# Some Quick Background on Vapor Intrusion

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**Vapor intrusion** involves the migration of chemical vapors in the soil and groundwater to enter buildings through foundation cracks and joints. Sometimes vapor intrusion can result in long-term exposure of contaminants at harmful levels.

- Affects maybe 1/4 of the estimated inventory of 500,000 US brownfields sites.
- At present, no general EPA guidance, though draft guidance has been prepared.
- States regulate, but often very different standards in use.
- Also jurisdictional issues - who is in charge- OSHA? EPA? State?
- No agreement on site investigation practices.
- Limited use of quantitative modeling- very fieldwork based, empirical.

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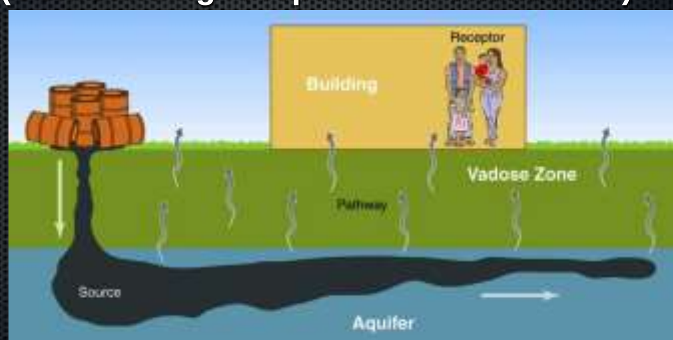
In environmental health risk assessment, for there to be a human health risk there must be a completed exposure pathway, involving identification of a

**- Source (But what if Source Strength is Variable?)**
**- Migration Route (What temporal variation is possible?)**
**- Receptor (Confounding receptor level situations?)**

-Does depth to GW matter?

-Does rain/ice make a difference? Other Seasonal/weather effects?

-What about non-VI background?




(Interstate Technology & Regulatory Council, 2007)

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- So the first step is to decide if a chemical is of concern (a COC)
- Set a maximum allowable exposure, assuming 70 years in a home, 350 days a year at home, whether children are involved...
- Set a regulatory indoor air concentration for the COC ($C_{indoor}$)
- Widely varying, workplace to residence, state to state

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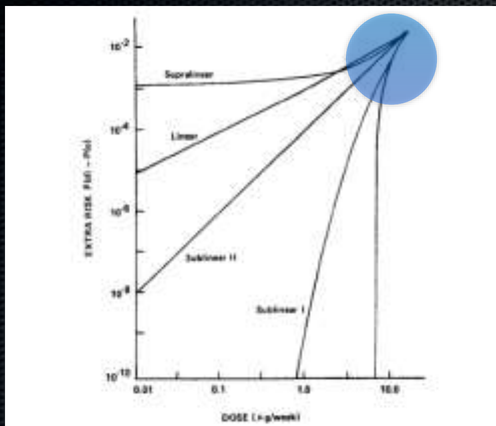


**Figure 4:** Low dose properties of five dose-response functions. Results of alternative extrapolation models for the same experimental data. NOTE: Dose-response functions were developed for data from a benzo-[a]pyrene carcinogenesis experiment in mice conducted by Lee and O'Neill.[11]

## Fundamental problem- extrapolation from animal data to low dose exposures

From *Handbook of Carcinogen Testing* by: Milman, H.A.; Weisburger, E.K.
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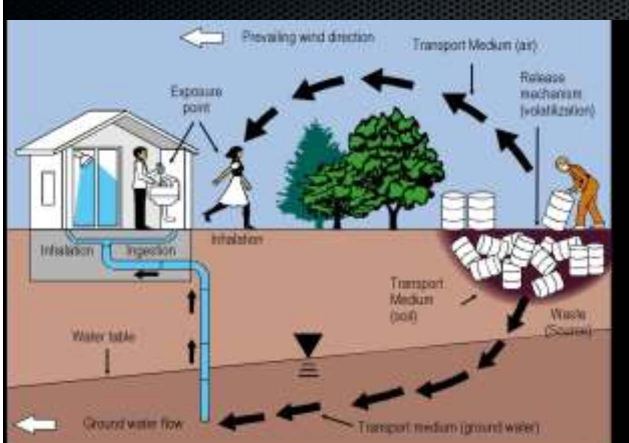


From NEWMOA- "Improving Site Investigation"

Keep in mind- Other exposure routes can come into play (including resident-caused exposures)

Also, can stop drinking polluted water, but replacing the 20 $m^3$/day of air we breathe is tough.

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EPA recommends mitigation for vapor intrusion cancer risks at $10^{-5}$ or $10^{-6}$

Radon cancer risk @ 2 pCi/L
Non-smokers: 4 per 1000 risk ($10^{-2.4}$)
Smokers: 32 per 1000 risk ($10^{-1.5}$)

**Important policy implications regarding being protective against VI risk**

| | | |
|---|---|---|
| | **Zone 2** counties have a predicted average indoor radon screening level between 2 and 4 pCi/L **(orange zones)** | **Moderate Potential** |
| | **Zone 3** counties have a predicted average indoor radon screening level less than 2 pCi/L **(yellow zones)** | **Low Potential** |

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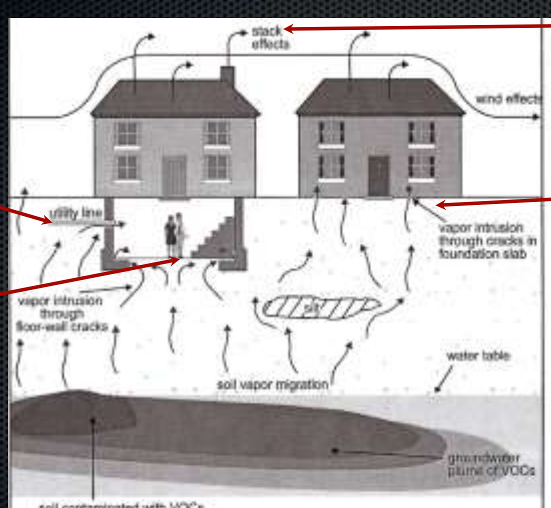
Results in building depressurization of 1 to 50 Pa (5 Pa typical)

“Preferential Pathway”

“Slab”

Subslab



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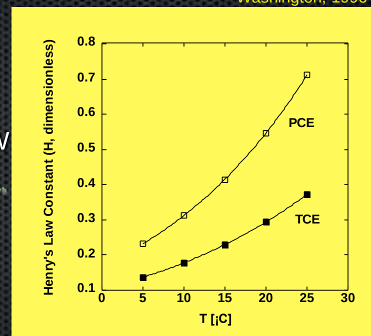
## Henry's Law relates expected soil vapor concentrations to $C_{groundwater\ source}$

$$C_{soil\ gas} = H\ C_{GW}$$

VT TCE GW Screening 1.19 µg/L, Shallow Soil gas 5 µg/m³

Washington, 1996




Shallow groundwater temperatures (Collins, 1925)

If MCL for TCE in drinking water is 5 µg/L leads to about 1 mg/m³ soil gas. EPA recommends non-cancer toxicity level inhalation conc. of 2 µg/m³ (1.2 µg/m³ cancer screening level at $10^{-6}$)

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**Table 2.** Residential screening levels for selected VOCs.

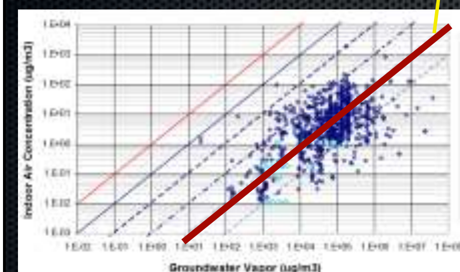
| State | Benzene Groundwater | Benzene Soil Gas | Benzene Indoor Air | TCE Groundwater | TCE Soil Gas | TCE Indoor Air | PCE Groundwater | PCE Soil Gas | PCE Indoor Air |
|---|---|---|---|---|---|---|---|---|---|
| Alaska | 5 | 3.1 | 0.31 | 5 | 0.22 | 0.022 | 5 | 8.1 | 0.81 |
| California | NA | 36.8 | 0.084 | NA | 528 | 1.22 | NA | 180 | 0.41 |
| Colorado | 15 | NA | 0.23 | 5 | NA | 0.016 | 5 | NA | 0.31 |
| Connecticut | 130 | 2480 | 3.3 | 27 | 752 | 1 | 340 | 3798 | 5 |
| Indiana | 85-850 | 250-1400; 25-140^a | 2.5 | 4.6-700 | 120-2000; 8-200^a | 1.2-4.1 | 7.4-1100 | 320-5200; 32-520^a | 3.2-10 |
| Louisiana | 2,900 | NA | 12 | 10,000 | NA | 59 | 15,000 | NA | 110 |
| Maine | NA | NA | 10^b | NA | NA | NA | NA | NA | NA |
| Massachusetts | 3000 | NA | 0.3 | 30 | NA | 1.37 | 50 | NA | 0.04 |
| Michigan | 5800 | 150 | 2.9 | 15,000 | 700 | 14 | 25,000 | 2100 | 42 |
| Minnesota | NA | 1.3-4.5 | 1.3-4.5 | NA | NA | NA | NA | NA | 20 |
| New Hampshire | 2000 | 95 | 1.9 | 50 | 54 | 1.1 | 80 | 68 | 1.4 |
| New Jersey | 15 | 16 | 2 | 1 | 27 | 3 | 1 | 34 | 3 |
| New York | NA | NA | NA | NA | NA | 5 | NA | NA | 100 |
| Ohio | 14 | 31 | 3.1 | – | 122 | 12.2 | 11 | 81 | 8.1 |
| Oklahoma | 5 | 3.1 | 0.27 | 5 | 0.17 | 0.017 | 5 | 0.33 | 0.33 |
| Oregon | 160 | NA | 0.27 | 6.5 | NA | 0.018 | 78 | NA | 0.34 |
| Pennsylvania | 3500 | NA | 2.7 | 14,000 | NA | 12 | 42,000 | NA | 36 |

Notes: Units are µg/L for groundwater and µg/m³ for soil gas and indoor air. See individual state guidance documents for additional information, including limitations and exceptions. Trigger or action levels for mitigation based on indoor air concentrations may be higher than the screening levels shown. ^a Second range of values shown is for subslab soil gas. ^b Chronic exposure value.

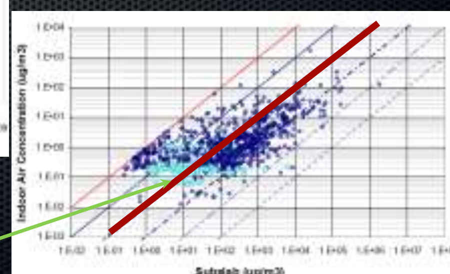
From Eklund, Folkes, Kabel, Farnum, in EM, 2007.

## U.S. EPA empirical "attenuation factor" approach for predicting indoor air concentrations

- Based upon empirical observation.
- $C_{indoor}/C_{groundwater\ source}$ =$10^{-4}$




**Groundwater Source- fairly conservative**




- $C_{indoor}/C_{subslab}$ = $10^{-2}$ to $10^{-3}$

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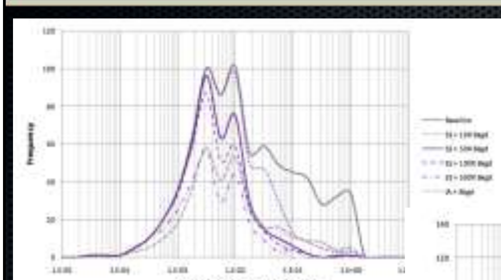
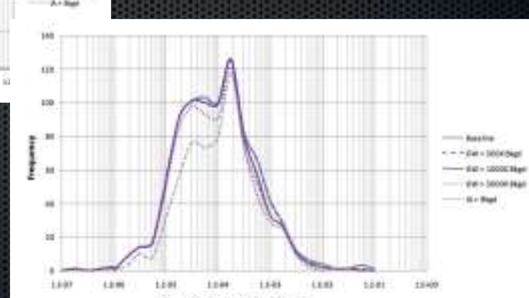



**EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings (March 16, 2012)**




$$AF_{VI} = \frac{C_{IA-VI}}{C_{SS}} \times \frac{C_{SS}}{C_{SV}}$$

$$AF_{VI} = AF_{bldg} \times AF_{soil}$$

overall vapor intrusion attenuation factor ($AF_{VI}$)

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**Table 4.** Attenuation values used in state VI guidance

| State | Attenuation Coefficients: Groundwater | Shallow Soil Gas | Deep Soil Gas | BTEX | Crawl Spaces |
|---|---|---|---|---|---|
| Alaska | 0.001 | 0.1 | 0.01 | NA | NA |
| California | NA | 0.01 - 0.002 | same as shallow | NA | 0.002 |
| Colorado | NA | 0.1 (subslab) | NA | NA | 1 |
| Connecticut | 0.001 | 0.001 | NA | NA | NA |
| Indiana | NA | subslab = 0.1 soil gas = 0.01 | 0.01 | NA | 1 |
| Louisiana | NA | NA | NA | NA | NA |
| Maine | NA | NA | NA | NA | NA |
| Massachusetts | Based on J&E model | NA | NA | Adjusted by 10x | NA |
| Michigan | Based on J&E model | 0.02 | 0.002 | NA | NA |
| Minnesota | NA | NA | NA | NA | NA |
| New Hampshire | Based on J&E model | 0.02 | 0.02 | Groundwater values adjusted by 10x | 1 |
| New Jersey | Based on J&E model | 0.02 | NA | 0.002 | 1 |
| New York | NA | NA | NA | NA | NA |
| Ohio | 0.001 | 0.1 | 0.01 | NA | NA |
| Oklahoma | | 0.1 (subslab) | 0.1 (8-10 ft) | NA | 1 |
| Oregon | 0.002 | NA | NA | NA | NA |
| Pennsylvania | NA | 0.01 | NA | NA | NA |

VT screening 0.1 relative to shallow soil gas, 0.01 to deep soil gas.

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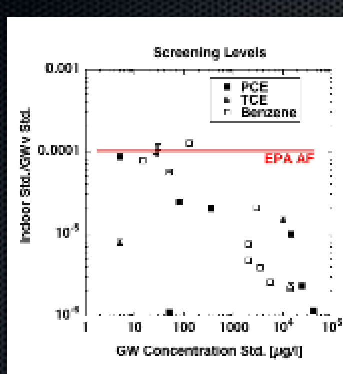


Data for CO, LA, CT, MA, NH, MI, PA. Henry's Law constants for benzene, TCE and PCE from EPA website, 25° C

Higher GW Concentration Standards associated with higher assumed AFs.

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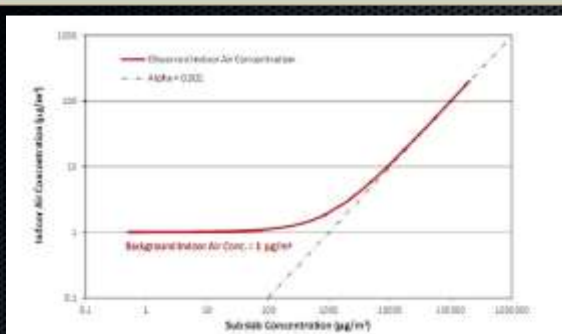

**EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings (March 16, 2012)**

The empirical Attenuation Factor includes contributions from the "true" Attenuation Factor ($AF_{VI}$) and (indoor) background. In EPA analysis, $C_{SV}$ represents COC concentration at any reference point in the soil path (including at the source).

$$AF_{EMP} = \frac{C_{IA}}{C_{SV}} = \frac{(C_{IA-VI} + C_{IA-BKGD})}{C_{SV}} = AF_{VI} + \frac{C_{IA-BKGD}}{C_{SV}}$$

$$AF_{EMP} = [\, AF_{bldg} + \frac{C_{IA-BKGD}}{C_{SS}} \,] \times AF_{soil}$$

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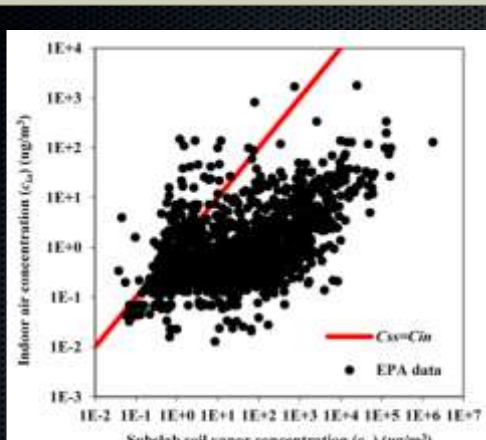


Fig. 5 Indoor Air Concentration as a function of subslab concentration [23].

It is a real effect, of concern in almost all data sets for the chlorinated solvents (i.e, TCE, PCE)

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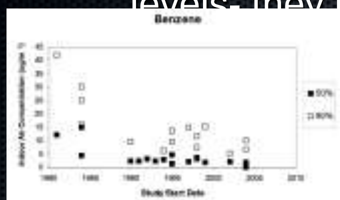
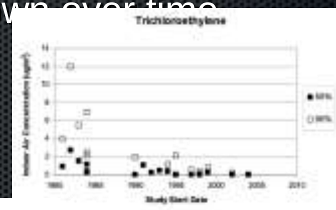
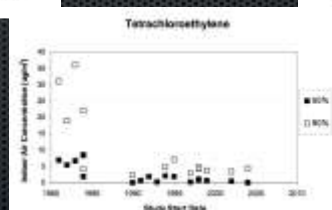
## Need to watch what values you assume for background levels- they have gone down over time




Source: Background Indoor Air Concentrations of VOCs in North American Residences: A Compilation of Statistics and Implications for Vapor Intrusion by Helen Dawson (EPA)




- A number of VOCs have typical (median) background concentrations above the $10^{-6}$ risk level (benzene, carbon tetrachloride, chloroform, methylene chloride, PCE)
- Several others exceed $10^{-6}$ risk levels about 10% of time (1,2-DCA, TCE, vinyl chloride)

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## How far is far enough??


$$D_e\left(\frac{\partial^2 C}{\partial x^2}+\frac{\partial C^2}{\partial y^2}\right)=0$$

Lowell and Eklund, 2004

Solved simple 2-D Laplace Equation

insignificant at lateral distances of only η = 5. The value of 100 ft given in the U.S. EPA guidance is a conservative upper limit for sites with groundwater shallower than 10 ft and diffusion-limited vapor transport. Our work suggests that the risk from breathing contaminated indoor air from subsurface contamination need only be investigated for buildings within a relatively short distance (e.g., within one or two residential sized lots) from the edge of the contamination plume.

Echoed in various guidance documents, but challenged by Abreu and Johnson, 2005 for homogeneous soils.

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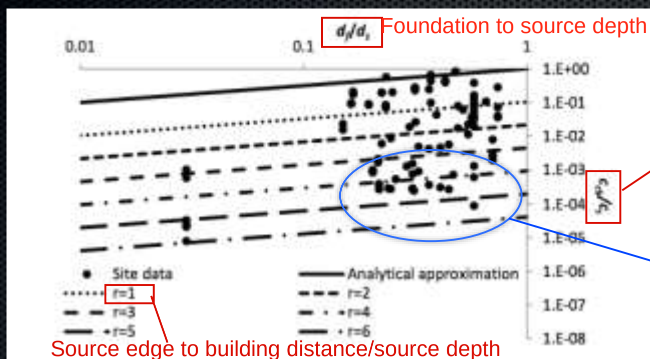
## How close should GW Source measurements be?




Yao et al. *Vadose Zone Journal*,2013

Subslab to Source Concentration

Unusually high source to slab attenuation can have an origin in GW sources that are not really that "close"

Consider 2 m deep basement, 4 m deep source, sampling GW at r= 5 i.e., 20 m away, can lead to significant extra attenuation

Also, at what depth to sample GW?

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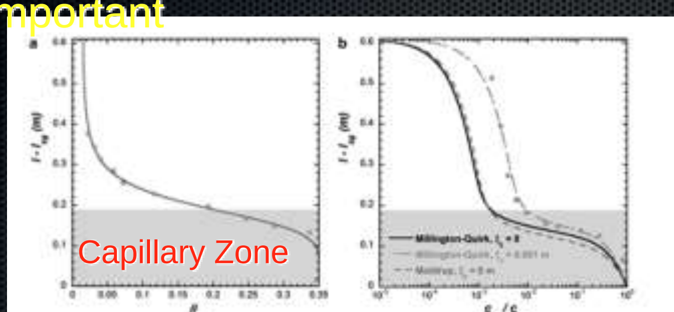
## Capillary zone resistance is very important




From Shen et al., *Env. Engineering Sci.* , 2013

Shows extent to which open porosity filled with water; diffusion through water layer slow

Shows how dramatically COC concentration drops through capillary zone- big part of $AF_{soil}$

**Relates to critical issue- the role of GW vertical concentration profiles**

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# Indoor Air sampling

Typical TO-15 with 6L summa

Intrusive, expensive, and is it even reliable as an indication of risk?

Need a lot of care to avoid being misled by background.

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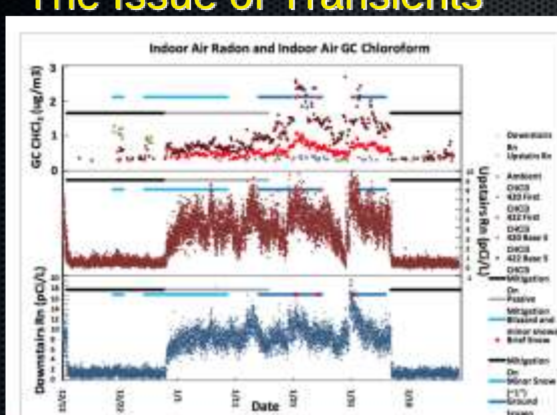
# The Issue of Transients




Sample data from a 2013 AEHS Conference Workshop by Schumacher et al. Samples from a duplex in Indianapolis.

Note the wide variability over short sampling times.

Correlation with Radon not particularly good.

Seasonal variability in indoor air higher than in subslab.

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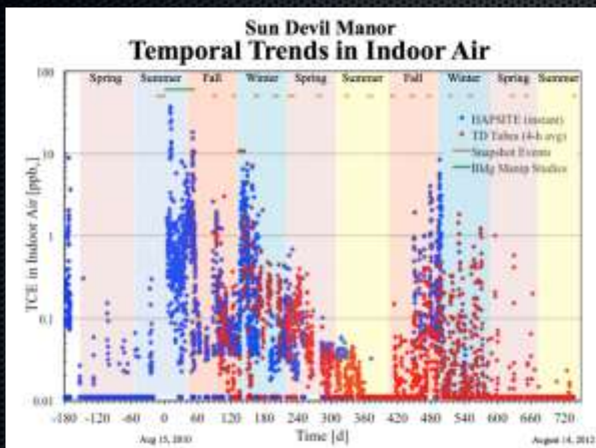
# Another example from Utah




From a paper by Lutes, Johnson and Truesdale, AEHS, 2013.

So what would be the recommended action?

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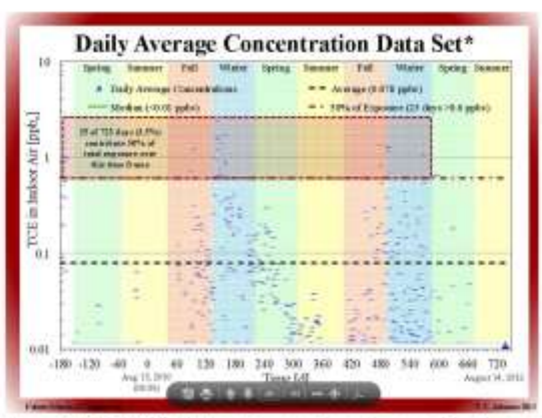
# Episodic Peaks Drive Exposure

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




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

Courtesy: Henry Schuver, EPA

# The majority of VI exposure could be unpredictable!

One time assessments are increasingly unlikely to be considered satisfactory…

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# Soil gas and subslab

- Subslab still very intrusive, and can be misleading (discussed in modeling results)
- Soil gas often misunderstood. "Open field" soil gas of limited value in understanding what happens in the presence of buildings, paving, or even frozen ground surface.

# Mathematical Models

- Johnson and Ettinger 1-D screening tool.
- Basis for EPA spreadsheet approach.
- Can either over- or under-predict values relative to more complete 3-D analysis; forced 1-D aspect creates an unrealistic situation of all contaminant vapor from beneath a structure being taken into the structure (see Yao et al. 2011, *ES&T).*

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## Multiple Lines of Evidence

- Indoor Air Sampling (properly conducted)
- Groundwater Sampling (properly conducted)
- Soil Vapor Sampling (including subslab)
- Modeling

There is a general feeling that reliance on only one or two lines of evidence can be misleading- Reliable VI characterization remains a significant challenge and complete investigation can be expensive.

## Paul Johnson, and Henry Schuver

### Now What Do We Do?

Assuming that indoor air measurements will continue to be weighted heavily in future VI pathway assessment…

- evaluate the robustness of practicable combinations of different sampling durations and frequencies (daily, weekly, 3-weeks, seasonal)

**What is a "robust" VI sampling plan?**

One that produces data that lead to a high probability of correct and confident answers to questions like:

- Is the VI pathway complete?
- Are the indoor air concentrations and resulting exposures over periods of interest likely to exceed thresholds of concern?

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### The Burden of Proof for Chemical VI

- Original Presumption:
  - VI pathway incomplete, until shown otherwise
- Evidence (from buildings over VI source areas):
  - Soil Gas Intrusion – occurs in episodic time periods
    - with some varying amount of subsurface chemical vapors
    - Assess. difficult, costly, and can be inaccurate
- Alternative (rebuttable) approach for CVI*
  - VI pathway is 'complete' to some degree (poss. Signif.)
    - Until demonstrated otherwise:

* As for Radon

From Henry Schuver, EPA

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## Summary

- There exists a large variation in Attenuation Factors, for reasons that are only partly understood.
- Essential to consider background concentrations (and to measure or at least use current estimates).
- How close should a GW monitoring well be, to be reliable?
- There needs to be the awareness of transients, some very short term, some seasonal, and some very long time scale.

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# Resources


- United States Environmental Protection Agency (USEPA). Office of Solid Waste and Emergency Response (OSWER). *EPA's vapor intrusion database: evaluation and characterization of attenuation factors for chlorinated volatile organic compounds and residential buildings* (EPA 530-R-10-002). March **2012.**
- United States Environmental Protection Agency (USEPA). Background Indoor Air Concentrations of Volatile Organic Compounds in North American Residences (1990–2005): A Compilation of Statistics for Assessing Vapor Intrusion. Office of Solid Waste and Emergency Response (OSWER). EPA 530-R-10- 001, **2011.**
- United States Environmental Protection Agency (USEPA). *Superfund Vapor Intrusion FAQs*. **2012**. www.epa.gov/superfund/sites/npl/Vapor_Intrusion_FAQs_Feb2012.pdf
- United States Environmental Protection Agency (USEPA). *Vapor Intrusion Screening Level (VISL) Calculator*. Office of Solid Waste and Emergency Response (OSWER) and Office of Superfund Remediation and Technology Innovation (OSTRI), March **2012**.

# Resources (Cont'd)


- United States Environmental Protection Agency (USEPA). Office of Solid Waste and Emergency Response (OSWER). EPA's conceptual model scenarios for the vapor intrusion pathway (EPA 530-R-10-003). February **2012**
- NYSDOH (New York State Department of Health). 2006. Guidance for Evaluating Soil Vapor Intrusion in the State of New York. Troy, N.Y.: Center for Environmental Health, Bureau of Environmental Exposure Investigation. (www.nyhealth.gov/environmental/indoors/vapor_intrusion/).
- Interstate Technology and Regulatory Council (ITRC). *Vapor Intrusion Pathway: A Practical Guideline*. Washington, D.C., **2007.**


Courtesy: Professor Kelly Pennell, UKY