COMMUNITY-SPECIFIC **A**TTENUATION **F**ACTORS & **P**OINT **O**F **C**OMPLIANCE for chemical VAPOR INTRUSION

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Outline

- Scope
- 1) Early Approaches - Attenuation Factors
- 2) Current Approaches - Indoor Air Sampling
- 3) Proposed Combination
  - *Improved* Indoor Air Sampling – for accessible bldgs.
  - *Improved* Attenuation Factors – for *in*accessible bldgs.
- Summary: Providing more accurate & effective Assessments for
  - 100% of the Buildings

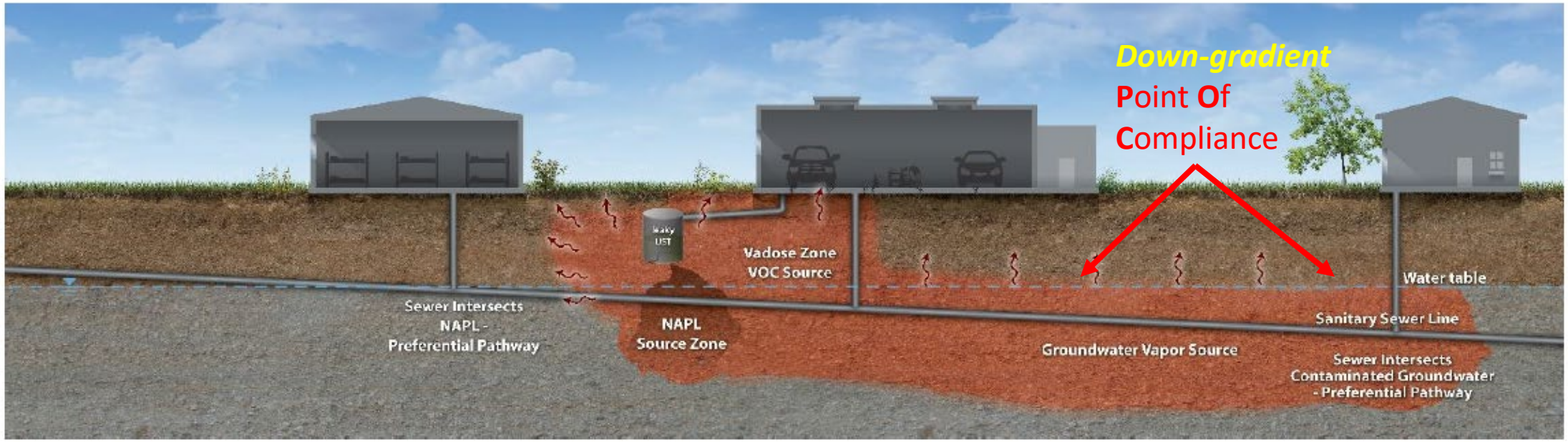
Indoor Environments – **Scope**
Soil Gas *intrusion into* **Indoor Air**

- Focus here: ***chemical*** Vapor Intrusion (VI)
  - More specifically, **human-made** chemicals:
    - **Not** naturally-occurring **Radon**, although:
      - Excellent **Tracer** of soil gas intrusion into indoor air
      - Significant **Hazard** for cancer, as *initiator*, & with possible interactions with chemical *promoters*
  - ***Chlorinated***-chemical Vapor Intrusion (cVI), aka VI
  - **Recalcitrant***-chemicals, e.g.:
    - **chlorinated**,
    - *some* **per- and polyfluoroalkyl substances [PFAS]**

*As more easily **degradable** compounds,
e.g., most petroleum compounds, are often
Bio-degraded/broken down into **less toxic** components **prior to** completing a pathway into **indoor air**

Figure 1. Example VI CSM Scenario - Vapor Intrusion Matrix of Technologies for Selecting the Most Effective Investigative Strategies

Focus/Scope here: Off-site *Community* **downgradient** of the release
(Not overlying the original release in the unsaturated zone)



Point of Compliance (POC) in 'deep-native' soil gas only subject to diffusive flow, and away from Human-built subsurface structures that could induce advective flow & form locally-reduced conc.

Modified from:

DoD Vapor Intrusion Handbook
Fact Sheet Update No: 007
Date: July 2019

CLEARED
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Matrix for Selecting Vapor Intrusion Investigation Technologies

1a) **Early** History of Efforts to Assess VI Exposures (that are Verifiably-Accurate)

- RCRA **E**nv. **Indicators** (*Feb*. **1999**) **VI is real**, ***N****ot* due to indoor background
  - So 'look to the **latest guidance**'
- **Attenuation Factors (AF)**
  - RCRA EI VI Guidance (**2001**) **J&E *model***-predicted **AF**
    - without indoor air samples – attempts to validate model, was only possible if, changed soil types from silty-clay to sand
  - OSWER (**2002**) ***Empirical*** (measured assoc. indoor air data across the US) **AF**
    - Based on **national** (EPA Regional & State) data collated by Dr. H. Dawson

VI Attenuation Factors (AF), are used to estimate Indoor air conc. – by simplifying the complex

- VI Attenuation Factors (AF)
  - **Ratio** of concentrations (**indoor** to **subsurface** [~*proximate* **source conc**.])

$$AF = \frac{\textbf{1}\ \text{ug/m}^3\ \text{in indoor air}}{\textbf{1000}\ \text{ug/m}^3\ \text{in soil gas}} = \mathbf{0.001}$$

Can also be considered the fraction of indoor air that is from soil gas

- ***Early*** methods used the:
- **Measured subsurface** soil gas **Conc**. in proximity of an occupied building
  - and
- **Multiplied** that **by** either a model-derived, or previously measured, **Attenuation Factor**, typically ***from*** *some* ***other sites*** (within your **state or nation**);
- To calculate an **estimated** indoor **air conc**. in the building(s) **from VI**

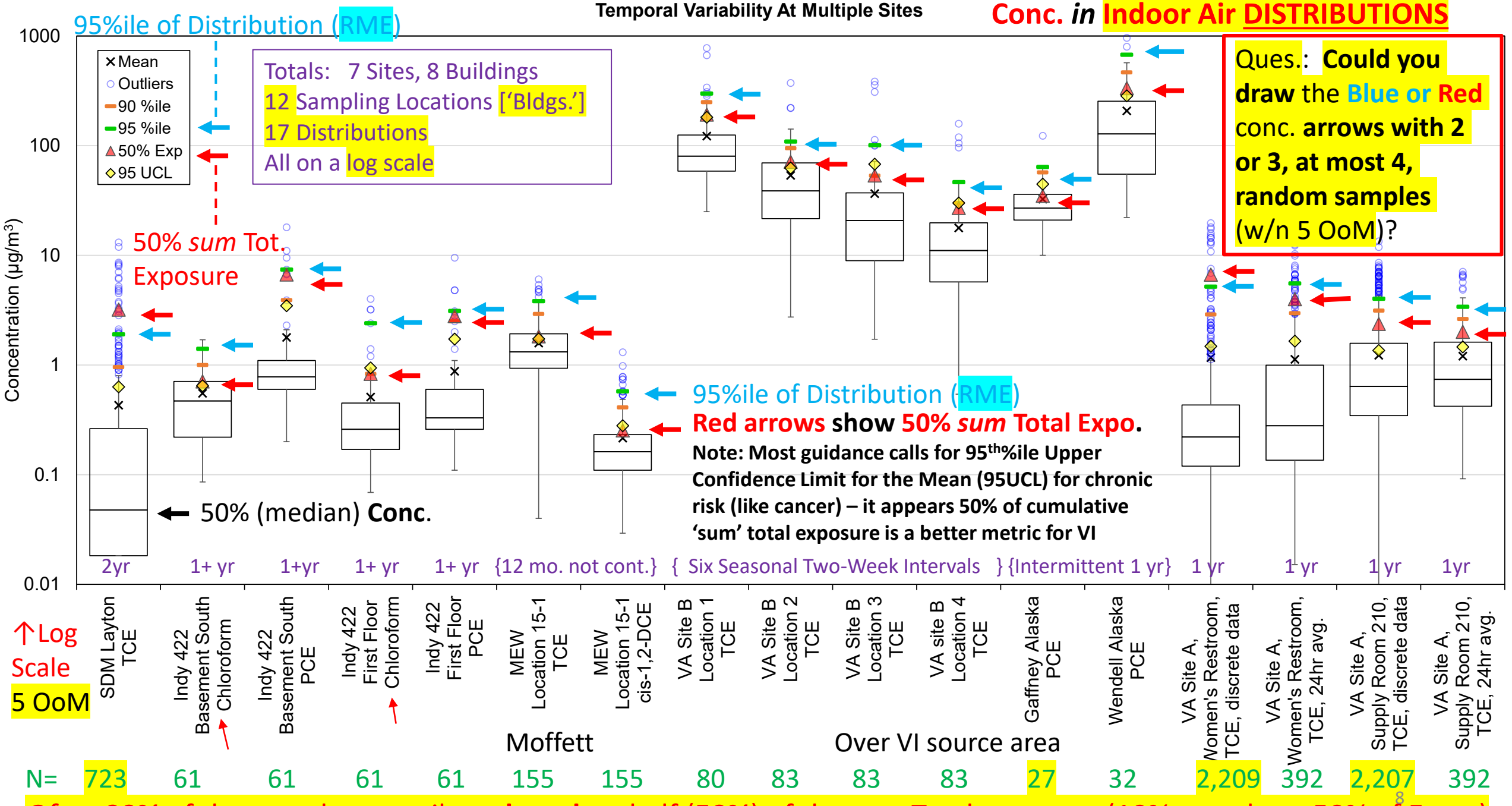
2a) **Current** Efforts to Assess VI Exposures (that are Verifiably-Accurate)

- **Indoor Air**
  - USEPA-OLEM (**2015**) '**more than one**' *indoor **air** (IA)* sample
  - States & EPA (as of **2021**) Summary by Dr. Levy at AEHS March 2021*
  - **2023** *still* **~2-3 indoor air samples per bldg.**, from ***small*** **subset of bldgs**.
  - Most guidance **do NOT** specify **WHEN** to sample; *most* **random**, some winter focus
    - Studies show indoor air conc. are **highly variable** across time (e.g., **3% of days** can cause **½ total exposure**)
  - Typically, *only* a **One-'time' assessment** – before a **Final decision** on bldgs. & entire Site
    - When there are **many changes** in source, weather, bldg. cond. etc. varying **over years/decades**
  - **P**oint **o**f **C**ompliance (**POC**) is often **Indoor Air (**& exceedances only cause **1 bldg. mitigation** (less often focus is on soil gas media conc. to be cleaned up))

*See https://iavi.rti.org/assets/docs/02_Guidance_on_Sampling_Temporal_Variability_2021_AEHS.pdf

Temporal Variability At Multiple Sites

Conc. *in* Indoor Air DISTRIBUTIONS



Often **90%** of the samples contribute **less than** half (**50%**) of the *sum* Total exposure (10% samples > 50% of Expo.)

Proposed: Improvements & Integration of Current & Early Methods

- 2b) Overcoming Limitations of **Current** Methods
  - Testing indoor air sampling effectiveness, suggests:
    - **Improvements** in indoor sampling methods are **needed**
    - **Access** to indoors to sample is a **major barrier**

- 1b) Overcoming Limitations of **Early** Methods
  - Generic AF are based **other types** of buildings, climates, releases, …
  - But we can **calculate** an **AF** from all the **neighbors** that had indoor air sampled
  - **If** a **majority** of bldgs. were **sampled**, their AF distribution **could represent unsampled** bldgs.

2b) Testing Effectiveness of Current Indoor Sampling
with & w/o continuous Indicators & Tracers (I&T) guiding IA sampling times

- Ranking Effectiveness of different Sample Scheduling strategies[1]

Goals of sampling Using **Max. of 4** samples[2]	90th %ile dist. Short-term	50th%ile of total exposure[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 (winter/heating)	67%	84%	Better	
• I&T (**Rn**) guided times (**any** season)	65%	86%	Better	
• I&T (**Rn**) guided times (**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 …*) submitted for pub.
[2] Using max. not in explicit in most guidance (but RAGS), typically too few samples to calculate 95UCL, so **should be 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 – can also be used to **avoid detection of VI** (we recommend occupants monitor their bldg. Rn)
[5] Majority of cases provides ***mis-information*** reporting '**all safe**' when they are **Not**
[6] Possibly due to longer pathway from source of VOC needing sustained period of high intrusion relative to nearby Rn

Most effective Indoor air samples are *timed* by *Continuous* I&T monitoring, but …

- **Access** to personal living/working spaces for sampling is often a **Barrier** even for short-period samples at **convenient/random times**, and often only **1/10** to **1/4 of bldgs**. are *even sought* to allow indoor air sampling
  - Often **unsampled** bldgs. are simply **assumed** to have **lower VI** than those tested
- EPA-ORD has field trials where volunteers are **allowing meters** to be placed for continuous I&T measurements to identify the times for chemical **sampling at VI *peaks*** & **access** appears to be **approaching ½ bldgs**. asked to participate*
- If enough continuous I&T sampling was possible by **volunteer**, bldgs. the **observed AF** from **~½ of the buildings** **(with indoor air samples)** could be used to **represent** the range of AF for **bldgs. without indoor air samples**

*Potential for selection bias as lower income households have less time and flexible schedules to volunteer/participate

1b) VI Attenuation Factors (AF), are used to: Simplify the Complex

- *Recall*: VI Attenuation Factors (AF)
  - Ratio of concentrations (**indoor** to **subsurface** [~*proximate* **source conc**.])

$$AF = \frac{\textbf{1}\ \text{ug/m}^3\ \text{in indoor air}}{\textbf{1000}\ \text{ug/m}^3\ \text{in soil gas}} = \mathbf{0.001}$$

- We *now* know: AF **combine** a wide variety of factors from both:
  - **Natura**l &
  - **Human-built E**nvironment (**HbE**)

- **Both** categories are **very complex & variable**
  - *Opinion* – **Human-built E**nvironments (**HbE**) are **MUCH *less* predictable**
    - (vs. **Laws of Nature) –** which are constant, but we can rarely monitor the full extent of variation

We now know **Attenuation Factors** involve: Different Levels & Additive‘+’ Complexity

- **Natural** environments are **complex enough**
  - But we have 100s of years study of ‘constant’ natural ‘laws’ & predicting their behavior (GW)
    - Human-induced GW flow (e.g., due to pumping) should be considered, but not that variable
- HbE *& human* ***behavior*** influences on vapors are **much less predictable**
  - Human-engineered designs/construction and activities/alterations in/to the subsurface have **evolved over hundreds of years** (+ climate change)
  - **Condition** (e.g., vapor permeability) of modern &/or abandoned human-built structures/modifications in the subsurface are **often unknown** & human behavior often unpredictable
- **Combination** of both Natural & Human-built structures **& behavior** variables influencing vapor intrusion **conc**. can often become **essentially *unpredictable*** on an individual bldg. basis (***continuous*** monitoring ***critical***)
  - Accurate VI ***predictions*** could be considered **T**echnically **I**mpracticable (**TI**)

VI (Subsurface-to-Indoor air) **AF** are Building-Specific
& vary across time

- Limited to ~'no' evidence that **a/few** tested bldgs. can represent other bldgs.*
- However, accurate documentation of the distribution of attenuation factors
  - for *every* building with VI concerns was considered
- Economically & **Technically Impracticable**
  - for **typical/affordable** VI assessments/protection, *especially* without **access** for samples
- So, VI assessment guidance developed to be generically applicable across:
  - National (e.g., US)
  - EPA Region
  - States
  - Large districts of a State (e.g., Bay Area/San Francisco)

*Some correlations in relative temporal variability across bldgs. But not predictable magnitude of conc. for risk decisions.

Generic (non-bldg.-specific) **AF** for risk screening are & ***should be*** overly-protective (for most bldgs.)

- Generic screening values are intended and designed to be protective for most (e.g., **95%** of the people/settings, as in EPA VI Guidance, 2002, 2015)

GOAL = Max. 5% ERROR rate in screening exposures

- But generic soil-gas to indoor air AFs can become:
  - ***Too* overly-protective** when they include:
  - **Too-wide of variety** of
    - Natural and
    - Human-built environments
  - **NOT present** in **the** community being assessed
    - & can **over*-predict** indoor air concentration (due to VI) & **screen-in** in **too many** buildings **here**
  - i.e., when the **bldgs. under investigation** are ***under-represented* by** the population of bldgs. used to calculate the 'generically' protective AF

*Older generic AF will not represent buildings more recently built which could have different air exchange rates (often lower) and thus older AF could ***under***-predict indoor air conc. for these newer bldgs.

The single community where VI potential is being assessed now, is the most important

- Thus, it appears that <u>much of the variability in large-scale generic AF could be reduced</u> by developing a **community-scale AF**,
  - Specifically for the bldgs. In the community of interest

  &
- Development of a community-specific AF *could* include sampling
  - All accessible potentially-VI-impacted buildings over time, & be:
  - Reasonably Affordable
  - Accomplished in a reasonable timeframe
  - Accurately protecting the community at risk
  - Without being overly protective
    - Because it is **NOT based on evidence from bldgs./conditions not in the community**

Examples of wide-ranging variable factors influencing VI AF that can be **narrowed for a single community**

- Spill (composition & conditions) & Extent/Conceptual Site Model of chemical sources, NAPL/dissolved, release(s), migration, etc. …
- Natural Environment
  - Above ground – climate, weather (norms & range of variability)
  - Subsurface – soil types, geology, hydrology, … (~relatively related)
- Human-built Environment (history & occupant behavior)
  - Above ground
    - Building designs, construction, age, condition, modifications, operations, occupancy, …
  - Sub-Surface – non-natural, human modified/built 'zone of confusion' (w/ history)
    - Sewer & Utility designs, Active and Abandoned:
    - Utility pipelines, trenches, cut &/or soil/C&D fill areas, disrupted soils, buried foundations
    - Wooden & brick piping, … [causing fascinating investigations/presentations]

Considering these factors; Suggests the use of AF could be improved:

- If:
  - Based on conc. in ‘native-deep’ soil gas (**below** the Human ‘zone of confusion’)
  - Developed for each **individual bldg**. (with measured subsurface & indoor air conc.)
    - & then
  - Use of the ‘high-end’ or **maximum AF** from **across** the Community/Site to:
    - Estimate indoor air conc. in all *inaccessible-unsampled* bldgs. In the Community
      - &
    - Back-calculate the acceptable conc. in ‘deep’ soil gas (POC) **to protect the *entire* Community**

Proposed (Future) Combination of Improved Approaches

- Measured indoor Air
  - Collected when VI is ‘turned on’
  - In **all accessible** bldgs.
- Community-specific measured AF-based on
  - Using ‘deep’ soil gas conc. & max./’high-end’ AF observed in the Community
  - For estimating indoor air conc. in **all inaccessible-unsampled** bldgs.
- On-going Monitoring – for as long as source remains
  - Primarily focused on soil gas conc. at the POC, with some on-going:
  - Rotational ~randomly-selected bldg. indoor air testing when VI is ‘turned on’
    - That would ideally eventually sample indoor air in all 100% of bldgs.

Outline of Historical & Proposed Assessments

Phase	Media samples for:	Attenuation Factor	Indoor Air samples	Bldg-specific Exposures	Site-wide Exposures
Early	Source Conc.	Model Predicted	Estimated site-wide	Model Estimated **POC = soil gas**	Model Estimated
Current	Bldg. selection for sampling priority (spatial variability)	Large Area Generic National State 'Bay Area' Defines area of VI	Measured (tempo.) **random** samples Represents **<50% of Exposure** (temporal var.)	Measured 'high' vapor conc. + other 'priority' bldgs., typically 10-25% of bldgs.	**75-90%** bldgs. Unsampled are **Assumed < or ~** observed in priority bldgs.
Proposed addition to *Soil Gas Safe Commun.* approach	Source Conc. in soil gas at **POC (& Cleanup Level)**	Large Area Generic defines area, *Then sampling develops a* Community/Site-Specific (**Max. AF Observed**)	Measured I&T guided to peak, Represents **~~100% of Exposure time** (temporal)	Measured, 100% 'accessible' bldgs. Represents **~>50% of all bldgs.** (spatial)	**~<<50% bldgs. Estimated** using **Community-Specific AF** (max. observed)

Social & Participatory incentives with Community-Specific Attenuation Factors

- The max./'high end' observed* fraction of the underlying source conc. found in indoor air (in the community, AF)
  - is used in the screening criteria for **unacceptable source conc**. under all other (unsampled) buildings (expected <<50% of the entire community at risk of VI).
- Any *un*sampled bldg. could have a higher (max. site) AF, & thus it is to the benefit of the occupants of all bldgs. to get their indoor air sampled, to **help protect; not only themselves** in their own building, but to help keep **the entire community** from unacceptable exposures from underlying chemical wastes
- **Use of the max**./'high end' AF from across the site in unsampled bldgs. provides an incentive for Responsible Parties to **get more indoor air samples**

*Verified to not be due to an indoor source

Summary

- While no ‘silver bullet’
  - for instantly accurate, low-cost and easy assessments:
- Such a **Community-specific** approach that,
- Uses indoor air sample from all accessible bldgs. guided by I&T to **sample peaks,** &
- Uses the best **site-specific evidence** available, to estimate indoor air conc. in bldgs. *that can **not** be **sampled***, at this time.
  - Rather than leaving unsampled bldgs. Completely un-evaluated, assumed ‘safe’, or
  - Using an overly generic AF to Over- or Under- protect such bldgs.
- This approach Improves on Generic AF by using **actual neighbors’ measured AF** values & ‘native-deep source’ soil gas conc. & could:
- Have multiple benefits including, being *more*:
    - Protective for all (100%) bldgs.
    - Practical
    - & possibly Cost-effective
  - than typical approaches to VI assessments today

Thank You

- Questions?