Soil Vapor Sampling Methods for Vapor Intrusion Assessments

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This training is an excerpt from the vapor intrusion training that Dr. Hartman has been presenting to Federal & State regulatory agencies, DOD facilities, consulting groups, and stakeholders around the country. As of January 2010, Dr. Hartman has given vapor intrusion or soil gas training to over 30 State Regulatory agencies, to regulators from all 50 states at the ASTSWMO national meeting, and at the National UST conference in 2006 & 2008 & 2009. Dr. Hartman is also an instructor on assessment methods in the ASTM, ITRC, API, and EPA-OUST vapor intrusion training courses.

Lecture notes are at the bottom of each slide so that if played out as a hard-copy, the presentation can be a useful reference document.
Course Overview

• Review of Some Fundamentals
• Quick Review of VI Guidances
• Indoor Air Sampling Issues
• Soil Gas Sampling Methods
• Additional Sampling Issues
• Field Demonstrations

The training course consists of the following parts. The emphasis will be on parts 4 through 6.
What Is Vapor Intrusion?

Vapor intrusion refers to the upward migration of contaminants in the vapor phase from groundwater, soil, or soil gas contamination sources.

Key Criteria Influencing Risk Assessment:
- Risk level (1 in 10,000? 100,000? 1,000,000?)
- Toxicity of Compounds
- Exposure Factors (time, rates, ventilation)

Key criteria to the risk determination are the risk level, the toxicity of the contaminant, and the exposure factors. These parameters are often much more important than model parameters such as soil porosity and pressure gradients.
A Couple of Fundamentals

• Units
• Attenuation (alpha) Factors

There are a number of basic principles that need to be understood in order to understand and effectively manage the vapor intrusion pathway. Some of these principles you may not have had in school or have never really used them, so you are rusty. We will be using them throughout the rest of this training so we will review them now.
Most Common VI Bloopers

Unit Confusion:
• Assuming ug/L equivalent to ppbv
• Assuming ug/m3 equivalent to ppbv
• Going from ug/m3 to ug/L
• Vacuum units: in Hg to inches H2O

Screening Levels:
• Comparing to CHHSLs
• Not calculating correct levels

Two of the most common mistakes being made by practitioners
The Most Common Goof

1 ug/L Benzene equals:

a) 1 ppbv
b) 1 ppmv
c) 330 ppbv
d) None of the Above

Vapor units is one of the most common mistakes being made by practitioners in this field. Let’s see how you do:
A Future Common One:

100 inch of Water = ? Inches of Hg
a) 5
b) 8
c) 10
d) 15

Another common unit that is mixed up by consultants
<table>
<thead>
<tr>
<th>Sample Name</th>
<th>Sample Date</th>
<th>VFH (ug/L)</th>
<th>Benzene (ug/L)</th>
<th>Toluene (ug/L)</th>
<th>Ethylbenzene (ug/L)</th>
<th>m,p-Xylenes (ug/L)</th>
<th>o-Xy (ug)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VP-1-5</td>
<td>30-Aug-07</td>
<td>ND&lt;200</td>
<td>0.4</td>
<td>ND&lt;1.0</td>
<td>ND&lt;1.0</td>
<td>ND&lt;1.0</td>
<td>ND&lt;</td>
</tr>
<tr>
<td>VP-1-15</td>
<td>30-Aug-07</td>
<td>620</td>
<td>4.1</td>
<td>ND&lt;4.0</td>
<td>ND&lt;4.0</td>
<td>ND&lt;4.0</td>
<td>ND&lt;</td>
</tr>
<tr>
<td>VP-1-25, LPV</td>
<td>30-Aug-07</td>
<td>40,000</td>
<td>1200</td>
<td>ND&lt;100</td>
<td>ND&lt;100</td>
<td>110</td>
<td>ND&lt;</td>
</tr>
<tr>
<td>VP-1-25, 3PV</td>
<td>30-Aug-07</td>
<td>13,000</td>
<td>400</td>
<td>ND&lt;100</td>
<td>ND&lt;100</td>
<td>110</td>
<td>ND&lt;</td>
</tr>
<tr>
<td>VP-1-25, 7PV</td>
<td>30-Aug-07</td>
<td>7,800</td>
<td>200</td>
<td>ND&lt;100</td>
<td>ND&lt;100</td>
<td>ND&lt;100</td>
<td>ND&lt;</td>
</tr>
</tbody>
</table>

Note the units for the samples in this table: ug/L
### Table 5  PRELIMINARY SCREENING EVALUATIONS

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Sample Name</th>
<th>Concentration (ug/L)</th>
<th>Default Attenuation Factor</th>
<th>Indoor Air Concentration (ug/m³)</th>
<th>OEHHA Chronic Inhalation RULs (ug/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>VP-1-25</td>
<td>1,200</td>
<td>0.001</td>
<td>1.20</td>
<td>60</td>
</tr>
<tr>
<td>Toluene</td>
<td>VP-2-25</td>
<td>420</td>
<td>0.001</td>
<td>0.42</td>
<td>300</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>VP-6-25</td>
<td>30</td>
<td>0.001</td>
<td>0.03</td>
<td>2,000</td>
</tr>
<tr>
<td>Xylenes</td>
<td>VP-1-25</td>
<td>110</td>
<td>0.001</td>
<td>0.1</td>
<td>700</td>
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<td>MTBE</td>
<td>VP-1-25</td>
<td>170</td>
<td>0.001</td>
<td>0.2</td>
<td>8,000</td>
</tr>
</tbody>
</table>

1200 ug/L = 1,200,000 ug/m³

CA-EPA 1 e-5 allowable benzene value: 4.2 ug/m³

The preliminary screen used a default attenuation factor of 0.001 and shows in this table that the site passes.

But wait a minute, the units are different from Table 1.

If the measured result was really 1,200 ug/L then the correct number to use in this table would be: 1,200,000 ug/m³.

Which units are correct?
Although concluding in the text that it was not necessary to go to the next step, the consultant did so anyway. The consultant used the J-E model to determine the risk from the soil gas data. First, they used the wrong version of the spreadsheet.

This time they reached the opposite conclusion. This is odd since site-specific screening is generally less conservative than preliminary screening. What happened? They now made the comparison based upon hazard index rather than the RELs shown in Table 5.

But wait, the units have changed again! Now they are in ppmv. Same numerical value, but different units from both Table 1 & Table 5.
A common term in the vapor intrusion “community” is the attenuation factor also called the alpha factor. The soil gas alpha factor is a ratio of the indoor air concentration to the soil gas concentration. The groundwater alpha factor is a ratio of the indoor air concentration to the groundwater concentration times its Henry’s constant.

Since indoor air values are lower than subsurface values, alpha factors tend to be less than 1, hence lower numbers mean greater attenuation. Thus, inverse alpha factors are often easier to understand.

The EPA draft guidance uses very stringent alpha factors, determined empirically from a limited data base. For petroleum hydrocarbons, more recent data bases are showing that the alphas should be orders of magnitude lower.
In the draft VI guidance, alpha factors can are summarized vs. depth in Figure 3. As you can see in Figure 3a, the highest soil gas alpha is 0.002 at 5 feet below the structure. The inverse is 500.

For groundwater, Figure 3b shows the highest alpha is ~.001. The inverse is 1000.
Using Alpha Factors to Calculate Screening Levels

For Soil Gas:
\[ C_{sg} = \frac{C_{\text{indoor}}}{\alpha_{sg}} \]

For Groundwater:
\[ C_{gw} = \frac{C_{\text{indoor}}}{(H\alpha_{gw})} \]

Example: \( C_{\text{in}} \) benzene = 3.1 ug/m3
\[ C_{sg} (5') = \frac{3.1}{0.002} = 1500 \text{ ug/m3} \]

By using alpha factors, one can calculate screening levels or allowed levels for soil gas and groundwater by knowledge of the acceptable indoor air concentration.

You need to know what the screening levels are before you go into the field so that you choose the proper analytical methodology.
If you are a consultant or RP, you need to know which agency has jurisdiction and what their vapor intrusion policy is in order to know what approaches are allowed and what the allowable levels are.
The current EPA draft VI guidance consists of 3 tiers, consisting of 6 questions. Tier 1 is essentially a screening survey asking basic questions such as whether volatile compound contamination exists and whether buildings exist.

Tier 2 consists of 2 questions/steps: Q4 & Q5. Question 4 is so restrictive (i.e., very low screening levels) that just about every site is sucked in, similar to a vortex or hopper. Question 5 allows more sampling options, is not as conservative, and may be the best tier/question to work within.

Tier 3, question 6, allows for only two investigatory methods, indoor air or sub-slab soil gas, and has very restrictive (i.e., very low screening levels) criteria. Once at this level, it is extremely hard to get out and requires expensive and repeated sampling.
Newest Changes (2012?)
EPA OSWER VI Guidance

• Tier 1: **Primary** Screening
  – Q1: VOCs present?
  – Q2: Near buildings?
  – Q3: Immediate concern?

• Tier 2: Source Screening
  – Generic screening using near-source samples

• Tier 3: Pathway (Building) Assessment
  – Multiple lines of evidence (sg & gw)
  – Sub-slab & Indoor Air Data

The changes currently being considered by the EPA would make the vapor intrusion pathway even more stringent. Few sites would screen out and indoor sampling (sub-slab or indoor air) is required in most cases.
Guidance Updates

• Fed EPA (OSWER & Superfund)
  – Moving to sub-slab & indoor air
  – 7 to 30 day indoor air sampling period
  – Att factor of 0.1 for SG & 0.001 for GW
  – Modeling no longer an exit

• EPA-OUST: Guidance for HCs by 2012
  – Exclusion criteria?
  – Testing of Biovapor model

Here are some of the proposed changes to the OSWER guidance, due out in 2012.

Meanwhile, OUST is coming out with their own guidance for petroleum hydrocarbons also in 2012.
Allowable Benzene in GW
1e-6 risk

• New OSWER Guidance:
  0.31 ug/m3/0.001 = 0.31 ug/L/0.2 = 1.5 ug/L

• CA-LUFT Exclusion Value: 1000 ug/L

~700 times lower than database suggests!!
Allowable Soil Gas Levels
(Benzene 1e-6 Risk, residential)

<table>
<thead>
<tr>
<th>State</th>
<th>Alpha</th>
<th>1/Alpha</th>
<th>Risk Based Level (ug/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPA Now</td>
<td>0.002</td>
<td>500</td>
<td>155</td>
</tr>
<tr>
<td>EPA 2012?</td>
<td>0.1</td>
<td>10</td>
<td>3.1</td>
</tr>
<tr>
<td>CA</td>
<td>0.002</td>
<td>500</td>
<td>42</td>
</tr>
<tr>
<td>NJ (Subslab)</td>
<td>0.05</td>
<td>200</td>
<td>60</td>
</tr>
<tr>
<td>MO</td>
<td></td>
<td></td>
<td>118,000</td>
</tr>
<tr>
<td>TN</td>
<td>0.0013</td>
<td>780</td>
<td>2,414</td>
</tr>
<tr>
<td>CT</td>
<td>0.1</td>
<td>10</td>
<td>192</td>
</tr>
</tbody>
</table>

A summary of the allowable benzene levels in soil gas shows large variation and illustrates the main points: the new EPA guidance is 50x more restrictive and allowable levels are variable from State to State.
CA Agencies

- CA-DTSC (& LA-RWQCB)
  - Soil Gas, VI, & Mitigation “Advisory”
  - CHHSLs (thanks to OEHHA)
- EPA Region 9
  - Follows the EPA Draft VI Guidance
  - Adopted Region 3 Screening Levels
- SF-RWQCB
  - ESLs include aliphatics!
- Central Valley Boards
  - Want Residential Criteria Applied Regardless of Site Use

Here is a summary of the vapor intrusion policy/guidances for some California regulatory agencies. DTSC has soil gas collection & analytical guidance document, a vapor intrusion guidance document, and recently issued a mitigation document. The San Francisco Water Board has issued their own ESLs. The Central Valley & some Bay Area agencies are requiring residential criteria at all sites, whether current use is commercial or residential, to avoid hassles of deed restrictions and future monitoring of property use.
Proposed DTSC Changes

- Preference for Sub-slab Samples
- Collect Exterior SG Samples At Source
- Repeated Sampling of Soil Gas
- Preference for Gaseous Tracers
- Raising Sub-slab AF to 0.1 (10x stricter)
- Tougher Methods for Naphthalene
- Lower RBSL for Ethylbenzene - done
- A Decision Matrix??

Some changes DTSC proposed in their forums in June 2009
ITRC VI GUIDANCE

• Practical How-to Guide
• Stepwise Approach
• Investigatory Tools (Toolkit)
• Thorough Discussion of Mitigation
• Scenarios Document
• Four Training Dates in 2011

ITRC has recently finished it’s vapor intrusion guidance document. It consists of 2 documents: A practical guideline and a separate scenarios document. A 2-day classroom training course is ongoing.
ASTM convened a technical workgroup in 2005 to write a standard for vapor intrusion as it applies to property transactions. The standard was originally released on March 3, 2008. A revised standard was released in June 2010.
The Standard identifies the following search distances. Note the long distances.

Slide courtesy of Anthony Buonicore, Chairman ASTM VI Task Group
Liability Concerns

- Phase I Environmental Consultant
- Prospective/Current Property Owner
- Property Lender
- Property Insurer

Liability concerns is a big part of vapor intrusion. Those at risk include consultants, property owners (past, current & future), lenders, and insurance companies.

Slide courtesy of Anthony Buonicore, Chairman ASTM VI Task Group
Regulatory Approach for HC Sites

• Current Regulatory Approaches:
  – USEPA: Guidance not recommended for UST sites
  – ASTM: Screening distance reduced from 100’ to 30’
  – Some agencies include a 10X biodegradation factor
  – ITRC: Use vertical profile to demonstrate

• Data suggests these approaches are overly conservative for most petroleum release sites

Presently, most vapor intrusion guidances ignore bioattenuation. For those that discuss or consider it, there is a range of approaches to account for it. Some States simply decrease the distance of concern. Some give a 10 times allowance (typically by increasing screening levels) for bioattenuation. There is general recognition that these regulatory approaches tend to be overly conservative.
Robin Davis of the Utah DEP compiled a petroleum vapor data-base to determine the thickness of clean overlying soil necessary to fully attenuate vapors from their respective dissolved source strengths. There are 180 paired benzene SV & GW field measurements from 48 geographic locations; 14 events beneath buildings. Conservative screening criteria emerge showing that vapors associated with dissolved benzene sources of about 1,000 ug/L or less are attenuated with 5 feet of clean overlying soil.

Slide courtesy of Robin Davis, Utah DEP
Based on these studies, a LUFT site is assumed to present no unacceptable risk from vapor intrusion if site conditions indicate that there is:

- *Dissolved* groundwater concentrations below 1000 micrograms per liter (ug/L) for benzene and 10,000 ug/L for TPH and 5’ from receptor.

- Free product is 30 or more from receptor

Under these conditions, it is assumed that natural attenuation is sufficient to mitigate concentrations.

CA State Water Boards are proposing to adopt the exclusion criteria in their new LUFT manual.
Methods to Assess VI

- Indoor Air Sampling
- Groundwater Sampling
- Soil Phase Sampling
- Predictive Modeling
- Measure Flux Directly
- Soil Gas Sampling
- Supplemental Tools/Data

In this part of the seminar, we will discuss the primary techniques/tools used to assess the vapor intrusion pathway, including the pros & cons of each.
The keys to effective vapor intrusion assessments are picking the proper approach, determining the correct screening levels, sample & analyze correctly and efficiently, know when and how to use supplemental assessment tools, and to know how to demonstrate bioattenuation if petroleum hydrocarbons are the COC.
More Key VI Ingredients

- Experience of the Collector/Consultant
  - Have they done this before?
  - Do they understand RBSLs?
  - Quality/experience of field staff? Sr or Jr?

- Get Enough Data Near/Around/Under

- Legal Perspective
  - How conservative to be or not be?

The most important ingredient for cost effective and efficient VI investigations is the experience of the person/firm doing the collection. Is the collection being done by a firm that has prior experience? Is it a routine part of their services or an occasional part? Do they put experienced people in the field who can think or junior staff who aren’t well versed? This applies to the consultant and their subcontractors.

Soil gas, like soil, is not homogenous in most cases. So you need enough data to give decent coverage near, around, or under the receptor. Simpler collection systems with small volumes are advantageous as there is less to go wrong and enable higher production per day (20+ samples per day). Less expensive analytical methods (8021, 8260) enable more analyses for reasonable cost. Real-time data can be extremely helpful to track soil gas contamination laterally and vertically.

Legal considerations often dictate what additional work needs to be done at what standards.

All of these issues affect the investigation progress.
Indoor Air Measurement

- Pros:
  - Actual Indoor Concentration
- Cons:
  - Where From?
    - Inside sources (smoke, cleaners)
    - Outside sources (exhaust, cleaners)
    - People activities – NO CONTROL!
  - Time-intensive protocols
  - Snapshot, limited data points
  - Expensive!!

Measuring indoor air might seem to be the most direct and simplest approach, but it has its share of problems. The biggest problem is background sources of contaminants. Many commonly used household products contain some of the target compounds of concern. For example, benzene from gasoline, PCE from dry cleaned clothes, TCA from degreasing cleaners. In addition, the protocols are laborious, intrusive, offer little control, and are expensive. For these reasons, the EPA and many States shy away from this method. However, this method may still be the method of choice if the contaminant of concern is not one commonly found in household products (e.g., 1,1 DCE).
Ambient air is getting cleaner but still above 1 in 1 million risk levels.
Contaminants in indoor air may be from household products, not vapor intrusion.

Slide courtesy of Dr. Tom McHugh, GSI, Houston, TX
New Indoor Source of 1,2-DCA

**KEY POINT:** Indoor concentration of 1,2-DCA increasing over time. New indoor source = molded plastic (e.g., toys, Christmas decorations).

A recently discovered source for 1,2 DCA: molded plastics from China!

Slide courtesy of Dr. Tom McHugh, GSI, Houston, TX
Cleaning Your Dishes?
(or Polluting Your House)
### Dawn VOC Analysis Results

<table>
<thead>
<tr>
<th>Compound</th>
<th>Unit</th>
<th>Level</th>
<th>EL (8 h)</th>
<th>El-Dec 19</th>
<th>19-Dec 19</th>
<th>29-Dec 19</th>
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<td>n-Hexane</td>
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<td>10</td>
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<td>ND</td>
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<td>Trichloroethylene</td>
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<td>0.2</td>
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</table>
Dawn – No Wonder She’s Smiling

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Got Gas?

The hidden source of contamination at a site in Los Angeles
## BBQ Sample Results

<table>
<thead>
<tr>
<th>Analyte</th>
<th>BBQ</th>
<th>Garage</th>
<th>Patio</th>
<th>Garage #2</th>
<th>Closet</th>
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<tbody>
<tr>
<td>Methane</td>
<td>40%</td>
<td>90%</td>
<td>100%</td>
<td>nd (0.1%)</td>
<td>nd (0.1%)</td>
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<tr>
<td>n-hexane</td>
<td>1700</td>
<td>2000</td>
<td>10000</td>
<td>nd (15)</td>
<td>nd (15)</td>
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<tr>
<td>cy-hexane</td>
<td>750</td>
<td>5500</td>
<td>12000</td>
<td>nd (20)</td>
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<tr>
<td>n-heptane</td>
<td>460</td>
<td>710</td>
<td>3100</td>
<td>nd (50)</td>
<td>nd (50)</td>
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<tr>
<td>Benzene</td>
<td>270</td>
<td>340</td>
<td>1900</td>
<td>6.5</td>
<td>7.9</td>
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<tr>
<td>Toluene</td>
<td>150</td>
<td>110</td>
<td>1200</td>
<td>44</td>
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<tr>
<td>Xylenes</td>
<td>40</td>
<td>105</td>
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<td>113</td>
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<td>Tri-methyl benzene</td>
<td>3</td>
<td>85</td>
<td>25</td>
<td>110</td>
<td>nd (10)</td>
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<tr>
<td>Tri-methyl pentane</td>
<td>nd (200)</td>
<td>300</td>
<td>nd (200)</td>
<td>nd (20)</td>
<td>nd (20)</td>
</tr>
</tbody>
</table>

Natural gas contains high amounts of benzene and could be the major source for sub-slab and indoor air in neighborhoods containing natural gas service.
Indoor Air Sampling Lessons

- Always Collect Ambient Air Sample
- Hardware Issues
  - Blanks
  - Performance – Proper Rate?
  - Fittings Tight? Cross-threaded?
  - Pen/marker Type – Don’t use Sharpies
  - Gauges on cans, not on flow chokes

There are issues that need to be considered when sampling indoor air and when interpreting the data. Sampling issues include the hardware, time period for collection, and things as simple as the type of marker used to label the samples.
Details of Soil Gas Sampling

• Soil Gas Methods
• Sampling & Analysis Issues
• Sampling Strategies
• Bioattenuation of Hydrocarbons
• Other Tools/Approaches

This presentation will focus specifically on soil gas sampling and analysis since it is currently the most preferred approach around the country and, if you have a vapor intrusion problem, the chances are high you will be required to oversee or work with soil gas data. If time allows, it also will cover sampling strategies, how to assess bioattenuation, and a description of some other assessment tools to supplement soil gas data.
Which Soil Gas Method?

- Active?
- Passive? (limited use)
- Flux Chambers? (limited use)

**Active method most often employed for VI**

There are three types of soil gas methods. **Active** refers to actively withdrawing vapor out of the ground. It gives quantitative values. **Passive** refers to burying an adsorbent in the ground and letting the vapors passively contact and adsorb onto the collector. It does not give quantitative data and hence can not be used for risk applications, except for screening. Surface flux chambers were discussed previously.

The active method is the one most applicable to risk assessments.
Passive Soil Gas

• Pros:
  – Easy to Deploy
  – Can Find Contamination Zones
  – Low Permeability soils

• Cons:
  – Does not Give Concentration
  – No Less Expensive

Considered as Screening Tool by Most Agencies

Passive soil gas methods consist of the burial of an adsorbant into the group for a period of time (typically 5 to 10 days) and the subsequent retrieval of the adsorbant for measurement. The contaminants “passively” diffuse and adsorb onto the collector over time. The method is easy to deploy and is proven to find contamination zones. However, the method does not yield concentration values and thus can’t be used for risk-based applications. Ongoing efforts to “calibrate” the method to give concentration data are inconclusive.

As a result, this method is considered by most regulatory agencies to be a screening method. It can be used to locate contamination zones on larger parcels where the contamination is not already defined.
Passive Soil Gas Samplers

Examples of passive collectors.
Direct Flux Measurement
(Flux Chambers)

• Pros:
  – Direct Measurement of Intrusion

• Cons:
  – Proper Location?
  – Protocols Debated
  – How to Use Data?

Surface flux chambers are attractive because they give a direct measurement of the flux into the structure or out of the soil. This eliminates the need to know the effective diffusivity and the uncertainty inherent in the models. The biggest drawback with chambers is whether they can be placed in the proper locations in an existing structure. Also, few regulators, consultants, or vendors have used them, so they are unfamiliar of the protocols to use and how to interpret the data. As a result, regulatory acceptance is limited. In slab-on-grade structures or undeveloped lots or crawl spaces, surface flux chambers may be the best method to use. Chambers will also prove useful to support the presence of bioattenuation.
Static Flux Chamber

Photo of a static flux chamber equipped with a LandTech GEM 2000 real-time oxygen, carbon dioxide, and methane analyzer used to collect data continuously.
Active Soil Gas

• Pros:
  – Representative of Subsurface Processes
  – Higher Screening Levels
  – Relatively Inexpensive
  – Can Give Real-time Results

• Cons:
  – Mass Transfer Coefficient Unknown
  – Spatial Variability
  – Protocols still debated

Measurement of soil gas is a common approach around the country. Actual soil gas data are reflective of subsurface properties, are less expensive than indoor air measurements, and allow real-time results. The screening levels are also higher so there is less chance to be chasing blanks.

There are some drawbacks, including the lack of knowledge of the effective diffusivity, very restrictive fail levels for sub-slab data, and debate over how & where to collect samples.
Probe Installation Methods

• Driven Probe/Rod Methods
  – Hand Equipment, Direct-Push
  – Collect sample while probe in ground

• Vapor Mini-Wells/Implants
  – Inexpensive & easy to install/remove
  – Allow repeated sampling
  – Near surface & deep (down auger flights)
  – Can “nest” in same bore hole

There are two common ways to collect active soil gas samples: collection through a probe or rod driven into the ground or collection through a vapor well buried into the ground. Both methods give reliable data.

The vapor wells consist of small diameter, inert tubing and offer advantages when vertical profiles are desired or when repeated sampling events are likely. Multiple tubes can be “nested” in the same borehole.
Collection through the probe rod is advantageous if only one sampling round is required. Seals at the base of the probe are advisable, especially if depths are shallow and larger volume samples (>1 liter) are collected.
Soil Gas Implants

Soil gas implants nested in same borehole at three different depths. This method provides better seals at the intervals you wish to sample, can be removed after installation or left in place if repeated sampling is anticipated.
Multi-Depth Nested Well

Soil Vapor Nested Well

Our vapor implants are inexpensive, unintrusive and offer repeated analysis at multiple depths.

A schematic of a multi-depth nested vapor well.
Probe Considerations

- **Tubing Type**
  - Rigid wall tubing ok (nylon, teflon, SS)
  - Flexible tubing not (tygon, hardware store)
- **Probe Tip**
  - Beware metal tips (may have cutting oils)
- **Materials Used to Bury Probes**
  - Sand, cement
- **Equipment Blanks**
  - Need to collect blank through collection system

Some of the issues that need to be considered when installing probes include:

**Tubing Type**: Small diameter tubing offers advantages over large PVC pipe. Flexible tubing tends to leak.

**Probe tip**: Metal tips may have blanks due to the cutting process.

**Equilibration time**: How long to wait, especially if air knives are used to clear holes or larger drill rigs are used?

**Equipment blanks**: need to collect blank through the collection system. Trip blanks not enough.
Some Lessons Learned

• Do not mark sample locations with spray paint: toluene

• Watch what you use to seal holes

Soil gas implants nested in same borehole at three different depths. This method provides better seals at the intervals you wish to sample, can be removed after installation or left in place if repeated sampling is anticipated.
Equilibration Time - Tubes

~60% after 2 hrs, 70% after 4 hrs, 85% after 8 hrs
Equilibration Time – Through Rod

~80% immediately, 100% after 1 hr
A test of the influence of tubing type was performed in February 2008 at the Lemoore NAS research site. Six different tubings were nested together in the same borehole. Soil gas concentrations were measured on 2 occasions two days apart. The sampling order was reversed from day 1 to day 2 to eliminate any purge volume effects.
This is a chromatogram of the air from inside polyethylene tubing off of a direct-push rig.
Soil Gas Sampling Issues

• Sample Size
  – Greater the volume, greater the uncertainty
  – Smaller volumes faster & easier to collect

• Containers
  – Canisters: More blank potential. Higher cost
  – Tedlars: Good for ~2 days. Easier to collect

• Flow Rate
  – Really not imp. But most agencies < 200 ml/min

• Tracer/Leak Compound
  – Crucial for sub-slab & larger sample volumes
  – Gases (He, SF6, Propane) & Liquids (IPA)

Lower detection levels requires more careful protocols. Important sampling considerations include sample volume, container type, flow rate, and leak testing to ensure valid samples are collected.

Smaller volumes require less complicated sampling systems and minimize the chances for leakage from the surface and desorption off soil. Recent studies have shown no difference in soil gas values regardless of whether small (0.5 L) or large (100 L) volumes are collected.

Sample containers must be inert, clean, and handled properly (no cooling or heat). Canisters have longer holding times, but have the potential for blanks (carry-over from previous samples), cost more, and can be trickier to fill. Tedlar bags are good for ~2 days, are less expensive, and suitable for concentrations of 1 ppbv or higher.

Sample flow rate is of concern to many agencies, but recent data are showing it not to be a factor.

Tracer/leak compounds are generally required to ensure sample integrity because small leaks can create significant effects at such low concentrations. The larger the volume extracted and the more complicated the sampling system, the greater the potential for leaks.
Sample Volumes

A 6-liter Summa can is about the size of a basketball. A 400 cc mini-can is about the size of a baseball.

Lower volumes give more control on sample location, require less time to collect, and minimize chances of breakthrough from the surface or other sampling zones in nested wells.

For soil gas samples, most labs only require 50 cc of sample, so small canisters (<1 liter) are sufficient volume.
Container Issues

Large vs. mini-canisters

Filling a tedlar bag with syringe
Use of Tedlar Bags

Advantages offered by Tedlars:

- Many Consultants More Familiar With than Swageloks
- Easy to Fill: Perastalic Pump, Syringe, Lung Box
- Disposable - No Chance of Carry-over/False Positives
- Allows Repeat Analysis of a Sample if in Field
- Allows Measurement of Gaseous Tracer
- Allows On-site & Off-site Analysis of Same Sample!

The use of tedlar bags for soil gas samples has many advantages and is allowed by many agencies.
Soil vapor samples can be easily transferred from a tedlar bag into an evacuated canister in the field for longer holding times or for more security during sample shipping.
Beware of the Hardware

The tackle box on the left shows the required hardware to collect soil gas samples in Summas.

The syringe to the right is the only collection device required for on-site analysis of soil gas.
Poor Hardware

Canister sampling is hardware intensive. Only use labs that have good, well-kept hardware.
Leak testing methods using liquid tracers and gaseous tracer compounds.
Liquid Leak Tracer Method

• Pros
  – Fast & easy
  – Can cover multiple spots easily
  – Very conservative (100 ug/L = 0.1% leak)
• Cons
  – Typically qualitative
  – Don’t know results in real-time without lab
  – Small leak can raise detection limits of VOC analysis

OK Method if Lab On-site

If covering the entire sampling train is desired, a tent shroud can be used. The tracer, either a liquid or gas, is emplaced in the shroud. The concentration can be measured in the tent and in the sample with a handheld meter or on-site lab.
Gas Leak Tracer Method

• Pros
  – Quantitative
  – Real-time results with portable meters

• Cons
  – More complicated and slower. Increases costs
  – Harder to cover multiple locations, especially with Direct Push

Best Method if No Lab On-site

If covering the entire sampling train is desired, a tent shroud can be used. The tracer, either a liquid or gas, is emplaced in the shroud. The concentration can be measured in the tent and in the sample with a hand-held meter or on-site lab.
Post-Run Tubing (PRT) Fitting

Picture of the post-run tubing (PRT) connector used by most direct-push rigs. Fitting can leak if threads not sealed properly. The use of tracers can identify if leaks in the connections are present.
A typical sampling arrangement used for collection of samples on adsorbants. Note the abundance of fittings and the need for duplicate cartridges for breakthrough.
Soil Gas Sampling for HCs

- Might Need to Sample <5’ bgs
  - If samples >5’ bgs exceed allowable levels
  - How to know? On-site analysis best
  - If not, collect samples anyway
- Always Collect Oxygen Data
- Might Need Soil Phase Data

There are some differences in soil gas sampling for petroleum hydrocarbon VOCs than for chlorinated solvents. If samples at deeper depths exceed allowable values, shallower samples may need to be collected to document the effect of bioattenuation. Oxygen data should always be collected to document presence of the aerobic zone. Soil phase data may be needed to document the presence of a clean soil layer.
Some Final Sampling Issues

• Individual Certified Clean Canisters  
  – Not needed if DL > 5 ug/m3
• Residual Vacuum in Canisters  
  – Not critical for soil gas samples
• Dedicated Flow Restrictors  
  – Not necessary if cleaned between samples

A few additional sampling considerations.
Common Soil Gas Analyses

• VOCs
  – Soil & Water Methods: 8021, 8260
  – Air Methods: TO-14, TO-15, TO-17
• Hydrocarbons
  – 8015 m, TO-3
• Oxygen, Carbon Dioxide
  – ASTM 1945-96
• SVOCs (sorbent methods)
  – Air Methods: TO-4, TO-10, TO-13

This slide gives a summary of the most common analytical methods used for soil gas samples.
Soil Gas Analysis Issues
(TO-14/15 or 8260 or 8021)

• All Methods Give Reliable Results
• Detection Level Discriminator:
  – TO Methods: <1 to 1 ug/m³
  – 8021: 2-5 ug/m³
  – 8260: 10-100 ug/m³
• On-Site Analysis:
  – Extremely Helpful for VI
  – Minimizes False Positives

A variety of analytical methods are available to measure soil gas samples, but no federal guidance document exists specifying any one. Methods 8021 and 8260 are soil & water methods but give accurate results for soil gas samples at detection levels above 10 ug/m³. The toxic organic methods (TO) are designed for ambient air samples, so they give accurate results for soil gas samples at much lower detection levels. The TO methods require extensive hardware and are far more expensive. The criteria for selection should be which method(s) reach the required detection limits.

On-site data are extremely useful to ensure that the samples do not have tracer/leak levels above acceptable levels, provide real-time data for decision making, and to validate detections seen in the off-site data. If measured values are high, then the on-site methods (8021, 8260) are more appropriate to use than the ultra-sensitive TO methods. If on-site values are low or below detection, then the samples can be measured off-site by the TO methods.
High SG Concentrations Create Headaches

• Typical Soil Gas Concentrations
  – Benzene near gasoline soil: >100,000 ug/m³
  – TPH vapor: >1,000,000 ug/m³
  – PCE under dry cleaner: >100,000 ug/m³

• TO-15 Maximum Conc: 2,000 ug/m³
  – Must do large dilutions, DL goes up
  – False positives from hot samples

• Canister & Hardware & Instrument Blanks

Typical soil gas concentrations at leaky UST, dry cleaner, and industrial solvent sites are in the 100,000s to 1,000,000 of ug/m³. But, for 1 in 1 million risk, the risk-based screening levels are less than 10 to 100 ug/m³. This large concentration range creates a number of analytical headaches.

The TO-methods and hardware (canisters, flow chokes) are not designed for such high concentrations. System carryover, large dilutions, and contaminated canisters increase the potential for false positives, raises reporting levels, and gives air labs logistical fits which limits the utility of these methods.

The 8260 and 8021 methods can’t get lower than 10 to 100 ug/m³ so they may not reach required DLs.

In practice, a combination of these methods is the best approach. If expected values are high, then the 8021 & 8260 are advantageous to use than the ultra-sensitive TO methods. If expected values are low, then the TO methods offer advantages.
Don’t Forget 8021

• Can get to 1 ug/m3 for TCE, CCl4, PCE
• Can get to ~25 ug/m3 for Benz & Naphthalene
• 5 minute run time for benzene, TCE & PCE
• Cost ~ 1/5 of TO-15

Method 8021 is the forgotten method out there, but it has great sensitivity and offers many advantages over the other analytical methods if only a few target compounds exist.
On-site TO-15 Scan/SIM

• Simultaneous Scan/SIM mode enables
  < 10 ug/m3 for All VOCs &
  ~ 1 ug/m3 for subset of compounds.
• Only 2cc of Sample. Eliminates Hardware
• Real-time Analysis in Structures: Control!
• Two “Mobile Air Labs” Now Operational
• Can Go Into Automated Mode

New equipment allows on-site TO-15 analyses. New GC/MS equipment enables simultaneous Scan/SIM mode meaning you can measure for all VOCs (>60 compounds) at DLs < 10 ug/m3 while simultaneously measuring for a subset of compounds at lower detection levels (<2 ug/m3). Only 2 cc of sample are required for analysis, so much of the sampling hardware can be eliminated, reducing chances of false positives.

This capability enables real-time analysis in structures. This might eliminate need for unsupervised time-integrated sampling.
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.

- Continuous analyzers
  - Real-time monitoring

- Pressure Measurements
  - Can help interpret indoor air results

Refer to ASTM E2600-08 Table X.1 for summary table

There are some other inexpensive tools/data that can be applied to better evaluate some of the default model parameters and the vapor intrusion pathway. These tools/data have much more influence on the resulting risk than measurement of soil porosity and cost about the same.

Radon can be used to determine a site-specific alpha that may be 10 to 100 times lower than the default alpha allowed.

Tracers can be used to measure the room ventilation rates and may give values 2 to 10 times higher than the default value, especially for commercial sites.

Automated continuous analyzers exist that can provide large amounts of data at low cost with remote monitoring via the internet.

Pressure measurements can be helpful when interpreting indoor air data.
Issues of Contention

- Spatial Variability
- Repeated Sampling?
- Sub-slab vs. Near-slab Samples
- Bioattenuation (& How to Account for it)

Issues currently being debated.
Spatial Variability – What to Do?

- Soil Gas Not Homogeneous
- Spatial & Vertical Variations Exist
- Don’t Chase 1 pt Anomalies
- Get Enough Data Near/Around/Under
- On-site Analysis Enables Real-Time Decisions

Soil gas, like soil, is not homogenous in most cases. So you need enough data to give decent coverage near, around, or under the receptor. Simpler collection systems with small volumes are advantageous as there is less to go wrong and enable higher production per day (20+ samples per day). Less expensive analytical methods (8021, 8260) enable more analyses for reasonable cost. Real-time data can be extremely helpful to track soil gas contamination laterally and vertically.
How Often to Sample?

- Depth Below Surface
  - 3’ to 5’ bgs generally considered stable
  - Temporal Studies Ongoing
- Seasonal Effects – How Important?
  - Most studies show less than 5x
- Extreme Conditions?
  - Heavy rain
  - Extreme heating/cooling

The closer to the surface, the more the potential temporal variation. Depths of 3’ to 5’ below the surface are generally considered deep enough to get repeatable data and resampling is not required by most agencies.

Historical radon data around houses show variations less than a factor of 10 in cold climates. Recent VOC data from Endicott show soil gas variations less than a factor of 4 over 15 months. Larger variations may be likely in areas of extreme temperature variation (northern climates), during heavy periods of precipitation, and when the structure’s heating or ventilation systems are operative.

In general, if the soil gas concentrations are below allowed levels by a factor of 10, there should be no need to repeat sampling.

If conditions suggest that temporal variations may be significant and if the measured values are close to the fail level, then repeated sampling may be appropriate and vapor implants are a good approach.
Soil Gas Temporal Study

This is an enlargement of the data from three probes at the same location but at different depth (3’, 8, & 17’ bgs). This plot consists of over 600 points per probe collected once per hour over a 4 week period from mid March to mid April 2007. The soil gas concentrations varied by less than 10% over these four days even for probes only 3 feet below the surface in a highly permeability sand lithology (sand dune). These data suggest that soil gas data are not affected by typical meteorological variations.
A study funded by Chevron Corp examined the effect of meteorological parameters on soil gas concentrations at a hydrocarbon contaminated site in Wyoming. There was no clear correlation between most of the meteorological parameters and soil gas concentrations.

Three similar studies funded by EPA-ORD (NERL) at Vandenberg AFB in spring 2007 & LeMoore Naval Station in 2008 & 2009 showed similar results.

Slide courtesy of Paul Johnson, ASU and Chevron Corp.
Sub-Slab vs. Near-Slab Samples?

Are sub-slab samples the best to collect?
Sub-Slab vs. Near-Slab

- Some States Require (NY, NJ)
- Very Intrusive; Legal Complications
- HCs: If O₂ High, Near-slab OK
- Cl-HC: Deeper (>7’) exterior data appears to reflect sub-slab conc.

The draft EPA OSWER VI guidance advocates sub-slab samples and some State agencies agree. Some are fearful that the contaminants build-up under the slab (“ponding effect”). But, sub-slab sampling is intrusive and often leads to legal complications. By Fick’s law, the sub-slab concentration can be no higher than the source concentration, so if the source is below, collection of exterior soil gas samples at the source depth or at some depth closer to the source will give useful data and not create as many legal headaches.

If high oxygen levels exist all around the slab at a shallow depth, and the slab small, it is likely that bioattenuation under the slab is occurring and shallow soil gas will be representative of sub-slab soil gas.
Practical Strategies
(Things to Do)

- Get Enough Data
- Consider Less Expensive Methods (8021, 8260)
- CL-HCs: Vertical Profiles Around Structure
- HCs: Oxygen Profiles Around Structure
- Use Radon for Slab-Specific Alpha
- Measure Ventilation Rate
- Have Competent Subs
- Check Your Units!

These are things you want to do/allow to practically and cost effectively assess this risk pathway.
Previews of the VI Future

• VI Likely to be a Concern at Your Sites
• Variable Regulatory Guidance Makes Assessment Tricky & Slow
• ASTM Standard Increase # of Sites
• New EPA OSWER Guidance to be Stricter
• Hydrocarbons to be Less of a Concern

Here are some predictions & previews of the vapor intrusion pathway for the next few years.
Want to Know More?

• ITRC 2-day VI Training 2011
  – January 20 & 21: San Antonio
  – April: NJ
  – June: Detroit
  – Oct: Denver
• EPA VI Workshop – AEHS San Diego 3/2011
• HC VI Workshop – AEHS San Diego 3/2011
• Battelle Conf – Reno, June 2011

Upcoming vapor intrusion training.
Existing Documents & Training

• Soil Gas Sampling SOPs
  – Soil Gas Sampling, Sub-slab Sampling, Vapor Monitoring Wells/Implants, Flux Chambers (www.handpmg.com)

• Other
  – ITRC VI Guidance (www.itrcweb.org)
  – API Soil Gas Document (api.org)
  – ASTM E2600-08: Good Summary Table in App X

More documents.
VI Documents

• Overview of SV Methods (www.handpmg.com)
  – LustLine Part 1 - Active Soil Gas Method, 2002
  – LustLine Part 2 - Flux Chamber Method, 2003
  – LustLine Part 3 - FAQs October, 2004
  – LustLine Part 4 – Soil Gas Updates, Sept 2006
  – LustLine – VI For Petroleum Hydrocarbons, Nov 2010

• Robin Davis’ Articles on Bioattenuation:
  – Lustline #61 May 2009
  – LustLine #52 May 2006 (www.neiwpcc.org)

A summary of some existing documents.
VI Websites & Links

- www.handpmg.com
  - Soil Gas Information
  - Other Site Assessment Methods
- www.itrcweb.org
- www.api.org
- EPA-OSWER’s New VI Site:
  http://www.epa.gov/oswer/vaporintrusion/