25th California Unified Program
Annual Training Conference

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

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Presentation Outline

1. Background / Qualifications.
2. What is the Soil Gas to Indoor Air "Attenuation Rate" and Why is it Relevant?
3. Complications Associated With Using VOC Data for Calculating Attenuation Rates.
4. Radon Gas Sources & Characteristics.
5. Radon Measurement.
6. Typical Radon Measurement Results.
7. Comparison of Radon and VOC Attenuation Rates.
8. Long Term Monitoring of Attenuation Rates.
9. Advantages of Radon Monitoring.
10. Observations from Radon Monitoring.

Background / Qualifications

Glenn Tofani Background / Qualifications

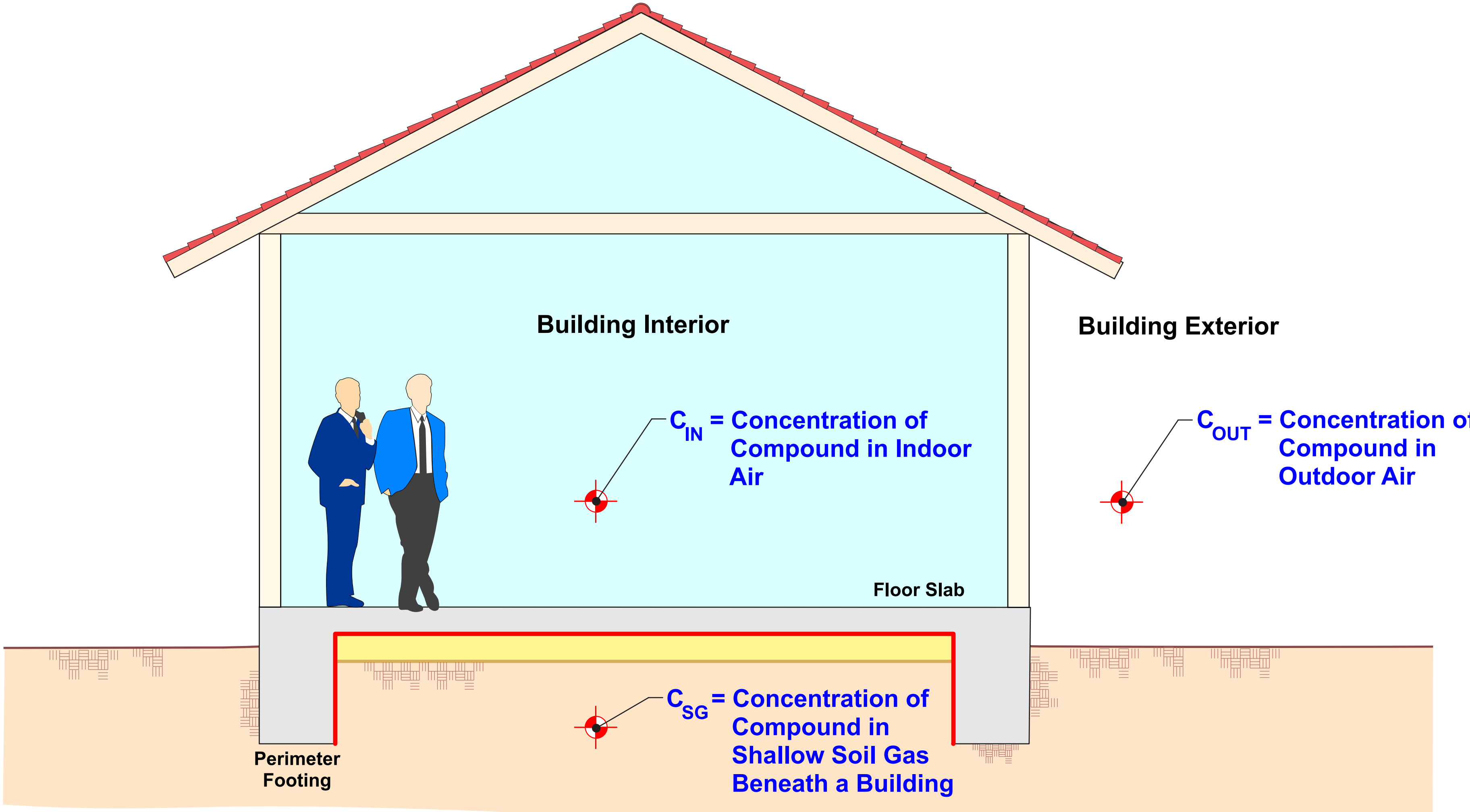
- BSCE from CSULB in 1982. MSCE from CSULB in 1983.
- Principal Engineer with GeoKinetics / Advanced Construction Technologies
- Taught undergraduate / graduate engineering classes at CSULB and UCI.
- Licensed Geotechnical Engineer, Civil Engineer, Engineering Contractor, General Building Contractor, Hazardous Waste Contractor, etc. in California.
- Licensed Civil Engineer in 15 other states.

Glenn Tofani Background / Qualifications

- **Performed long term VOC diffusion and chemical compatibility testing for most membrane manufacturers.**
- **Designed / installed / tested soil gas mitigation systems at more than 20,000 buildings to date.**
- **Performed radon testing for purposes of establishing soil gas to indoor air attenuation rates at more than 1,500 buildings to date.**

What is the Soil Gas to Indoor Air Attenuation Rate & Why is it Relevant?

Soil Gas to Indoor Air Attenuation Rate



Soil Gas to Indoor Air Attenuation Rate = $C_{SG} / (C_{IN} - C_{OUT})$

Why is the Soil Gas to Indoor Air Attenuation Rate Relevant?

- Allowable risk-based indoor air contaminant (VOC) levels have been established by various regulatory agencies (e.g. Federal and State EPAs & RWQCB).
- Soil gas screening or action levels can be obtained by multiplying the allowable indoor air concentration for any contaminant by the Attenuation Rate for that contaminant.
- Currently, very conservative generic soil gas screening levels are often used as action or clean-up levels.

Why is the Soil Gas to Indoor Air Attenuation Rate Relevant?

- **Currently, a very low and conservative default Attenuation Rate of 33* is often used by regulatory agencies to evaluate indoor air exposure risks and establish soil gas screening levels.**

* **Based on EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings Dated March 16, 2012.**

Why is the Soil Gas to Indoor Air Attenuation Rate Relevant?

- The actual Attenuation Rate for most buildings is much higher. For buildings with engineered vapor barriers, the actual Attenuation Rate may be orders of magnitude higher.
- The use of an overly conservative Attenuation Rate increases construction and maintenance costs and prevents development at some sites.

Complications Associated With the Use of VOC Data When Attempting to Establish Attenuation Rates

Complications Associated With the Use of VOC Data When Attempting to Establish Attenuation Rates

1. The VOC source concentrations at most sites are too low for measurement of Attenuation Rates.
   - Soil gas to indoor air Attenuation Rates for most buildings are typically 1,000 or greater.
   - Soil gas to indoor air Attenuation Rates for buildings with vapor intrusion mitigation barriers are often greater than 10,000.
   - Soil gas VOC levels typically need to be at least an order of magnitude greater than the indoor air Practical Quantification Limit (PQL) in order for the data to be suitable for calculating Attenuation Rates with a reasonable confidence level.

Example – Calculation of Attenuation Rate Using VOC Data

Consider a building having a soil gas to indoor air Attenuation Rate of 1,000.

Assume: Contaminant of concern is PCE.

Idealized conditions:

No significant indoor air VOC levels - so low detection limits can be achieved.

No interior or ambient air sources of PCE.

Indoor air detection limit (EPA TO-15 SIM) is 0.1 µg/m^3.

Indoor air Practical Quantification Limit (PQL) (EPA TO-15 SIM) is 0.3 µg/m^3.

Example – Calculation of Attenuation Rate Using VOC Data

The absolute minimum soil gas PCE concentration necessary under these idealized conditions in order to quantify the PCE concentration in the indoor air and calculate an Attenuation Rate is 300* µg/m^3 (i.e. PQL x AR = 0.3 X 1,000).

*** The soil gas screening level for PCE in a residential setting using the default A.R. of 33 is 15 µg/m^3.**

Example – Calculation of Attenuation Rate Using VOC Data

The absolute minimum soil gas PCE concentration necessary under these idealized conditions in order to quantify the PCE concentration in the indoor air and calculate an Attenuation Rate is 300* $\mu g/m^3$ (i.e. PQL x AR = 0.3 X 1,000).

In order to reliably calculate an Attenuation Rate, the source concentration should be higher . . . perhaps 10 to 100 x PQL x AR or about 3,000 $\mu g/m^3$ to 30,000 $\mu g/m^3$.

This is for a building with a relatively low Attenuation Rate. Higher source concentrations would be necessary at most buildings where the attenuation rate is >1,000.

At many sites, the soil gas VOC levels will not be high enough to reliably calculate Attenuation Rates.

Complications Associated With the Use of VOC Data When Attempting to Establish Attenuation Rates

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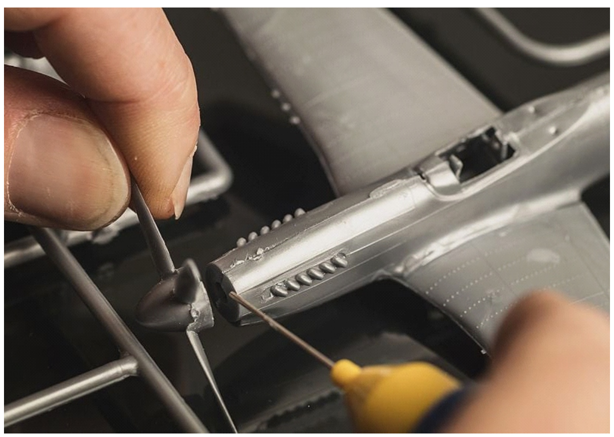
2. For many of the common contaminants of concern, sources are often present on the interiors of buildings.



Complications Associated With the Use of VOC Data When Attempting to Establish Attenuation Rates

1. The VOC source concentrations at many sites are too low for measurement of Attenuation Rates.
2. For many of the common contaminants of concern, sources are often present on the interiors of buildings.

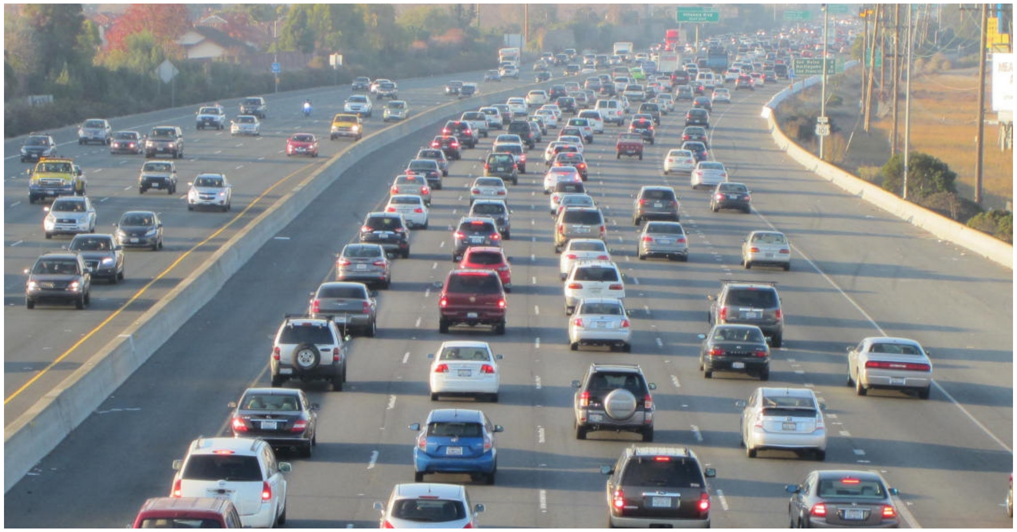
   This issue can be more pronounced at recently constructed buildings since many construction materials off-gas significant levels of VOCs.

   The EPA Office of Chemical Safety and Pollution Prevention lists over 450 consumer products that contain PCE.

   It is often difficult, if not impossible, to differentiate between VOCs associated with soil gas intrusion and VOCs associated within interior sources.

Complications Associated With the Use of VOC Data When Attempting to Establish Attenuation Rates

1. The VOC source concentrations at many sites are too low for measurement of Attenuation Rates.
2. For many of the common contaminants of concern, sources are often present on the interiors of buildings.
3. At many sites, contaminants of concern may also be present in the ambient air.



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1. The VOC source concentrations at many sites are too low for measurement of Attenuation Rates.
2. For many of the common contaminants of concern, sources are often present on the interiors of buildings.
3. At many sites, contaminants of concern may also be present in the ambient air.

   The indoor air comes from the ambient air. When VOCs are present in the ambient air they are also likely to be present in the indoor air at comparable levels.

   This is often an issue with benzene and other fuel hydrocarbons which are present in engine exhaust. It is also a common issue with chloroform, bromodichloromethane and other potable water disinfection by-products.

Complications Associated With the Use of VOC Data When Attempting to Establish Attenuation Rates

1. The VOC source concentrations at many sites are too low for measurement of Attenuation Rates.
2. For many of the common contaminants of concern, sources are often present on the interiors of buildings.
3. At many sites, contaminants of concern may also be present in the ambient air.

For these reasons, it is most often not possible to determine soil gas to indoor air Attenuation Rates using VOC data.

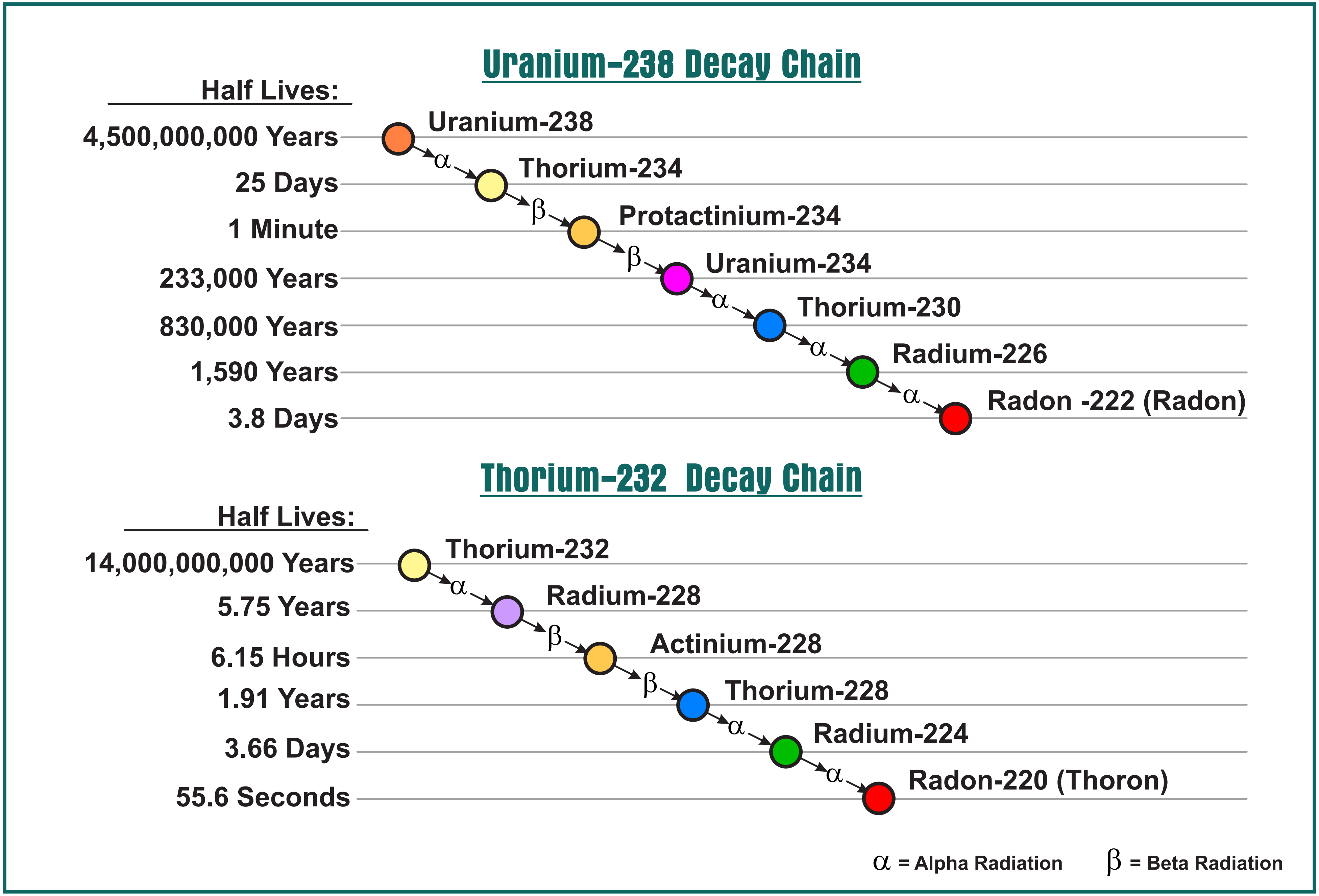
At most sites, radon gas is present at sufficient levels in the soil gas to reliably measure its building-specific soil gas to indoor air Attenuation Rate.

Radon gas can be used as a surrogate for VOCs to estimate their Attenuation Rates.

Radon Gas Sources & Characteristics

What is Radon?

- Radon is a naturally-occurring radioactive gas.
- The relevant isotopes of radon are produced by the decay of Uranium and Thorium that are present in most soils and rock at low levels.



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Radioactive Decay Chains That Produce Radon

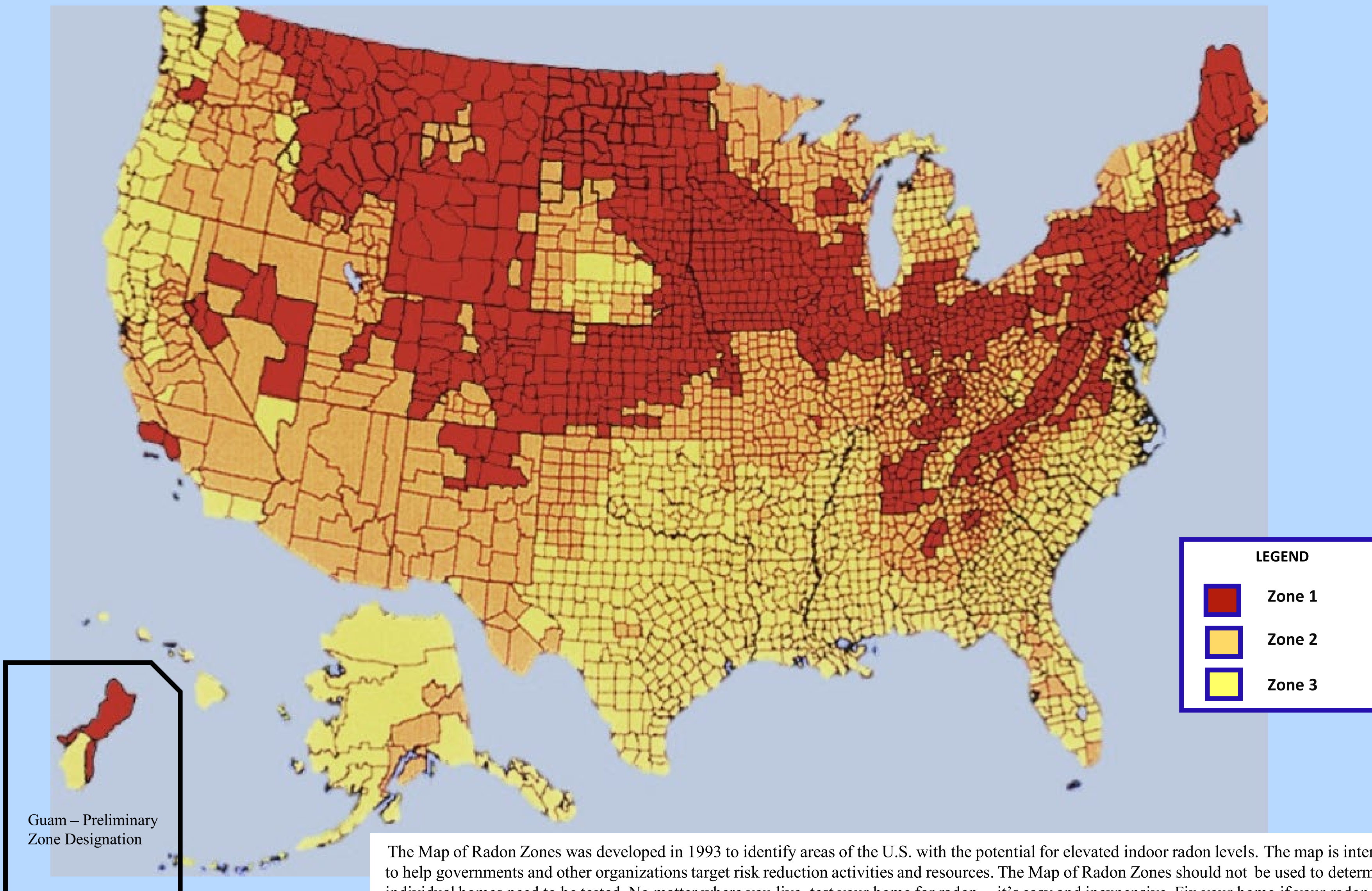
Figure 9.1.1

What is Radon?

- Radon is a naturally-occurring radioactive gas.
- The relevant isotopes of radon are produced by the decay of Uranium and Thorium that are present in most soils and rock at low levels.
- There are 37 isotopes of radon with half-lives ranging from a few nano-seconds up to 3.8 days.
- Radon 222 (Radon) has the longest half-life (3.8 days) and is therefore the most common form of radon that is present in soil gas.

What is Radon?

- Another isotope of radon commonly found in soil gas is Radon 220 (Thoron) with a half-life of about 56 seconds.
- Radon is present at easily detectible levels at most sites.



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 rad on potential for a specific area.

402-F19-004

EPA Map of Radon Zones

Figure 9.2.1

CALIFORNIA - EPA Map of Radon Zones

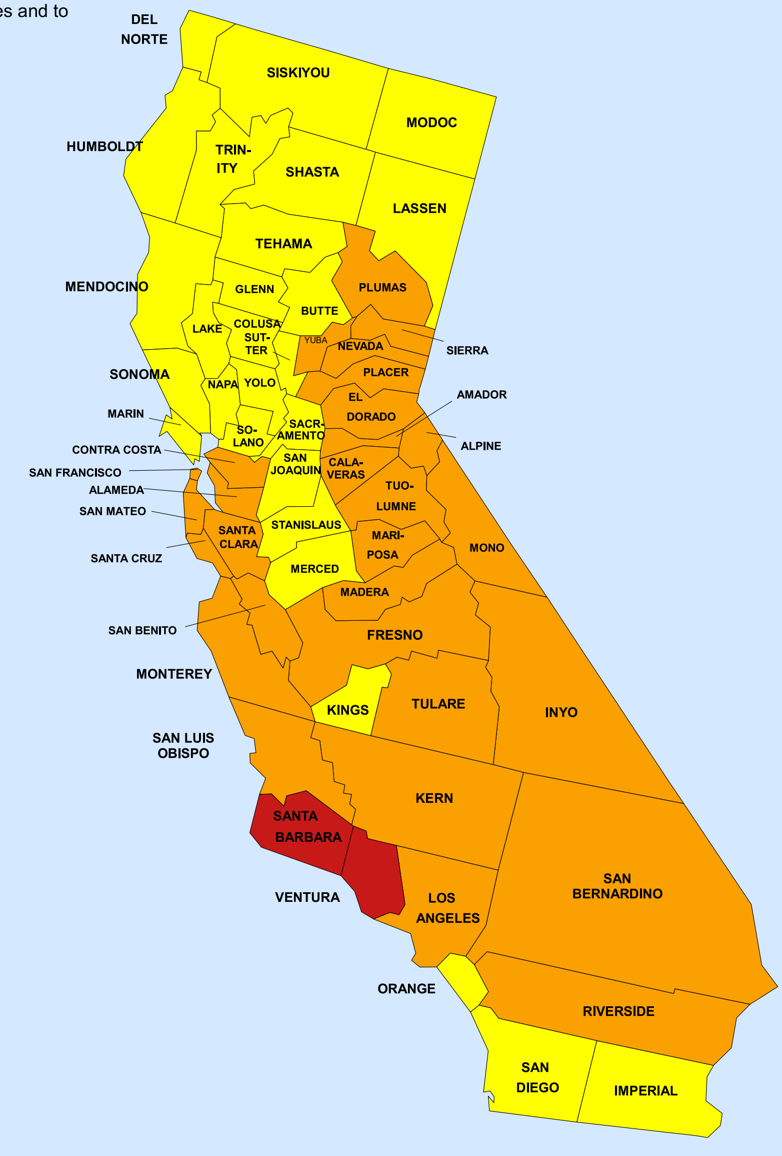
http://www.epa.gov/radon/zonemap.html

The purpose of this map is to assist National, State and local organizations to target their resources and to implement radon-resistant building codes.

This map is not intended to determine if a home in a given zone should be tested for radon. Homes with elevated levels of radon have been found in all three zones.

All homes should be tested, regardless of zone designation.

IMPORTANT: Consult the publication entitled "Preliminary Geologic Radon Potential Assessment of California" (USGS Open-file Report 93-292-I) before using this map. See http://energy.cr.usgs.gov/radon/grpinfo.html This document contains information on radon potential variations within counties. EPA also recommends that this map be supplemented with any available local data in order to further understand and predict the radon potential of a specific area.



What is Radon?

- Another isotope of radon commonly found in soil gas is Radon 220 (Thoron) with a half-life of about 56 seconds.
- Radon is present at easily detectible levels at most sites.
- GeoKinetics' data indicates Radon levels in the shallow soil gas in California are typically between 150 and 300 pico-Curies per liter (pCi/L).

Radon Measurement

Measurement of Radon Levels

- Electronic radon detectors measure the presence of alpha particles that result from the decomposition of radon and its daughter products.

Accustar Alpha Track

Airthings Wave

Activated Charcoal

Radstar GM 1-2

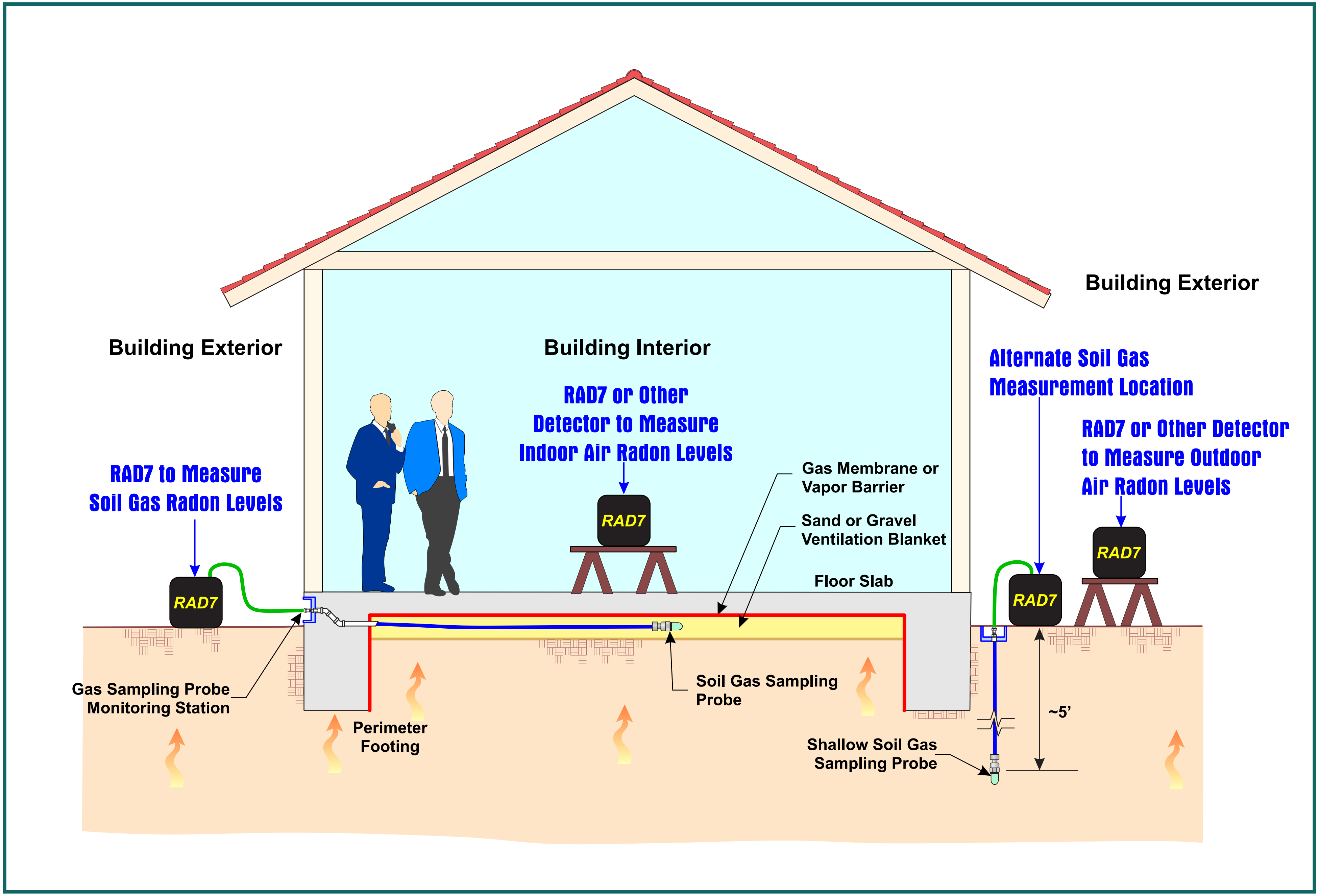
Measurement of Radon Levels

- Electronic radon detectors measure the presence of alpha particles that result from the decomposition of radon and its daughter products.
- Some of the more sophisticated devices can distinguish between Radon 222 (Radon) and Radon 220 (Thoron) based on spectral analysis of the alpha radiation.

Detector	Approximate Cost	Typical Measurement Interval	Resolution	Detector	Approximate Cost	Typical Measurement Interval	Resolution
 Durridge RAD7	$12,000	1 Min. to 5 Min.	~0.001 pCi/L	 Airthings Wave	$200	5 Min.	~0.2 pCi/L
 Radstar GM 1-2	$2,100	6 Min.	0.1 pCi/L	 Radon Eye	$180	60 Min.	~0.2 pCi/L
 Radex MR107	$270	1 Hour	0.1 pCi/L	 Accustar Alpha Track	$35	Long Term	0.6 pCi/L
 Luft	$250	6 Min.	0.1 pCi/L	 Activated Charcoal	$25	Long Term	0.1 pCi/L

Common Radon Detectors, Costs & Specifications

Figure 10.1.2



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Typical Radon Measurement Protocol

Figure 10.1.3

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RAD7 – Radon Detector

Figure 10.1.4

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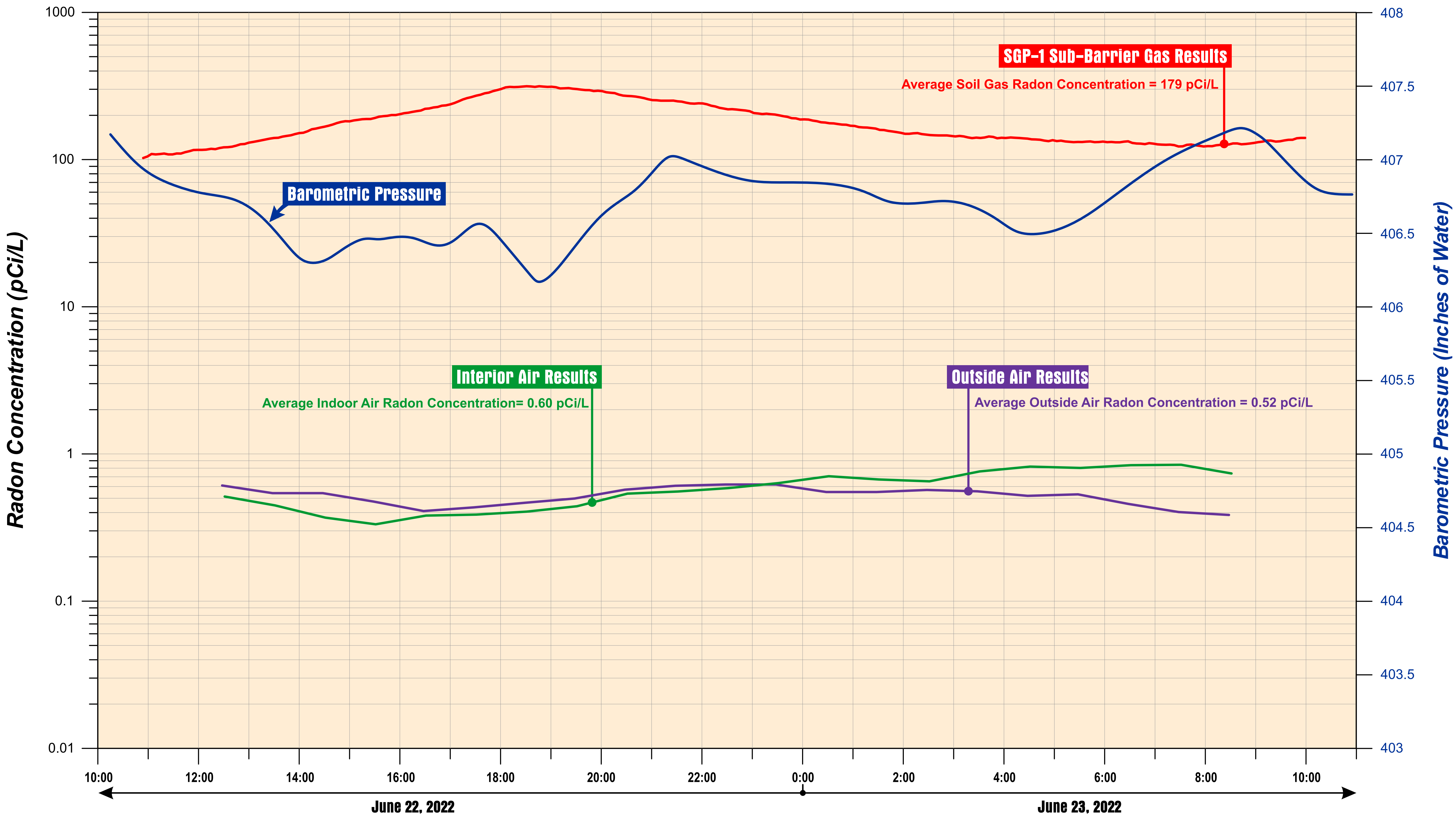
Photograph of Radon Testing

Figure 10.1.5

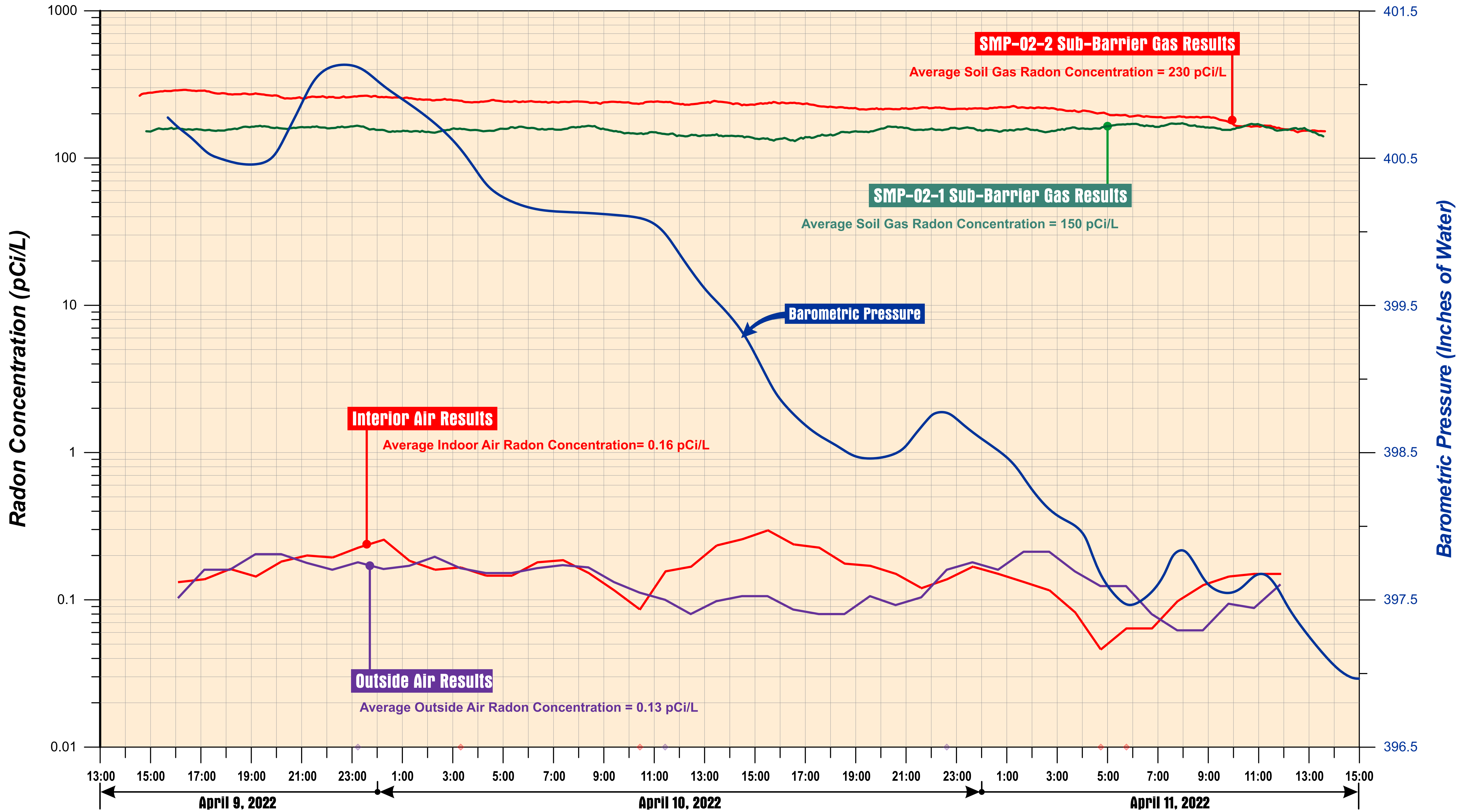
Typical Radon Measurement Results



Attenuation Rate = 179 pCi/L / (0.60 pCi/L – 0.52 pCi/L)
= 2,238

Typical Radon Measurement Results

Figure 11.1.1



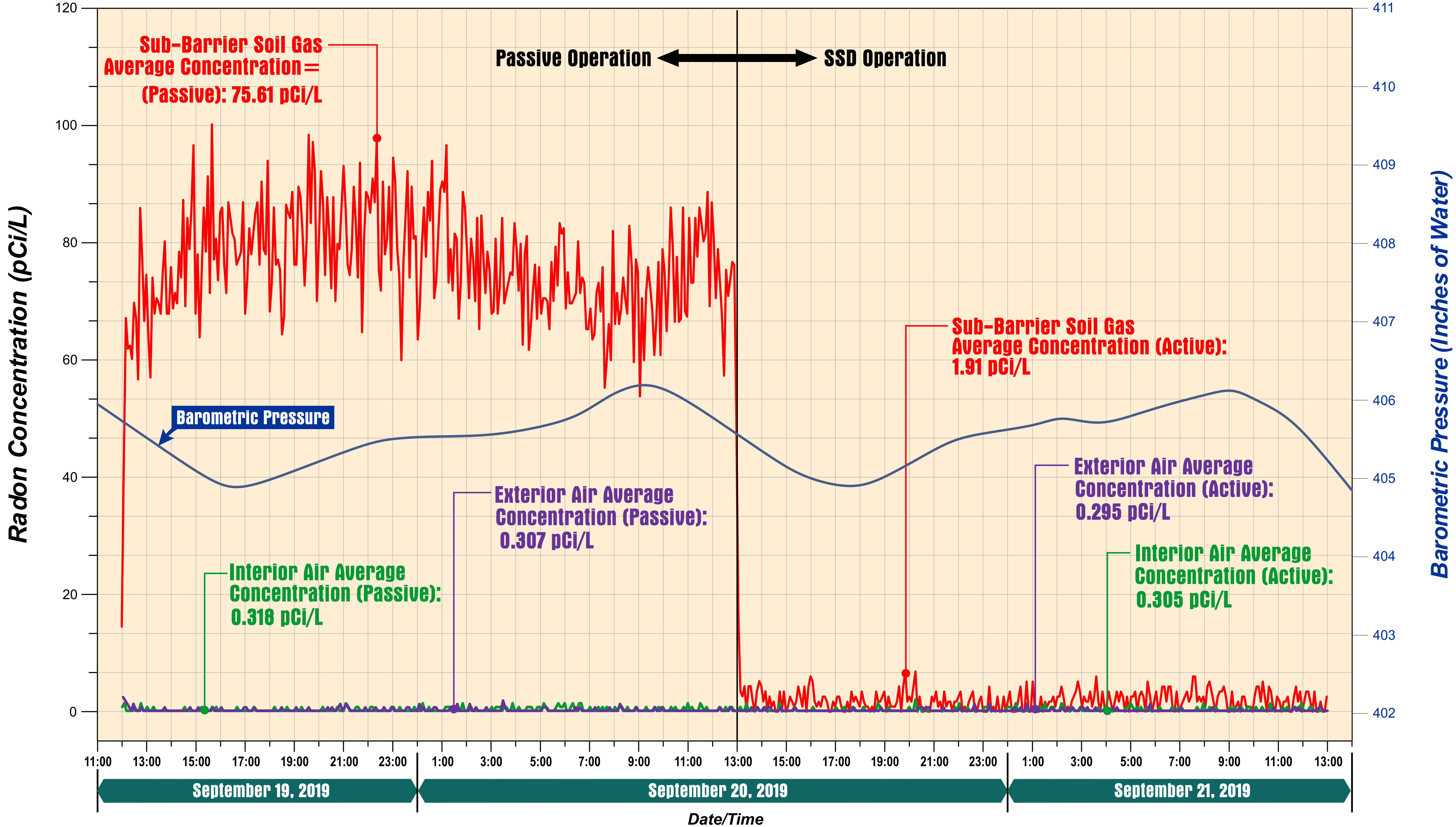
Average Soil Gas Radon Concentration = 190 pCi/L

Attenuation Rate = 190 pCi/L / (0.16 pCi/L - 0.13 pCi/L)

= 6,333

Typical Radon Measurement Results

Figure 11.1.2



Passive Attenuation Rate = 75.61 pCi/L / (0.318 pCi/L - 0.307 pCi/L)
= 6,874

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Typical Radon Measurement Results

Figure 11.1.3

Comparing Attenuation Rates for Radon and VOCs

Comparing Attenuation Rates for Radon and VOCs

- Radon gas tends to be distributed more uniformly in the soil gas beneath a building.
- Radon gas levels tend to exhibit less seasonal variation and remain more constant over extended periods of time.
- Radon is relatively mobile and not sorbed onto concrete or other building materials.

For these reasons, the soil gas to indoor air Attenuation Rates for radon and various VOCs may differ.

However, in most cases, Attenuation Rates determined based on radon measurements are likely to be reasonably representative of those for VOCs since they are subject to the same transport mechanisms.

Long Term Monitoring of Attenuation Rates

Long Term Monitoring of Attenuation Rates

What if the condition of a building changes?

How would regulators or occupants know if a soil gas intrusion issue develops?

- Indoor air radon levels can be monitored continuously with relatively inexpensive radon detectors.

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Indoor Air Radon Detector for Long Term Monitoring (Airthings Wave)

Figure 13.1.1

Long Term Monitoring of Attenuation Rates

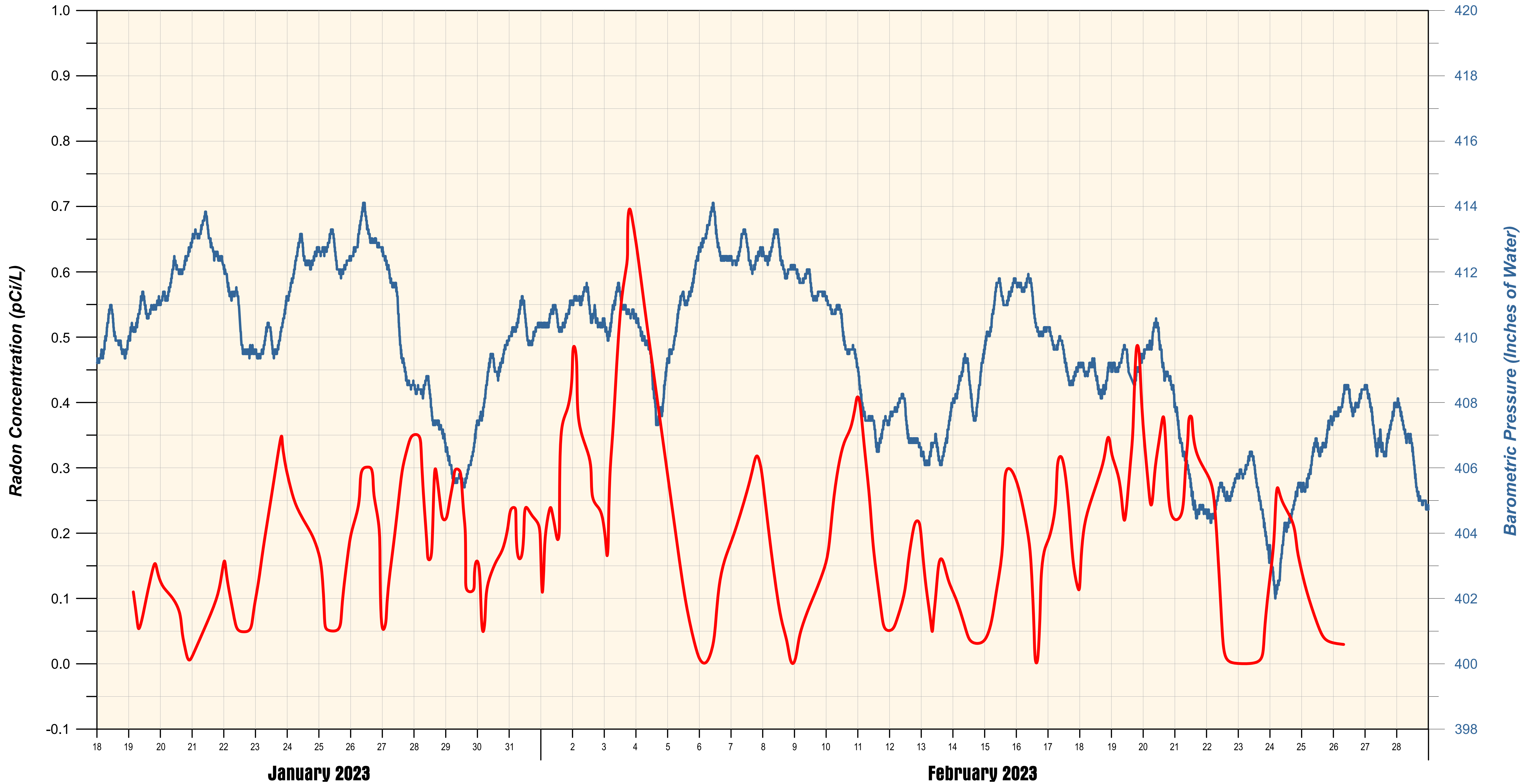
What if the condition of a building changes?

How would regulators or occupants know if a soil gas intrusion issue develops?

- Indoor air radon levels can be monitored continuously with relatively inexpensive radon detectors.
- Data can be downloaded from these monitors via Bluetooth without interior access.
- Soil gas radon levels are relatively stable over extended periods of time.

Long Term Monitoring of Attenuation Rates

- Once the soil gas radon level has been established, the indoor air radon level can be used to track the building-specific soil gas to indoor air Attenuation Rate over time.
- If the building conditions change (foundation damage, decreased ventilation rate, etc.), higher indoor air radon levels will be detected.



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Long Term Interior Air Testing Results

Figure 13.1.2

Advantages of Radon Measurements For Establishing Building-Specific Soil Gas to Indoor Air Attenuation Rates

Advantages of Radon Measurements For Establishing Building–Specific Soil Gas to Indoor Air Attenuation Rates

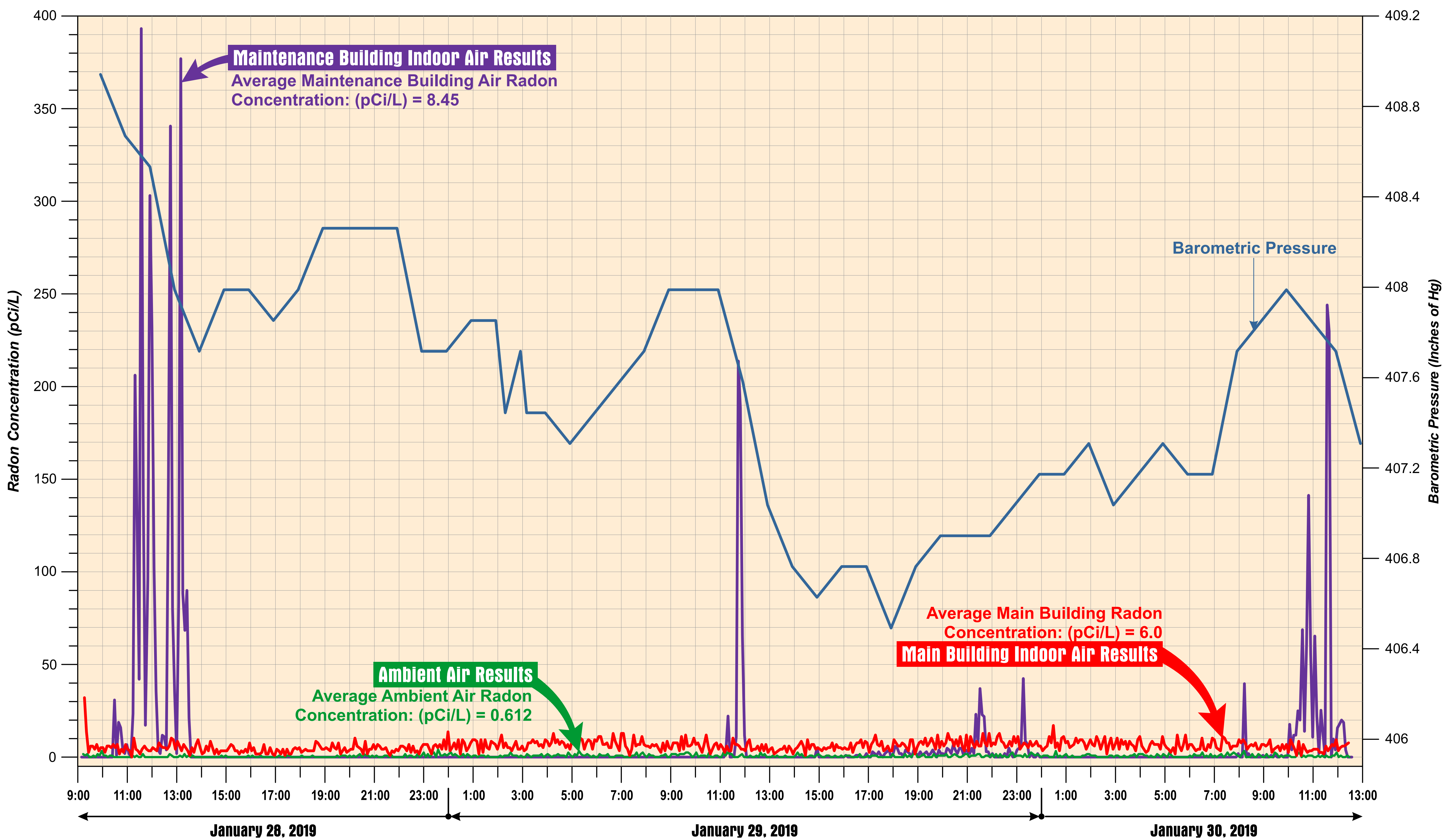
1. Generally high source to detection limit ratios - typically greater than 100,000:1. If soil gas intrusion is occurring, it is easily detected in real time.
2. Normally* no interior radon sources.
3. Ambient air radon levels are usually low and easy to quantify.
4. Low cost detectors are available for long term monitoring.

* Brick, granite and other natural stone can off-gas small amounts of radon.

Observations Made From Radon Monitoring Results

Observations Made From Radon Monitoring Results

- Actual building Attenuation Rates are typically much lower than would be anticipated based on diffusion tests performed on membrane samples.
- Soil gas advection through imperfections in a vapor barrier, or other openings, represents the primary mechanism through which soil gas enters most buildings - not diffusive flow.
- Soil gas intrusion is often driven by daily and weather-related fluctuations in barometric pressure. Spikes in indoor air radon levels are often evident during periods of falling barometric pressure.



Radon Monitoring Results for Unmitigated Building

Figure 15.1.1

Observations Made From Radon Monitoring Results

- Actual building Attenuation Rates are typically much lower than would be anticipated based on diffusion tests performed on membrane samples.
- Soil gas advection through imperfections in a vapor barrier, or other openings, represents the primary mechanism through which soil gas enters most buildings - not diffusive flow.
- Soil gas intrusion is often driven by daily and weather-related fluctuations in barometric pressure. Spikes in indoor air radon levels are often evident during periods of falling barometric pressure.
- Direct soil gas intrusion pathways can often be identified by screening for Thoron (Half Life = 56 sec) in indoor air using a real-time detector.

Questions?