Measurement of Soil Gas to Indoor Air Attenuation Rate Using Radon as a Naturally Occurring Tracer Gas

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Session D1: Innovative Tools for Evaluating Vapor Intrusion Risk
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*Licensed in CA,
Not licensed in all states

Speaker Bio

- Education
  - B.S. Chemistry / Applied Mathematics
    (2008 St. Edwards University, Austin, TX)
  - M.S. Civil Engineering
    (2015 Texas A&M University, College Station, TX)
- Work History
  - 10 years consulting (2008 – 2017, 2021-current)
  - 5 years Regulator (Alameda County, 2017 – 2021)
- Registered Civil Engineer (CA Lic No C91063)
- Relevant VI Experience
  - VIMS/SVE design engineer
  - Developed guidance documents for VIMS design, construction CQA, commissioning sampling, and long-term stewardship at Alameda County Department of Environmental Health

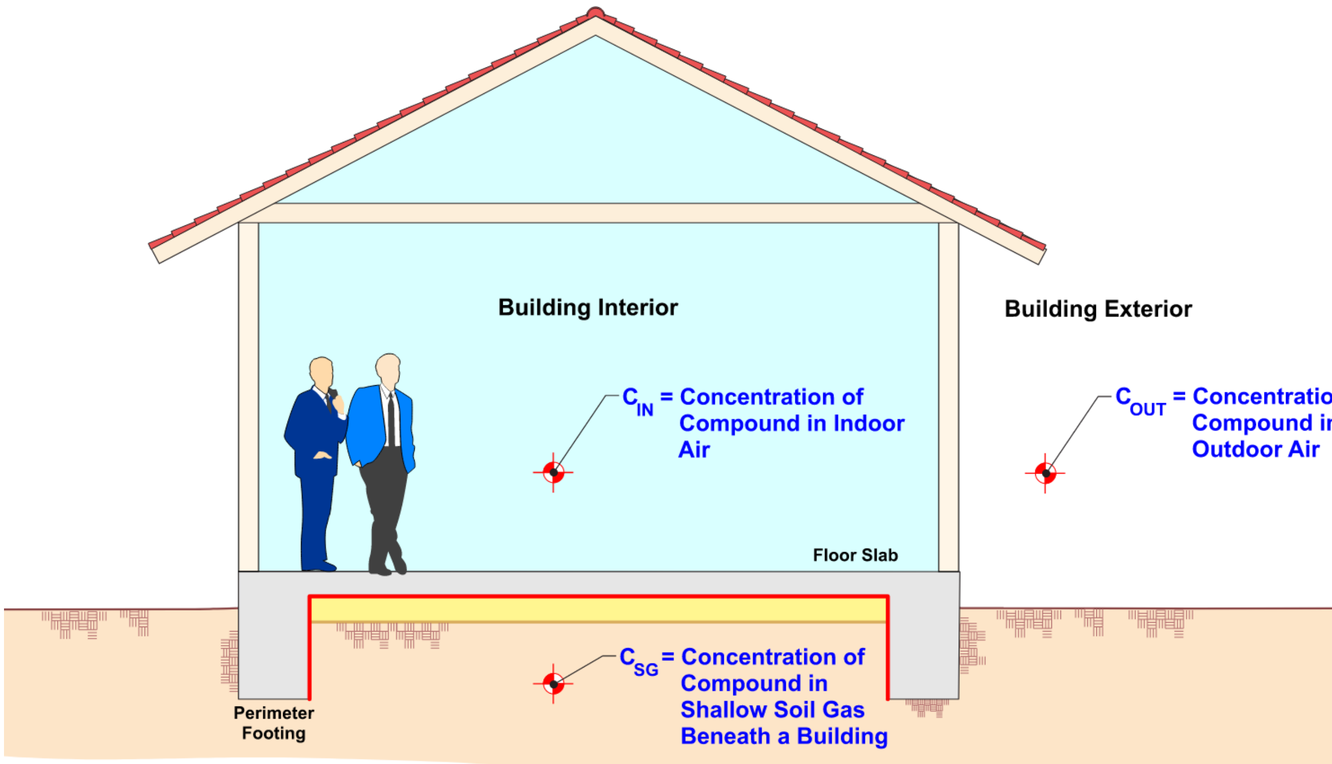
Overview

1. Problem Statement & Objective
2. Background
3. Limitations of Traditional TO-15 sampling
4. Ideal Solution: Conservative Tracer
5. Radon as a Conservative Tracer
6. Methodology
7. Analysis
8. Sources of Error
9. Closing

Problem Statement and Objective

- Characterization of VI Risk via traditional methods is prone to issues:
  - False Positives / Interference
  - Effects of Building Operations
  - Weather / seasonal effects
  - Data Density
  - $$$
- Characterization of VI Risk with radon as LOE
  - Robust and resistant to interference
  - Time-series data
  - Versatile (bulk VI & point of entry identification)
  - Cost effective

Background



Pore Gas to Indoor Air Attenuation Factor (α)

$$\alpha = \frac{C_{VI}}{C_{SG}} \approx \frac{C_{IN} - C_{OUT}}{C_{SG}}$$

Typically 0.03 or 0.001

Attenuation Rate

$$AR = \frac{1}{\alpha} = \frac{C_{SG}}{C_{IN} - C_{O}}$$

Typically 33 or 1,000

Protection Factor

$$PF \sim AR$$

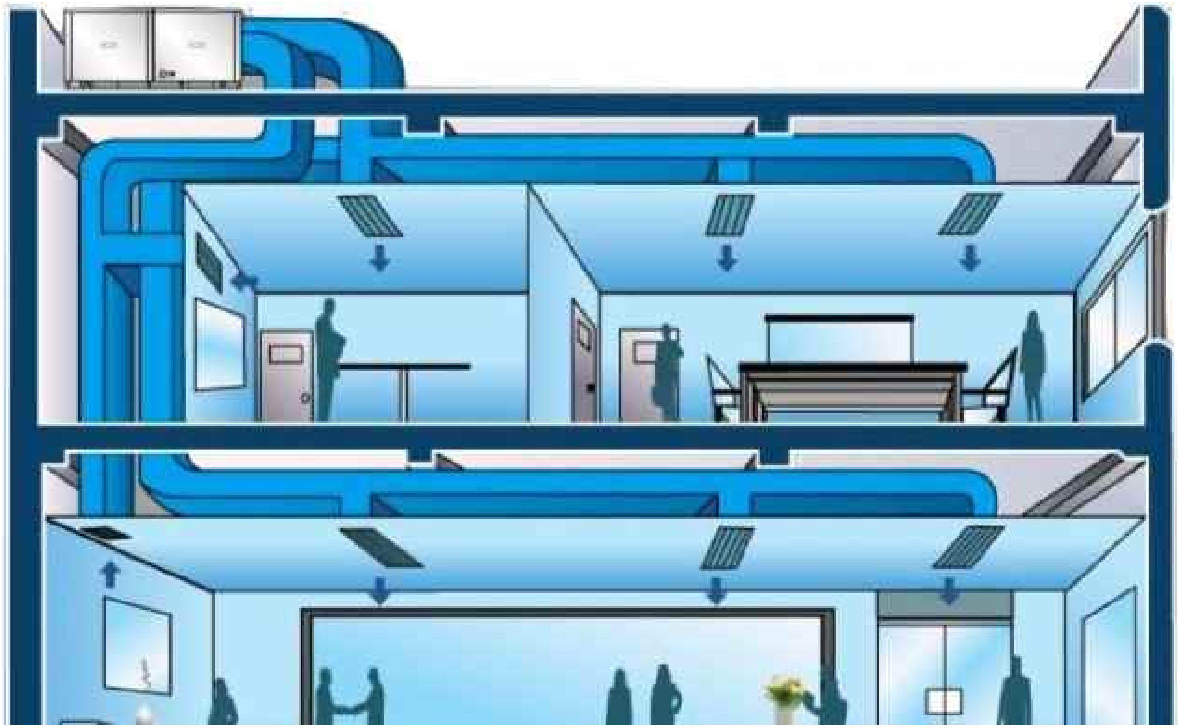
Varies, >5,000 to 100,000

Limitations of Traditional TO-15

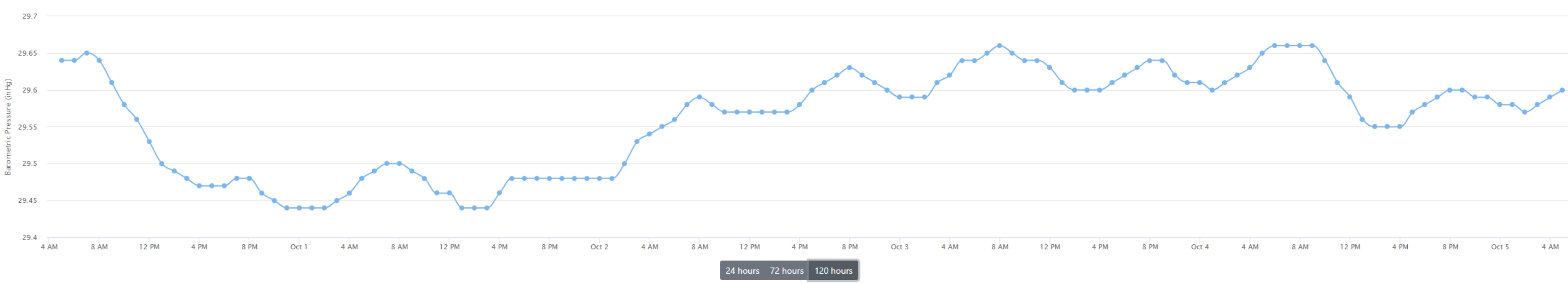
- Difficult to control/ eliminate indoor/outdoor air sources, particularly in occupied spaces
- Example: USEPA Office of Chemical Safety and Pollution Prevention > 450 consumer products with PCE

- False Positives

Limitations of Traditional TO-15



- False Positives
- Sensitive to BP & Building Operation



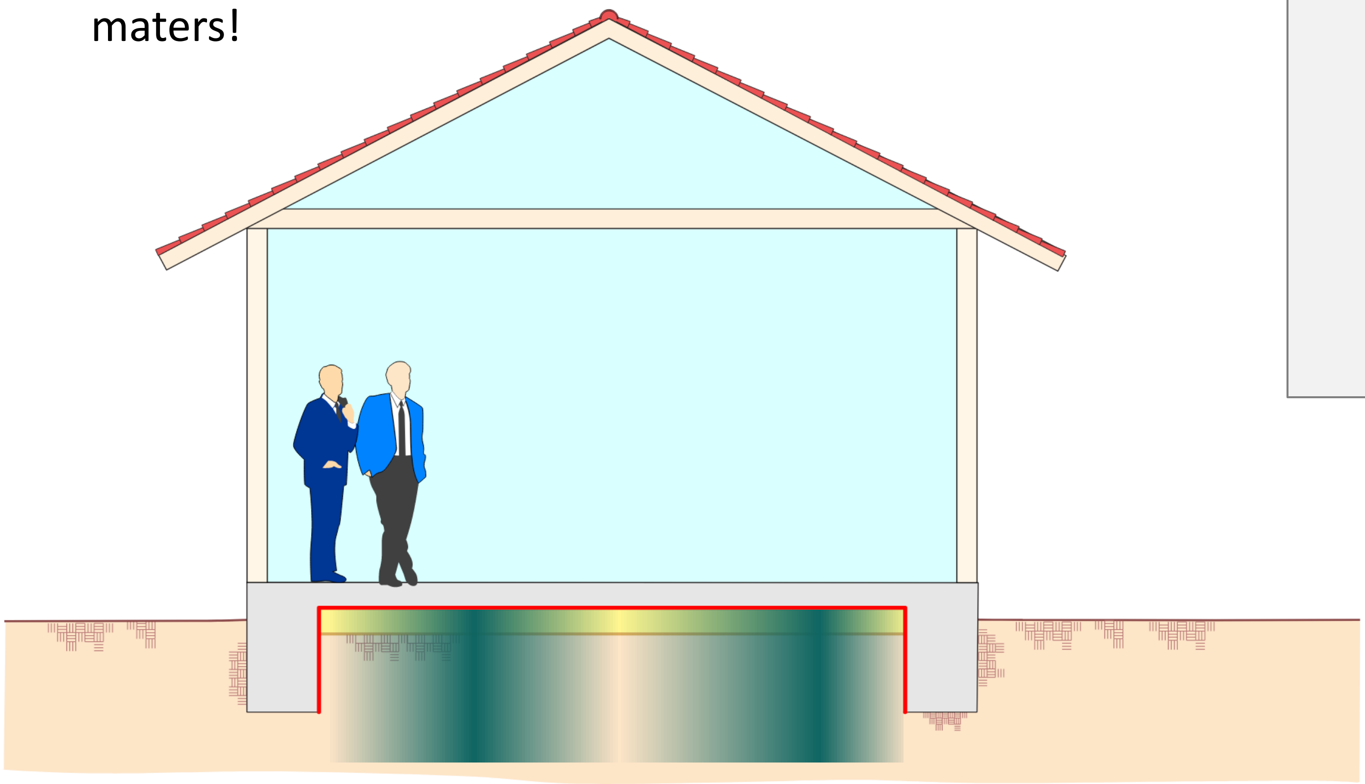
Source: https://barometricpressure.app/nashville (9/30/2022)

Limitations of Traditional TO-15

Sample density rarely meets/exceeds density of homogeneous air space.

Locations of points of entry matter!

The location and magnitude of source material maters!



- False Positives
- Sensitive to BP & Building Operation
- Sample Density and Anisotropy

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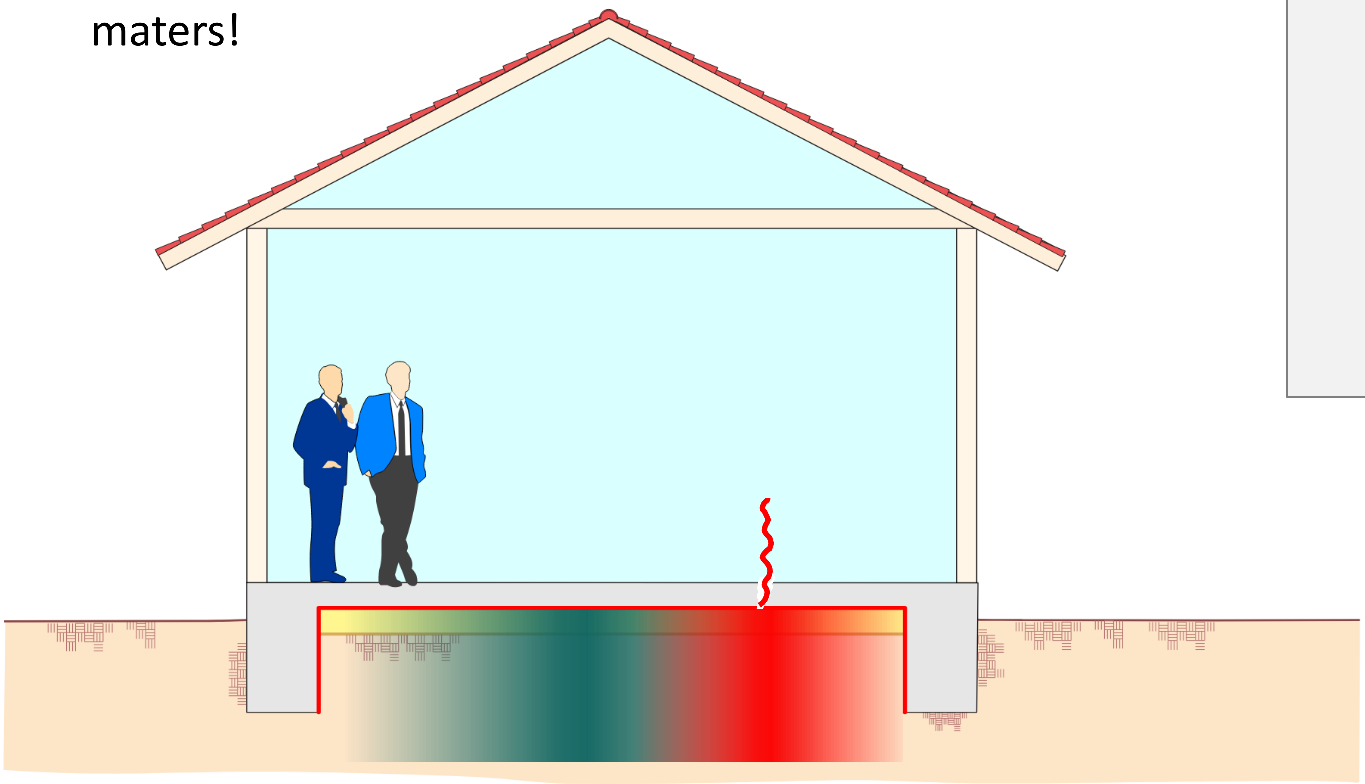

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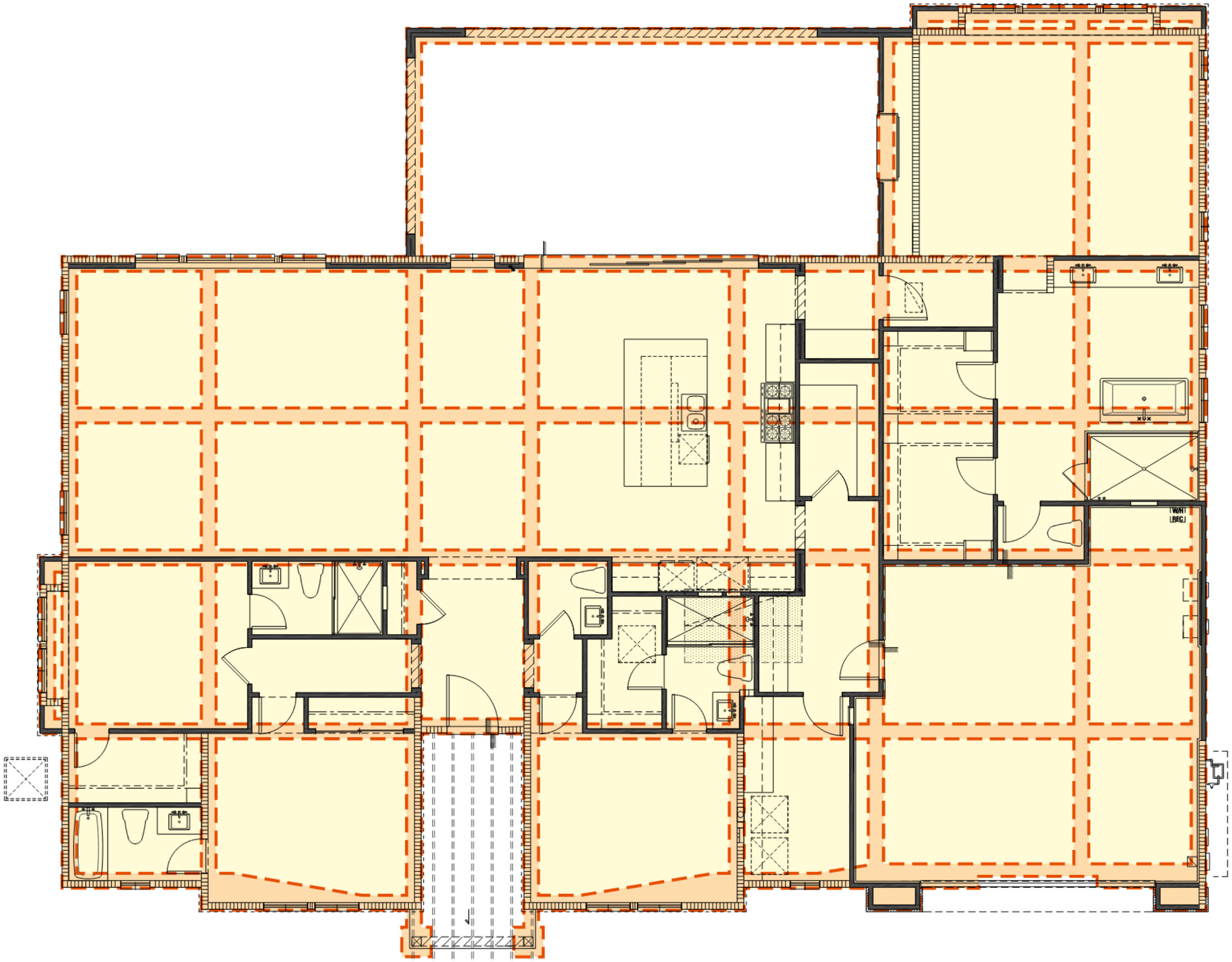
Limitations of Traditional TO-15



- False Positives
- Sensitive to BP & Building Operation
- Sample Density and Anisotropy

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Limitations of Traditional TO-15

- Laboratory Reporting Limits
- Default α typically 0.03 to 0.001
  - $C_{SG} > 10{,}000 \times PQL_{IA}$

- False Positives
- Sensitive to BP & Building Operation
- Sample Density and Anisotropy
- Quantification Limits

Ideal Solution: Conservative Tracer

	TO-15	Radon
No sources other than VI	Poor	Good
Detectible in indoor air with low reporting limits	Good	Excellent
Distinguishable from ambient air	Good/Poor	Good/Poor
Conservative	Poor	Excellent*
Homogeneous and isotropic in sub-surface	Poor	Excellent
$[\text{Tracer}]_{SG}$ >> $[\text{Tracer}]_{IA}$ (at least 3 OOM)	Varies	Good
Sampled selectively	Excellent	Excellent
Sampled continuously	Poor	Excellent
Sampled cost effectively	Poor	Excellent
Highly diffusive	Varies	Excellent

*Radon is only conservative for sufficiently low residence times

Radon as a Conservative Tracer

Naturally Occurring & Abundant

Soil gas concentrations are proportional to SA/M ratio

	Outdoor Air [pCi/L]	Indoor Air [pCi/L]	Soil Gas [pCi/L]	Groundwater [pCi/L]
Lower Value	<0.1	<1	20	100
Typical Value	0.2 0.4[2]	1 to 2 1.25[2]	200 to 2,000	
Upper Value	30	3,000	10,000	3,000,000

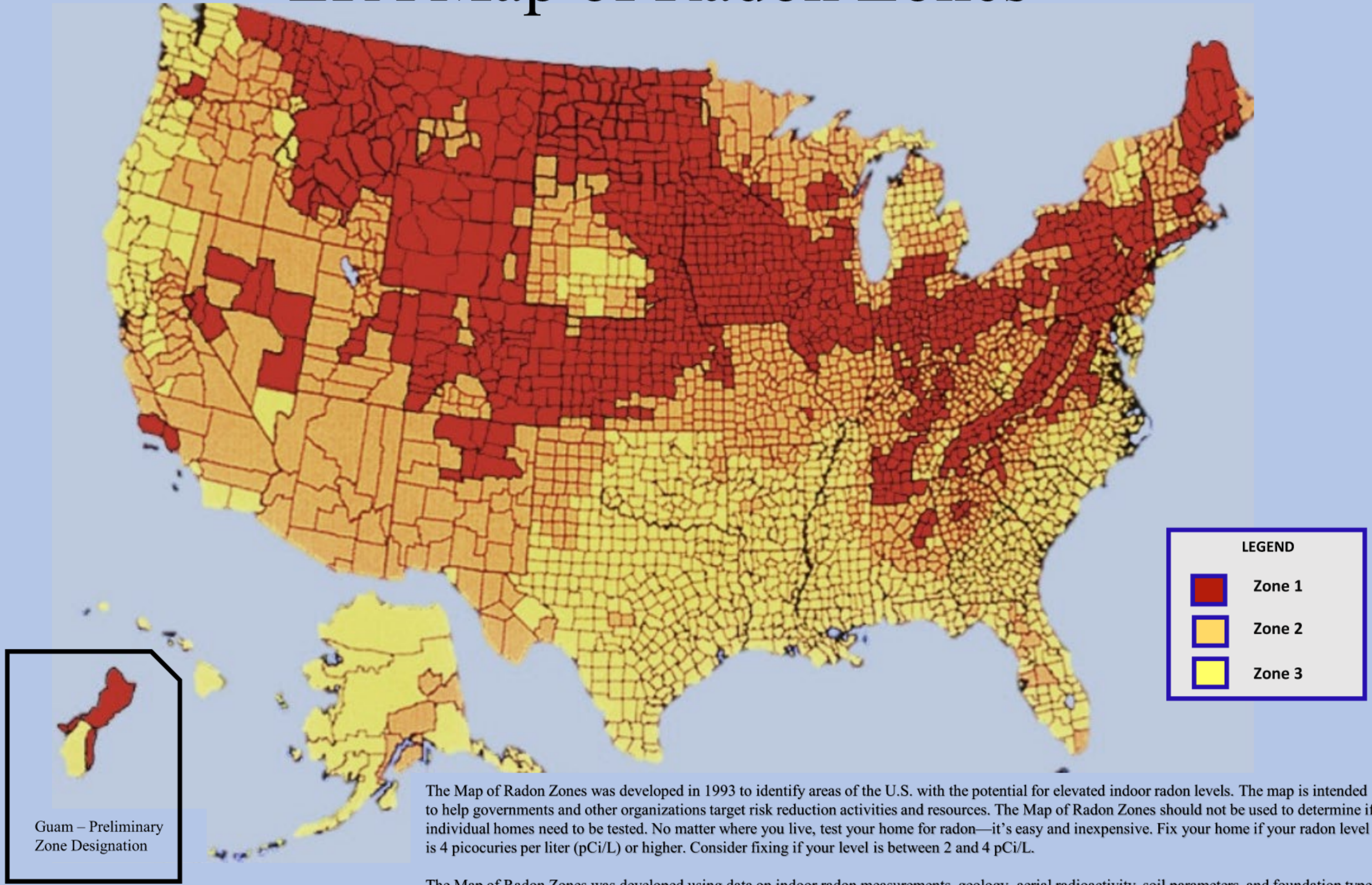
Adapted from "The Geology of Radon", USGS, 1992 unless otherwise noted

[2] Marcinowski *et* al, "National and regional distributions of airborne radon concentrations in U.S. homes", Health Phys. 66, 699-706, 1994

Unites of Measures: Curie (Ci) or Becquerel (Bq)

1 pCi = 2.2 decay/minute

EPA Map of Radon Zones

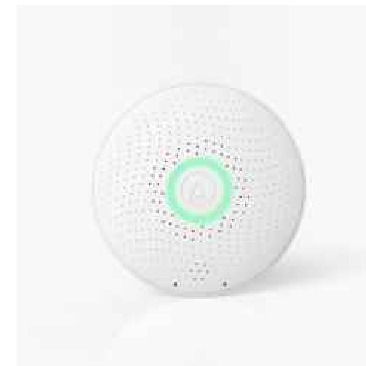


The Map of Radon Zones was developed in 1993 to identify areas of the U.S. with the potential for elevated indoor radon levels. The map is intended to help governments and other organizations target risk reduction activities and resources. The Map of Radon Zones should not be used to determine if individual homes need to be tested. No matter where you live, test your home for radon—it's easy and inexpensive. Fix your home if your radon level is 4 picocuries per liter (pCi/L) or higher. Consider fixing if your level is between 2 and 4 pCi/L.

The Map of Radon Zones was developed using data on indoor radon measurements, geology, aerial radioactivity, soil parameters, and foundation types. EPA recommends that this map be supplemented with any available local data in order to further understand and predict the radon potential for a specific area.

- Radon Measurement
  - Lucas Cell
  - Ion Chamber
  - Alpha Track
  - Activated Charcoal

Radstar GM 1-2



AirThings Wave

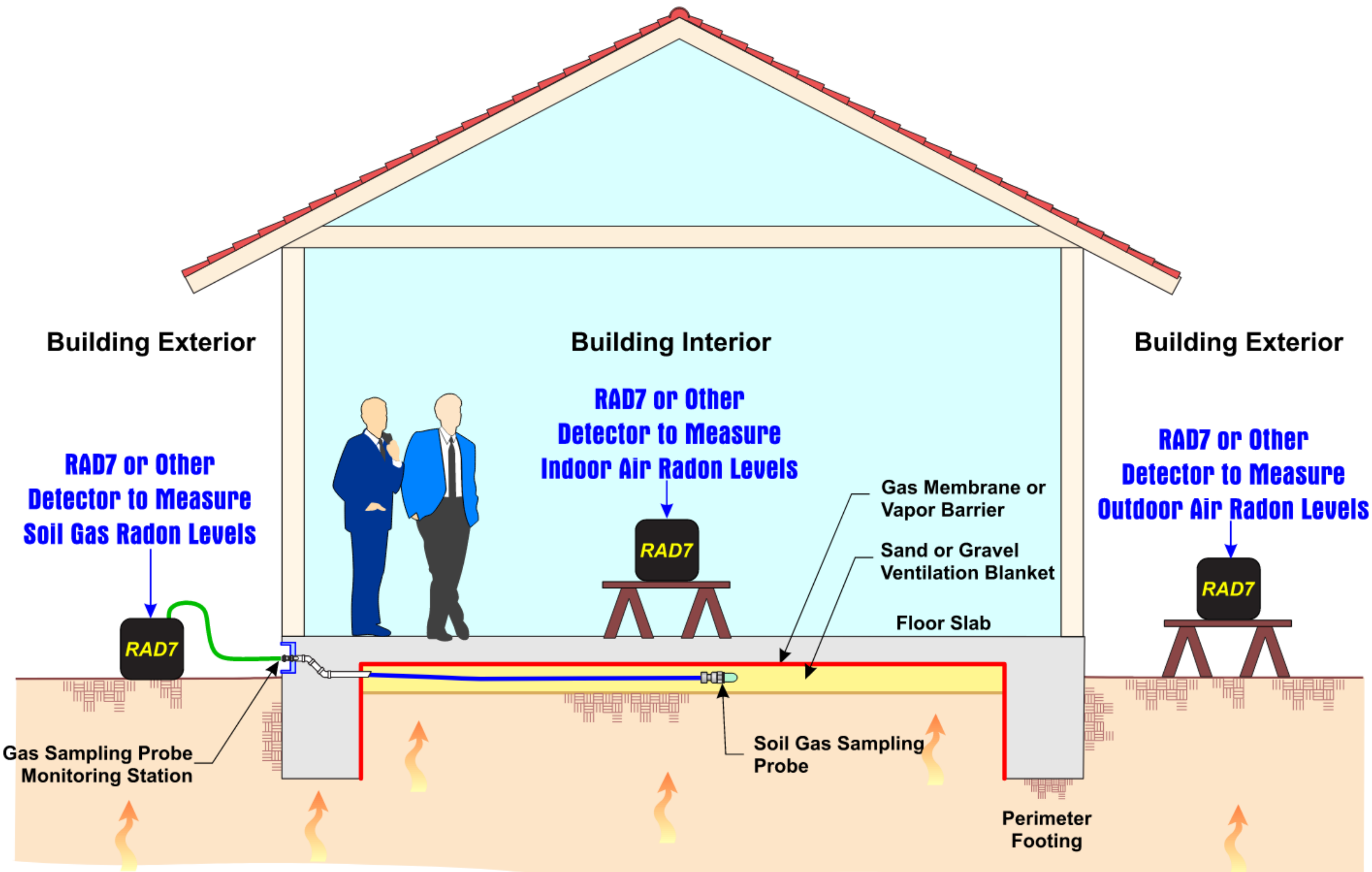
Accustar Alpha Track

Activated Charcoal

Methodology

- Sensitivity
  - CPH
  - Standard Deviation & Accuracy
- Resolution
- Measurement Rate
- Thoron?

Methodology



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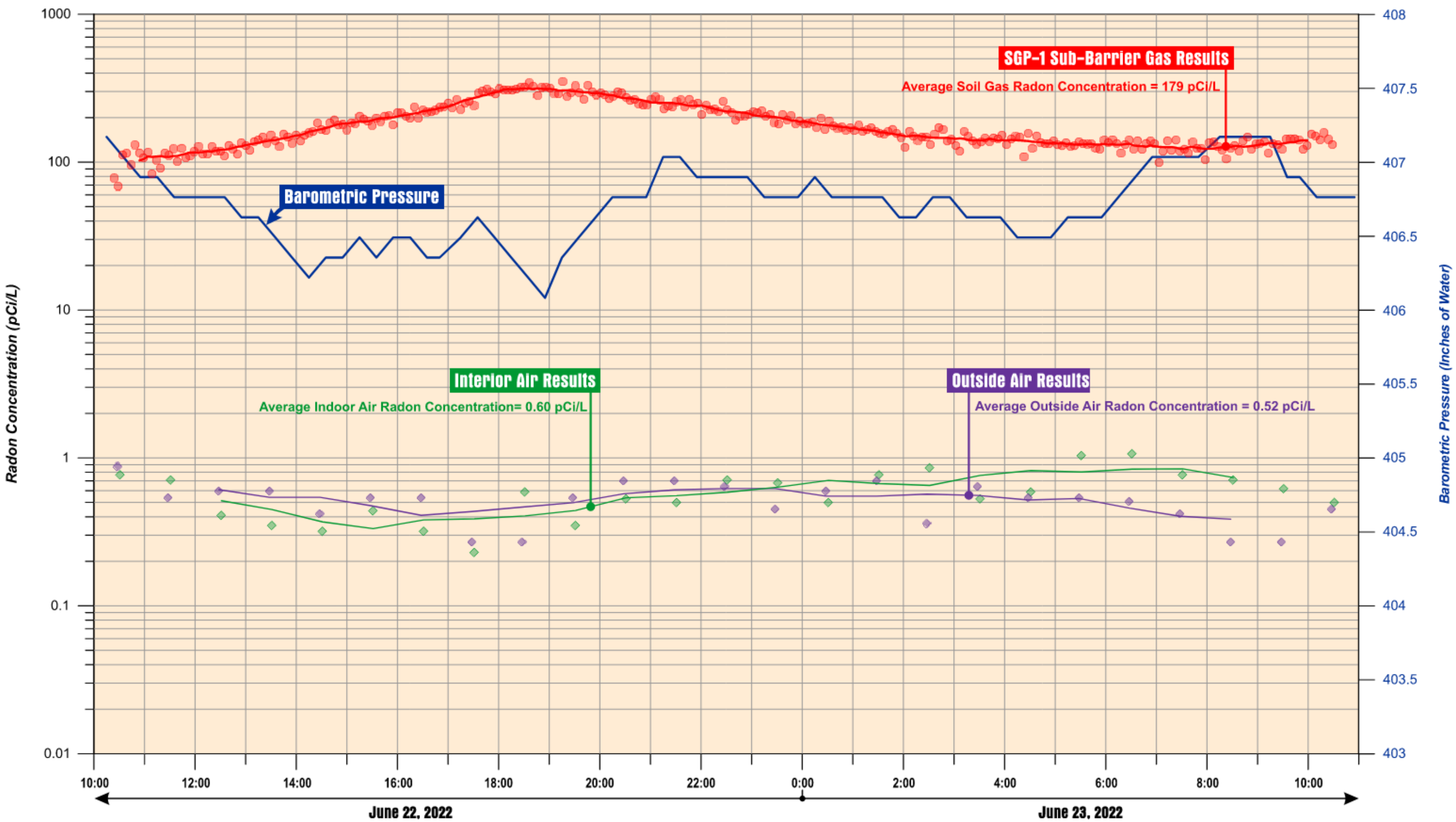
Methodology

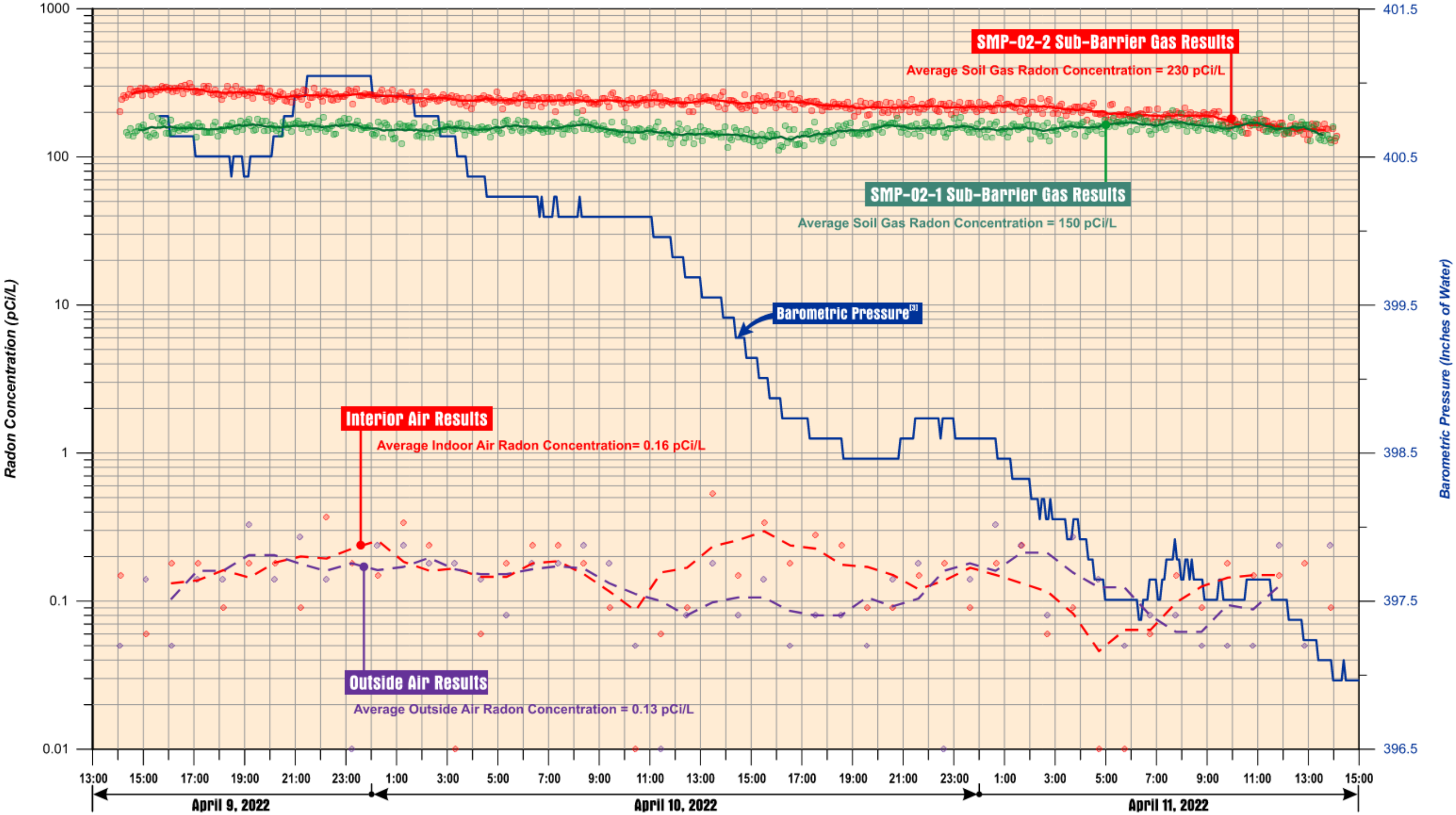
Methodology

Analysis



Location	Average $[Rn]_{SG}$ (pCi/L)	Average $[Rn]_{IA}$ (pCi/L)	Average $[Rn]_{AA}$ (pCi/L)	Protection Factor	Attenuation Factor
SGP-1	179	0.60	0.52	2,200	0.00045

Analysis



Location	Average $[Rn]_{SG}$ (pCi/L)	Average $[Rn]_{IA}$ (pCi/L)	Average $[Rn]_{AA}$ (pCi/L)	Protection Factor	Attenuation Factor
SMP-01	150	0.16	0.13	5,000	0.00020
SMP-02	230	0.16	0.13	7,700	0.00013

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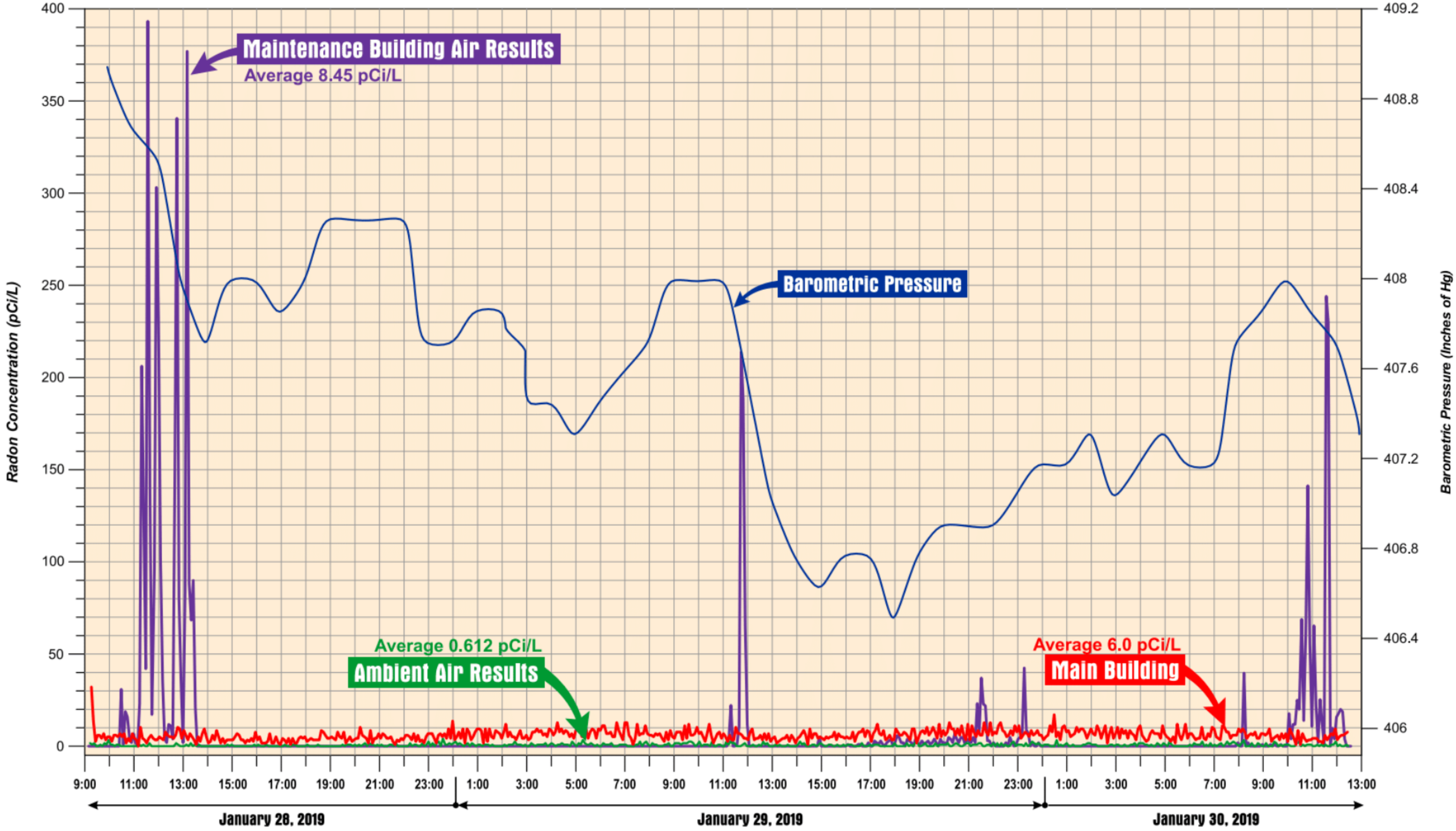
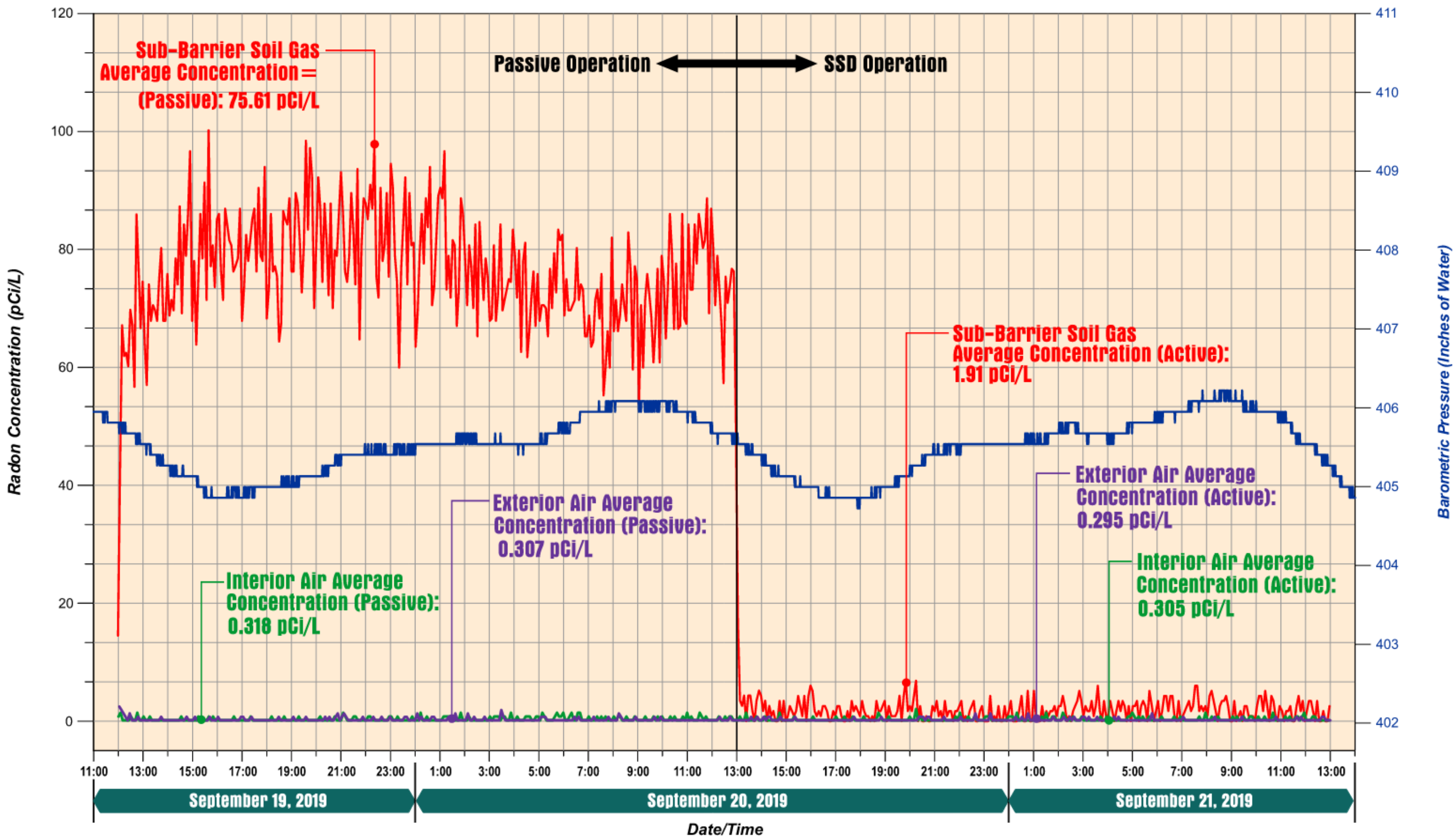
Analysis



Maintenance Building Air Results
Average 8.45 pCi/L
Barometric Pressure
Average 0.612 pCi/L
Ambient Air Results
Average 6.0 pCi/L
Main Building
Radon Concentration (pCi/L)
Barometric Pressure (Inches of Hg)
400
350
300
250
200
150
100
50
0
409.2
408.8
408.4
408
407.6
407.2
406.8
406.4
406
9:00 11:00 13:00 15:00 17:00 19:00 21:00 23:00 1:00 3:00 5:00 7:00 9:00 11:00 13:00 15:00 17:00 19:00 21:00 23:00 1:00 3:00 5:00 7:00 9:00 11:00 13:00
January 28, 2019
January 29, 2019
January 30, 2019

Analysis



40 x dilution from active SSDS

6,900 PF from EBS

Error

- Radon sources
  - Earth materials
  - Glass
  - Welding
- Signal to Noise Ratio and Measurement Interval
- Decay?

Error

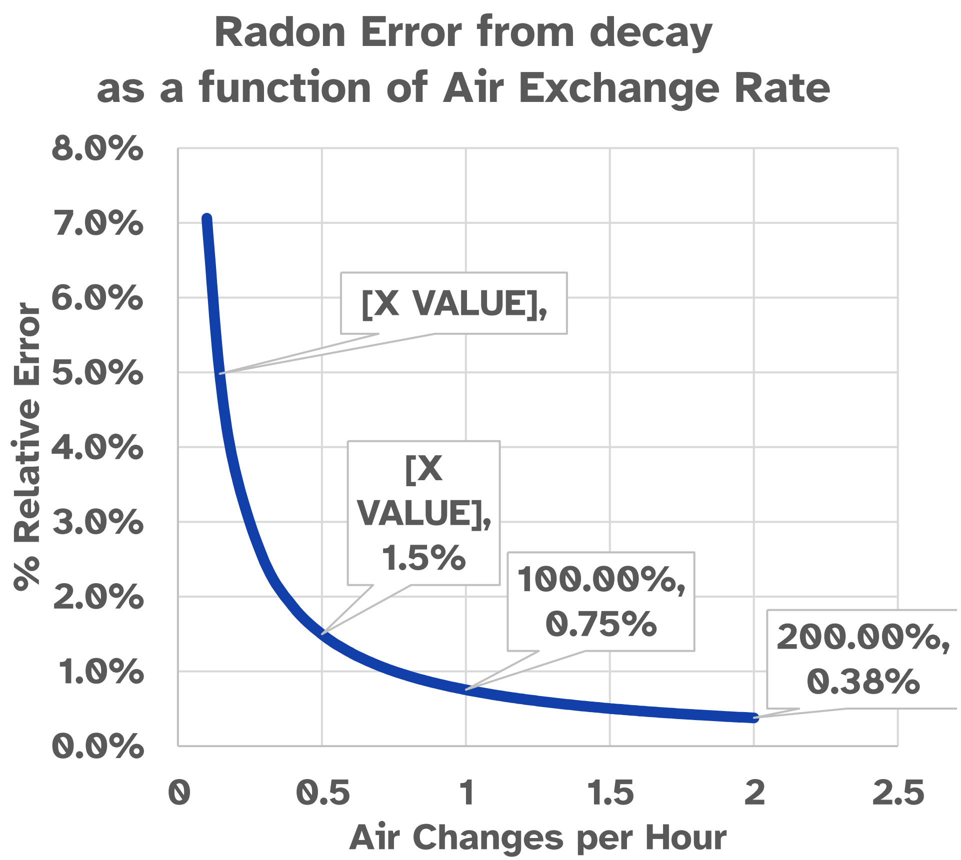
CMFR, ideal mixing, incompressible fluid, at steady state (1st order decay)

$$k = \frac{\ln(2)}{\lambda_{\frac{1}{2}}}$$

$$\tau = \frac{V}{Q} = \frac{1}{ACH}$$

$$C_{obs} = \frac{C_0}{1 + k * \tau}$$

$$\% \, Error = \frac{|C_{obs} - C_0|}{C_0}$$



Closing

- Radon is a tool in the toolbox for MLOE investigations
- Limited applications for soil gas, excellent applications for sub-slab gas
- Not a substitute for TO-15 data during initial characterization
- Potential substitute for TO-15 in long-term monitoring

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