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EID Some 'pipe-direct & indirect' VI

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Why You should [Continuously] Monitor ITS for CVI Assessments

Henry Schuver*, Brian Schumacher, John Zimmerman, Chris Lutes, Chase Holton, & Robert Truesdale

EPA VI Workshop at 2020 AEHS West-Coast Conference

San Diego, Calf., March 17

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Previous workshop slides & audio at:

https://iavi.rti.org/workshops.html

*Personal Perspective & Presentation – Does not represent Agency policy

See: http://epa.gov/oswer/vaporintrusion

RTI INTERNATIONAL

Overview – of what we are going to talk about

- Introduction & Executive Summary
- Why, What & How to collect supplemental measurements?
- Evolving understanding of the implications from two data-rich studies
- New analyses testing relationships
- Functional Categories of scenarios – & new building studies
- Next Steps
- Your input

Objective: To make VI risk decisions **more** similarly (quantitively) **confident** as other exposure routes

- For over 20 years we've known VI exposures can be more significant than from other exposure pathways; e.g.,
  - GW ingestion; Currently, and perhaps since the 1980s?
    - Unavoidable inhalation exposures of ~20,000 liters/day (residential)
- Typical Groundwater-ingestion risk-decision confidence levels:
  - Long-term average exposures (e.g., cancer) use 95th% Upper Conf. Limit
  - Short-term risks (e.g., developmental issues) shorter-term 'high-end' conc. (RME)

- This is an enormous challenge for VI
  - Exposure conc. are the result of a long[1] list of interacting factors influencing the conc. in indoor air (across time and space)

Challenges in VI Exposure Decision-Making (per building & site-wide)

- High Variability
  - Spatial - (limited w/n residential bldg., but especially between buildings)
  - Temporal - (OoM across: hours, days, weeks, months, years, decades[1])
- **Only indoor conc**. of **target CVOC**s **represent all factors** influencing VI
  - Due to Time & money ($) to sample & analyze, disruption of occupants, etc.
- Only Limited # of (indoor CVOC) samples[2] (across space & time)

- Typically too few samples to characterize exposures over space & time:
  - To allow confident est. of '**high-end**' exposures and long-lasting decisions, e.g.,:
    - RME (~95th%ile) and/or 95th Upper Confidence Limit (UCL)

*

What can we do for [Temporal] confidence?

1 – Collect 58 typical 'random' indoor air CVOC samples – per building (res.) …

2 – Collect ~'continuous' indoor air CVOC samples – per building for …

3 – Measure ~'continuous' ITS levels/conc. – per building for … And:

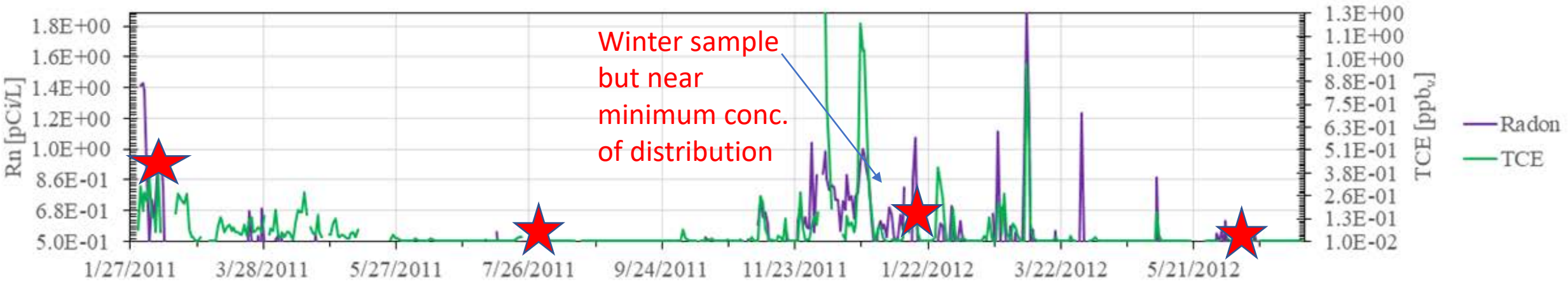
- ***Try to*** collect (a few[1]) CVOC samples during VI=ON-High conditions (as ITS predict)
- Collect **regularly-scheduled** CVOC samples – 'business as usual'
  - Compare to ITS cond./conc. during CVOC sampling to surrounding time periods (%iles)
- Use ITS-sensors ***auto-triggering*** device to collect CVOC sample when ITS 'elevated'

Why ‘continuous’ measurements?

Because: a ‘few’ indoor chemical air samples is typical

- What level of **confidence** is possible (w/o <u>some</u> ‘continuous’ data)?

We have **<u>no context</u>** for ‘**elevated**’ exposure without some more-frequent/**<u>continuous</u>** data



What ITS should we measure 'continuously'?

- To improve CVI Assessments
  - Given an "apparently endless number of hard-to-identify, measure, and predict factors …
  - All influencing the resulting variable indoor air concentrations [conc.]"[1,2]
- "ONLY indoor air conc. can represent ALL variables/factors involved" [3]
  - "we want supplemental measures/metrics that can **represent** as many [of these factors influencing indoor air conc. from CVI] as possible" [3]
- We should be measuring a **Conc**. in indoor air – *if* practical
  - Frequently – across Time
  - Frequently – across Space (between buildings – for site-wide decisions)
- Evidence suggests we measure: Indoor **Radon**, Temperature & Pressure

Indicators, Tracers & Surrogates

These ITS are closely related but ***unique***; *& usefully combined?*

Summary of conceptual relationships

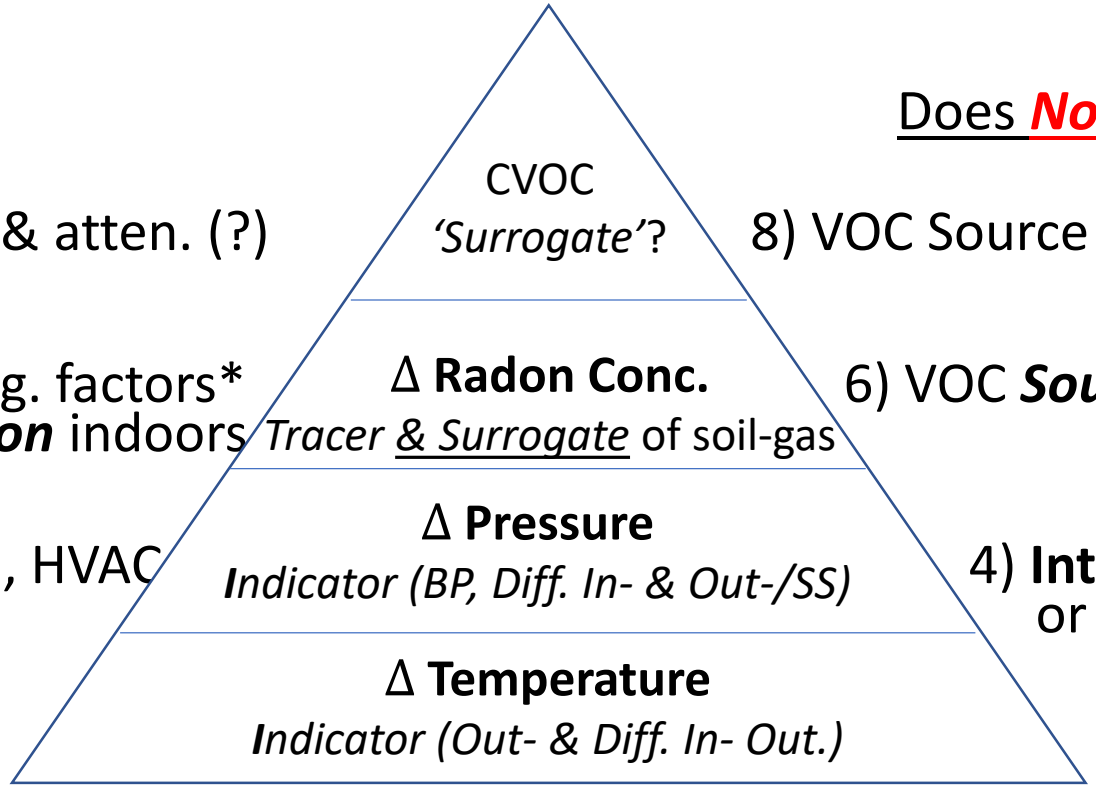
Includes:

7) Deep migration & atten. (?)

5) All nearby & bldg. factors* mixing *&* ***integration*** indoors

3) Wind (sp. & dir.), HVAC

1) Common Driver



Does ***Not*** include:

8) VOC Source loc. & variation (Space & Time)

6) VOC ***Source*** **loc./vari**. & deep **migrat.**

4) **Integration** of Areas (SubSlab) or Time, Air Ex. Rates (AER)

2) **Wind** (sp. & dir.), HVAC

***Indoor Rn **conc**. **when** CVOC is sampled

What VI-related **Conc**. in indoor air can we measure; cost-effectively & frequently?

- What (Conc. in indoor air) is related to/representative of CVI decision points?
  - CVOC sources partition into **Sub-surface[1]/soil-gas**
  - Migrate to areas near buildings in **Sub-surface/soil-gas**
  - **Sub-surface/soil-gas** intrudes into and mixes in indoor air at some conc.

  - The **Conc. of sub-surface/soil-gas** in indoor air is likely related to the **CVOC conc**., &
    - 'Low' conc. of sub-surface/soil-gas in indoor air is likely[2] related to 'Low' CVOC conc.
    - 'High' conc. of sub-surface/soil-gas in indoor air is likely related to 'High' CVOC conc.

Summary of Working Hypothesis

Evidence to-date supports

- **Only**[1] ***when*** the conc. of '**soil-gas**' in indoor air is '**elevated**'
  - (VI = ON & **High**)

- **Can**[2] the conc. of **chemicals** indoors from soil-gas (VI) be '**elevated**'

How can we measure the **Conc**. of 'soil-gas' in indoor air?

- **Radon** is a common component of sub-surface/soil-gas &
  - Is likely quantitatively representative of the conc. of sub-surface/soil-gas
  - Radon conc. could be considered a Surrogate[1] for the conc. of sub-surface/soil-gas, &
  - Practical to measure – frequently[2]/~continuously
- Conc. **of** Radon (Rn) indoors is[3] a ***Surrogate*** of the **amount**[4] of soil gas in indoor air
  - **Continuous** monitoring of Radon can show ***when*** CVI conc. can[3] be 'elevated'

Radon - Statistical Assoc. of Indoor Conc. across **Time**

Using **Time Series (Linear) Regression**; results for Two components:

Time Series Regression ***Not practical***, computationally for typical-site application – But highly informative when applied

1) Direction of Conc. change. (*Qual.*)

99% (EPA-IN-Duplex)
99.9% (SDM-UT)

Changing conc. direction together

Note Background (outdoor) Rn & < Det. Limit for TCE

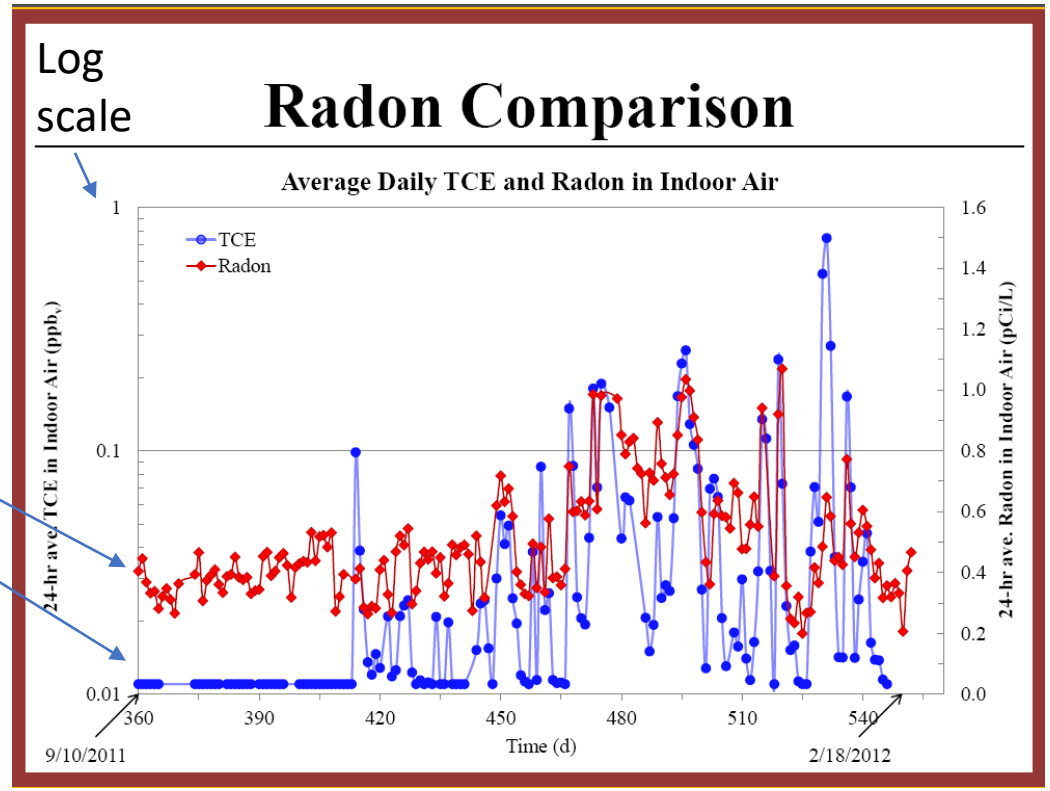
2) Magnitude

*Quant*itative 'proportionality' of conc. change

40% (EPA-IN)
25%-60% (SDM-UT)

~ ½ of change in TCE Conc. 'explained by' the change in Rn conc. (R^2)

Not confident enough for risk decision making



Sun Devil Manor (SDM), Layton, Utah

For Site application tried Next:

Medical-screening / decision approach using categories of numbers (2x2 tables)

What can you do with that understanding?

- For ***Temporal*** variability – Three possible methods:

- 1 – ***Try to*** Schedule CVOC sampling during high-VI (Rn) conditions

- 2 – Collect **regularly-scheduled** CVOC samples
  - Compare to Rn conc. during CVOC sampling to previous time periods (%iles)
    - If Rn conc. were 'elevated' during CVOC sampling, CVOC conc. can* be elevated

- 3 – Use Rn-sensor & ***auto-triggering*** device to collect CVOC sample when Rn conc. are 'elevated (e.g., >95th%ile)

*Makes it possible & raises probability; but does not guarantee it

Realities of – Using ITS (e.g., Rn) or Not
(for **Temporal** variability)

- ***Not*** *knowing* what the conc. of soil-gas (Rn) was during CVOC sampling
  - **Ensures** only '**random**' sampling **accuracy**
    - Of 1/20 (**5**%) chance of indoor air samples representing **conc. of concern** (e.g., **>**95th%ile)

- ***Knowing*** that soil-gas (Rn) was ***NOT*** 'elevated' during CVOC sampling
  - **Means** there is '**~no**' **chance** (~1%) of CVOC sample conc. being 'elevated'

- ***Knowing*** that soil-gas (Rn) was 'elevated' during CVOC sampling
  - **Ensures** an **increased** (~40%)[1] **probability** that CVOC conc will **also** be **elevated**

More specific Objectives:
Address some Still challenging Questions:

- No often addressed in existing guidance[1] &
- To make confidently-protective long-lasting site-wide VI-exposure decisions

- How many samples?

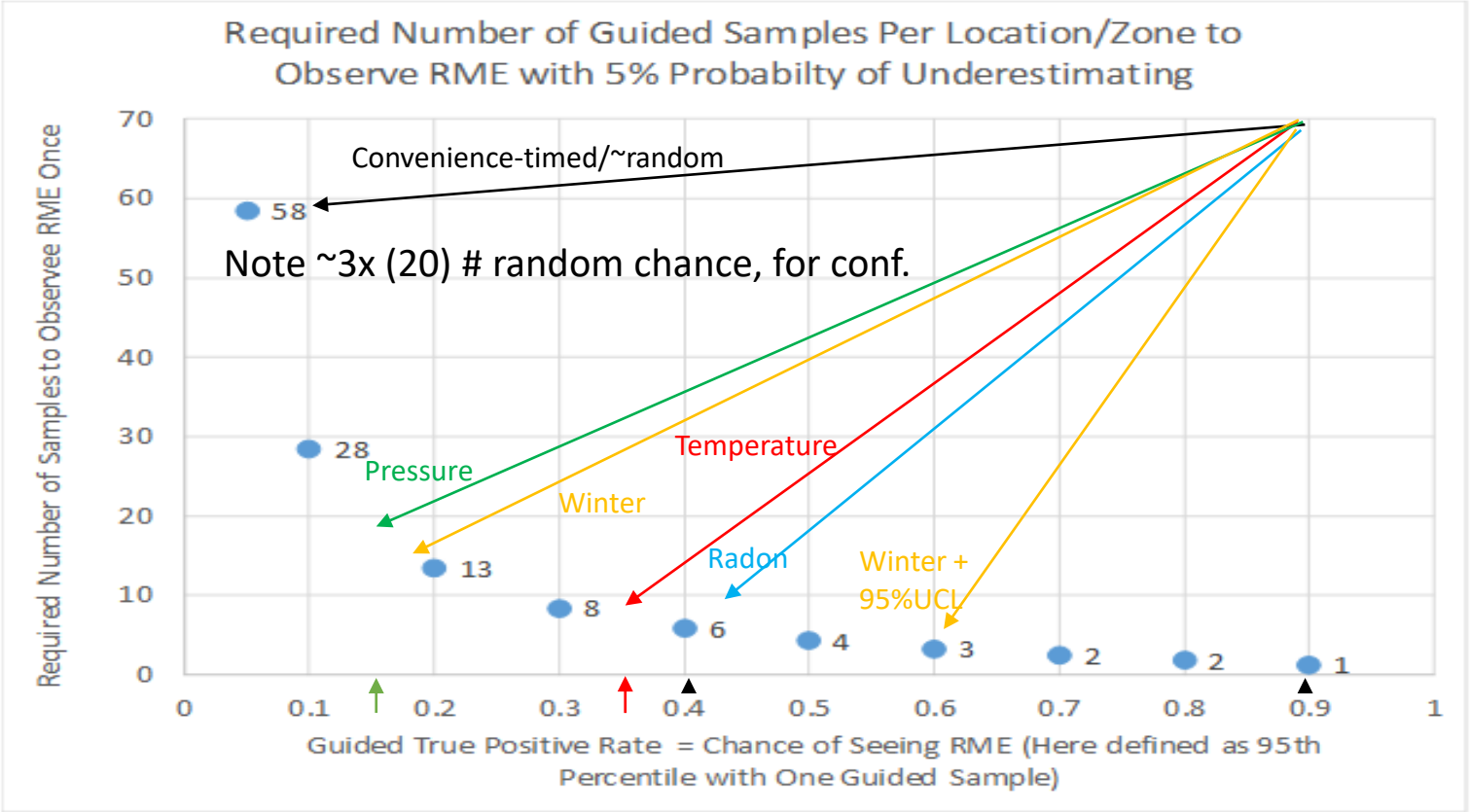
- Where (e.g., which buildings) should the samples be from?

- When (e.g., under what conditions) should the samples be from?

How many Samples Needed to represent 95th%ile (RME)

Using ITS' **Positive** Predictive Values Lowers Sample # Needed w/ High (95%) Confidence - Using *ITS-Guided* IAQ samples

To address **Temporal** variability: **Per Building**



Note: Winter + 95%UCL Means 3 VOC samples in winter and then calculating the UCL for those values – typically results in risk conc. > than any observed; PRP use unlikely?

Number of samples needed to 'know' you have one sample > target TCE conc. of 95th%ile (1.5 ug/m3)

[Guided sample # from evidence at a house, Sun Devil Manor – VI research house (formerly ASU), Layton, UT]

Where? – How do you identify the buildings to represent site-wide VI?

for a confident decision?

- One the very first questions for VI sample planning
- Evidence for Spatial – is much less-well developed than for Temporal
  - Studies require many buildings – not easily researched
    - Volunteers with any evidence much appreciated

- Existing studies/evidence and concepts – will be presented

Given access to the **building** of highest concern for VI;

(When? &)

How Many [1] indoor-air samples are needed?

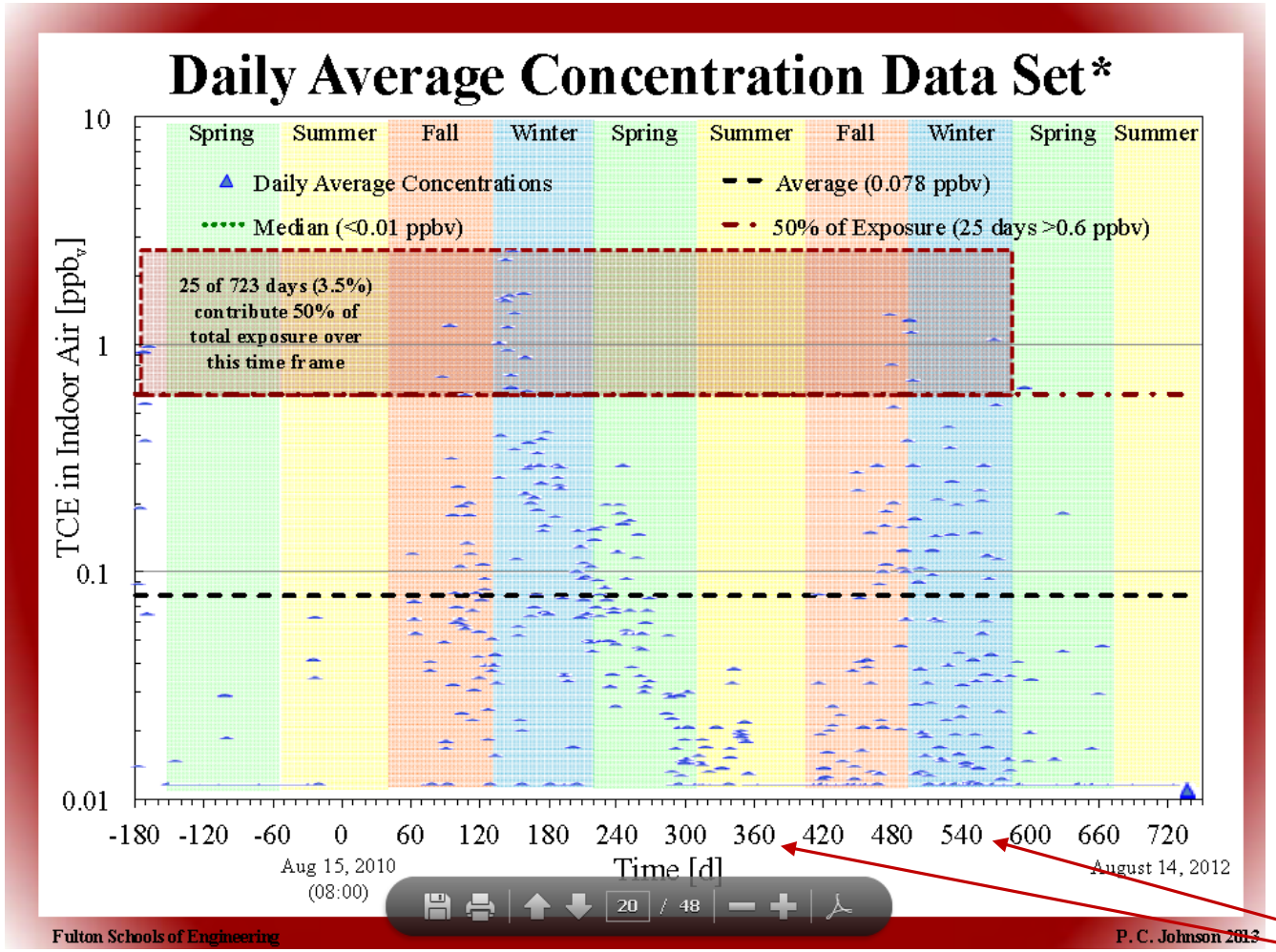
for a confident decision? – Hint: It's related to how conc. are to level of concern

- ***If*** indoor air conc. are greater than (>) acceptable risk levels:
  - 100% of the time? [2]
  - 50% of the time?
  - 10% of the time?
  - 3.5% of the time?

Indoor air is *variable* & Episodic Peaks can Drive Exposure

25 days (*3.5%*) present **more exposure** than the other 698 days

One building w/ 2-hr indoor air samples for ~ 2 years



Chemical VI (TCE) at ASU's 'Sun Devil Manor' (SDM) CVI research house

Period when Radon was measured

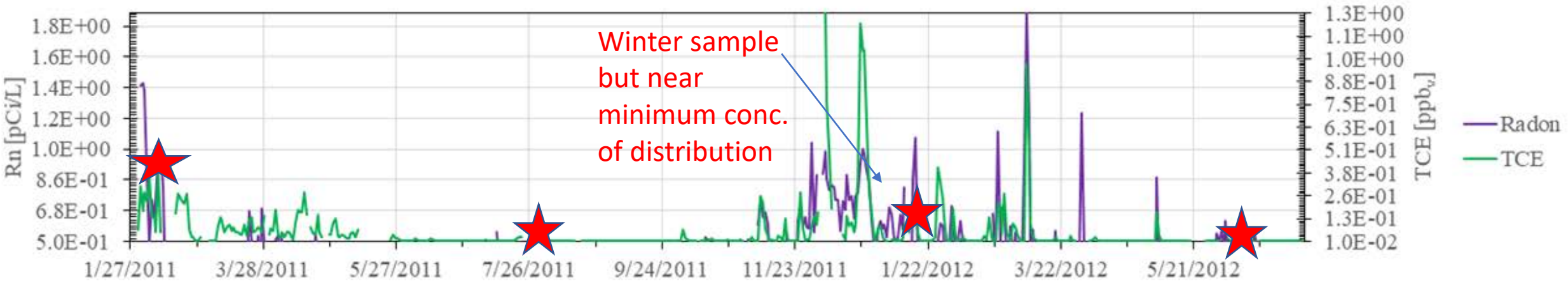
Dr. Paul Johnson's slide 20/48 - Note audio recording of presentation also available at: https://iavi.rti.org/attachments/WorkshopsAndConferences/05_Johnson_03-19-13.pdf

Why continuous measurements?

Because: A ‘few’ indoor chemical air samples is ~typical

- What level of **confidence** is possible w/o ‘continuous’ data?

We have **no reference** for ‘**high-end’** exposure without some more frequent/**continuous** data



While it would be **helpful** to have **continuous** CVOC samples from **all** bldgs. w/ poten. VI:

- That is not practical for many site investigations
- But continuous measurements of some Indicators and Tracers is:

- So the next best thing is to have some **Indicators** and **Tracers** that can:
  - **Represent/incorporate/integrate**
    - **As many** of the long list of **variable factors** influencing indoor air conc. **as possible**

What can we measure 'continuously' that relates-to & has-an-association w/ indoor $CVOC_{VI}$ conc?

- VI has almost infinite number of factors influencing exposure pt. conc.
- What can we measure*:
  - Frequently
  - Practically
  - Affordably
- that has an documented <u>quantitative</u> assoc. w/ indoor $CVOC_{VI}$ conc?;
- So that it **increases** our **understanding** of how likely our indoor air samples are to <u>represent 'high-end'</u> exposures, &
- <u>Allows quantitative confidence</u> in VI risk management decisions?

*in a given building, i.e., is building-specific

Temperature & Chimney effect

- One common Environmental condition leading to pressure & air flow
- ‘Hot’ air is less dense and raises up
- Effect on buildings thoroughly studied in 1980’s research on Radon*
- Observed increased intrusion of soil gas (including Radon) was generally associated with higher indoor temperature relative to outdoor (Differential Temp.)
  - As hotter indoor air rose up and ‘sucked in’ air from below (some soil gas)
- Temperature measures/metrics:
  - Outdoor
  - Differential (indoor - outdoor)
  - Radon indoor – reflects the building’s actual response to this on amount soil gas entry

*first hypothesized chemical vapor intrusion (Nazaroff et al. 198_?)

Why? Stack Effect Influences Soil Gas Entry ***and*** *Air Exchange*

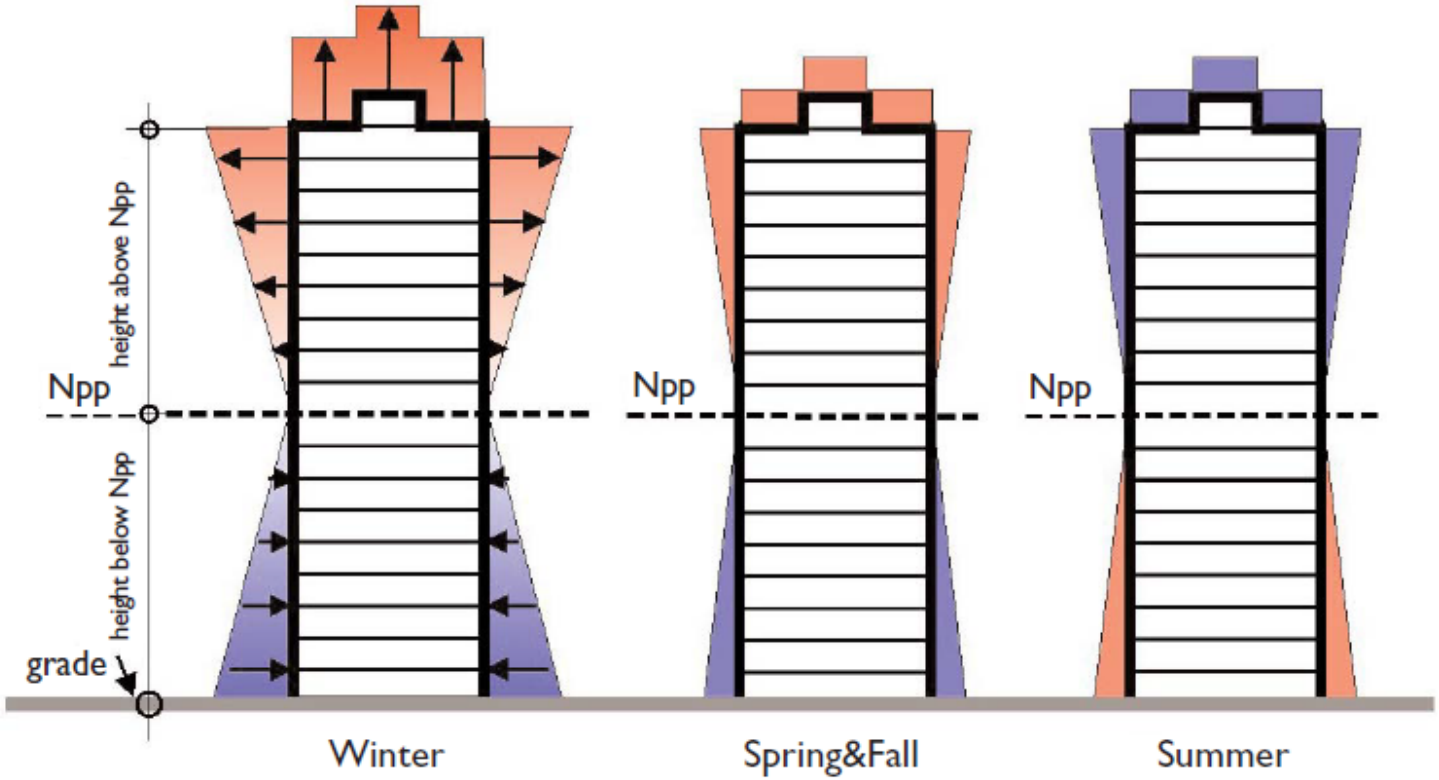


Figure Credit: Quirouette, R. L., and B. Arch. *Air pressure and the building envelope*. Ottawa: Canada Mortgage and Housing Corporation, 2004.

Equation Credit: Hui, S.C. 2003. *Lecture: Air Movement and Natural Ventilation*. Department of Mechanical Engineering, The University of Hong Kong. Used by Permission from Dr. Hui. Available at http://www.arch.hku.hk/teaching/lectures/airvent/sect03.htm.

3.3 Flow caused by thermal forces

If the building's internal resistance is not significant, the flow caused by stack effect may be estimated by:

$$Q = K \cdot A \cdot \sqrt{2 \cdot g \cdot \Delta h \cdot \frac{T_i - T_o}{T_i}} \quad \text{if } T_i > T_o$$

$$Q = K \cdot A \cdot \sqrt{2 \cdot g \cdot \Delta h \cdot \frac{T_o - T_i}{T_o}} \quad \text{if } T_o > T_i \qquad (7)$$

where Q = air flow rate (m^3/s)
K = discharge coefficient for the opening (usually assumed to be 0.65)
A = free area of inlet openings (m^2)
Δh = height from lower opening (mid-point) to neutral pressure level (m)
T_i = indoor air temperature (K)
T_o = outdoor air temperature (K)

"In very "leaky" houses it is possible that the amount of air exchange driven by a large indoor/outdoor temperature differential will "outweigh" the greater soil gas entry" (Lutes)

Pressure - Differential

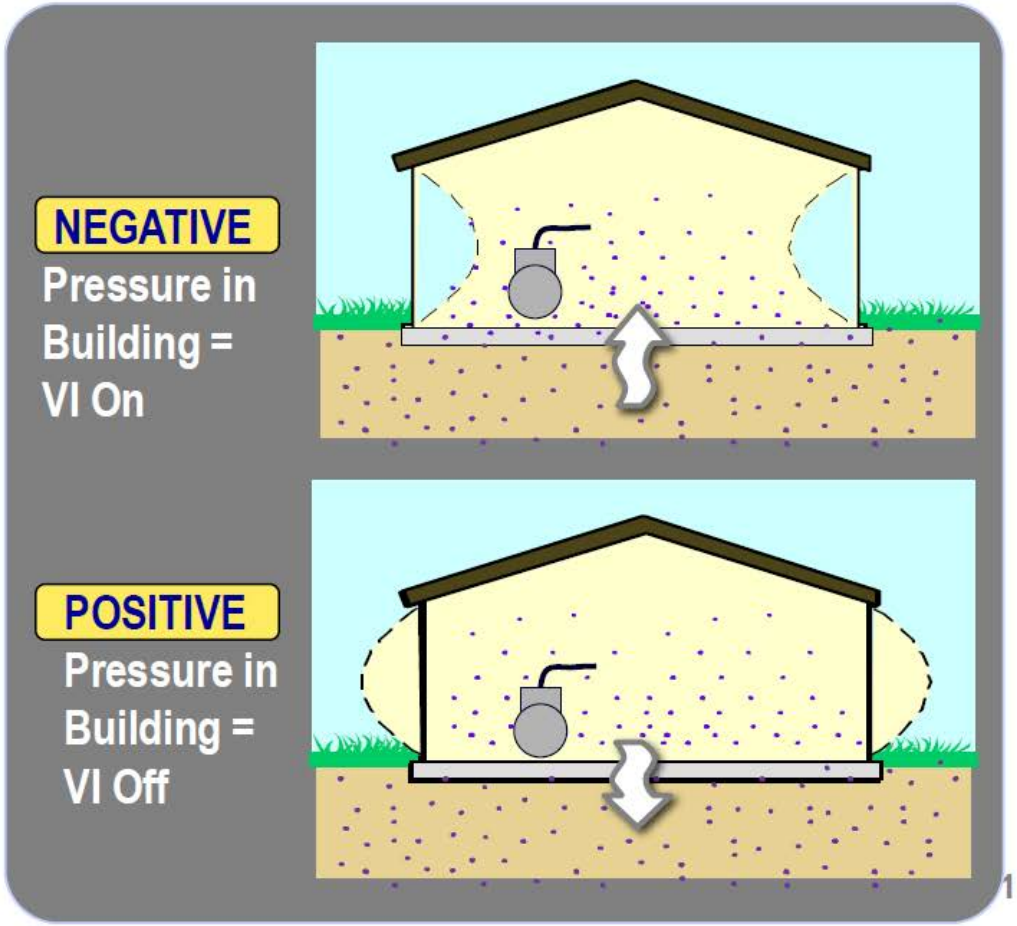
- Measure of the actual Force causing air flow (advective VI)
  - e.g., caused by Temp. differentials &/or winds

- Pressure measures/metrics:
  - Outdoor (barometric)
  - Indoor
  - Differential (indoor - outdoor)
  - Differential (indoor - sub-slab)

  - Radon indoor – reflects the building's actual response to this on the amount of soil gas entry

Where VI CSM: Differential Pressure (in- out or SS)

- Differential pressure caused by environmental factors (e.g., wind) and building operations, can *indicate*…
  - Building under-pressurization (VI "on")
  - Building over-pressurization (VI "off")
- Pressure fluctuation may be more dominant driver than time-averaged dP



"Barometric pressure data is used primarily to look at the change … (up or down) of say 0.3" of Hg or more. [I]f you can't collect this long term at a particular building it is fine to use the local weather station if you can get hourly data" (C. Lutes).

Image: Beckley, L. 2014. AEHS, San Diego, CA

Pressure in VI Conceptual Site Model

- Natural/Environmental Factors:
  - Barometric pressure
  - Wind effects (speed, direction, fluc.)
  - Stack effects
- Anthropogenic/Building Factors:
  - Opening and closing of windows and doors
  - Operation of HVAC systems, fans, other air exchangers

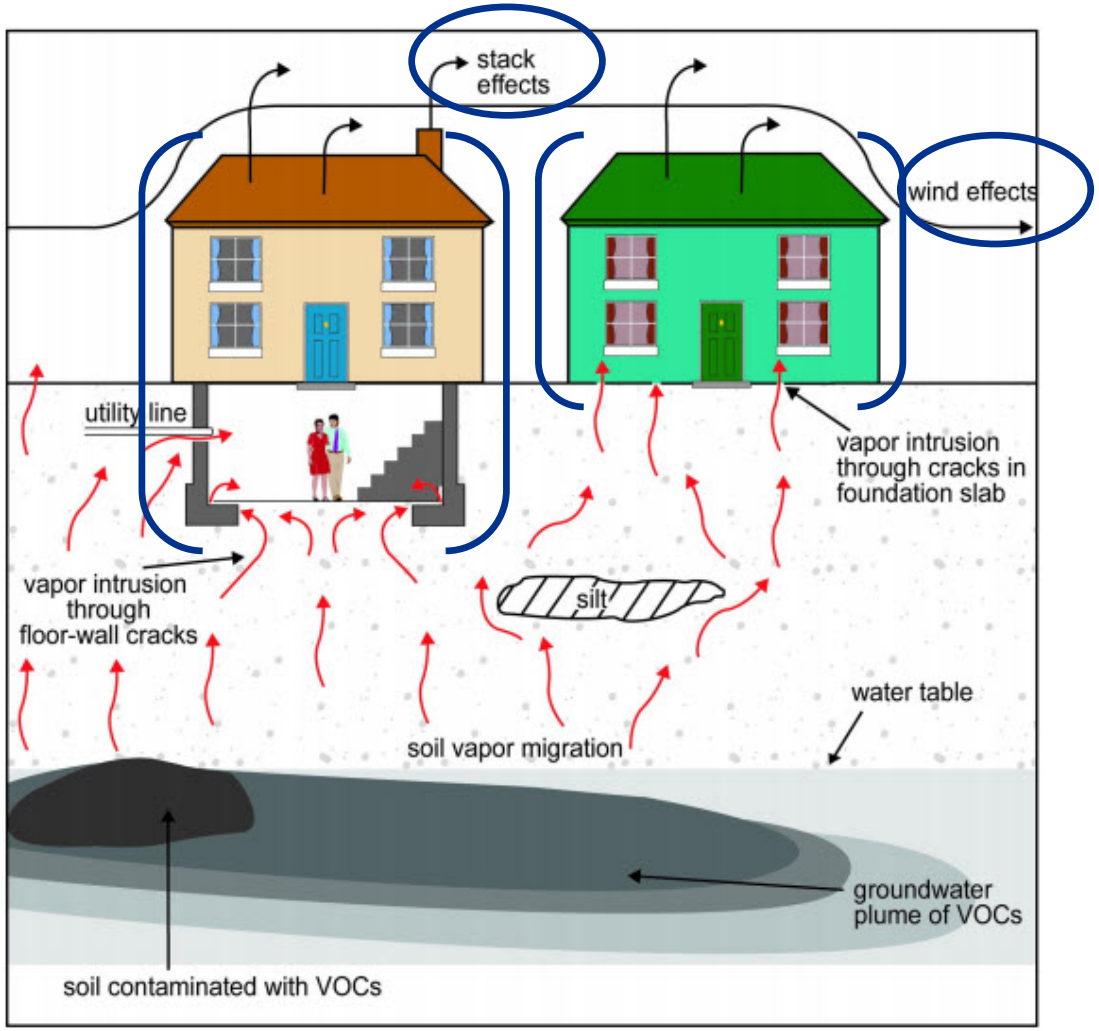


Image: USEPA, 2002

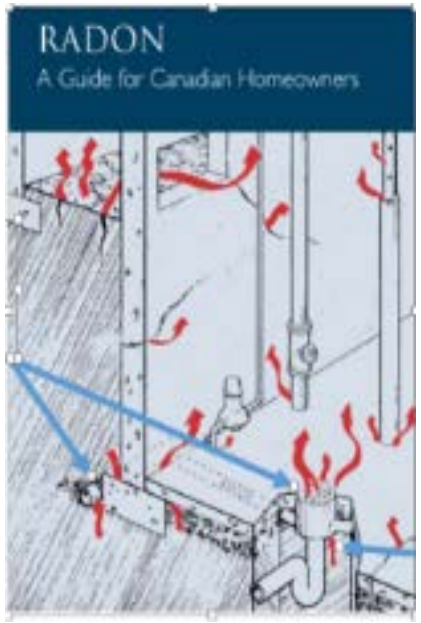
Radon conc. in indoor air

- Radon (Rn) is a gas that is a component of nearly all soil gas
- Rn is a Tracer of soil gas movement, and
- Its conc. in indoor air can represent the amount of soil gas in indoor air
- While there can be many variables determining the absolute conc. of Rn in a building's indoor air, radon's relative conc. over time in the indoor may be considered to represent the general amount of soil gas in indoor air over time (i.e., the amount of soil gas intrusion).

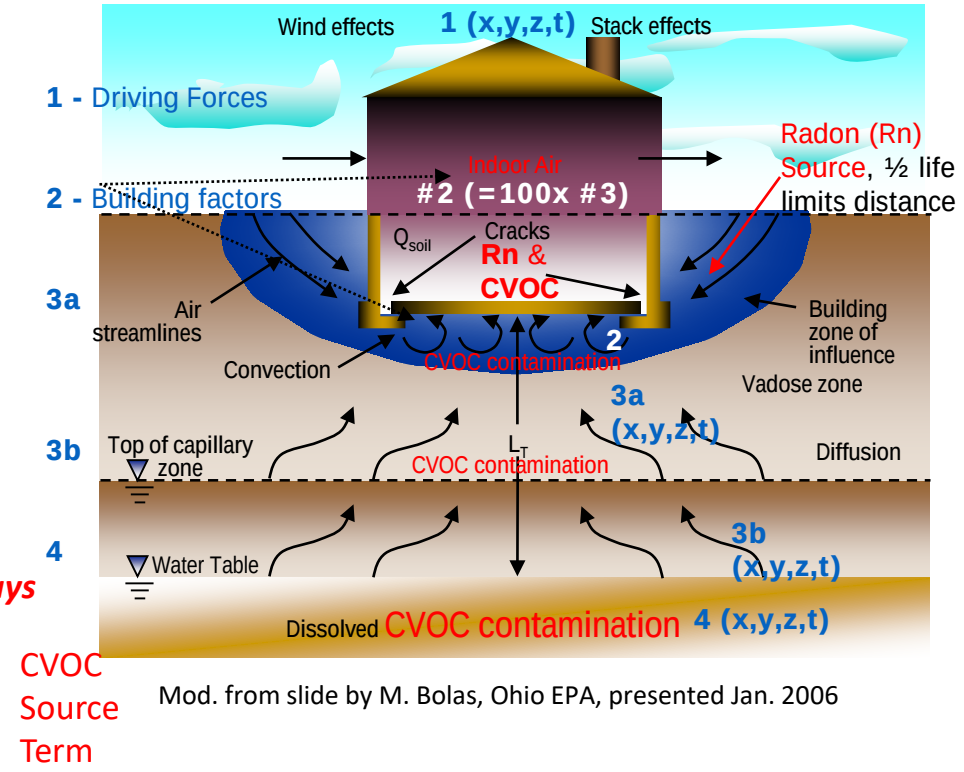
Conceptual Site Model (CSM) of ***Soil-Gas*** Intrusion

Radon can reflect/represent all factors above diffusion

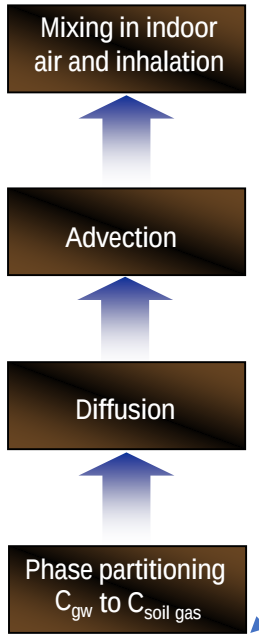
Four *Categories*-of-*Variables for Chlorinated* VOC (*CVOCs*) components



Bldg. are complex, incl. ***Pipe Flow pathways***



Mod. from slide by M. Bolas, Ohio EPA, presented Jan. 2006



Indoor radon conc. **<u>can</u>** represent this [**99%** of Atten.] (EPA VI Database, 2010?)

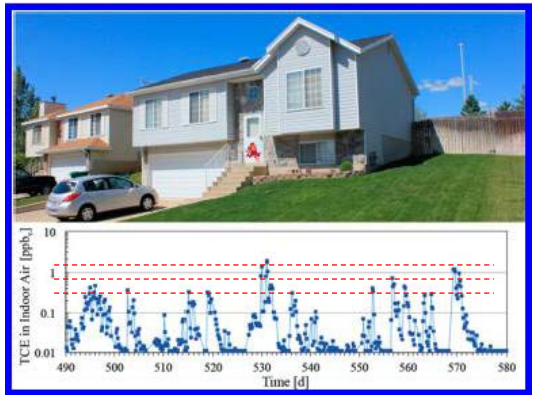
Indoor radon conc. can **<u>not</u>** represent [**1%** of Atten.] (EPA VI Database, 2010?

Bottom Line = ONLY indoor air <u>conc</u>. can represent ALL variables/factors involved & we want supplemental measures/metrics that can represent <u>as many as possible</u>

Guidance for *When* to Sample indoor air?

Initial guidance developed based on generally *non*-quantitative evidence

- For collecting Indoor Air samples, across ***Time***:
  - Seasonal – EPA & States …
    - (based on some analyses & GW analogy)
  - Temperature – PA (best I've seen), ….
    - (based on some retrospective analyses/testing)
  - Pressure – EPA VIG, States …
    - (based on some limited analyses)
  - Radon* – NH, WI, OR, CA, AK, MN?



Sun **D**evil **M**anor (SDM)

Layton, Utah

*Using Rn attenuation factor (indoor conc./sub-slab conc.) List from presentation by A. Miller, at AEHS Oct. 2018
Note: not supported by most of the evidence I've seen, likely due to spatial variability (e.g., between SS ports).

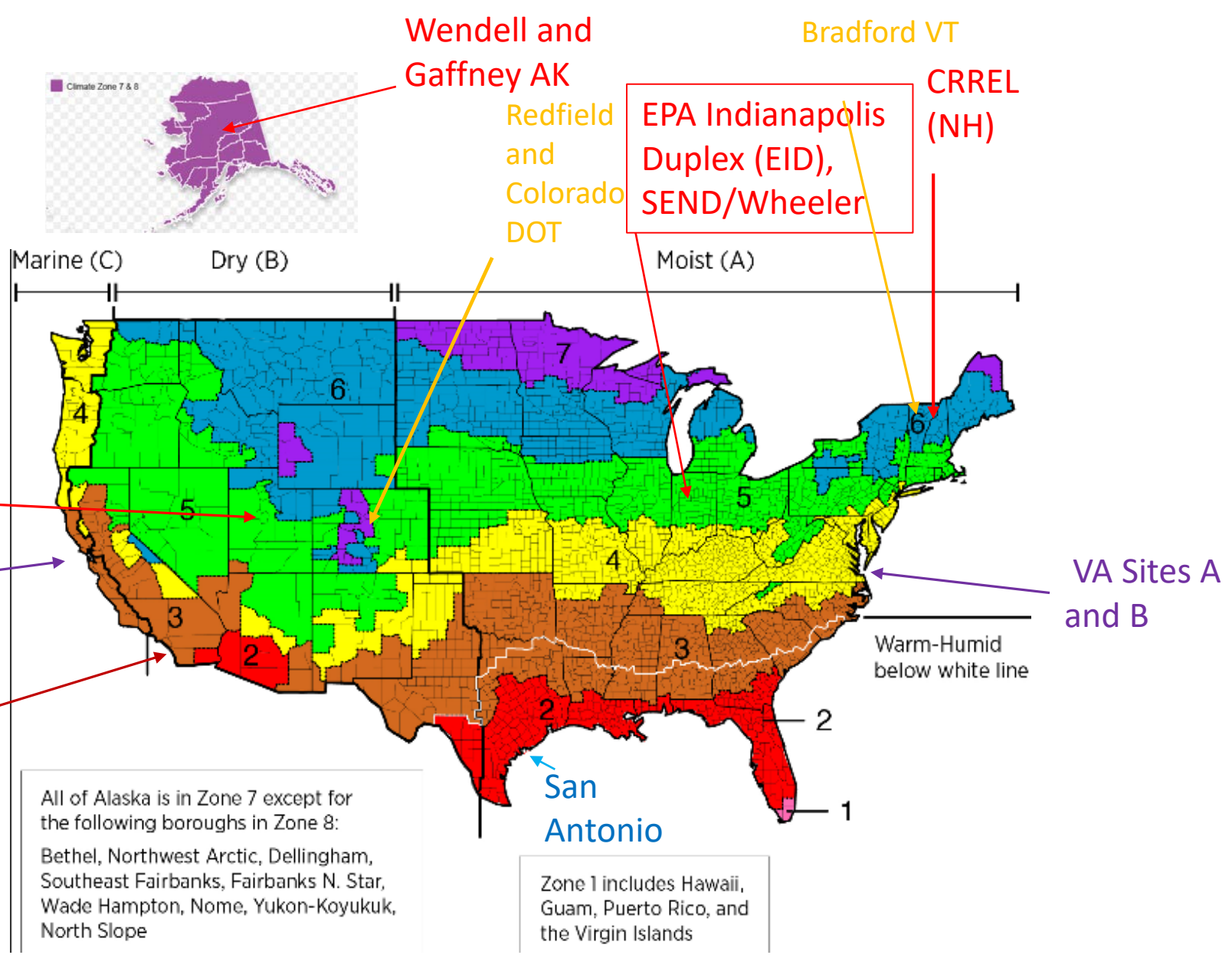
We wanted to quantitatively test the Indicators & Tracers w/ evidence of associations w/ CVOC conc.

- In hopes of developing useful Methods (e.g., SW-846 methods) for screening-for, focusing-on & the collection-of ‘high-end’ VI conc., using 7 measures/metrics:
- Temp.
  - Outdoor
  - Differential (indoor - outdoor)
- Pressure
  - Outdoor (barometric)
  - Differential (indoor - outdoor)
  - Differential (indoor – sub-slab)
- Radon
  - Indoor
  - Differential* (indoor - outdoor) [*Not yet tested]

Measurable evidence comes from a specific building; in a specific scenario – Scenario bins

- Measurable evidence – is specific
- Attempts to generalize observations too widely has led to errors
  - In extrapolation to:
    - Other buildings
    - Similar buildings, in other types of VOC sources, soils and/or migration pathways
    - Same building at different times (e.g., Ice damns one winter in EID)
- We want scenario bins/categories as general as possible but reliably/usefully comparable to new ‘similar’ ‘matched’ scenarios, and
- We are building scenario bins up from the cases where we have high-quality and data-rich studies/observations

Studying Some – New data from new sites across the IECC Climate Zones



Slide from Chris Lutes, Jacobs

IECC zones Reprinted form https://basc.pnnl.gov/images/iecc-climate-zone-map

SDM - Matrix of CSM scenario-categories

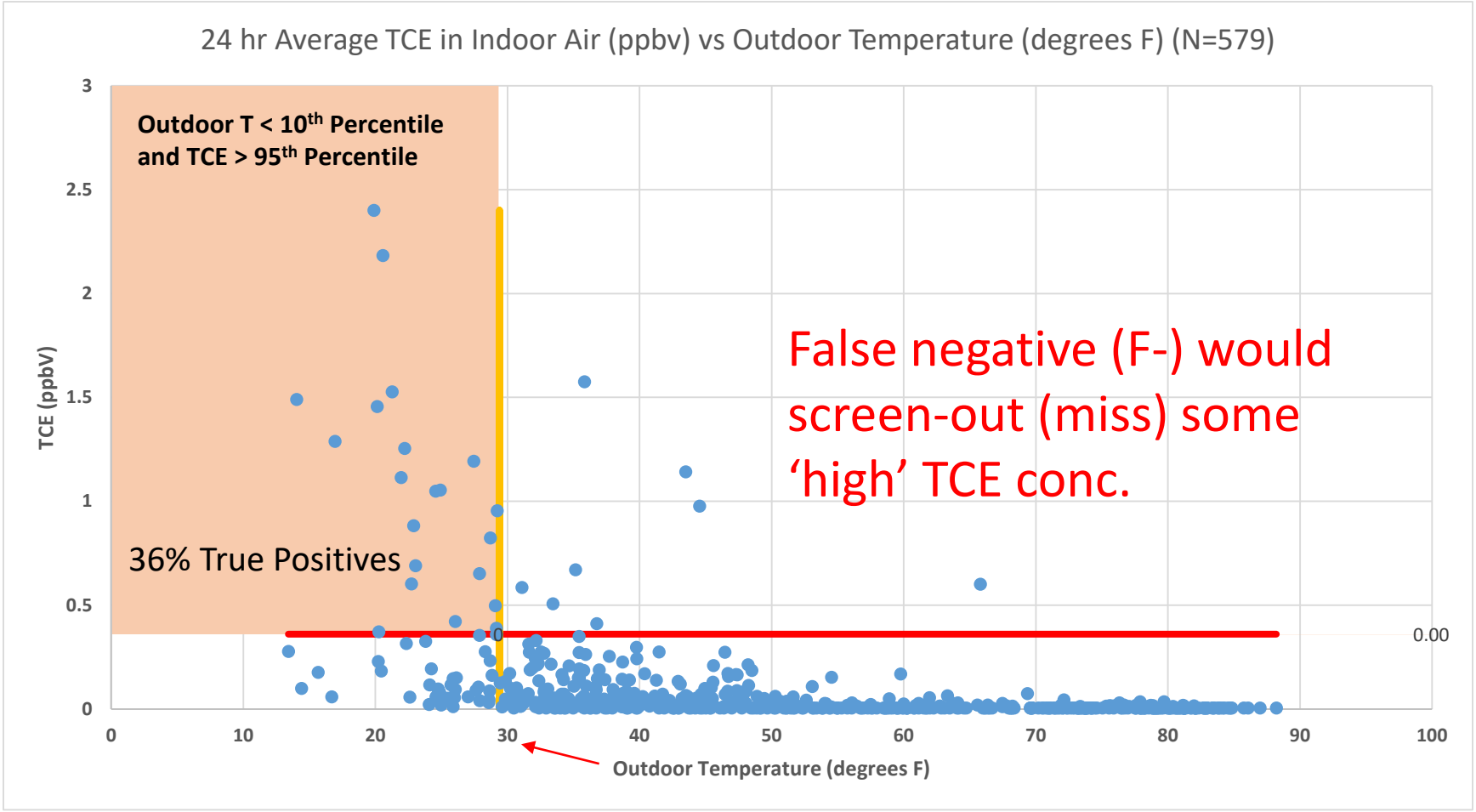
Type & Depth to VOC source	Building type & size (ft2)	Foundation	Sub-foundation horizontal permeable	Preferential pipe pathway	Bldg-Climate zone (Temp)	Press./ Wind speed & direction	Intrusion primarily Advect. vs Diffusive
Shallow Soil	Modern sub-urban SFR Mod. 2k	Slab-on-Grade (SoG)	Continuous horizontal/ permeable	High	1-3	Low	Advective
Deep Soil	Legacy Urban MF	Split level – SoG & basmt	Discontinuous - impermeable	Low-Mod.	4	Mod.	Diffusive
Shallow GW	Non-Res. >10k ft2	Full basement		None	5	High steady direct	50-50
'Deep' GW	Non-Res. >100k	Crawlspace -dirt floor			6-8	High varying direction	

EID* - Matrix of CSM scenario-categories

Type & Depth to VOC source	Building type & size (ft2)	Foundation	Sub-foundation horizontal permeable	Preferential pipe pathway	Bldg-Climate zone (Temp)	Press./ Wind speed & direction	Intrusion primarily Advect. vs Diffusive
Shallow Soil	Modern sub-urban SFR Mod. 2k	Slab-on-Grade	Continuous horizontal/ permeable	High	1-3	Low	Advective
Deep Soil	'Legacy' Urban Multi-Family	Split level – SoG & basmt	Discontinuous - impermeable	Mod.	4	Mod.	Diffusive
Shallow GW	Non-Res. >10k ft2	Full basement		Low	5	High steady direct	50-50
'Deep' GW	Non-Res. >100k	Crawlspace -dirt floor		None	6-8	High varying direction	

*EPA Indianapolis Duplex, with underlined conditions different than SDM

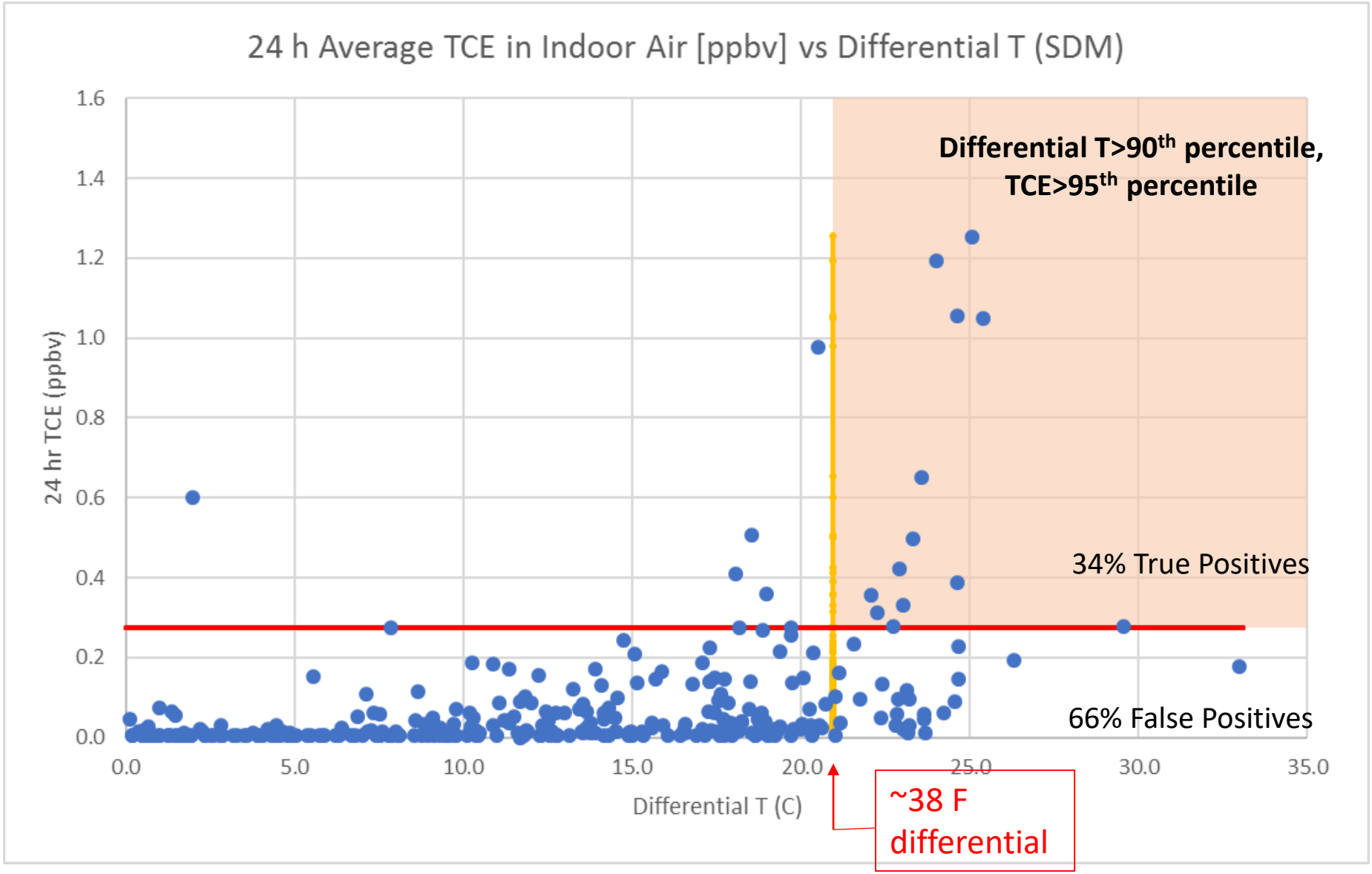
SDM Outdoor Temperature Indicator Approach for RME – comparison of same day ‘grab’ results



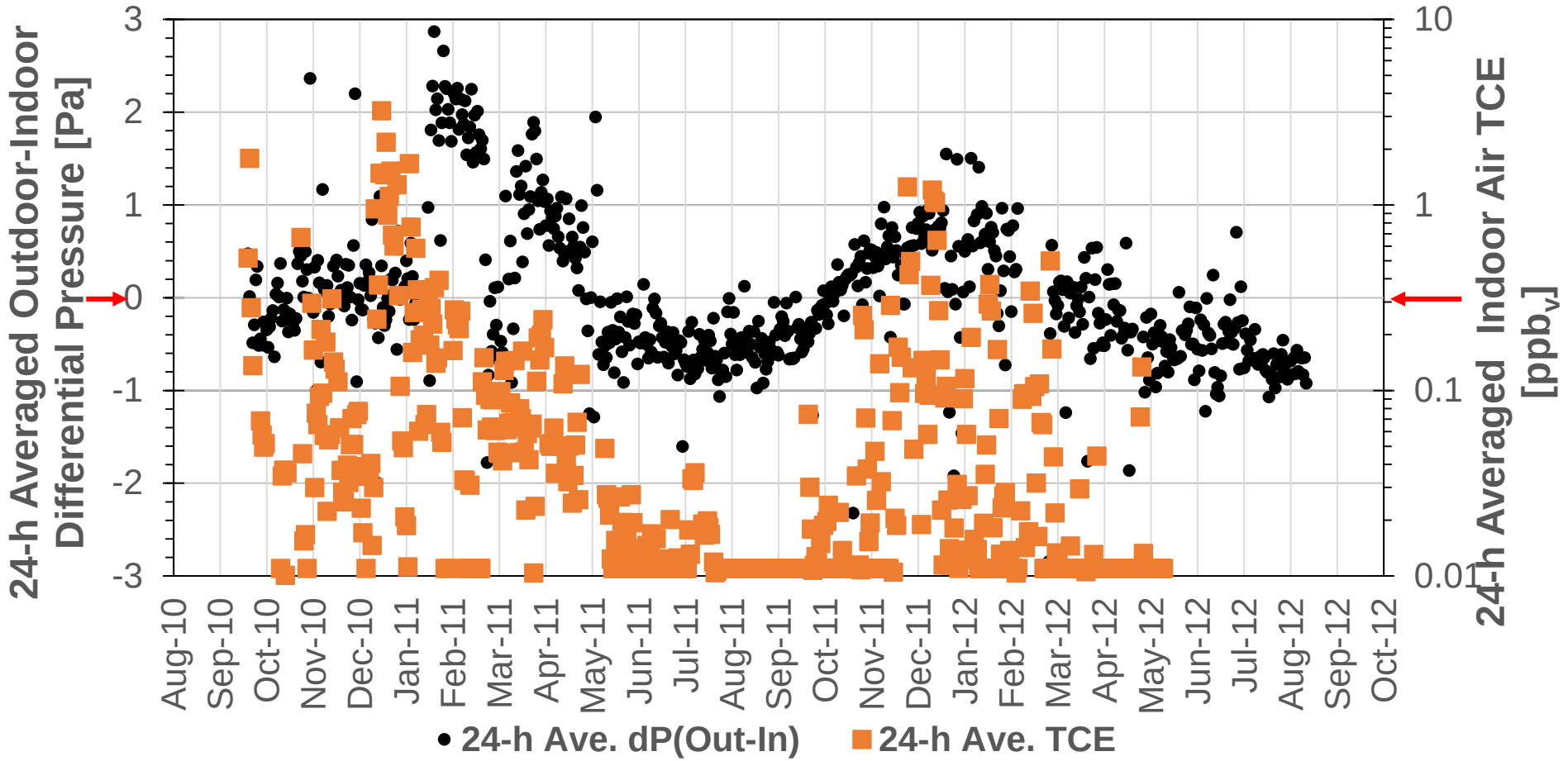
Note: 24-hr avg. below freezing

SDM Differential Temperature Indicator

(>90th%) Approach for RME –'grab' results



Pressure Differential (Outdoor-Indoor) as an Indicator: When do we sample?



Data from Holton et al., 2013

Radon - Statistical Assoc. of Indoor Conc. across **Time**

Using **Time Series (Linear) Regression**; results for Two components:

Time Series Regression ***Not practical***, computationally for typical-site application – But highly informative when applied

1) Direction of Conc. change. (*Qual.*)

99% (EPA-IN-Duplex)
99.9% (SDM-UT)

Changing conc. direction together

Note Background (outdoor) Rn & < Det. Limit for TCE

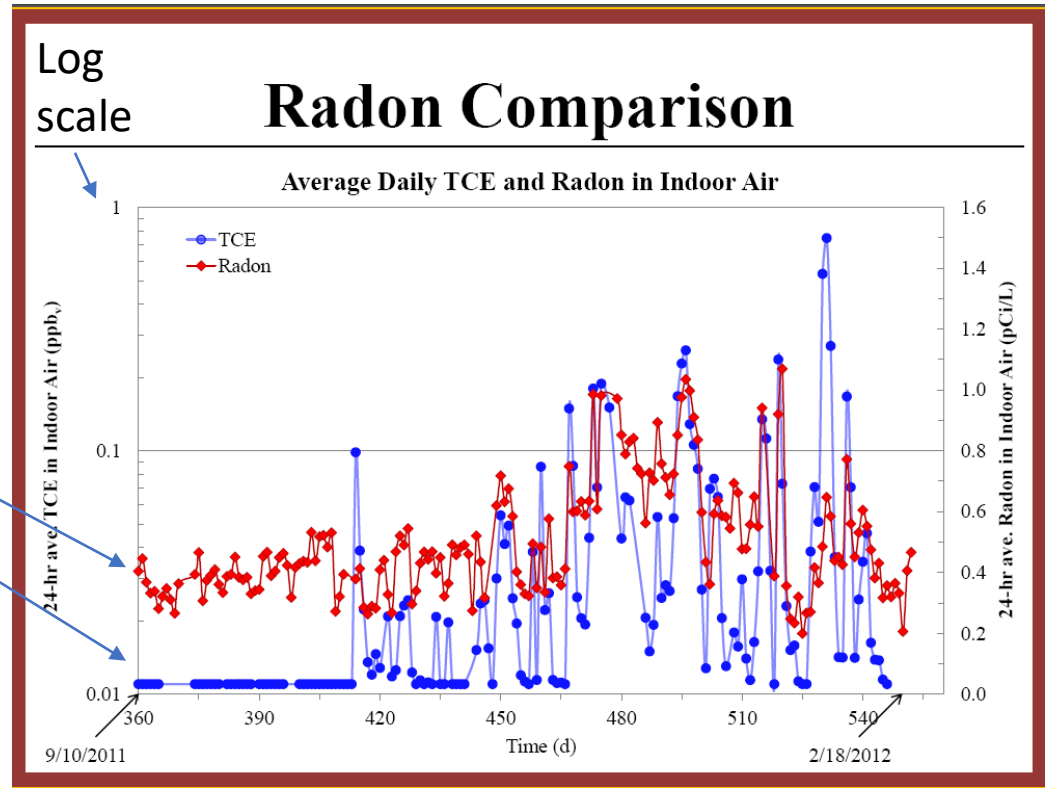
2) Magnitude

*Quant*itative 'proportionality' of conc. change

40% (EPA-IN)
25%-60% (SDM-UT)

~ ½ of change in TCE Conc. 'explained by' the change in Rn conc. (R^2)

Not confident enough for risk decision making



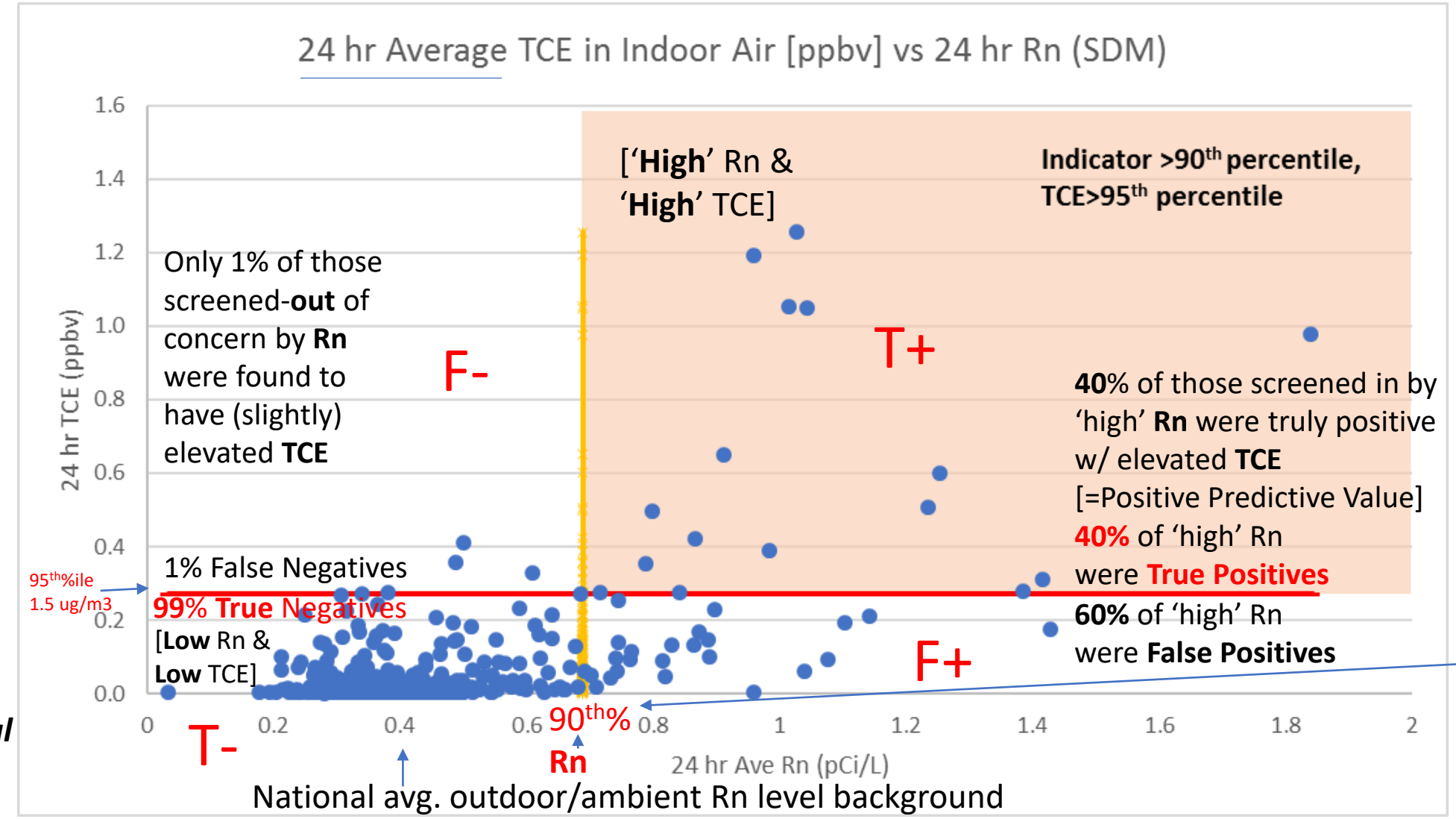
Sun Devil Manor (SDM), Layton, Utah

For Site application tried Next:

Medical-screening / decision approach using categories of numbers (2x2 tables)

Indoor Radon *conc.* (*not* Diff.) as Indicator of TCE RME; grabs in any Time order

However;
Not easy to use:
Trying to estimate when Rn is going to be elevated (>90%ile) and then schedule the chemical sample collection ***is Not practical***



SDM has Very **Low** Radon

90th%ile = **~0.7 pCi/L**

& has a preferential (pipe) pathway

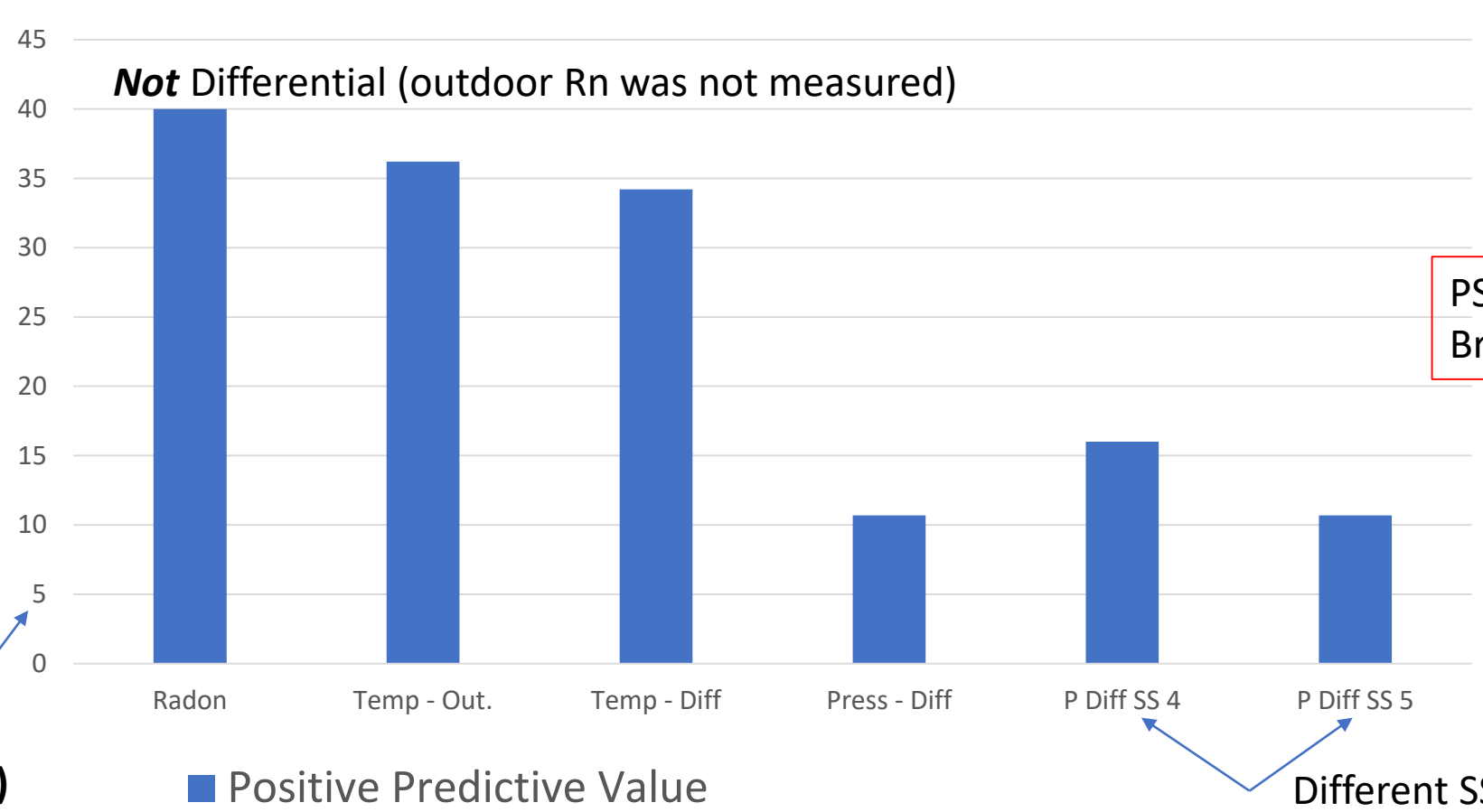
Diagnostic (Exposure) Screening of SDM house data, statistics by Kurtz

Looking for >95th% conc. of TCE, **99%** of the data 'Indicated' by non-elevated (<90th%) Rn were **correctly** 'screened **out**'

Diagnostic (Exposure) Screening 'grab' Results
Positive Predictive Value - SDM

(probability of '**High**' (>90th%ile) ITS samples identifying '**High**' chemicals (**>95% RME**))

Note: PSA & Mammography ~30% Positive Predictive Value



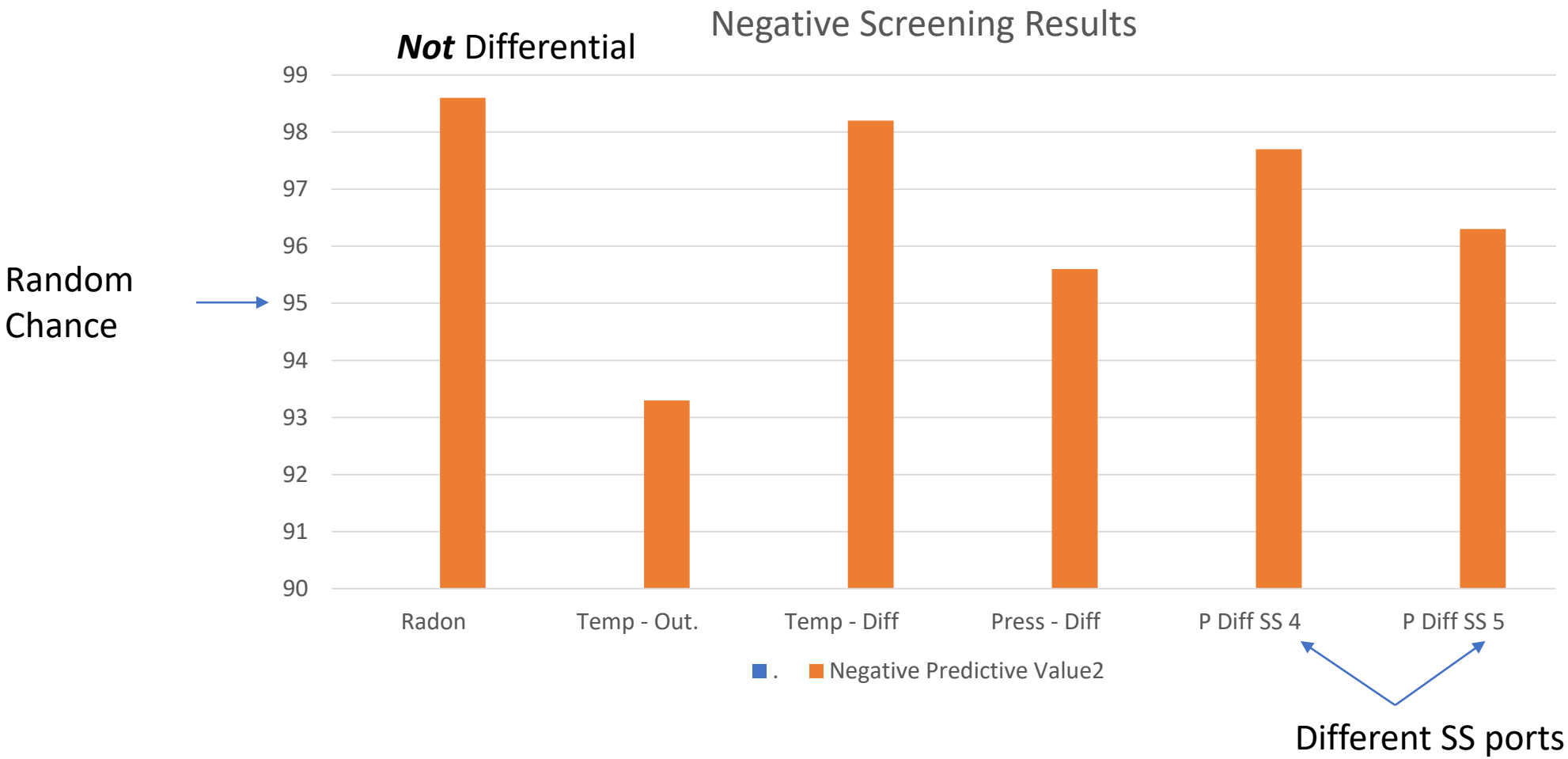
PSA ~ 30% PPV
Breast C. ~15-30% PPV

Random chance (5%)

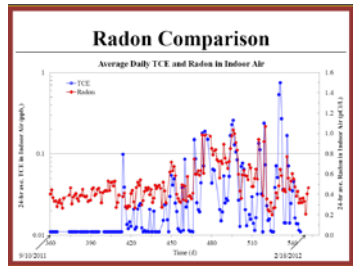
Different SS ports

Having **Rn** >90th%ile provides 40% (**8x higher chance**) of CVOC conc. being in the upper 95th%ile

Diagnostic (Exposure) Screening ‘grab’ Results
Negative Predictive Value – SDM [one house]
(probability of ‘**Low**’ ITS samples identifying ‘**Low**’ chemicals (<95%ile RME))



Summary CSM for ITS in CVI



Indoor **CVOC gas** Conc. (3)

99 to 99.9% correlation in direction of conc. change

FOLLOWERS of Soil-Gas/Vapor Intrusion

Indoor **Radon** Conc. (**Diff**. (indoor-out) - surrogate of soil gas conc

Conc./% of Soil Gas in indoor air

All Building – Entry, Mixing & Retention factors

(Sub-Slab) CVOC gas Conc. (2)

Preferential 'Pipe'

(**Outdoor**/Barometric) **Diff**. (Indoor-Out) **Pressure** **Diff**. (SS-Indoor)

[Integrates indoors] [SS-port-specific]

DRIVERS of Soil-Gas/Vapor Intrusion

HVAC … **Wind** (Speed, Direction, Fluctuations)

Lower density of indoor air

(**Outdoor**) **Temperature** **Diff**. (In-Outdoor)

'Shallow' subsurface Advection migration factors

Near-Building Advective migration Zone

'Deep' subsurface Diffusion migration factors (vary)

CVOC gas Conc. (1)

CVOC Source – Liquid/NAPL (conc. & part. vary)

Thank You

Indicators, Tracers & Surrogates

Supplemental Lines of Evidence are ***Not*** Equal

Summary of conceptual relationships

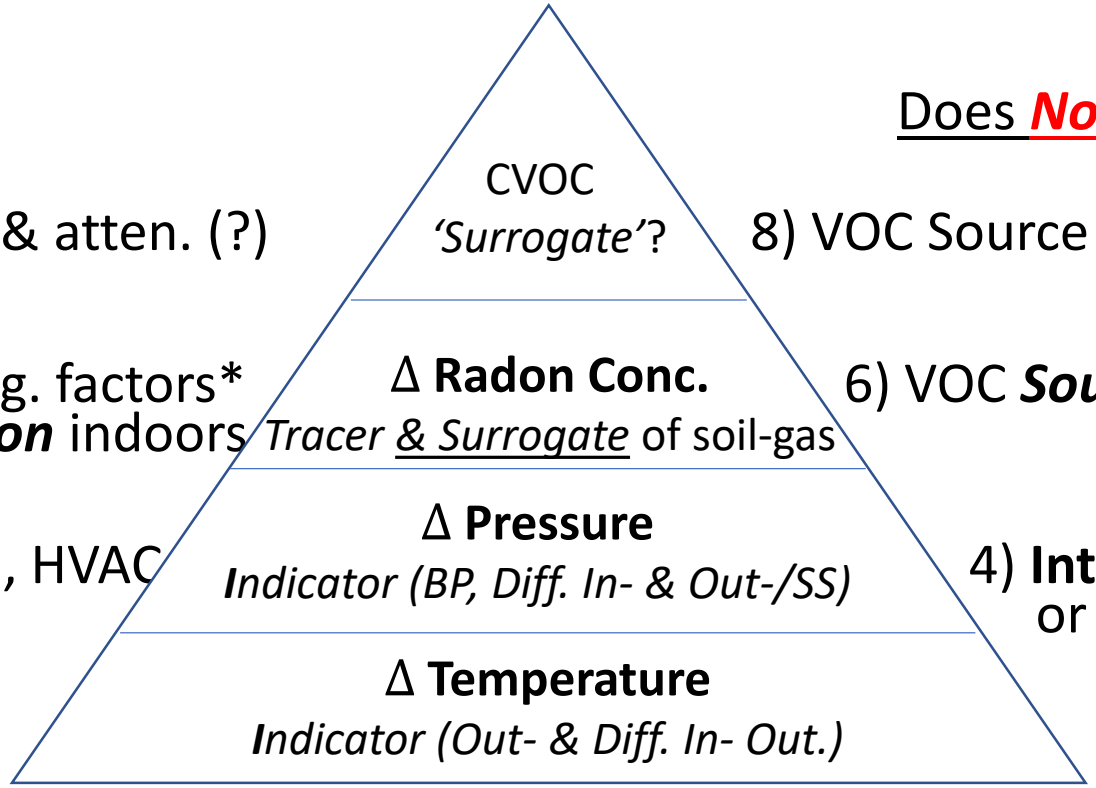
Includes:

7) Deep migration & atten. (?)

5) All nearby & bldg. factors* mixing & ***integration*** indoors

3) Wind (sp. & dir.), HVAC

1) Common Driver



Does ***Not*** include:

8) VOC Source loc. & variation (Space & Time)

6) VOC ***Source*** **loc./vari**. & deep **migrat.**

4) **Integration** of Areas (SubSlab) or Time, Air Ex. Rates (AER)

2) **Wind** (sp. & dir.), HVAC

***Indoor Rn **conc**. **when** CVOC is sampled

When should we be measuring the conc. of soil-gas in indoor air? – Frequently-Continuously

What is a practically-measurable tracer of soil-gas? – Radon (Rn)

Risk-decision points for assessing VI

Often using *High-end* conc. to address **potential** (future) risks

b/c We want a **short** assessment period, but *Long-lasting* Protection

- For VI: Exposure (indoor air) Conc. ~ Risk (residential)

- Long-term/Chronic risks
  - Average (mean) exposures (conc.)
    - **95%** Upper Confidence Limit (95UCL) for the Mean = High-end Average conc.

- Short-term (e.g., developmental) risks
  - Reasonable Maximum exposures (RME) (for indoor res. inhalation ~conc.)
    - **90^{th}-98^{th}** percentile (%ile) of the exposure concentration over the short-term, e.g., 1-day
      - USEPA-ORD – has described developmental effects as influenced by periods as short as 1-day*

* USEPA-ORD Guidelines for Developmental Toxicity Risk Assessment, 1991

Risk decision points are precise (ug/m3) Conc. cut-points in indoor air; From:

- Liquid CVOC **Source** conc. vary by Orders of Magnitude (OoM)
- CVOC Source (liquids) partition into a **Gas** (1) at some conc.
- Mixes in Soil **Gas** (2)
  - As it migrates to and some amount enters/intrudes into &
- Mixes in indoor air (**Gas** 3)

- In summary – predicting indoor air conc. due to VI is predicting the conc. of a Gas within a Gas, within a Gas

  - Can be expected to vary over space and time