Improving **Pro**tection for **V**apor **I**ntrusion***GW****

Indoor Environments Assoc. Symposium

Oct. 5, 2026

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Disclaimer: *The views expressed in this presentation are **those of the author** and do not necessarily represent the views or policies of the U.S. EPA.*

*__V__apors *from* a dissolved (**groundwater**) source with a **chlorinated-VOC** focus, representing *all* recalcitrant **V**apor **F**orming **C**hemicals, partitioning into the subsurface atmosphere & **'swept'** into Indoor **(Built)** environs

How does VI Occur? & VI Capture Zone

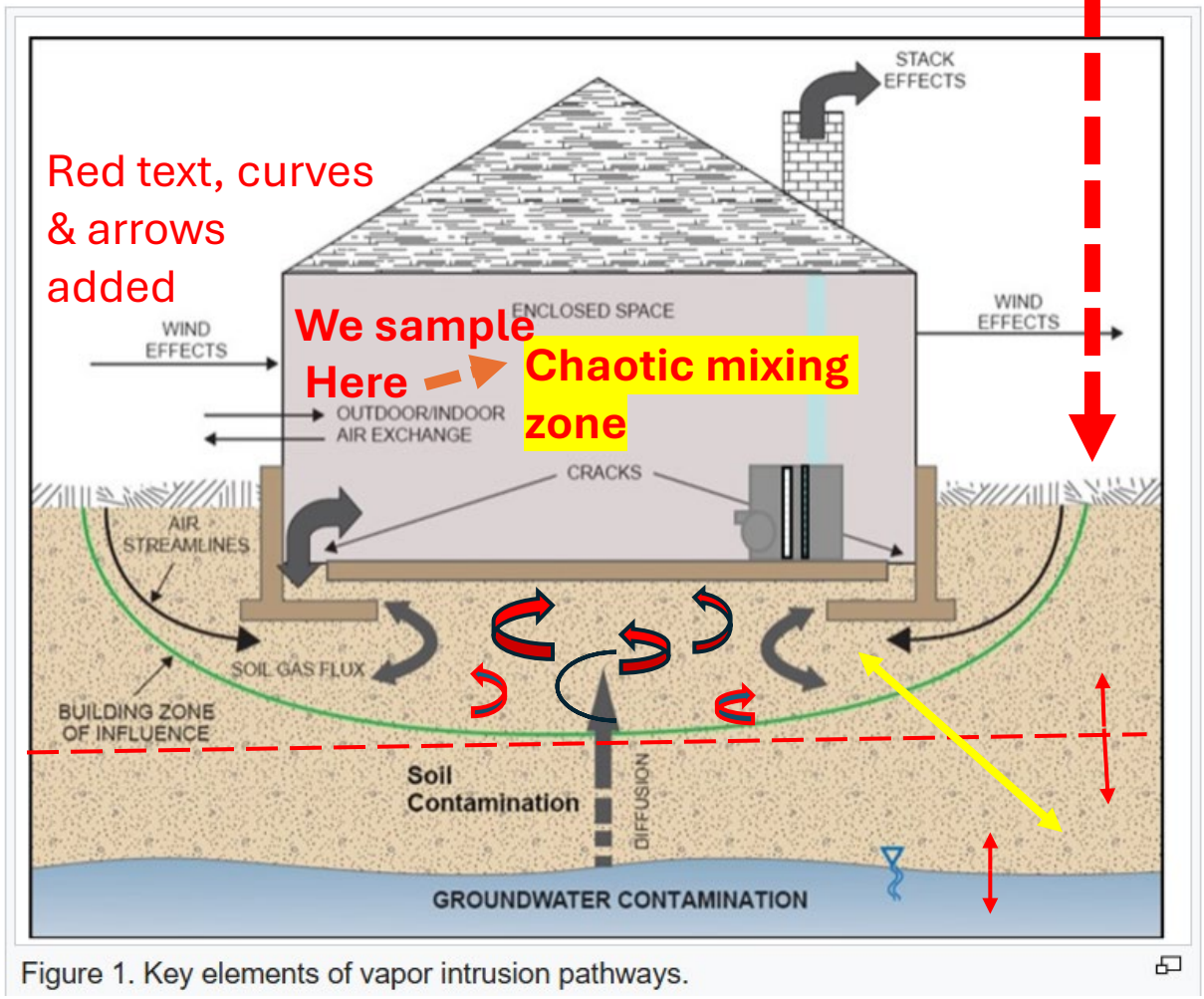
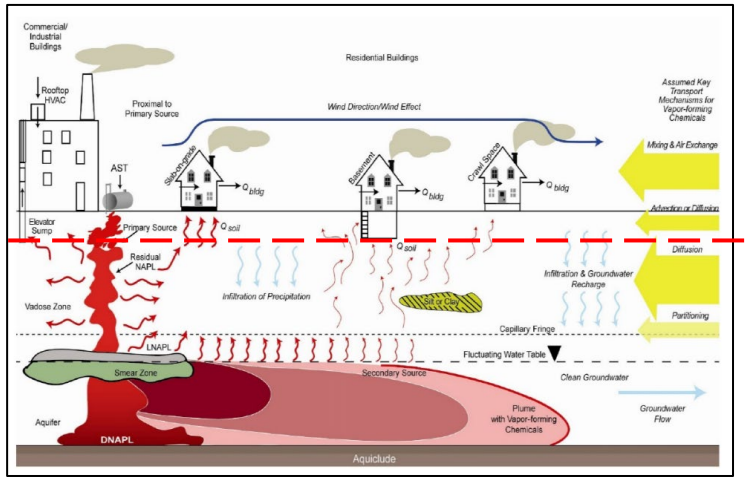


Figure 1. Key elements of vapor intrusion pathways.



Un-workable

Complex but Work-able-

Identification of Alternative Vapor Intrusion Pathways Using Controlled Pressure Testing, Soil Gas Monitoring, and Screening Model Calculations

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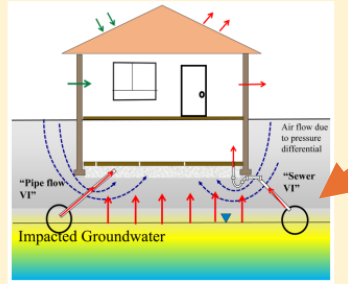
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Supporting Information

ABSTRACT: Vapor intrusion (VI) pathway assessment and data interpretation have been guided by an historical conceptual model in which vapors originating from contaminated soil or groundwater diffuse upward through soil and are swept into a building by soil gas flow induced by building underpressurization. Recent studies reveal that alternative VI pathways involving neighborhood sewers, land drains, and other major underground piping can also be significant VI contributors, even to buildings beyond the delineated footprint of soil and groundwater contamination. This work illustrates how controlled-pressure-method testing (CPM), soil gas sampling, and screening-level emissions calculations can be used to identify significant alternative VI pathways that might go undetected by conventional sampling under natural conditions at some sites. The combined utility of these tools is shown through data collected at a long-term study house, where a significant alternative VI pathway was discovered and altered so that it could be manipulated to be on or off. Data collected during periods of natural and CPM conditions show that the alternative pathway was significant, but its presence was not identifiable under natural conditions; it was identified under



Vapor Migration can be both Slow & Fast

- *Typically* **Slow** in the **Natural** environment
  - **Diffusion** (vertical & horizontal **permeability**)*

- *Typically* **Faster** in the human **'Built'** environment
  - **Advective / flow** (rate ruled by Bldg. **pressure** fields)**

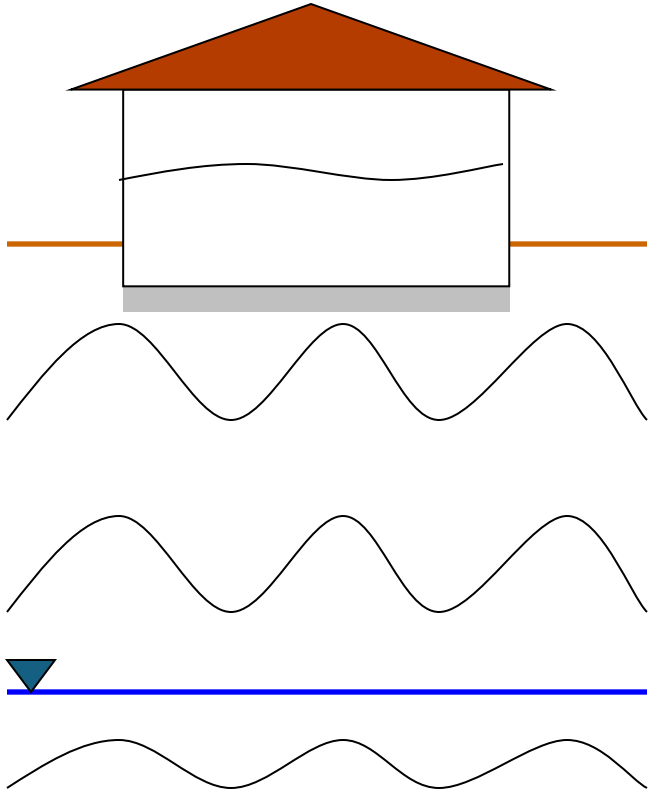
* Can be faster near **(3-5') ground surface** due to **barometric pressures**

** **Including** the reach of the **'capture zone'** of lower indoor pressures
Typically 3-6 ft (e.g., Rn) surrounding Buildings' subsurface boundaries
Infrequently / unpredictably episodically **'100s' ft** in preferential pathways such as **within &/or in bedding** of connected **conduits, sewers etc.**

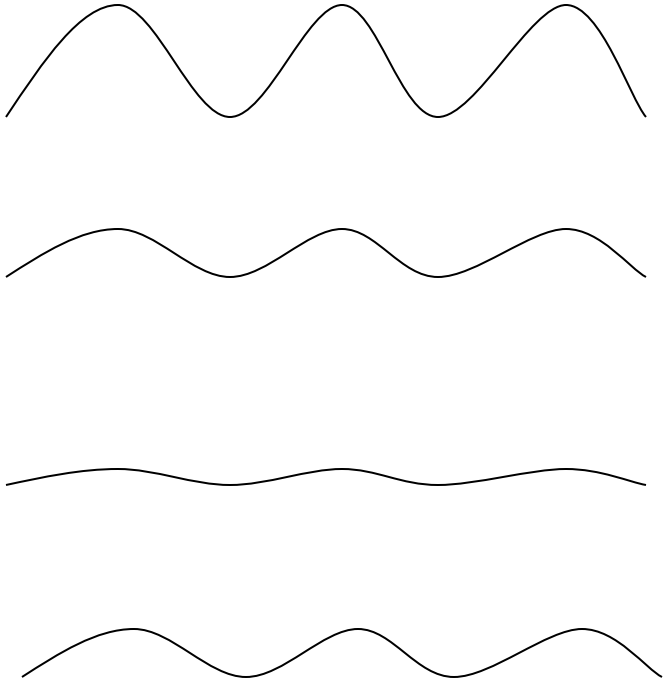
[*Use of Indoor Air Data for Vapor Intrusion Evaluations,* by David J. Folkes, PE, 20**06**]

1f) Conceptual Model [Variability Problem]

Spatial Variability



Temporal Variability



[20**26**]



[**Indoor Air – in 2026** we see:
Log-Normal Distribution
Rare **Hourly 1E^{x}** conc.
Changes but **Same**
~Seasonal/Qtrly Sampling]

[**Groundwater**
Normal 'Bell' Curve
~Seasonal ~3-10x) **conc. changes**
Seasonal/Qtrly **Sampling**]

How Expanding Successful Approaches for Groundwater can

(by including the **Vapor** phase)

Prevent **V**apor **I**ntrusion$_{GW}$*

Groundwater Forum – Monthly Call

Oct. 1, 2026

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Summary* - for improved **Pro**tection for VI_{GW}

- *Addressing* **V**apor **I**ntrusion ***in*** *the* **Natural** environment, i.e.,
  - ***Measuring*** *&* ***Controlling/Remediating*** **vapor contamination** in **Soil Gas**:
- Would be **More Protective**;
  a) **Simpler** to Assess (accurately)
  b) Less **Disruptive**
  c) More **Confident**/Predictive
  d) **Cost-Effective**
  e) **Broader** (community-wide)
  f) **Quicker** (reducing exposures sooner)
  g) **Longer lasting**
  h) More **Verifiable** (repeatedly) &
  i) Clearly-**Communicable** for the public (as convincingly **Pro**tected),
- **than** using a *few* **Indoor Air samples** in a *few* **Buildings** (w/n '**Built** Env.')

*Inspired by Lenny Siegel, Director of CPEO who is devoted to improving environmental communication

Addressing **V**apor **I**ntrusion ***in*** *the* **Natural** environment, **would be More: PROTECTIVE**

- As shown in the earlier **Conceptual Model** of VI
  - We are currently (& have for >25 years)
  - **ASSESSING** (Sampling for) **VI** in **Indoor Air**
    - IA = location of ~**most variable conc.** (**>10^3**)) & we are Now **Recognizing:**
  - ***Measuring (& Controlling/Remediating)*** *vapor* **contamination** in
- **Natural subsurface environment (soil gas) would be More:**
  - **PROTECTIVE of Human Health & the Environment**

    & better Meet:
- **USEPA Framework:**
- **Pillar 1**: "**Clean Air, Land, and Water* for Every American**"

*for VI_{GW} Ground Water (GW) that is the source of Vapors in Soil Gas (& **part of a GW cleanup**)

a) **Simpler** to Assess **Soil Gas** conc. (in Nature) (accurately; than in Indoor Air)

- We've Successfully **Assessed Groundwater** contamination Risks
  - Using **Samples from Groundwater** collected over **frequency** appropriate for its Variability of contaminant conc.
    - **Normal**ly-distributed (**bell curve**) w/ typically **~3x** conc. variations
  - On an **On-going basis** (~seasonally, as needed) to monitor/ensure/**show**
  - Contamination is **Away**/**NOT entering** the human **Built** environment (**water wells**)
    - **Where human exposure** is **expected / un-avoidable**
- We **Could** **Assess Soil Gas** contamination **Risks** for **VI**
  - Using **Samples** from **Soil Gas** collected over appropriate **Frequency**,
- ***But:*** **Don't now, enough** to **show VI is *Not* entering Built Environ.**
  - **To prevent Intrusion during infrequent peak 'sweeping' events**

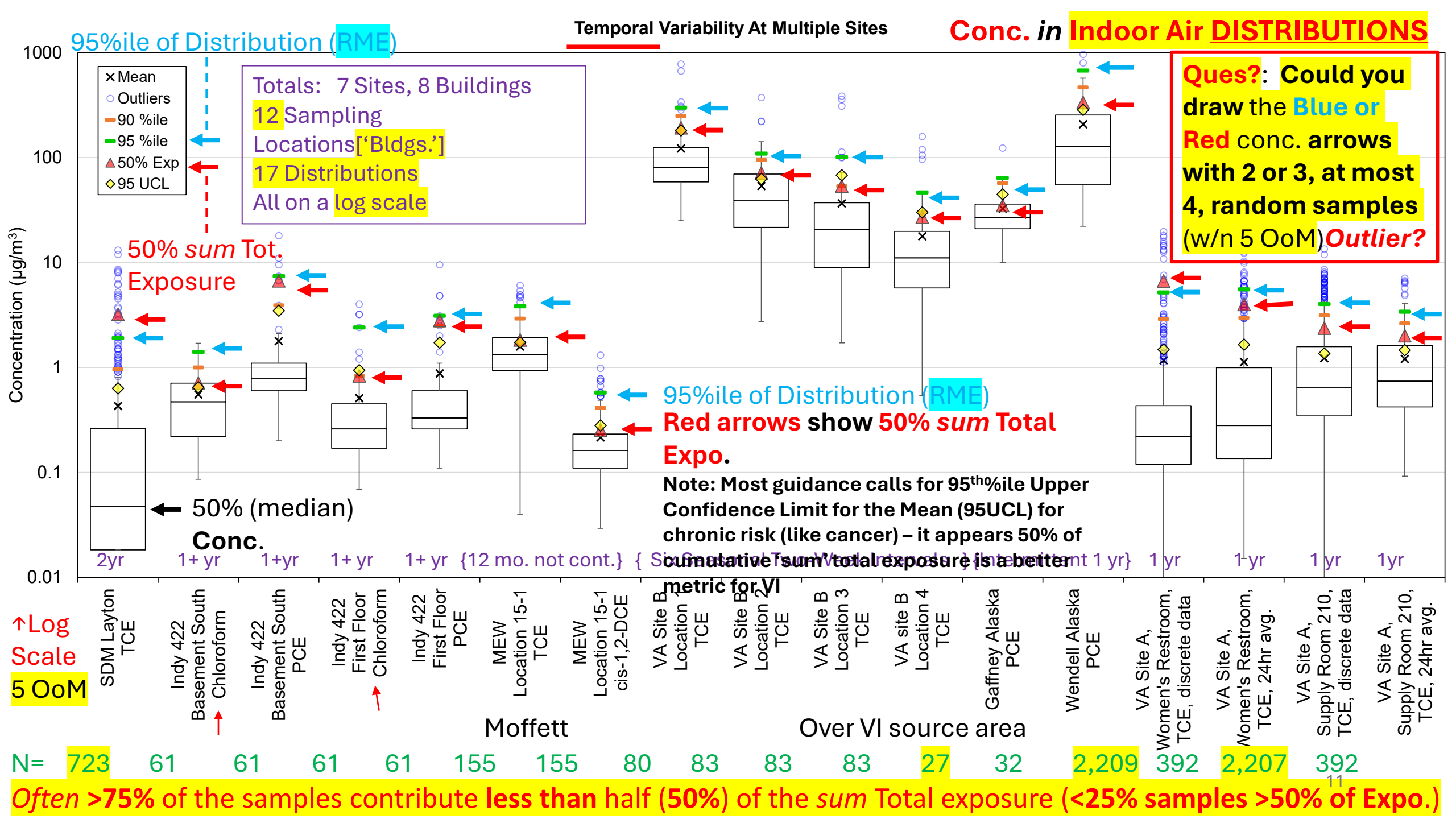
b) **Less Disruptive:** In **Natural** environment Using Soil Gas *Sampling/Control/Remediation*

- **Access** to indoor (often **personal) spaces** (for **IA samples**) is:
  - **Disruptive** to occupants (personal life-styles, schedules, etc.)
  - **Lengthy & expensive permission** for **Access** process
  - Scheduling **actual visits** within Occupants **daily schedules**
  - Need to **Remove all products** and **materials** that could contribute **cVOCs**
  - **Needs to be BUILDING specific ~impossible to include all 'at risk'**
- Active or Passive Soil Gas **sampling, controls and remediation** could be largely implemented within **public right-of-way** areas to make accessible **many properties** with local approvals

c) **More Confident**/Predictive Assessments

- **Soil Gas** sampling – In **Natural** environment
  - (beyond human-Built 'Capture Zones')
- With **on-going** (e.g., **Qtrly**) monitoring for the **Nature, Extent** & **Rate** (& Direction) of **Migration** of vapor Contamination

- Can be completed with a **higher level of confidence** *than*:
  - A few (2-4) day-long indoor air samples spread over a few months to a year for an Indoor (**chaotic zone**) Air sampling Assessment
    - Where vapor conc. are most unpredictable & infrequently but OoM higher conc.
      - & Which evidence shows to produces
    - Relatively **low level of confidence of ~<50% ~ 'flip of a coin'**


Temporal Variability At Multiple Sites
Conc. in Indoor Air DISTRIBUTIONS
95%ile of Distribution (RME)
Mean
Outliers
90 %ile
95 %ile
50% Exp
95 UCL
Totals: 7 Sites, 8 Buildings
12 Sampling Locations['Bldgs.']
17 Distributions
All on a log scale
Ques?: Could you draw the Blue or Red conc. arrows with 2 or 3, at most 4, random samples (w/n 5 OoM) Outlier?
50% sum Tot. Exposure
95%ile of Distribution (RME)
Red arrows show 50% sum Total Expo.
Note: Most guidance calls for 95th%ile Upper Confidence Limit for the Mean (95UCL) for chronic risk (like cancer) – it appears 50% of cumulative sum total exposure is a better metric for VI
50% (median) Conc.
Concentration (µg/m³)
1000
100
10
1
0.1
0.01
↑Log Scale
5 OoM
2yr
1+ yr
1+yr
1+ yr
1+ yr
{12 mo. not cont.}
{ Six Seasonal Four Week Intervals }
{Intermittent 1 yr}
1 yr
1 yr
1 yr
1yr
SDM Layton TCE
Indy 422 Basement South Chloroform
Indy 422 Basement South PCE
Indy 422 First Floor Chloroform
Indy 422 First Floor PCE
MEW Location 15-1 TCE
MEW Location 15-1 cis-1,2-DCE
VA Site B Location 1 TCE
VA Site B Location 2 TCE
VA Site B Location 3 TCE
VA site B Location 4 TCE
Gaffney Alaska PCE
Wendell Alaska PCE
VA Site A, Women's Restroom, TCE, discrete data
VA Site A, Women's Restroom, TCE, 24hr avg.
VA Site A, Supply Room 210, TCE, discrete data
VA Site A, Supply Room 210, TCE, 24hr avg.
Moffett
Over VI source area
N= 723 61 61 61 61 155 155 80 83 83 83 27 32 2,209 392 2,207 392
Often >75% of the samples contribute less than half (50%) of the sum Total exposure (<25% samples >50% of Expo.)
11

d1) **Cost-Effective Assessing** Vapor Contamination **In** or **Near** *Individual* Buildings is:

- ***Not*** Cost Effective
- **$20-$60k** per Bldg. **for just IA Sampling**
  - ***If*** you get **ACCESS**
  - & ***If*** you **ONLY** consider the **Maximum Conc**. out of four, you get: **Probability of Accuracy** is **~< the 'flip of a coin'** (~50%)
  - Surrounding Bldgs. not getting Mitigation have ~>50 chance of un-detected Un-acceptable VI, due to Not:
    - Being sampled at all
    - Being sampled at the Time when VI was turned on.

Testing '**ACCURACY**' of Current Indoor Sampling/**Bldg**.

In One-bldg. *studies* (No Spatial variability), i.e., Only **Temporal** variability *with* ***&*** *w/o* continuous ***Indicators & Tracers*** (**I&T**) guiding IA sampling times

- Ranking Effectiveness of different Sample Scheduling strategies[1]

'Accuracy'

Goals of sampling = Using single **Max. conc. # from 4** samples[2]

	90th %ile dist. Short-term	50th%ile of total expo.[3] Long-term	**Summary**
• **Low** radon (Rn), Tracer, **Do NOT** sample **Now**	19%	32%	Lowest[4]
• **Random** [commonly used method]	**35%**	**48%**	**Low**[5]
• Seasonal (**ONLY** **winter**/heating) – '*wait for it*'	67%	84%	Better
• I&T (**Rn**) guided times (**any** season)	65%	86%	Better
• I&T (**Rn**) guided and (ONLY in **winter**/heating)[6]	**89%**	**98%**	**Best**

Flip of a Coin 50%

[1] Ranking **simplified** ~results of sampling in 12 bldgs./zones in Fig. 2 & 3 **Lutes et al**. (*Sample Scheduling* …) subm. for pub.

[2] Using max. not in explicit in most guidance (but RAGS), typically too few samples to calculate 95UCL, so **common?**

[3] Used in instead of 95UCL of Mean in our study, since better for VI, but Not in guidance, so how common?

[4] Two-edged sword – un-RP could use to **avoid detection of VI** (recommend occupants be aware of/monitor their bldg. Rn)

[5] Majority of cases provides ***mis-information*** reporting '**all safe**' when they are **Not**

[6] P Due to longer pathway from source of VOC needing sustained period of high intrusion relative to nearby Rn Can do better w/ ITS-timed

d-2) **Addressing/Mitigating** Vapor Contamination **In** or **Near** *individual* Buildings is: **Not Cost Effective**

- **If** an unacceptable problem ***happened*** to be detected**:**
- **A Bldg.-specific response could be Effective for that Bldg.**

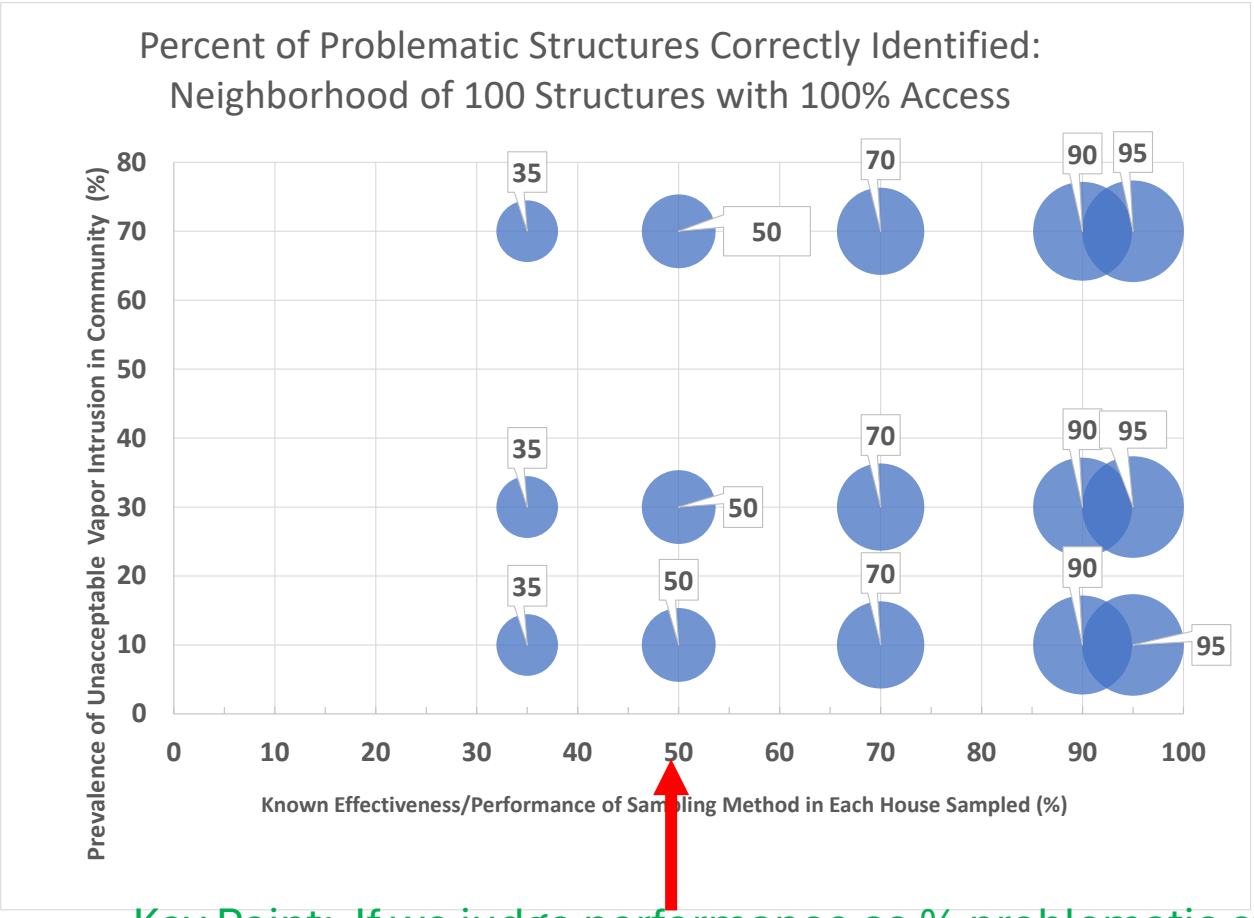
- **But is likely to be similarly:**

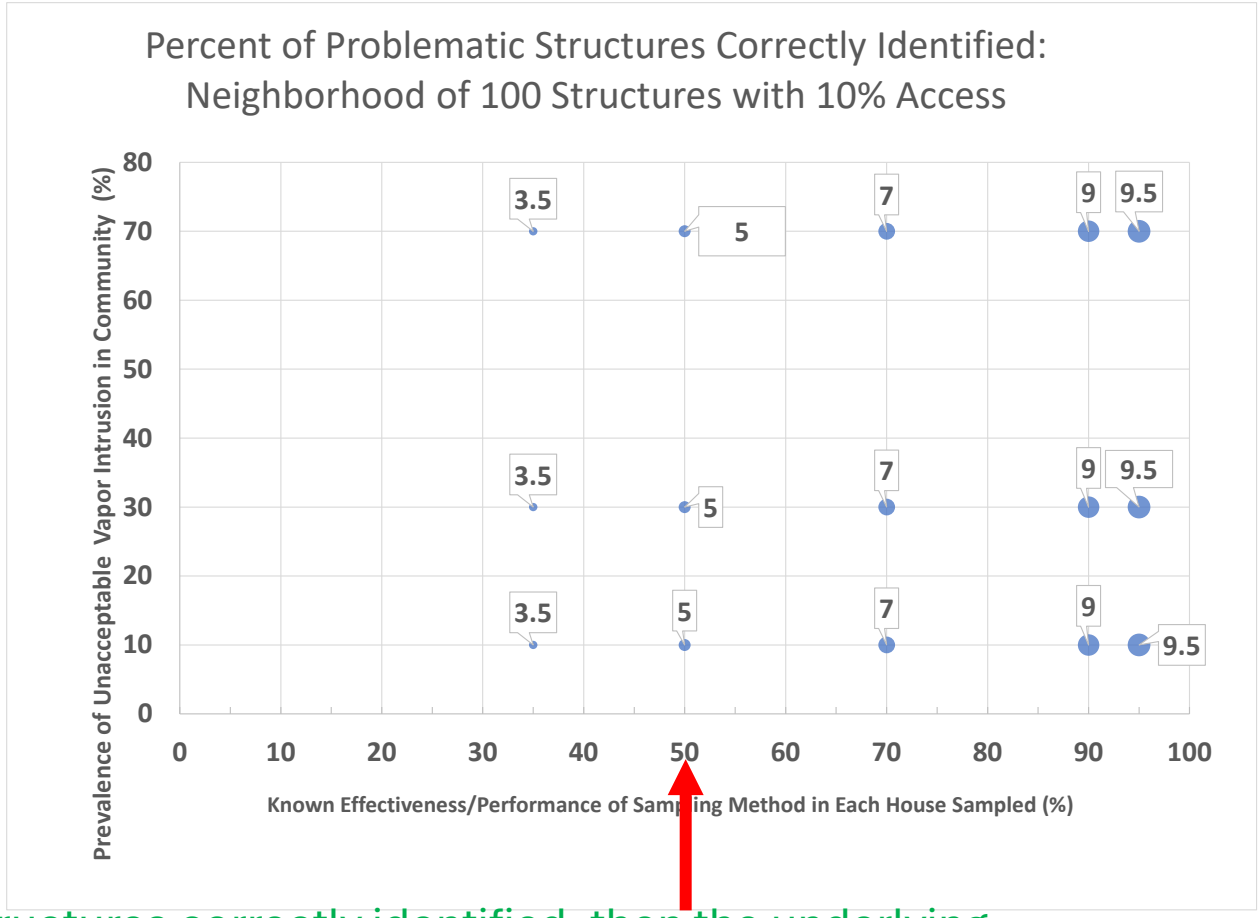
  - ***Not*** **Cost Effective** **overall** given that many other nearby Bldgs. maybe similarly impacted on other days & these would get no protection, &
  - Furthermore, the **'Mitigation' costs** to prevent single digit ug/m^3 conc. can be **$10-$40k** *or more* **per Bldg**., e.g., if structural repairs are needed

Percent of Problematic Structures Correctly Identified:

Combined #1) Sample **Accuracy** & #2) the amount of **Access**

100% Access *vs.* **10% ACCESS**





Key Point: If we judge performance as % problematic structures correctly identified, then the underlying prevalence is controlled for, and in Summary, the Overall **Performance** is **PRIMARILY** limited by **ACCESS**, and *secondarily* by Sampling strategy performance.

e) **Broader** (community-wide)

- **As mentioned above Soil Gas sampling in public right-of-way** areas can make **accessible many properties**
- **and like our successful methods used for GW contamination,**
- **We can Assess**
  - **The entire plume of contamination for possible exposures**

- **Providing *much Broader* community-wide benefits than ever**
  - **Possible via:**
- **“**a ***few*** **Indoor Air samples** in a ***few*** **Buildings”**

f) **Quicker** (reducing exposures sooner)

- As discussed above,
  - **Gaining Access**, for **IA sampling** is a **Lengthy** process (per bldg.)
    - &
  - Accessing ***all*** individual **Bldgs**. (at risk of VI) is unlikely or **VERY *LENGTHY***
  - **Realistic time limits & limited access permissions, e.g., 10%, can severely limit the meaningfulness of indoor air sampling**
    - **Providing minimal protection, e.g., 5%* probabilities & thus ~not useful**
- **Soil Gas sampling/controls/remediation** can often be **implemented faster and more** clearly show **protection by maintaining a 'clean buffer zone' preventing unacceptable exposures**

* Note this value (**5%**) is the **OPPOSITE** of the typical **95%** Confidence level we use for GW protection

g) **Longer Lasting** - Protection

- The limited **Duration** of **typical** **Assessments** limits the
  - **Duration of Protection**
- There are too **many variables** in each of the **Natural & Built** environments and given they also **interact**, there is **little** about VI that remains **constant over time**,
- **Indoor Air** Sample based **Assessments** that rarely last more than
  - A **few months to one year** – even if fully accurately for that period …
  - Are unlikely to remain equally valid over time as numerous variables:
  - Extent their range beyond that exhibited in the assessment
- Soil gas sampling can and should be on-going for lasting protection

h) **Verifiable** (effectively ‘continuously’)

- **On-going monitoring** of vapor **conc. in soil gas** that can **demonstrate a ‘safe’ buffer between hazardous levels** of vapor **&** human occupied **Built environments** (where human exposures to contaminated air is unavoidable) can be effectively **‘continuous’**
- Because contaminant **vapors migrate slowly** by **diffusion** in soil gas within the **Natural environment**, the **frequency of sampling** to **verify that un-acceptable conc. of vapors are Not** moving into **the reach of advective sweeping flow** in the **‘capture zone’ of the Built** environment, can be **‘continuously’** verified by on-going, reasonable, affordable, & practical **~quarterly** soil gas monitoring

i) **Clearly-Communicable** (Protection)

- Regulators with monitoring-based **knowledge of the extent** of **slow-moving/diffusing vapor** contamination **being a 'safe' distance from** the **reach of** infrequent but **highly sweeping advective flow** along/in the human Built environments, including subsurface structures;
- **Can clearly communicate the Protection provided** by this 'safe buffer' zone to Prevent their exposure to vapor contamination
- The public is familiar with protection provided by a 'safe separation/buffer distance' from contamination, e.g., in groundwater and from other hazards

- Protection needs to consider inevitable preferential pathways for vapor flow along the subsurface disturbances outside of buried structures/piping as well as within buried structures/pipes/conduits etc. that commonly lead directly to each and every individual Building, of an impacted community

Summary* - for improved ***Environmental*** Protection

- *Addressing* (***Detecting*** & ***Controlling/Remediating***) Vapor contamination, from Groundwater, **as close to the Groundwater source as possible** (i.e., at least *with**in** the* **Natural** environment);
- Would be **More Protective**;
  - Simpler to Assess (accurately)
  - Less Disruptive
  - Cost-Effective
  - Broader (community-wide)
  - Quicker (reducing exposures sooner)
  - Longer lasting
  - Verifiable (repeatedly) &
  - Clearly-Communicable for the public (as convincingly protected),
- ***than*** using a *few* **Indoor Air samples** in a *few* **Buildings** (w/n '**Built** Env.')

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QUESTIONS and/or COMMENTS?

- Are Welcome Now or Later
- Thank You

- Potential next focus area – **Cost-Effectiveness**
  - IA Assessment vs. Vapor Remediation (incl. health effects avoided)
  - e.g., Lybarger et al., ___ for Dissolved phase contamination