Key Advances in Vapor Intrusion Assessments at Contaminated Sites

October 30, 2014

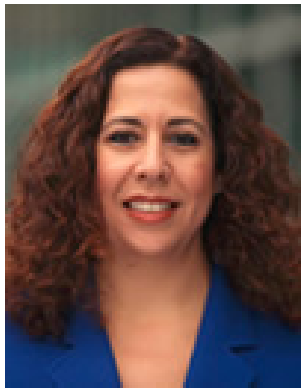
SERDP DOD • EPA • DOE | ESTCP

Welcome and Introductions

Rula Deeb, Ph.D.
Webinar Coordinator

Welcome and Introductions

Rula Deeb, Ph.D.
Webinar Coordinator

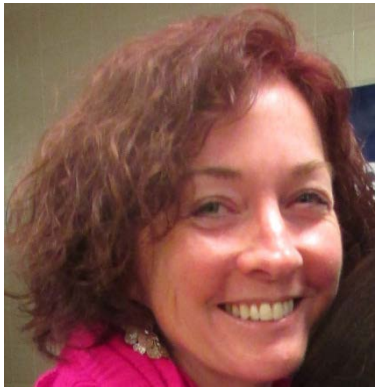


Webinar Agenda

- ReadyTalk instructions for audience
  Dr. Rula Deeb, Geosyntec (5 minutes)
- Overview of SERDP and ESTCP, and webinar series goals
  Dr. Andrea Leeson, SERDP and ESTCP (5 minutes)
- Validated Methods to Distinguish Between Vapor Intrusion and Indoor Sources of Volatile Organic Compounds
  Dr. Thomas McHugh, GSI (30 minutes + Q&A)
- Multi-Year Monitoring of a House Overlying a Dilute Chlorinated Hydrocarbon Plume: Implications for Vapor Intrusion Pathway Assessment
  Dr. Paul Johnson (30 minutes + Q&A)
- Final Q&A session
  Moderated by Rula Deeb

SERDP and ESTCP Overview

Andrea Leeson, Ph.D.
Deputy Director



SERDP DOD • EPA • DOE | ESTCP

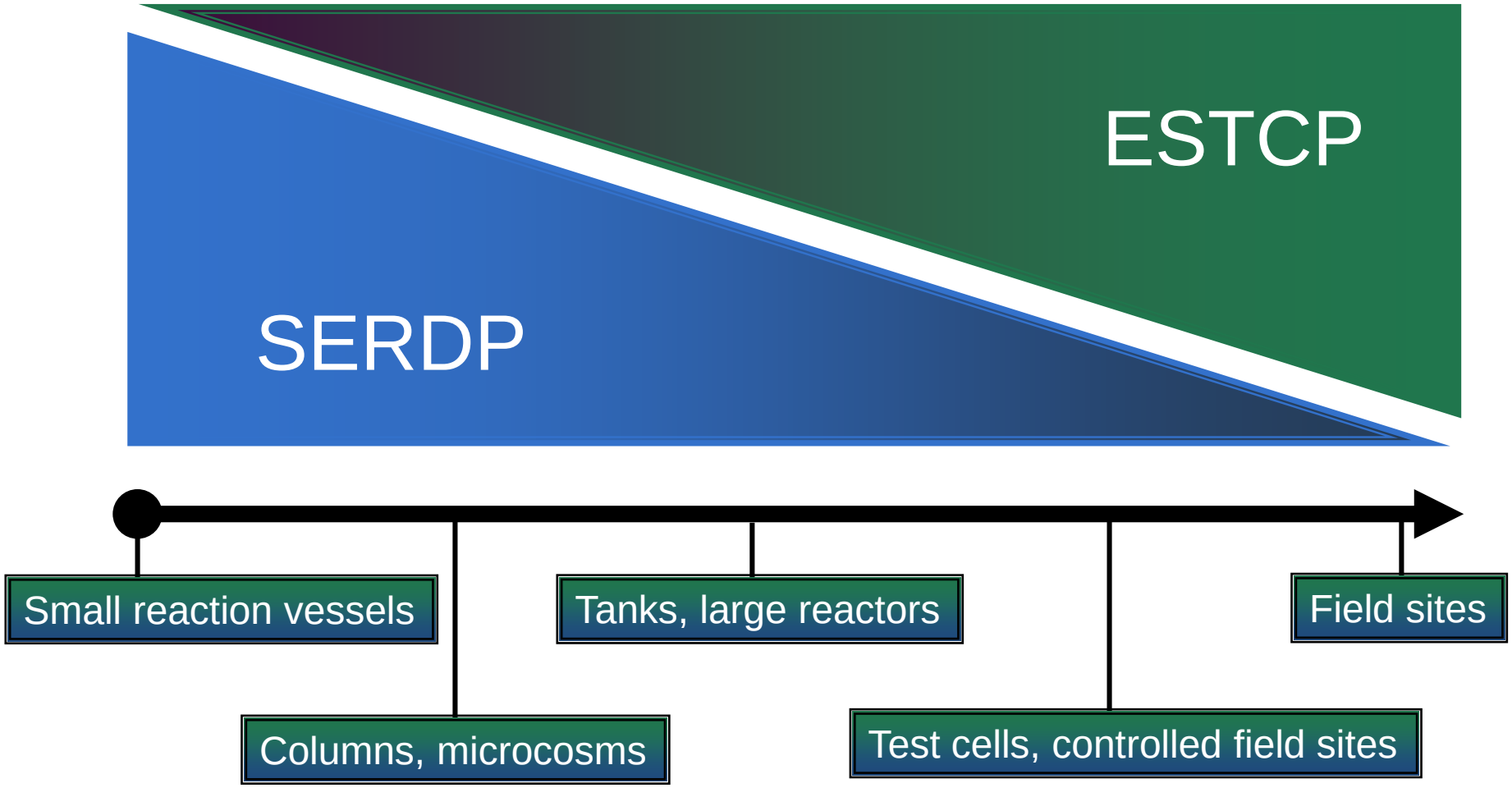
SERDP

- Strategic Environmental Research and Development Program
- Established by Congress in FY 1991
  - DoD, DOE and EPA partnership
- SERDP is a requirements driven program which identifies high-priority environmental science and technology investment opportunities that address DoD requirements
  - Advanced technology development to address near term needs
  - Fundamental research to impact real world environmental management

ESTCP

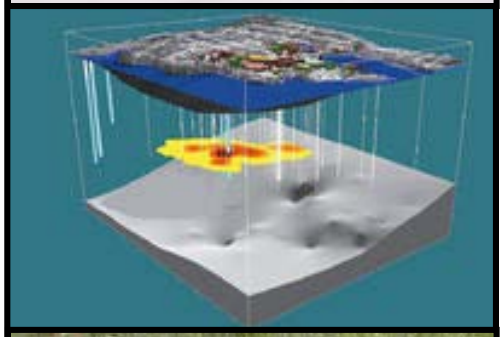
- Environmental Security Technology Certification Program
- Demonstrate innovative cost-effective environmental and energy technologies
  - Capitalize on past investments
  - Transition technology out of the lab
- Promote implementation
  - Facilitate regulatory acceptance

Scales of Research



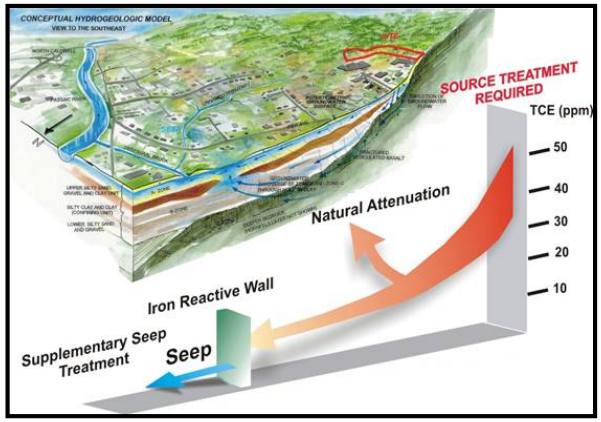
Program Areas

1. Energy and Water
2. Environmental Restoration
3. Munitions Response
4. Resource Conservation and Climate Change
5. Weapons Systems and Platforms



Environmental Restoration

- Major focus areas
  - Contaminated groundwater
  - Contaminants on ranges
  - Contaminated sediments
  - Wastewater treatment
  - Risk assessment



SERDP and ESTCP Launch a Webinar Series

DATE	WEBINARS AND PRESENTERS
October 30, 2014	Key Advances in Vapor Intrusion Assessments at Contaminated Sites • Dr. Paul Johnson (Arizona State University) • Dr. Thomas McHugh (GSI Environmental)
November 6, 2014	New Tools for Advancing our Understanding of Marine Mammal Behavioral Ecology • Dr. Kelly Benoit-Bird (Oregon State University) • Dr. Patrick Miller (St. Andrews University)
November 20, 2014	Novel Sampling Approaches for Improving the Management of Contaminated Sediment Sites • Dr. Philip Gschwend (Massachusetts Institute of Technology) • Dr. Bart Chadwick (SPAWAR Systems Center Pacific)
December 4, 2014	Waste to Energy Technologies • Mr. Patrick Scott (Lockheed Martin) • Mr. Steven Cosper (U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory)

http://serdp-estcp.org/Tools-and-Training/Webinar-Series

SERDP
DOD • EPA • DOE

ESTCP

Validated Methods to Distinguish Between Vapor Intrusion and Indoor Sources of Volatile Organic Compounds

Thomas McHugh, Ph.D.
GSI Environmental

SERDP DOD • EPA • DOE | ESTCP

Validated Methods to Distinguish Between Vapor Intrusion and Indoor Sources of Volatile Organic Compounds

ESTCP ER-201025 and ER-201119

Thomas McHugh, GSI Environmental

Project Team Members

- Lila Beckley, GSI
- Ignacio Rivera-Duarte, Navy SSC Pacific

- Kyle Gorder, Hill AFB (*left*)
- Erik Dettenmaier, Hill AFB (now Chevron) (*right*)

Vapor Intrusion vs. Indoor Sources

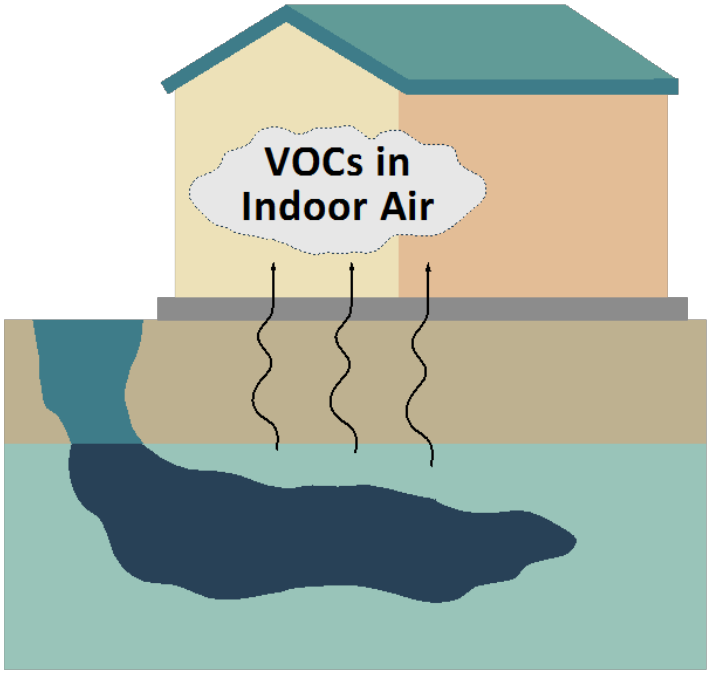
- Overview of VI investigations
- Indoor sources of VOCs
- On-site GC/MS analysis protocol
- Stable isotope analysis
- Recommendations

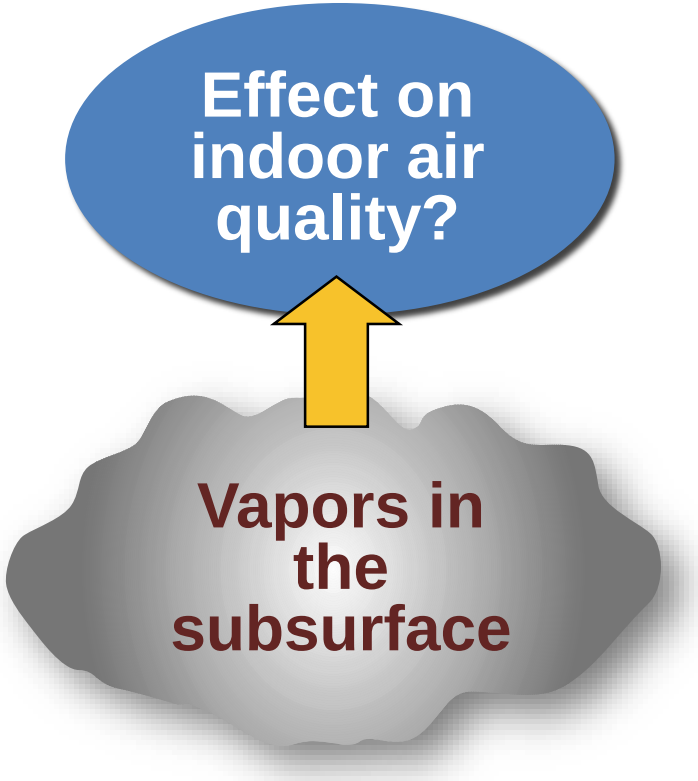
Vapor Intrusion vs. Indoor Sources

- Overview of VI Investigations
- Indoor Sources of VOCs
- On-site GC/MS Analysis Protocol
- Stable Isotope Analysis
- Recommendations

Vapor Intrusion: The basics

- Definition: Vapor intrusion is the vapor-phase migration of volatile organic compounds (VOCs) from the subsurface into indoor air





Why Focus on Indoor Air Testing?

- Goal: Quickly and accurately determine if vapor intrusion is resulting in VOC concentration exceedances in indoor air

Source Identification

- Find and remove indoor sources of VOCs to allow for accurate evaluation of vapor intrusion

Risk Evaluation

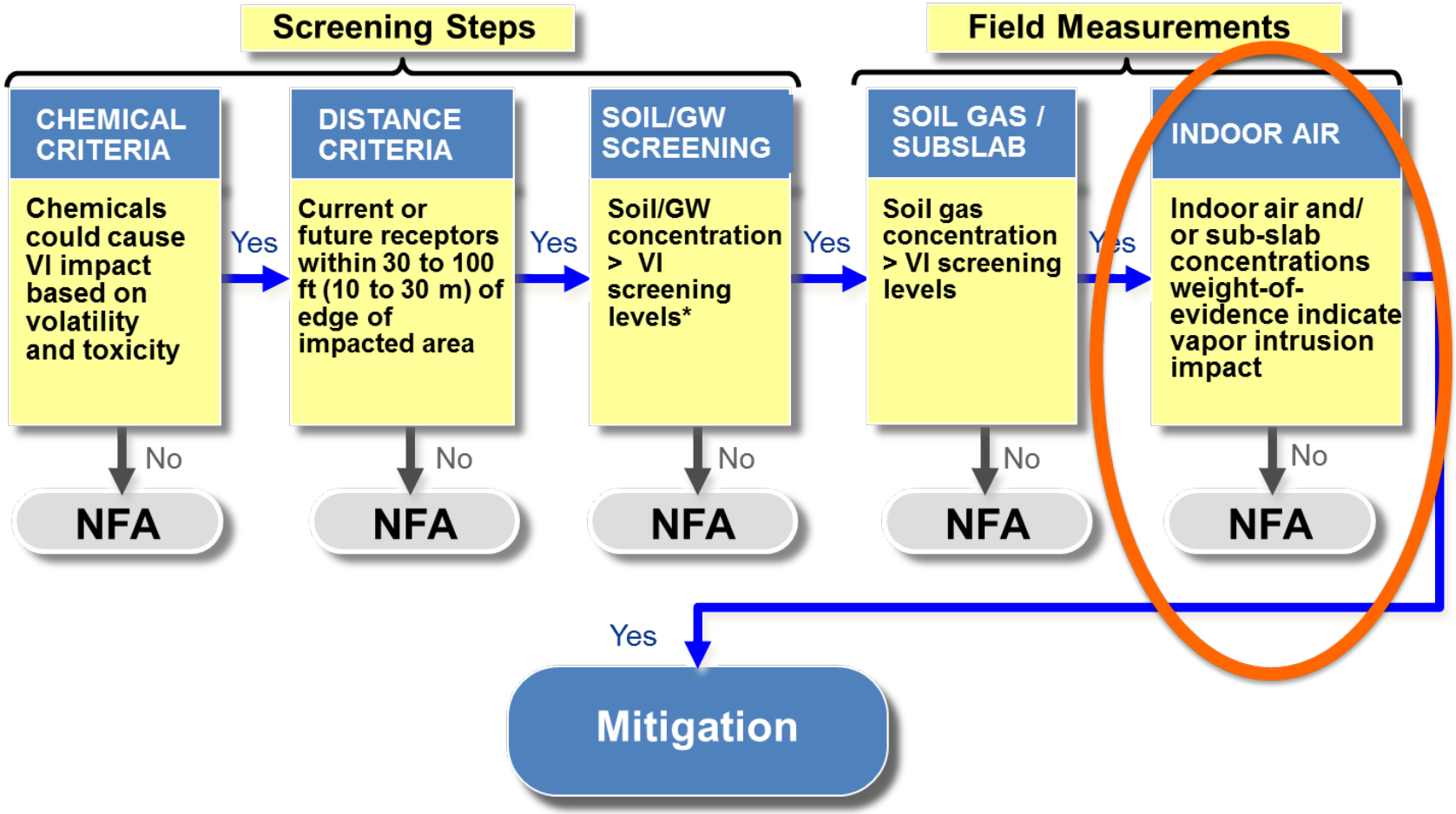
- Directly measures exposure concentrations

Mitigation / NFA

- Quickly and accurately determine need to response action

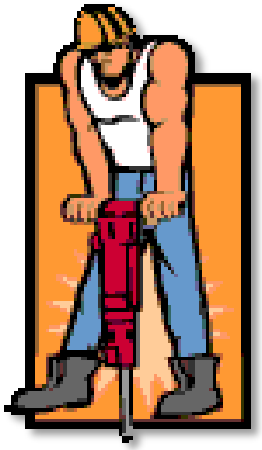
Key point: The evaluation methods presented here save time and money by distinguishing between VI and indoor sources of VOCs

Typical VI Evaluation Process



Sub-Slab Samples

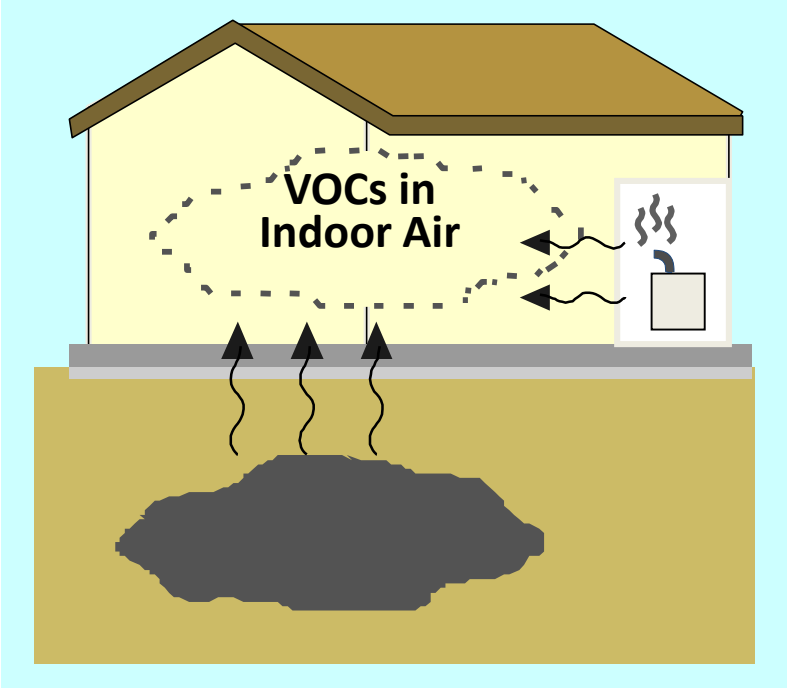
- **What**: VOC concentrations under building
- **How**: Sample points through building floor
- **Problems**
  - Spatial variability
  - Attenuation factor (e.g., radon)
  - Downward migration of indoor VOCs
  - May miss sewer and other preferential pathways



Key point: Sub-slab/soil gas data can miss a subsurface source (false negative) or detect an indoor source (false positive)

Let's Go Indoors: The Challenge

- Testing of indoor air is most direct way to identify vapor intrusion impacts
- Indoor sources of VOCs are ubiquitous (e.g., cleaners, glues, plastic, etc.)
- Detection of VOCs in indoor air does not necessarily indicate vapor intrusion

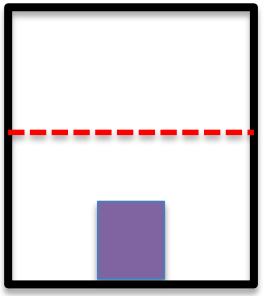


Key point: Indoor air samples are easy to collect; no extrapolation required to estimate exposure

Let's Go Indoors: Data Interpretation

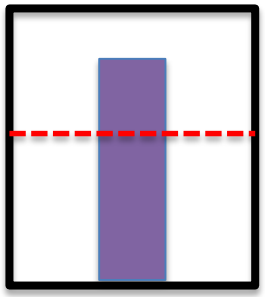
If COC Conc. <u>BELOW</u> Screening Level

- Monitor, if needed to evaluate temporal variability
  - Cost effective options available
- No Further Action



If COC Conc. <u>ABOVE</u> Screening Level

- Identify source (indoor vs. VI)
- Mitigate source, if needed
  - Remove indoor source
  - Intercept subsurface source



Key point: Interpretation of indoor air data is very simple (if you can identify the source)

Vapor Intrusion vs. Indoor Sources

- Overview of VI investigations
- Indoor sources of VOCs
- On-site GC/MS analysis protocol
- Stable isotope analysis
- Recommendations

Petroleum Hydrocarbons

- Sources of VOCs in indoor air

Petroleum Hydrocarbons

- Sources of VOCs in indoor air

Chlorinated Solvents

- Email bulletin, October 2010

Technical Update

Topics, trends and news in the environmental industry...

TCE Contamination Affects Community's Water Wells

"The TCE, which was banned from public use in the 1970s, was detected at levels greater than the U.S. EPA's maximum contaminant level for public drinking water."

Key point: Many people believe that TCE and other chlorinated solvents are no longer used in industrial operations or consumer products

Chlorinated Solvents

Gun Cleaner: $19.95
>90% TCE

Pepper Spray: $3.99
>90% TCE

Hobby Glue: $4.95
>90% PCE

Plastic Ornament: $4.95
1,2-DCA

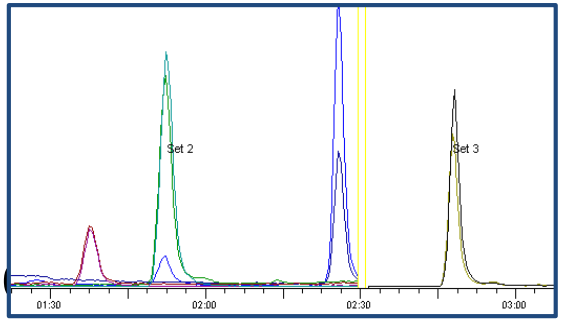
Key point: Chlorinated VOCs are legal and are still used in a wide variety of consumer products currently available for purchase

Vapor Intrusion vs. Indoor Sources

- Overview of VI investigations
- Indoor sources of VOCs
- On-site GC/MS analysis protocol
- Stable isotope analysis
- Recommendations

On-Site Analysis: Portable GC/MS

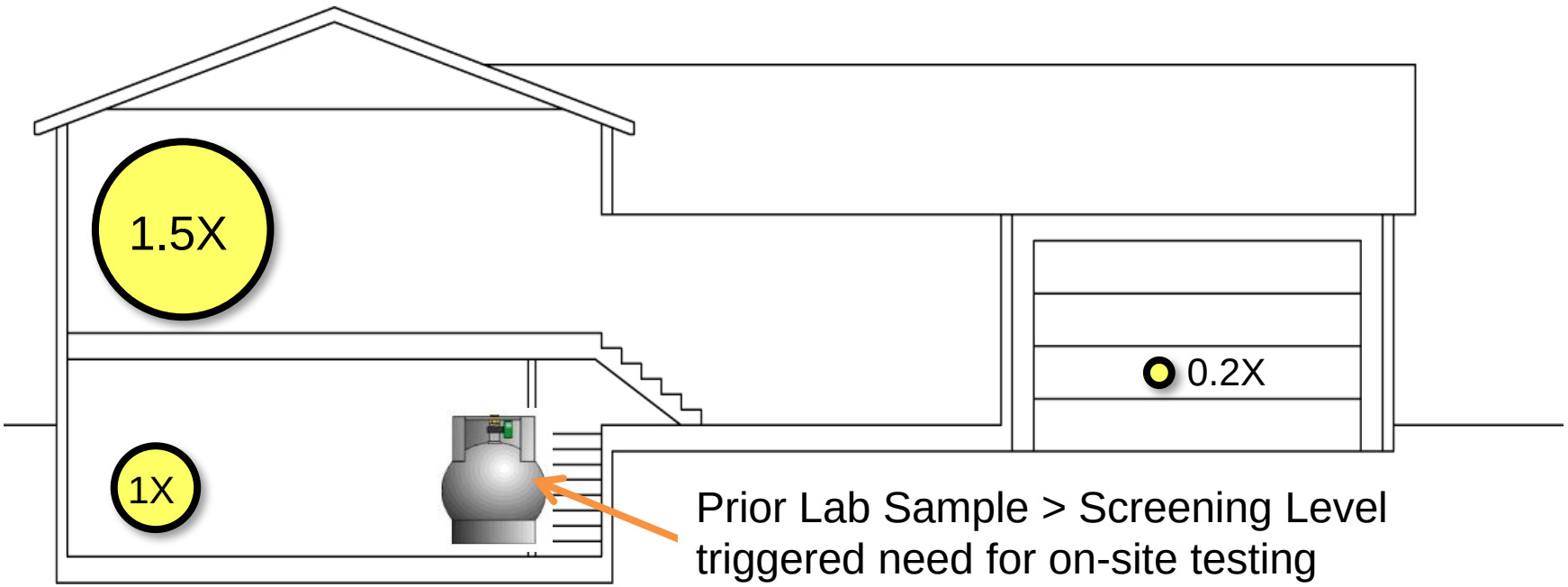
- Inficon HAPSITE®
- Key features
  - GC/MS and MS-Only operating modes
  - Custom GC/MS methods
    - Positive ID for 5-10 compounds
    - ~6 min sample turn time
    - Low quantitation limits
- Can use off-site samples for "definitive" (i.e., comparison to screening levels)



Key point: Approach relies on instrument with rapid sample throughput, high sensitivity and precision, quantitative and semi-quantitative capabilities

On-Site Analysis

- Area by area results



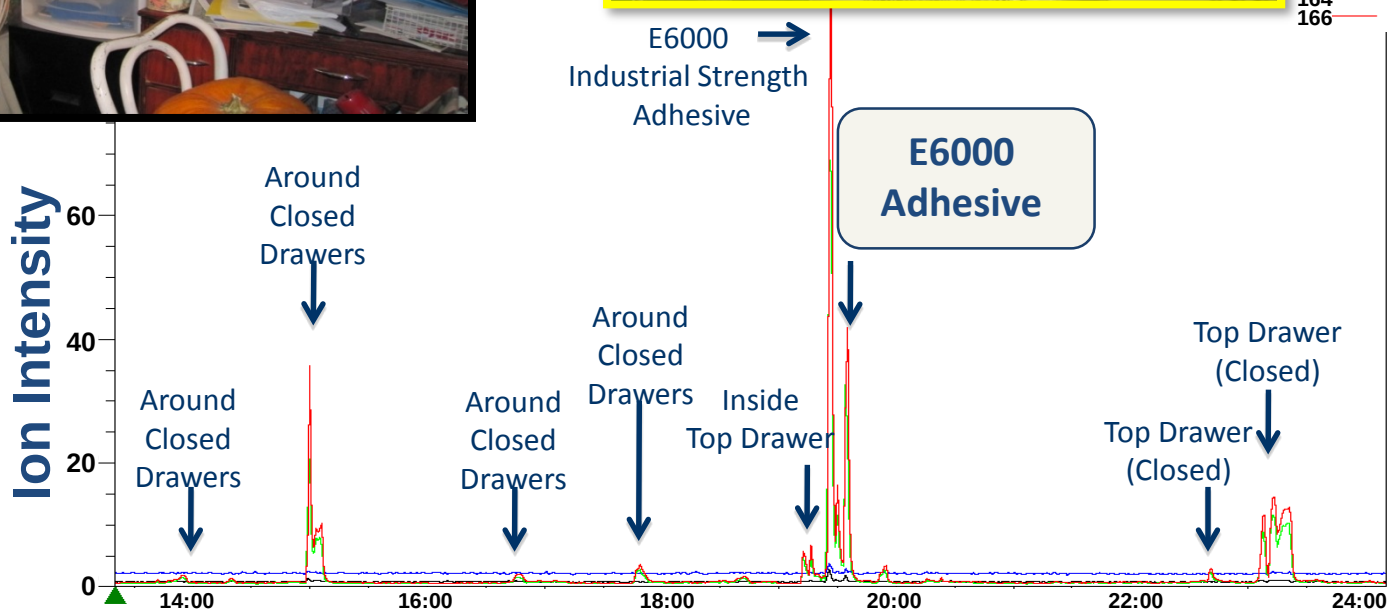
Goal: Find the source

On-Site Analysis (Cont'd)

- Room by room results – Upstairs

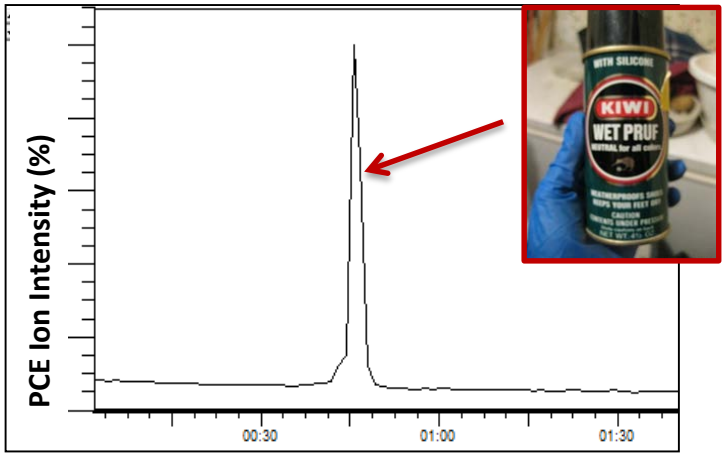
Goal: Find the source

On-Site Analysis (Final Step)

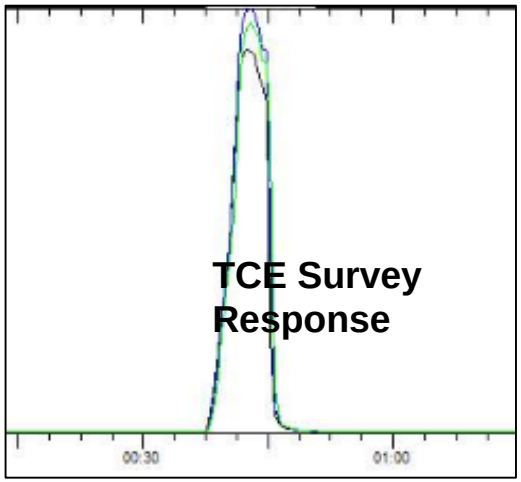


On-Site Analysis (Final Step)

- Indoor source

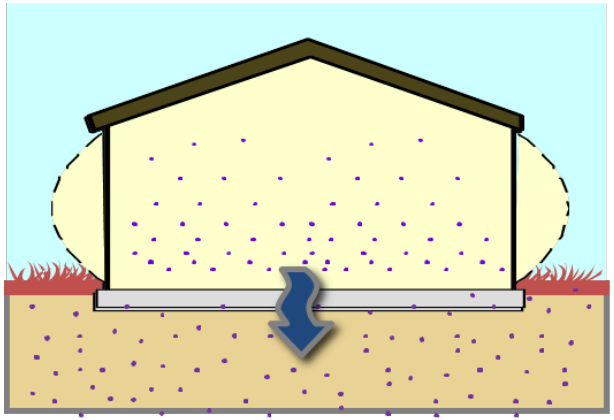


- Vapor entry point

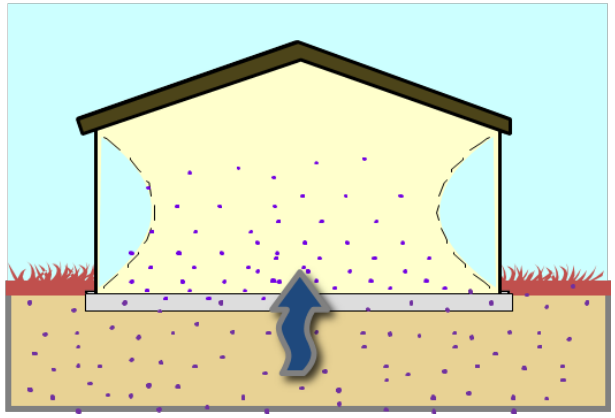


Building Pressure Control Option

POSITIVE
Pressure in Building = VI Off



NEGATIVE
Pressure in Building = VI On



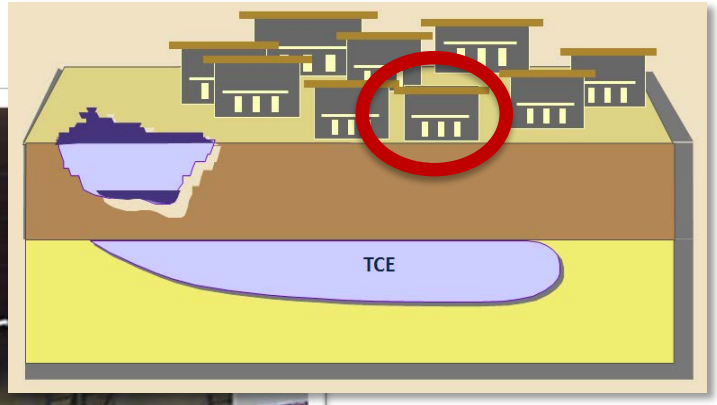
McHugh et al., 2012, "Evaluation of Vapor Intrusion Using Controlled Building Pressure", Environ. Sci. Technol.
McHugh et al., ESTCP Project ER-200707

General concept

1. Use controlled **negative** pressure to <u>turn on</u> vapor intrusion
2. Evaluate potential for vapor intrusion using on-site analysis procedure
3. "Make it worse" to address <u>temporal variability</u>

Case Study: Warehouse

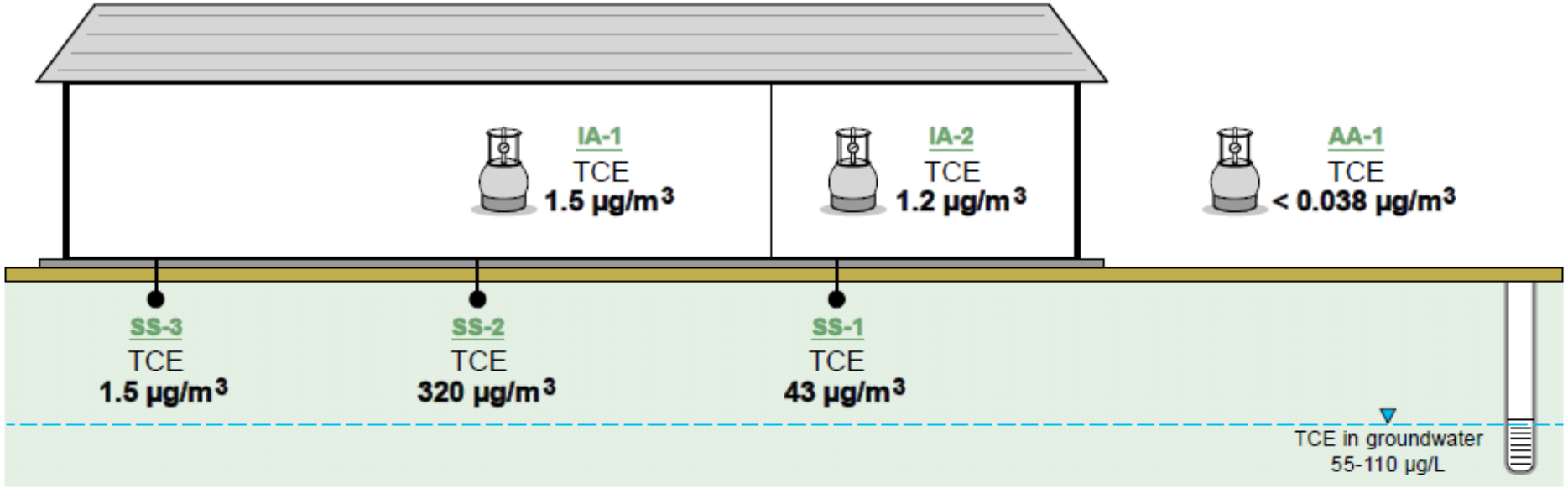
- 20,000 sqft supply distribution warehouse
- Many potential indoor and subsurface VOC sources



Conventional vs. On-Site Protocol

Conventional

Conventional Program	No. Samples	TCE Concentration
Indoor Air (8 hr)	2	**1.2 – 1.5 ug/m^3**
Sub-slab	3	**1.5 – 320 ug/m^3**
Groundwater	2	**55 - 96 ug/L**



Conventional vs. On-Site Protocol

Conventional

Conventional Program	No. Samples	TCE Concentration
Indoor Air (8 hr)	2	**1.2 – 1.5 ug/m^3**
Sub-slab	3	**1.5 – 320 ug/m^3**
Groundwater	2	**55 - 96 ug/L**

On-site protocol (baseline evaluation, 22 samples)

3 HAPSITE samples:

TCE 0.97 – 1.7 ug/m^3

8 HAPSITE samples:

TCE 0.81 – 2 ug/m^3

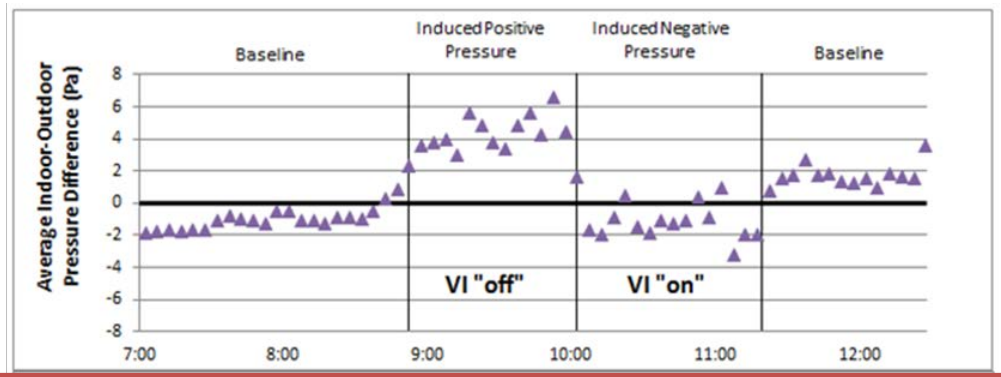
5 HAPSITE samples:

TCE 0.75 – 1.8 ug/m^3

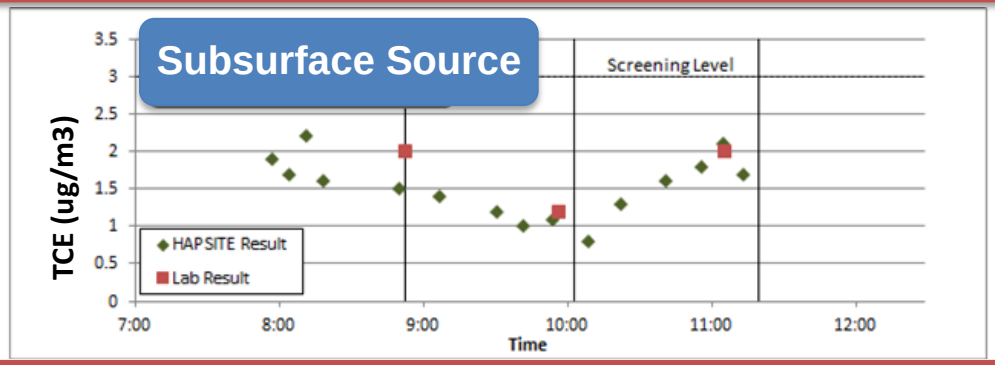
6 HAPSITE samples:

TCE 1.5 – 4.1 ug/m^3

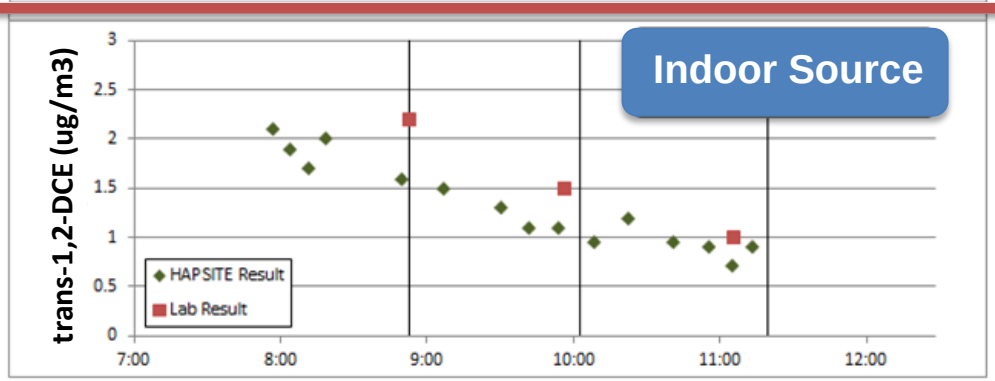
Pressure Control Results



1



2



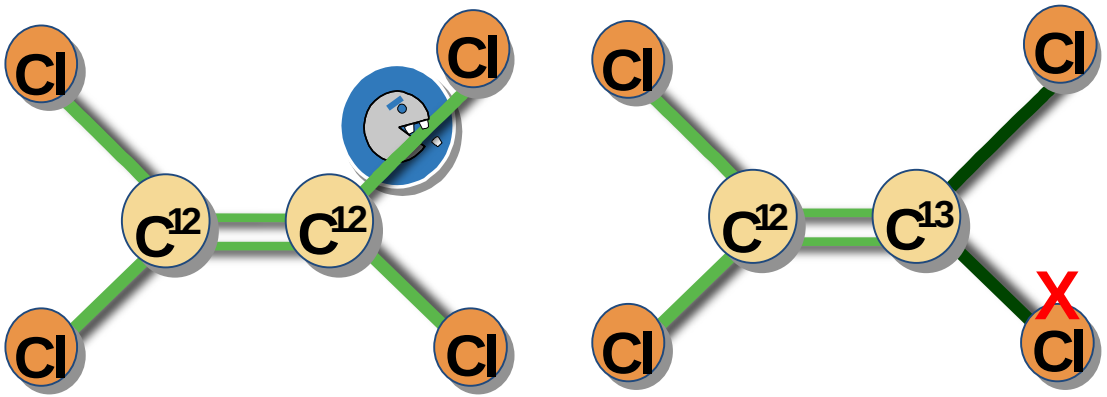
3

Vapor Intrusion vs. Indoor Sources

- Overview of VI investigations
- Indoor sources of VOCs
- On-site GC/MS analysis protocol
- Stable isotope analysis
- Recommendations

Technology Description

- Stable isotope fractionation
  - Kinetic Effect: Biodegradation causes enrichment in PCE containing ^{13}C

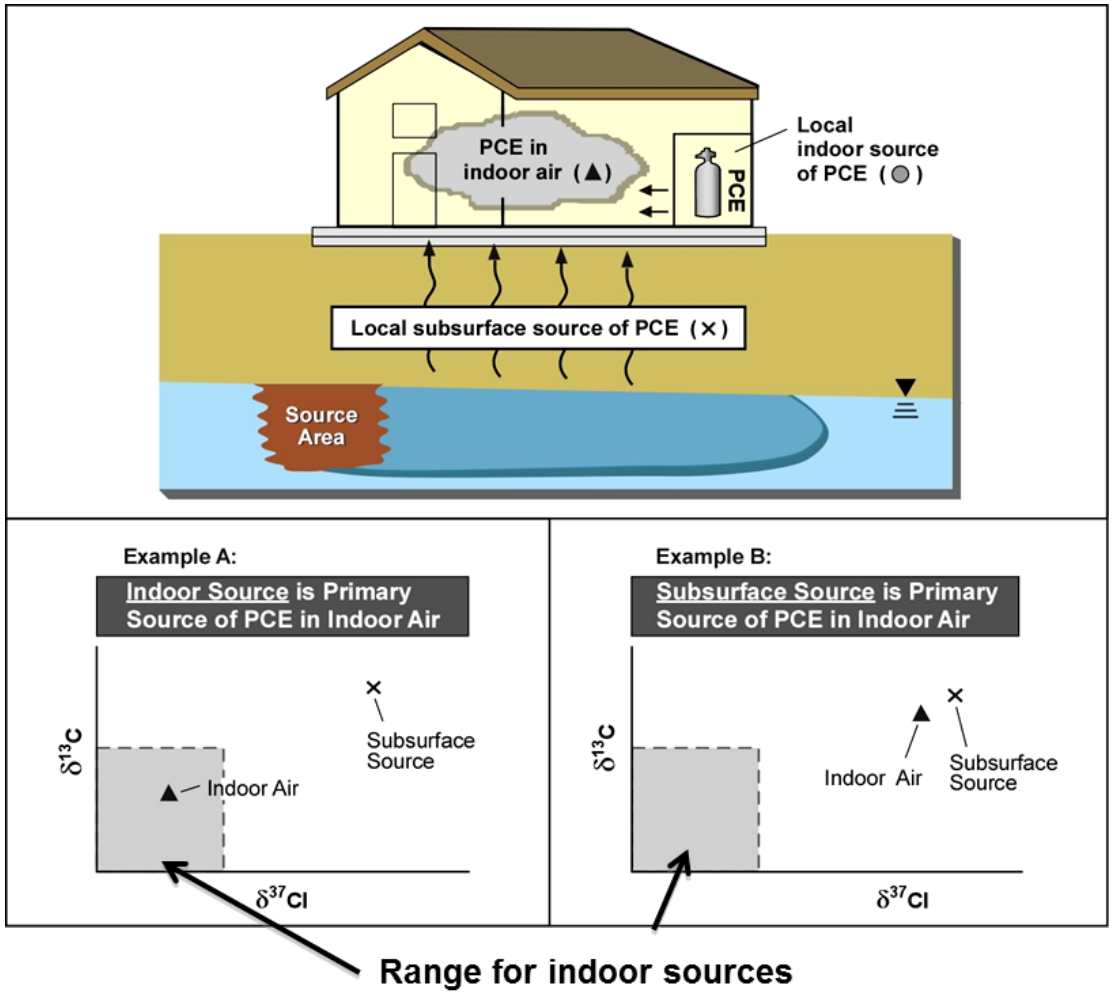


Biodegradation of PCE:

^{12}C – Cl bond easier to break than ^{13}C – Cl bond.

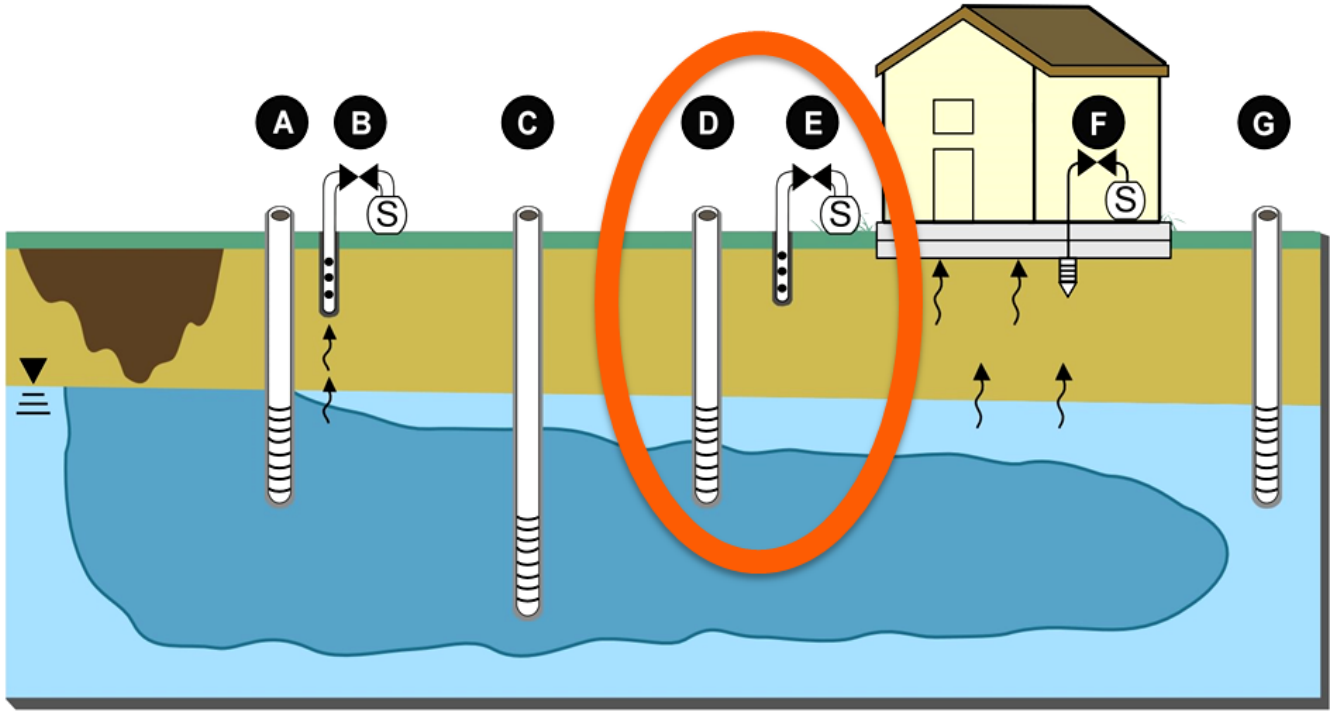
Key Point: Differences in isotope ratios between samples can indicate different sources: indoor vs. subsurface

Applications of CSIA to Vapor Intrusion



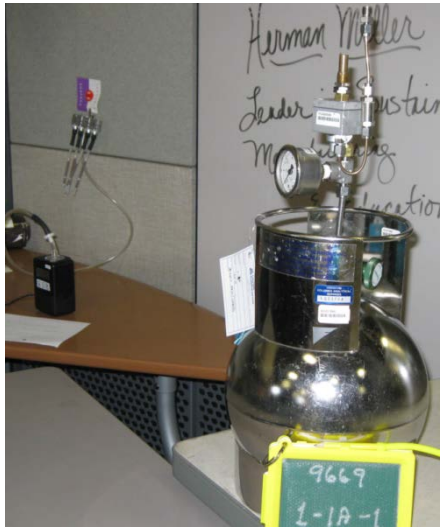
Application Protocol

1. Subsurface sample locations



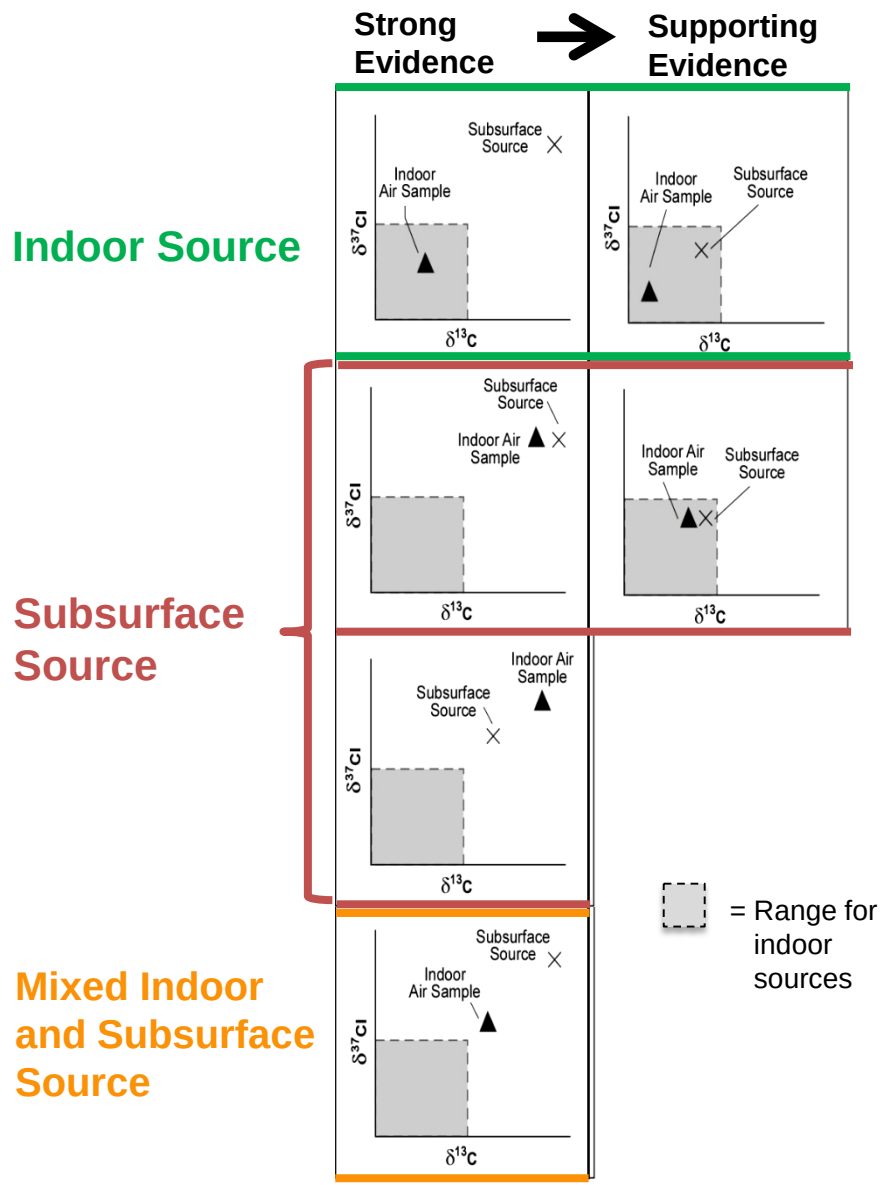
Protocol (Cont'd)

2. Choose indoor air sample locations
3. Collect samples per validated steps
   - Estimate sample concentrations to ensure collection of correct sample mass



Protocol (Cont'd)

4. Interpret results per matrix



Vapor Intrusion vs. Indoor Sources

- Overview of VI investigations
- Indoor sources of VOCs
- On-site GC/MS analysis protocol
- Stable isotope analysis
- Recommendations

Recommendations

- Goal: Quickly and accurately determine if vapor intrusion is resulting in VOC concentration exceedances in indoor air

Indoor Air Testing

- Measure VOC Concentration
- Compare to applicable screening level

Source Identification

- VI vs. Indoor Source
  - On-site analysis
  - Isotope analysis
  - Building pressure control

Follow up as needed

- Temporal variability concern: low cost indoor air monitoring using passive samplers
- Real vapor intrusion: Mitigate

Validation Studies: On-Site Analysis

Investigation Method	Validation Study	Publications
On-Site GC/MS Analysis: Use real-time compound-specific analysis to follow the "smoke trail" back to the indoor source of vapor entry point	ESTCP ER-201119 Google "ESTCP ER-201119" for project report and application protocol	Beckley et al., 2014, Env. Forensics, 15(3), 234-243 Gorder and Dettenmair, 2011, GWMR, 31(4), 113-119

Validation Studies: Isotopes

Investigation Method	Validation Study	Publications
<u>Compound-Specific Isotope Analysis (CSIA)</u>: Use the isotope fingerprint of the target VOC to distinguish between vapor intrusion and indoor sources of VOCs	ESTCP ER-201025 Google "ESTCP ER-201025" for project report and application protocol	McHugh et al., 2011, ES&T, 45(14), 5952-5958 Kilsch et al., 2013, J. Chromatography A, Vol. 1270, pp. 20-27

Validation Studies: Pressure Control

Investigation Method	Validation Study	Publications
<u>Building Pressure Cycling</u>: Change the building pressure to turn on and turn off vapor intrusion in real time	ESTCP ER-200707 Google "ESTCP ER-200707" for project report and application protocol	McHugh et al., 2012, ES&T, 46(9), 4792-4799 USEPA Environmental Technology Verification (ETV) Program: http://www.epa.gov/etv/vrvs.html

For additional information, please visit http://www.serdp-estcp.org

Speaker Contact Information:
temchugh@gsi-net.com; 716-876-9261

Q&A Session 1

SERDP DOD • EPA • DOE | ESTCP

Multi-Year Monitoring of a House Overlying a Dilute Chlorinated Hydrocarbon Plume: Implications for Vapor Intrusion Pathway Assessment

Paul Johnson, Ph.D.
Arizona State University

SERDP DOD • EPA • DOE | ESTCP

Lessons Learned from Monitoring a House Overlying a Dissolved Chlorinated Hydrocarbon Plume Under Natural and Controlled Depressurization Conditions

SERDP Project ER-1686

Paul C. Johnson
Ira A. Fulton Schools of Engineering, Arizona State University

(w/C. Holton, P. Dahlen, H. Luo, K. Gorder, E. Dettenmaier)

SERDP DOD • EPA • DOE | ESTCP

SERDP ER-1686 Overview

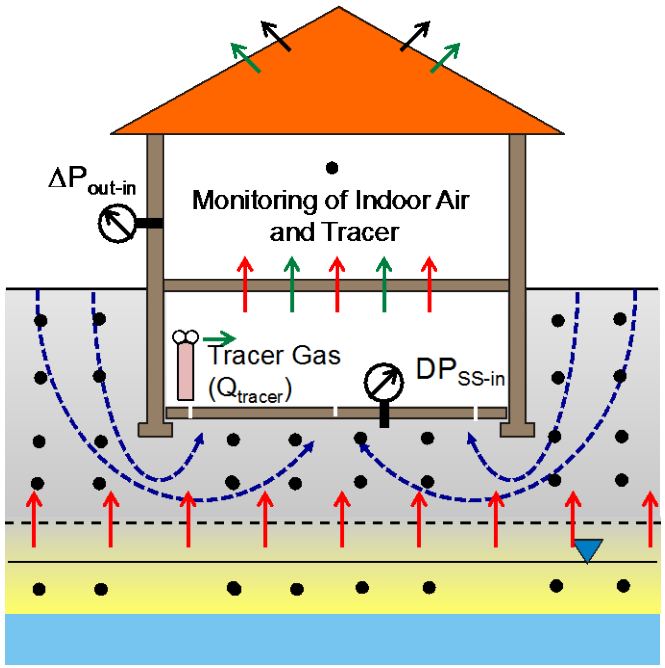
Objective: Collect a long-term and high-frequency vapor intrusion (VI) data set

Why?: It does not exist. Needed to answer key VI pathway assessment plan questions – major data gap in the VI field

Goal: Increase confidence and cost-effectiveness in VI pathway assessment

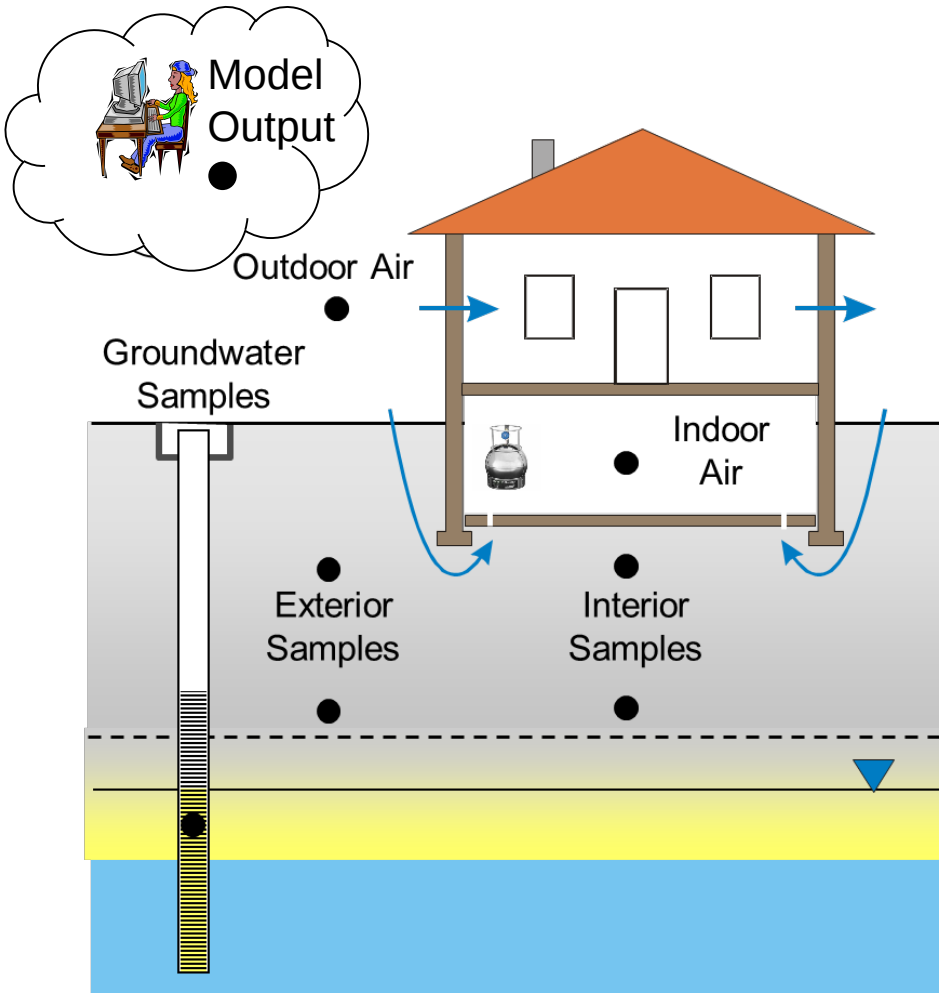
Data Collection:

- **Phase I**: Natural conditions (921 days)
- **Phase II**: Controlled building under-pressurization condition (325 days)
- **Phase III**: Controlled under-pressurization and natural conditions, with modifications to subsurface infrastructure (460+ days)



Data: CHCs and radon in indoor air and soil gas, pressure differentials, exchange rate, environment (wind, temperature, etc.), tracer gas, effective diffusion coefficients

MLE* VI Pathway Assessment Paradigm



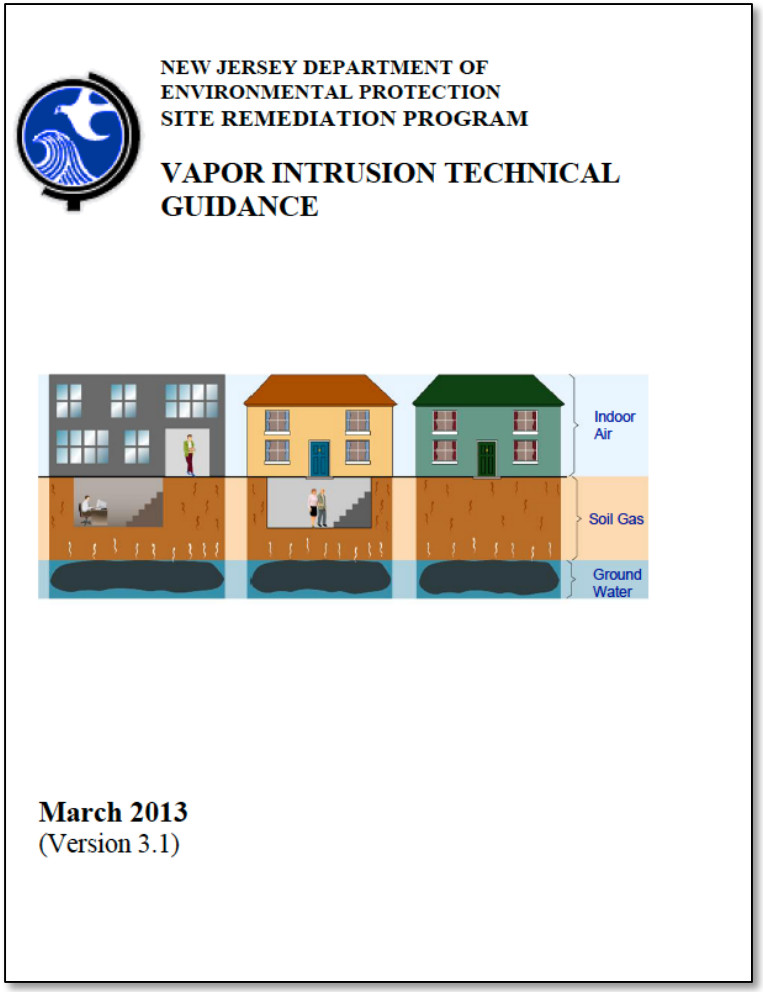
* MLE = multiple lines of evidence

- Heavy weighting of indoor air data
- Decisions made using a few samples
- Sometimes short sampling windows or seasonal data (*e.g., fall, winter*)
- Usually 24-h indoor samples; might include portable detectors or passive samples

Question: Do MLE outcomes depend on plan specifics?

(date/time/season, number of samples, sampling duration)

Multiple Lines-of-Evidence Guidance


NEW JERSEY DEPARTMENT OF
ENVIRONMENTAL PROTECTION
SITE REMEDIATION PROGRAM

VAPOR INTRUSION TECHNICAL GUIDANCE

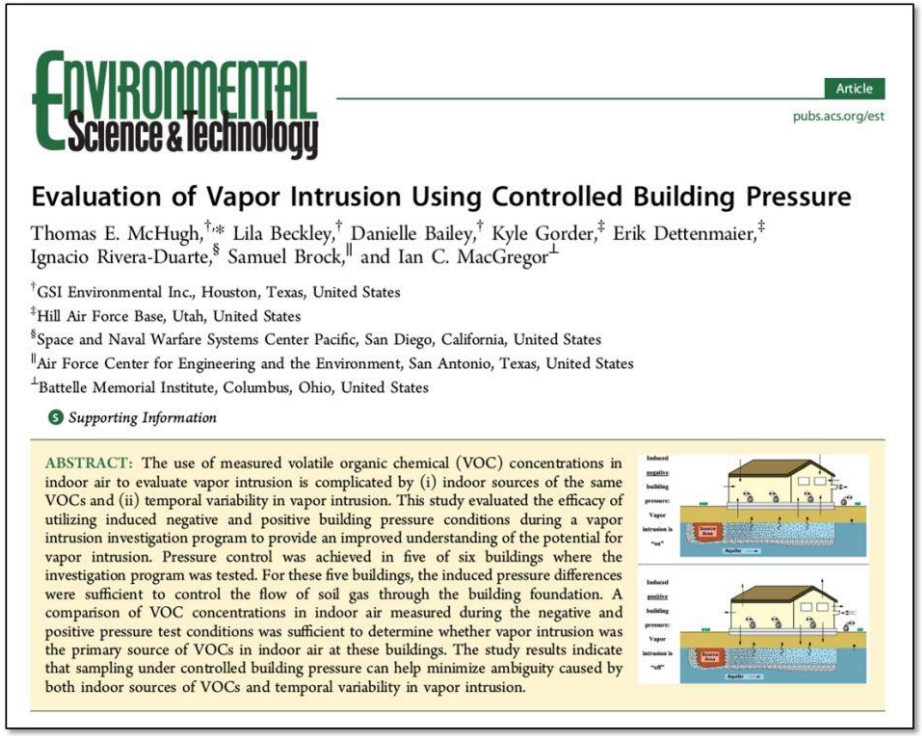
March 2013
(Version 3.1)

"When IA samples are being collected as a primary assessment tool for the determination of the VI pathway**, the sample event should take place between November 1 and March 31**.

Based on seasonal weather patterns, these dates are generally "worst case" conditions for VI to occur.

Assuming there are no other contradictory lines of evidence, **the single round of indoor/ambient air samples should be able to determine whether the VI pathway is complete."**

Controlled Pressure Method (CPM) Testing



Environmental Science & Technology

Article

pubs.acs.org/est

Evaluation of Vapor Intrusion Using Controlled Building Pressure

Thomas E. McHugh,[†,*] Lila Beckley,[†] Danielle Bailey,[†] Kyle Gorder,[‡] Erik Dettenmaier,[‡] Ignacio Rivera-Duarte,[§] Samuel Brock,[∥] and Ian C. MacGregor[⊥]

[†]GSI Environmental Inc., Houston, Texas, United States
[‡]Hill Air Force Base, Utah, United States
[§]Space and Naval Warfare Systems Center Pacific, San Diego, California, United States
[∥]Air Force Center for Engineering and the Environment, San Antonio, Texas, United States
[⊥]Battelle Memorial Institute, Columbus, Ohio, United States

Supporting Information

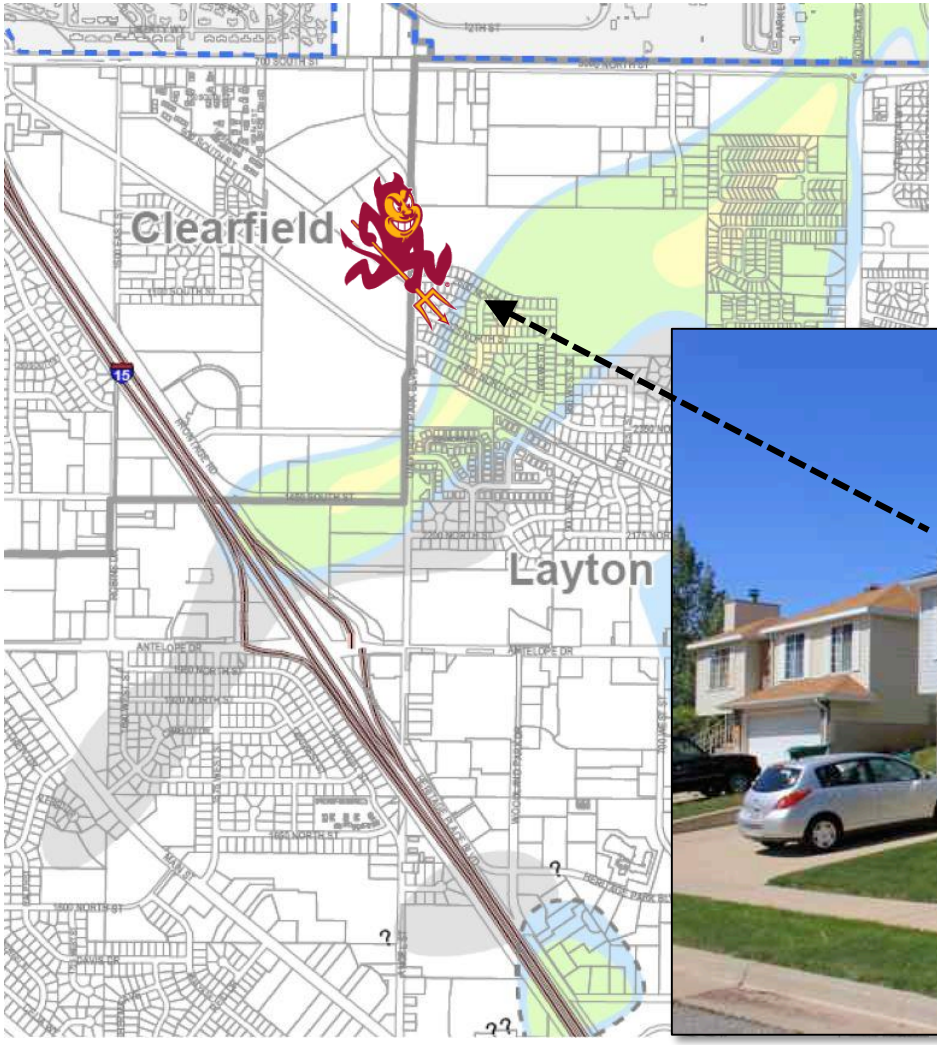
ABSTRACT: The use of measured volatile organic chemical (VOC) concentrations in indoor air to evaluate vapor intrusion is complicated by (i) indoor sources of the same VOCs and (ii) temporal variability in vapor intrusion. This study evaluated the efficacy of utilizing induced negative and positive building pressure conditions during a vapor intrusion investigation program to provide an improved understanding of the potential for vapor intrusion. Pressure control was achieved in five of six buildings where the investigation program was tested. For these five buildings, the induced pressure differences were sufficient to control the flow of soil gas through the building foundation. A comparison of VOC concentrations in indoor air measured during the negative and positive pressure test conditions was sufficient to determine whether vapor intrusion was the primary source of VOCs in indoor air at these buildings. The study results indicate that sampling under controlled building pressure can help minimize ambiguity caused by both indoor sources of VOCs and temporal variability in vapor intrusion.

- Proposed alternative to sampling under natural conditions
- One-time short-term test

Questions: Will CPM outcomes depend on application date, season, duration?

How do CPM results compare with true impacts under natural conditions?

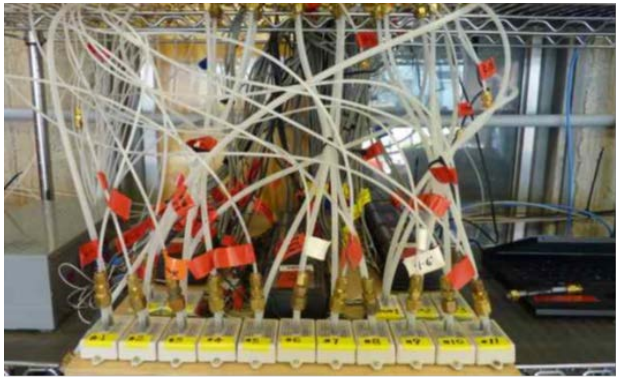
Sun Devil Manor (Layton, UT)

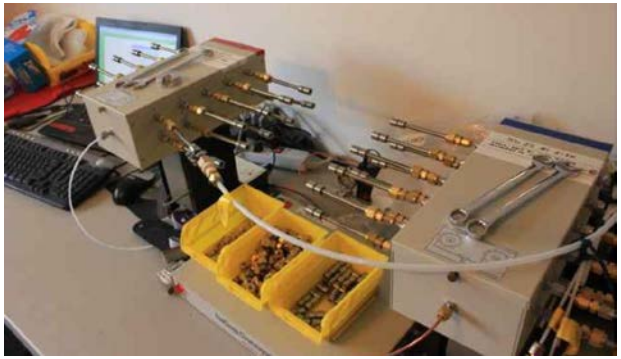


- 10 – 60 mg/L TCE and 1,1 DCE in groundwater
- 1500 pCi/L radon in soil gas

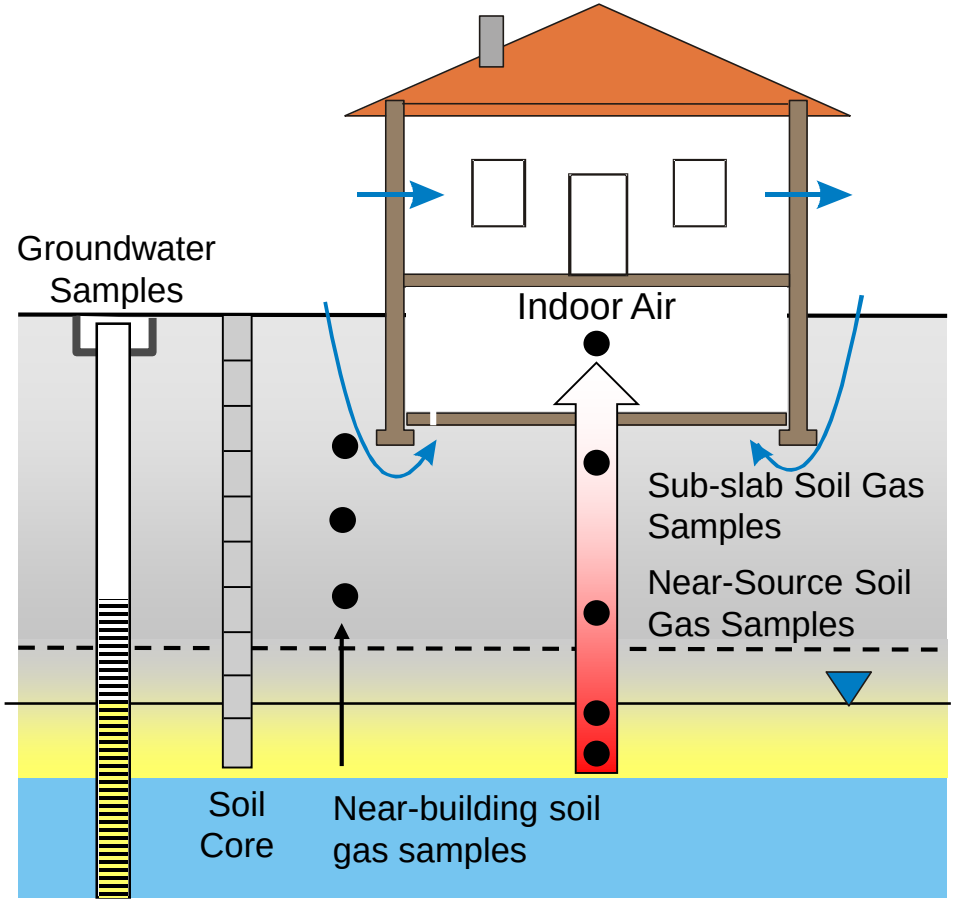
Monitoring and Characterization

Indoor Monitoring





Results: Variability Along the VI Pathway



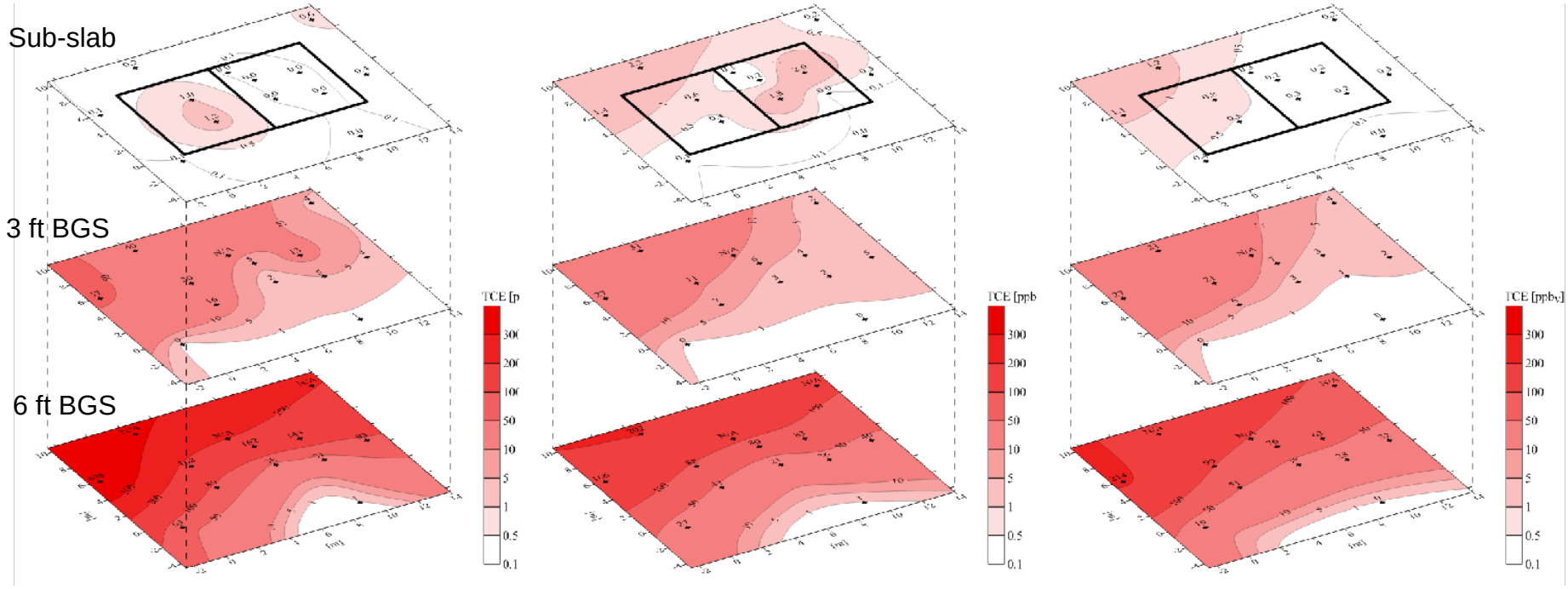
Observations from SDM

Media and Depth	Spatial Variations	Temporal Variations
Indoor Air (lower level)	Unknown	1000X
Sub-slab Soil Gas	10X – 100X	10X
3-ft BS Soil Gas	10X	2X
6-ft Below Slab Soil Gas	3X	50% (about mean)
Shallow Ground water	2X	50% (about mean)

Key Result: Near-source data more consistent in time and space than near-surface data

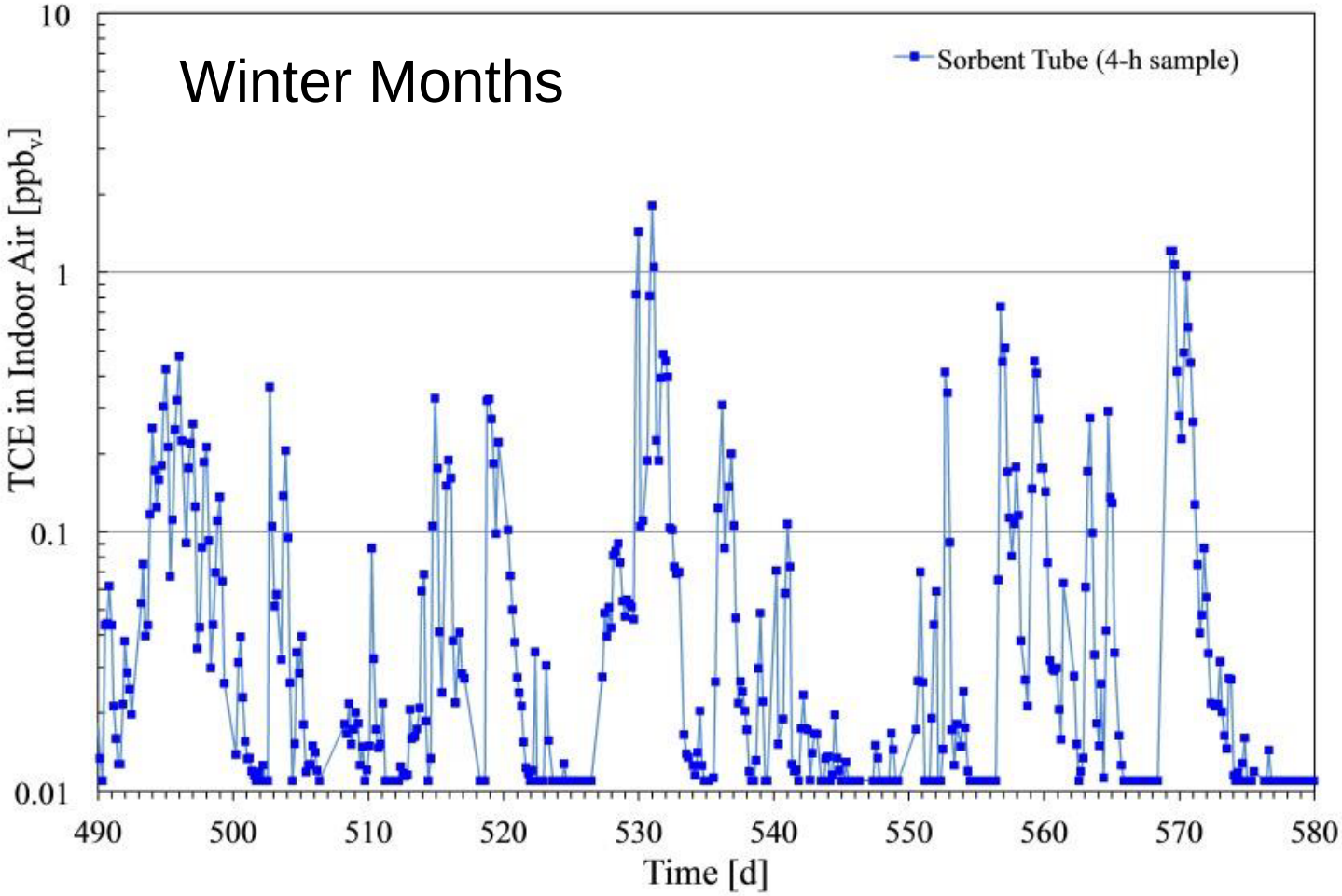
Key Result: Value of intrusive sub-slab sampling not clear

Results: Variability Along the VI Pathway



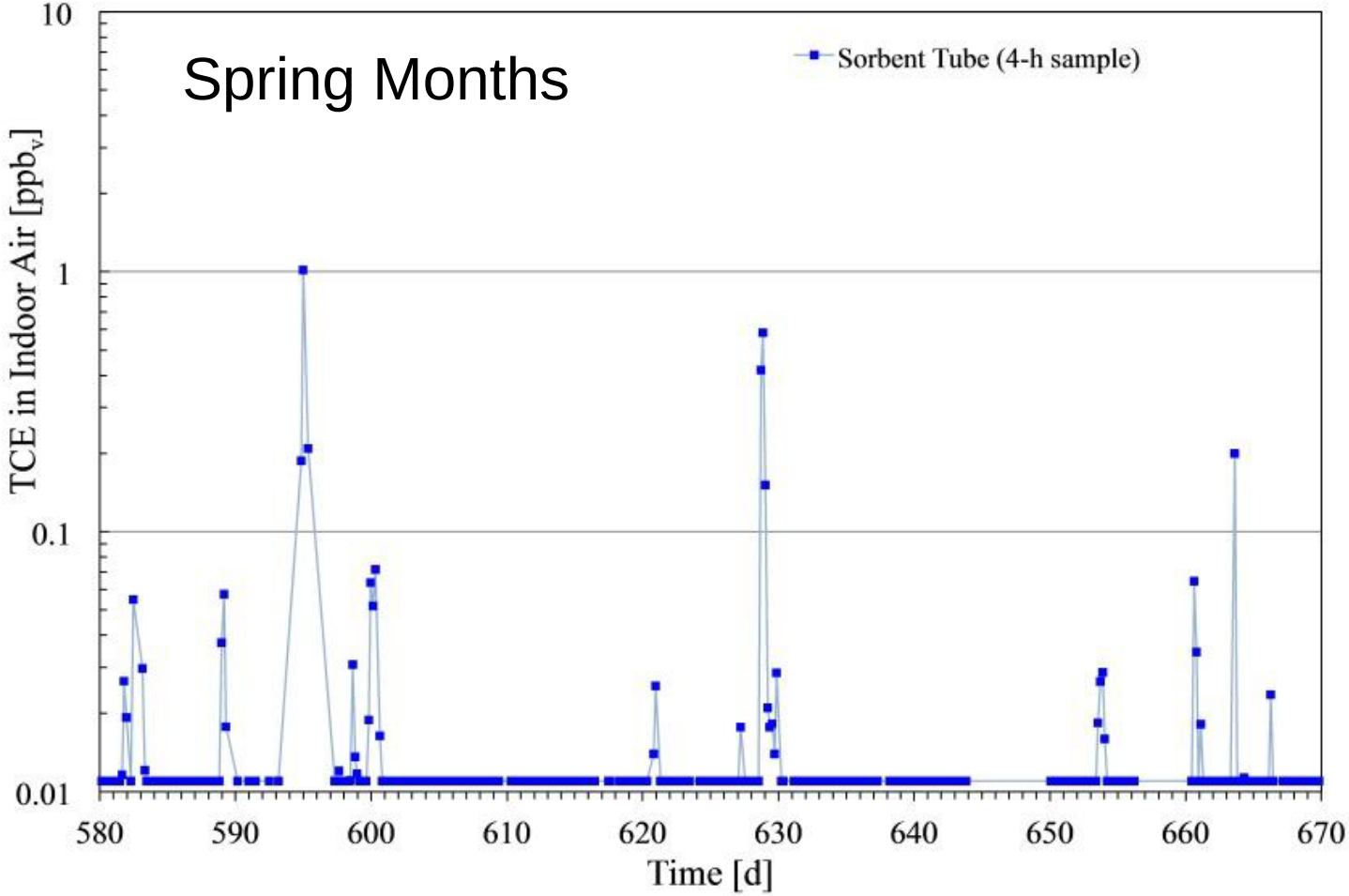
August January February

Indoor Air Concentrations



*Holton et al., ES&T, **2013**, 47, 13347-13354*

Indoor Air Concentrations



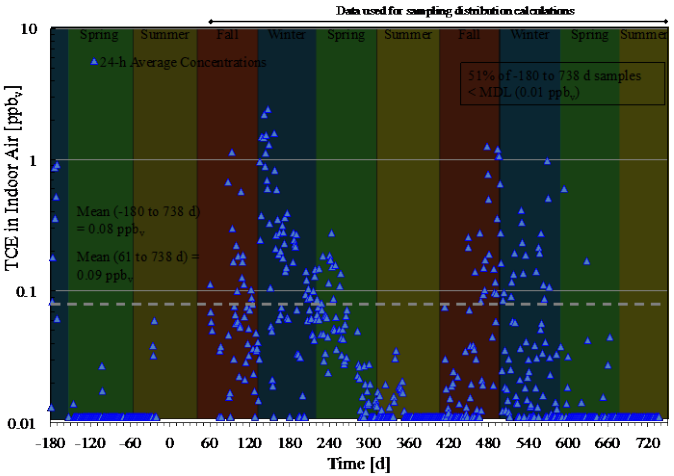
*Holton et al., ES&T, **2013**, 47, 13347-13354*

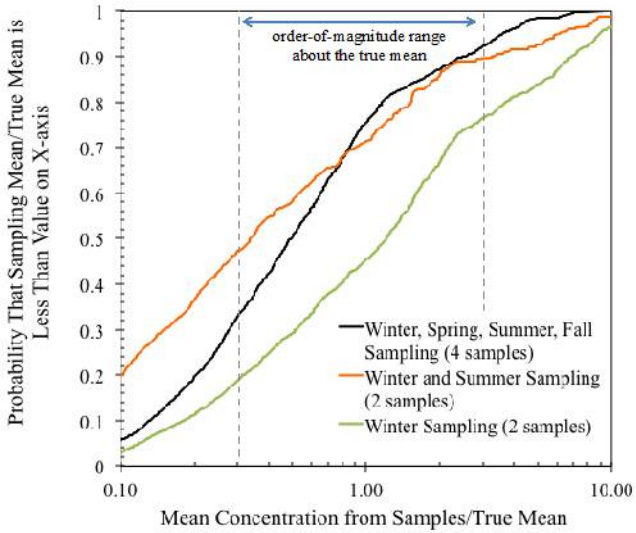
Indoor Air Sampling Plans and Decision-Making

1. Create synthetic 24-h sample data from high temporal resolution data
2. Divide samples into four seasons
   - Fall, Winter, Spring, Summer
3. Perform 10,000+ simulations for three VI pathway assessment plans
   - 4 samples (Fall, Winter, Spring, Summer)
   - 2 samples (Winter, Summer)
   - 2 samples (Winter, Winter)
4. Analyze statistics, assess decision

Results: Analysis of Sampling Outcomes

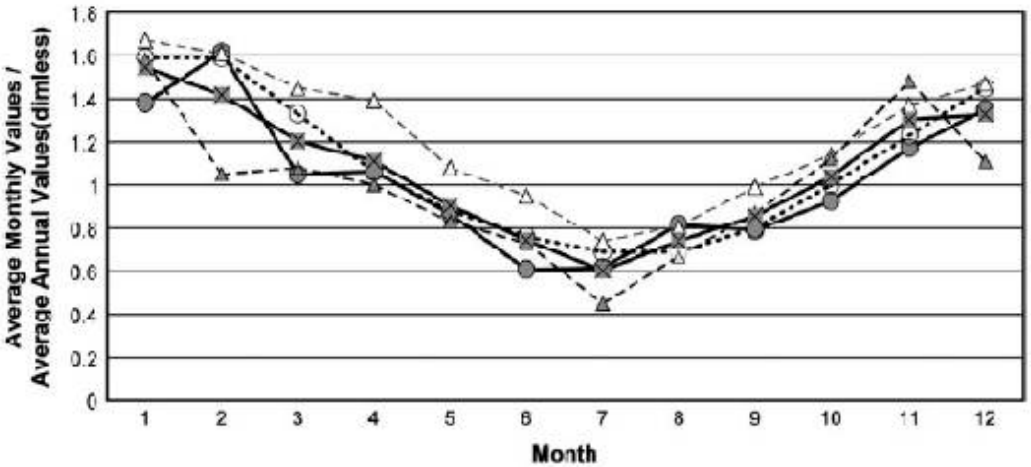
- High potential for false negative result concerning VI occurrence
- High potential to incorrectly characterize long-term exposure
- High potential to incorrectly characterize maximum short-term exposure
  - About half of all 24-h samples would come back non-detect
  - Only about 50% chance that sample results would have a mean concentration inside a 10X range about the true mean concentration





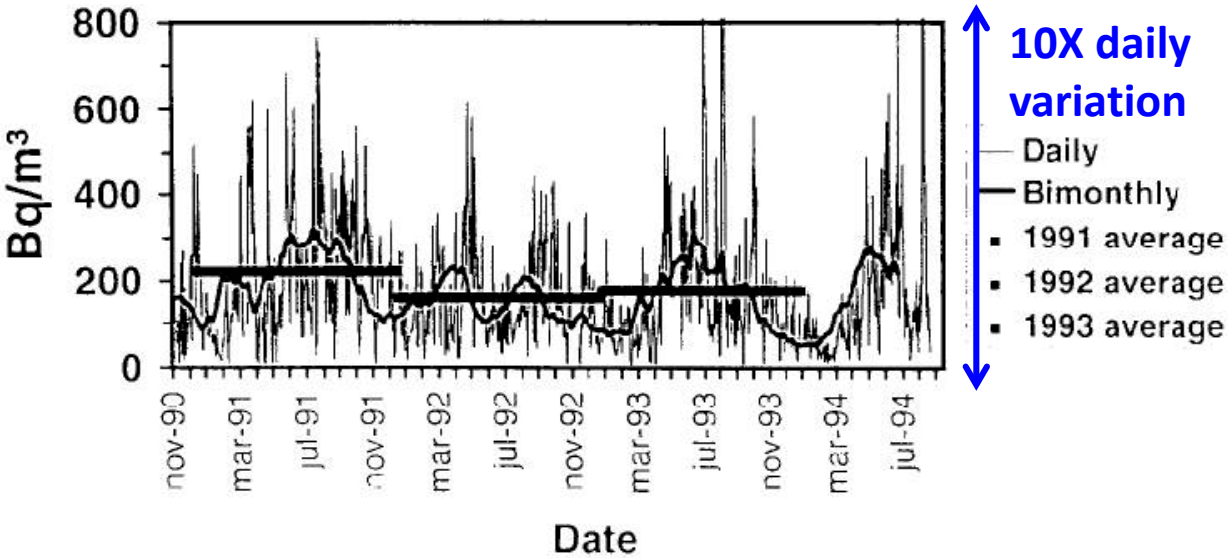
*Holton et al., ES&T, **2013**, 47, 13347-13354*

Temporal Changes in Indoor Air – Others



3X seasonal variation

Folkes et al., *GWMR*, ***2009***, 29 (1), 70-80. Colorado CHC, UK radon, etc.

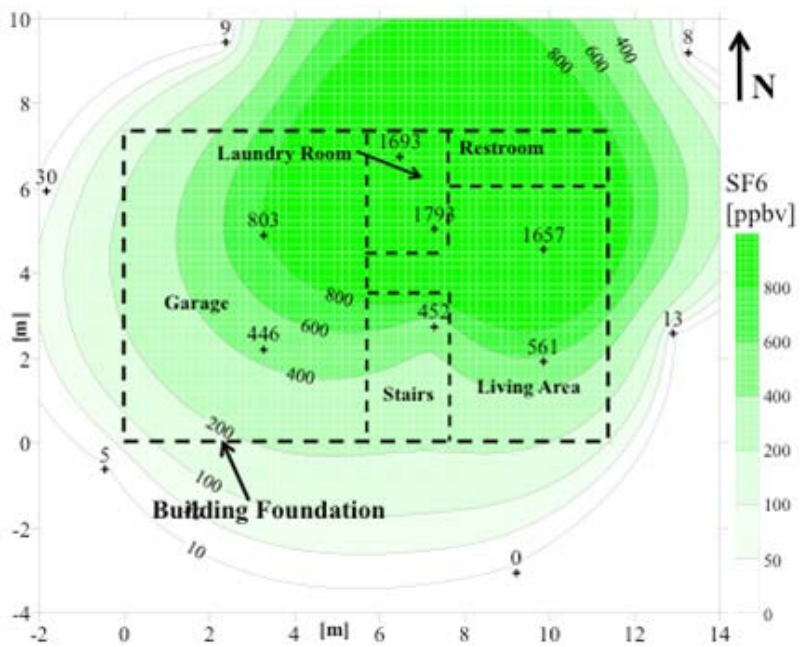


10X daily variation

Hubbard et al. *Environment International*, **1995**, *22*, S715-S722 Sweden homes

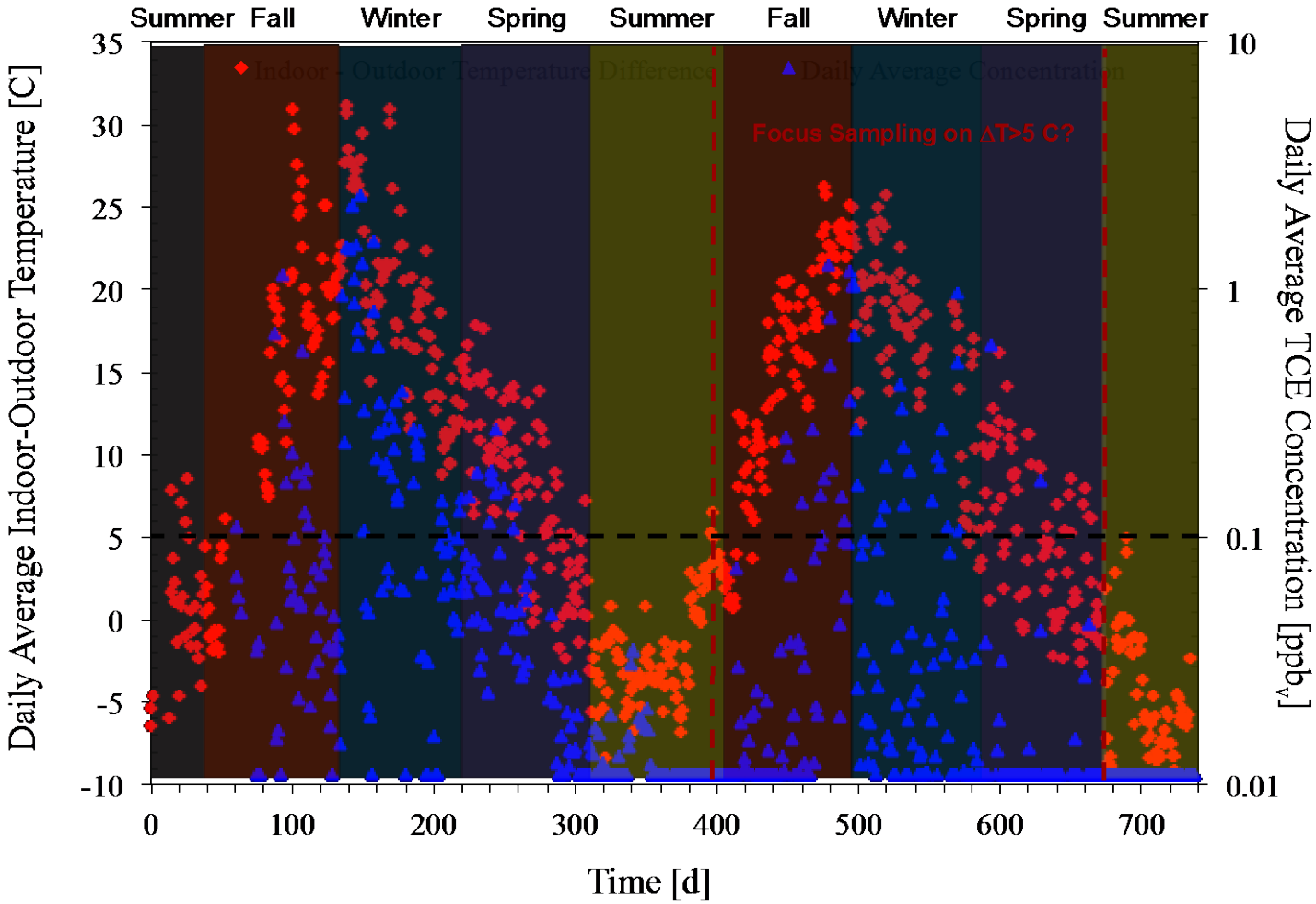
Other Lessons Learned from Phase I

- Indoor Sources
  - Can create subsurface soil gas plumes
  - This can confound MLE data interpretation in ways not previously anticipated
- Radon
  - VI behavior different from CHCs at this site
  - Not useful as quantitative surrogate



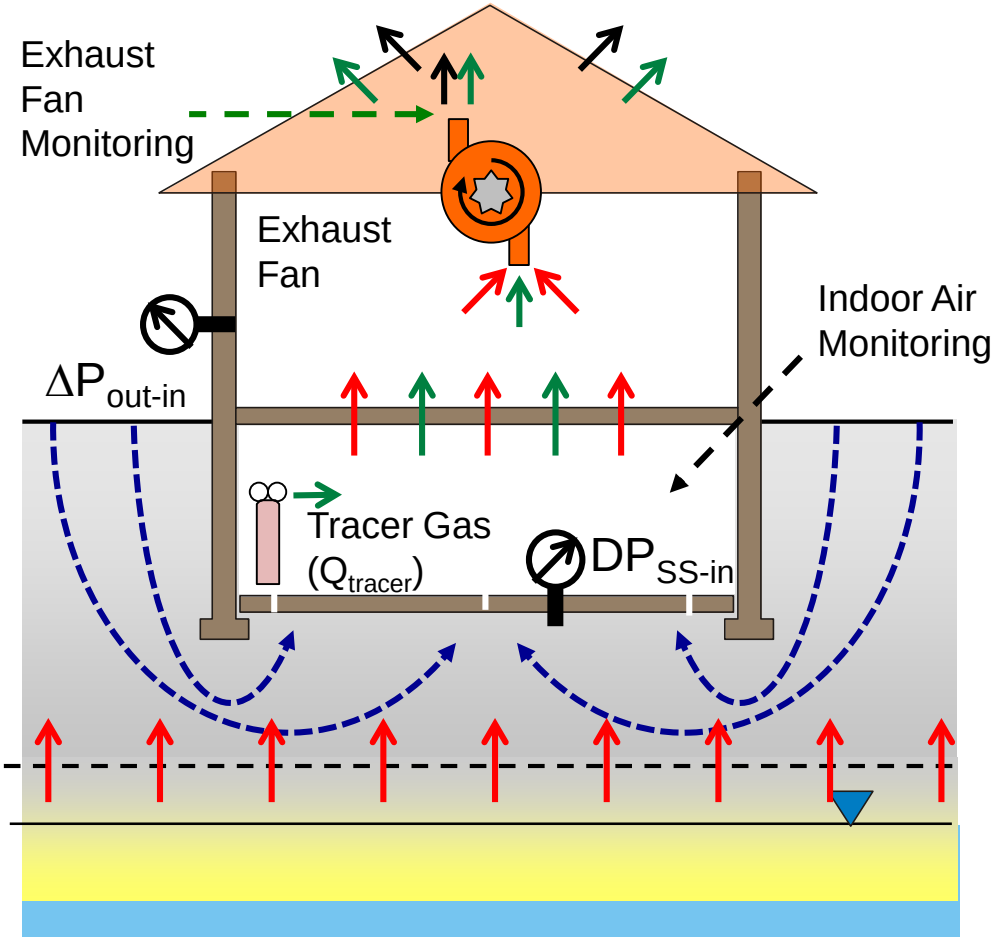
Indoor tracer appearance in sub-slab soil gas

Other Lessons Learned from Phase I



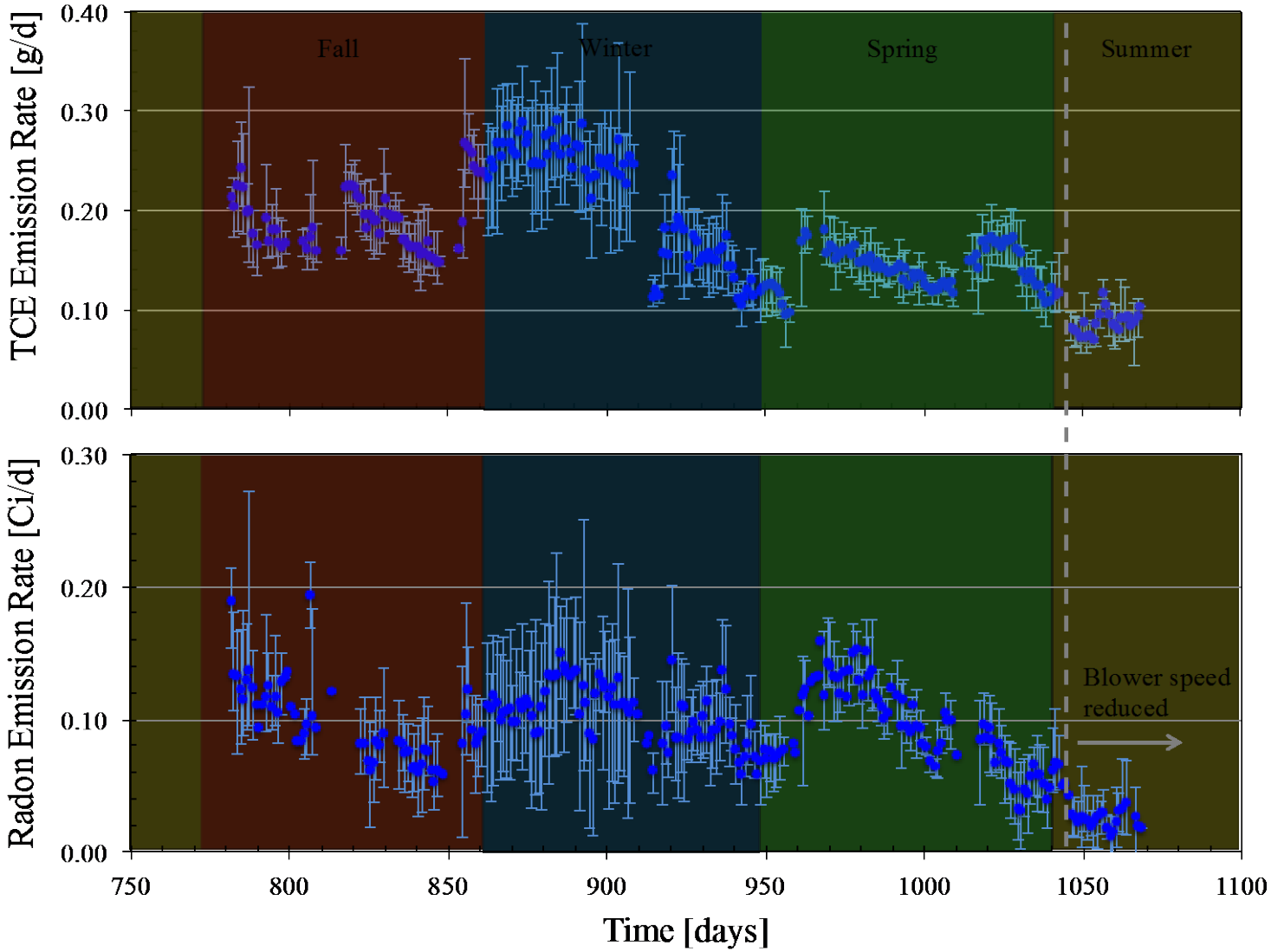
Strong correlation only with indoor-outdoor temperature difference

Phase II: Controlled Pressure Method (CPM)



- House maintained at constant under-pressurization
  (11 Pa outdoor-indoor)
- Tracer gas released at known rate
- TCE, radon, and tracer monitored in blower exhaust
- QB and emission rates into house calculated
- Compare vs. natural conditions

Results: Controlled ΔP Emission Rates



Results are relatively constant with time

Results do not depend on date, time, or season

Comparison: CPM vs. Natural Conditions

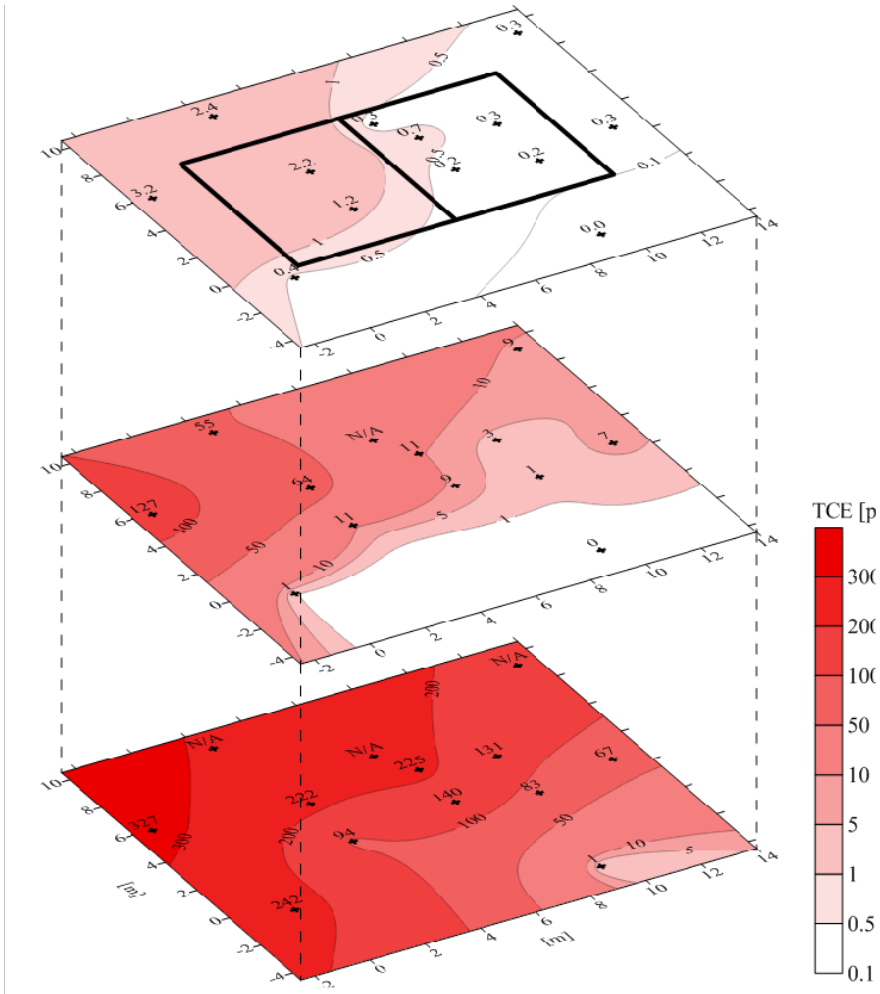
	Concentration Comparison			
	TCE [$\mu g/m^3$]		Radon [pCi/L]	
Condition	Natural Conditions (128 to 730 d)	CPM (780 to 1045 d)	Natural Conditions (170 to 673 d)	CPM (780 to 1045 d)
Mean	0.35	9.3	0.45	5.0
Median	0.068	9.1	0.39	4.8
Maximum	13	12	1.9	8.2
Minimum	<0.04	6.0	<0.25	1.7

CPM Results >> long-term average exposure concentrations

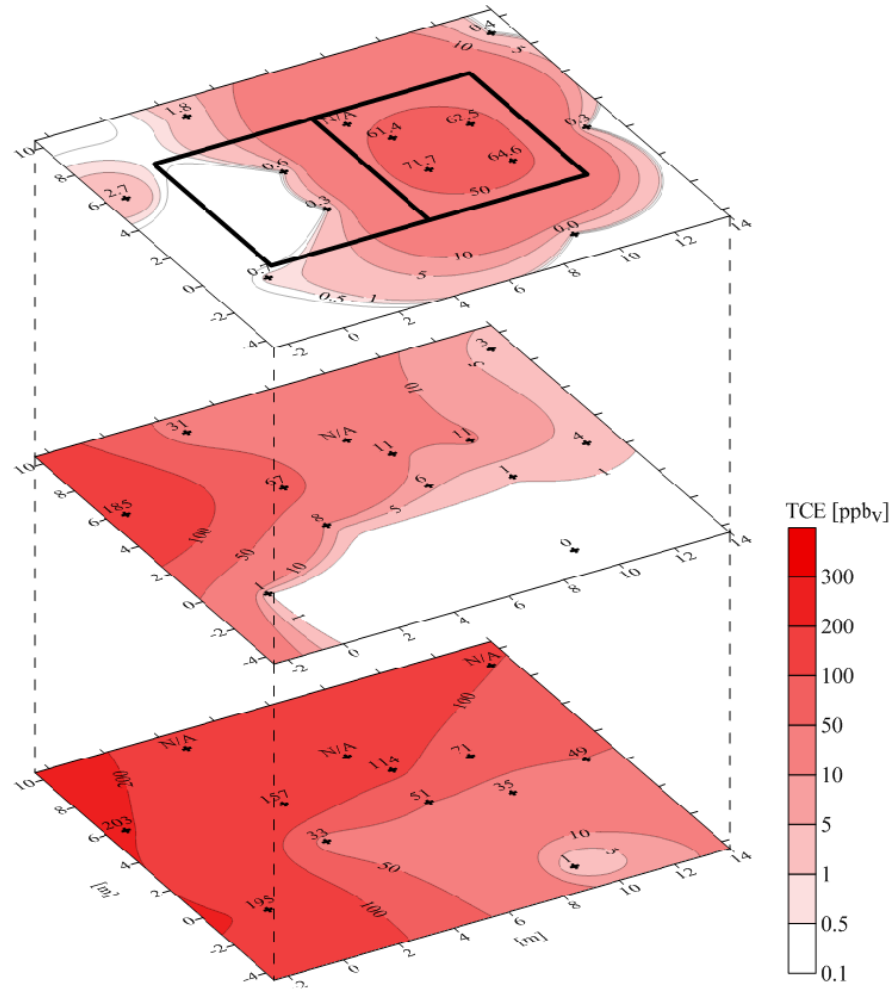
CPM results are similar to maximum impacts under natural conditions

No false negatives in CPM test results

Phase II: Other Observations

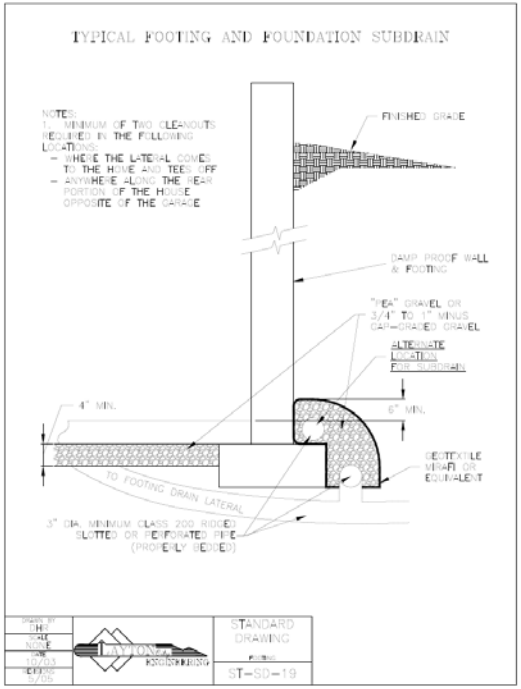


Natural Conditions

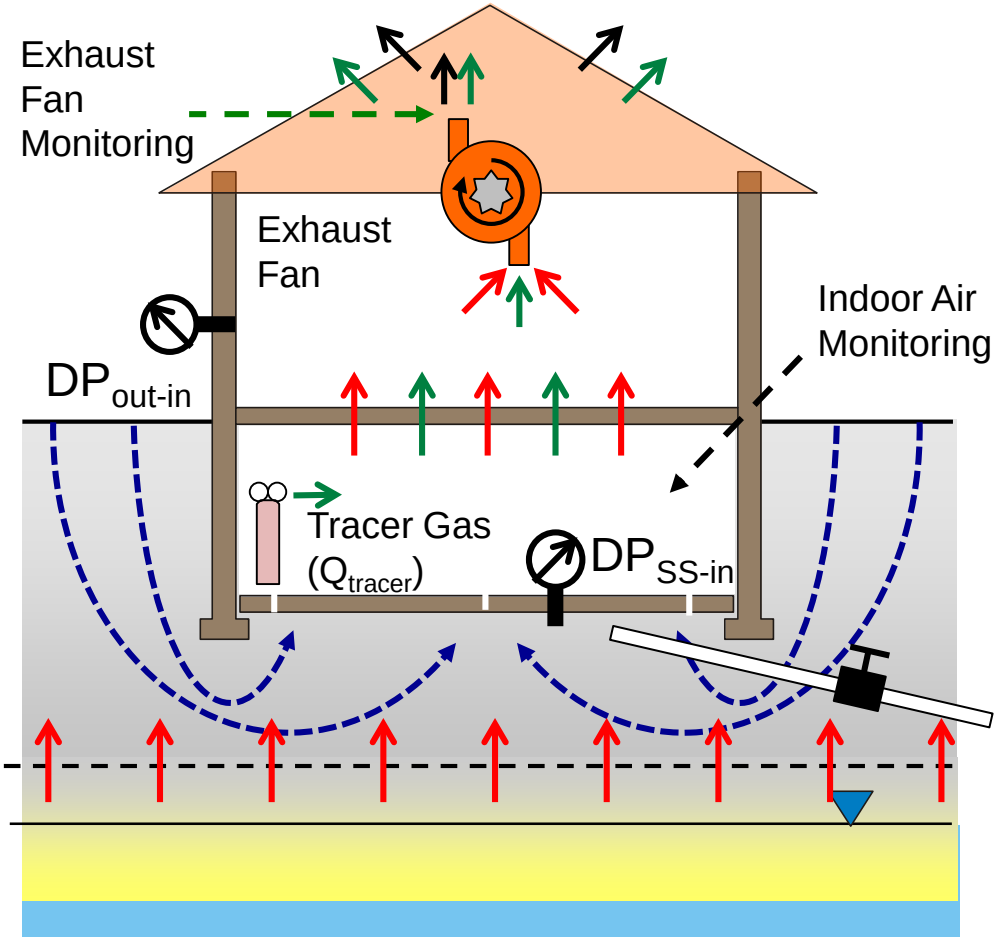


CPM Conditions

Land Drain Discovery and Manipulation



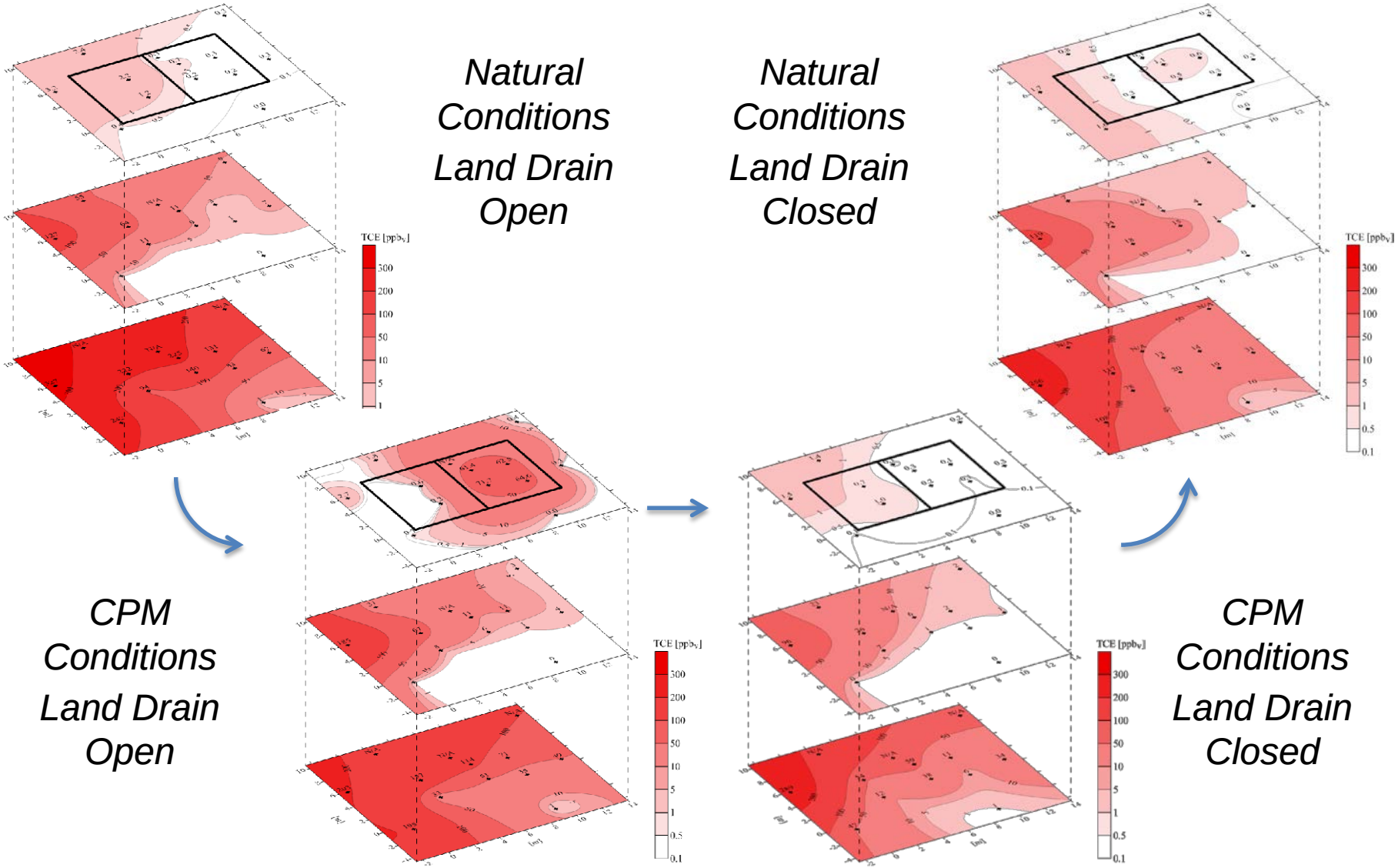
Phase III: Closed Land Drain Lateral



Phase III: Close land drain lateral

- Maintain house at constant under-pressurization for about 3 months
- Turn off blower, study house under natural conditions for about a year

Phase III Observations



Conclusions

- Be cautious when extrapolating shallow soil gas and indoor air measurements beyond that point-in-space and time
- There is a risk of false negatives (and false positives) when using current guidance to assess VI occurrence; there is also the risk of mischaracterizing VI exposure
- Controlled-pressure method testing looks promising as a one-time short-term “Yes/No” VI pathway test; greater confidence in results than for sampling under natural conditions
- Contributing VI pathways are difficult to identify with current site and pathway characterization information and tools; not sure yet if this is important or not.

Note: this is a unique one-of-a-kind data set; we do not yet know if observations at this site are representative of VI behavior at other sites

For additional information, please visit:
https://www.serdp-estcp.org/Featured-Initiatives/Cleanup-Initiatives/Vapor-Intrusion

https://iavi.rti.org/WorkshopsAndConferences.cfm

Speaker Contact Information

paul.c.johnson@asu.edu; (480) 965-9115

SERDP DOD • EPA • DOE | ESTCP

Q&A Session 2

SERDP DOD • EPA • DOE | ESTCP

The next webinar is on Thursday November 6

New Tools for Advancing our Understanding of Marine Mammal Behavioral Ecology

http://www.serdp-estcp.org/Tools-and-Training/Webinar-Series/11-06-2014

SERDP DOD • EPA • DOE | ESTCP

Please take a moment to complete the survey that will pop up on your screen when the webinar ends

SERDP DOD • EPA • DOE | ESTCP