University of Washington Superfund Research Program

Agency Seminar Series at EPA Region 10

"Temporal Changes in Vapor Intrusion Behavior and Implications for Conventional Pathway Assessment Paradigms"

June 15, 2011
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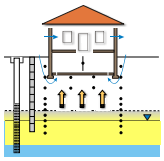
Changes in VI Behavior with Time: In-Progress Results from a Multi-Year Study



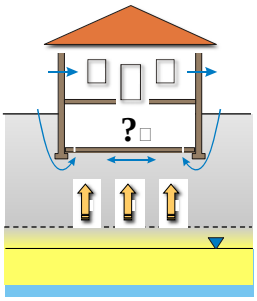
Paul C. Johnson
Emma Luo
Paul Dahlen
Chase Holton
Ira A. Fulton Schools of Engineering
Kyle Gorder
Erik Dettenmaier
Hill AFB

Vapor Intrusion (VI) Overview

Vapor intrusion (VI) is a possibility wherever buildings are in close proximity to impacted soils or groundwater

VI is a dynamic process reflecting vapor source, subsurface, building, occupant, and weather characteristics

Similar to, but also different from radon intrusion.

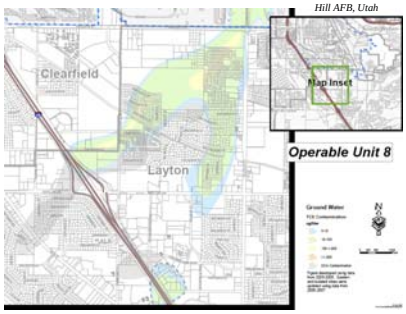


Potential consequences range from concentrations of no significance, to unacceptable long-term/chronic exposures, and occasionally to short-term impacts (explosion, acute effects).

Common VI Scenarios

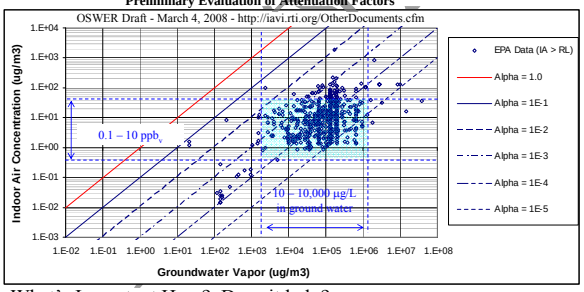
- Buildings overlying CHC-impacted groundwater is more typical than over DNAPL sources.
- Many well-publicized neighborhood-scale sites *(CDOT, Redfields, Hill AFB, NY sites, etc.)*.
- Most available empirical data corresponds to these types of situations

Chlorinated Hydrocarbon Spill Sites



Empirical Experience (CHC Sites)

U.S. EPA's Vapor Intrusion Database:
Preliminary Evaluation of Attenuation Factors



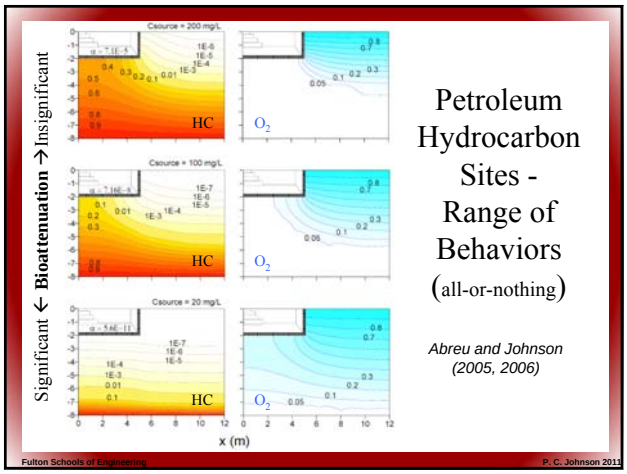
What's Important Here? Does it help?

- Unacceptable impacts occur at some sites at very low GW concentrations
- Little to no impact occurs at other sites with very high GW concentrations

Common VI Scenarios

- A few buildings overlying NAPL-impacted soils is more typical scenario. Few neighborhood-scale settings.
- Potential short-term consequences more severe than for CHC sites.
- Oxygen resupply, source-building separation, and physical features may be major factors.
- Low conc. sources not expected to pose significant risks.
- Potential risks associated with methane often overlooked.

Petroleum Hydrocarbon Spill Sites



Petroleum Hydrocarbon Sites - Range of Behaviors (all-or-nothing)

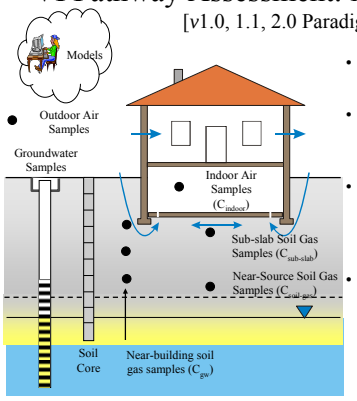
Abreu and Johnson (2005, 2006)

PCJ's VI Taxonomy


- VI Sites
  - Chlorinated - Recalcitrant
    - Vadose Source (High Strength)
    - GW Source (High Strength)
    - GW Source (Low Strength)
      - High/low – what chemical(s)?
        - How many buildings?
  - Petroleum HC - Aerobically Bio-D
    - Low O_2 Behave Like CHC
      - No bio-attenuation
    - NAPL Source (High Strength)
      - CH_4 Issues?
    - GW Source (Low Strength)
      - Prob. low risk, but Is it really a plume?

VI Pathway Assessment: MLE Approach

[*v*1.0, 1.1, 2.0 Paradigms]



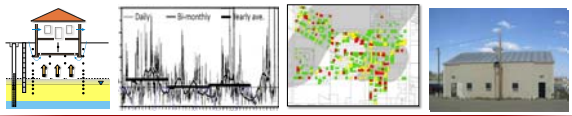
- Heavy weighting on indoor air data
- Decisions made using a few samples, (*typically 24-h or less time-averaged indoor air*)
- Sometimes short sampling windows or seasonal data (*i.e., fall, winter, spring, summer, rainy, dry*)
- Some use of passive samplers and sorbent tubes for longer durations; low use of point-in-time and point-in-space sniffers (*i.e., TAGA, HAPSITE*) for indoor source identification

Conventional Beliefs Underlying VI Pathway Assessment Practice

- Temporal changes in VI impacts occur, with variations spanning about an order-of-magnitude
- 24-h duration samples address any short-term fluctuations in indoor air concentrations
- A few 24-h samples sprinkled across longer time will identify any longer-term (seasonal) temporal changes
- Consistency in results across a few samples provides confidence that VI is understood. Other results can be averaged or anomalies discarded.
- Multi-day or multi-week samples might be better, but not yet clear how to do this right
- Can identify indoor sources via inventories

Background: State-of-the-Science

- Factors that might induce temporal changes have been identified, but quantitative cause-effect relationships are not known (and are difficult to discern with existing data)
- Some higher-frequency/longer-term indoor radon data available
- Some higher-frequency/longer-term soil gas data available
- Some lower-frequency/longer-term/multi-building indoor air data for groundwater/soil contaminants available
- Difficulty an assessing changes in VI behavior using typical data sets, given analytical variability and confounding by indoor air sources



Questions

So…given this background:

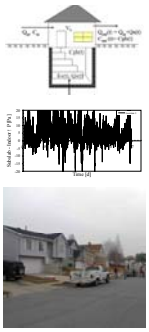
- Is there a scientific foundation for our current approach to sampling (and for conventional VI wisdom)?
- Is it possible to design practicable sampling plans that are sufficiently robust under conditions of unknown temporal behavior?
- Do we need new tools or approaches for assessing the vapor intrusion pathway?

Studies of Changes in VI Behavior with Time →

Ongoing Temporal Behavior Studies

Study through Simulation

- 3-D transient numerical code
- Incorporating actual driving forces (wind, barometric pressure)
- Looking at effects of site conditions (depth, soil type, biodegradation, etc.)



Study through Monitoring

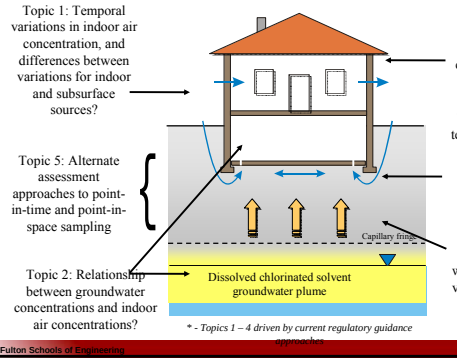
- Residence over dilute chlorinated solvent plume
- Intensive monitoring
- High frequency/long duration monitoring of indoor air, building characteristics, and driving factors

ASU/H. Luo et al. (2007-present)

(ASU/Hill AFB SERDP project)

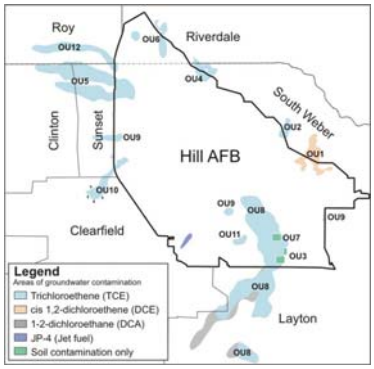
SERDP-Funded Project

Emphasis on Studying Temporal Changes



* - Topics 1 – 4 driven by current regulatory guidance approaches

Hill AFB Off-Site Plumes



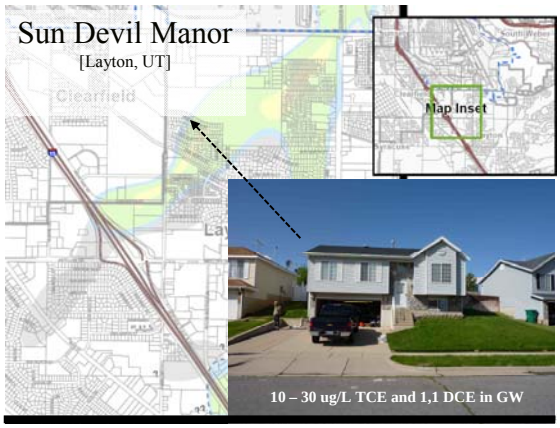
Hill AFB Situation:

About 3000 homes above dissolved CHC plumes (10 – 100 ug/L; mean about 30 ug/L)

About half of the home-owners have opted for indoor monitoring at least once

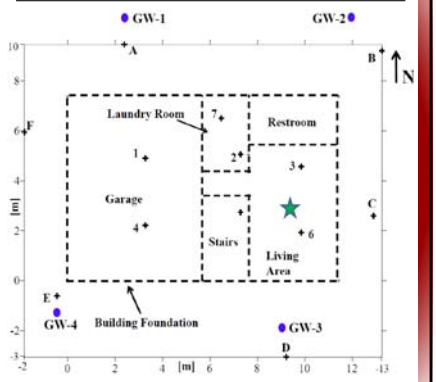
Sun Devil Manor

[Layton, UT]



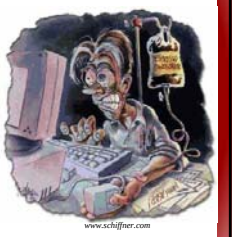
Monitoring Network

+ Multi-level soil gas and groundwater sampling points
- Indoor air monitoring (VOCs, radon)
- Differential pressures, soil moisture, soil temperature
- Weather (wind, barometric pressure, rainfall, outdoor temp)
- HVAC operation, indoor T, exchange rate (SF$_6$)



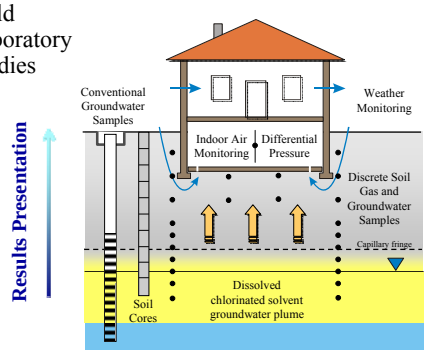
Data Collected to Date

- **Indoor air:** 4000+ indoor air samples across 14 months at 2 h and 4 h intervals
- **Snapshots:** soil gas and groundwater, 6 events over 9 months
- **Weather:** wind, outdoor temp, relative humidity, rainfall, sampled every 15 min for 9 months
- **Building Dynamics:** diff press, indoor air temp HVAC operation, indoor temp, sampled every 2 min or 10 min across 9 months
- **Soil Conditions:** soil temperature and soil moisture monitored every 10 min for 9 months
- **Radon:** every 2 hours for about 3 months and 3 soil gas snapshots
- **Indoor Air Exchange Rate:** measured about every 30 min over 3 months

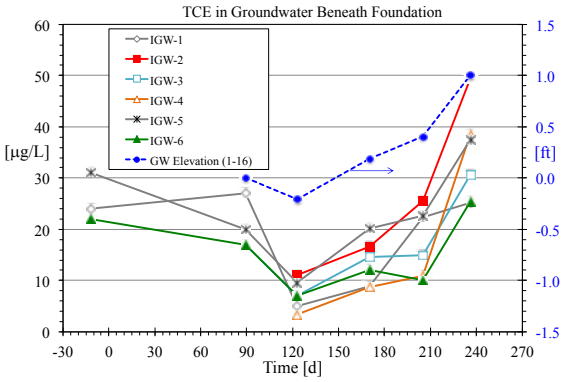


Technical Approach

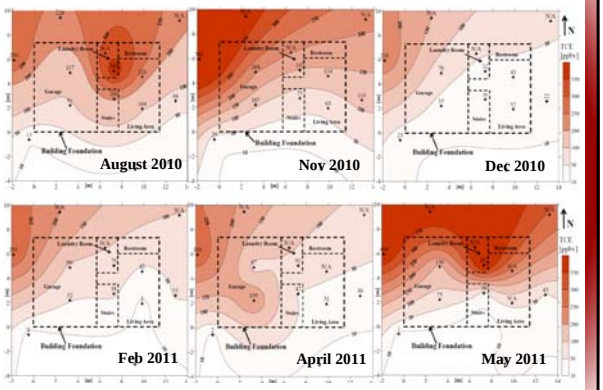
Field
Laboratory
Studies



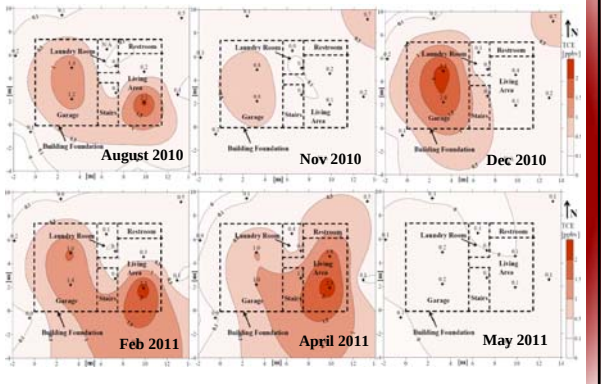
Sub-Slab Shallow Groundwater



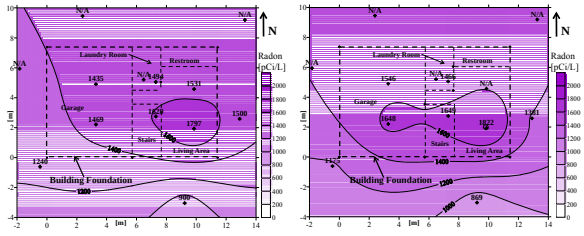
TCE in Soil Gas at 6-ft Below-slab Depth



TCE at Sub-slab Soil Gas Depth

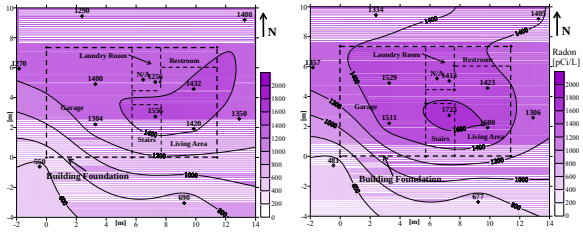


Soil Gas Snapshots: Radon 1.8 m (6 ft) Below Slab



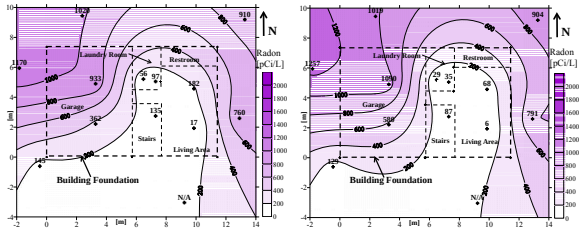
January 2011 April 2011

Soil Gas Snapshots: Radon 0.9 m (3 ft) Below Slab



January 2011 April 2011

Soil Gas Snapshots: Radon at Sub-slab Depth

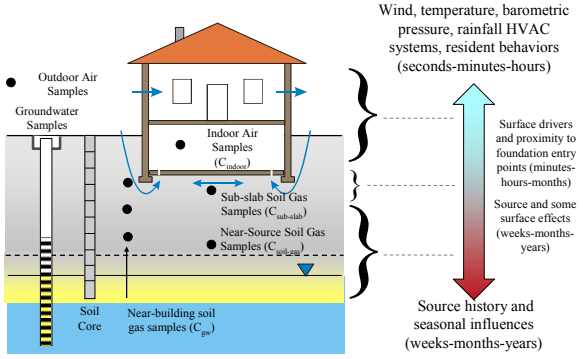


January 2011 April 2011

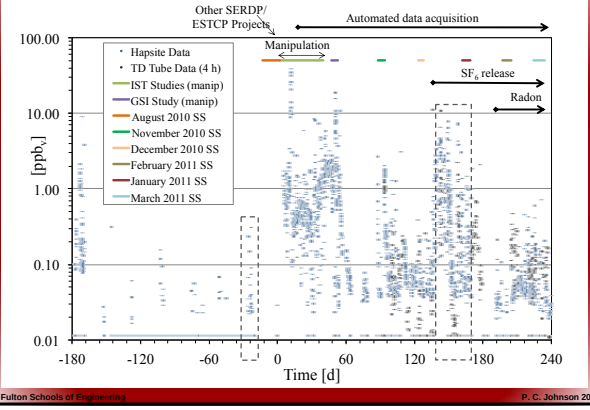
January 2011

Changes with Time?

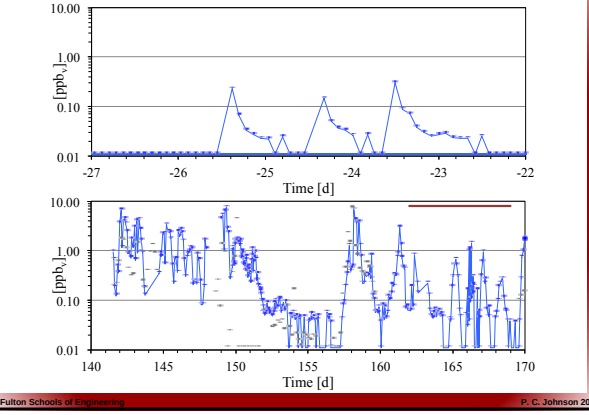
Buildings and their Surroundings are Dynamic Systems



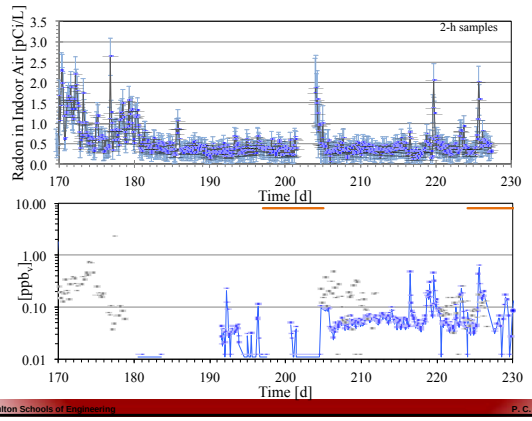
TCE Indoor Air Concentrations



TCE Indoor Air Concentrations



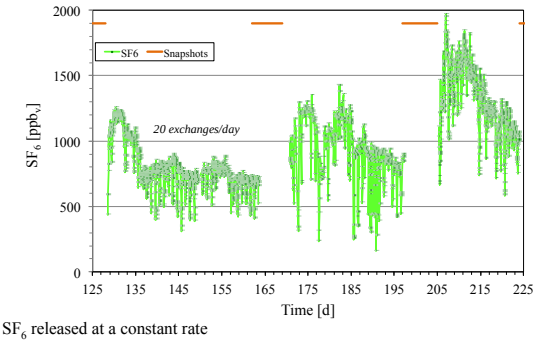
TCE vs. Radon Indoor Air Concentrations



Observations and Thoughts

Observations	Thoughts
Temporal concentration behavior appears to be "structured" and not random or statistically distributed	Typical sampling plans not robust enough for these conditions
Over some time periods the temporal behavior has a repeatable daily pattern	This is very different from the behavior conceptualized and anticipated by guidance.
There are periods of relative VI inactivity with sporadic VI activity	Different monitoring tools and paradigms are needed.
There are periods of relative VI activity with sporadic VI inactivity	

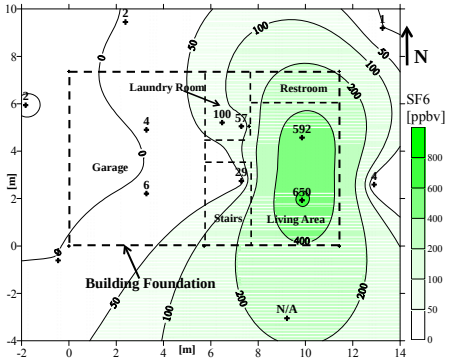
Air Exchange Rate (E_B)



SF_6 released at a constant rate

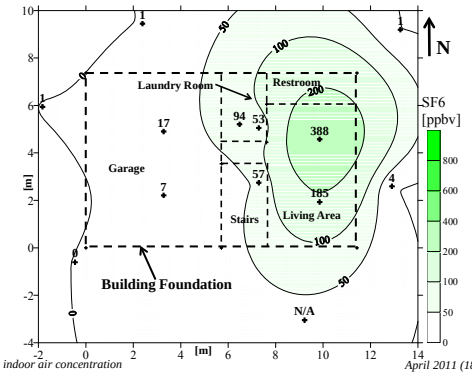
Daily fluctuations in SF_6 conc. correspond to variations of about 2X in E_B = 18 to 28 d^{-1} (50% of the time in the data set; V_B=350 m^3)

Snapshot of Sub-Slab SF_6



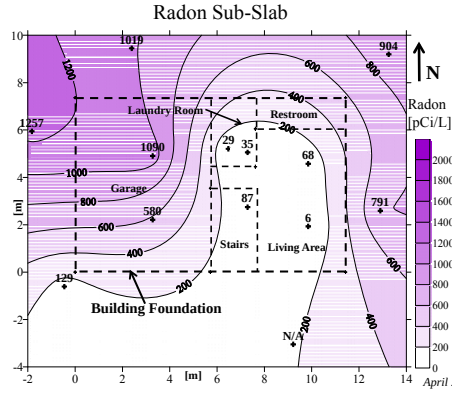
700 ppb$_v$ indoor air concentration *January 2011 (120 d SF_6)*

Snapshot of Sub-Slab SF_6



1000 ppb$_v$ indoor air concentration *April 2011 (180 d SF_6)*

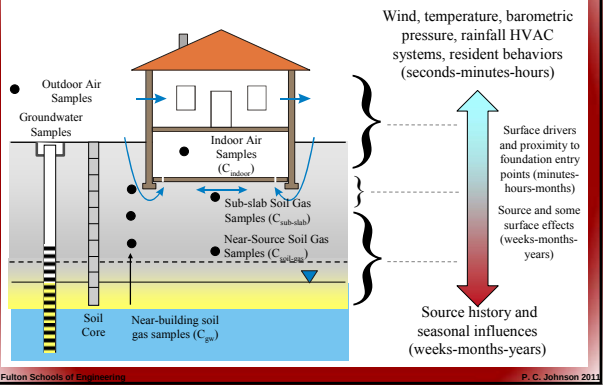
Soil Gas Snapshot:
Radon Sub-Slab



April 2011

Changes with Time?

Buildings and their Surroundings are Dynamic Systems



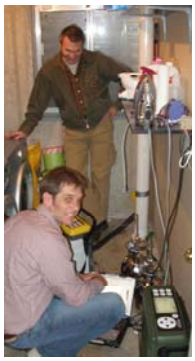
Key Results to Date

Comprehensive long-term data set (only one of its kind) – illustrates previously unanticipated intermittent VI behavior

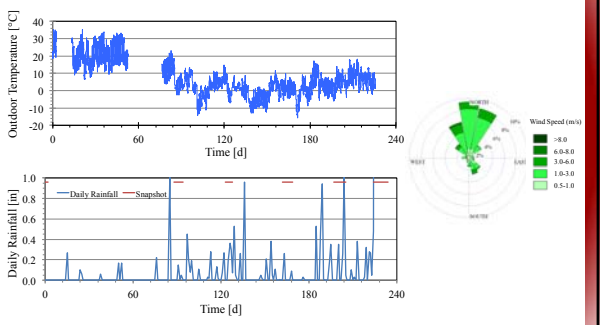
Data show that current pathway snapshot-style assessment schemes are not likely to be robust.

Tracer release conclusively shows that indoor air sources can cause soil gas plumes and storage in the subsurface.

Data will be useful for evaluating cause-effect relationships



In Progress - Data Mining: Cause-Effect Relationships



Lessons-Learned Thoughts about Needs for the Future

For building-specific pathway assessment:

•Quick/reliable identification of indoor sources (portable/sensitive tools)

•Proven means of manipulating buildings in short-term to overcome time variability of natural driving forces (*i.e., forced depressurization, T. McHugh and this study*) – is the short-term behavior of these tests indicative of long-term and could history of indoor sources still confound the test?

•Practicable longer-term real-time monitoring, with occupant awareness (real-time needed to spot the inadvertant introduction of new indoor sources)

Next Steps – SERDP Project

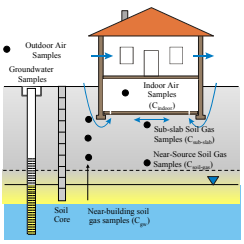
Continued monitoring under natural conditions through 12/2011

Dissipation of indoor SF_6 source soil gas plume and impact to indoor air

Manipulated building conditions in 2012 – depressurize to eliminate building changes as a driving factor:

•This allows assessment of changes in groundwater release rate with time

•Also allows evaluation of building depressurization as a VI assessment tool



Transition Plan

Open Access for Other Projects:

•SERDP ER-1687 *Vapor Intrusion from Entrapped NAPL Sources and Groundwater Plumes: Process Understanding and Improved Modeling Tools for Pathway Assessment* (Illangasekare, CSM)

•ESTCP ER-0702 *Application of Advanced Sensor Technology to DoD Soil Vapor Intrusion Problems* (Reisinger, Burris, Hinchee IS&T)

•ESTCP ER-0707 *Protocol for Tier 2 Evaluation of Vapor Intrusion at Corrective Action Sites* (McHugh/GSI)

•ESTCP ER-0830 *Development of More Cost-Effective Methods for Long-Term Monitoring of Soil Vapor Intrusion to Indoor Air Using Quantitative Passive Diffusive-Adsorptive Sampling Techniques* (McAlary/Geosyntec)

•ESTCP ER-1025 *Use of Compound-Specific Stable Isotope Analysis to Distinguish Between Vapor Intrusion and Indoor Sources of VOCs* (McHugh/GSI)

Thanks to:

SERDP (for funding!)

Kyle Gorder and Erik Dettenmaier, Hill AFB for collaborations/monitoring/supporting/etc.

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