Overview of Vapor Intrusion and Characterization of Exposure Risks

Presented by
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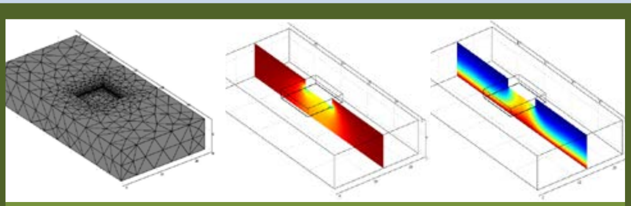


$$J_T = q \cdot C - D_{ig} \nabla C$$

$$D_{ig} = d_i^{air} \cdot \frac{\eta_g^{10/3}}{\eta_T^{2}}$$

$$q = \frac{k \cdot \rho_g \cdot d\phi}{\mu_g}$$

$$d\phi = gz + \int_{P_0}^{P} \frac{dP}{\rho}$$

BROWN

Superfund Research Program

NEWMOA/ Brown SRP
Vapor Intrusion Workshop

September 26 and 26, 2013

University of Kentucky

Overview

Some Key Questions for Today

- Vapor Intrusion
  - What is it?
- Exposure Risks
  - Are they possible?
  - What is the nature and extent?
- Multiple Lines of Evidence
  - How can we interpret the results?

Vapor Intrusion

What is it?

What is it?

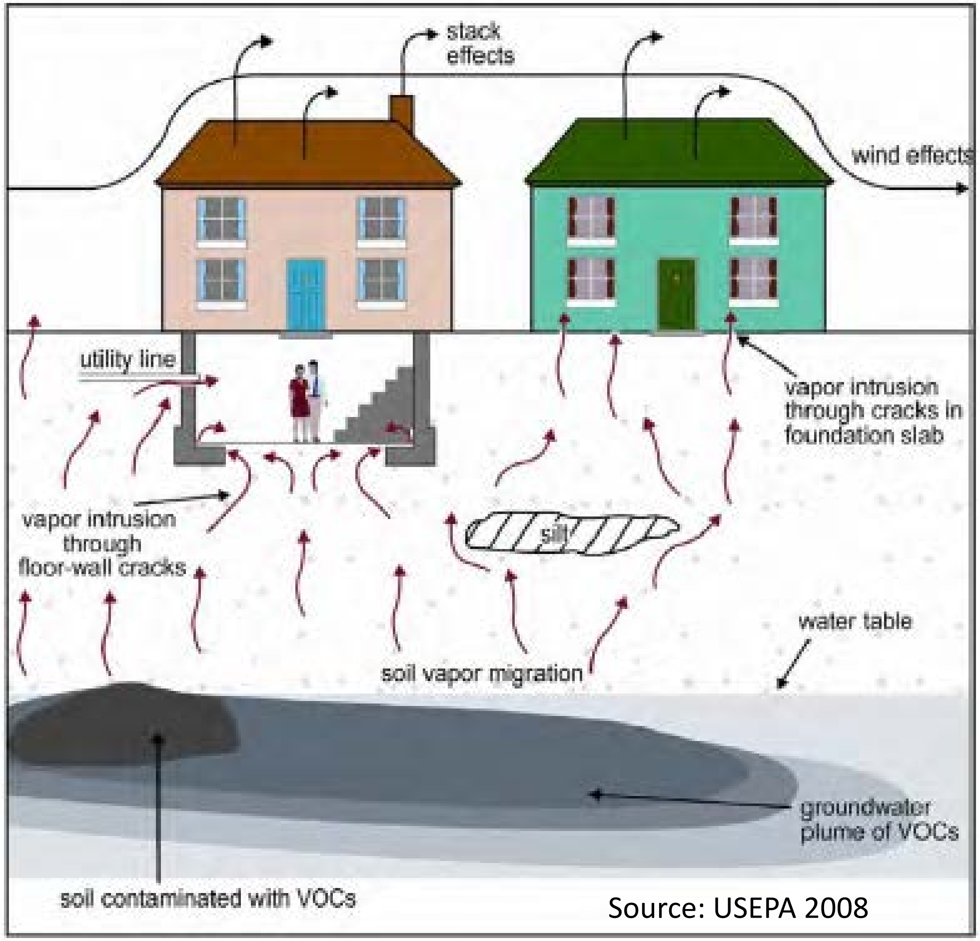
Migration of subsurface vapors into indoor air spaces.

How is it different than other exposures?

Unlike dermal and ingestion exposures, exposure pathway can not be avoided —people have few alternatives to breathing ambient air.

Is it a "real" concern?

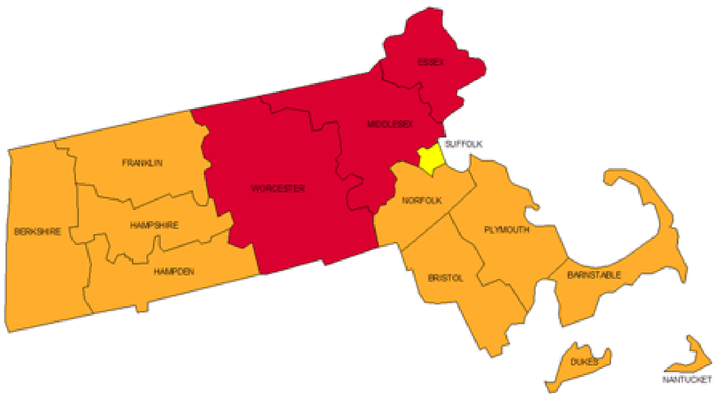
Yes. Vapor intrusion has been documented at numerous hazardous waste sites. EPA requires the pathway be evaluated as part of site assessments, but finalized regulatory guidance has not been issued.



Source: USEPA 2008

Vapor Intrusion

Volatile Organic Chemicals (VOCs) vs. Radon



(red)	**Zone 1** counties have a predicted average indoor radon screening level greater than 4 pCi/L (pico curies per liter) **(red zones)**	**Highest Potential**
(orange)	**Zone 2** counties have a predicted average indoor radon screening level between 2 and 4 pCi/L **(orange zones)**	**Moderate Potential**
(yellow)	**Zone 3** counties have a predicted average indoor radon screening level less than 2 pCi/L **(yellow zones)**	**Low Potential**

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

Radon Cancer Risk at 2pCi/L (Recommended level to mitigate)

Non-smoker

4 cancers per 1000 people

Risk = 4/1000 = $10^{-2.4}$

Smoker

32 cancers per 1000 people

Risk = 32/1000 = $10^{-1.5}$

Vapor Intrusion

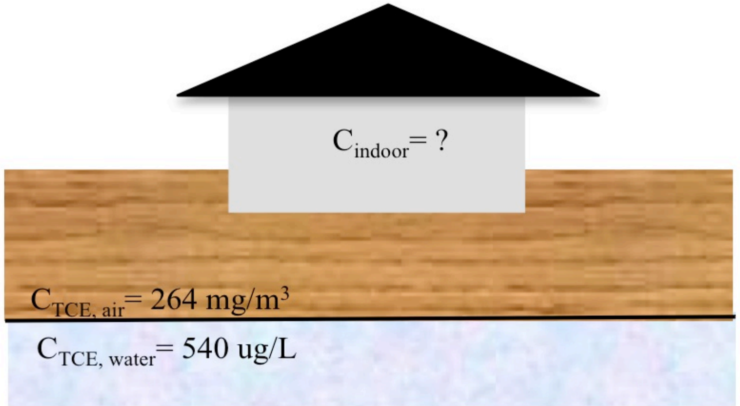
What chemicals are concerns?

Water-Air Equilibrium Partitioning:

If we assume equilibrium partitioning between the groundwater and the soil vapor, then we can apply Henry's Law.

$$K_H = \frac{C_{air}}{C_{water}}$$

K_H = Henry's Law dimensionless partitioning constant (for TCE~0.5)
C_{water} = Concentration in groundwater
C_{air} = Concentration in air at the soil/water interface



Example: In Rhode Island, the non-potable groundwater standard for TCE is 540 µg/L. Applying Henry's Law, $C_{TCE,air}$= 264 mg/m^3, which is less than the OSHA PEL (537 mg/m^3). However, it is substantially higher than the residential indoor air health-protective range set by EPA 4.3×10^{-4} mg/m^3 to 2.1×10^{-3} mg/m^3.

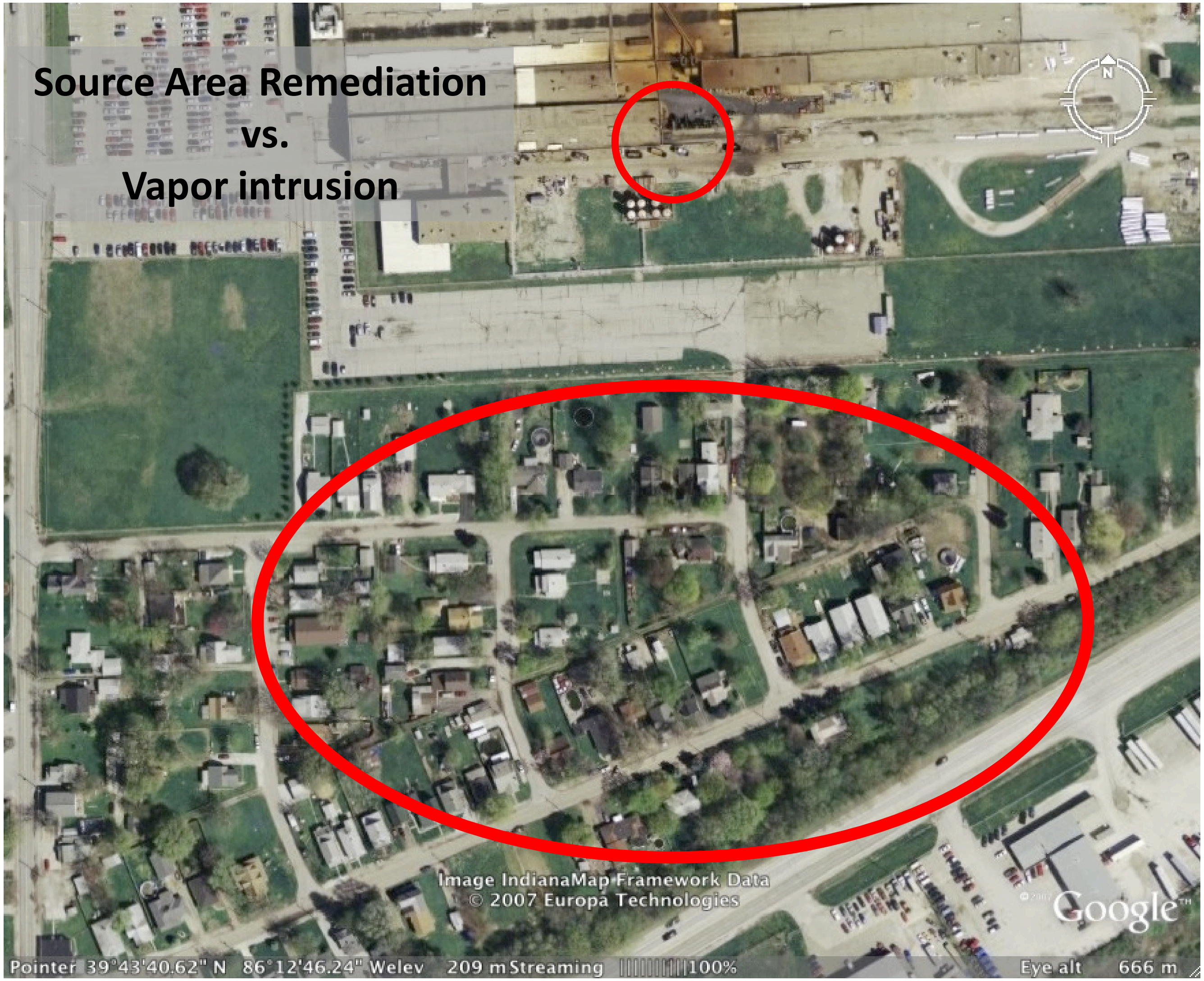
VOCs (some SVOCs) are vapor intrusion chemicals.

Petroleum hydrocarbons are known to biodegrade. Vapor intrusion of petroleum hydrocarbons are managed differently (www.epa.gov/oust/cat/pvi/).

This workshop focuses on VOCs that are not readily biodegraded (e.g. PCE, TCE, etc.)

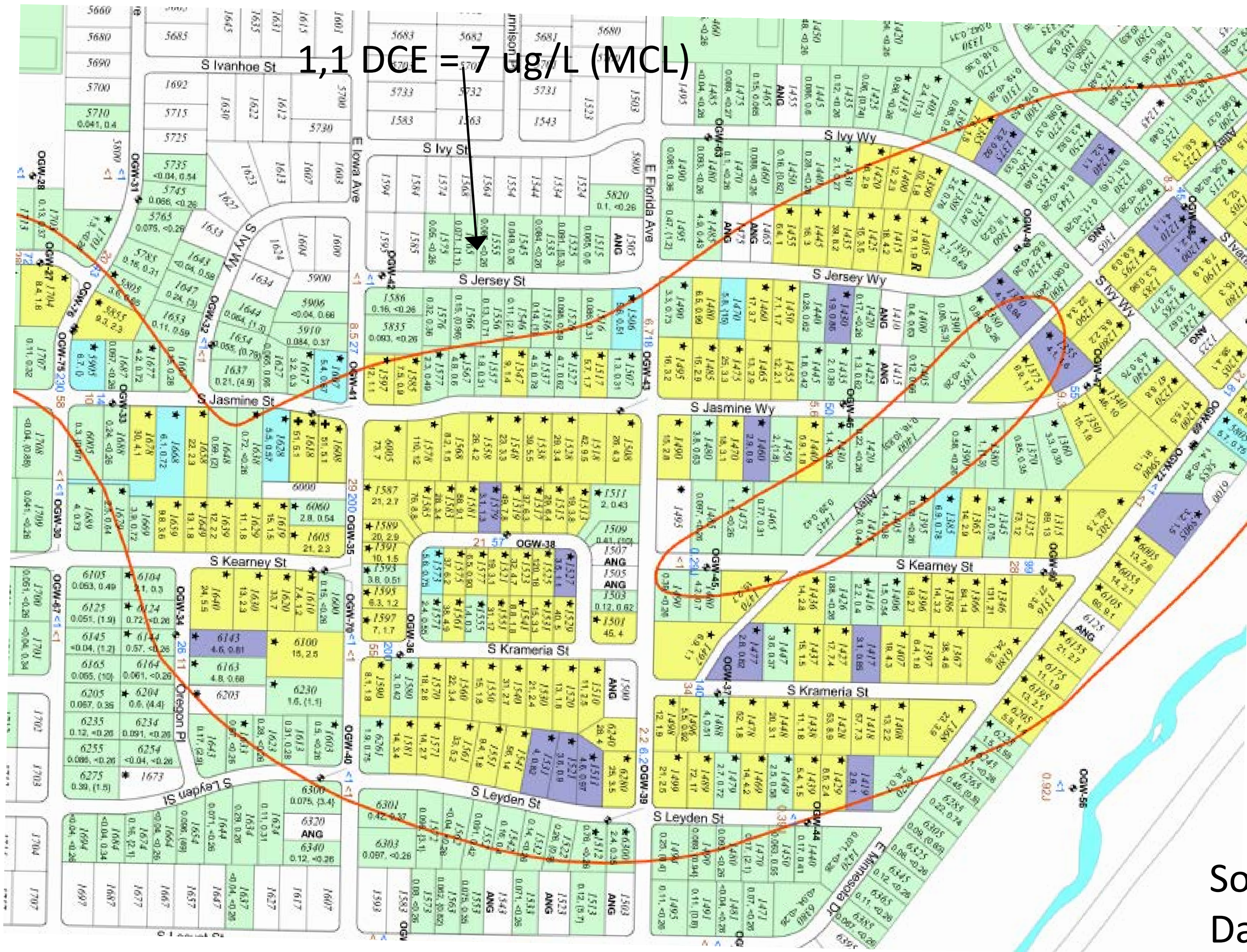
Vapor Intrusion

Which poses the greater challenge?



Vapor Intrusion

Example: Redfield Site, CO



Colored squares indicate indoor contamination.

Over 700 homes were "sampled."

Stars indicate mitigation

Source:
David Folkes, Envirogroup

Vapor Intrusion

Community Perception

"Hi, I'm from the government. I am here to drill a hole in your floor…"

--Lenny Siegel, Center for Environmental Protection and Oversight (CEPO)

Community Outreach and Involvement Plans are an important part of vapor intrusion

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- Characterization
  - How can we interpret the data?

Exposure Risks

Are they possible?

Attenuation factors ("alpha values")

$$\alpha_i = \frac{\text{Indoor Air Concentration}}{\text{Soil Gas Concentration}_{\text{collected at location i}}}$$

α_{source} = 0.001 and $\alpha_{subslab}$=0.1 for generic screening values.

Useful Tool: 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.

*www.epa.gov/oswer/**vaporintrusion**/documents/**VISL-Calculator**.xlsm*

Exposure Risks

Are they possible?

*www.epa.gov/oswer/**vaporintrusion**/documents/**VISL-Calculator**.xlsm*

VISL-Calculator.xls

OSWER VAPOR INTRUSION ASSESSMENT

Vapor Intrusion Screening Level (VISL) Calculator Version 3.1, June 2013 RSLs

Parameter	Symbol	Value	Instructions
Exposure Scenario	Scenario	Residential	Select residential or commercial scenario from pull down list
Target Risk for Carcinogens	TCR	1.00E-06	Enter target risk for carcinogens
Target Hazard Quotient for Non-Carcinogens	THQ	1	Enter target hazard quotient for non-carcinogens
Average Groundwater Temperature (°C)	Tgw	25	Enter average of the stabilized groundwater temperature to correct Henry's Law Constant for groundwater target concentrations

View Checked Chemicals

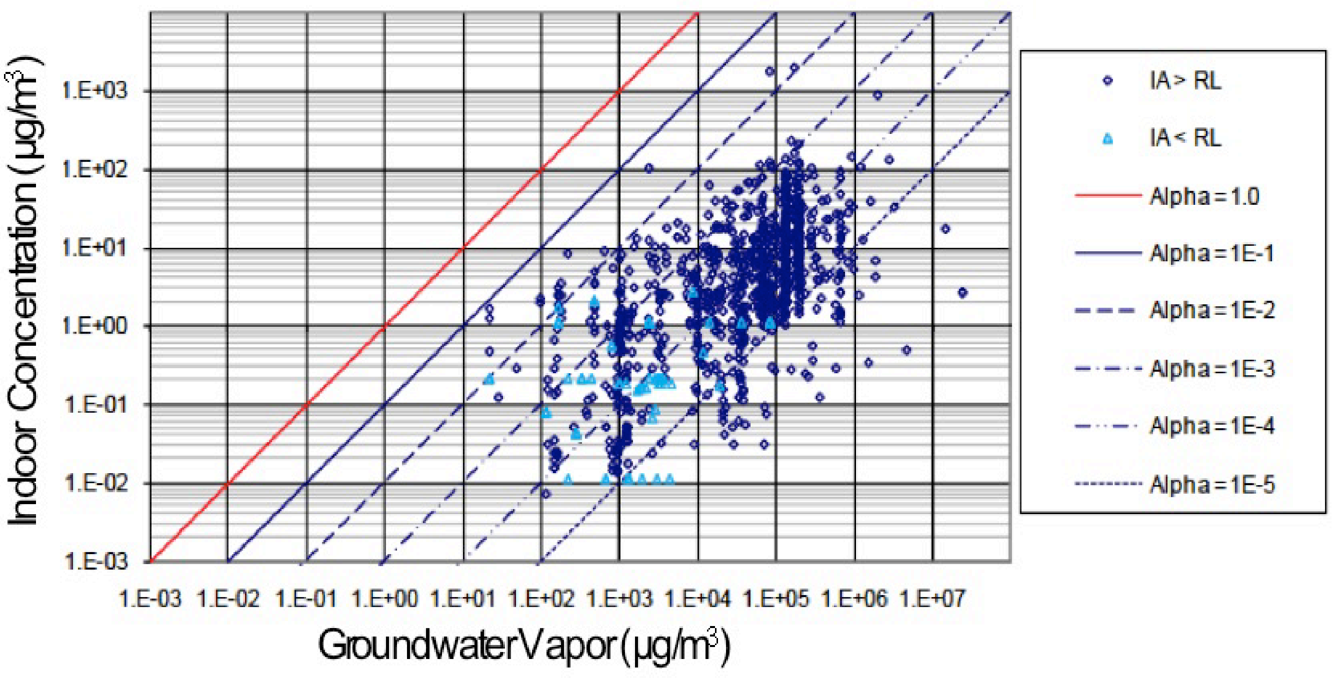
View All Chemicals

	CAS	Chemical Name	Is Chemical Sufficiently Volatile and Toxic to Pose Inhalation Risk Via Vapor Intrusion from Soil Source? Cvp > Cia,target? Yes/No	Is Chemical Sufficiently Volatile and Toxic to Pose Inhalation Risk Via Vapor Intrusion from Groundwater Source? Chc > Cia,target? Yes/No	Target Indoor Air Conc. @ TCR = 1E-06 or THQ = 1 MIN(Cia,c;Cia,nc) (ug/m^3)	Toxicity Basis C/NC	Target Sub-Slab and Exterior Soil Gas Conc. @ TCR = 1E-06 or THQ = 1 Csg (ug/m^3)	Target Ground Water Conc. @ TCR = 1E-06 or THQ = 1 Cgw (ug/L)	Is Target Ground Water Conc. < MCL? Cgw<MCL? Yes/No (MCL ug/L)	Pure Phase Vapor Conc. @ 25°C Cvp (ug/m^3)	Groundwater Vapor Conc. Chc (ug/m^3)
	75-52-5	Nitromethane	Yes	Yes	2.7E-01	C	2.7E+00	2.3E+02	--	1.18E+08	1.30E+08
	79-46-9	Nitropropane, 2-	Yes	Yes	9.0E-04	C	9.0E-03	1.9E-01	--	8.25E+07	8.27E+07
	924-16-3	Nitroso-di-N-butylamine, N-	Yes	Yes	1.5E-03	C	1.5E-02	2.8E+00	--	3.99E+05	6.85E+05
	88-72-2	Nitrotoluene, o-	No Inhal. Tox. Info	No Inhal. Tox. Info	--	--	--	--	--	1.39E+06	3.32E+05
	111-84-2	Nonane, n-	Yes	Yes	2.1E+02	NC	2.1E+03	1.5E+00	--	3.07E+07	3.06E+07
	109-66-0	Pentane, n-	Yes	Yes	1.0E+03	NC	1.0E+04	2.0E+01	--	2.00E+09	1.94E+09
	75-44-5	Phosgene	Yes	Yes	3.1E-01	NC	3.1E+00	4.6E-01	--	7.56E+09	4.66E+09
	123-38-6	Propionaldehyde	Yes	Yes	8.3E+00	NC	8.3E+01	2.8E+03	--	9.91E+08	9.18E+08
	103-65-1	Propyl benzene	Yes	Yes	1.0E+03	NC	1.0E+04	2.4E+03	--	2.21E+07	2.24E+07
	115-07-1	Propylene	Yes	Yes	3.1E+03	NC	3.1E+04	3.9E+02	--	1.97E+10	1.60E+09
	75-56-9	Propylene Oxide	Yes	Yes	6.6E-01	C	6.6E+00	2.3E+02	--	1.68E+09	1.68E+09
	129-00-0	Pyrene	No Inhal. Tox. Info	No Inhal. Tox. Info	--	--	--	--	--	4.90E+01	6.57E+01
	110-86-1	Pyridine	No Inhal. Tox. Info	No Inhal. Tox. Info	--	--	--	--	--	8.85E+07	4.50E+08
	100-42-5	Styrene	Yes	Yes	1.0E+03	NC	1.0E+04	9.3E+03	No (100)	3.59E+07	3.48E+07
	630-20-6	Tetrachloroethane, 1,1,1,2-	Yes	Yes	3.3E-01	C	3.3E+00	3.2E+00	--	1.08E+08	1.09E+08
x	79-34-5	Tetrachloroethane, 1,1,2,2-	Yes	Yes	4.2E-02	C	4.2E-01	2.8E+00	--	1.20E+08	4.25E+07
x	127-18-4	Tetrachloroethylene	Yes	Yes	9.4E+00	C	9.4E+01	1.3E+01	No (5)	1.65E+08	1.49E+08
	811-97-2	Tetrafluoroethane, 1,1,1,2-	Yes	Yes	8.3E+04	NC	8.3E+05	4.1E+04	--	2.60E+10	2.23E+09
	109-99-9	Tetrahydrofuran	Yes	Yes	2.1E+03	NC	2.1E+04	7.2E+05	--	6.29E+08	2.88E+09
x	108-88-3	Toluene	Yes	Yes	5.2E+03	NC	5.2E+04	1.9E+04	No (1000)	1.41E+08	1.43E+08
	76-13-1	Trichloro-1,2,2-trifluoroethane, 1,1,2-	Yes	Yes	3.1E+04	NC	3.1E+05	1.5E+03	--	3.66E+09	3.65E+09
	87-61-6	Trichlorobenzene, 1,2,3-	No Inhal. Tox. Info	No Inhal. Tox. Info	--	--	--	--	--	2.05E+06	9.20E+05
	120-82-1	Trichlorobenzene, 1,2,4-	Yes	Yes	2.1E+00	NC	2.1E+01	3.6E+01	Yes (70)	4.49E+06	2.84E+06
x	71-55-6	Trichloroethane, 1,1,1-	Yes	Yes	5.2E+03	NC	5.2E+04	7.4E+03	No (200)	8.90E+08	9.07E+08
x	79-00-5	Trichloroethane, 1,1,2-	Yes	Yes	1.5E-01	C	1.5E+00	4.5E+00	Yes (5)	1.65E+08	1.55E+08
x	79-01-6	Trichloroethylene	Yes	Yes	4.3E-01	C	4.3E+00	1.1E+00	Yes (5)	4.88E+08	5.15E+08
	75-69-4	Trichlorofluoromethane	Yes	Yes	7.3E+02	NC	7.3E+03	1.8E+02	--	5.94E+09	4.36E+09

Exposure Risks

Are they possible?

Comparison of Chlorinated Hydrocarbon Concentrations in Indoor Air and Groundwater Vapor (Source: EPA 2012), IA=indoor air, RL=reporting limit



Prof. Eric Suuberg will discuss in detail (next presentation).

Note: Using the VISL calculator, TCE groundwater concentration is 1.1 ug/L for 10^{-6} risk. MCL (5 ug/L) is used as limit for screening.

Exposure Risks

A difficult question: What is the nature and extent?

Excerpt from EPA Superfund Vapor Intrusion FAQs

http://www.epa.gov/superfund/sites/npl/Vapor_Intrusion_FAQs_Feb2012.pdf

"Multiple Lines of Evidence"

In general, therefor … lines of evidence to support decision-m … ined the role of lines of evidence. For ex … 007 guidance (ITRC 2007) and DoD's 2009 VI handbook (DoD 2009). Lines of evidence to evaluate the VI pathway may include, but are not limited to, the following:

- Source of the contaminants (dry cleaner, mill or gas station, for example).
- Indoor air data.
- Sub-slab (or crawl-space) soil gas data.
- Concurrent outdoor air data.
- Soil gas data, including some level of vertical and spatial profiling, as appropriate.
- Groundwater data, including some level of vertical and spatial profiling, as appropriate.
- Data trends.
- Background, internal and external, sources.
- Building construction and current conditions, including utility conduits.
- Site geology and history.
- Tracer data.
- Contaminant ratios.

Vapor Intrusion

"Draft" Final VI Guidance

Released for Comment, April 2013:

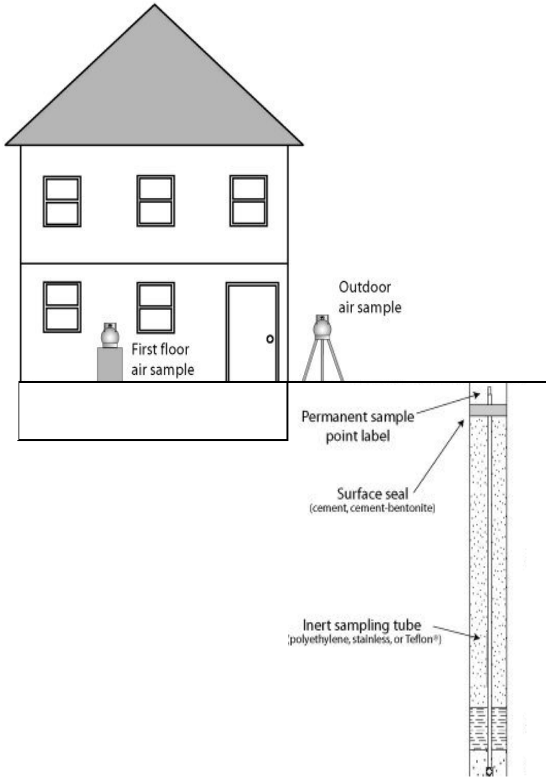
http://www.epa.gov/oswer/vaporintrusion/documents/vaporIntrusion-final-guidance-20130411-reviewdraft.pdf

Exposure Risks

What is the nature and extent?

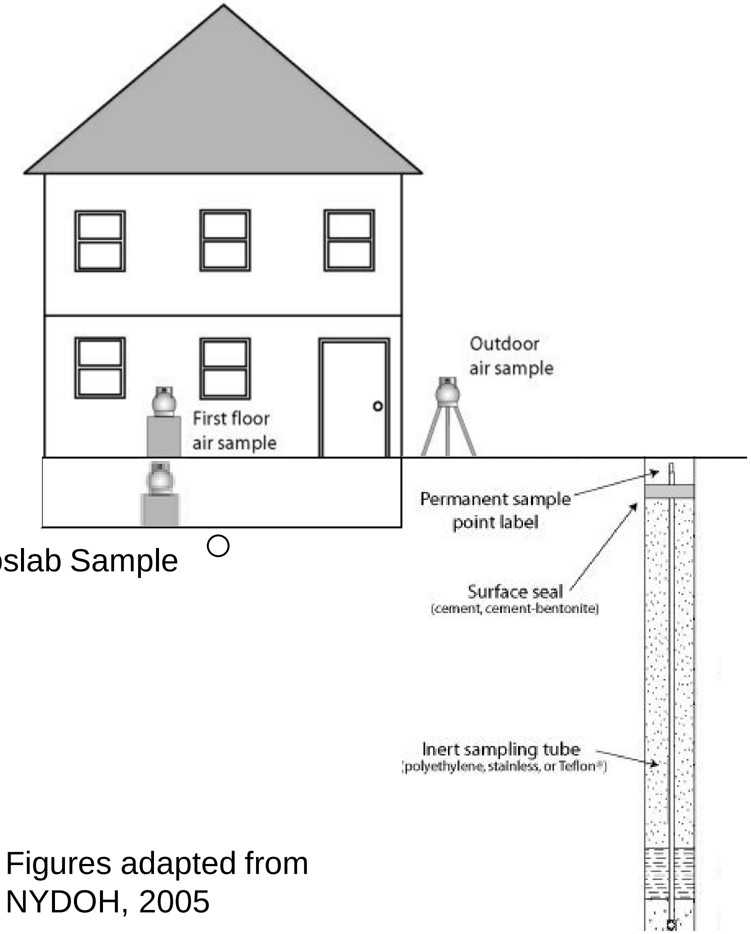
How should we characterize the vapor intrusion pathway?

a) Sample indoor air
b) Modeling
c) Sample groundwater
d) Sample soil vapor
e) All of the above



Exposure Risks

What is the nature and extent?



Subslab Sample

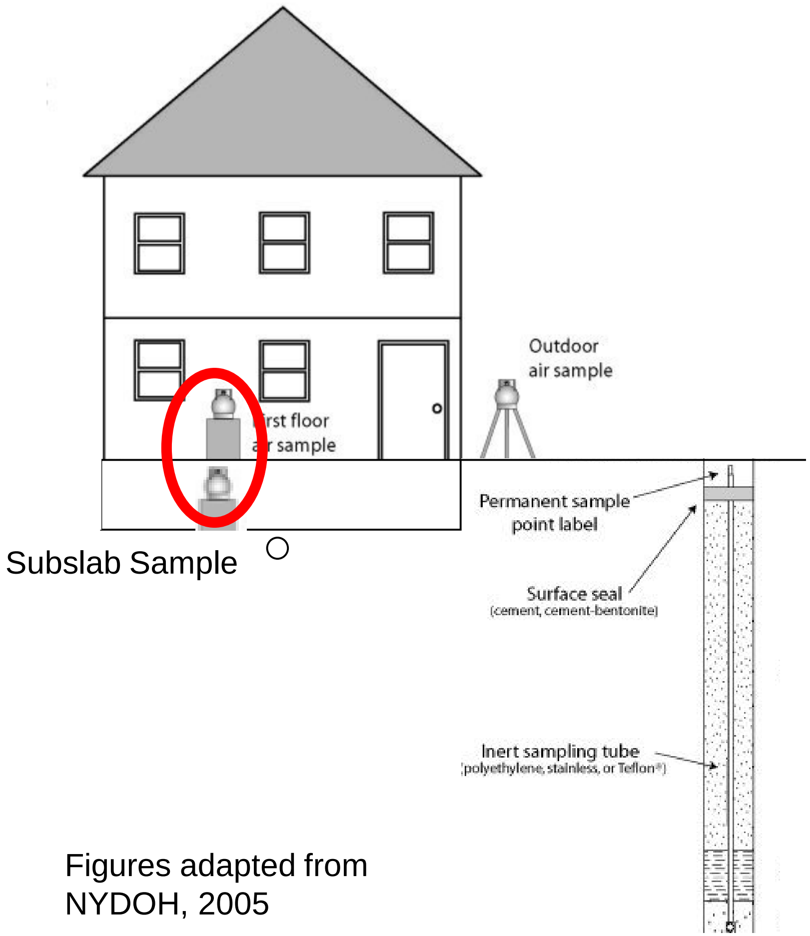
Figures adapted from NYDOH, 2005

Three Common Approaches

1. Indoor Air
2. Subslab Soil Gas
3. Adjacent “Nearby” Soil Gas

Exposure Risks

Indoor Air Samples



Figures adapted from NYDOH, 2005

Common Rationale: Most direct measure of health risks

Flawed Conclusion: Elevated chemical concentrations in indoor air are a result of VI*

Difficult Reality: In many cases, background concentrations exceed EPA 10^{-6} (and even 10^{-5}) risk levels

*Note: VI (Vapor Intrusion)

Exposure Risks

Indoor Air Samples

TO-15 using a 6L summa canister is most common

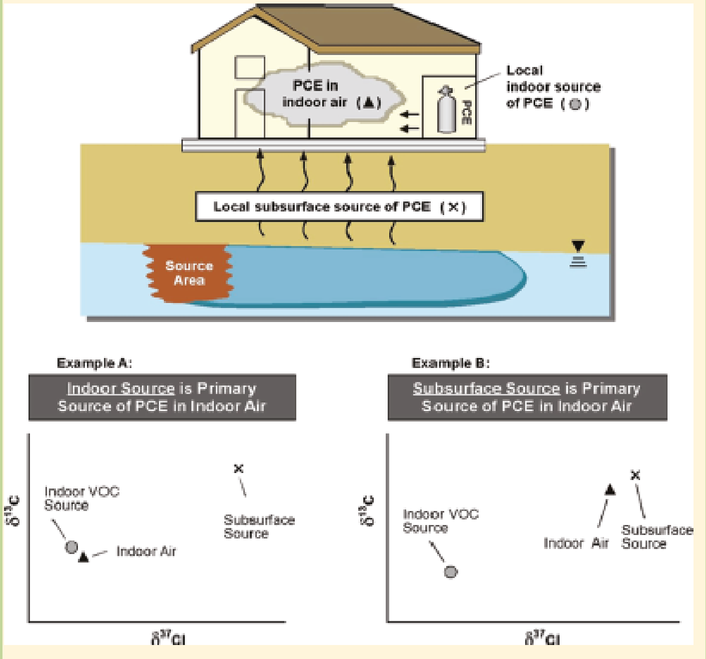
Many references for proper collection

Example: MassDEP

- Residential: 24 hours
- Commercial: 8 hours
- *min of 4 hours
- Multiple sampling events required

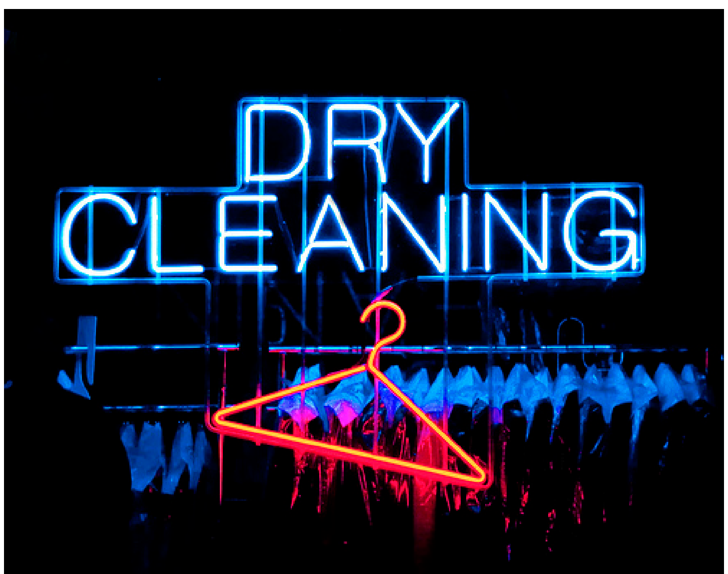
Emerging research:

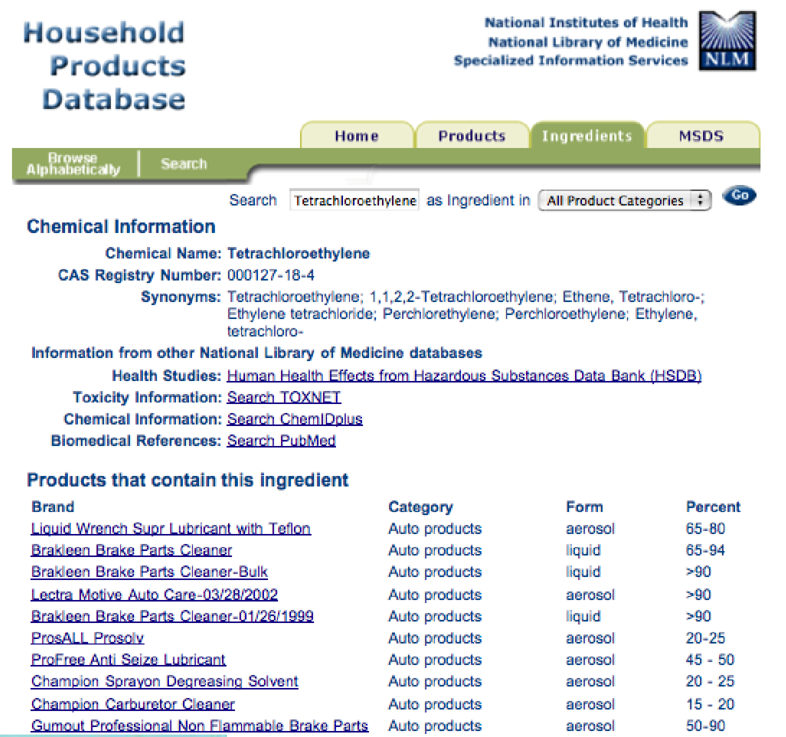
Application of CSIA to Distinguish Between Vapor Intrusion and Indoor Sources of VOCs
McHugh et al. (Environmental Science & Technology, 2011)



Exposure Risks

Indoor Air Challenges





Household Products Database

National Institutes of Health
National Library of Medicine
Specialized Information Services

Home | Products | Ingredients | MSDS

Browse Alphabetically | Search

Search Tetrachloroethylene as Ingredient in All Product Categories Go

Chemical Information

Chemical Name: Tetrachloroethylene
CAS Registry Number: 000127-18-4
Synonyms: Tetrachloroethylene; 1,1,2,2-Tetrachloroethylene; Ethene, Tetrachloro-; Ethylene tetrachloride; Perchlorethylene; Perchloroethylene; Ethylene, tetrachloro-

Information from other National Library of Medicine databases

Health Studies: Human Health Effects from Hazardous Substances Data Bank (HSDB)
Toxicity Information: Search TOXNET
Chemical Information: Search ChemIDplus
Biomedical References: Search PubMed

Products that contain this ingredient

Brand	Category	Form	Percent
Liquid Wrench Supr Lubricant with Teflon	Auto products	aerosol	65-80
Brakleen Brake Parts Cleaner	Auto products	liquid	65-94
Brakleen Brake Parts Cleaner-Bulk	Auto products	liquid	>90
Lectra Motive Auto Care-03/28/2002	Auto products	aerosol	>90
Brakleen Brake Parts Cleaner-01/26/1999	Auto products	liquid	>90
ProsALL Prosolv	Auto products	aerosol	20-25
ProFree Anti Seize Lubricant	Auto products	aerosol	45 - 50
Champion Sprayon Degreasing Solvent	Auto products	aerosol	20 - 25
Champion Carburetor Cleaner	Auto products	aerosol	15 - 20
Gumout Professional Non Flammable Brake Parts	Auto products	aerosol	50-90

/household/brands?tbl=chem&id=177&query=Tetrachloroethylene&prodcat=all   Page 1 of 2

Molded Plastic (Christmas ornaments, toys, etc.) can be a source of 1, 2 DCA

Exposure Risks

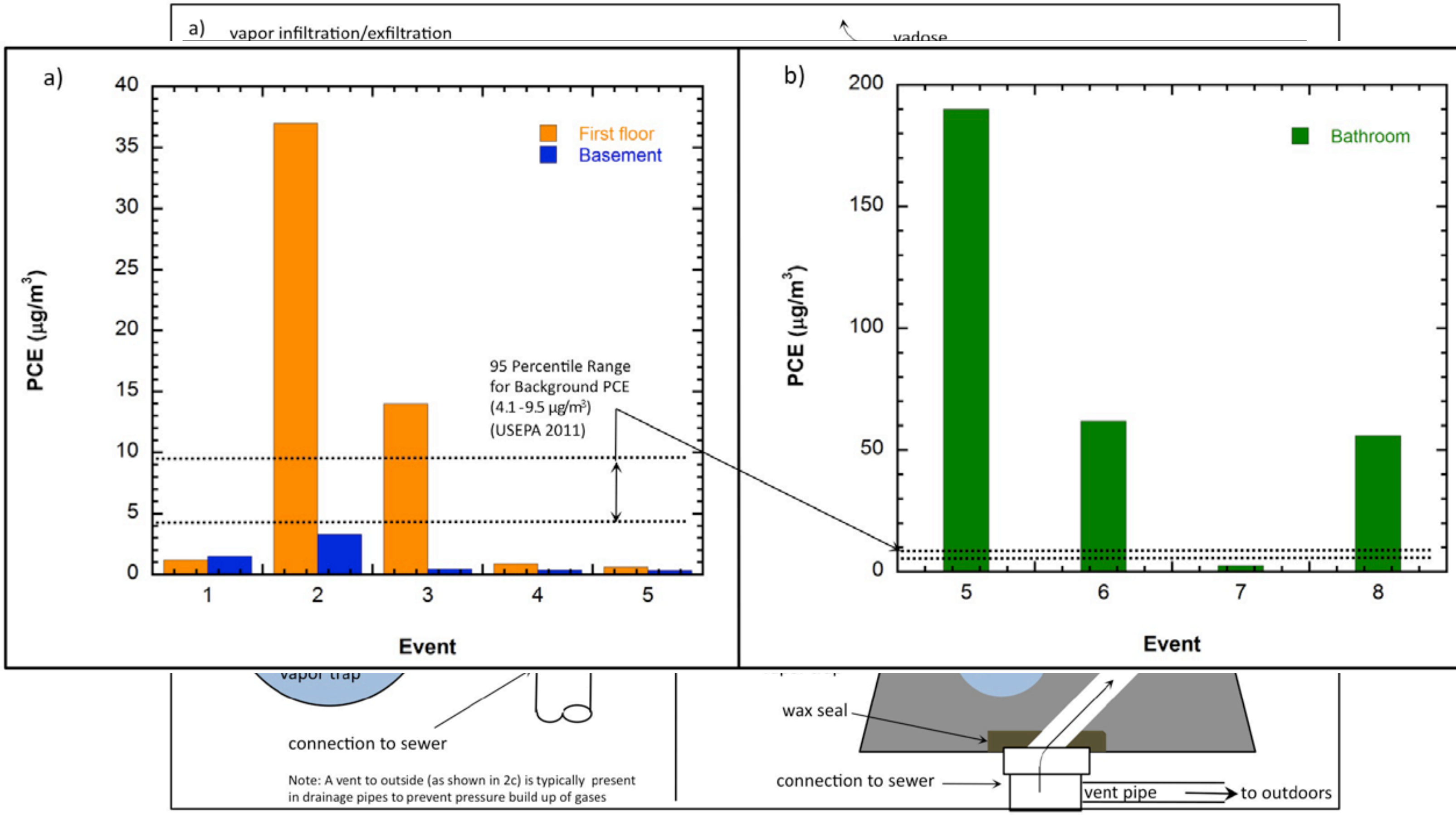
Indoor Air Challenges

- 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)
- Expect that at any site, these compounds could exceed risk based closure criteria, even in the absence of vapor intrusion

Useful Reference: 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.**

Exposure Risks

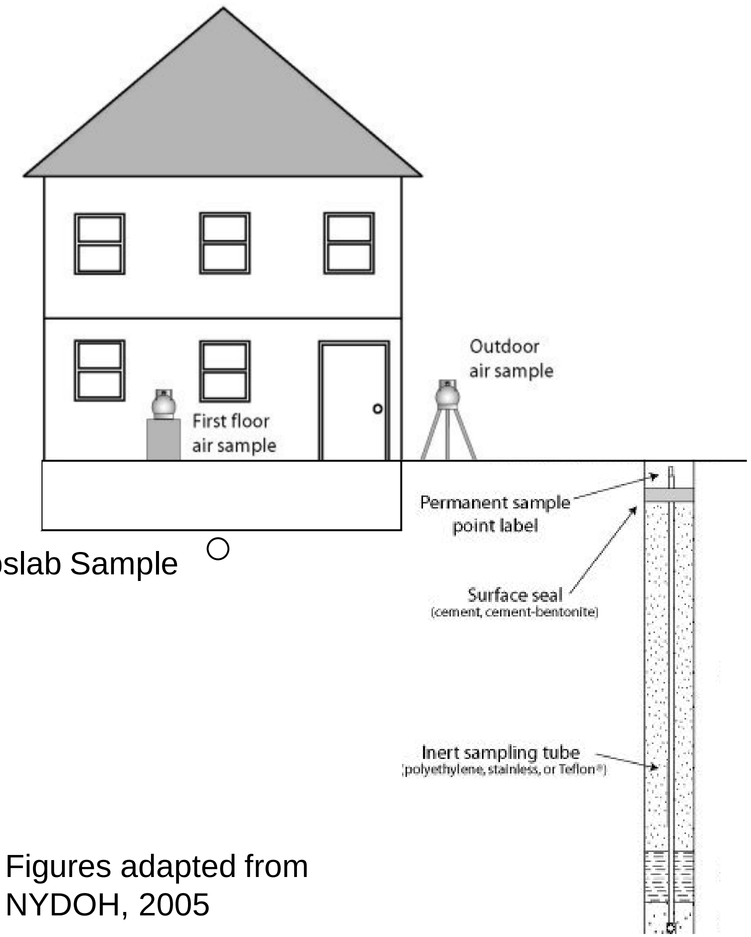
Indoor Air Challenges



Pennell et al, *Ground Water Monitoring and Remediation (*2013)

Exposure Risks

What is the nature and extent?



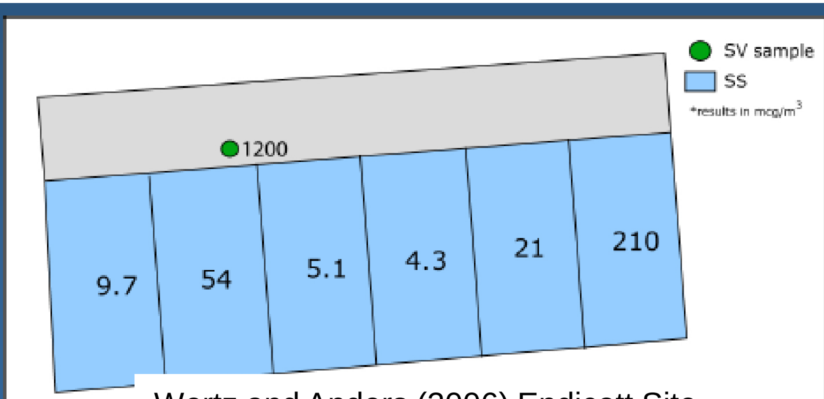
Subslab Sample

Figures adapted from NYDOH, 2005

Three Common Approaches

1. Indoor Air
2. Subslab Soil Gas
3. Adjacent Soil Gas

Are these methods reliable and how can we interpret the data?



Wertz and Anders (2006) Endicott Site

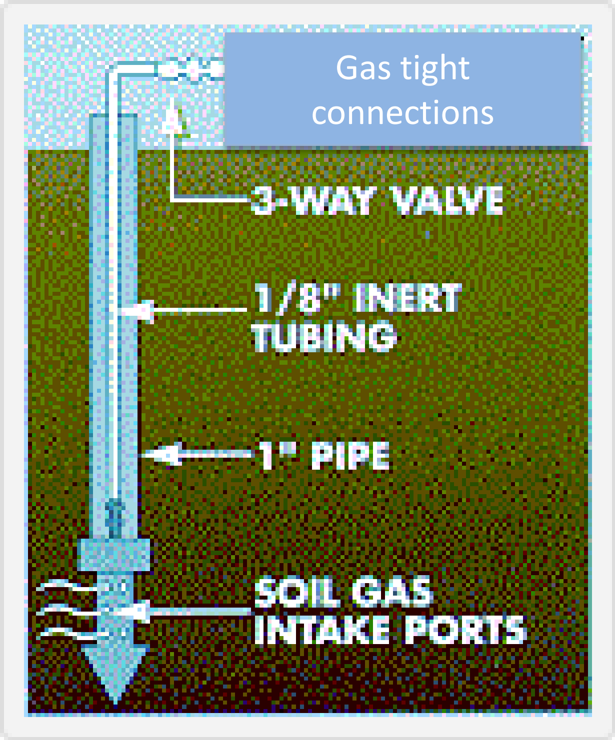
Exposure Risks

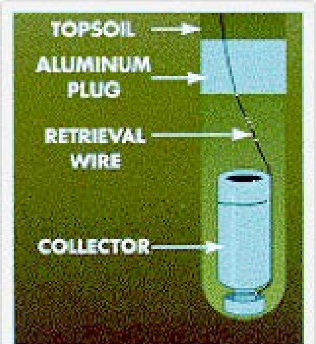
Sampling Soil Gas

TO-15 using 1L or 6L summa canister is common

Many references for proper collection (e.g. ITRC 2007, NYDOH 2006)

Passive samples (TO-17) are also possible. Some agencies recommend passive sampling only be used for "qualitative" purposes.





Schematics from: Viridian, Inc.

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  - How can we interpret the data?

Multiple Lines of Evidence

How can we interpret the data?

How should we characterize the vapor intrusion pathway?

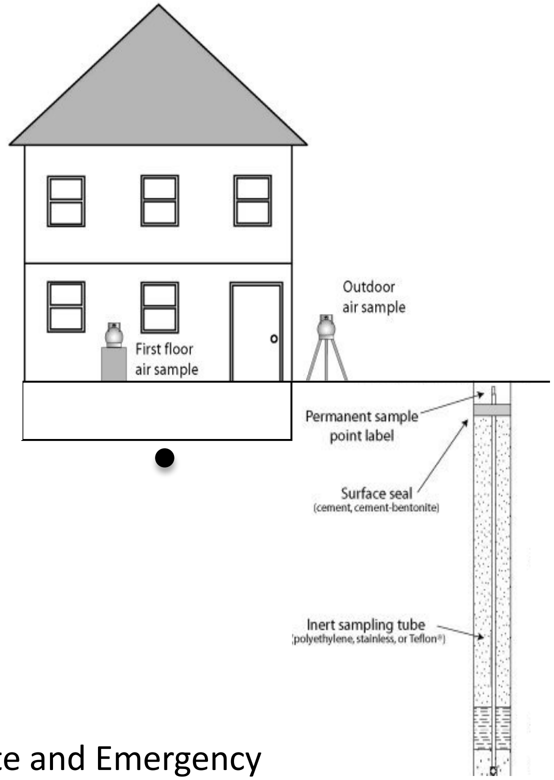
a) Sample indoor air

b) Modeling

c) Sample groundwater

d) Sample soil vapor

e) All of the above



Useful Reference:
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**

Multiple Lines of Evidence

1-D vs. 3D

- 1-D widely used for screening
- Johnson & Ettinger, 1991 (basis for EPA spreadsheets)
  - Output: "Alpha Values"

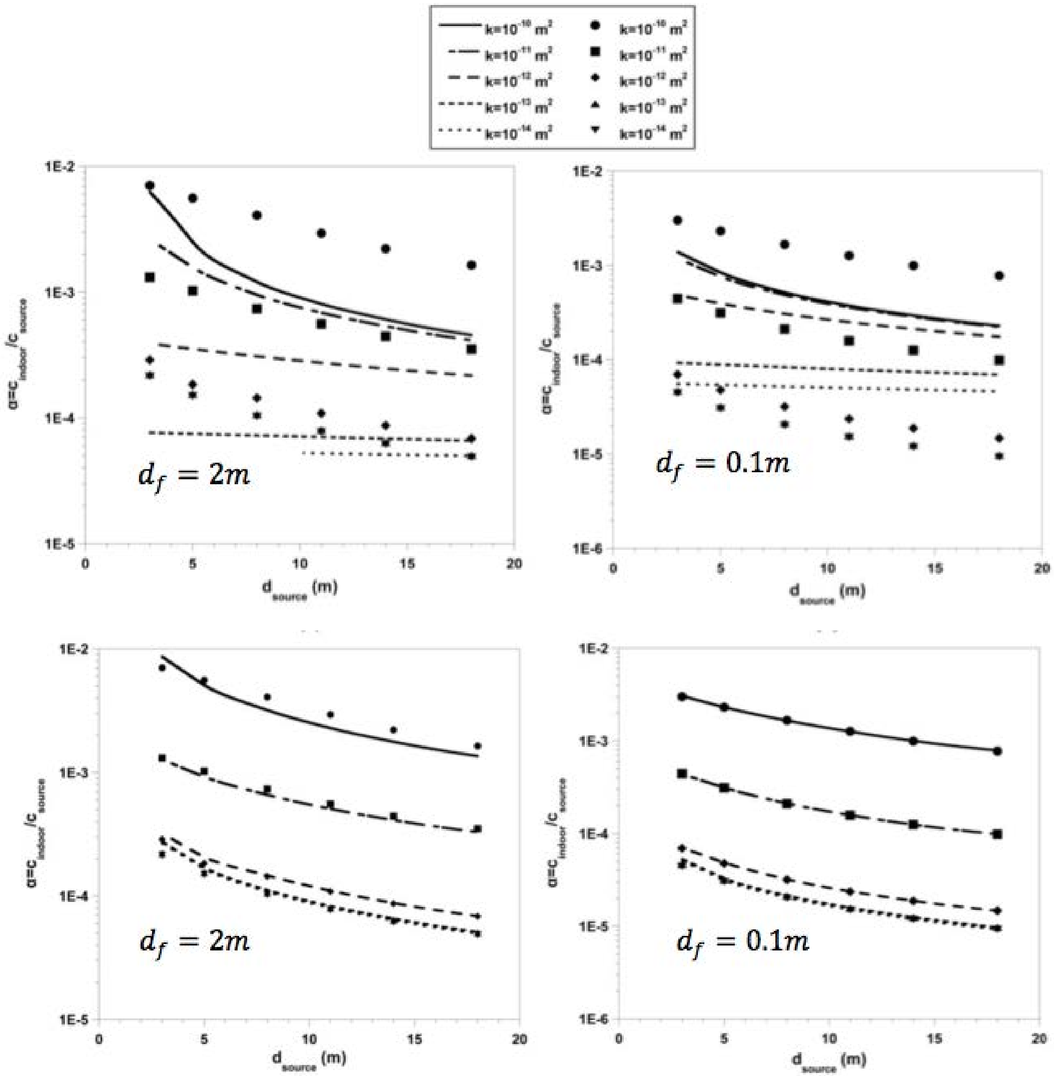
- 3-D Research
  - Output: Soil gas concentrations, subslab concentrations, alpha values
    - Ex: Pennell et al (2009) and Abreu and Johnson (2005).

Multiple Lines of Evidence

1-D vs. 3D

- Steady state and homogenous
  - 3-D points
  - J&E lines

- Can be improved with minor modifications

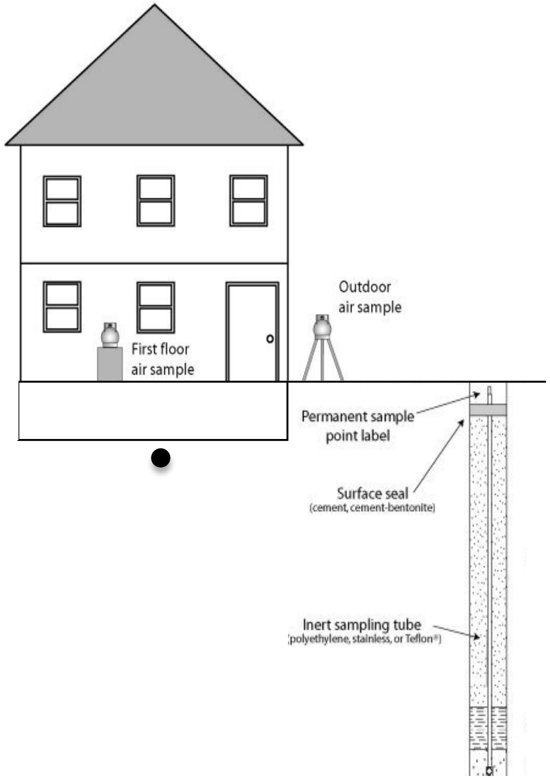


Yao et al., 2011 (ES&T)

Multiple Lines of Evidence

How can we interpret the data?

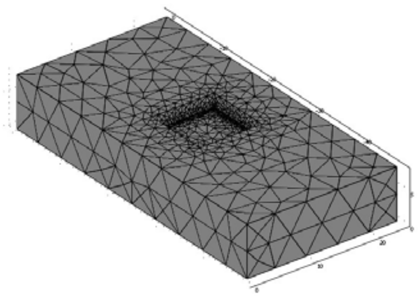
Field Study 2010-2013:
Integrate Brown SRP's vapor intrusion model with field data for a site in the Metro-Boston area. One of the first attempts to calibrate a 3-D vapor intrusion model with field data.



Multiple Lines of Evidence

3D Vapor Intrusion Model

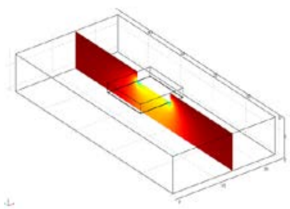
Model Domain



Gas Transport

$$q = \frac{k \cdot \rho_g \cdot d\phi}{\mu_g}$$

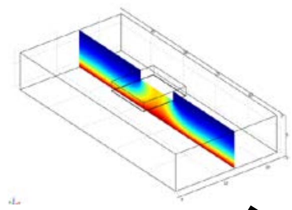
$$d\phi = gz + \int_{P_0}^{P} \frac{dP}{\rho}$$



Chemical Transport

$$J_T = q \cdot C - D_{ig} \nabla C$$

$$D_{eff,i}^{gas} = D_i^{air} \frac{\eta_g^{10/3}}{\eta_T^2} + \frac{D_i^w}{K_H} \frac{\eta_w^{10/3}}{\eta_T^2}$$



Indoor Air Concentration

$$C_{indoor} = \frac{M_{ck}}{A_e \cdot V_b + Q_{ck}}$$

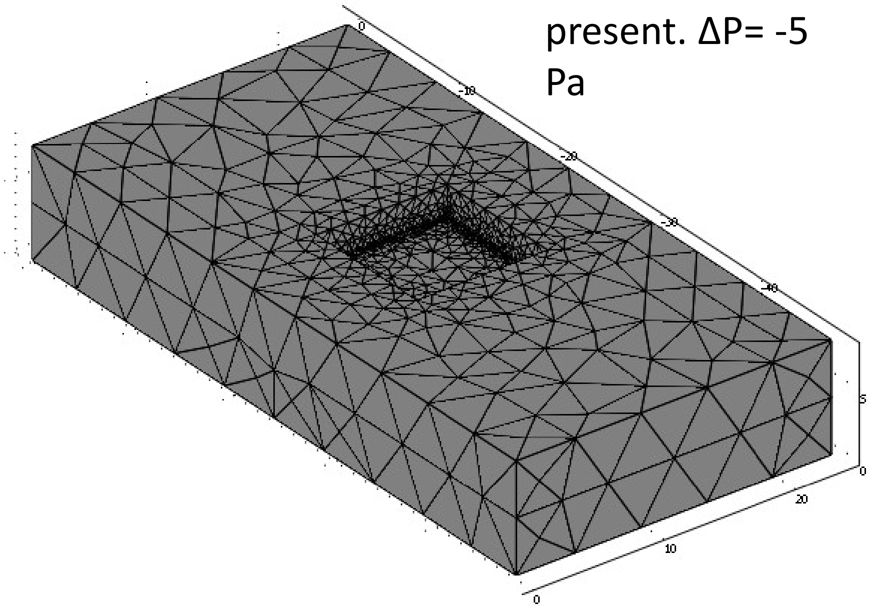
Many iterations may be required to obtain a properly converged solution.

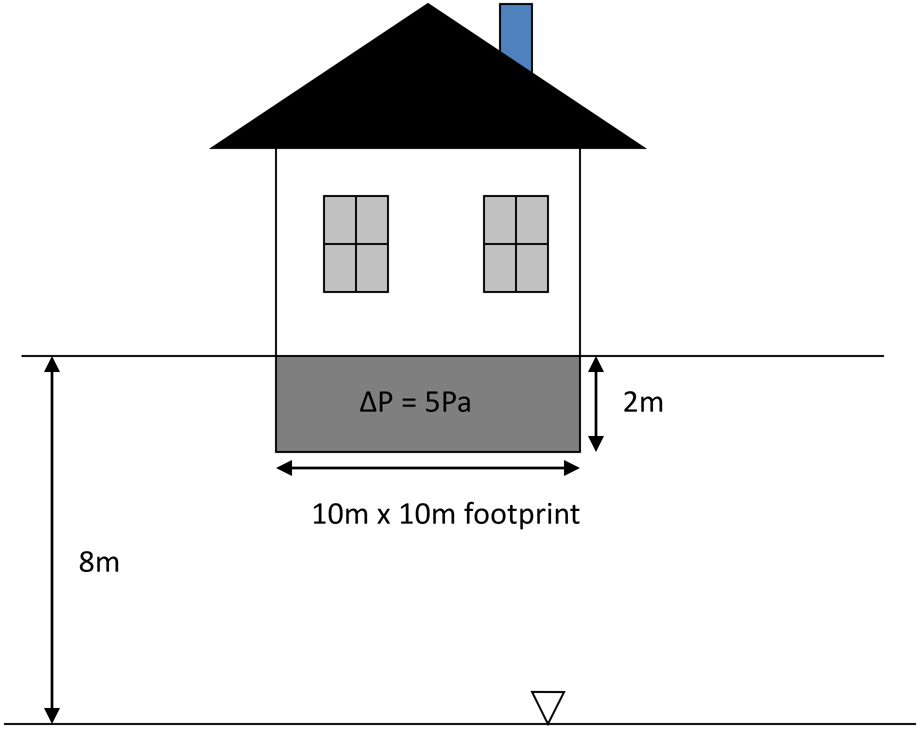
Note: J&E is based on "similar" model equations (in 1-D form). The actual situation modeled by J&E is different in that it includes several 1-D simplifications.

Multiple Lines of Evidence

3D Vapor Intrusion Model

Perimeter foundation crack present. ΔP= -5 Pa





Afternoon session will elaborate

Multiple Lines of Evidence

3D Vapor Intrusion Model

Gas Flow Through Soil

$$q = \frac{-\kappa\rho}{\mu}\frac{dP}{dx}$$

Darcy's Law for one dimensional incompressible flow

$$q = \frac{-\kappa\rho}{\mu}\nabla\phi$$

$$\phi = gz + \int_{Po}^{P}\frac{dP}{\rho}$$

Darcy's Law for 2D or 3D incompressible flow

q : *specific dischrg* (L/T)

κ: *permeability of the soil* (L^2)

μ:*visc.of the fluid* (M/LT)

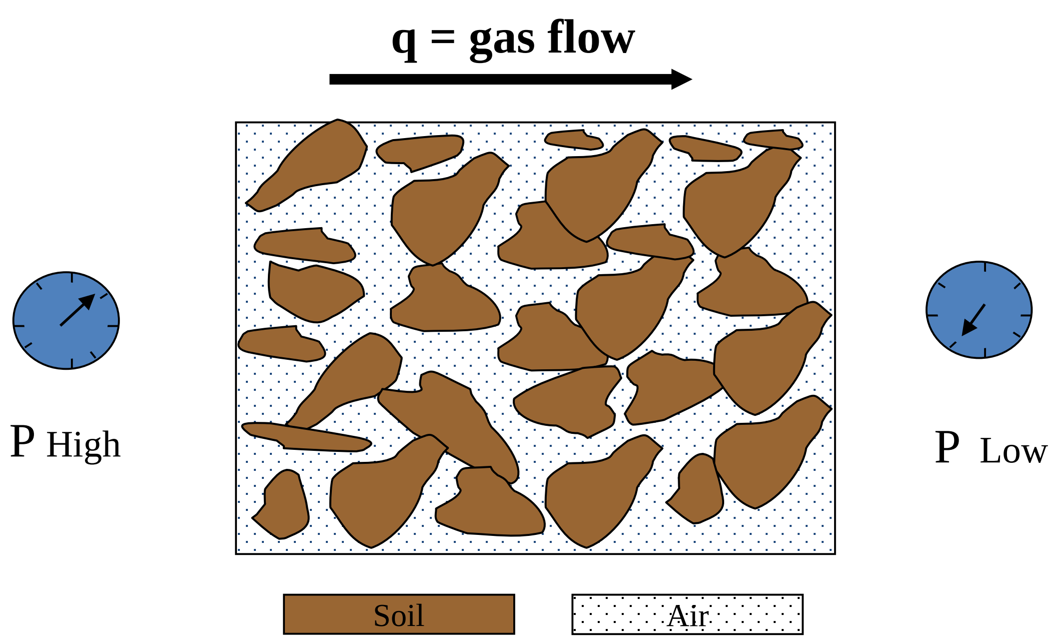
ρ:*density of the fluid* (M/L^3)

ϕ : *fluid potential*

P: *pressure of the fluid* (M/LT^2)

z: *elevation* (L)

g:*gravitational acceleration* (L/T^2)



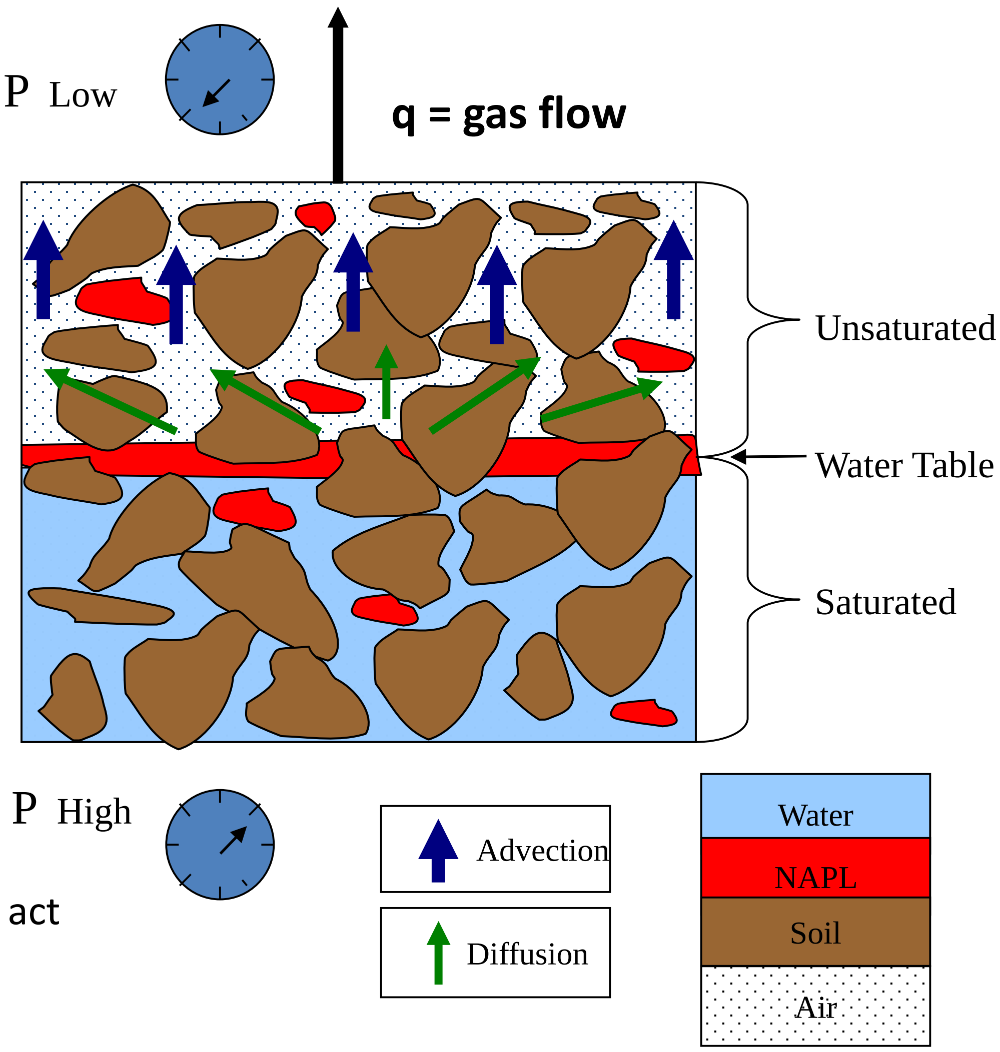
Multiple Lines of Evidence

3D Vapor Intrusion Model

Chemical Transport

$$J_T = qC - D^{gas}_{eff,i}\nabla C$$

$$D^{gas}_{eff,i} = D_i^{air}\frac{\eta_g^{10/3}}{\eta_T^{2}} + \frac{D_i^{w}}{K_H}\frac{\eta_w^{10/3}}{\eta_T^{2}}$$

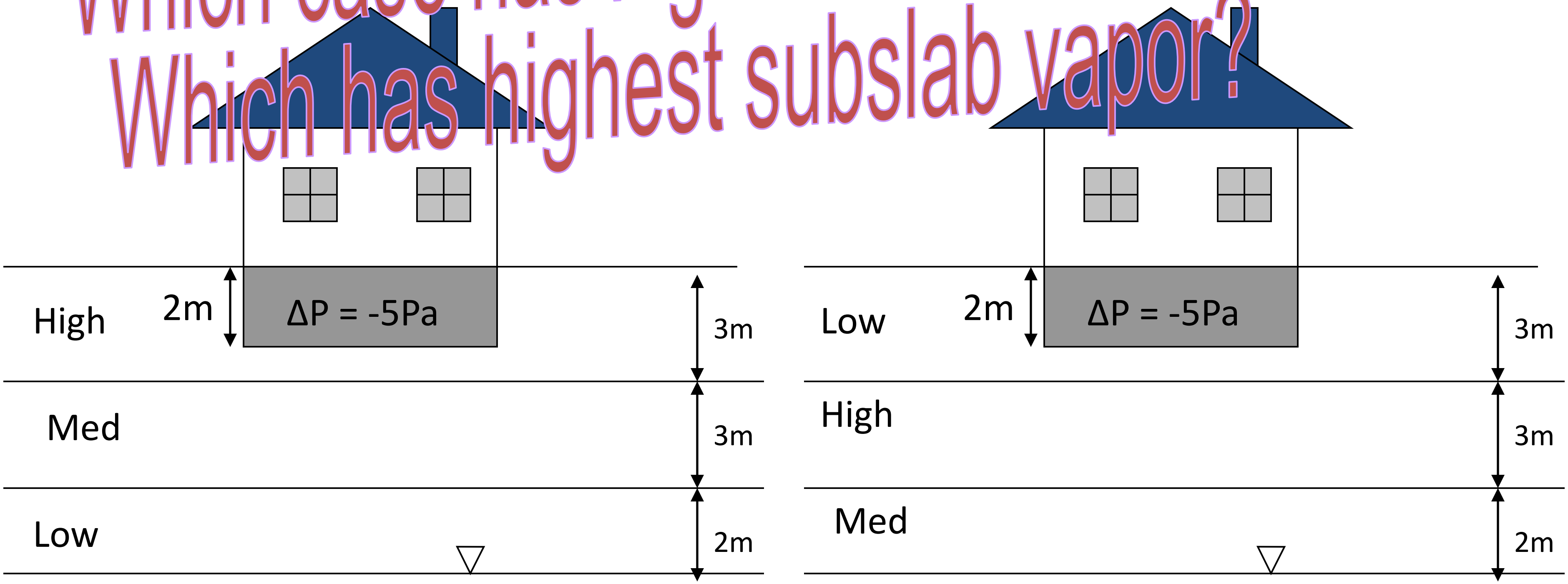


Non-aqueous liquids (NAPL) and residual contamination in groundwater and/or soil can act as the source for vapor contamination

Multiple Lines of Evidence

Comparison

Which case has highest indoor air?
Which has highest subslab vapor?



<u>High Permeability/Diffusivity</u>
$k_{High} = 10^{-10}\ m^2$, $D^{gas}_{eff,i}$ High $= 1.05E\text{-}6\ m^2/s$

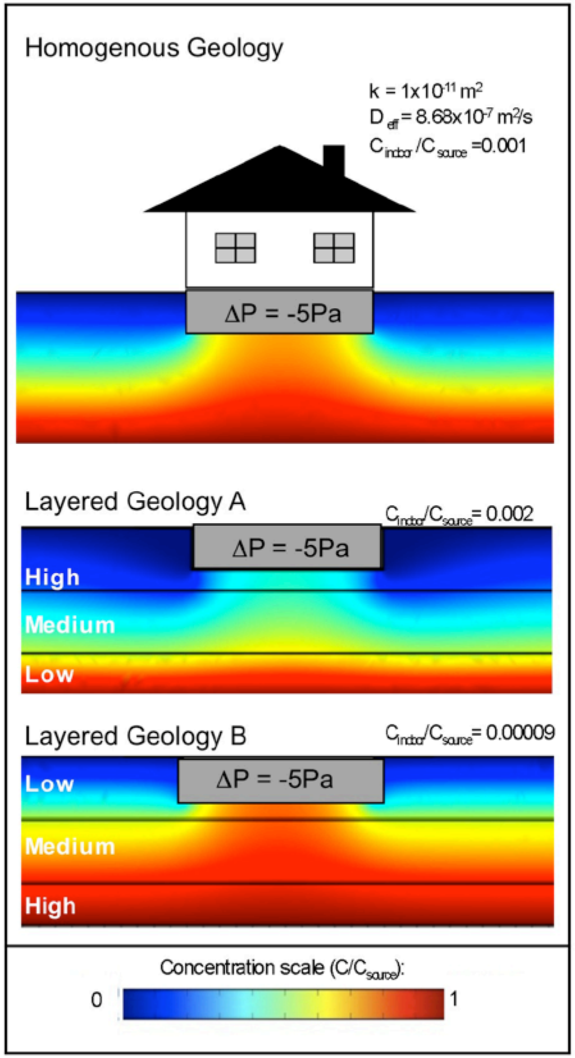
<u>Medium Permeability/Diffusivity</u>
$k_{Medium} = 10^{-12}\ m^2$, $D^{gas}_{eff,i}$ Medium $= 8.68E\text{-}7\ m^2/s$

<u>Low Permeability/Diffusivity</u>
$k_{Low} = 10^{-14}\ m^2$, $D^{gas}_{eff,i}$ Low $= 4.37E\text{-}7\ m^2/s$

Multiple Lines of Evidence

3D Vapor Intrusion Model

- Concentrations beneath the building (subslab) are lowest for Layered Geology A; however this case results in the greatest mass flow of contaminant entering the building.
- Layered Geology B has a subslab concentration that is similar to the homogenous soil, yet the indoor air concentration is predicted to be an order of magnitude less.



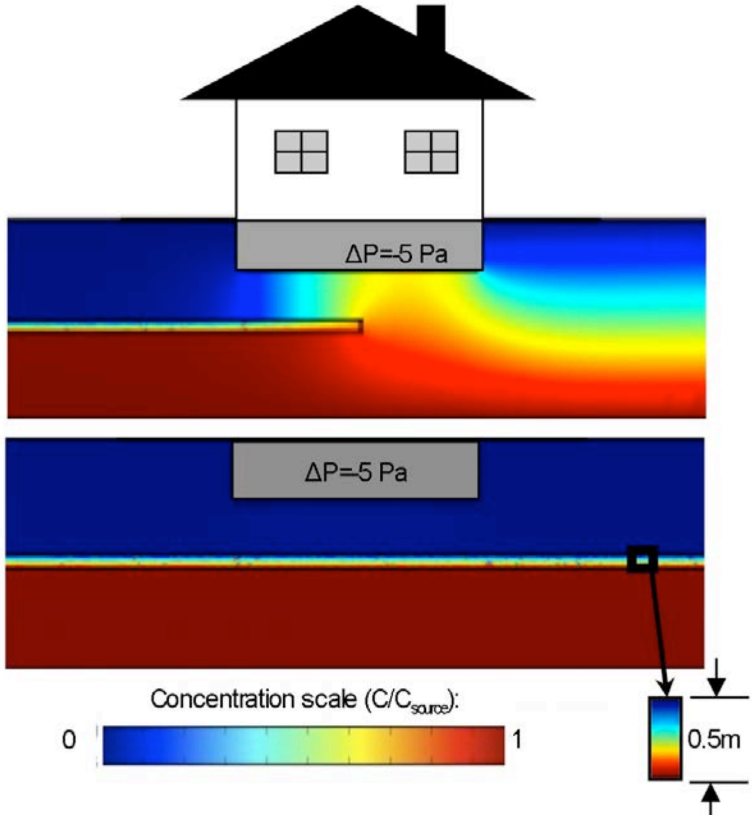
Left

Right

Multiple Lines of Evidence

3D Vapor Intrusion Model

Saturated Clay layers



- Buildings, parking lots, adjacent structures and water-saturated soil layer can act as caps and prevent vapor phase discharge to the atmosphere.

Soil surrounding clay, $K=10^{-11}$ m^2	Indoor Air (mg/m^3)
Continuous Clay	0.0029
Discontinuous Clay	0.16

Bozkurt et al 2009

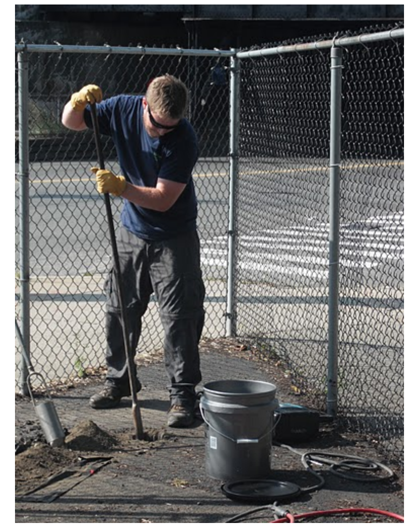
Multiple Lines of Evidence

Field Sampling and Modeling

Purpose of the research was to test our vapor intrusion model and gain improved understanding of a vapor intrusion site

Multiple Lines of Evidence

Field Sampling and Modeling



Collaboration of two SRPs (Boston University and Brown University)

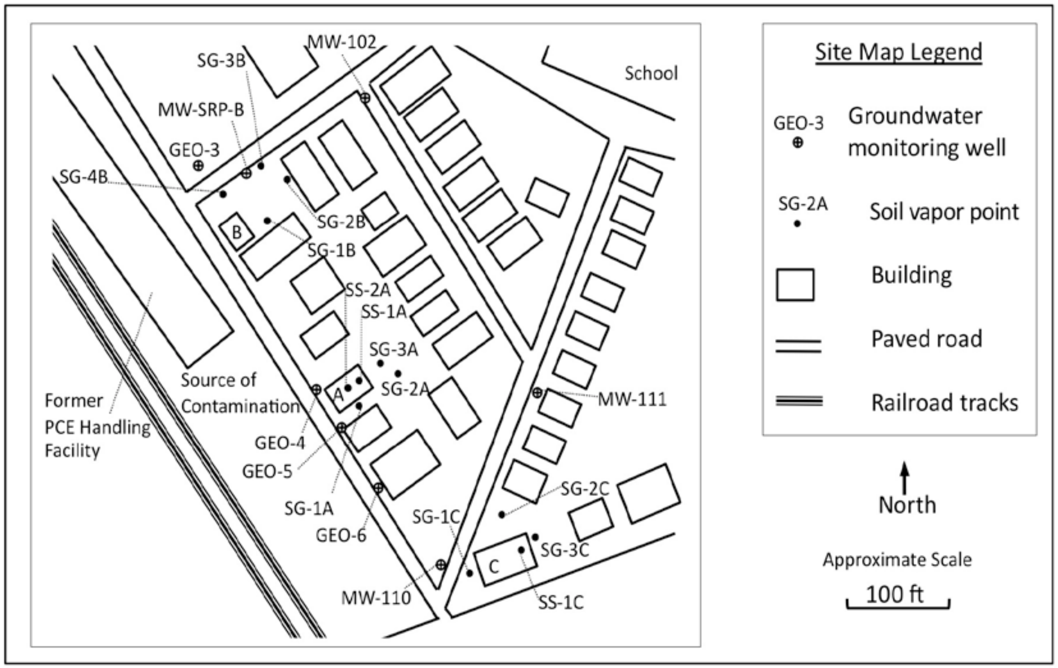
Research Team: Mike McClean (BU),Leigh Frigluglietti (BU), Jenn Ames (BU), Kelly Pennell, Eric Suuberg, Flint Kinkade and Ray Chappel (Viridian), Madeleine Scammell (BU), Yijun Yao and Rui Shen - Not Shown (Brown)

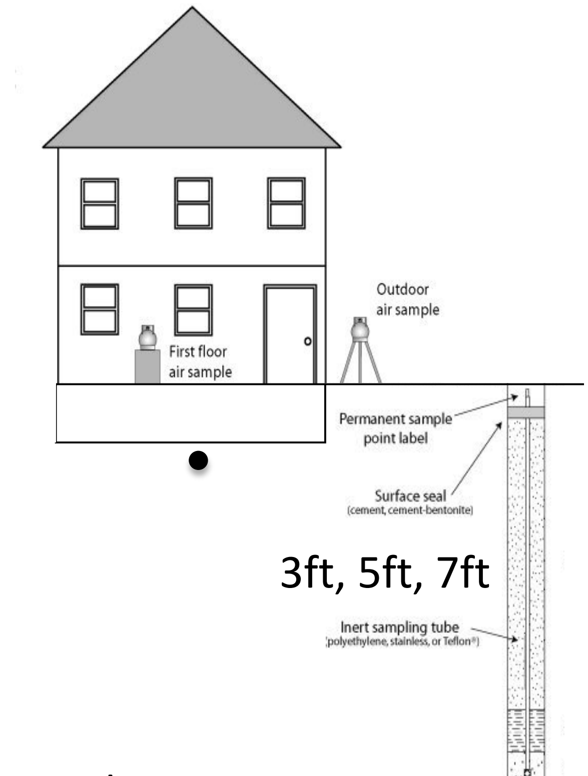
Multiple Lines of Evidence

Sample Installation

Multiple Lines of Evidence

Field Sampling

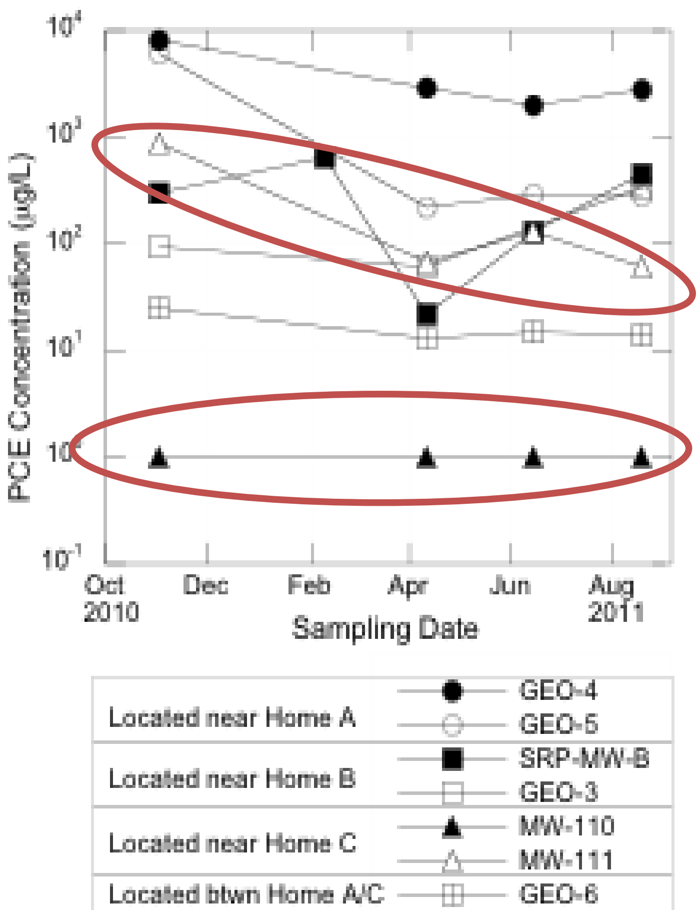


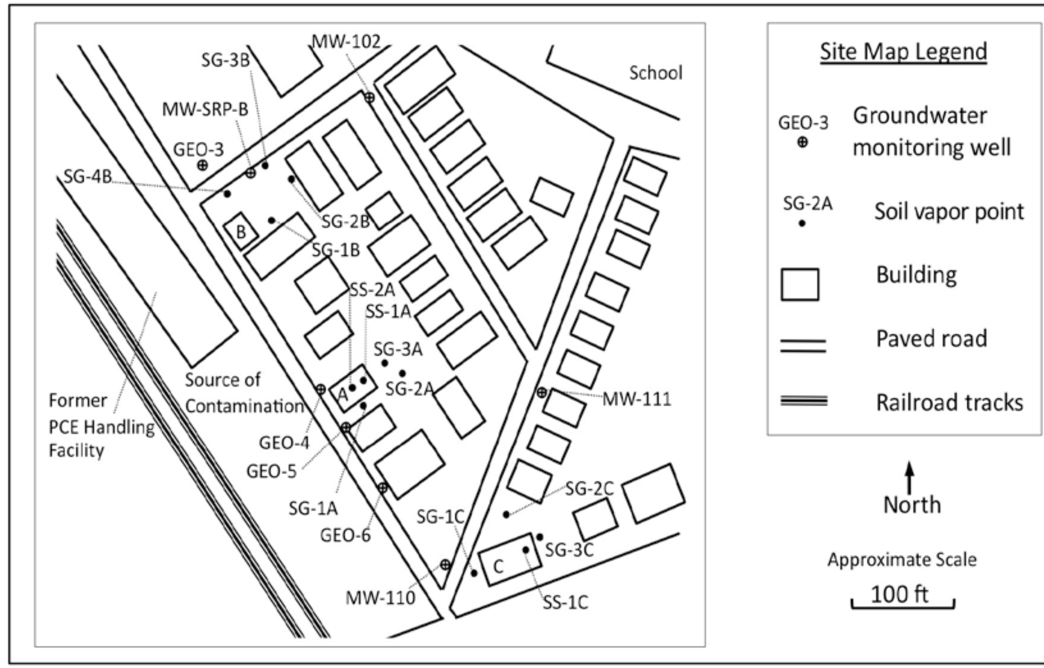


5 rounds of sampling – Groundwater, soil vapor, indoor air, outdoor air

Multiple Lines of Evidence

Field Sampling

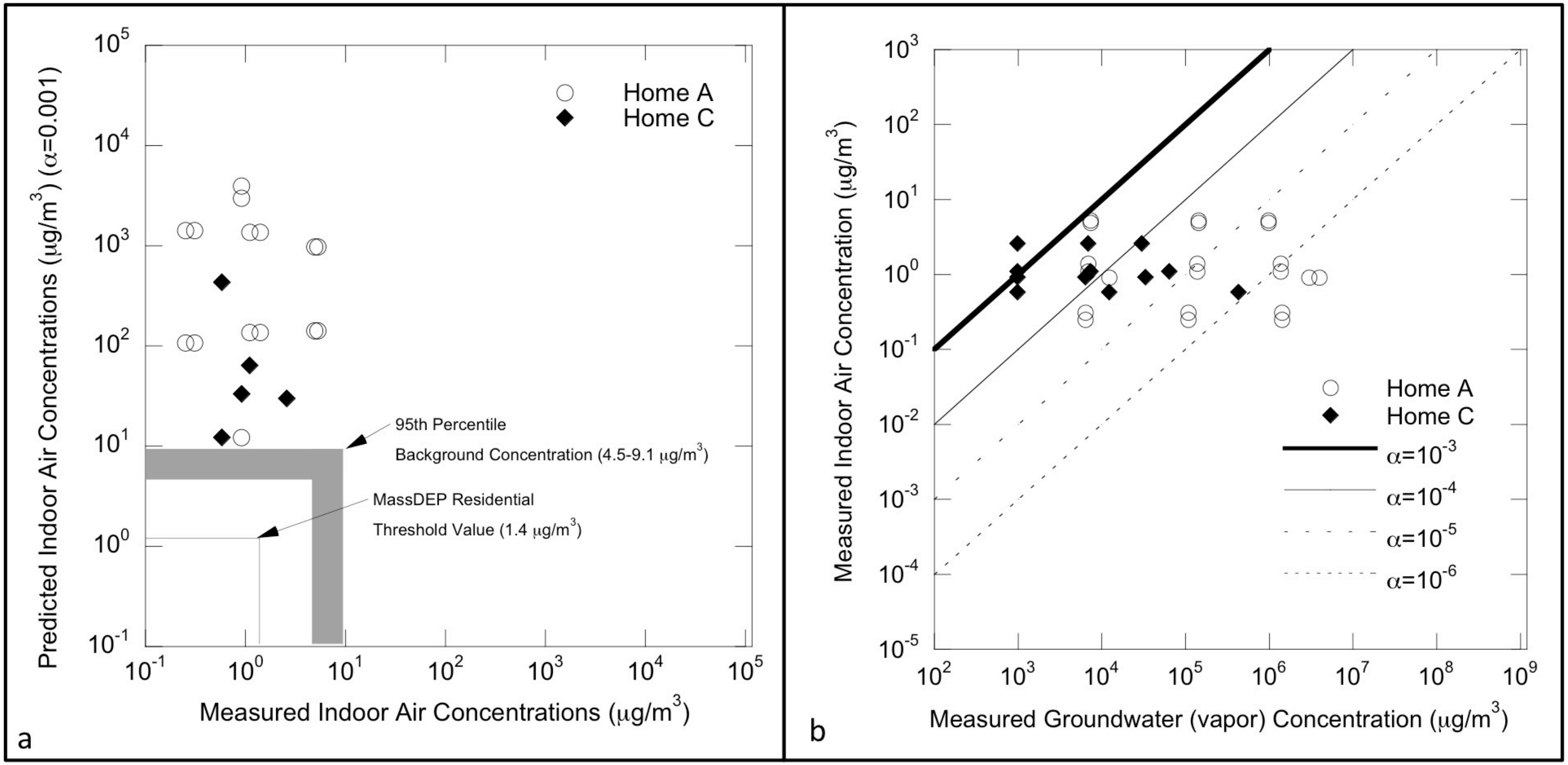




Pennell et al 2013 (submitted to ES&T)

Multiple Lines of Evidence

Groundwater vs. Indoor Air



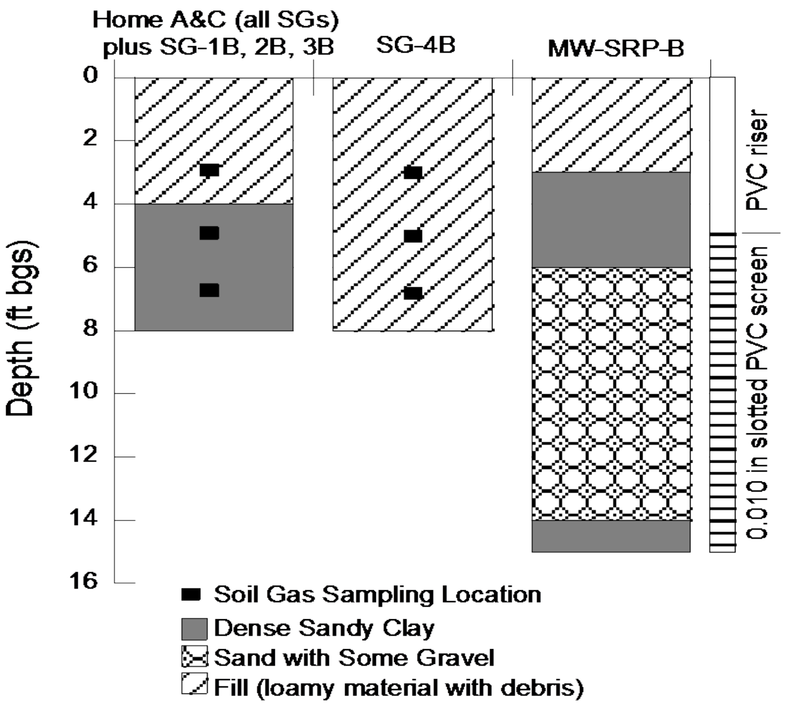
Comparison of Measured Indoor Air Concentrations to Predicted (generic screening) Indoor Concentrations (a) and Measured Groundwater (Vapor) Concentration (b).

Pennell et al 2013 (submitted to ES&T)

Multiple Lines of Evidence

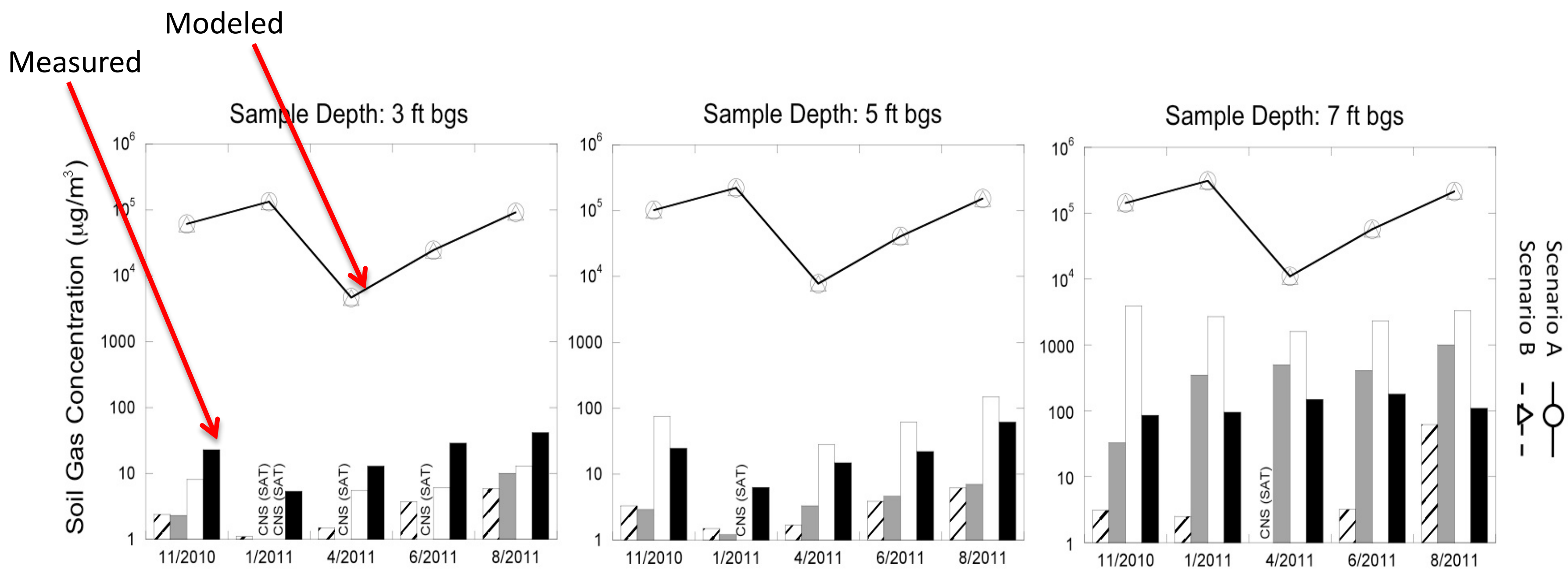
Hypothesis for Low Attenuation Factors

- Soil moisture within the layered geologic system was limiting vapor transport.

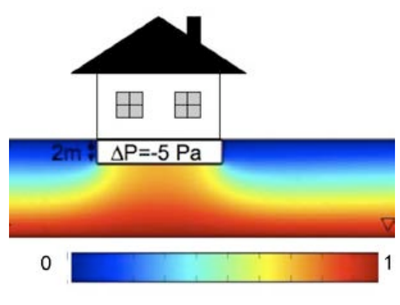


Multiple Lines of Evidence

Soil Gas Data with Model (1-layer system)



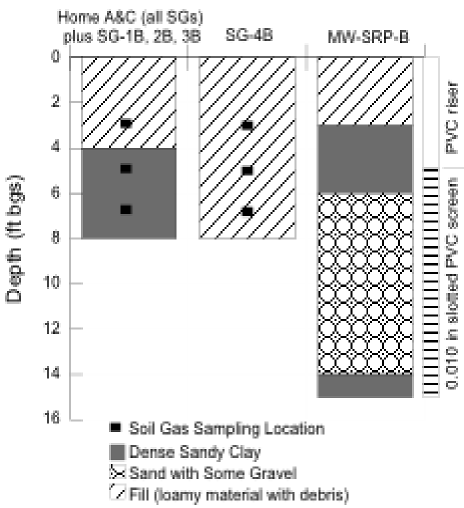
Scenario	Layer	Soil Type	Depth (ft)	Moisture (%)	Total Porosity	Permeability (m^2)	D_{eff} (m^2/s)	α 3D
A	1	LS	11	20	0.39	1.55E-12	1.00E-06	1.6E-04
B	1	SC	11	50	0.385	1.46E-13	1.86E-07	4.5E-05

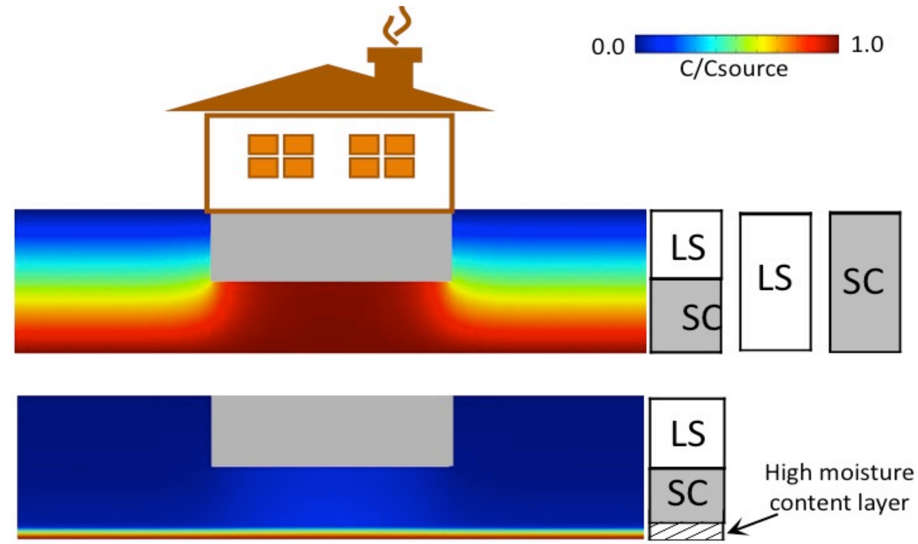


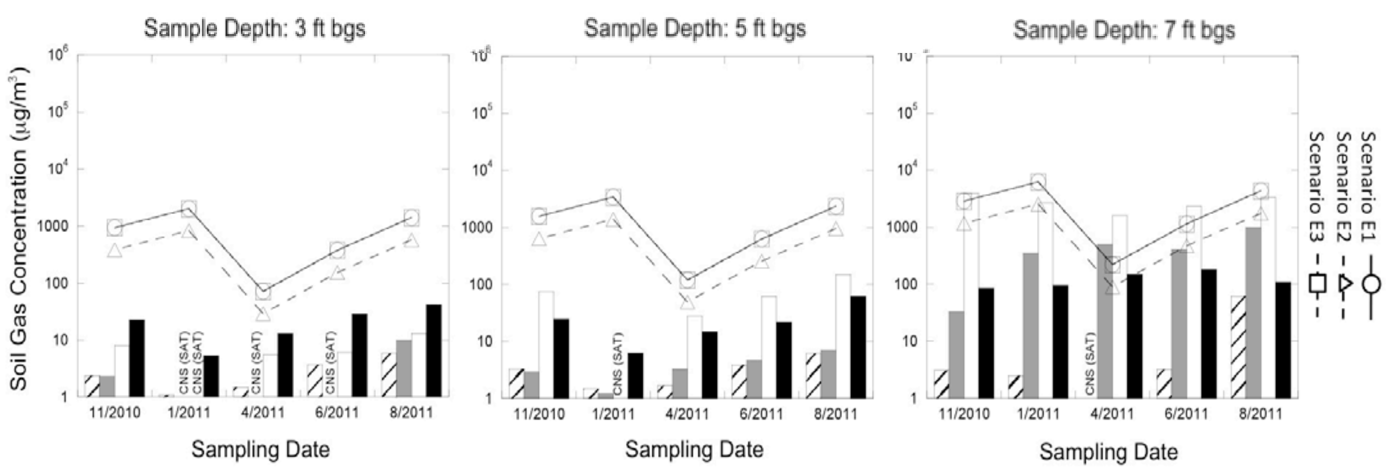
$$\alpha = \frac{C_{indoor}}{C_{gw} \cdot H}$$

Pennell et al 2013 (submitted to ES&T)

Multiple Lines of Evidence







Pennell et al 2013 (Submitted ES&T)

Multiple Lines of Evidence

Modeling as a tool

- 1-D widely used for screening
  - Johnson & Ettinger, 1991 (basis for EPA spreadsheets)
  - Most values are constrained by EPA
  - Output: "Alpha Values"

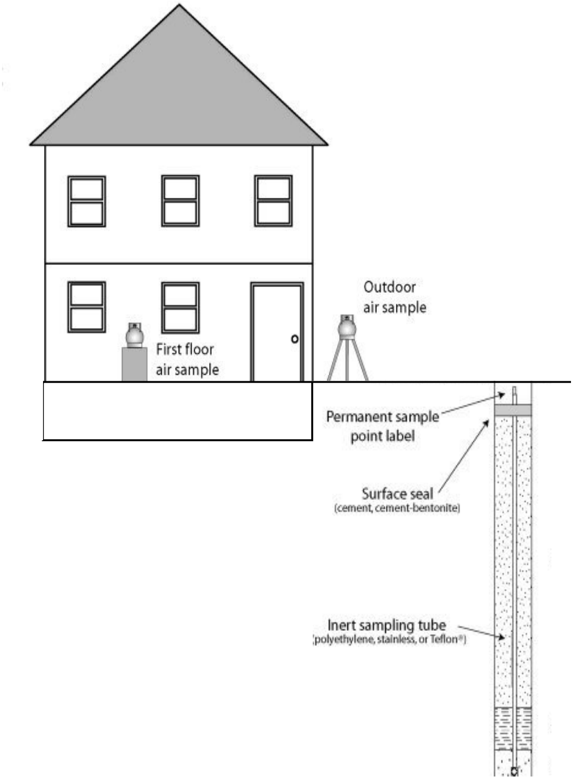
- 3-D Research
  - Ex: Pennell et al (2009) and Abreu and Johnson (2005).
  - User can define input parameters to fit site-specific observations.
  - Output: Soil gas concentrations, subslab concentrations, alpha values

Multiple Lines of Evidence

All of the above

How should we characterize the vapor intrusion pathway?

a) Sample indoor air
b) Modeling
c) Sample groundwater
d) Sample soil vapor
e) All of the above



Conclusions

- "Multiple lines of evidence" is currently the best approach for characterizing VI exposure risks.
- Concentration data is most useful when it is accompanied by site specific information (e.g. geology, depth, surface features, a well-developed conceptual site model).
- Modeling is a tool. It can be used to evaluate and interpret field data. It provides insight into various factors that may be important.

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**.
- 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.**

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