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

The Case for: **Addressing Vapor Contamination in the Natural Environment**

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RTI INTERNATIONAL Jacobs AEHS Foundation GSI ENVIRONMENTAL PRAXIS ENVIRONMENTAL TECH. INC

Outline

1) **Background** – Over >30 years we've learned VI is a real Challenge
   - **VI exposure pathway** is **Long**, **Complex** and **Highly Variable**

2) **Sampling for indoor E**xposure **P**oint **C**oncentrations **(EPC)**
   - We've **Tried in ~Every Way** (***Not*** yet **Cost-Effective**)

3) **How we Could do Better**
   - **Control Vapor Migration** within the **Natural Environment**
     - **Verify effectiveness in the Natural Environment (in soil gas)**
     - More **Cost-Effectively*** than Current (indoor air sampling-based) Approaches

* Improved **Effectiveness** (**pro**tection) & lower **Cost** (& Implementability) are the primary subjects of our current research including this Workshop (in our goal of higher Cost-Effectiveness)

1)
Background for – The VI Challenge

- In the* 'Beginning'
  - GPRA, MaDEP & Colo. DPH&E
  - Industry (& Reg.) input & Exposure-Principals of Public Health
    - Vapor is a **Temporary** problem - (Dilution is solution)
    - Needs to be (can only) be **Modeled**
    - Unacceptable **Conc**. at Exposure Pt. Needs to be **Proven** in **Each Building** (Bldg.) **before any responses**
- Traditions Developed – RCRA (2001), OSWER Draft (2002), OLEM Final (2015) + __
  - **GW-like:** Seasonal (but **Expo. Point Conc.**) sampling (2 – 4 per year)/Bldg. & __% of Bldgs. (representing others)
  - **Un-like GW**: One-'time' Exposure Point Conc. sampling for ~permanent 'walk away' Decisions
    - & ~**No Nature, Extent or Rate of Migration** of (vapor) contamination
- What we know Now
  - 1986 **R**CRA **F**acility **I**nvestigation (RFI) Guide & earlier Guidance addressed Vapor (*somewhat*)
  - Vapor is **Not Temporary** – On-Going as long as vapor-forming (e.g., cVOCs**) in e.g., GW
  - **Can Not** be accurately **Modeled** OR **Cost-Effectively Sampled** (at Expo. Pt.)
  - In-effective Sampling does NOT provide Protection of Human Health & allows un-acceptable Expo. & Disease
- How we Could do Better
  - Studying **Cost & Effectiveness** of our current approaches – Today's **Workshop**
    - Incl. approaches **more similar to** what *made* **GW approaches** so **Successful**

* In my perspective/experience; **& new recalcitrant vapor-forming contaminants, e.g., some PFAS etc. …

Vapor Intrusion Protection Cost-Effectiveness Simulation Tool (2.0)

Part 3) The focus of this Introduction*

- 3) a test scenario where an approach similar to that typically used for addressing ***dissolved*** groundwater contamination is used and begins with an assumed well-defined CVOC-contaminated groundwater (GW) dissolved-phase plume extent that is stable (i.e., no longer expanding) and the use of **physical/engineering approaches to control the migration and extent of the associated *vapor*-plume** to **keep** unacceptable vapor concentrations **outside of** estimated generic, or community-specific vapor 'capture zones' surrounding occupied buildings, as well as any connected conduits/preferential pathways [aka **HBE**].

*Some of the topics we are trying to quantitively simulate & study

Goal: EPA's "Core Mission"*

- "the [EPA] agency's **core mission**
  - of
  - **protecting human health** and the environment."*
- My Opinion
- **Implies** inclusion of ***all*** "uncontrolled" **contamination**
  - causing exposures with risks for human health
- **Not** discounting **some forms** of contamination
  - Especially, if the form/phase is **equally,** or even **more toxic**, than typically addressed
    - That is
- Being *as* **Protective** for **Vapor Phase** as we are for **Dissolved Phase** contam.

* OMB spokesperson in Oct. 10, 2025 article

Overview
Recipe for **Extending** Vapor Intrusion **Exposures**

- Use **Indoor Air** (Exposure Point Conc.) as **THE metric**; & thus:
  - Allow **Un-natural** (& **Un-predictable**) **Attenuation** in **H**uman **B**uilt **E**nviron.
  - Use **easy-to-collect Indoor Air** samples (‘**random**’ over **Space & Time**) in:
    - **Few** ‘friendly’ **Access**ible Buildings (w/o recognition of how #/% limits representativeness)
    - **Few** (2-4) **short time**-period (e.g., 24 hr.) indoor air **samples** (~1%/yr. (0.05% Expo. Period))
      - i.e., Not Continuous sampling (e.g., **Not** even One month or season of One year)
  - Use few ‘random’ **indoor air** results for **site-wide** long lasting/**forever decisions**
    - & develop (*easy-to-observe*) empirical Attenuation Factors – that can **under-estimate** VI*

*At other/more sites

Overview

Recipe for **Stopping/Preventing** VI **Exposures**

- **Don't** Use **Indoor Air** (Exposure Point Conc.) as **THE metric**;
  - **Control migration** of cVOCs in soil gas to **Keep it Out** of the **H**uman **B**uilt **E**nviron.
    - **Don't** Allow **Un-natural** (& **Un-predictable**) **Attenuation** in **H**uman **B**uilt **E**nviron.
  - **Avoid Un-natural** (& **Un-predictable**) **Attenuation** in **H**uman **B**uilt **E**nviron.
    - **Don't USE** easy-to-collect **Indoor Air** samples (~'**random**' over **Space & Time**) in:
  - **USE** ~easier-to-collect **Soil Gas** samples for full **Extent** of cVOCs over **Space & Time** (in nature)
    - **Don't USE Few** easily **Access**ible Buildings (w/o recognition of how # limits accuracy
  - **Use** samples **of Contaminated Media** to determine *full* **Extent & Rate** of **Migration** of **contam**.
    - **Don't USE Few** (2-4) **short time**-period (e.g., 24 hr.) indoor air **samples** (~1%/yr. (0.05% Expo. Period))
      - i.e., Not Continuous sampling (e.g., Not even One season of One year)
  - **USE Soil Gas - ~Seasonally of each Year** cVOC remains, at least starting & on as needed
    - **Using** exposure-**risk-based conc. to define extent** of contamination In **natural** environment
- **USE** rotating **voluntary** Continuous (intervals) or ITS-**Timed Indoor Air** samples to
  - **Verify** effectiveness/**Protection** (during periods of expected high intrusion)
- For *site-wide responses* providing cost-effective & *verifiable* **Protection**

Definition – for today's discussion

- Natural Attenuation is defined as occurring in the Natural Environ.
- '***Un***-Natural' Attenuation is defined as;
- Attenuation of contamination within:
  - Human-**modified** (natural/native) subsurface materials and/or
  - Human-**made conduits** leading to,
    - **Or Directly Entering into** and attenuating within,
- Human-**Built (occupiable) Environments**
  - That were **designed for human use**, occupation and other activities,
  - i.e., ***Not*** including, being designed or permitted for, the **dilution and/or treatment** of other's **uncontrolled chemical waste releases**

Reminder of **Goals** for today's Workshop

- Better understanding of how to [*more* **cost-effectively**] manage vapor intrusion risks
- Specific goals for improved VI risk assessment & management
  - **Prevent unacceptable exposures** to hazardous waste vapors intruding into the community's indoor air
    - which can be **unavoidable** for occupants,
  - **with confidence, ASAP & lasting until the GW-cVOC cleanup is completed**;
  - **And w/o unnecessary disruptions** to the **lives/lifestyles** of the **Community**, e.g., elevated **health concerns**/fears, or other social and/or **financial impacts** (e.g., perceived **loss of value** of their property) for community owners and/or occupants;

Optimizing Cost-Effectiveness* of Cleanups (Health Protection) Time implications for Costs

- **Conceptual** estimates for Cleanup Costs ($)
  - **Preventing** a release $1 K
  - **Quickly stopped** release & **quick cleanup** $10 K – 100 K
  - **Moderately-**quickly **stopped** release & moderately-quick **cleanup** $1,000 K (1M)

  - **('Legacy' site)** years late to stop release & **fast** cleanup $10 Million
  - " " " " " " **slow** " $100 M
  - " " " " **~No control** (e.g., of **vapor media**)** $1+ Billion

* **Critical to RCRA** as (only) **polluter pays** for cleanups & government ensures effectiveness & public 'costs' are minimized

(incl. medical **health effects, lost work costs paid for by public or RP (gen. w/o pain & etc.)

Background:
In the Beginning, it was believed …

- Vapors could **Not** be a **problem** risk
  - **Because they quickly disperse away (& can't be a problem that long)**

  - Thus, **before** we RPs take this **seriously**
  - Regulators would **Need to Prove:**
    - The pathway is **Complete** (e.g., it is ***not*** from **indoor sources**)
    - Can cause **Unacceptable** exposures
    - Can cause **Health Impacts**

Summary closeout for underlying Myth 1: Vapors are **only a temporary issue**, as they disperse quickly w/o exposure issues

- However,
- As long as recalcitrant volatiles (e.g., chlorinated VOCs) **remain in groundwater** (as they have for many (**~6) decades** so far) they **will continue to partition/volatilize** into **overlying soil gas**
- And, **as long as these vapors are allowed to enter** human-*modified* **natural** environments **leading to (&/or directly into) human-*built*** environments their concentrations undergo
- ***un*-Monitorable,** (*un*-Predictable) **& un-Natural A**ttenuation
- (**un^2-MNA**) within the **HBE** prior to their **inhalation by occupants**

Addressing Myth 2
We Now Know

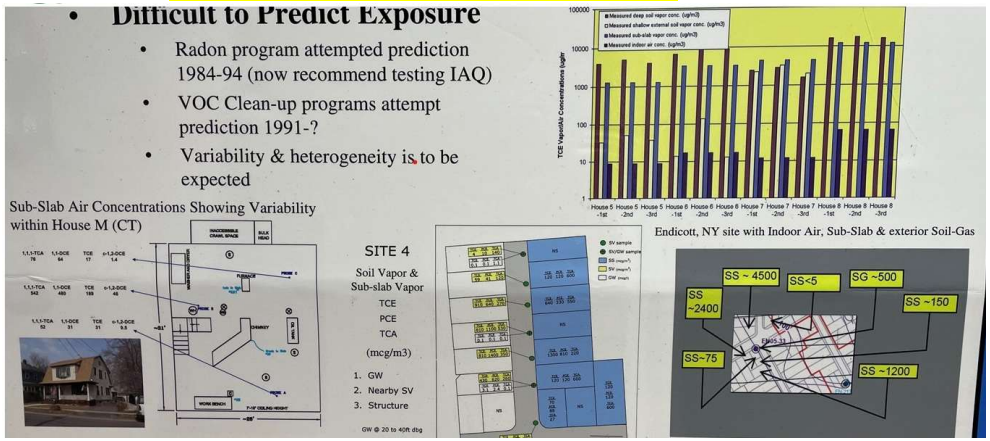
- Vapors **can** present a risk
  - They **don't always** quickly disperse away
    - & *Current* sources* of vapors will be here for many Decades (e.g., from cVOCs in GW)
  - **R**esponsible **P**arties **should take this seriously** – Because:
    - **Regulators/Researchers have shown:**
    - The pathway **can be 'complete'** (from release to inhalation exposure, **not** Backgrnd)
    - Can cause **unacceptable** exposures
    - Can cause **health impacts –** Some **Statistically Significant >95% Confident**

      - **Assessment** using samples with the **Confidence** of 'flipping a Coin' (**~50-50**)
      - But if the # of **Health impacts** observed were only **94% confident** the illness is '**thrown out**' as not causally related to the exposures

*New vapor forming chemicals are being made (e.g., some volatile PFAS, + …)

RP concerns for **Bldg.-Specific** Variation **were Valid** – as shown in (my) 2005 Poster

- >10x variation in **S**ub-**S**lab (**SS) conc.** across ~10 ft of small house (CT 1999-2000)
- >10x variation in **SS conc.** across adjacent homes (NY, 2000-03)
- 75-4500 ug/m3 in **SS conc.** adjacent row homes (**Endicott**, NY, ~2003)
- **Shallow *external* S**oil **G**as is *poorly* related to indoor **conc.*** (NY ~03)
- Groundwater is ***very poorly*** related to indoor air conc. (across US)



*__SS__ only somewhat better,
but indoor are from 'random' times

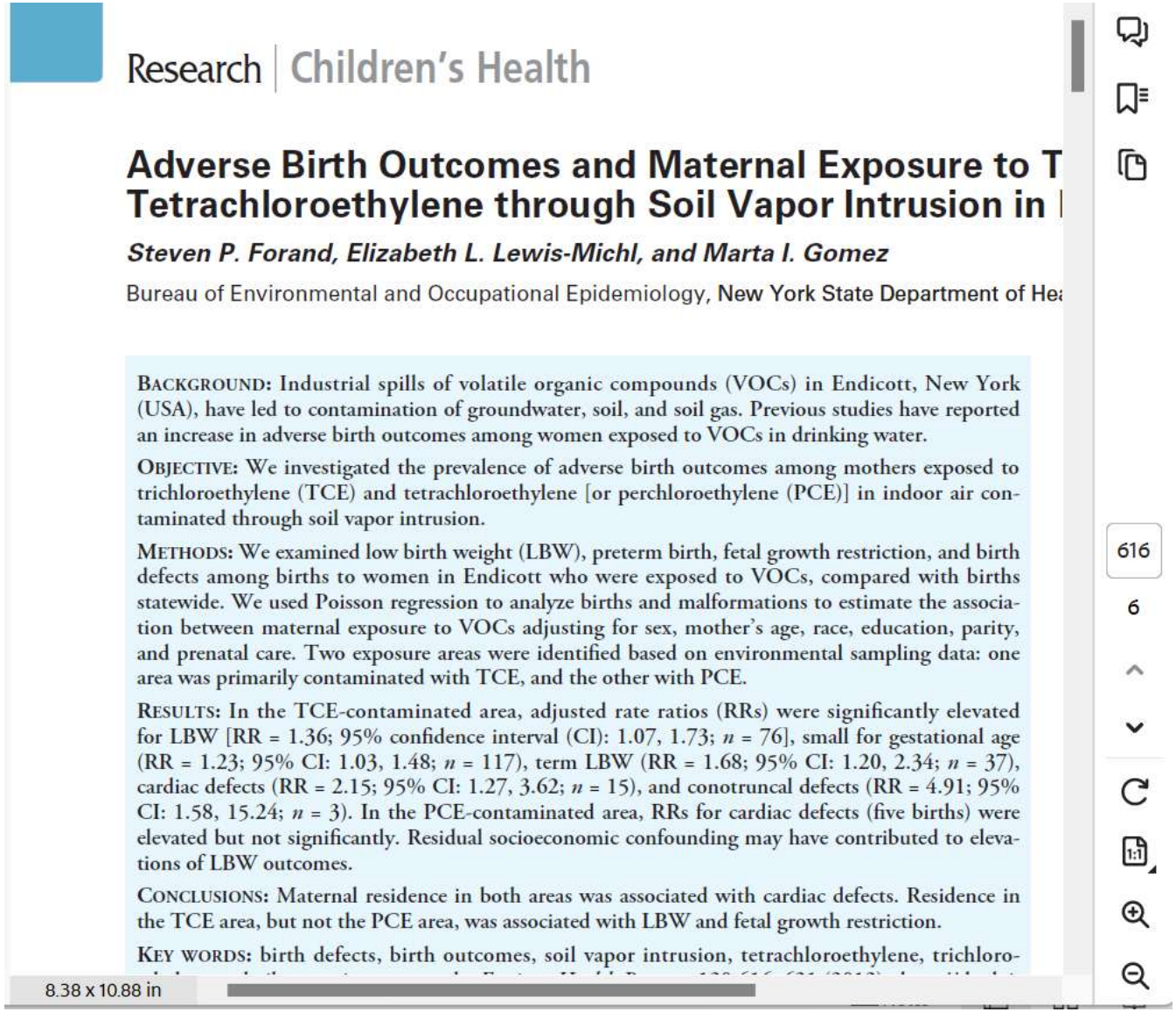
2012

~1000 births in 10 yrs (VI exposed)
~250 birth defects/effects (~~1/4)

~5x increase in **fetal heart valve** defects

Also:

Separate Paper Several Adult **Cancer** effects assoc. w/ TCE statistically elevate**d**



Research | Children's Health

Adverse Birth Outcomes and Maternal Exposure to T Tetrachloroethylene through Soil Vapor Intrusion in

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Bureau of Environmental and Occupational Epidemiology, New York State Department of Hea

BACKGROUND: Industrial spills of volatile organic compounds (VOCs) in Endicott, New York (USA), have led to contamination of groundwater, soil, and soil gas. Previous studies have reported an increase in adverse birth outcomes among women exposed to VOCs in drinking water.

OBJECTIVE: We investigated the prevalence of adverse birth outcomes among mothers exposed to trichloroethylene (TCE) and tetrachloroethylene [or perchloroethylene (PCE)] in indoor air contaminated through soil vapor intrusion.

METHODS: We examined low birth weight (LBW), preterm birth, fetal growth restriction, and birth defects among births to women in Endicott who were exposed to VOCs, compared with births statewide. We used Poisson regression to analyze births and malformations to estimate the association between maternal exposure to VOCs adjusting for sex, mother's age, race, education, parity, and prenatal care. Two exposure areas were identified based on environmental sampling data: one area was primarily contaminated with TCE, and the other with PCE.

RESULTS: In the TCE-contaminated area, adjusted rate ratios (RRs) were significantly elevated for LBW [RR = 1.36; 95% confidence interval (CI): 1.07, 1.73; n = 76], small for gestational age (RR = 1.23; 95% CI: 1.03, 1.48; n = 117), term LBW (RR = 1.68; 95% CI: 1.20, 2.34; n = 37), cardiac defects (RR = 2.15; 95% CI: 1.27, 3.62; n = 15), and conotruncal defects (RR = 4.91; 95% CI: 1.58, 15.24; n = 3). In the PCE-contaminated area, RRs for cardiac defects (five births) were elevated but not significantly. Residual socioeconomic confounding may have contributed to elevations of LBW outcomes.

CONCLUSIONS: Maternal residence in both areas was associated with cardiac defects. Residence in the TCE area, but not the PCE area, was associated with LBW and fetal growth restriction.

KEY WORDS: birth defects, birth outcomes, soil vapor intrusion, tetrachloroethylene, trichloro-

616

6

8.38 x 10.88 in

We now Know VI varies over **Space & Time** **Combined** Effects ~*often* finding **No Exposure**

- VI exposures are Building (**Bldg.**)**-specific**
  - (**Room-specific**, but we should be following the Rn 'worst' room policy)
- *'Funder' response: Exposures should be assumed to be Acceptable until **proven** Not to be, **in each Bldg**.*
  - *Lack of Knowledge – Defaults to **No Exposure** Problem*
- VI exposures **vary** episodically **over Time** (by **10x – 1000x**)
- *'Funder' response: Exposures should be assumed to be Acceptable (forever more), unless **proven** Not acceptable,* in the few ***2 – 4 days**** *sampled (~**1%** of yr & **0.05%** of exposure period)*
  - *Default of Ignorance means Not detecting, i.e., No Exposure Problem*

*Typical few (2 – 4) random/calendar 24 hr. grab samples

Indoor Air Samples are Effective (for some scenarios)

- A Single grab ('proper') indoor air sample can detect 100% of **Continuously Unacceptable** indoor air conditions (very rare)

- **Two** to **Four** typically-collected indoor air samples can be expected to often detect **Frequently Unacceptable** indoor air conditions (rare)

- However, evidence from **Continuous** Indoor Air Monitoring **shows**:
  - **Most** VI-conc. are **NOT** **Continuously** or **Frequently Un-acceptable** &
    - **Two** to **Four** typically-collected indoor air samples **can be expected to**
    - **Fail to Detect Most VI** exposures (***If*** e.g., **90%** of **exposure** occurred in only **10% of time**)

2)

Sampling for **E**xposure **P**oint **C**onc.

However, evidence from **Continuous** Indoor Air Monitoring **shows**:

- **Most** VI-caused conc. are **NOT Continuously** or **Frequently Un-acceptable**
- But the 'typical' peak-driven **log-normal distributions** of conc. can cause ***Un-acceptable*** **Short-term** risks (e.g., developmental, birth and childhood risks)
- **AND also** ***Un-acceptable*** **Long-term average** exposures (for **Chronic** risks e.g., cancers, nerve & organ function, etc.).

If the vapor intrusion investigation is complete, the review of the data must be made to determine whether some form of remedial action is appropriate at the site. Step 13 is the final decision point in the assessment of the vapor intrusion pathway. The investigator must reach a conclusion on the status of the site—no further action, additional monitoring, or mitigation. This decision is often left to the regulatory agency. Mitigation is discussed further in Chapter 4.

4. REMEDIATION

Remediation of vapor intrusion impacts may be required when the results of the site investigation phase (Chapter 3) indicates that indoor air concentrations of volatile compounds exceed screening levels in existing buildings or are likely to exceed screening levels in future buildings. When remedial action is required, a remedy or combination of remedies must be selected, implemented, operated, maintained, and/or monitored to control vapor intrusion until the source of the vapors is eliminated.

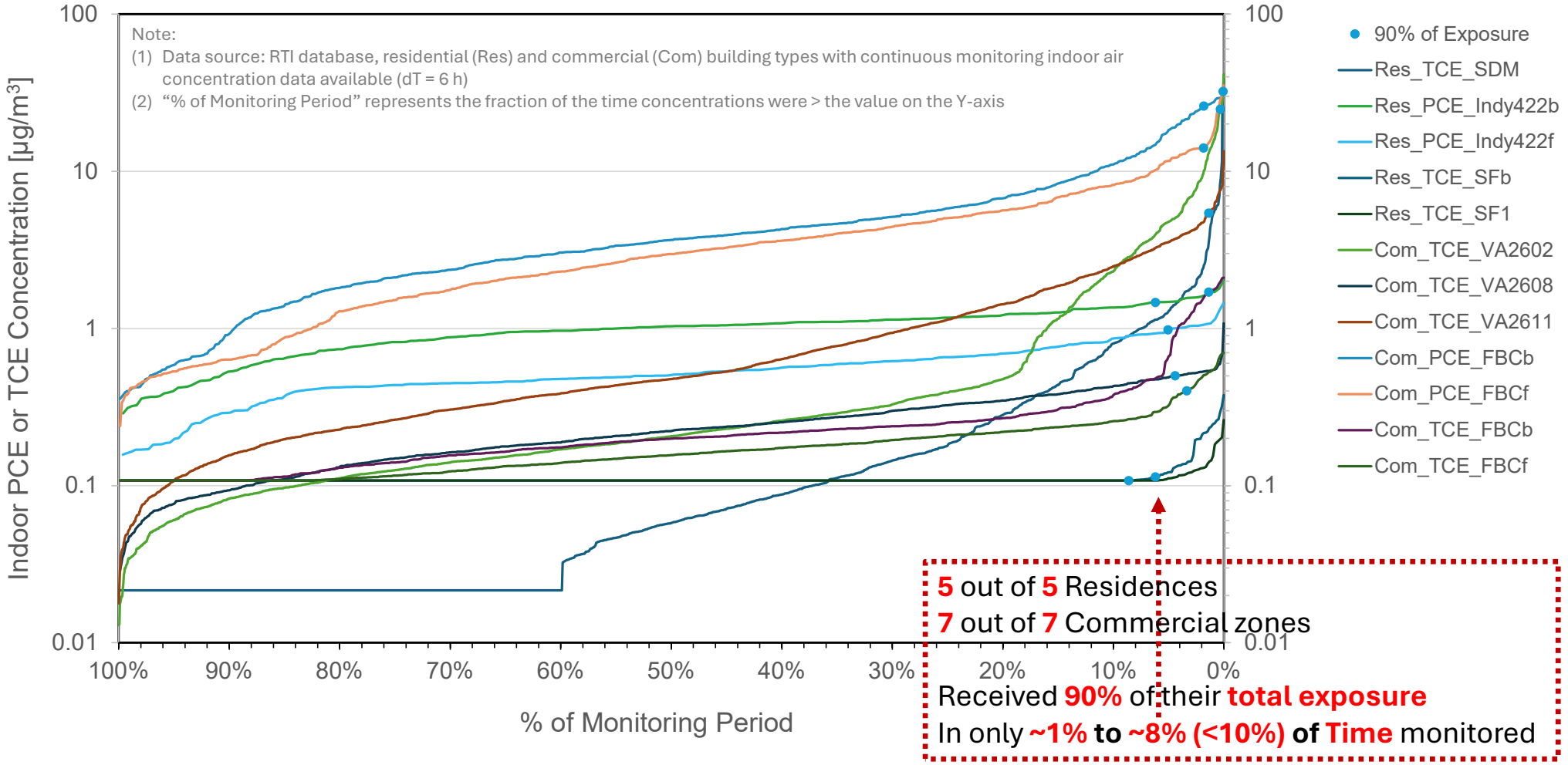
- We spent about 15 years ~only collecting (GW-like):
  - Short-duration of TIME (1-day) convenient (~randomly-timed) samples from
    - Presumed more exposed/susceptible bldgs. across SPACE
  - For a few to four Seasonal samples
  - To represent VI exposures in that Bldg.
    - & __#__ Un-sampled nearby Bldgs.
  - For ~all future time

However, evidence from ~>2015 **Continuous** Indoor Air Monitoring **shows**:

- **Most** VI-caused conc. are **NOT Continuously** or **Frequently** **Un-acceptable**
- But the 'typical' **peak-driven** **log-normal distributions** of conc. can cause:
  - ***Un-acceptable*** **Short-term** risks (e.g., developmental, birth and childhood risks)
- **AND also**
  - ***Un-acceptable*** **Long-term** **average** exposures
    - (for **Chronic** risks e.g., cancers, nerve & organ function, etc.).

- And a few randomly-timed (& located) indoor air samples cannot represent community VI Exposures & Risks

Indoor Air PCE or TCE Concentration Distribution Over Full Monitoring Period at Select Vapor Intrusion Sites; with Estimate of 90% of Exposure for Each Study



5 out of **5** Residences
7 out of **7** Commercial zones
Received **90%** of their **total exposure**
In only **~1%** to **~8% (<10%)** of **Time** monitored

Assessing Indoor Air (at the Exposure Point)

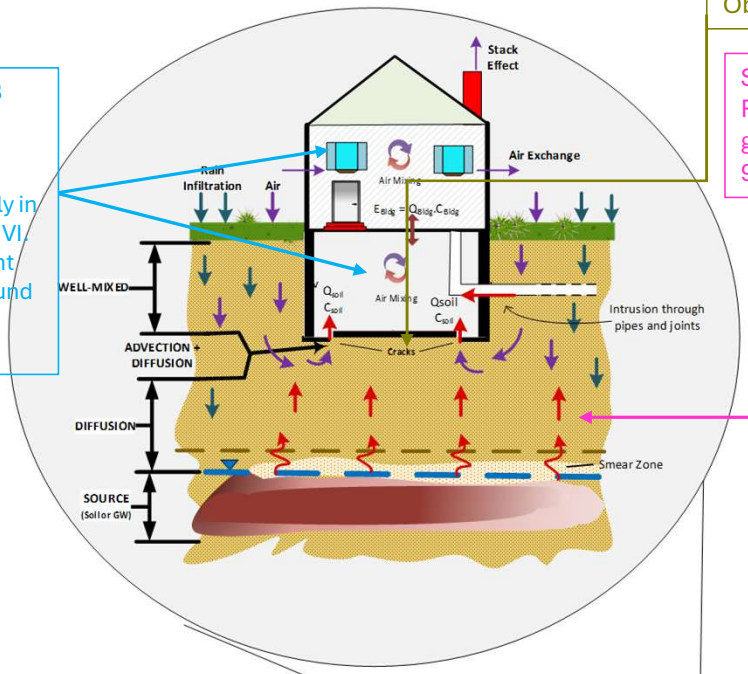
- VI pathway is often **long, complex and highly variable**

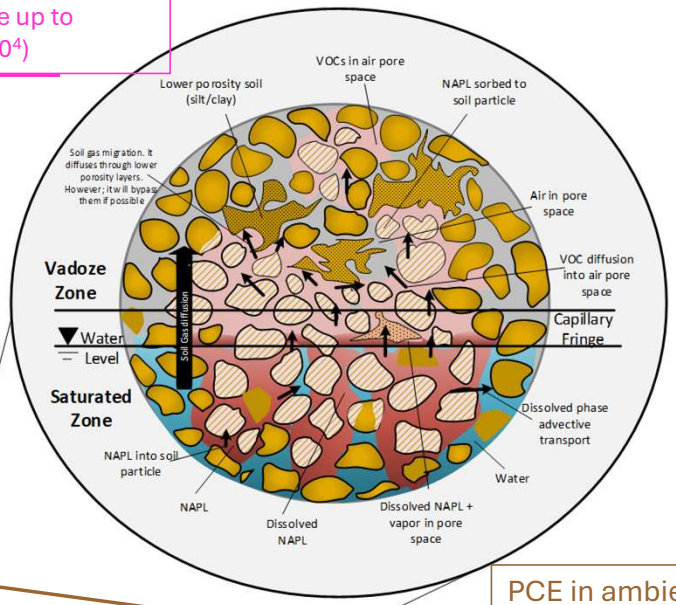
- Assessing VI at the **End**
  - of a long, complex and highly variable pathway
  - i.e., (**Exposure Point** (indoor air) is
  - Very (too) Complex & not Cost-Effective
    - To be Protective of Public Health

Indoor air PCE VISL 10.8 µg/m^3
(TCR=1E-06 or HQ=1)
Concentrations up to 200 µg/m^3 observed commonly in residences attributable to VI. (EPA VI Database). Current 95th percentile in background homes is 2.8 µg/m^3

Observed residential subslab soil gas up to 2x10^5 µg/m^3

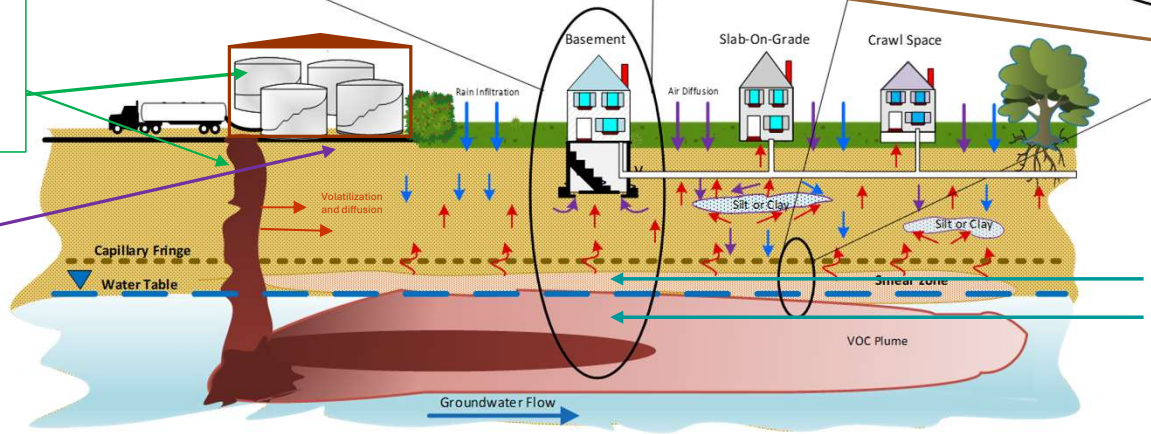
Soil Gas VISL 360 µg/m^3; Residential site external soil gas observed range up to 90,000 µg/m^3 (9x10^4)





Maximum theoretical gas phase concentration over or at equilibrium with pure PCE in tank or soil gas 1.65x10^8 µg/m^3.

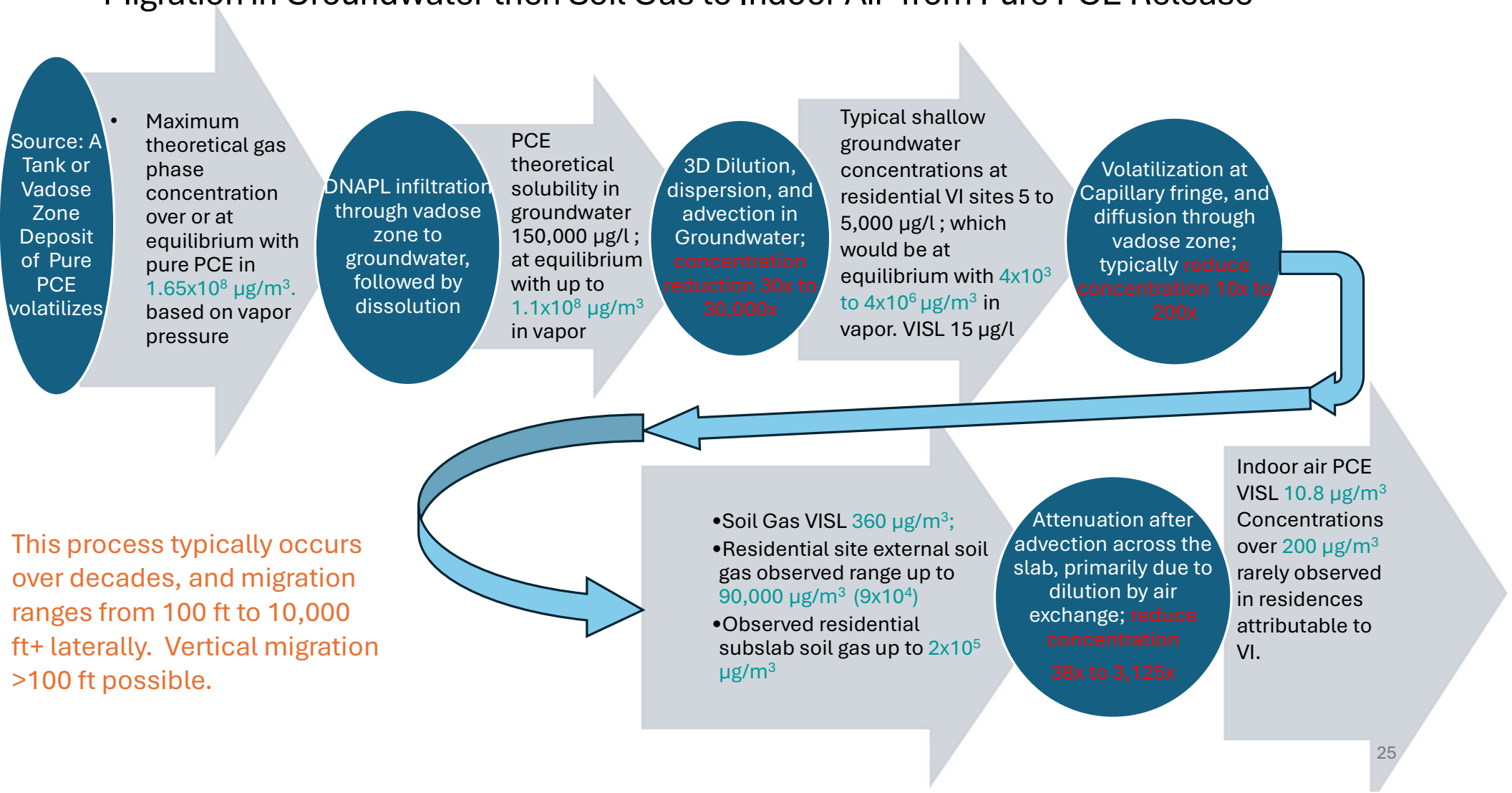
Concentrations up to 1x10^7 µg/m^3 PCE observed in source building subslab soil gas



PCE in ambient air third quartile 0.14 µg/m^3; max 13.5 µg/m^3

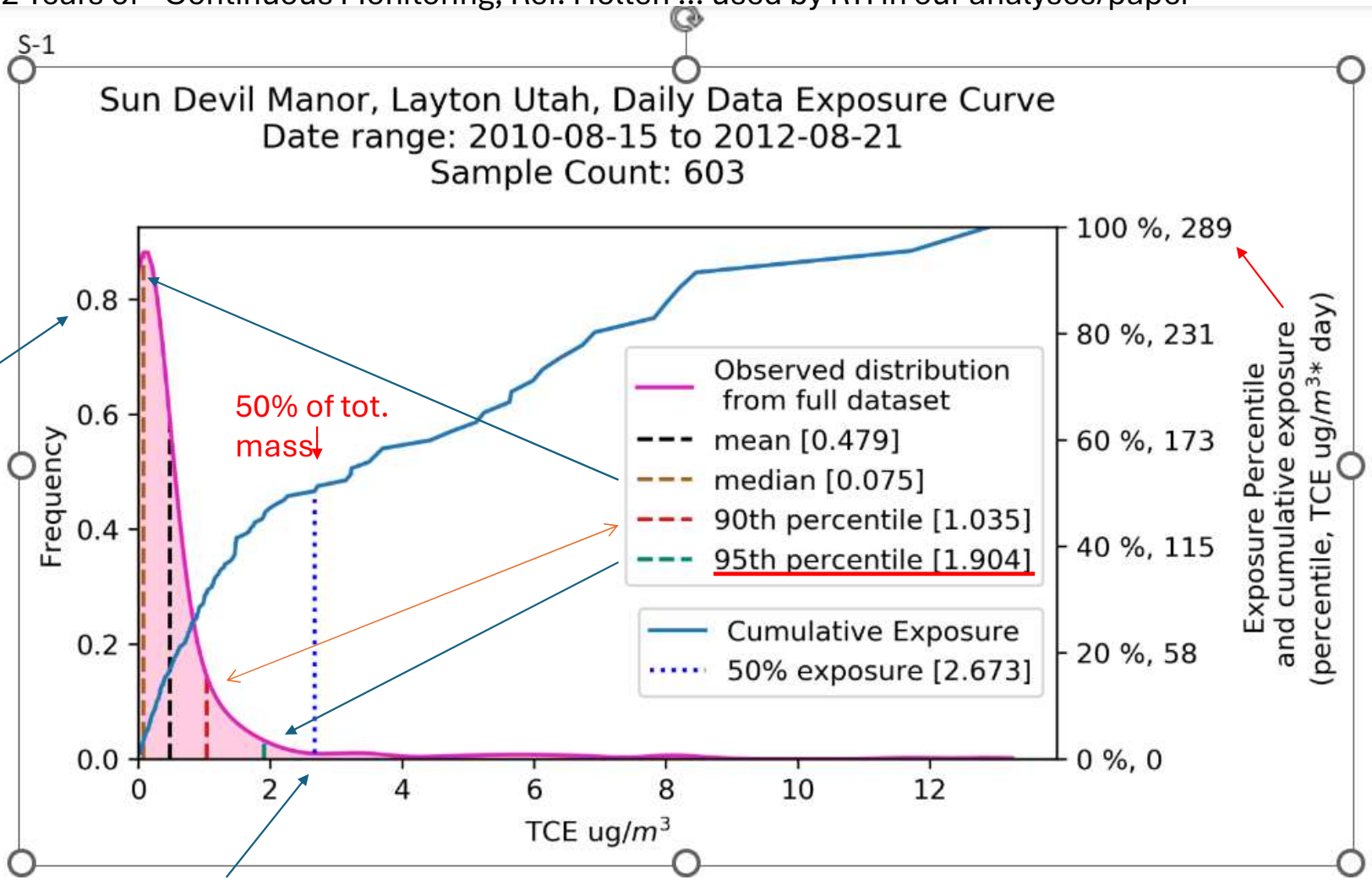
PCE theoretical solubility in groundwater 150,000 µg/l, Would be at equilibrium with up to 1.1x10^8 µg/m^3 in vapor at water table. Maximum observed groundwater concentration at residential sites is equivalent to 1x10^7 µg/m^3 groundwater vapor. However, reduction of one OOM at least is typically observed at water table,to 1x10^6 µg/m^3

Migration in Groundwater then Soil Gas to Indoor Air from Pure PCE Release



This process typically occurs over decades, and migration ranges from 100 ft to 10,000 ft+ laterally. Vertical migration >100 ft possible.

First long-term continuous indoor air sampling results
2 Years of ~Continuous Monitoring; Ref. Holten … used by RTI in our analyses/paper

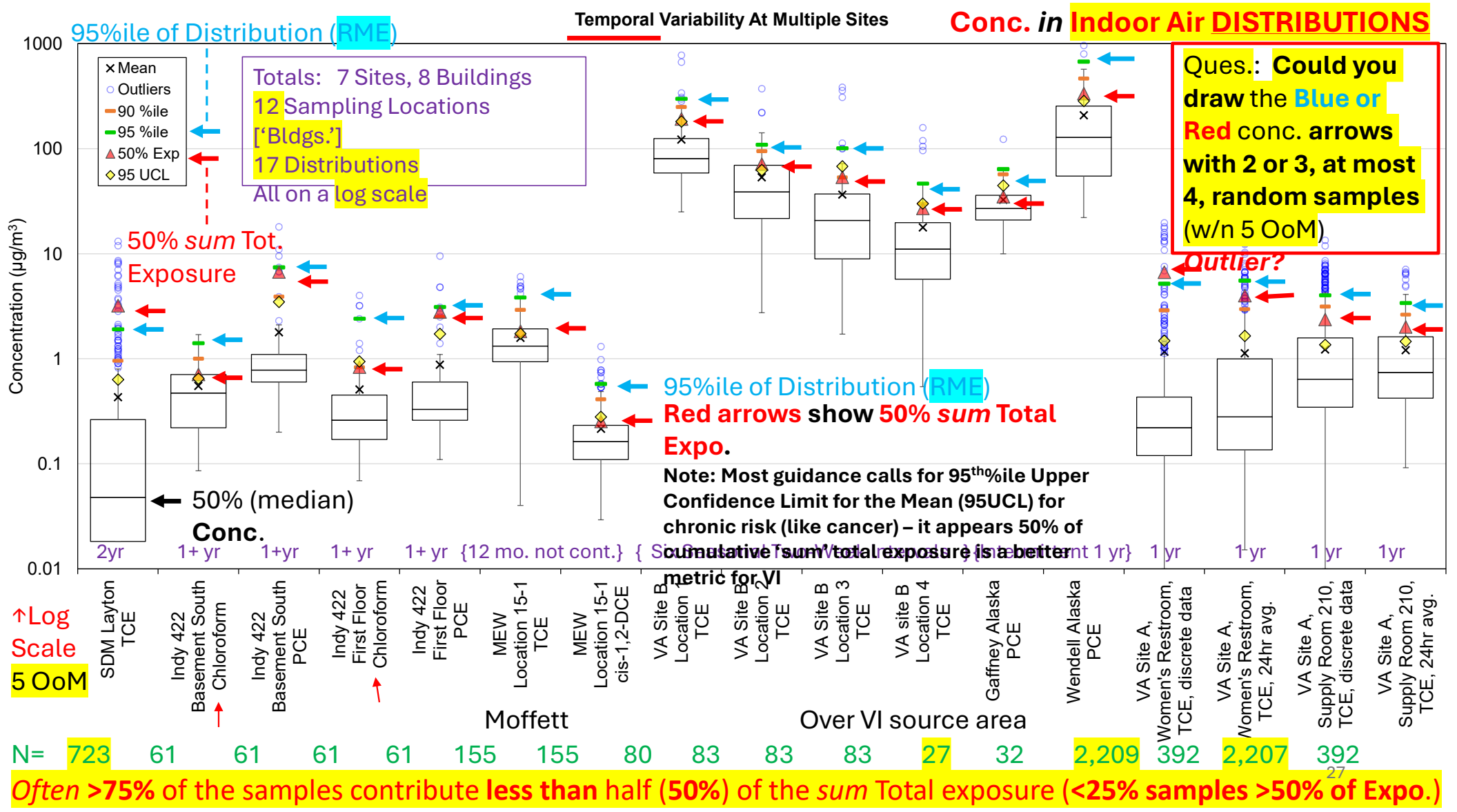


Fraction of Freq. **Data** (& Time for equal timed samples) w/ **~85% of time** with ~~0 conc. & ~~0 total exposure

2.673 ug/m3 = ~98th%ile

Even **RME** is missing >50% of **Long-Term Average** exposure mass

50% of total exposure from 3.5% of the time/samples w/ conc. >2.673 ug/m3 = 98th%ile



Often **>75%** of the samples contribute **less than** half (**50%**) of the *sum* Total exposure (**<25% samples >50% of Expo.**)

Perspectives* on **Compounding Variability** (over **Space** & **Time**)

- Everyone is better with **spill** Recovery/Controls/Cleanups **Sooner**
  - The more aggressive the better
- Easier to understand and predict in the Natural Environment
  - Human Behavior determines the HBE so Less understood & predictable
- Chasing the Tail of the Problem
  - Assessing indoor air quality (sampling) all individual bldgs. at all risks of VI can consume ALL the resources ($, staff, time, energy) we have
- Resources used to 'cut off' /remove contamination in the subsurface sooner will benefit many more people by lowering exposures for decades to come

* H. Schuver's

My Conceptual Sampling for 1 Bldg. w/ similar 'Coverage', (RFI pg.164)

Media/ Event for Observed Variation	Est. Range of Variation over (3yrs) at one Location	Est. Mid-Point of Variation over Time	Sampling Freq. for similar 'coverage'	Attenuation Mid-Point In OoM	Cum. Total OoM Observed Variation/ Uncertainty
Dissolved in GW	1-3x ?	3x ?	**4** / Yr	0.3	0.3
Partitions into Deep Soil Gas	1 – 10 x ?	3x ?		0.3	1.0
Shallow Soil Gas < HBE	20x ?	10x ?	__ / Yr	1.0	2.0
Entering the **Human Built Environment**					
In Conduits	10-1000x ?	100x ?	__ / Yr	2.0	4.0 ?
In Buildings	100-1000x ?	100x ?	365 days/ Yr	2.0	6.0 ?? (See 3 >DL)
End of VI pathway is the **most difficult** to represent by samples – (***if* Not Continuous**)					

Latest Efforts - Assessing Indoor Air Quality$_{VI}$ (published ~weeks ago, Kram et al. '25)*

- Continuous indoor air sampling over 3 to 4 days during 'weather events' in four buildings (~along Pacific coast of US)
- Calculated correlations for higher Indoor Air conc.$_{VI}$ with lower barometric pressures and/or winds 'pulling' contaminated soil gas upwards (through buildings)
- Gathered historical barometric pressures/winds from weather data over last 10 years
- Uses correlations (from 3-4 days) and 10 years of weather data to predict **10 years** of **Building-specific** exposure from VI

* Kram, M.L., and R. Solgi, 2025.
"Empirically-Derived Building-Specific Learning Models for Predicting Occupant Vapor Intrusion Exposures".
Remediation, v.35, issue 2; https://doi.org/10.1002/rem.70016

Testing Effectiveness of Current Indoor Sampling

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]

Goals of sampling = Using single **Max. conc. # from 4** samples[2]	90th %ile dist. Short-term	50thO%ile of total expo.[3] Long-term	**Summary**
• **Low** radon (Rn), Tracer, **Do NOT** sample **Now**	19%	32%	Lowest[4]
• Random [commonly used method] ***Flip of a Coin 50%***	**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**

[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

We now Know

- VI indoor exposures **vary over Time** (by 10x – 1000x)
  - Typical* sampling gives **~50/50 probability** of correctly identifying unacceptable exposures (in the bldg. sampled)
    - **Could have flipped a Coin** – instead of (access, clearance, collection, analyze …) x 4 times*
      - &
    - **Saved $20,000 – $60,000** / building

*few (4) random/calendar 24 hr. grab samples (& 50-50 **ONLY** if we **Use** the **Maximum** conc. (**not** as "outlier')

Sampling for **E**xposure **P**oint **C**oncentrations

We've **Tried** in **~Every** (possible) **Way**

- **Not yet** found to be ***Cost*-Effective** (20**00**-20**25**)
  - Slowly improving Effectiveness of Indoor Air sampling
    - Finding most exposure occurs in unpredictable episodic 'peak' events
    - As we approach ~**Continuous sampling** in **Each Bldg**.
      - Un-realistically Costly & still
      - Limited by Access
        - Access is Social/Community Decision (likely perineal problem)
- Continuous sampling in All 'exposed bldgs.' is
  - **Not likely** to be **Cost-Effective** in the foreseeable future
    - &
  - **Ineffective** Sampling **Does Nothing** for Cleanup or Control of Exposures
    - False-Negative (un-Protective) decisions only EXTEND EXPOSURES

Assessing VI (currently Bldg. by Bldg.) is very Complex, Time consuming and Expensive

- Can use up too many resources, &
  - Does almost **NOTHING** to **Reduce** human **Exposure** (**or S**ource **C**onc.)
  - A **Few indoor samples** will ONLY Identify a problem that is **Continuously** (or **Frequently) Unacceptable**
    - So, typically, **Source** (& **Exposure**) **remains** longer & longer …
- **Needs to be Simpler** to have a chance to be:
  - **More Protective/accurate**
    - &
  - **Cost-effective**

We **now** Know **Access** CONTROLS (indoor) sampling **Results**

- We **only sample* some __% of exposed bldgs**.
  - Typically 1/3 to 1/10
- (& **assume** those are **representative** of all unsampled bldgs.)

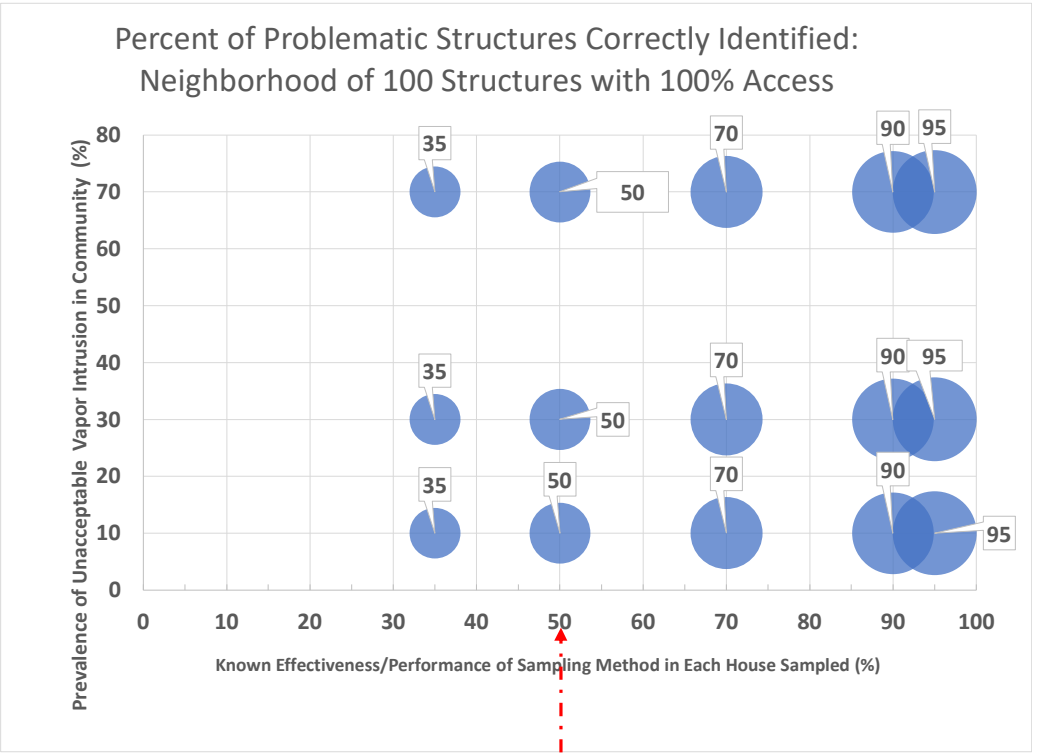
- Traditionally this is an attempt at cost-effective sampling
- Now it is typically **Socially Determined** by community cooperation to give access to indoor/personal spaces to sample for toxic intrusion
  - That could **Decrease** the **Value** of their **Bldg.**
    - and /or
  - **Stigmatize** them compared to neighbors (who didn't allow sampling)

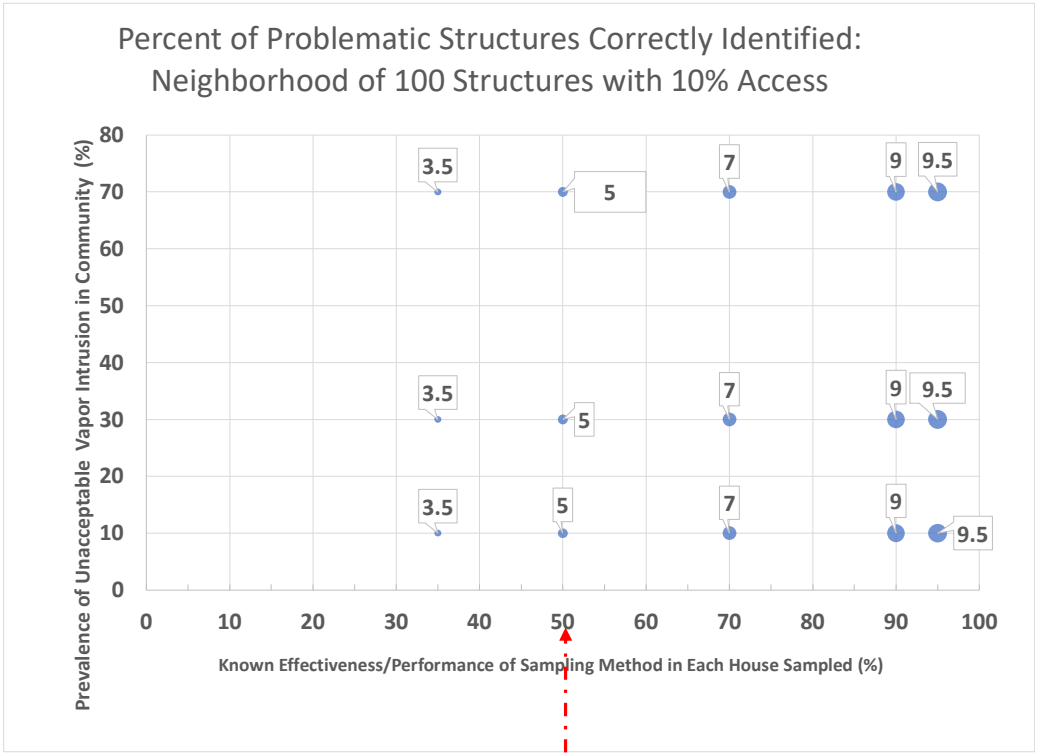
Documentation of the % of Exposed Bldgs. Accessed/Sampled is Critical for Understanding ACCURACY of Indoor Air based VI Assessment

- When using Indoor Air as a single/key basis for Assessing VI risks
- Access to sample indoors is a **pre-condition dominating** what you can possibly find
- Almost regardless of how accurate your sampling techniques are
- For many years we have been struggling to improve indoor air sampling methods to improve their accuracy *somewhat*
- Now we see that a clear social-based parameter (Access) dominates sampling accuracy before we can even begin consider sampling field methods

CL1

Percent of Problematic Structures Correctly Identified:
Given the amount of **Access** to Sample
100% Access *vs.* **10**% Access





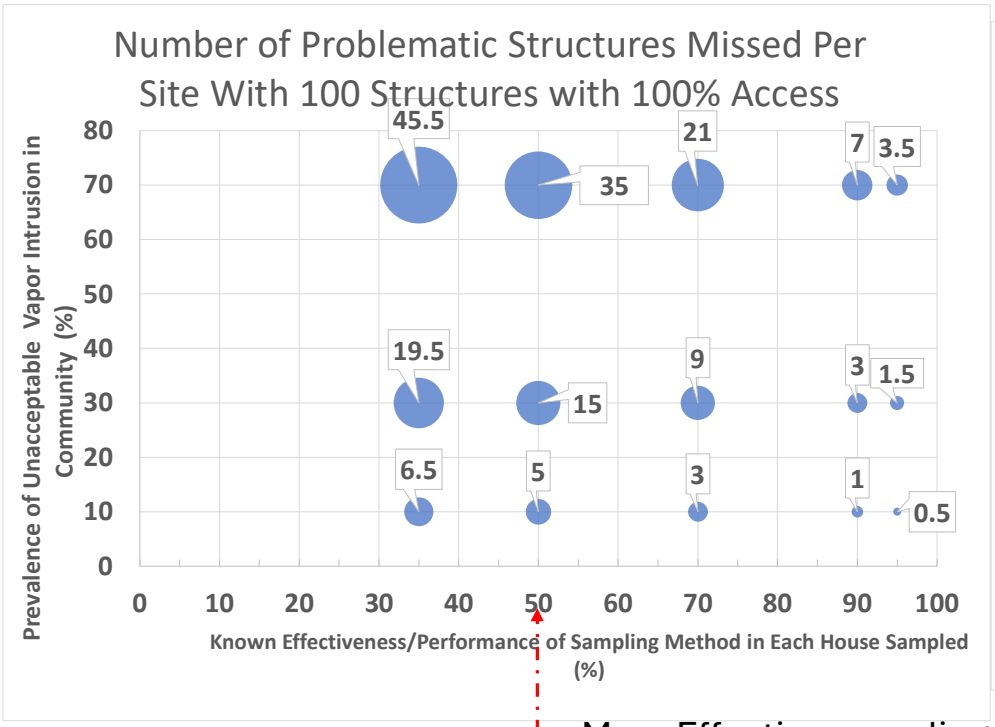
Key Point: If we judge performance as % problematic structures correctly identified, then the underlying prevalence is controlled for, and the performance is primarily limited by access, and secondarily by sampling strategy performance.

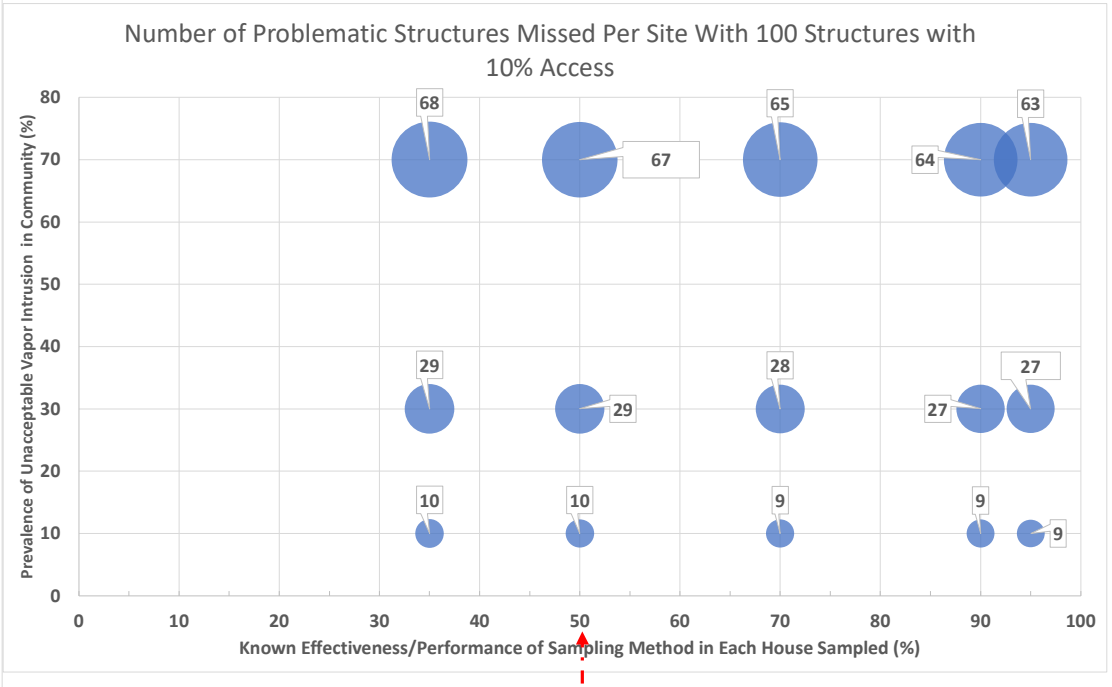
Slide 37

CL1 Need to add key point
Lutes, Christopher, 2025-09-29T14:00:45.659

CL1 0 Add percent signs or number of houses
Lutes, Christopher, 2025-09-29T14:01:29.369

Number of Problematic Structures Missed
Given the amount of **Access** to Sample
100% Access *vs.* **10**% Access





More Effective sampling most impacted by limited Access

Key point: viewed in these units, access percentage, sampling strategy effectiveness and underlying (unknown) true prevalence of the problem influence the number of structures missed.

Myth 2: Exposures should be assumed to be Acceptable until proven Not to be, in each Bldg.

- As long as we allow this (unpredictable) **unnatural attenuation** to continue,
  - i.e., Until **Proven** to have **Unacceptable** concentrations at the point of inhalation
- In each and every building exposed to these vapors,

- **Unacceptable exposures will continue**, Unless …
  - **Monitoring** at the point of exposure is **Continuous** (>>90%~100% of time)
    - That is
  - Across All time (exposed) & in Every exposed Building i.e., UNREALISTIC

In Summary

- As long as we allow **un**-Monitored **un**-Natural Attenuation (un^{2}MNA) of vapors within the Human Built Environment (HBE)
  - that are **as unpredictable**,
- As all combined **natural and human '**behaviors' over the period from when the area was first developed (and contaminated) by humans up the present time,
  - and
- Into the future for as long as vapor contamination remains …
- Unavoidable indoor Vapor exposures will continue ~un-detected*

*Unless, e.g., communities observe elevated disease rates plausibly associated with the contamination & are able to obtain more informative (e.g., continuous sampling) studies

3)
How we Could do Better

Control **Vapor** **Migration** within the **Natural Environment**

More **Cost*-Effectively** than Current Approaches

Control vapor migration in Nature before it enters the **H**uman **B**uilt **E**nvironment

- If the migration of vapor contamination (from groundwater or soil sources)

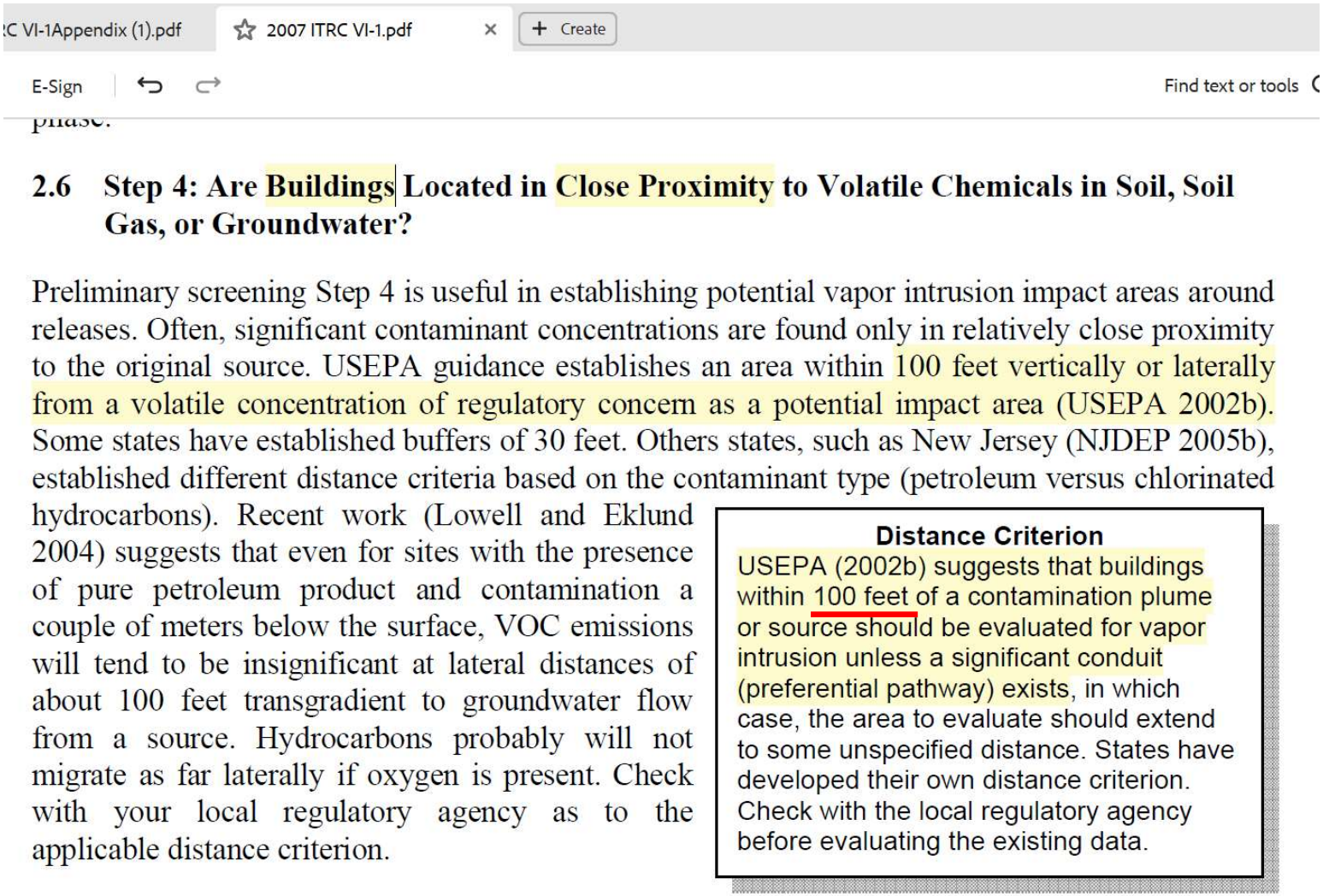
could be controlled within, the Natural Environment

  - Prior to their entry into the **HBE**

- Human exposures could be **verifiably prevented** for a reasonable* cost, &
  - Also **avoid** the impossible *pre-condition* of needing **access** to private spaces in every exposed building
  - while also potentially **stigmatizing** cooperative individuals and communities (as well as any health issues due to their exposures) but whose ***only 'fault' is ...***
- That **their Bldg. did not** adequately **attenuate/treat** the **un-controlled releases** of other's hazardous wastes passing through their living spaces

*Reasonable cost is **not nothing**, but comparable to that used to successfully control exposure & prevent disease from groundwater contamination (i.e., not as low cost as free flowing vapors into HBE)

If you want to Screen Out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E-Sign | Find text or tools

phase.

2.6 Step 4: Are Buildings Located in Close Proximity to Volatile Chemicals in Soil, Soil Gas, or Groundwater?

Preliminary screening Step 4 is useful in establishing potential vapor intrusion impact areas around releases. Often, significant contaminant concentrations are found only in relatively close proximity to the original source. USEPA guidance establishes an area within 100 feet vertically or laterally from a volatile concentration of regulatory concern as a potential impact area (USEPA 2002b). Some states have established buffers of 30 feet. Others states, such as New Jersey (NJDEP 2005b), established different distance criteria based on the contaminant type (petroleum versus chlorinated hydrocarbons). Recent work (Lowell and Eklund 2004) suggests that even for sites with the presence of pure petroleum product and contamination a couple of meters below the surface, VOC emissions will tend to be insignificant at lateral distances of about 100 feet transgradient to groundwater flow from a source. Hydrocarbons probably will not migrate as far laterally if oxygen is present. Check with your local regulatory agency as to the applicable distance criterion.

Distance Criterion

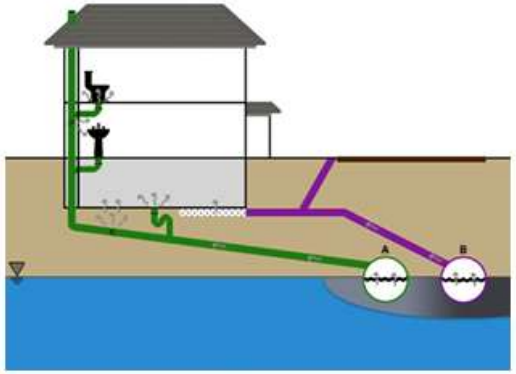
USEPA (2002b) suggests that buildings within 100 feet of a contamination plume or source should be evaluated for vapor intrusion unless a significant conduit (preferential pathway) exists, in which case, the area to evaluate should extend to some unspecified distance. States have developed their own distance criterion. Check with the local regulatory agency before evaluating the existing data.

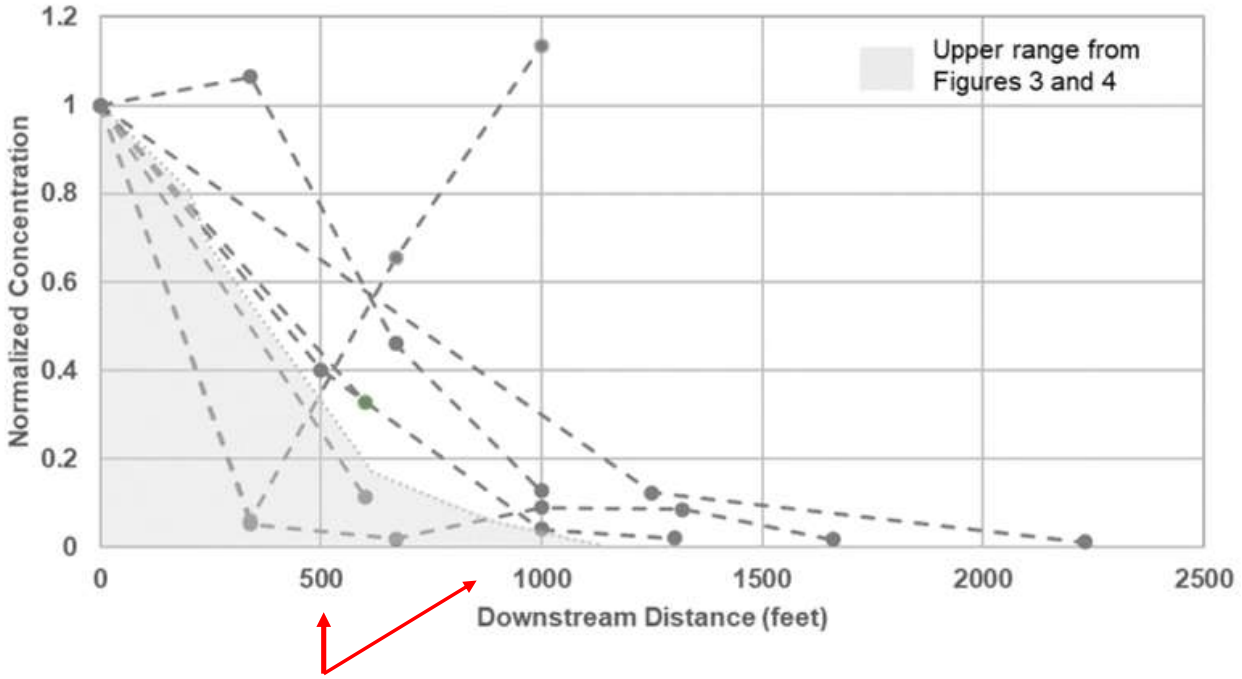
Separation Distance – To Screen-In to concern for VI [and Screen-Out]

Sewer Vapor Downstream Migration

Groundwater infiltration through sewer lines

(higher risk scenario)





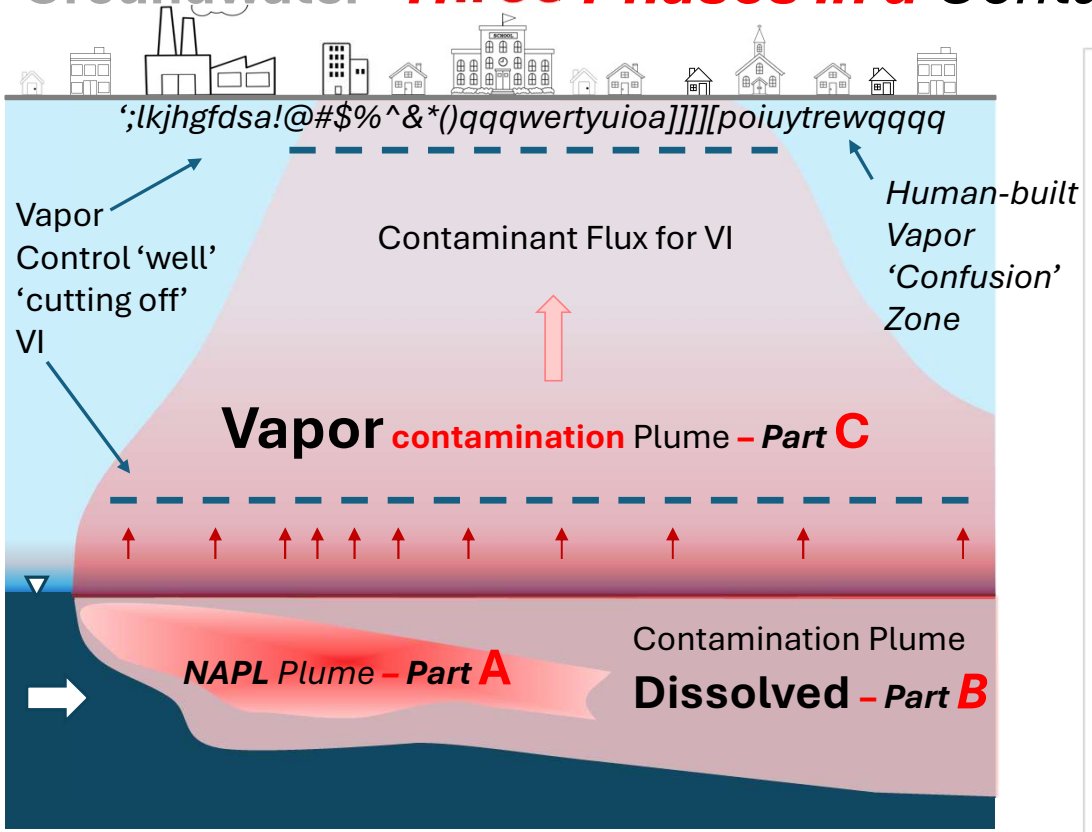
Reference: Beckley and McHugh, 2020, A conceptual model for vapor intrusion from groundwater through sewer lines, Science of the Total Environment, 698, 134283

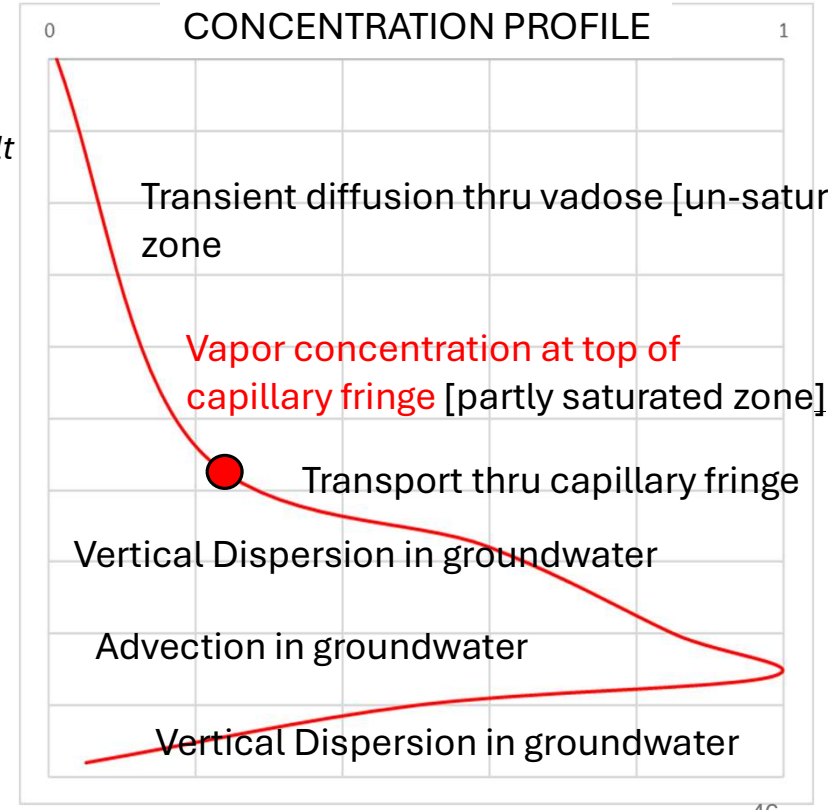
Addressing Environmental Contamination (Vapor) in the Natural (not Human-Built) Environment

- **Field Techniques successfully used** for Soil Vapor Extraction (SVE)
  - **High-Conc.** Primary Source releases, e.g.,
    - **Unsaturated zone NAPL** spill residuals
- **Have been adapted/used** to address the migration of vapor contamination from **more dilute (groundwater-vapor)** sources
  - For example, the capture/control of unacceptable exposure-based vapor conc. in the natural environment and **prior to entering the HBE**
- That is, **where Human Exposures are Likely & ~Unavoidable**

Cross-Section view of **Source** *of Contamination for Vapor Intrusion*

Conceptual Model for Upward Mass Flux from Contaminated Groundwater – ***Three Phases in a*** *Contamination* ***Plume*** ***(A, B, C)***

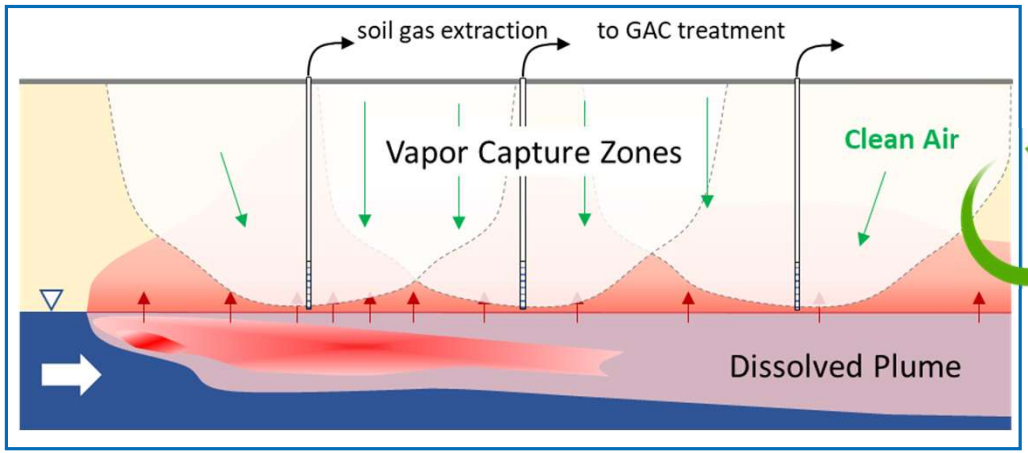


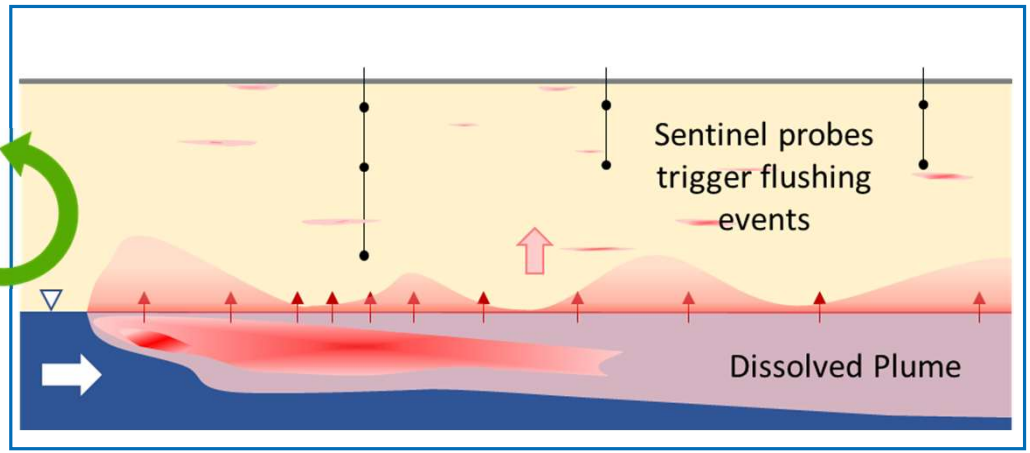


[Figure by Bo Stewart, PhD, *modified with inserted text italicized for this Introduction]*

Design & Operational Concept for SGM

- **Rotate application of mobile SVE across an array of wells covering area above the contaminated GW plume**
  - Flush numerous target pore volumes from a well and move to the next one
  - Monitor vapor concentrations across the vertical extent of the vadose zone
  - Repeat the rotation of extraction wells





*Conceptual** - Traditional & Optimized Cleanup Activity Costs Priority / Amounts

*mine

Explo

Primary Source\GW Remediation	Mapping Extent GW / SG	Indoor Air Sampling to Identify Exposures	Control/Reduce VI Conc./Exposures	Verifying Protection of Cleanup/Controls
$$	$$$ / $	$$$$$$ ~$30k/bldg	$	$
		~$60,000	~$10,000	
		~10 samples/bldg. ~2 Bldgs. Sampled	~1 SSDS/Bldg. mitigation, if access	
Primary Source/Spill Remediation	**Mapping Extent GW & SG**	**Prioritizing Exposures Probabilities**	**Control/Reduce VI Vapor Conc./ Prob. Exposure**	**Verifying Protection**
$$$ sooner the better	$$ / $$$	$	$$$$$$$ ~Lot size, air/trtmt	$$
Row = Sum Total $		~$70,000	~$70,000	
Summary		2 Bldg accessed both both Exposed >std, 1 Mitigated, 1 missed *If* 10% Access 18?	~3-6 Bldg./Lots **Protected** by Vapor-plume migration controlled	On-going seasonal soil gas monitoring to document safe distance separated

It's Time we Considered a **Comprehensive** Conceptual Model of all cVOC* Contamination

- **All phases/forms/plumes** of (hazardous waste) Contamination
  - NAPL
  - Dissolved
  - Vapor
- **None** of which **belongs**/should be in Human **Built** Environment
  - Where Human **Exposures are Very Likely & ~Un-avoidable**
- Groundwater **Remedies** that do NOT include **ALL 3** phases (vapor)
  - Should be considered ***In*-Complete**
  - **GW** plume monitoring **not** including associated **vapor migration** should be
    - ***Not* 'Under Control'**

*including newer vapor forming chemicals (e.g., some volatile PFAS, + …

Summary for the Jury *(my original Title)*

The Case for:

Remedies to Uncontrolled Releases

Addressing All Forms* of Contamination

Cost-Effectively

in the Natural Environment

Allowing *only* **M**onitored ***Natural**** **A**ttenuation (MNA) of Vapors

*e.g., **Vapor**-phase

Not in **H**uman-modified/**B**uilt **E**nvironments

Thank You (members of the Jury)

- Please consider these concepts & evidence in your decisions
  - Involving (the often forgotten) vapor-phase contamination
- These unnecessary exposures could be Controlled
  - Cost-Effectively