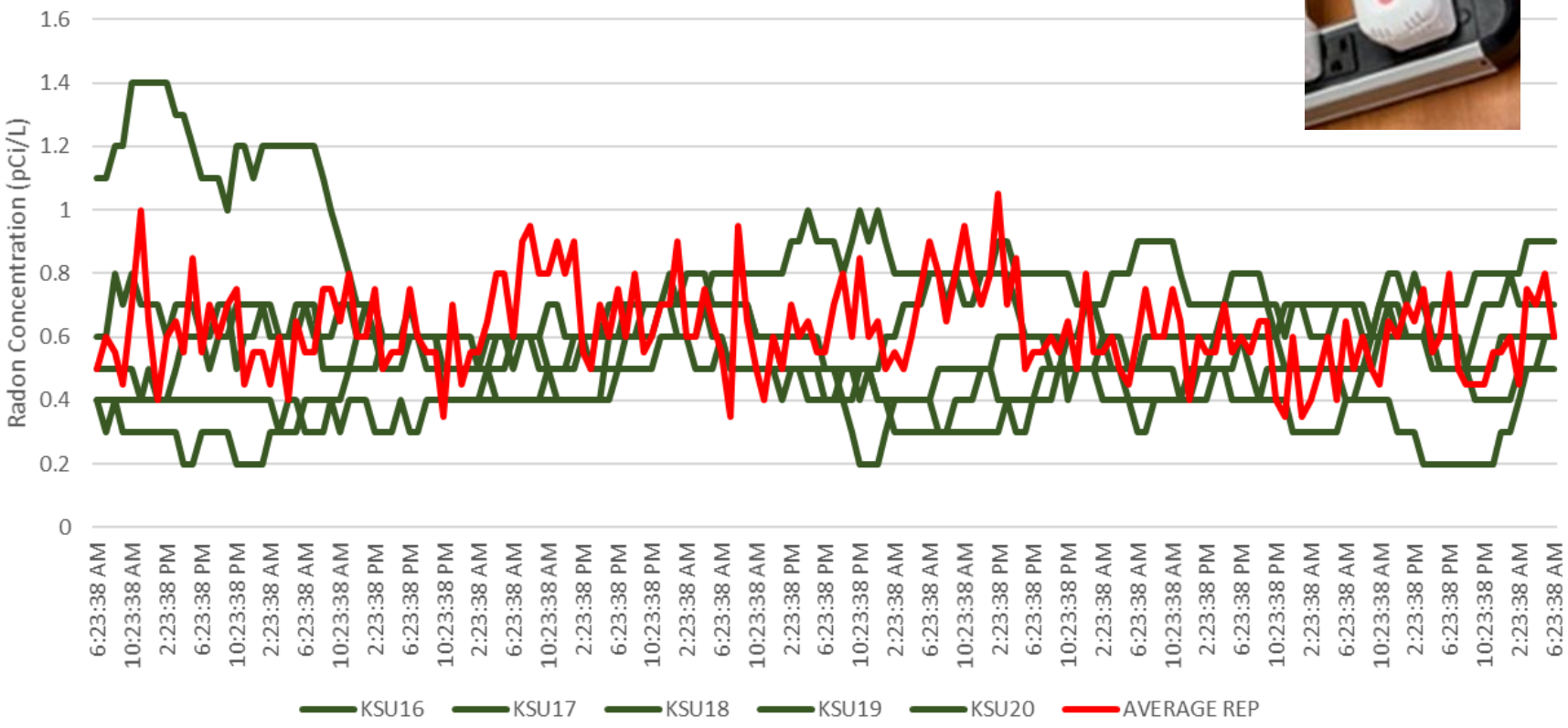
Average Radon Concentration: 0.6 pCi/L

Standard Deviation: 0.033

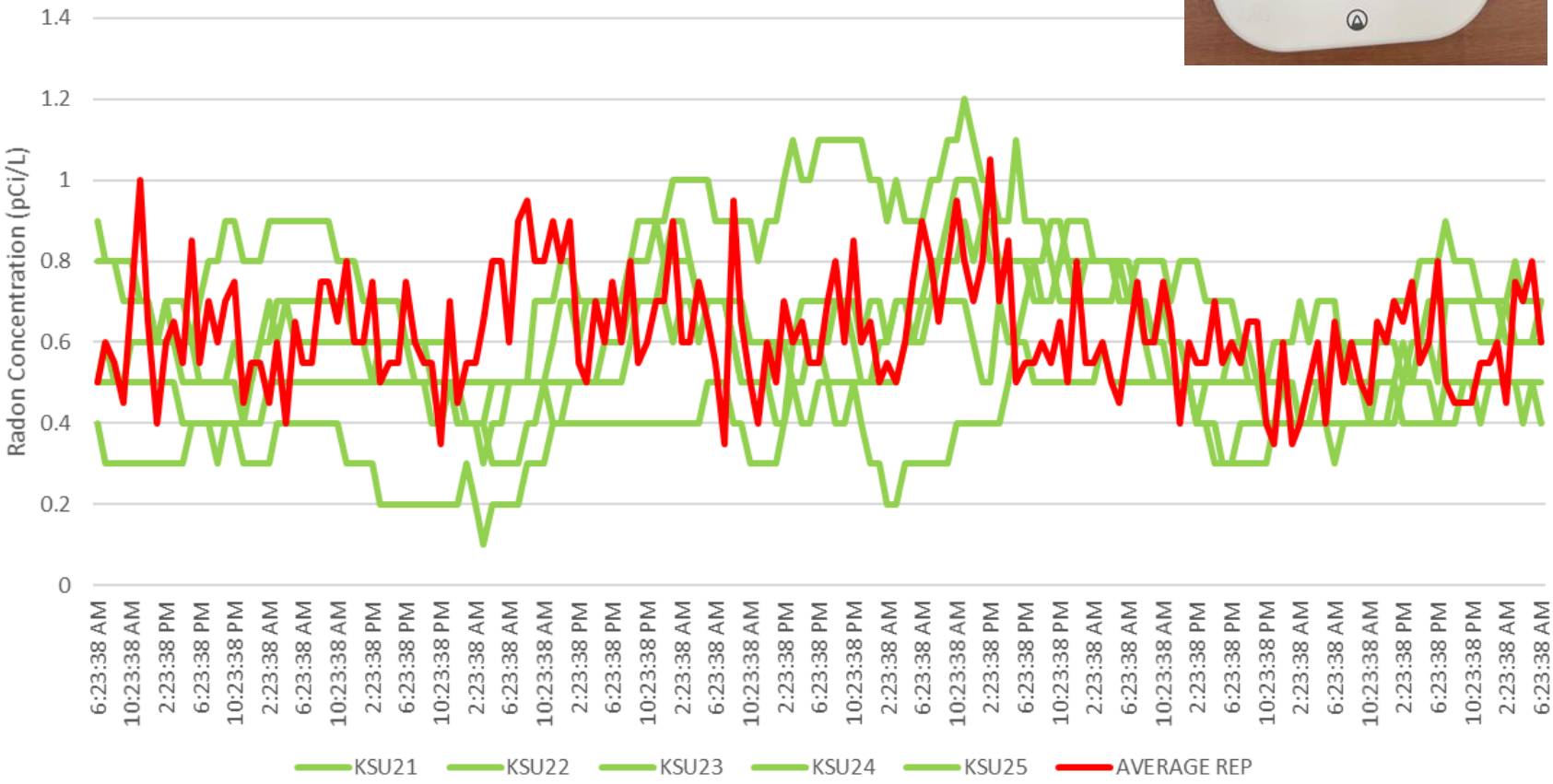
Average Individual Percent Error: 3.96%



Lüft to REP Comparison for Ambient Air
Average Radon Concentration: 0.6 pCi/L
Standard Deviation: 0.099
Average Individual Percent Error: 15.97%



View Radon to REP Comparison for Ambient Air
Average Radon Concentration: 0.6 pCi/L
Standard Deviation: 0.085
Average Individual Percent Error: 12.42%

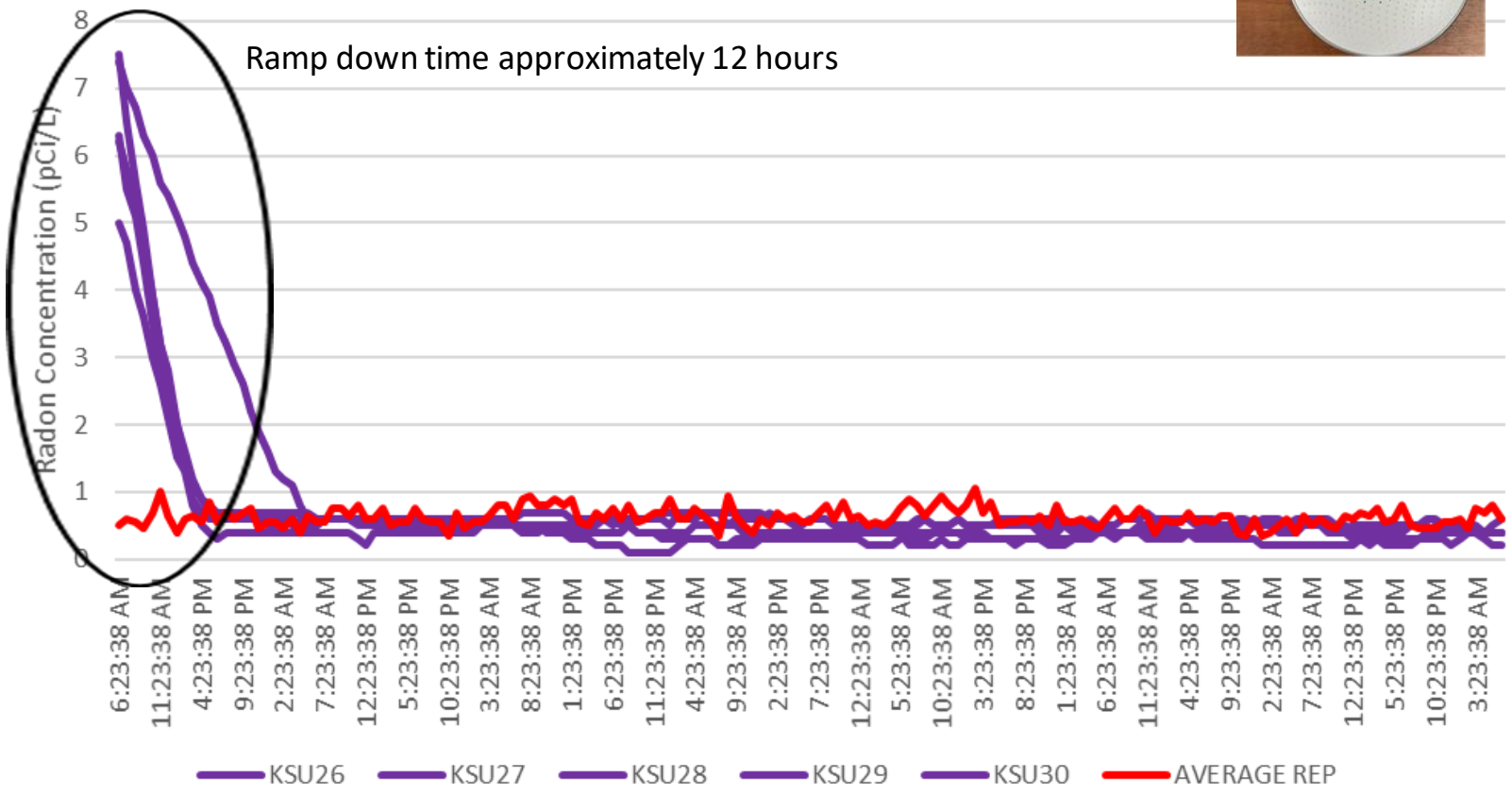


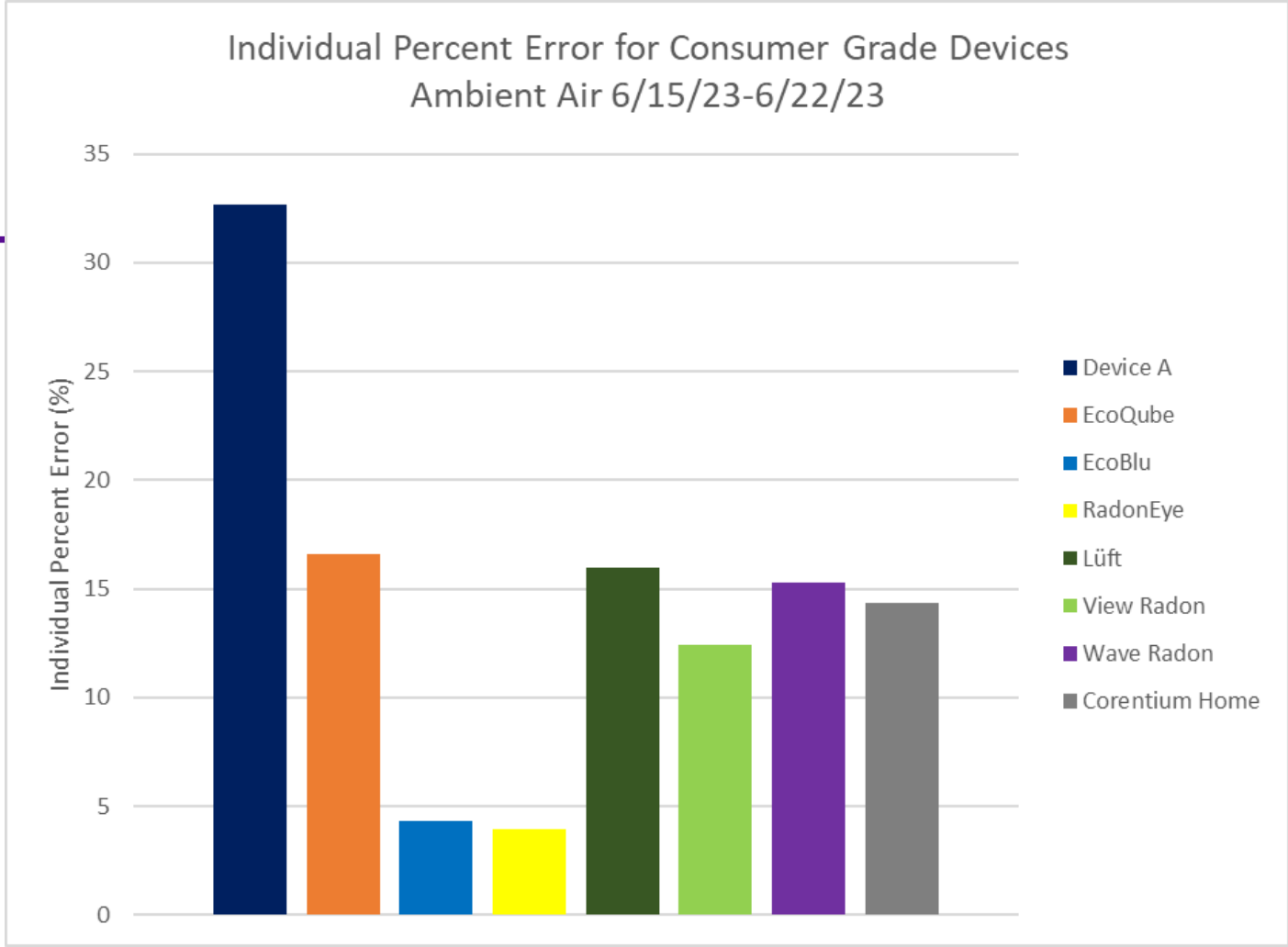
Wave Radon to REP Comparison for Ambient Air

Average Radon Concentration: 0.7 pCi/L

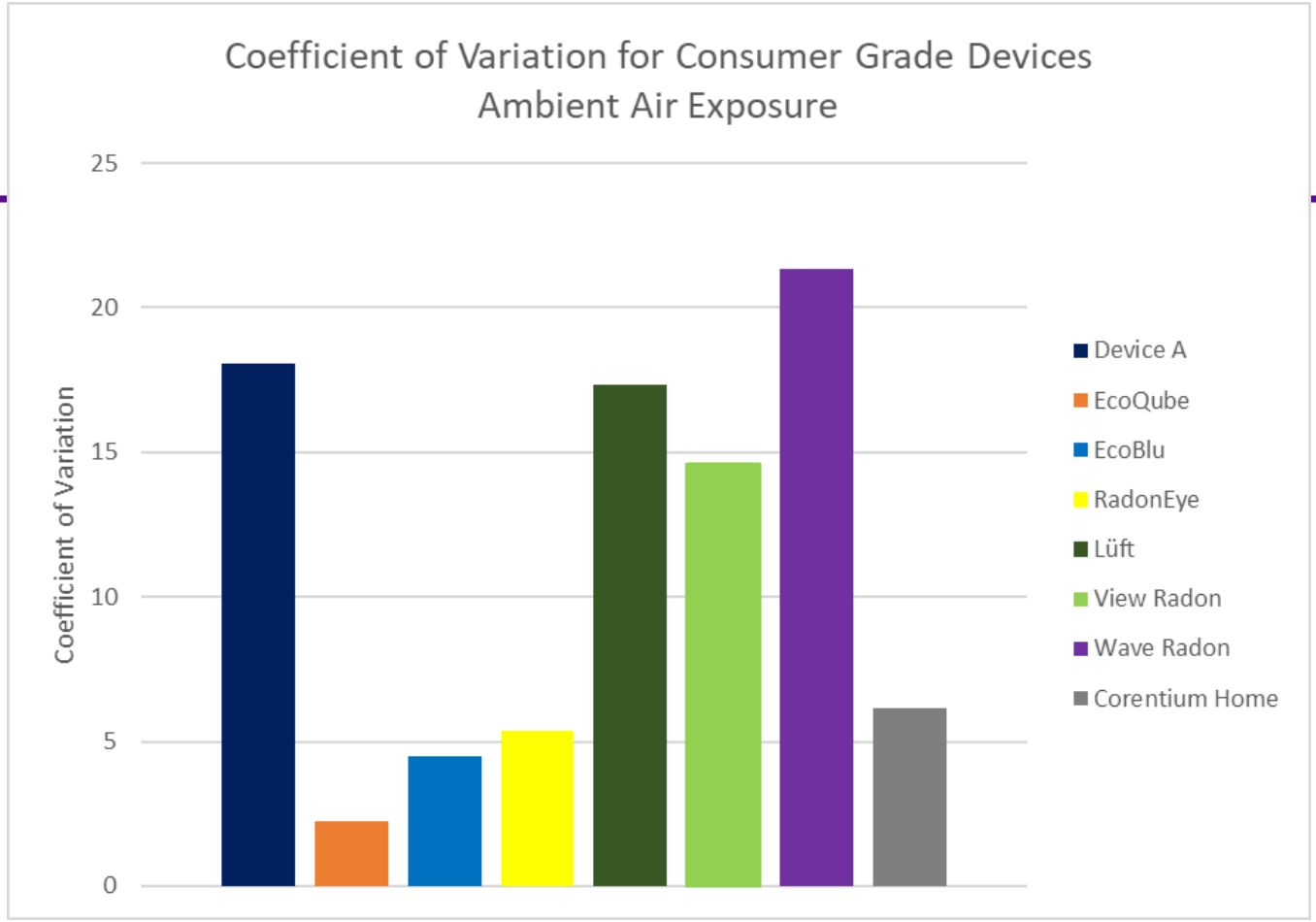
Standard Deviation: 0.148

Average Individual Percent Error: 15.27%





Individual Percent Error (IPE): The degree from which a single measure value (X) deviates from the conventionally true value (T)



Coefficient of Variation (CV): The ratio of the standard deviation to the mean. The higher the CV, the greater dispersion around the mean.

Exposure 3

Goal: 25-30 pCi/L

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°F
  - 73.1°F
  - 72.7°F
- Humidity:
  - 27.1%
  - 21.0%
  - 21.3%
- Barometric Pressure:
  - 27.00 in Hg
  - 28.68 in Hg
  - 28.64 inHg

Summary of Results for Exposure 3

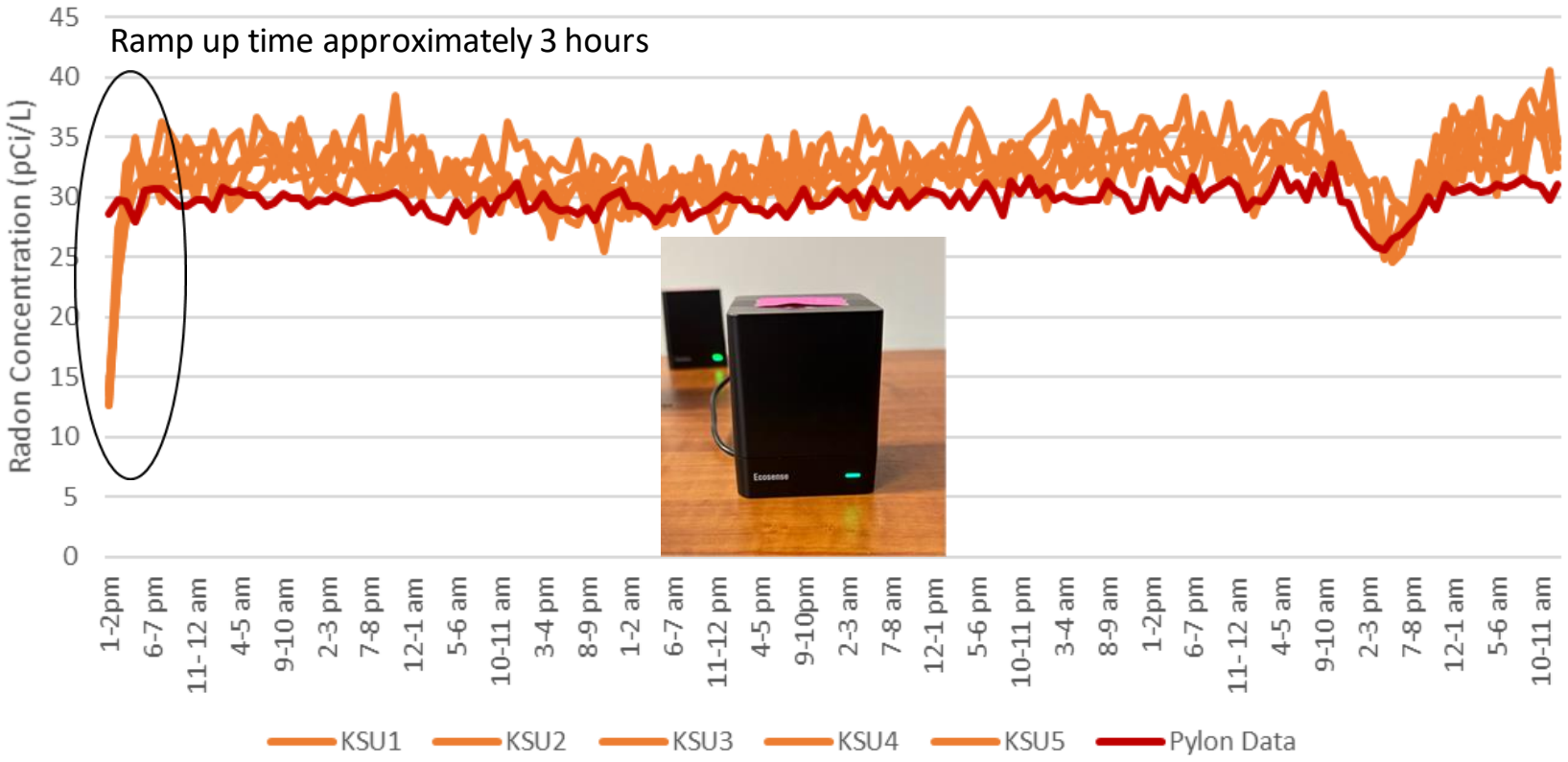
Device	Average Individual Percent Error Across all 5 devices	Coefficient of Variation (Should be ≤15%)	Average Radon Concentration (pCi/L)
Device A	3.39%	2.69%	29.9 pCi/L
EcoQube	11.3%	2.91%	32.2 pCi/L
EcoBlu	13.3%	1.65%	24 pCi/L
RadonEye	4.29%	3.63%	26.5 pCi/L
Lüft	12.6%	2.27%	25.7 pCi/L
View Radon	5.95%	8.74%	27.4 pCi/L
Wave Radon	4.24%	4.78%	28.6 pCi/L
Corentium Home	13.1%	5.44%	24.1 pCi/L

Electronic Integrating Devices

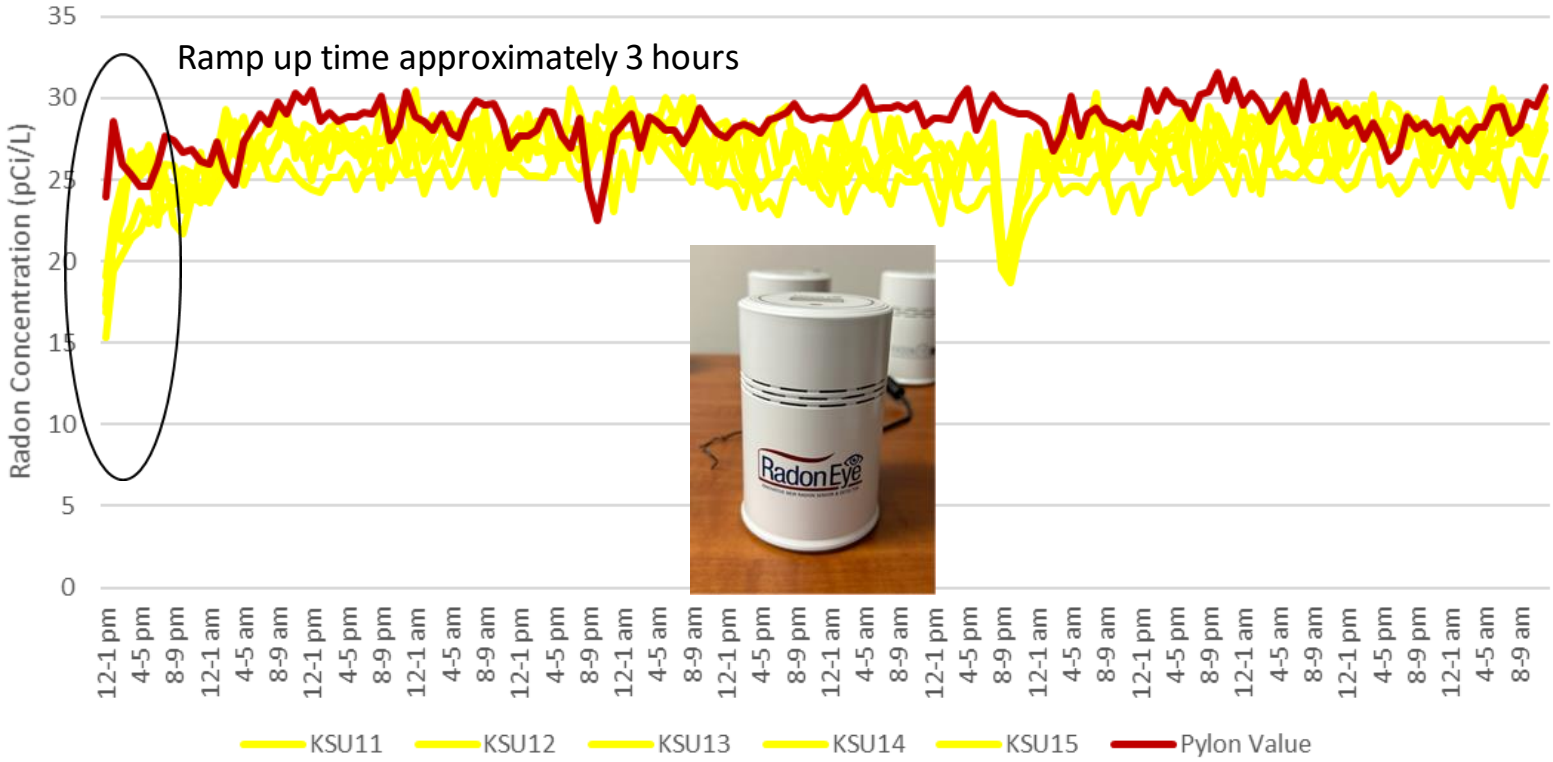
- These do not allow retrievable hourly data

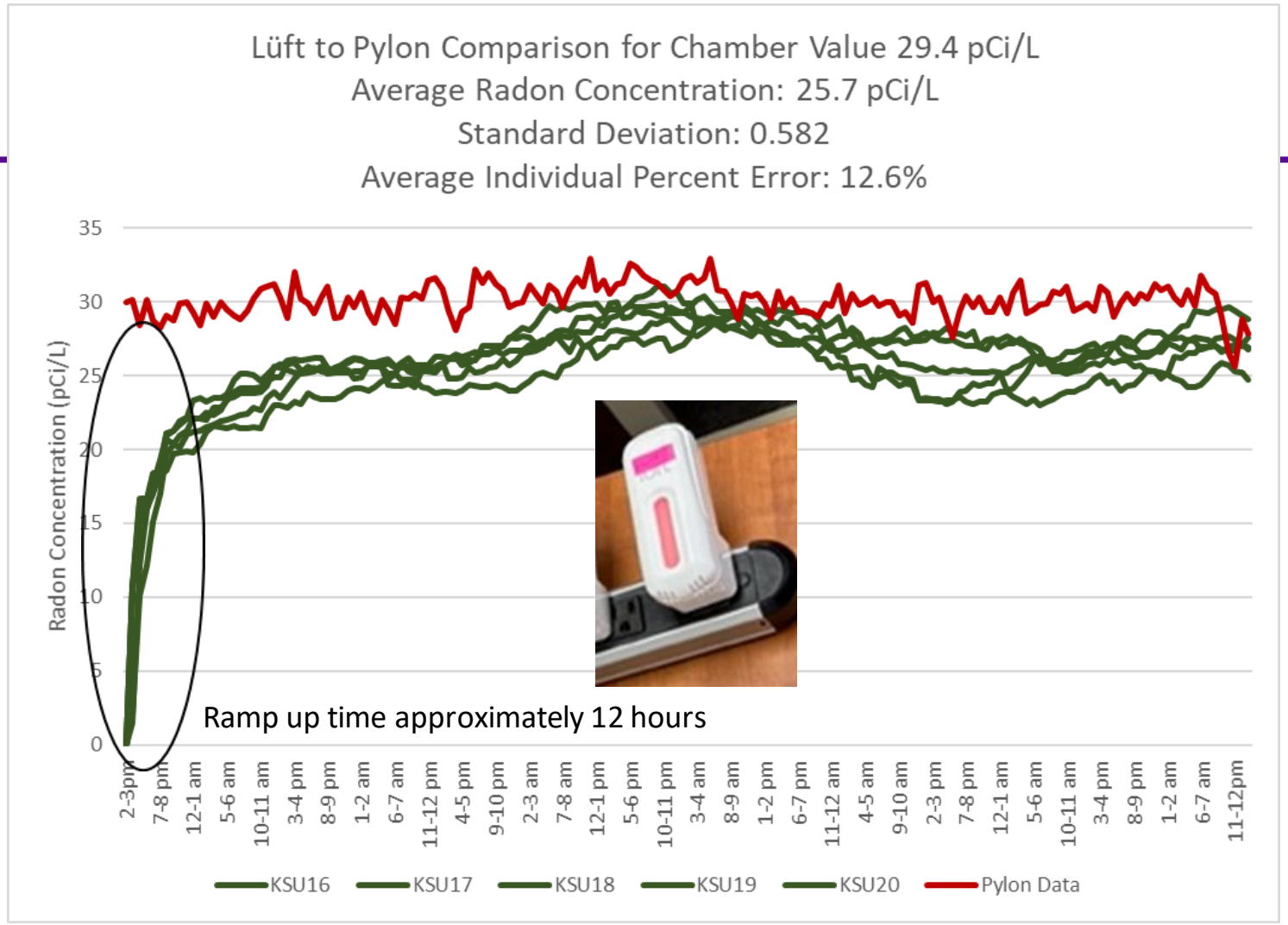
	Device A (Chamber Value of 28.9 pCi/L)	EcoBlu (Chamber Value of 27.7 pCi/L)	Corentium Home (Chamber Value of 27.7 pCi/L)
Average Individual Percent Error	3.39%	13.32%	13.1%
Standard Deviation	0.804	0.396	1.31
Average Radon Concentration	29.9 pCi/L	24 pCi/L	24.1 pCi/L

EcoQube to Pylon Comparison for Chamber Value 28.9 pCi/L
Average Radon Concentration: 32.2 pCi/L
Standard Deviation: 0.935
Average Individual Percent Error: 11.3%

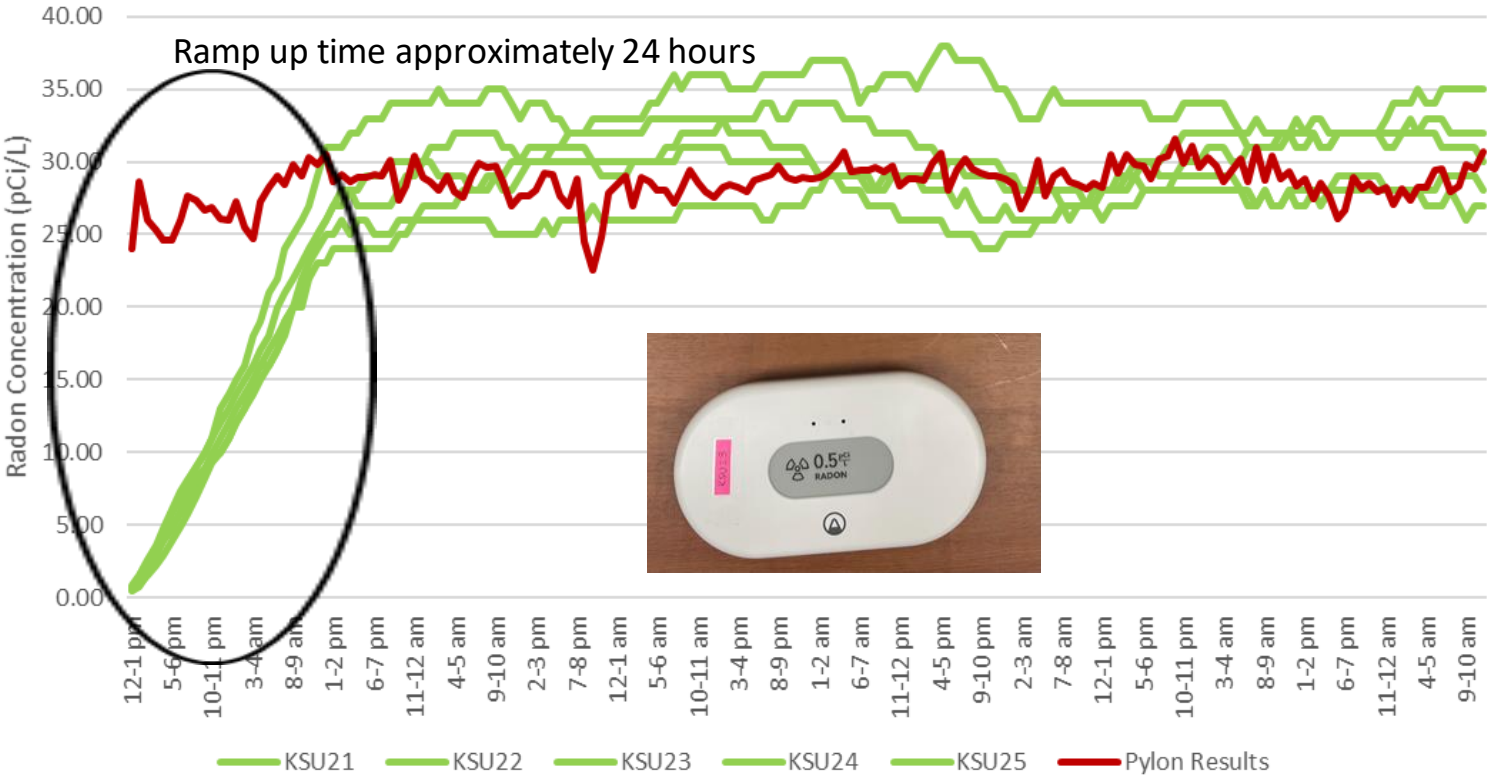


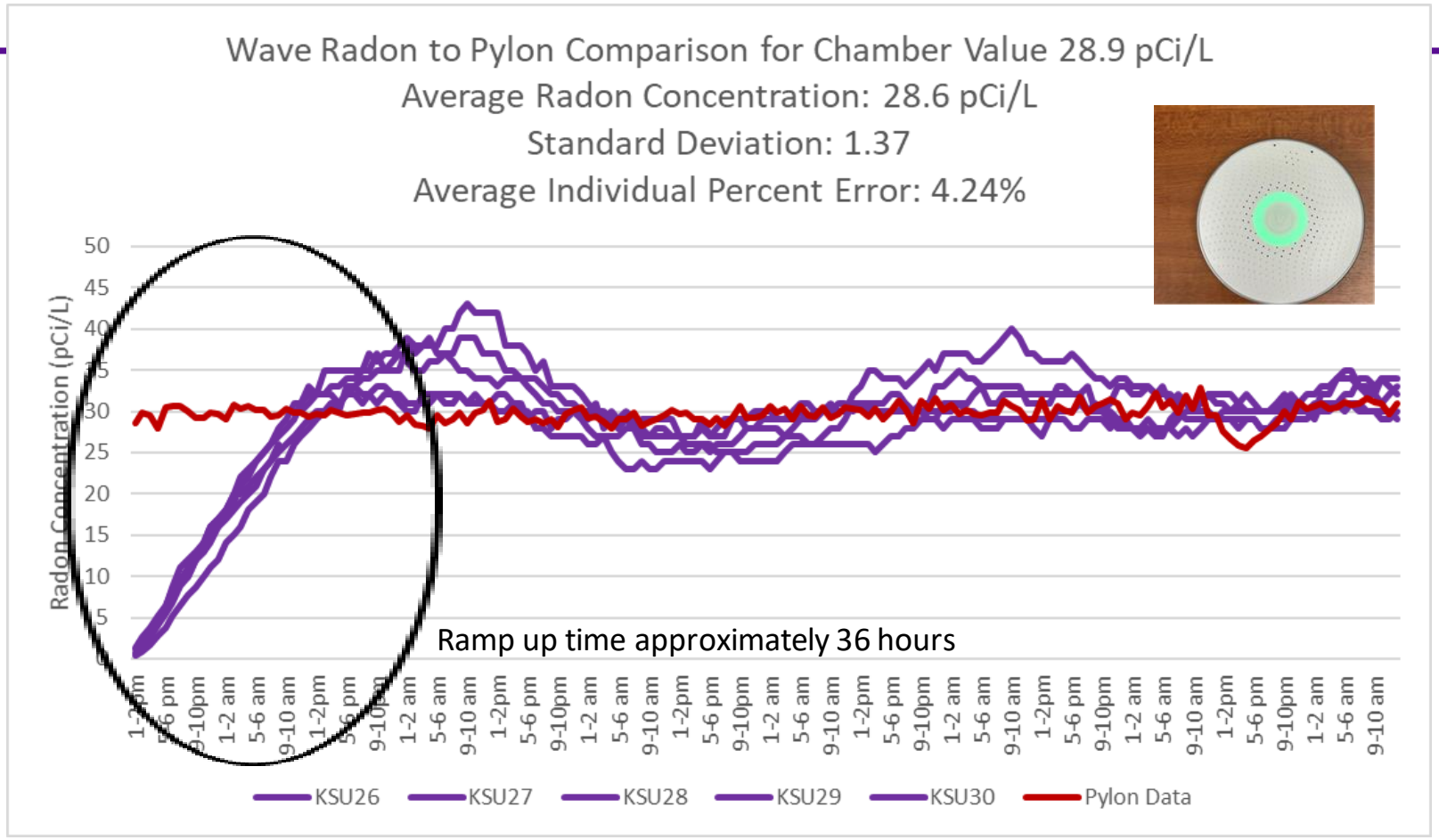
RadonEye to Pylon Comparison for Chamber Value of 27.7 pCi/L
Average Radon Concentration: 25.5 pCi/L
Standard Deviation: 0.963
Average Individual Percent Error: 4.29%

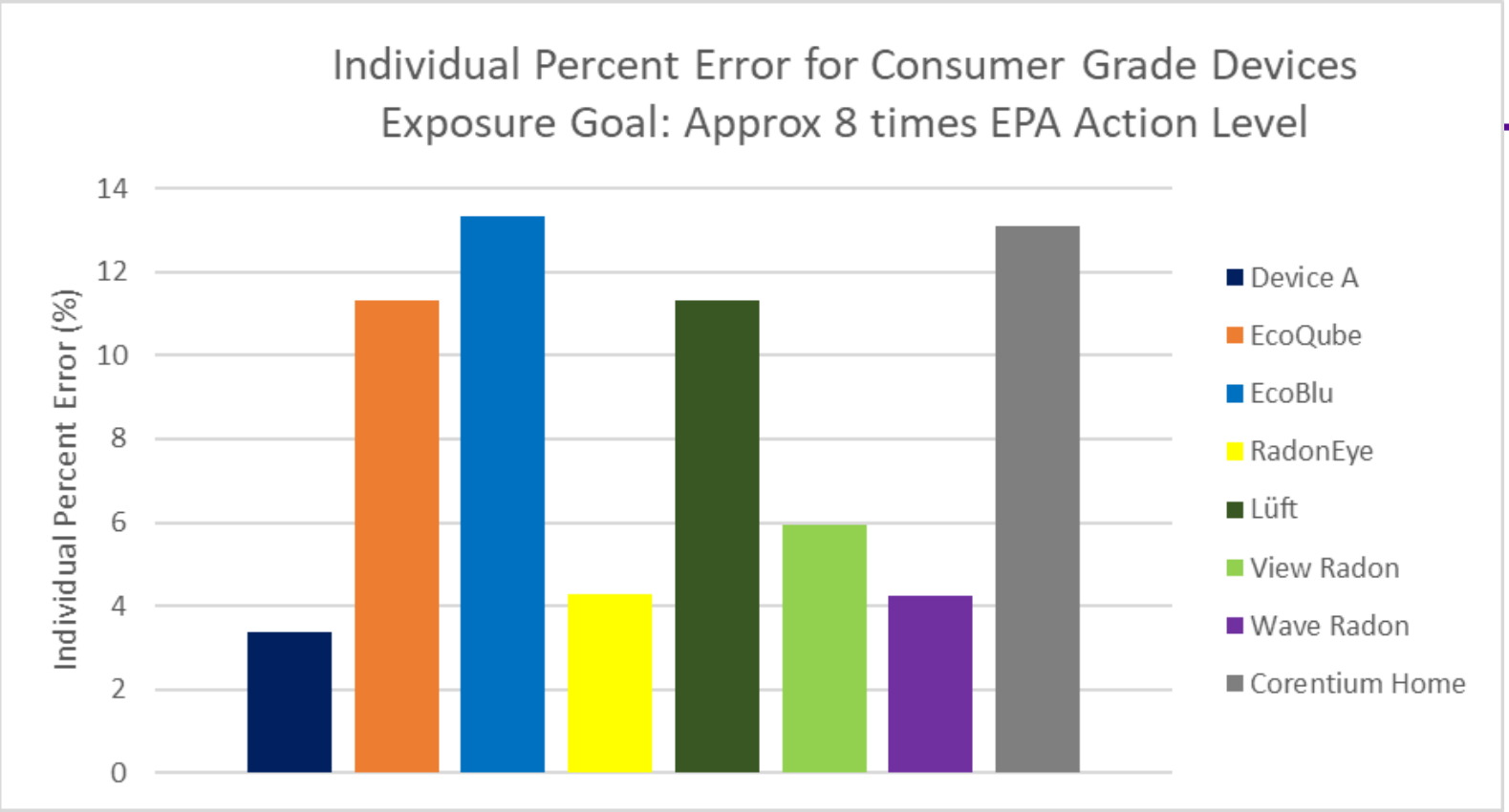



Lüft to Pylon Comparison for Chamber Value 29.4 pCi/L
Average Radon Concentration: 25.7 pCi/L
Standard Deviation: 0.582
Average Individual Percent Error: 12.6%
Radon Concentration (pCi/L)
35
30
25
20
15
10
5
0
2-3pm
7-8 pm
12-1 am
5-6 am
10-11 am
3-4 pm
8-9 pm
1-2 am
6-7 am
11-12 pm
4-5 pm
9-10 pm
2-3 am
7-8 am
12-1 pm
5-6 pm
10-11 pm
3-4 am
8-9 am
1-2 pm
6-7 pm
11-12 am
4-5 am
9-10 am
2-3 pm
7-8 pm
12-1 am
5-6 am
10-11 am
3-4 pm
8-9 pm
1-2 am
6-7 am
11-12pm
Ramp up time approximately 12 hours
KSU16
KSU17
KSU18
KSU19
KSU20
Pylon Data

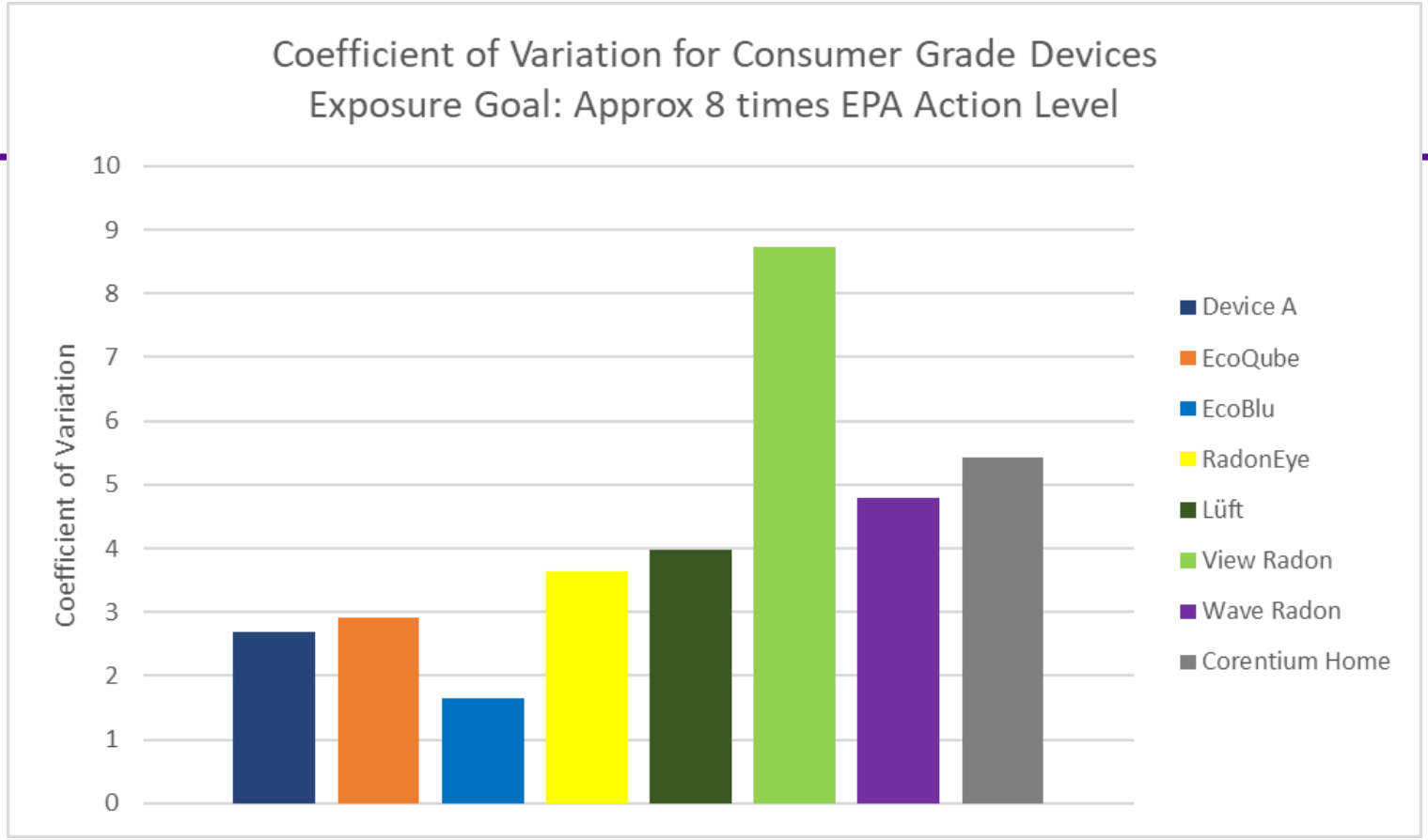
View Radon to Pylon Comparison for Chamber Value 27.7 pCi/L
Average Radon Concentration: 27.4 pCi/L
Standard Deviation: 2.40
Average Individual Percent Error: 5.95%




Wave Radon to Pylon Comparison for Chamber Value 28.9 pCi/L
Average Radon Concentration: 28.6 pCi/L
Standard Deviation: 1.37
Average Individual Percent Error: 4.24%
Radon Concentration (pCi/L)
50
45
40
35
30
25
20
15
10
5
0
Ramp up time approximately 36 hours
1-2pm
5-6 pm
9-10pm
1-2 am
5-6 am
9-10 am
KSU26
KSU27
KSU28
KSU29
KSU30
Pylon Data

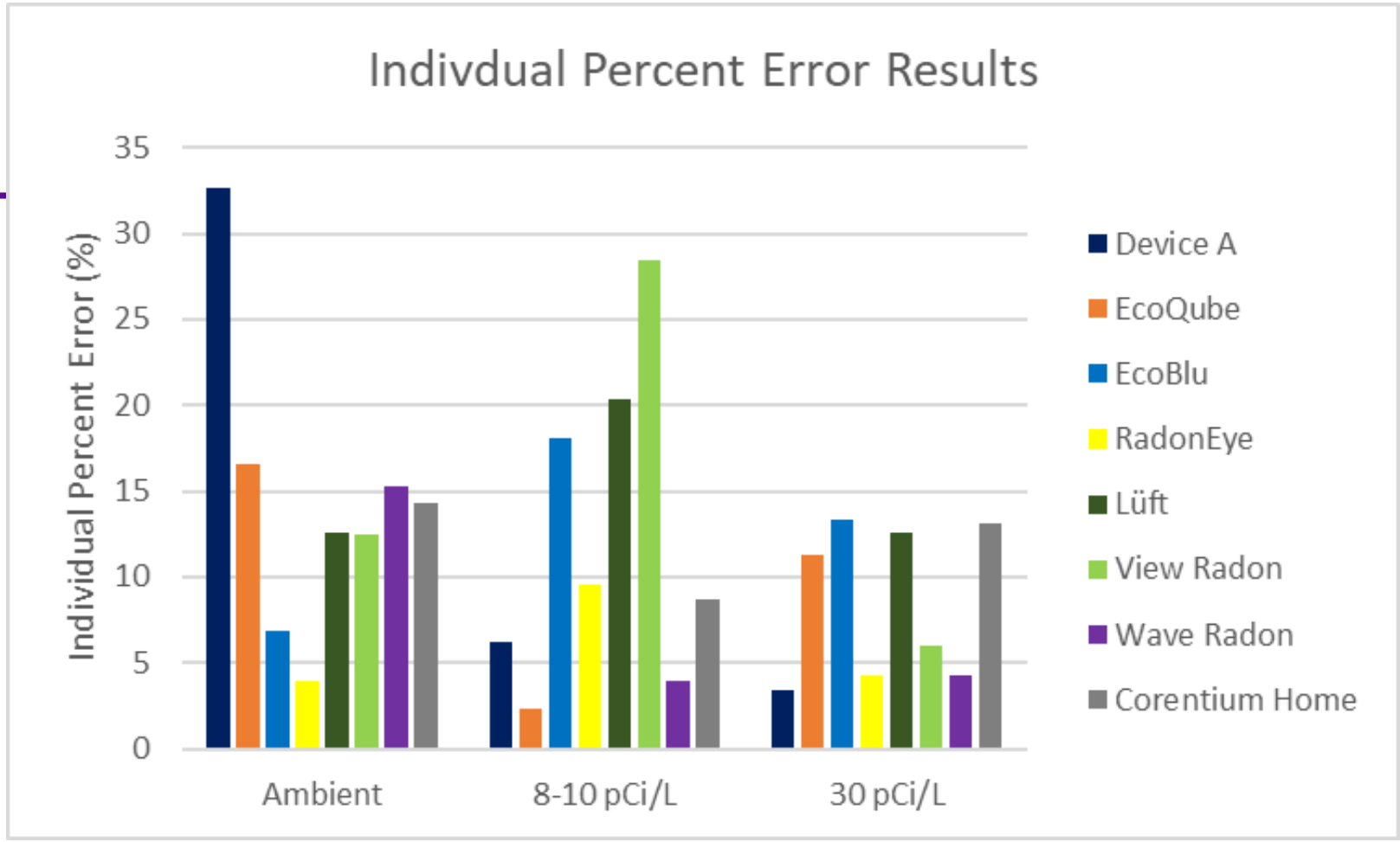


Individual Percent Error (IPE): The degree from which a single measure value (X) deviates from the conventionally true value (T)



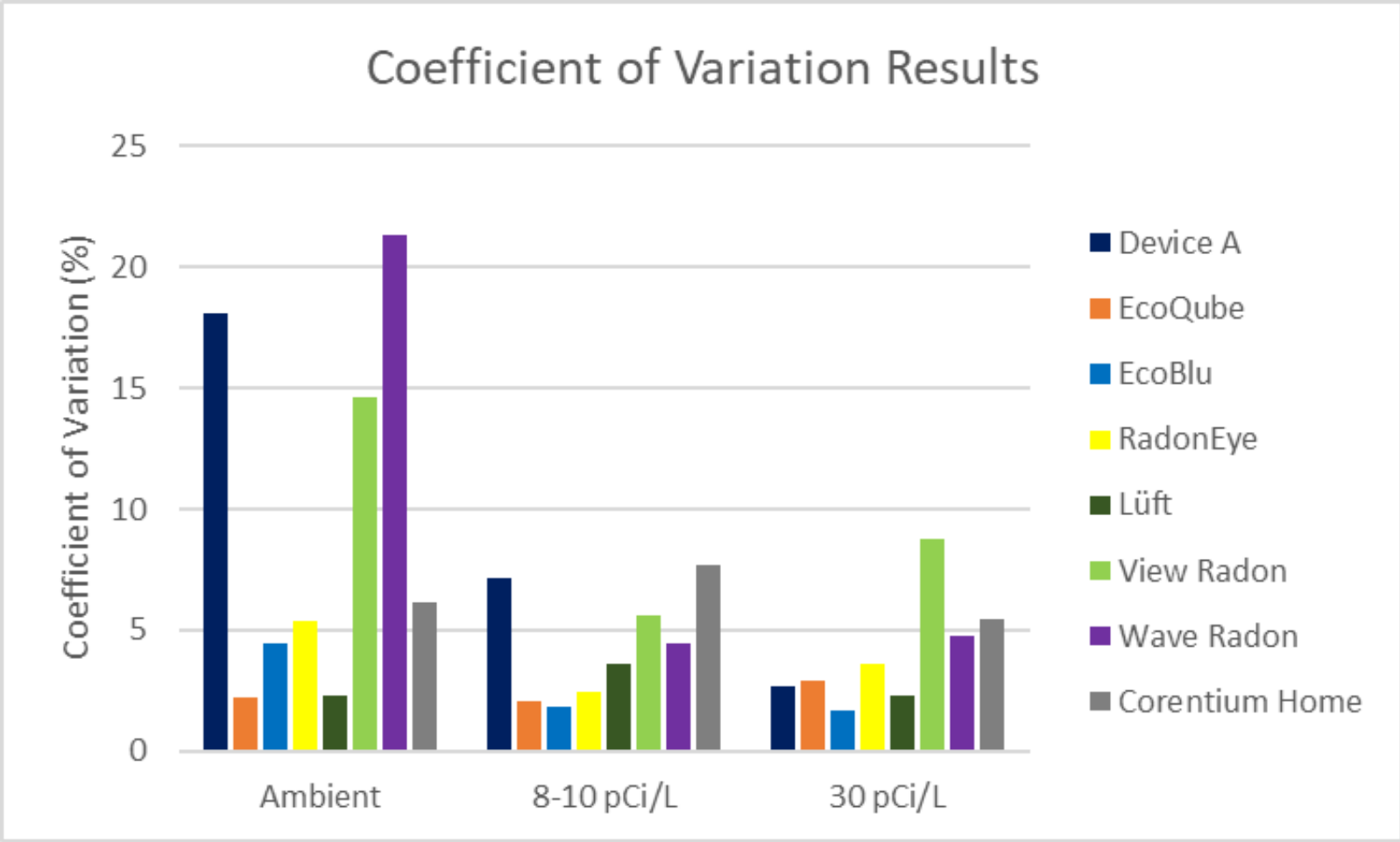
Coefficient of Variation (CV): The ratio of the standard deviation to the mean. The higher the CV, the greater dispersion around the mean.

Summary Data



Expect lower IPE for higher concentrations

-More radon there is to measure the more accurate/precise our results



Coefficient of Variation is relative measure of variation

Future Work

- Expose five copies of each device model to at least three times the low integrated concentration to test for proportionality
- Proportionality
  - The test for proportionality is the difference between the averages of the IPEs from the two sets of tests in the STAR
  - MS-PC Criteria
    - The difference between the average IPE of a set of five devices exposed at a non-zero low concentration and the average IPE of a set of five devices exposed at a high concentration shall be in the range of 0 ± 15%
      - The IPE of each individual measurement shall be in the range of 0 ± 25%, and the CV of each set of measurements shall be no greater than 15%

Contact Information

Alexandra Bahadori

785.532.6026 (general office)

785.532.3957 (direct)

adbaha@ksu.edu

Brian Hanson

785.532.4996 (direct)

bhandon@ksu.edu

NRPS Contact

radon@ksu.edu

KSU Radon Training

radoncourse@ksu.edu

KSU Radon Chamber

radonchamber@ksu.edu