Vapor Intrusion Pathway: A Practical Guideline

17 November 2009
New Orleans, LA

Vapor Intrusion - So What?

August 8, 2005
DANGER BENEATH OUR FEET

“IS MY FAMILY SAFE?”: A COMMUNITY VIEW OF VAPOR INTRUSION

Vapors End Deal for New School 54
A defunct Rochester charter school located in the former Mapedale Party House, once eyed by the city as a possible site for a public school, is now considered by the city to be too contaminated to consider buying.
Overall Course Objective

To Improve the State of the Practice of Vapor Intrusion Investigation and Mitigation

Course Overview

Vapor Intrusion Pathway

- Introduction / Framework
- VI Investigative Approach
- Site Investigative Tools
- Data Review / Background
- Mitigation
ITRC Vapor Intrusion Pathway: A Practical Guideline

- Key vapor intrusion issues
  - Investigative strategies
  - Phased, iterative process
  - Background contamination
  - The “toolbox”
  - Conceptual site model
  - Future land use
  - Remediation technologies
  - Closure strategies
  - Qualified consultants

ITRC – Shaping the Future of Regulatory Acceptance

- Host organization
- Network
  - State regulators
    - All 50 states and DC
  - Federal partners
    - DOE
    - DOD
    - EPA
  - ITRC Industry Affiliates Program
- Wide variety of topics
  - Technologies
  - Approaches
  - Contaminants
  - Sites
- Products
  - Documents
    - Technical and regulatory guidance documents
    - Technology overviews
    - Case studies
  - Training
    - Internet-based
    - Classroom
- Academia
- Community stakeholders
**Introduction to VI Pathway / Investigative Framework**

**Key Topics**
- Why the fuss over VI?
- Definition of vapor intrusion
- Technical basics
- Special influences
- Community issues
- Regulatory guidance
- Preliminary Screening Steps
- Distance Criterion
- Site Investigation Steps

**Introduction / Framework**
- VI Investigative Approach
- Site Investigative Tools
- Data Review / Background
- Mitigation

**Historical Perspective**

- **The Missing Pathway Period**
  - 1989: MA DEP Hillside School Investigation
  - 1991: J&E Model published

- **1998 – 2000**
  - USEPA includes VI in EI Determination
  - USEPA holds DC Vapor Summit

- **2001 – 2002**
  - USEPA Subsurface Vapor Intrusion Guidance

- **2007 – 2008**
  - NH DES Residential IA Assessment Guide
  - ASTM VI Standard
  - ITRC VI Practical Guideline
  - ITRC VI Scenario Document
VI Regulatory State Guidance

States with Regulatory VI Guidance in 2004

States with Regulatory Guidance in 2009

Magnitude of VI Cases – No Further Action (NFA)?

As of October 2007, only 6% of the responding states have re-opened a closed case due to the VI pathway.

50% of the states have the authority to re-open a closed case based on site-specific information due to the VI pathway.
Interdisciplinary Challenge

- Risk assessor
- Mechanical engineer
- Community relations coordinator
- Industrial hygienist
- Environmental scientist
- Soil scientist
- Hydrogeologist
- Analytical chemist
- Legal professional
- Real estate agents
- Banks
- Insurance agents

Vapor Intrusion

The migration of volatile chemicals from the subsurface into overlying buildings (USEPA 2002a)

<table>
<thead>
<tr>
<th>Commercial/Industrial Worker</th>
<th>Resident Living over Plume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working over Plume</td>
<td>Basement or Crawl Space</td>
</tr>
<tr>
<td></td>
<td>Without Basement</td>
</tr>
</tbody>
</table>

- Indoor Air
- Vadose Zone Soil Gas
- Soil and Groundwater Contamination
**What Is a VI Compound?**

- Compounds of concern
  - Volatile organics
  - Semi-volatile organics
    - i.e., naphthalene
  - Mercury
  - PCBs
  - Dioxins
- USEPA VI Guidance identifies 114 compounds
- State guidance varies in number of compounds

**Sources of Vapor Intrusion**

- Soil contamination
- NAPL (nonaqueous phase liquid)
- Groundwater plumes
- ??????
Vapor Pathway into Structures

Pathway
- Partitioning to vapor phase
- Diffusion in vadose zone
- Advection near building
- Dilution in building

Factors Affecting Movement in the Vapor Phase

Rainfall - Infiltration may displace soil-gas containing VOCs (volatile organic compounds) to dryer soil underneath a building and prevent mass loss to the atmosphere

Temperature - Higher indoor temperature compared to outdoor temperature may create a “stack” effect

Wind and Barometric Fluctuation - Inside pressure relative to outside pressure

Source: Figures from Massachusetts DEP
Building Design and Ventilation

- Air exchange rate - the rate at which outdoor air replaces indoor air
  - HVAC
  - Ventilation
    - Exhaust pollutants from a fixed source
    - Dilute pollutants from all sources within a space

Appendix C in ITRC VI Practical Guidance discusses building types.

Attenuation Factor Concept

\[ \alpha_{sg} = \frac{C_{\text{indoor}}}{C_{\text{sg}}} \]

- Indoor Air
  - 10 μg/m³
- Soil Gas (shallow)
  - 500 μg/m³

\[
\begin{align*}
\alpha_{sg} &= 10/500 \\
\alpha_{sg} &= 0.02 \text{ (shallow soil gas)}
\end{align*}
\]
Attenuation (Alpha) Factors

\[ \alpha_{sg} = \frac{C_{indoor}}{C_{sg}} \]

\[ \alpha_{gw} = \frac{C_{indoor}}{(C_{gw} \times H)} \]

Lower alpha means higher attenuation

Variation in current regulatory VI guidance:

- EPA \( \alpha_{sg} = 0.1 \) for sub-slab
- CA \( \alpha_{sg} = 0.01 \) for sub-slab
- NJ \( \alpha_{sg} = 0.02 \) for sub-slab
- NH \( \alpha_{sg} = 0.02 \) for sub-slab

Understanding Units

Your First Quiz

1 µg/L benzene equals

- 1 ppbv
- 24 µg/m³
- 307 ppbv
- None of the above
### Unit Conversion Table

**Soil Gas Unit Comparison**

<table>
<thead>
<tr>
<th>Units</th>
<th>Convert to</th>
<th>Multiply by</th>
</tr>
</thead>
<tbody>
<tr>
<td>μG/L</td>
<td>mg/m³</td>
<td>1</td>
</tr>
<tr>
<td>μg/m³</td>
<td>mg/m³</td>
<td>0.001</td>
</tr>
<tr>
<td>ppbv</td>
<td>μg/m³</td>
<td>MW/24</td>
</tr>
<tr>
<td>μg/m³</td>
<td>ppbv</td>
<td>24/MW</td>
</tr>
<tr>
<td>ppmv</td>
<td>mg/m³</td>
<td>MW/24</td>
</tr>
<tr>
<td>ppbv</td>
<td>mg/m³</td>
<td>MW/24,000</td>
</tr>
<tr>
<td>μg/L</td>
<td>μg/m³</td>
<td>1000</td>
</tr>
<tr>
<td>μg/m³</td>
<td>μg/L</td>
<td>0.001</td>
</tr>
<tr>
<td>μg/L</td>
<td>ppbv</td>
<td>24,000/MW</td>
</tr>
<tr>
<td>μg/L</td>
<td>ppmv</td>
<td>24/MW</td>
</tr>
<tr>
<td>ppbv</td>
<td>ppmv</td>
<td>0.001</td>
</tr>
<tr>
<td>ppmv</td>
<td>ppbv</td>
<td>1000</td>
</tr>
</tbody>
</table>

MW - molecular weight
mg/m³ - milligrams per cubic meter
μg/m³ - micrograms per cubic meter
μg/L - micrograms per liter
ppbv - parts per billion by volume
ppmv - parts per million by volume

### Converting Analytical Results

- \( \text{ppbv} = (\mu g/m^3 \times 24.45) / \text{MW} \)
- \( \mu g/m^3 = (\text{ppbv} \times \text{MW}) / 24.45 \)

MW - Molecular weight of the compound
Formulas are chemical-specific

---

### Preferential Pathway

- What are preferential pathways, and when are they significant?
  - Site conditions that result in significant lateral transport, enhanced convective flow, or a source within a building
    - Large subsurface utilities (e.g. storm drains)
    - Basement sumps
    - Elevator shafts
  - Models typically assume soil gas convection
    - CoCs entry into building through cracks is considered common
    - Utility connections should not be considered preferential pathways
Land Use

- Developed vs. future use
- Commercial vs. residential
- Institutional restrictions
- Sensitive populations
- Municipal zoning laws

Community Outreach

- Sensitive topic in community
- Strong community outreach helps inform and prepare
- Working with community groups
- Communication strategies

Refer to Appendix A, “Community Stakeholder Concerns” in the ITRC VI-1 2007
Multiple Lines of Evidence (MLE)

- Soil gas spatial concentrations
- Groundwater spatial data
- Background (internal and external / ambient) sources
- Building construction and current condition
- Sub-slab soil gas data
- Soil gas data
- Indoor air data
- Constituent ratios
- Soil stratigraphy
- Temporal patterns

Conceptual Site Model (CSM)

Simplified version (pictures and/or descriptions) of a complex real-world system that approximates its relationships
USEPA VI Guidance

OSWER Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Ground Water and Soils (November 2002)
www.epa.gov/correctiveaction/eis/vapor.htm

- USEPA is working on supplemental technical tools
  - USEPA's VI Database: Preliminary Evaluation of Attenuation Factors
  - Compilation of indoor air background concentrations
  - VI Screening Level Calculator
  - J&E Model and User's Guide (updated)
  - Conceptual Site Model (CSM) papers - theoretical (3-D) and case examples

Preliminary Screening Objectives

- Minimize amount of information needed for screening
- Eliminate sites that do not warrant further action
- Focus efforts on sites with higher potential for vapor intrusion
Preliminary Screening Steps

- **Step 1:** Does the site represent an acute exposure concern?
- **Step 2:** Are there sufficient characterization data to evaluate this pathway?
- **Step 3:** Are any of the site contaminants of concern both volatile and toxic?
- **Step 4:** Are buildings located in close proximity to volatile chemicals in soil, soil gas or groundwater?
- **Step 5:** Identify the appropriate occupant exposure scenarios and screening levels for this site.
- **Step 6:** Do the data exceed the appropriate generic screening levels?
- **Step 7:** Does the exceedance warrant further investigation?

Step 1 – Acute Exposure?

- Are site concentrations at acute levels?
  - Odors
  - Physiological symptoms
  - ATSDR MRLs (Agency for Toxic Substances and Disease Registry Minimal Risk Levels)
- Petroleum Hydrocarbons
  - LELs (Lower Explosive Limit)
Step 2 – Sufficient Data?

- Existing data
  - Groundwater
  - Soil
  - Soil gas
  - Indoor air
- Source characterization
- Pathway evaluation

Step 3 – Volatile Compounds?

- List of chemicals
  - USEPA Office of Solid Waste and Emergency Response (OSWER)
  - State lists
- If no, no further action
- If yes, compare to “quantitative” criteria (generic screening levels)
Step 4 – Distance Criteria?

- Lateral
- Vertical
- Preferential pathways may increase distance (relatively rare)
- Petroleum hydrocarbons vs. chlorinated solvents

Steps 5 – Exposure Scenarios and Screening Levels?

- Look-up tables
  - OSWER table
  - State screening levels
- Residential
- Non-residential
- Occupational
- Difference between chlorinated VOCs and petroleum hydrocarbons
## Step 6 – Data Comparison

- Compare site data to look-up table values
- Available for groundwater and soil gas
- Concentration < screening level
  - No further action (NFA)
- Concentration > screening level
  - Cannot screen out
  - **Does not mean vapor intrusion is occurring**
  - Need more information

## Step 7 – Further Investigation?

- Last step in the preliminary screening
- Data above screening levels
  - Additional investigation
  - Mitigation
Preliminary Screening Issues

- Issues
  - Screening criteria must be conservative
  - Screening levels are very low
    - Do not account for biodegradation
  - Most people agree conservative enough, but…
  - Very few sites are being screened out

- Choices
  - Realistic screening levels, if warranted
  - Accept that more site-specific data will be needed at most sites
  - Mitigation

Preliminary Screening Summary

Three possible outcomes

1. Screen out
   - Not common
2. Screen in
   - Most common
   - Screening targets may change as you collect site specific data
3. Mitigate
Site Investigation Phase

- Step 8: Choose a VI investigative strategy
- Step 9: Design a VI investigative work plan
- Step 10: Implement VI investigation work plan
- Step 11: Evaluate the data
- Step 12: Is additional investigation necessary?
- Step 13: Is mitigation warranted?

Refer to Chapter 3 in the ITRC VI-1 2007

Step 8: Choose an Investigative Strategy

- Decide the media and technical approach for assessing the VI pathway
- Characterization tools
  - Interior sampling
  - Exterior sampling
- Analyte list
- Use of supplemental data
Step 9: Design a VI Investigation Work Plan

Investigation work plan components

- Develop a site-specific CSM
- Identified data gaps
- Identify sampling locations
- Understand background
- Prepare for sampling
- Understand groundwater issues
- Community outreach
- Access issues
- Implementation
- Scheduling
- Impacted structures

Step 10: Implement VI Investigation Work Plan

- Schedule
- Expectations of field work
  - Worst-case conditions (e.g., heating season)
  - Seasonal differences
- Flexibility and property access
- Communication
Step 11: Evaluate the Data

- Do data make sense?
- Identify data gaps?
  - Do data exceed allowable levels?
  - Use site specific levels where appropriate.
- Revisit CSM

Step 12: Is Additional Investigation Necessary?

- Why do you need additional data?
  - Potential background sources
  - Possible variation temporal and spatial
  - Delineation
- Consider supplemental tools
  - Customized to the site conditions
Step 13: Is Mitigation Warranted?

• Is exposure pathway complete?
• Risk management decision
• Monitoring

VI Investigative Approach

Key Topics
• Site-specific features affecting VI
• Multiple lines of evidence (MLEs)
• Conceptual site models (CSMs)

Introduction / Framework
VI Investigative Approach
Site Investigative Tools
Data Review / Background
Mitigation
Ingredients for Effective VI Assessments

- Investigatory approach
- Determine correct screening levels
- Sample and analyze properly
- Know and use supplemental tools
- Demonstrating bioattenuation

Site-Specific Features

- Source
  - Degradable vs. non-degradable
  - VOCs vs. SVOCs
  - Vadose zone vs. groundwater
  - NAPL or not
- Pathway
  - Diffusion vs. advection dominated
  - Barriers: wet clay-rich layers, freshwater lens
  - Preferential pathways: highly permeable fill, openings in building envelope
- Receptor
  - Building pressure/vacuum, ventilation rates
  - Interior sources (background)
  - Sensitive populations
Multiple Lines of Evidence (MLE)

- Soil gas spatial concentrations
- Groundwater spatial data
- Background (internal and external / ambient) sources
- Building construction and current condition
- Sub-slab soil gas data
- Soil gas data
- Indoor air data
- Constituent ratios
- Soil stratigraphy
- Temporal patterns

MLE: Chemistry

- Groundwater
- External Soil Gas
- Near-Slab Soil Gas
- Sub-Slab Soil Gas
- Indoor Air
- Outdoor Air
MLE: Soil Properties

Coring and Visual Inspection

Particle Size Distribution

Flow, Vacuum, and Permeability

Porosity and Moisture Content

MLE: Weather Data

Barometric and Differential Pressure

Soil Gas Pressure over Time

Seasonal Trends from Weather Effects

Wind Speed vs. Building Vacuum
MLE: Gas Pump Tests

Gas Pumping Tests

Analysis of Pneumatic Properties

Concentration vs. Volume Purged

MLE: HVAC Monitoring

Pressure/Ventilation Testing

Electromagnetic Flow Meters

Smoke Pen

Test and Balance Reports
MLE: Building Pressure Manipulation

Adjust HVAC to pressurize building – do \([\text{VOCs}]_{\text{IA}}\) drop?
IA = Indoor Air

\[
\begin{array}{|c|c|c|}
\hline
\text{Concentration (µg/m}^3\text{)} & \text{Outdoor Air} & \text{Predicted IA} \\
\hline
\text{IA Pre-} & & \\
\text{Mitigation} & \text{IA Post-} & \text{Mitigation} \\
\text{Mitigation} & & \\
\hline
\end{array}
\]

Air flow doubled, but TCE dropped by 10x – indicates TCE originated from VI

\(\Delta P \sim 10 \text{ Pa}\)

Berry-Spark et. al., 2005

---

MLE: Degradation

Field Screening for \(O_2\) and \(CO_2\)

Comparison of Data to Model
MLE: Modeling

\[
\frac{C}{Co} = \frac{a}{r} \text{erfc} \left( \frac{r-a}{\sqrt{4D_{eff}} t} \right)
\]

Radial Diffusion in Vadose Zone

1-D J&E Model with Biodegradation

\[
a_{\text{bio}} = 1.1 \times 10^{-13}
\]

3-D Abreu and Johnson Model

Is This Your Site?

- Commercial/Industrial buildings
  - rooftop HVAC
  - Residual NAPL
  - Lateral diffusion
  - DNAPL

- Residential buildings
  - proximal to primary source
  - basement stack effect
  - slab-on-grade
  - primary source
  - UST

- Multi-Story buildings
  - ground-water flow
  - water table fluctuations
  - clean recharge water

Prepared by GeoSyntec for EPA
Conceptual Site Model (CSM)

- Simplified version (pictures and/or descriptions) of a complex real-world system that approximates its relationships

Components of a CSM

- Underground utilities and pipes
- Existing and potential future buildings
- Construction of buildings
- Type of HVAC system
- Soil stratigraphy
- Hydrogeology and depth to water table
- Receptors present (sensitive?)
- Nature of vapor source
- Vadose zone characteristics
- Limits of source area and contaminants of concern
- Surface cover description in source and surrounding area

CSM Checklist is found in Appendix B in the ITRC VI-1 2007
Chlorinated VOCs in GW

- Stack effect
- Diffusion through vadose zone
- Volatilization from water table

Source

Fresh-Water Lens

- Assess off-gassing with combined shallow GW and deep soil gas samples
- Map “extent” in soil gas before selecting buildings for intrusive samples

Rainfall

“clean” soil

“clean” groundwater

Source
Geologic Barrier

- Soil cores to assess stratigraphy, soil texture, porosity, and moisture content
- Measure flow and vacuum in soil gas probes during purging and sampling
- Monitor ambient pressure/vacuum in soil gas probes = f (barometric pressure)
- Vertical profiles of soil gas concentrations in select locations

Chlorinated VOCs in Vadose Zone

- Calculate “expected” lateral diffusion profile
- Then collect samples at various distance along the pathway to check consistency
Large Buildings

- Talk with Facilities Engineer – review Test and Balance Report
- Monitor sub-slab to building pressure differential over time
- Review historic VOC use, storage, handling locations
- PID (photoionization detector) screening at select locations (floor drains, sumps, etc.)

Source Outside Building

- Review depth of footings vs. water table (barrier?)
- Soil gas and sub-slab samples and pressure differential
**Source Beneath Building**

- External data not as useful
- May want to consider SVE if concentrations are >> screening levels
- Assess spatial distribution in sub-slab concentrations
- Consider indoor air data with changes in HVAC operation

**Vacant Lot**

- Start with a cost-benefit analysis for soil gas monitoring program vs. proactive mitigation
  - Avoidance: build away from areas of suspected VOCs
  - Passive barrier (visqueen, HDPE, spray tars)
  - Passive venting (gravel layer and wind-turbines)
  - Passive barrier plus passive venting (option to go active)
  - Intrinsically safe design (podium construction)
Tall Buildings

Cold Climate
Neutral pressure plane

Hot Climate
Neutral pressure plane

Complicating Factors for VI Assessments

- Ultra low screening levels
  - Increases chances for false positives
- Inconsistent screening levels
- Allowed assessment methods
  - Vary among agencies
- Chlorinated vs. petroleum hydrocarbons
  - Treat same way?
  - Allow for bioattenuation – how?
Key Investigation Issues

- Experience of the collector/consultant
  - Have they done this before?
  - Do they understand risk base screening levels (RBSLs)?
  - Quality/experience of field staff? Senior or junior?
- Get enough data near/around/under
- Legal perspective
  - How conservative to be?

Summary

- One-size doesn’t fit all – customize to site-specific conditions
  - Let the science lead the logic
- Decide in advance what you expect the data to show
  - Consistency supports the conceptual site model
- Map out a plan for anticipated and potential outcomes
- Concentrations are not the only lines of evidence
Investigative Tools

Key Topics
- Sampling
  - Exterior verses interior
  - Groundwater
  - Soil
  - Soil Gas
  - Indoor Air
  - Analytical Methods
- Supplemental tools/data
- Modeling

Introduction / Framework
- VI Investigative Approach
- Site Investigative Tools
- Data Review / Background
- Mitigation

Data Quality Objectives
- Define/identify
  - Study goals
  - Contaminants of concern
  - Regulatory screening levels
- Complete
  - Pre-sampling building survey
  - Interior survey
  - Site screening
- Choose/establish
  - Sampling and analytical method
  - Number of samples
  - Reporting limits
- Collect
  - Samples
  - Quality assurance (QA) samples
- Establish
  - Validation procedures
**Interior vs. Exterior**

- Interior data (sub-slab and indoor air samples)
  - Access agreements, background challenges, scheduling
- Exterior data (soil gas and groundwater samples)
  - Is the pathway incomplete?
  - Data to support site-specific modeling
  - Improve scoping of internal data collection

**“Interior” Investigations**

- Public relations
  - Access agreements, fact sheets, meetings
- Removal of interior sources (if practical)
- Samples and “controls”
  - Outdoor, sub-slab, etc.
- Analytical methods, analytes, reporting limits
- Risk communication
- Potential litigation
“Exterior” Investigations

- “Map” the contamination
- Identify buildings with potential VI risks
- Identify target compounds
- Collect site-specific geologic/pneumatic data
- Minimize inconvenience to occupants/owners

“Bound the scope of the problem”

Groundwater Data

- Assess available data
  - Well location and construction
  - Aquifer characteristics
  - Interpolate – flow and direction
- Gather new data
  - Well location, construction, sampling
- Consider perched water, vertical profiles
- Incorporate long-term monitoring
Groundwater Sampling

- Issue: Proper sampling and interpretation of vertical profile of chemicals in groundwater concentration is critical
  - Each scenario below could give the same groundwater concentration, but vastly different soil vapor concentrations

Soil Phase Data

- Soil data generally not acceptable in VI investigations
  - 10X to 1000X losses of VOCs (EPA/600/SR-93/140)
- Existing soil data – line of evidence
  - Can screen in sites
  - Generally cannot be used alone to screen out sites
- Convert to soil gas concentrations
  - Partitioning equations exist
  - But equations tend to over predict soil gas concentration
- Sampling – minimize VOC loss – method 5035
  - However, methanol extraction causes elevated reporting limits, which are too high to be protective for vapor intrusion screening
Soil Gas Data

- **Pros**
  - Representative of subsurface processes
  - Measures concentrations in the gas phase
  - Higher screening levels (vs. Indoor Air)
  - Relatively inexpensive
  - Can give real-time results

- **Cons**
  - Attenuation factor is variable
  - Conservative Screening Levels (especially for PHCs)
  - Protocols still debated

Predictive Modeling

- **Pros**
  - Can use GW, soil (?), soil gas data
  - Relatively easy

- **Cons**
  - “screening level” model (~10X at best)
  - Which version to use?
  - Need to verify inputs
  - Needs to verify assumptions are met
### Model Assumptions

- One-dimensional vertical transport
- Steady state conditions
- No preferential pathways
- Uniform mixing within building
- Slab on grade or basement construction
- No biodegradation
- Homogeneous vadose zone
- Constant source concentration
- No gas generation (e.g., municipal waste)
- No barometric pumping

Prior to using model results, you need to ensure that model assumptions and site conditions are consistent.

### How Well Does J&E Predict?

- Hydrocarbons
  - No bioattenuation especially for deeper and lower concentration sources
  - **OFTEN OVER PREDICTS**

- Chlorinated solvents – deep source
  - Calculated SG value too high by >10x
  - **OFTEN OVER PREDICTS**

- Chlorinated solvents – surface source
  - Calculated SG value too low
  - **WILL UNDER PREDICT IF VAPOR CLOUD**
Soil Gas Sampling and Analysis Methods

- Sample collection issues
  - Active soils gas surveys
  - Passive soil gas surveys
  - Flux chamber surveys

- Sample analysis issues
  - Active soils gas samples
  - Passive soil gas samples
  - Surface flux chamber samples

Refer to:
Regulators Checklist for Reviewing Soil Gas Data,
Appendix F
(ITRC VI-1, 2007)

Get Enough Data

- Soil gas not homogeneous
- Lateral and vertical variations exist
- Don’t chase 1 point anomalies
- Get enough data near/around/under
- On-site analysis/field screening enables real-time decisions to select additional sampling locations
Which Soil Gas Method?

- Active?
- Passive?
- Flux Chambers? (supplemental tool)

Active method most often employed for VI

Passive Soil Gas

- Pros
  - Easy to deploy
  - Can find contamination zones
  - Low permeability soils

- Cons
  - May not give concentration
  - No less expensive (depending on analysis)

- Currently considered as screening tool
Direct Flux Measurement (Flux Chambers)

**Pros**
- Direct measurement of intrusion

**Cons**
- Proper location (may miss preferential paths)
- Protocols debated
- How to use data?
- Unsophisticated audience
- Regulatory acceptance limited

Static Flux Chamber

USEPA, 1996
Active Soil Gas Sampling

- Considerations
  - Purge and sample volumes
  - Flow rate, vacuum, and leak tests
  - Sample containers
  - Temporal effects
  - Real-time sample and analysis
  - Sample density and locations

Sub-slab Soil Gas Sampling

- Soil gas most likely to enter structure
  - May detect chemicals originating within building
- May collect indoor air concurrently for comparison
- Sample at slab base and/or at depth
- Permanent or temporary sample points
- Active and passive approaches
Soil Gas Sampling Issues

- **Sample size**
  - Larger the volume, larger the zone of influence
  - Smaller volumes faster and easier to collect

- **Containers**
  - Canisters: Potential carry over; Higher cost
  - Tedlars: Good for ~2 days; Easier to collect

- **Flow rate**
  - Not important for coarse soils. Most agencies < 200 ml/min

- **Tracer/leak compound**
  - Crucial for sub-slab and larger sample volumes
  - Gases (He, SF6, Propane) and Liquids (IPA)

Soil Gas Sampling Issues

- **Rain and meteorological parameters**
  - How long to wait after a rain event?
  - High winds? Sub-slab O₂ changes > 10 mph
  - Barometric pressure?
  - Time-integrated samples?
  - Existing data does not show large variations

- **Pneumatic testing**
  - Gives vadose zone permeability
SVOC Sampling

Some Final Collection Issues

- Individually certified clean canisters
  - Not needed if Detection Limit > 5 µg/m³
- Residual vacuum in canisters
  - Not critical for soil gas samples
- Dedicated flow controllers
  - Bellows type has large dead-volume
  - Calibrated orifice typically can be reused
Soil Gas Sampling Strategies

- Exterior vs. Interior (sub-slab)
- Repeated Sampling
- Documenting bioattenuation

Sub-Slab vs. Near-Slab Samples
Sub-Slab vs. Near-Slab

- EPA and some states prefer sub-slab
  - Ponding effect under slab?
  - Balls don’t run uphill

- Very intrusive

- Hydrocarbons: if O\textsubscript{2} high, near-slab okay

- CI-HCs: at source or mid-depth

Resampling of Soil Gas?

- Depth below surface
  - 3ft to 5ft below ground surface generally considered stable
  - Temporal studies ongoing

- Seasonal effects – how important?
  - Most studies show less than 5x

- Extreme conditions will have effect
  - Heavy rain
  - Extreme heating/cooling
Cause and Effect?

Wind direction

Pressure differential

Wind speed

O₂ and HC Concentrations

Rainfall

Barometric pressure

Slide courtesy of Paul Johnson, ASU and Chevron Corp

Temporal Variability in SG

Slide courtesy of Dr. William Wertz, NY-DEC
Spring to Fall SG Trend

Soil Gas Temporal Study

Probe A3 (TCE - Normalized)

Normalized Concentration

Time (3/16/07 to 4/10/07)
Indoor Air Sampling

SUMMA Canister  Evacuation Chamber

Air Sampling Pump with Sorbent Tubes  Tedlar Gas Sampling Bag  Glass Sampling Bulb

What could go wrong?

Indoor Air Measurement

- **Pros**
  - Actual indoor concentration, no modeling required
  - Relatively quick, no drilling or heavy equipment
  - Less spatial variability than soil vapor
    - One sample often adequate for typical basements

- **Cons**
  - Potential for background sources, typically addressed by:
    - Ambient air and sub-slab vapor samples
    - Survey of building materials and activities
  - No control (sample left unattended for up to 24 hours)
  - Typically more temporal variability than soil vapor
    - Up to one order of magnitude common for indoor air
  - Requires entering home
Coordinating with the Lab

- Select appropriate canister size
  - Based on required reporting limits (RLs)
    - e.g., Scan mode vs. SIM mode
- Canister cleaning
  - Batch versus individual
  - RLs used for certifying clean
  - Dedicated low level cans
- Flow regulator
  - Clean regulator too
  - Ensure no thread damage
  - Proper flow rate
- Consider spare canisters

Pressure Issues

- Canisters are large pressure gauges
  - Evacuated to very low pressure (.05 Torr = .002” Hg)
  - Reading is difference between inside and outside pressure
- Pressure will fluctuate with ambient pressure
- Pressure will reduce with increasing elevation
  - ~4 inches per mile
- Note: local “barometric pressure” is converted to sea level
  - Ambient pressure is actual pressure
Common Pressure Problems

- Field pressures too high or too low
  - Use a calibrated and reliable gauge
  - Gauges that come with the canisters are often inaccurate
- Initial field pressure is low
  - Initial field pressures less than about 28” Hg (corrected for elevation) likely indicate some leakage between the lab and field
- Final field pressures of zero indicate that sample collection terminated some time earlier
  - Likely an unknown sample collection time, unless checking of the regulator allows this to be back-calculated

Additional Pressure Problems

- Final field pressure is above 10” Hg
  - Likely due to incorrectly set or selected flow regulator, or plugged line
  - May not be sufficient sample to meet RLs
    - But have the lab check – often still enough sample
- Final lab pressure more than 2” Hg less than final field pressure
  - Correct for elevation
  - May indicate inaccurate field gauge
  - Or may indicate loss of vacuum
    - Dilution air equal to percent increase in sample volume
    - Potential cross-contamination during shipping & storage
Location

- Canister Placement in Homes
  - Basement (if present)
  - First floor
  - Ambient air
- Central living areas preferred
- Away from windows, vents, and doors
- Where they won’t be disturbed
- Avoid
  - Bathrooms
  - Utility/storage rooms
  - Laundry rooms
  - Hobby areas

Location, Location

- Canister placement in multi-family buildings
  - Same general guidelines as homes
  - Representative units to cover all portions of large buildings
    - Variable source conditions
    - Variable foundations
    - Utilities
  - Some upper floor units
    - HVAC
    - Elevators

<table>
<thead>
<tr>
<th></th>
<th>SOG</th>
<th>Basement</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCE in Condominium Units (ug/m³)</td>
<td>2.3</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>1.7</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.82</td>
</tr>
</tbody>
</table>

William Wertz, NY-DEC
**Location, Location, Location**

- Canister placement in commercial buildings
  - Sufficient samples to represent various
    - Areas of building
    - Plumes & source areas
    - Foundation conditions
    - HVAC zones
    - Sensitive populations
    - Influence of elevators
  - Avoid
    - Copy/printing rooms
    - Storage/utility areas

- PCE in Office complex (ug/m³)
  - SOG
  - Basement
  - 5 ug/L
  - 10 ug/L
  - 20 ug/L

**Other Indoor Air Issues**

- Sampling
  - How long? Grab, 8 hours, 24 hours?
  - How often? Once, twice, more?
  - Pen/marker emissions can be picked up.

- Data interpretation
  - Compare with outdoor air concentrations
  - Compare with sub-slab vapor concentrations
  - Less necessary for compounds with few background sources (e.g., 1,1-DCE)
Temporal IA Study

Temporal variability
Approximately a factor of 10 over 8 years

Portable Field Analyzers

- **VOCs**
  - Hand-held PIDs – 1 to 10 ppmv
  - ppbRae – 50 to 100 ppbv
- **Hydrocarbons**
  - Portable Flame Ionization Detectors (FID) (Foxboro, Photovac)
- **Oxygen, Carbon Dioxide, Methane**
  - LandTech GEM 2000
- **Methane**
- **Helium**
Pros & Cons – “Real Time” Portable Field Analyzers

- **Pros**
  - Identifies location and relative strength of background sources of VOCs in indoor air
  - Effective at “screening in” sites

- **Cons**
  - Generally in the parts-per-million range
  - Not effective at “screening out” sites
  - Sensitive to environmental conditions
  - Lack of specificity (not compound specific)

Common Air Analyses

- **VOCs**
  - BTEX, MTBE, TPH – Method TO-3A
  - Polar & nonpolar – Methods TO-15 (& SIM), TO-17
  - VOCs – Methods 8021B (modified) & 8260B (modified)

- **SVOCs**
  - SVOCs (PAHs) – Methods TO-13A (& SIM)

- **Pesticides & PCBs**
  - TO-4A, TO-10A (high-volume collection)

- **Fixed Gases**

Refer to:
Appendix D, Table D-3, ITRC VI-1, 2007
Common Soil Gas Analyses

- **VOCs**
  - Soil and Water Methods: 8021, 8260
  - Air Methods: TO-14, TO-15, TO-17

- **Hydrocarbons**
  - 8015 m, TO-3

- **Oxygen, carbon dioxide**
  - ASTM 1945-96

- **SVOCs**
  - TO-4, TO-10, TO-13
  - 8270 (?)

Soil Gas VOC Analysis

- All methods give reliable results
- Detection level discriminator
  - TO Methods: <1 to 10 µg/m³ $200-$350
  - 8260: 10 to 100 µg/m³ $100-$150
  - 8021: 2-10 µg/m³ $50-$100
- On-site analysis
  - Extremely helpful for VI
  - Real time verification
On-Site 8021 Analysis vs. Off-site TO-15 Analysis

On-site 8260 vs. Off-site TO-15

1,1-DCE by on-site lab and syringe (µg/L)
1,1-DCE by fixed lab and Summa (µg/L)

Avocet Consulting Group, 2006
High Soil Gas Concentrations Create Headaches

- Typical soil gas concentrations
  - Benzene near gasoline soil: >100,000 µg/m³
  - TPH vapor: >1,000,000 µg/m³
  - PCE under dry cleaner: >100,000 µg/m³
- TO-15 maximum concentration: 2,000 µg/m³
  - Must do large dilutions, detection limit (DL) goes up
  - False positives from hot samples
- Canister and hardware and instrument blanks
- Field screening very beneficial

New Advance: TO-15 Scan/SIM

- Simultaneous scan/SIM mode enables
  - <10 µg/m³ for All VOCs and
  - < 2 µg/m³ for subset of compounds
- Only 2cc of sample – eliminates hardware
- Real-time analysis in structures
Supplemental Tools/Data

- Site specific alpha using radon
  - Factor of 10 to 100 - $100/sample
- Indoor air ventilation rate
  - Factor of 2 to 10 - <$1,000 per determination
- Real-time, continuous analyzers
  - Can sort out noise/scatter
- Pressure measurements
  - Can help interpret indoor air results

Automated Analyzers

- GC and GC/MS (TO-15)
- Can reach ultra-low levels (1-10 ug/m³) for subset of compounds
- Can analyze 4 to 15 times per hour
- Up to 16 sampling ports
- Real-time feedback
Continuous Monitoring Data

Huntington Beach Site - Soil Gas

![Graph showing continuous monitoring data for CH₄, O₂, and CO₂ over time.]

Bioattenuation of Hydrocarbons

- Existing data suggest O₂ effective barrier
- Attenuation > 10,000 times
- Document by vertical profiles of contaminants of concern and O₂
- How to quantify?
Theoretical Bio Profile

- **O₂**
- **flux**
- **VOCs**

Increasing depth

Clean soil

Petroleum product

- **O₂**
- **CO₂**

Effect of Vapor Source Concentration and Depth

- **Modeling assumptions:**
  - Benzene source
  - Sand soil
  - Basement
  - \( l = 0.79 \text{ h}^{-1} \)
- Biodegradation is likely to have a significant effect on alpha for non-NAPL sources
- For NAPL sources, effect of biodegradation on alpha may be minimal due to oxygen depletion
- L: source-foundation distance

Slide courtesy of Dr. Lilian Abreu, Geosyntec Consultants, and API
**BioVapor**
A 1-D Vapor Intrusion Model with Oxygen-Limited Aerobic Biodegradation

*National Tanks Conference*
Sacramento, CA
March 30 - April 1, 2009

**KEY POINT:**
Version of Johnson & Ettinger vapor intrusion model modified to include aerobic biodegradation (DeVaull, 2007).

**Uses iterative calculation method to account for limited availability of oxygen in vadose zone.**

**Simple interface intended to facilitate use by wide range of environmental professionals.**

**Conclusions:**
What is BioVapor?

Version 1 available in Spring 2009.
Free from API web site.
Summary

- Multiple investigatory tools exist
- Selection is site/bldg specific
- Soil gas methods commonly used
- Soil gas sampling and analysis issues plentiful
- Supplemental tools can be helpful
- Bioattenuation of hydrocarbons common

Data Review and Background Evaluation

Key Topics
- Data quality review
- Groundwater, soil, soil gas data interpretation
- Other lines of evidence (supplemental tools/data)
- Indoor air data evaluation
- Background contributions
Typical Decision Process

1. Start with data quality review
   • Check for bias, consistency with CSM, etc.
2. Compare to appropriate screening levels
   • Protective, so if values < SL, likely no issue
3. Re-evaluate if data are > generic SLs
   • Review critical parameters and sanity checks
4. Utilize other lines of evidence
5. Consider option for pre-emptive mitigation

Data Quality Review

- Program design
  • Well justified scope of work based on CSM and DQOs
- Field methods
  • Samples representative and reproducible
- Laboratory methods
  • Analysis precise and accurate, reporting limits < targets
- Quality assurance / quality control
  • Duplicates, replicates, equipment blanks, container certification, outdoor air samples, building survey, etc.
- Assess consistency with CSM after each phase
  • Compare data to expectations

Refer to Appendix E, Quality Assurance Considerations, in the ITRC VI-1 2007
Common Data Quality Issues

- **Positive bias**
  - Equipment blank samples may show VOCs
  - May also find compounds unrelated to the site

- **Negative bias**
  - Adsorptive losses in sample train
  - Leaks (soil gas and sub-slab)
  - Volatilization losses (groundwater, soil)

- **Variability**
  - Spatial, temporal, operator

Exacerbated because target levels are so low

Reviewing Attenuation Factors

- Concentration (C) allowed = \( C_{\text{indoor}} / \alpha \)
- \( \alpha \) varies with depth and soil type
  - Sub-slab
  - Soil gas
  - Groundwater

- Three general sources for \( \alpha \) values
  - Empirical (EPA database)
  - From models (e.g. J&E Model)
  - Measured with tracers (radon, 1,1-DCE, etc.)
Interpreting GW Data

- Compare to look-up tables (conservative)
- Use attenuation factor
  - USEPA 2002, Figure 3 or local or state guidance
  - Use groundwater or soil gas alpha
- Use J&E model (if allowed)
  - Groundwater spreadsheet if allowed
  - Soil gas spreadsheet if convert to $C_{sg}$

Note: GW Data May Over-Predict Risk

GW Data Exercise

- TCE at 50 µg/L in GW
- GW depth 20’, sandy soil
- H constant = 0.5
- Residential Setting, allowed $C_{indoor} = 1 \mu g/m^3$
- Default GW alpha: 0.0005

Does TCE exceed allowable value?
Is vapor intrusion likely occurring?
Solution - GW Data Exercise

- TCE in soil gas \( \approx 50 \mu g/L \times 0.5 = 25 \mu g/L = 25,000 \mu g/m^3 \)
- TCE in indoor air \( \approx 25,000 \mu g/m^3 \times 0.0005 = 12.5 \mu g/m^3 \)
- Residential Setting, allowed \( C_{\text{indoor}} = 1 \mu g/m^3 \)

Does TCE exceed allowable value?
YES

Is vapor intrusion likely occurring?
It Depends

DISCUSSION: What does it depend on?

Interpreting Soil Data

- Soil data generally not acceptable for VI assessment by most agencies
- Look-up tables rarely exist
- Calculate soil gas concentration from soil data using partitioning equation (easier to use J&E soil spreadsheet to calculate soil gas concentration)

Note: Soil data often under predicts risk
(negative bias in soil data from volatilization losses)
Interpreting Exterior Soil Gas Data

- Compare to look-up tables (conservative)
- Use attenuation factor
  - USEPA 2002, Figure 3 or local or State guidance
- Use J&E model (if allowed)
  - Soil gas screen and advanced spreadsheets

Note: May or may not rule out individual buildings

Soil Gas Data Exercise

- Benzene at 6 µg/L at 5' bgs
- Sandy soil
- Commercial Receptor, allowed $C_{\text{indoor}} = 15$ µg/m³
- Default alpha: 0.002

Does the benzene value exceed allowable value?
Is vapor intrusion likely occurring?
Solution - Soil Gas Data Exercise

- Benzene indoor air $\approx 6 \, \mu g/L \times 0.002 = 0.012 \, \mu g/L = 12 \, \mu g/m^3$
- Commercial Receptor, allowed $C_{\text{indoor}} = 15 \, \mu g/m^3$

Does the benzene value exceed allowable value? No

Is vapor intrusion likely occurring? It Depends

DISCUSSION: What does it depend on?

Interpreting Sub-Slab SG Data

- Look-up tables
- Use attenuation factor
  - From local state guidance or EPA: 0.10
  - J&E Model is not really designed for sub-slab to indoor alpha
  - Consider radon to determine slab-specific alpha
- Potential for indoor air to impact sub-slab?
  - Buildings breathe both ways, so it is common to see chemicals from indoor sources in sub-slab samples
Interpreting Indoor Air Data

- Interpretation complicated by ambient background and indoor sources
- Are measured values > allowed?
- Is outdoor air > indoor air?
- If indoor > outdoor, how to determine if VI?
  - Compare to sub-slab concentrations
  - Use constituent ratios and tracers
  - Pressure measurements

Ambient (Outdoor) Air

PCE = Background (ambient)
Comparison to Outdoor Air Data

- Clean Air Act (1970, 1990, 1997) is helping
  - Yet still 20,000,000 kg of VOCs released each year
- Point sources vs. widespread air quality
  - Local dry cleaner
  - Nearby freeway
  - Large urban or industrial area
- Spatial and temporal variability
  - Effect of wind speed and direction, transient sources
- How many samples are needed?
  - Generally at least one for each day of indoor air sampling

Outdoor Air Quality – TCE

1996 Estimated County Median Ambient Concentrations
Trichloroethylene – United States Counties

10^{-6} target = 0.022 \mu g/m^3 (also off-scale!)
Ambient (outdoor) air quality has greatly improved over the last decade.

### Background Sources

- Background refers to concentrations not attributable to releases from a site, and is usually described as naturally occurring or anthropogenic (USEPA 2002)
  - Background concentrations may exceed risk-based levels in indoor air for some common VOCs
  - Background sources may be inside the building or present in ambient outdoor air
  - The final remedy may or may not eliminate a source of risks caused by background sources
  - Some states incorporate typical background concentrations into their screening values, but most do not
CERCLA Approach to Background

- Background contributions to the concentrations of contaminants associated with a release at a site COPCs (contaminants of potential concern) should be included in the risk assessment

**BUT**

- CERCLA does not generally clean up to concentrations below natural or anthropogenic background levels.

- Background information is important for risk managers making decisions about appropriate remedial actions

Source: "Role of Background in the CERCLA Cleanup Program" OSWER 9285.6-07P, April 2002

Indoor Sources

- Specific sources of indoor air contamination
  - Consumer activities
  - Household products
  - Building materials and furnishings
  - Ambient (outdoor) air
Published Indoor Air (IA) Background Data

- Reasonable place to start, but must consider
  - Variability between homes
    - Ventilation, habits, and hobbies
    - Urban vs. rural settings
  - Changes over time
    - Some studies are dated
  - Truncated data sets
    - Lots of Non Detects, makes statistics tough
  - Limited list of analytes versus USEPA, 2002, Table 1

USEPA Indoor Air (IA) Background Data

- Background indoor air concentrations of VOCs in North America
  - Indoor air concentrations have decreased over time since 1970
  - Background indoor air concentrations of some chemicals exceed risk based concentration (RBC, 1E-06)
    - e.g. benzene, carbon tetrachloride, chloroform, MtBE, PCE
  - Concentrations of some chemicals at vapor intrusion sites fall within the range of background indoor air concentrations
    - e.g., PCE, 111TCA

Dawson, 2008
Background IA Concentrations vs. Risk Based Concentrations

Benzene, PCE, MTBE, CCl₄ and Chloroform all have IA background > 10⁻⁶

Dawson, 2008

Plot of Typical “background” indoor air vs. 1E-4 to 1E-6 Risk Levels

Background exceeds 10⁻⁴ cancer risk level.

Site-specific Chemicals of Concern

Benzene = ND
PCE = 100 µg/m³

Benzene = COC
PCE = Background (not a COC)

Benzene = ND
PCE = <2.6 µg/m³ (soil gas)

Benzene = 300 µg/L
PCE = ND (gw)
**COCs = Multiple Lines of Evidence**

- Site-specific COCs
  - COCs not present in soil or groundwater are likely due to background sources
  - Media must be well characterized
  - Degradation products must be considered
  - Review Building Survey – are consumer products present that contain the compounds detected that are not COCs?

**Breathing Buildings**

- PCE 100 µg/m³
- PCE 10 µg/m³ (soil gas)
- PCE Not detected (gw)

Is this “vapor extrusion”? Why or why not?
Forensics: Constituent Ratios

- Comparing the ratio of two or more compounds in one media with another media (i.e., GW to SG, SG to IA)

- Constituent ratios can provide evidence for and against vapor intrusion

- Attenuation factors can be assessed by comparing values for various compounds (background contributions will tend to increase the alpha value)

Constituent Ratio Example

Constituent ratio for indoor air does NOT match the ratio for sub-slab soil gas

TCE = 80 µg/m³
DCE = 20 µg/m³

TCE = 0.5 x DCE

TCE 1000 µg/m³
DCE 2000 µg/m³

Most TCE in indoor air likely from a background source, but the rest (~10 µg/m³) may still be unacceptable
Marker Compounds or Tracers

- Characteristic of subsurface chemicals
- Detectable concentrations
- Rare in "background"
- Similar fate and transport properties
- Possible examples include:
  - 1,1-Dichloroethene
  - Radon
  - Trichloroethene (although still present in some cleaning solutions)

Indoor Air Data with & without ΔP

![Graph showing concentration over days after system installation](chart)

Days after system installation vs. Concentration (µg/m³)

<table>
<thead>
<tr>
<th>Compound</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,1 DCE</td>
<td>Blue</td>
</tr>
<tr>
<td>DCM</td>
<td>Red</td>
</tr>
<tr>
<td>1,1 DCA</td>
<td>Pink</td>
</tr>
<tr>
<td>1,1,1 TCA</td>
<td>Purple</td>
</tr>
<tr>
<td>1,2 DCA</td>
<td>Green</td>
</tr>
<tr>
<td>PCE</td>
<td>Yellow</td>
</tr>
<tr>
<td>TCE</td>
<td>Magenta</td>
</tr>
<tr>
<td>VC</td>
<td>Brown</td>
</tr>
</tbody>
</table>

Courtesy: David Folkes, EnviroGroup
Building Pressurization – TCE

Consideration of Variability

- Indoor air samples of 24-hours typically show up to an order of magnitude temporal variability
  - Radon industry addressed this by requiring samples to be collected over a longer period
- Deeper soil gas samples tend to have less temporal variability, but tend to overestimate risks for degradable compounds
- Season climate changes (hot/cold, wet/dry) are minimal in some areas, significant in others
Indoor Air Data Example

Retail Shopping Mall

<table>
<thead>
<tr>
<th>Tenant</th>
<th>Basement</th>
<th>1st Floor</th>
<th>1st Floor</th>
<th>1st Floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenant 1</td>
<td>Acetone - 12,400</td>
<td>Acetone - 35</td>
<td>Acetone - 18</td>
<td>Acetone - 83</td>
</tr>
<tr>
<td></td>
<td>Benzene - 1,447</td>
<td>Benzene - ND</td>
<td>Benzene - 1.1</td>
<td>Benzene - 0.8</td>
</tr>
<tr>
<td></td>
<td>MTBE - 7,860</td>
<td>MEK - 1,690</td>
<td>MEK - ND</td>
<td>MEK - ND</td>
</tr>
<tr>
<td></td>
<td>1st Floor</td>
<td>MTBE - 2.2</td>
<td>MTBE - 2.7</td>
<td>MTBE - 1.6</td>
</tr>
<tr>
<td></td>
<td>Acetone - 25,417</td>
<td>PCE - 2,281</td>
<td>PCE - 460</td>
<td>PCE - 1,322</td>
</tr>
<tr>
<td></td>
<td>Benzene - ND</td>
<td>THF - 1,010</td>
<td>THF - ND</td>
<td>THF - ND</td>
</tr>
<tr>
<td></td>
<td>MTBE - ND</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PCE - 79</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>THF - 79</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1st Floor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Acetone - 35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Benzene - ND</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MEK - 1,690</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MTBE - 2.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PCE - 2,281</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>THF - 1,010</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Acetone - 83</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Benzene - 0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MEK - ND</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MTBE - 1.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tenant 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tenant 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tenant 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All results reported in \( \mu g/m^3 \)

Mitigation

Key Topics
- Site remediation
- Institutional controls
- Building controls
- Barriers, venting, and treatment
- Special issues
- Closure

Lesson goal
- Think critically about approaches to mitigation

Introduction / Framework
- VI Investigative Approach
- Site Investigative Tools
- Data Review / Background
- Mitigation
Vapor Intrusion Mitigation

- What are the 3 general approaches?

Site Remediation

- Eliminate source of vapors
**Institutional Controls**

- Prevent exposure to vapors

**Building Controls**

- Prevent entry of vapors into building
Site Remediation Options

- Removal, e.g.
  - Excavation
  - SVE
- In situ treatment, e.g.
  - Biodegradation
  - In situ chemical oxidation (ISCO)
  - Zero valent iron
- Barriers
  - Allow off-site monitored natural attenuation (MNA)

Advantages of Site Remediation

- Permanent
- Need to do anyway
- May be lowest cost
- May address other exposure pathways
Disadvantages of Site Remediation

- May take too long
- May be too expensive
- Building may be in the way

Institutional Controls

- Legal mechanisms
  - Restrict use
  - Require controls
  - Require evaluation
Institutional Controls

Types?

- Deed notice
- Deed restriction
- Covenant
- Zoning requirement
- Use control area
- One-call notification
- Site management plan

Institutional Controls

Advantages?

- Lower cost
  - Compared to controls
- Quick to implement
  - Depending on type
- Allows time for site remediation
Institutional Controls

Disadvantages?
- Limits site use
- Hard to enforce over long periods of time
- Property value?

Building Controls

Lesson goal:
- Understand basic principles behind each approach, so that you can
  - Select the best approach based on building and site conditions
  - Deal with unusual conditions
  - Understand strengths and weaknesses of each approach
Mitigation Concepts

- Diffusion
- Advection
- Air exchange
- Remove Source

Barriers – Existing Buildings

- Seal cracks and penetrations
- Crawl space liners (e.g. LDPE)
Barriers – Existing Buildings

- Aerated floor system
- Raised floor (air tight)
- Vented air space

Barriers – New Buildings

- Liner below slab
  - Spray-on rubberized asphalt membrane
  - Geomembrane (e.g., HDPE)
Spray-On Barriers

No product endorsements intended by this presentation

Barrier Concept

- How do barriers work?

Sub-slab vapor concentrations before liner
• How do barriers work?

Sub-slab vapor concentrations after liner*

* No venting layer

• Vapors must diffuse or flow laterally

Sub-slab vapor concentrations after liner*

* No venting layer
**Barrier Diffusivity**

- For 100 mil liners that rely on diffusion to divert vapors, diffusivity should be about 5 orders of magnitude lower than the effective diffusivity of the soil.
- Typical soil diffusivities approx $10^{-6}$ to $10^{-8}$ m²/s.
- Therefore, liner diffusivity of $10^{-13}$ m²/s or lower will allow less than 1% of the vapors to diffuse through the material.

---

**Barrier Examples**

<table>
<thead>
<tr>
<th>Type</th>
<th>Use</th>
<th>Thickness</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible sheet</td>
<td>Crawl space liner</td>
<td>4-6 mils typical</td>
<td>X-laminated LDPE</td>
</tr>
<tr>
<td>Thick sheet</td>
<td>Liner below new concrete slabs</td>
<td>60-100 mils typical</td>
<td>HDPE</td>
</tr>
<tr>
<td>Spray on</td>
<td>Liner below new concrete slabs</td>
<td>60-100 mils typical</td>
<td>Geo-Seal™ Liquid Boot®</td>
</tr>
</tbody>
</table>

*No product endorsement intended by this presentation*
Barrier Integrity

- Key to barriers is integrity of seal
- Vapors can move by advection or diffusion through holes, gaps in seals at foundations and penetrations

Barrier Integrity

- Must be able to survive construction
  - Construction foot traffic, dropped tools, rebar
  - Pouring of concrete, aggregate
- Rigorous construction quality control essential
- Integrity testing recommended
  - Smoke tests
  - Indoor air tests
Liner Puncture Study

Number of holes per square meter

<table>
<thead>
<tr>
<th></th>
<th>Holes less than 2mm diameter</th>
<th>Holes greater than 2mm diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) (2) (3) CPE</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>(1) (2) (3) Hypalon</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>(1) (2) (3) LDPE</td>
<td>10</td>
<td>15</td>
</tr>
</tbody>
</table>

Note:
1. No geotextile
2. Geotextile on top
3. Geotextile both sides

from Folkes and Hunter 1984

Passive Venting Layers

- Provide vapor pathway to reduce $C_{ss}$

Riser Pipe

- Gravel,
- Sand,
- Geogrid, or
- Geotextile

$C_{ss}$
Spray-On Barrier & Vent

 Courtesy of CETCO Liquid Boot Company

No product endorsements intended by this presentation

Aerated Floor System

- Forms create continuous cavity below slab
- Passive or mechanical venting

* Provided courtesy of Pontarolo Engineering, Inc.
No product endorsement intended by this presentation
Passive Venting Mechanisms

- Passive venting layers rely on diffusion and natural pressure gradients
  - Thermal-induced pressure gradient

- Wind-induced pressure gradient
- Augment with wind turbine
Passive Venting Mechanisms

- Passive venting layers rely on diffusion and natural pressure gradients
  - Ventilation is primary mechanism, reducing sub-slab gas concentrations
  - May also depressurize venting layer

- Passive venting may not occur naturally at all times
  - Potential reverse stack effect
  - 10-50% as effective as active venting
Active Venting

- Active venting layers rely on fans to create suction (i.e., depressurize venting layer)
  - Passive vents are only 10 to 50% as effective as active systems

Sub-slab (Active) Depressurization

- Most widely applied and successful building control
- Existing buildings – no barrier or venting layer
- New buildings – typically include barriers and venting layers
- $1500 to $3000 to install

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Successful track record of performance, 90 to 99% reductions typical, 99.5% or greater reductions possible with well designed systems</td>
<td>Requires periodic maintenance</td>
</tr>
<tr>
<td>Adaptable technology, applicable to a wide variety of site conditions and geology</td>
<td>Wet and low permeability soils retard vapor movement</td>
</tr>
<tr>
<td>Can be applied to new and existing structures</td>
<td>Building-s specific conditions may limit options for suction pit, riser pipe, and fan locations.</td>
</tr>
</tbody>
</table>
SSD in Existing Building

To Fan
Riser Pipe
Seal
Suction Pit

How much suction is needed?

Recommended sub-slab depressurization levels to overcome indoor levels (EPA, 1993)
- 0.015 inches water column (WC) over entire slab
- 0.025 to 0.035 inches if measured in summer without exhaust fans running
  - However, good reductions (radon) often achieved with less depressurization due to sub-slab vapor concentrations (EPA, 1993)
  - New York State Department of Environmental Conservation suggests minimum 0.003 inches WC
Diagnostic Tests - Example

- Recreational facility in New York
- Multiple suction points tested - one shown in this example (S-1)
  - Shop vac used to apply -41" WC suction
  - Pressure difference measured at 11 test holes

$\Delta P = P_{\text{ss}} - P_{\text{building}}$

Postive $\Delta P$

Negative $\Delta P$

Courtesy Tom Hatton, Clean Vapor, Inc.
Baseline Pressure Differentials

Induced Pressure Differentials
Suction Test Results

Radius of Influence

\[ R^2 = 0.8614 \]
Adjustment for Fan Vacuum

<table>
<thead>
<tr>
<th>Device</th>
<th>Suction</th>
<th>Radius of Influence (at 0.01 in. WC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shop Vac</td>
<td>40 inches WC</td>
<td>60 feet</td>
</tr>
<tr>
<td>Blower</td>
<td>20 inches WC</td>
<td>30 feet</td>
</tr>
</tbody>
</table>

Radius of Influence

\[ R = 30 \text{ feet} \]
SSD Variations

Sub-Membrane Depressurization

CRAWL SPACE

SSD Variations

Block Wall Depressurization

Cinder block foundation wall
SSD Variations

Foundation drain depressurization

Passive vs. Active

<table>
<thead>
<tr>
<th>Passive Controls</th>
<th>Active Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Favored by many developers</td>
<td></td>
</tr>
<tr>
<td>• No active components or costs</td>
<td></td>
</tr>
<tr>
<td>• Less stigma perceived</td>
<td></td>
</tr>
<tr>
<td>• Barriers must be robust</td>
<td></td>
</tr>
<tr>
<td>• Venting must be provided</td>
<td></td>
</tr>
<tr>
<td>• Integrity should be tested (more difficult to test than active)</td>
<td></td>
</tr>
<tr>
<td>• Only works for new buildings</td>
<td></td>
</tr>
<tr>
<td>• Imperfections likely to exist</td>
<td></td>
</tr>
<tr>
<td>• Passive venting less effective</td>
<td></td>
</tr>
<tr>
<td>• Lack of performance data</td>
<td></td>
</tr>
</tbody>
</table>
### Passive vs. Active

<table>
<thead>
<tr>
<th>Passive Controls</th>
<th>Active Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Favored by many developers</td>
<td>• Less favored by developers</td>
</tr>
<tr>
<td>• No active components or costs</td>
<td>• Operation and maintenance needed</td>
</tr>
<tr>
<td>• Less stigma perceived</td>
<td>• Perceived stigma</td>
</tr>
<tr>
<td>• Barriers must be robust</td>
<td>• Highly effective (99.5% reduction)</td>
</tr>
<tr>
<td>• Venting must be provided</td>
<td>• Relatively low cost most cases</td>
</tr>
<tr>
<td>• Integrity should be tested (more difficult to test than active)</td>
<td>• Easily tested (pressures)</td>
</tr>
<tr>
<td>• Only works for new buildings</td>
<td>• New or existing buildings</td>
</tr>
<tr>
<td>• Imperfections likely to exist</td>
<td>• Easily modified</td>
</tr>
<tr>
<td>• Passive venting less effective</td>
<td>• Substantial performance data</td>
</tr>
<tr>
<td>• Lack of performance data</td>
<td>• Can initially be passive (convert to active system if necessary)</td>
</tr>
</tbody>
</table>

### Building Pressurization

- **Positive building pressures**
  - Requires increase intake air flow
  - Creates downward pressure gradient through slab
  - Increases energy costs
**Indoor Air Treatment**

- Typical residential unit
  - Size of shop vac
  - 22 lbs of carbon
  - Effective up to 1500 ft²
  - 3 speed 400-CFM fan – runs whisper quiet
  - Electricity demand = 60 watt light bulb

Source: www.allerair.com

**High Water Table**

- Mitigation options?
  - Install french drains and depressurize
  - Positive building pressure
  - Install false floor and depressurize
  - Indoor air treatment
  - If surface water, may be clean lens
Intrinsically Safe Design

Operation, Maintenance and Monitoring

- Operation
  - Electrical costs
  - Emission controls
- Maintenance
  - Fan replacement
- Monitoring
  - Testing
  - Inspections

Low Pressure Monitoring Panel
Courtesy Tom Hatton, Clean Vapor, Inc.
Closure

- When long term cleanup objectives are met
  - Building mitigation will no longer be required
  - Institutional controls can be retired/removed
- Consider how decisions to stop mitigation will be made at the beginning of program
- Collect sufficient information during operations and maintenance (O&M) to make closure decisions
  - Develop correlations between subsurface media concentrations and indoor air concentrations

Take Home Messages

- Vapor intrusion is a complex pathway
- Multiple lines of evidence approach is critical
- Tool box is large and growing
- Background sources & physical processes complicate data interpretation
- Science of vapor intrusion is advancing and changing
Itron Vapor Intrusion Pathway: A Practical Guideline (VI-1)

- Key vapor intrusion issues
  - Investigative strategies
  - Phased, iterative process
  - Background contamination
  - The “toolbox”
  - Conceptual site model
  - Future land use
  - Remediation technologies
  - Closure strategies
  - Qualified consultants

Itron Resources Available Online

- ITRC Vapor Intrusion Resources and Links
  - Documents
  - Surveys
  - Links
  - Contacts
  - Training

http://www.itrcweb.org/VaporIntrusion
ITRC VI Classroom Training

ITRC is offering 2-Day classroom training on the VI pathway that will include:

- Interactive Presentations
- Hands-on Exhibits
- Informative Handouts
- Problem Sets

**2010 Sessions:**

Norfolk, VA - March 22-23, 2010
TBD – July 12-13, 2010
Atlanta, GA – October 4-5, 2010