U.S. EPA "State of VI Science" Workshop

Reducing Vapor Intrusion Uncertainties by More Frequent Simple Measurements and Community Involvement

Review of ITS Concepts, Fact Sheets, and Results from Past Workshops

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30th Annual International Conference on Soil, Water, Energy, and Air, A Virtual Conference, March 22nd, 2021

Presentation archived at https://iavi.rti.org/

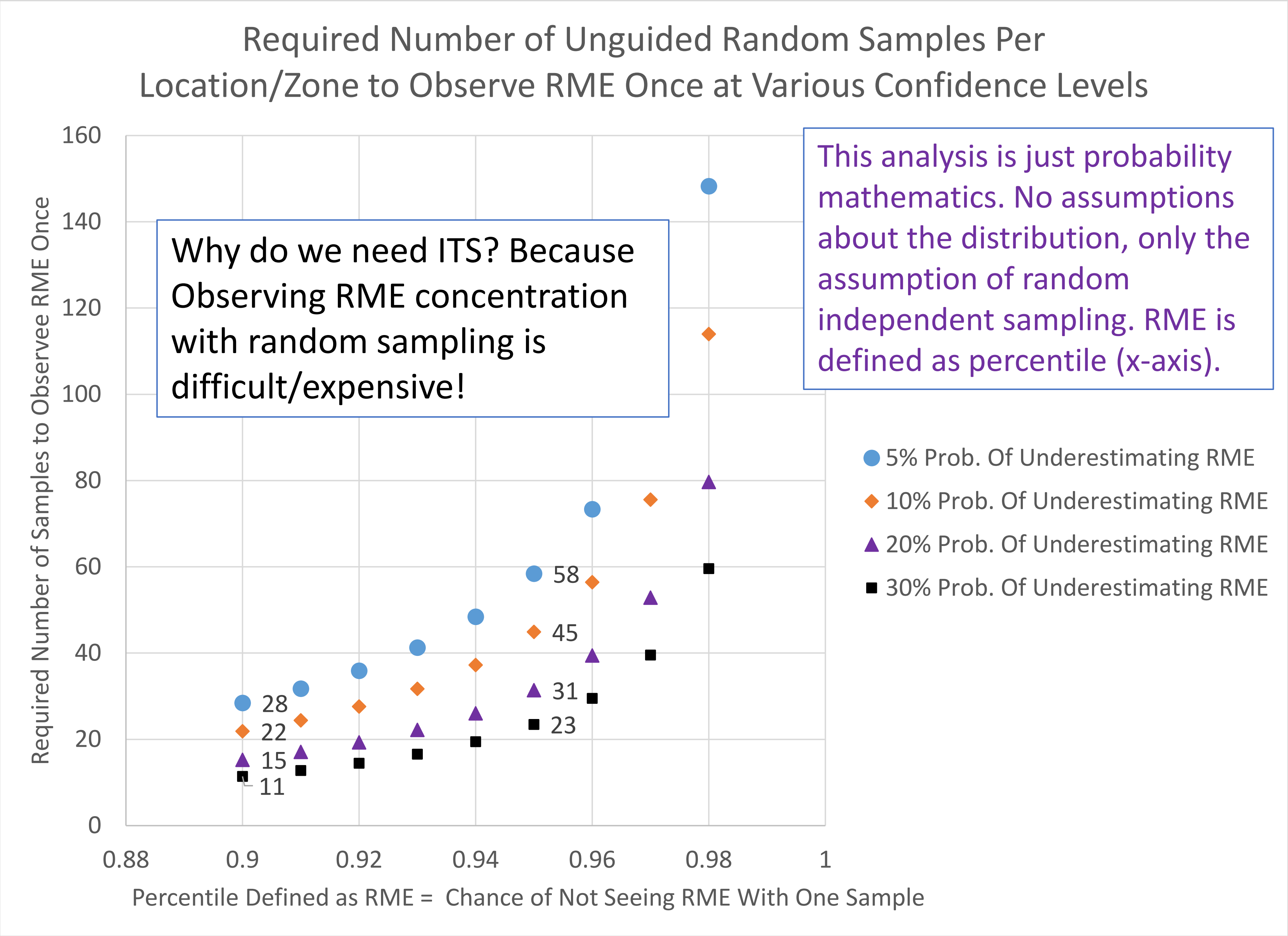
Why Do We Need Indicators, Tracers and Surrogates (ITS) to Guide Sampling?

EPA 2015 VI guide definition: **reasonable maximum exposure (RME)**

A semi-quantitative term, referring to the lower portion of the high end of the exposure distribution; conceptually, above the 90th percentile exposure but less than the 98th percentile exposure.

Here we discuss the exposure concentration, but don't forget that the exposure frequency and exposure duration are also part of RME.

Observing the RME concentration with random sampling is expensive!



Required Number of Unguided Random Samples Per Location/Zone to Observe RME Once at Various Confidence Levels
Why do we need ITS? Because Observing RME concentration with random sampling is difficult/expensive!
This analysis is just probability mathematics. No assumptions about the distribution, only the assumption of random independent sampling. RME is defined as percentile (x-axis).
Required Number of Samples to Observee RME Once
Percentile Defined as RME = Chance of Not Seeing RME With One Sample
0
20
40
60
80
100
120
140
160
0.88
0.9
0.92
0.94
0.96
0.98
1
28
22
15
11
58
45
31
23
5% Prob. Of Underestimating RME
10% Prob. Of Underestimating RME
20% Prob. Of Underestimating RME
30% Prob. Of Underestimating RME

Definition: Indicator

Metrics that can indicate elevated potential for chlorinated VOC (cVOC) exposures.

For example:

- An *indicator* in chemistry is a substance whose color varies with acidity or alkalinity (e.g., pH paper) .
- An *indicator* in biology is an animal or plant species that can be used to infer stress on a particular ecosystems (e.g., amphibians are sensitive to environmental toxins, drought).

For VI, season, temperature and differential pressure may be indicators of elevated cVOC levels.

Images reprinted from: http://sciencefair.math.iit.edu/techniques/PHTesting/PHTesting.jpg
http://news.psu.edu/story/140702/2002/05/01/research/lessons-toads

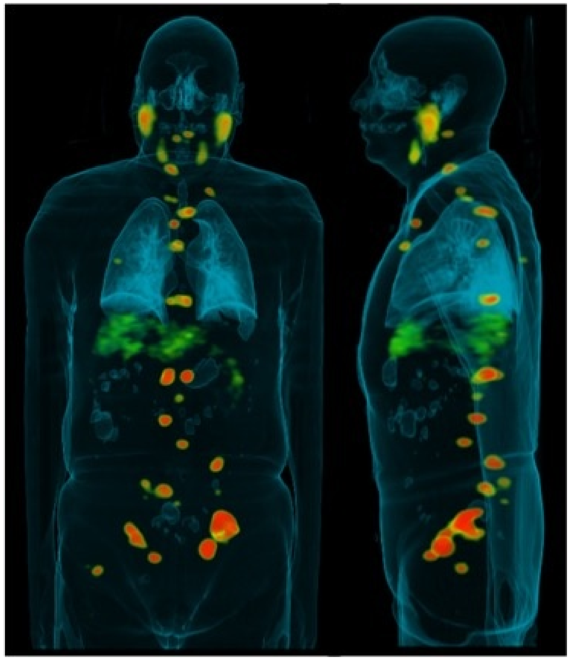
Definition: Tracer

Easily observable substances that physically move along with the target compounds of interest for VI (cVOCs)

For example:

- In water science and medicine an identifiable substance, such as a dye, soluble chemical, or radioactive isotope, that can be followed through the course of a mechanical, chemical, or biological process.

For VI radon is a tracer of soil gas entry across a foundation slab (and soil gas may have cVOCs).

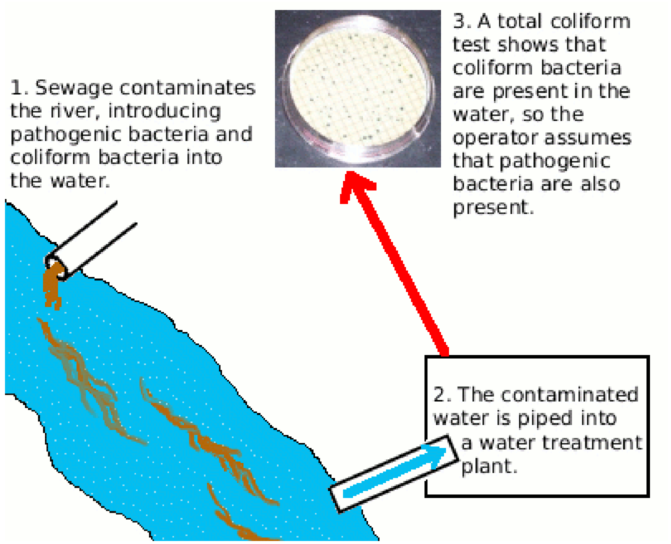


Photos reprinted from: http://newsroom.unl.edu/announce/files/file9957.png
https://meyercancer.weill.cornell.edu/news/2016-01-25/tracer-treatment-radiopharmaceuticals-home-hard-detect-cancers

Definition: Surrogate

Metrics with a quantitative relationship to the target compound for VI, sufficiently accurate to be a substitute.

"In the context of environmental microbiology and health risk assessment, we have defined surrogates as organisms, particles, or substances used to study the fate of a pathogen in a specific environment….The use of surrogates in these scenarios can allow quantification of the degree of exposure" (Sinclair et al., 2012) (e.g., fecal coliform)



Images from:
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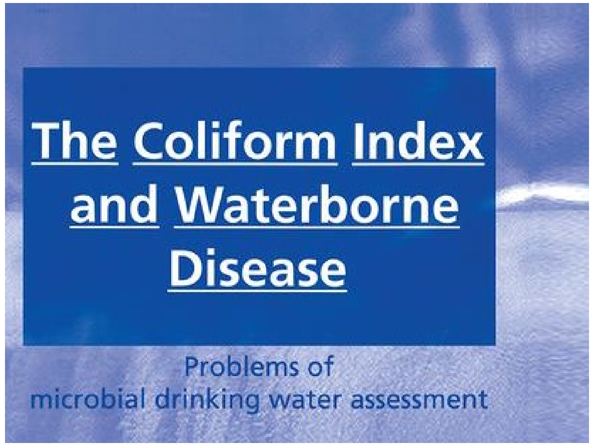


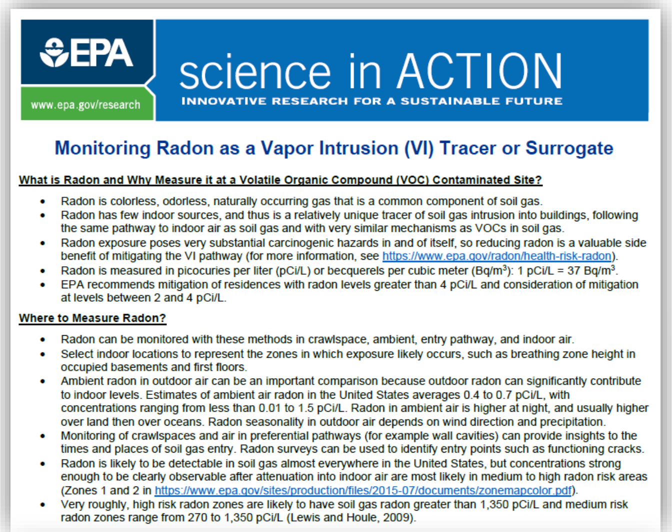
Sinclair, Ryan G., Joan B. Rose, Syed A. Hashsham, Charles P. Gerba, and Charles N. Haas. "Criteria for selection of surrogates used to study the fate and control of pathogens in the environment." *Applied and environmental microbiology* 78, no. 6 (2012): 1969-1977.

EPA Guidance and Fact Sheets on ITS

- EPA (2015) VI Guidance – *How to Use*
  - Buildings with radon greater in indoor air than ambient (outdoor) air are likely susceptible to soil gas intrusion…
  - Pressure differences during sampling can support insights about driving forces
  - EPA recommends documenting wind direction, precipitation information, temperature, and barometric pressure

- EPA ITS Fact Sheets- *What, Where, When, and How to Measure* (https://iavi.rti.org/workshops.html)

  Highlight best practices for
  - *Monitoring Radon as a VI Tracer or Surrogate*
  - *Measuring Pressure (Differential and Barometric) as a VI Indicator*
  - *Measuring Temperature as an Indicator for VI*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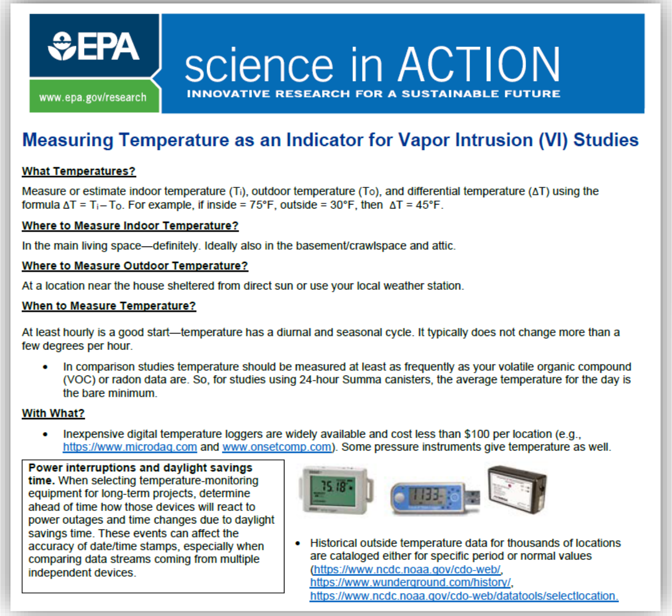
Monitoring Radon as a Vapor Intrusion (VI) Tracer or Surrogate

What is Radon and Why Measure it at a Volatile Organic Compound (VOC) Contaminated Site?

- Radon is colorless, odorless, naturally occurring gas that is a common component of soil gas.
- Radon has few indoor sources, and thus is a relatively unique tracer of soil gas intrusion into buildings, following the same pathway to indoor air as soil gas and with very similar mechanisms as VOCs in soil gas.
- Radon exposure poses very substantial carcinogenic hazards in and of itself, so reducing radon is a valuable side benefit of mitigating the VI pathway (for more information, see https://www.epa.gov/radon/health-risk-radon).
- Radon is measured in picocuries per liter (pCi/L) or becquerels per cubic meter (Bq/m^3): 1 pCi/L = 37 Bq/m^3.
- EPA recommends mitigation of residences with radon levels greater than 4 pCi/L and consideration of mitigation at levels between 2 and 4 pCi/L.

Where to Measure Radon?

- Radon can be monitored with these methods in crawlspace, ambient, entry pathway, and indoor air.
- Select indoor locations to represent the zones in which exposure likely occurs, such as breathing zone height in occupied basements and first floors.
- Ambient radon in outdoor air can be an important comparison because outdoor radon can significantly contribute to indoor levels. Estimates of ambient air radon in the United States averages 0.4 to 0.7 pCi/L, with concentrations ranging from less than 0.01 to 1.5 pCi/L. Radon in ambient air is higher at night, and usually higher over land then over oceans. Radon seasonality in outdoor air depends on wind direction and precipitation.
- Monitoring of crawlspaces and air in preferential pathways (for example wall cavities) can provide insights to the times and places of soil gas entry. Radon surveys can be used to identify entry points such as functioning cracks.
- Radon is likely to be detectable in soil gas almost everywhere in the United States, but concentrations strong enough to be clearly observable after attenuation into indoor air are most likely in medium to high radon risk areas (Zones 1 and 2 in https://www.epa.gov/sites/production/files/2015-07/documents/zonemapcolor.pdf).
- Very roughly, high risk radon zones are likely to have soil gas radon greater than 1,350 pCi/L and medium risk radon zones range from 270 to 1,350 pCi/L (Lewis and Houle, 2009).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Measuring Temperature as an Indicator for Vapor Intrusion (VI) Studies

What Temperatures?

Measure or estimate indoor temperature (T_i), outdoor temperature (T_O), and differential temperature (ΔT) using the formula $\Delta T = T_i - T_O$. For example, if inside = 75°F, outside = 30°F, then ΔT = 45°F.

Where to Measure Indoor Temperature?

In the main living space—definitely. Ideally also in the basement/crawlspace and attic.

Where to Measure Outdoor Temperature?

At a location near the house sheltered from direct sun or use your local weather station.

When to Measure Temperature?

At least hourly is a good start—temperature has a diurnal and seasonal cycle. It typically does not change more than a few degrees per hour.

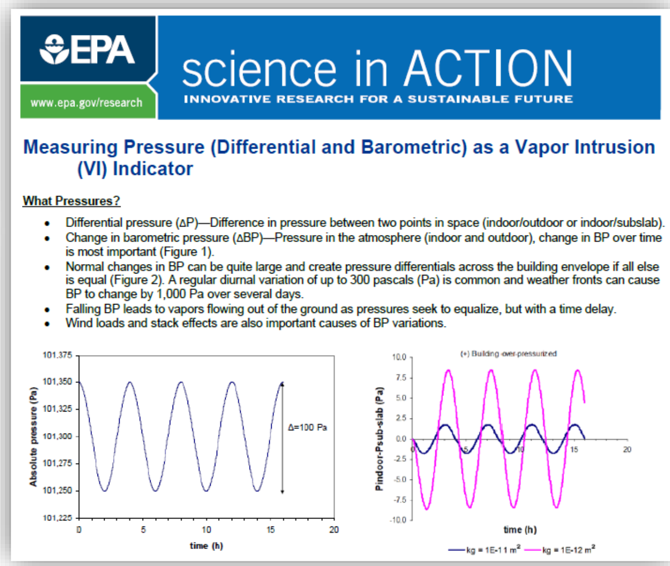
- In comparison studies temperature should be measured at least as frequently as your volatile organic compound (VOC) or radon data are. So, for studies using 24-hour Summa canisters, the average temperature for the day is the bare minimum.

With What?

- Inexpensive digital temperature loggers are widely available and cost less than $100 per location (e.g., https://www.microdaq.com and www.onsetcomp.com). Some pressure instruments give temperature as well.

Power interruptions and daylight savings time. When selecting temperature-monitoring equipment for long-term projects, determine ahead of time how those devices will react to power outages and time changes due to daylight savings time. These events can affect the accuracy of date/time stamps, especially when comparing data streams coming from multiple independent devices.

- Historical outside temperature data for thousands of locations are cataloged either for specific period or normal values (https://www.ncdc.noaa.gov/cdo-web/, https://www.wunderground.com/history/, https://www.ncdc.noaa.gov/cdo-web/datatools/selectlocation.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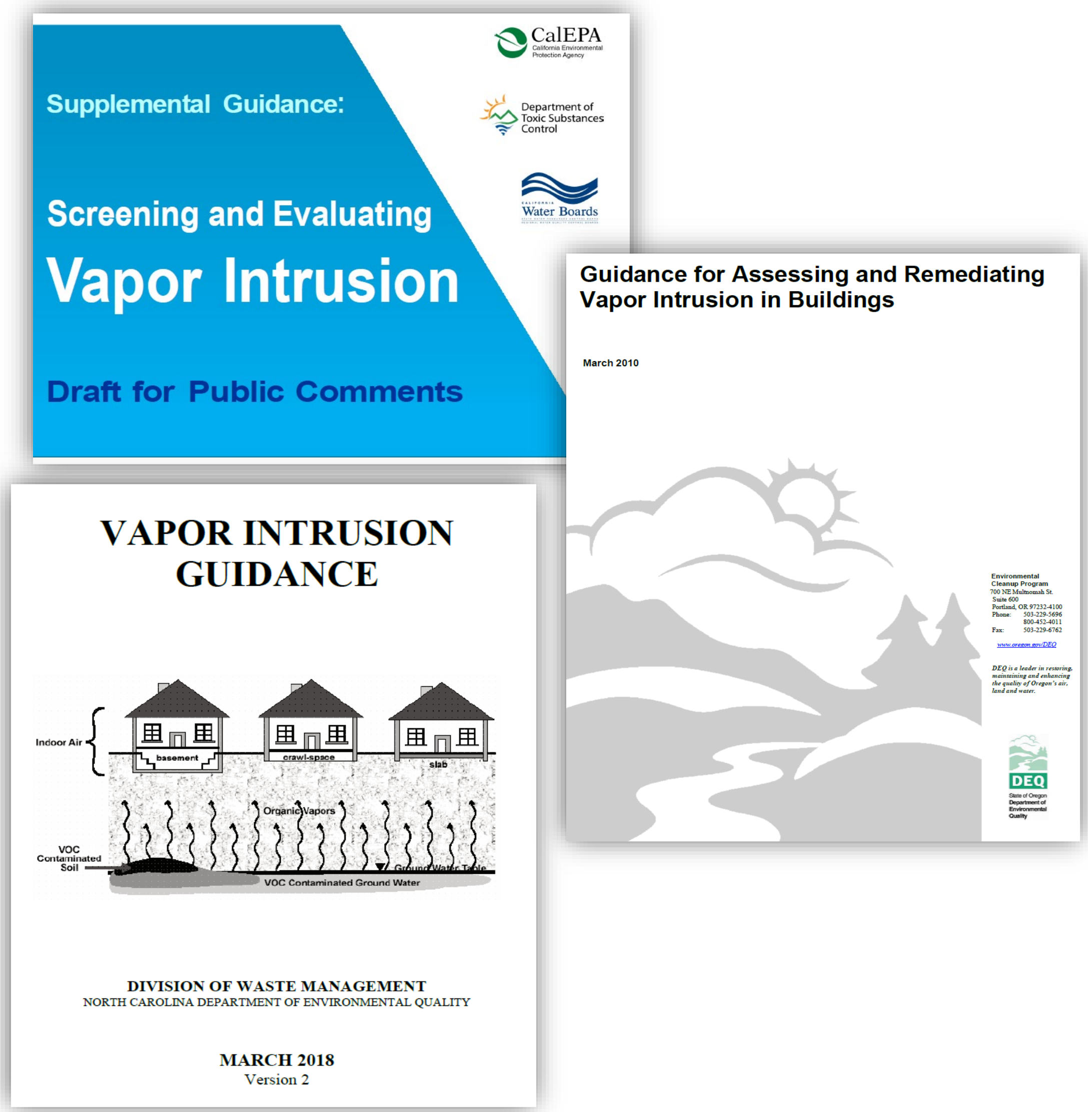
Measuring Pressure (Differential and Barometric) as a Vapor Intrusion (VI) Indicator

What Pressures?

- Differential pressure (ΔP)—Difference in pressure between two points in space (indoor/outdoor or indoor/subslab).
- Change in barometric pressure (ΔBP)—Pressure in the atmosphere (indoor and outdoor), change in BP over time is most important (Figure 1).
- Normal changes in BP can be quite large and create pressure differentials across the building envelope if all else is equal (Figure 2). A regular diurnal variation of up to 300 pascals (Pa) is common and weather fronts can cause BP to change by 1,000 Pa over several days.
- Falling BP leads to vapors flowing out of the ground as pressures seek to equalize, but with a time delay.
- Wind loads and stack effects are also important causes of BP variations.

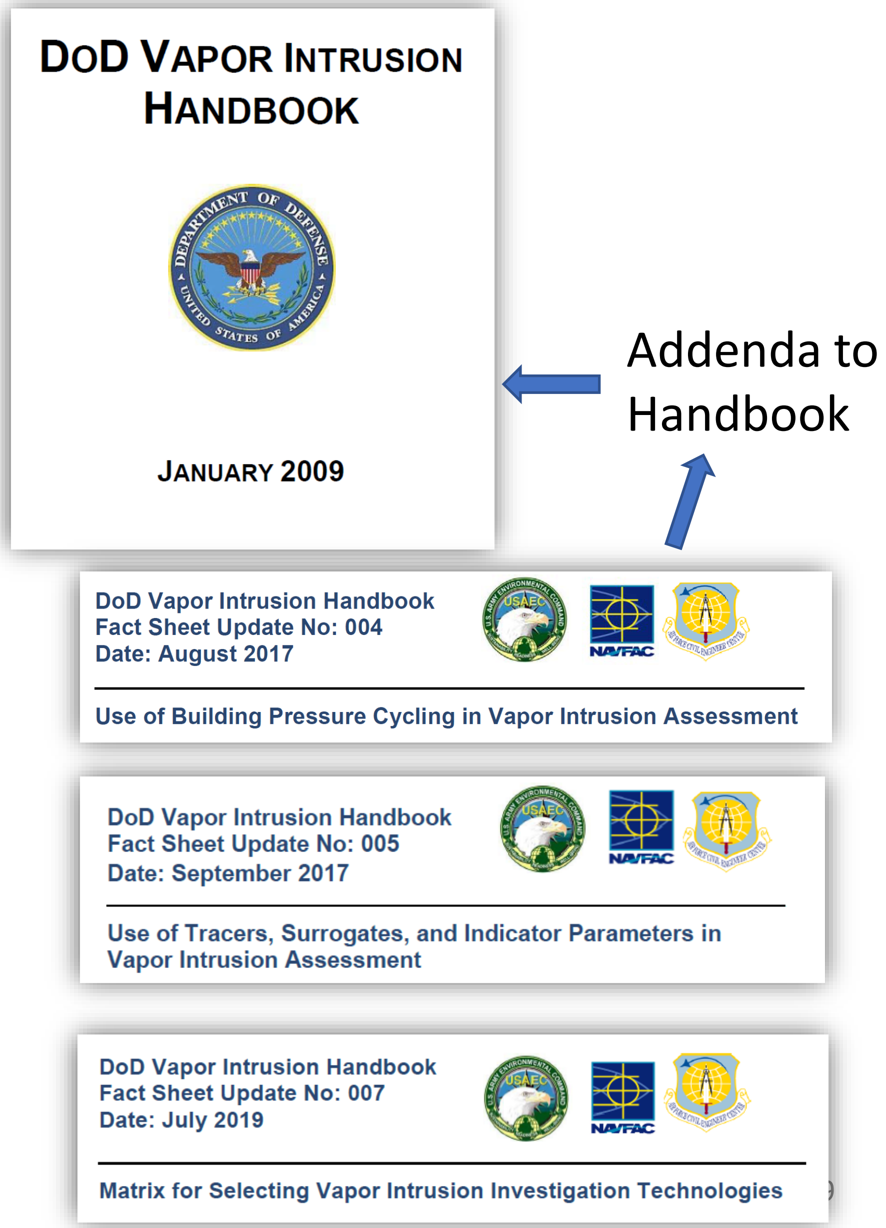
Examples of State VI Guidance on ITS

- CalEPA (2020) Draft Supplemental VI Guidance
  - Naturally-occurring radon or other tracers may be used for evaluating subsurface VI
- North Carolina (2018) VI Guidance
  - Radon can be monitored in indoor air and compared to outdoor levels
  - Sub-slab and indoor air radon may be used to estimate sub-slab to indoor air attenuation factors"
  - VI can be evaluated using … pressure data to demonstrate the driving force for soil gas entry … or evaluation of tracers
- Oregon (2010) VI Guidance
  - Subsurface and indoor radon can provide another line of evidence for evaluating VI potential
  - Changes in pressure can move gases … wind can enhance VI rates … collect barometric pressure and wind-speed during indoor sampling
- Alaska (2017) VI Guidance
  - Includes a 1-page section on 'Indicators, Tracers, and Surrogates' (T, P, and Rn) in a section on Investigative Strategies – Special Considerations.



Department of Defense (DoD) on Indicators and Tracers

- DoD (2009) VI Handbook
  - Radon data may help filter out data not associated with VI
  - Pressure can help assess need for further investigation
  - Temperature, barometric pressure and precipitation can influence vapor flux
- DoD (2017) Fact Sheet 004: Use of Building Pressure Cycling in Vapor Intrusion Assessment
  - Pressure fluctuations induce varying amounts of VI
  - Controlling building pressure can reduce spatial/temporal variability of indoor air concentrations due to VI
- DoD (2017) Fact Sheet 005: Use of Tracers, Surrogates, and Indicator Parameters in VI Assessments
  - Tracers, surrogates, and indicators can be used for several purposes as part of a VI assessment
- DoD (2019) Fact Sheet 007: Matrix for Selecting Vapor Intrusion Investigation Technologies
  - Building pressure differentials, radon, temperature differentials, and tracers can be used to assess VI



Summary on Indicators, Tracers, and Surrogates (ITS) for Vapor Intrusion

- ITS is needed to measure VI more efficiently and effectively – it's difficult/expensive to measure RME (e.g., 95th percentile) or to determine the 90% UCL on the mean.
- ITS is in use under State, DoD, and EPA guidance.
- ITS metrics (temperatures, pressures, radon) are relatively cost-efficient and simple to measure.
- Routine ITS measurements can help reduce uncertainties in VI assessments and may be complimentary to citizen science efforts.

Example Uses for ITS Data

1. Use weather forecasts and ITS knowledge to time traditional sampling towards potentially higher VI days.
2. Use automated sample collection devices triggered by weather-related ITS levels.
3. Retrospectively interpret previously collected (regularly scheduled) samples by comparison to ITS levels present when cVOC samples were collected to set observed concentrations within the context of a much longer ITS baseline distribution.
4. Use indicators or tracers to monitor mitigation system performance and indicate when inspection or resampling may be needed.

Applications of ITS at VI sites

- ITS can provide lower costs and higher temporal and spatial confidence at all stages of VI site investigation and response. For example
  - Screening: building/site selection, prioritization, seasonality, & VI (soil gas) susceptibility, past and current (historic context).
  - Assessment: best future sample locations and times for average and high-end concentrations (e.g., soil gas entry points); distinguishing subslab from indoor air sources; seasonality; other effective lines of evidence
  - Mitigation: post-mitigation monitoring, mitigation system effectiveness, long-term stewardship, change in conditions needing follow-up(
  - Risk Assessment: higher confidence in mean and high-end exposures; historical context; forecasting future vs. current risks.

Answering Questions on cVOC ITS in Indoor Air*

- Can the 95% UCL on mean be calculated with sufficient confidence?
- How should we account for uncertainty/variability in time and space?
  - Timing, type, number, location/zone, frequency, and duration of samples?
- Should maximum or 95th/90th percentile indoor concentrations be used if one is unable to calculate 95% UCLs?
- How can indicators/tracers/surrogates (ITS) increase confidence (and reduce uncertainty) in risk assessment and prediction?

(**Source: Loren Lund, 2020*)

Data Sets Used in Today's ITS Studies

New Analyses on Previous Data (Residential) – unoccupied, different ages, similar climates

- Sun Devil Manor (1980s Residential) – split-level, land drain open, no blower door
- Indianapolis Duplex (191X's Residential) –data from 2 floors; without mitigation

New Sites with New Data (Commercial) – mixed use, different climates

- Moffett Field Building 15 (large commercial) – normal operating conditions
- Gaffney Alaska (small commercial) – normal operating conditions
- Virginia Site A (large industrial) – two locations – normal operating conditions

We've been working on ITS concepts and performance metrics for about 5 years – *highlights from these workshops:*

- *March 2017* - defined ITS terms and introduced statistical and probability concepts (SDM and Indianapolis data; T, ΔP, Rn)
- *March 2018* - explored different indicators: barometric pressure, wind, rain/precipitation
- *October 2018* - explored more sites: commercial buildings, similarities and differences in behaviors across sites
- *March 2019* - explored data through XY correlations and 2:2 comparisons
- *March 2020* - temporal and spatial data from a variety of sites, focusing on conditions observed in the days leading up to peaks (i.e., 95^{th} percentile cVOCs)

Based on these experiences this year we are testing various calendar vs. ITS based sampling approaches. We are testing each approach to see:

- How well it performs across a variety of sites
- How well it predicts high-end cVOCs: 90th percentile, 95th percentile, 95% UCL