Vapor Intrusion Risk Pathway: Overview & Assessment Methods

EPA Region 3 LUST Technical Work Shop

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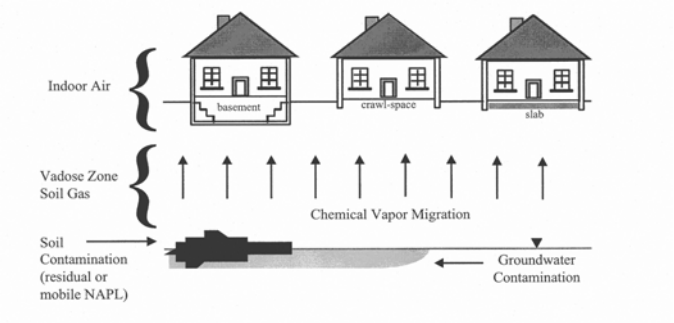
Blayne Hartman
Hartman Environmental Geoscience
H&P Mobile Geochemistry
858-925-7206
www.handpmg.com

This presentation is an overview of 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 May 2007, this training has been given to over 30 State Regulatory agencies, including ASTSWMO and the State Coalition of Dry Cleaners. Training has also been given to many PRPs such as the major oil companies, Armed Services, & EPRI.

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.

What Is Vapor Intrusion?



Key Assumptions:

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

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

Key assumptions 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.

Why Do You Care About VI?

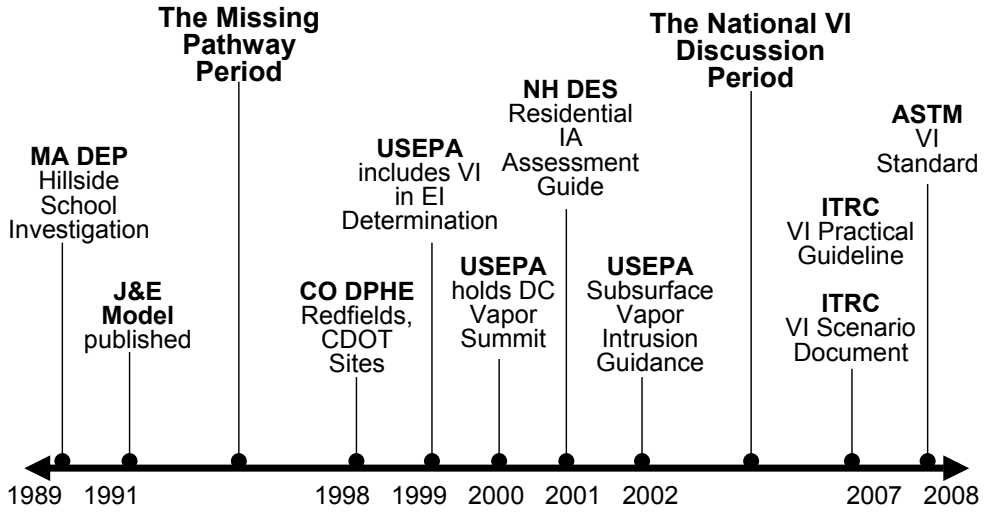
(Risk Often More Perceived Than Real)

- Health & Safety of Occupants
- EPA, ITRC, & State Guidances
- ASTM New Phase 1 Standard
- Attorneys & Citizen Groups
- Future Liability

In some cases, there is a real threat to occupants.

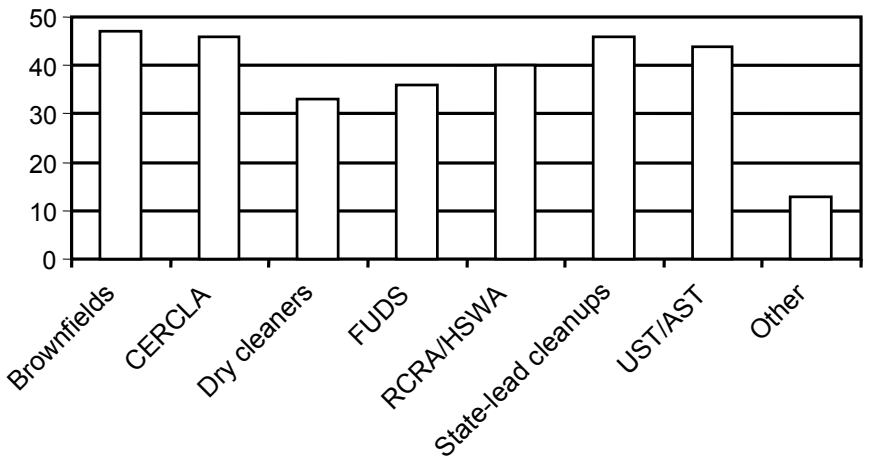
But in the majority of cases, the risk to occupants is exaggerated, hence the perception is greater than the real risk. Nevertheless, you need to worry about it because the EPA has identified it as a risk pathway, numerous states have their own guidance or policies, and citizen groups and of course, attorneys are making it an issue.

Historical Perspective



Concerns over vapor intrusion started circa 1990, but didn't really explode into a national concern until ~2000 with the Colorado CDOT & Redfield sites. The EPA wrote their draft guidance in 2002.
From 2002 to 2007 – lot's of discussion, but no guidance. Since 2007, individual States start filling in the lack of national guidance

VI Impact on Regulatory Programs



A survey of the States by ITRC in 2006 showed that concerns over vapor intrusion cuts across all regulatory programs:

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CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act (aka Superfund)

FUDS = Formerly Used Defense Sites

RCRA = Resource Conservation & Recovery Act

UST/AST = Underground Storage Tank / Aboveground Storage Tank

Review of VI Guidances

- EPA OSWER
- ITRC Guidance
- ASTM

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.

EPA-OSWER Draft Guidance

- Tier 1: **Primary** Screening
  - Q1: VOCs present?
  - Q2: Near buildings?
  - Q3: Immediate concern?
- Tier 2: Secondary Screening
  - Q4: Generic screening
  - Q5: Semi-site specific screening (alphas from charts & tables)
- Tier 3: Site-Specific Pathway Assessment
  - Q6: Indoor air (and/or subslab)

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 fail levels) that just about every site fails, 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.

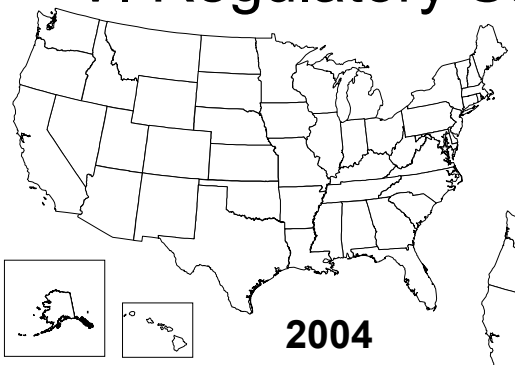
Tier 3, question 6, allows for only two investigatory methods, indoor air or sub-slab soil gas, and has very restrictive (i.e., very low fail levels) criteria. Once at this level, it is extremely hard to get out and requires expensive and repeated sampling.

Newest Changes (2009?)
EPA OSWER VI Guidance

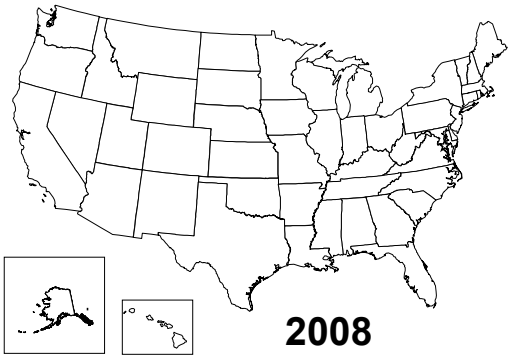
- Tier 1: **Primary** Screening
  - Q1: VOCs present?
  - Q2: Near buildings?
  - Q3: Immediate concern?
- Tier 2: Source Screening
  - Generic screening using near-source samples
- Tier 3: Pathway (Building) Assessment
  - Multiple lines of evidence (sg & gw)
  - Must go inside???

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.

VI Regulatory State Guidance



2004



2008

As of 2008, 24 states have VI guidance.

ITRC VI GUIDANCE

- Practical How-to Guide
- Stepwise Approach
- Investigatory Tools (Toolkit)
- Thorough Discussion of Mitigation
- Scenarios
- Classroom Training in 2008

ITRC has recently finished it's vapor intrusion guidance document. It consists of 2 documents: A practical guideline and a separate scenarios document. Internet training began in 2007. Classroom training started in 2008.

ASTM VI Standard

- Focus on Property Transactions
- Prescriptive Screening Distances
- No RBSLs (RBC)
- No Assessment Recommendations
- Legal Standards
- Mitigation
- Released March 3, 2008

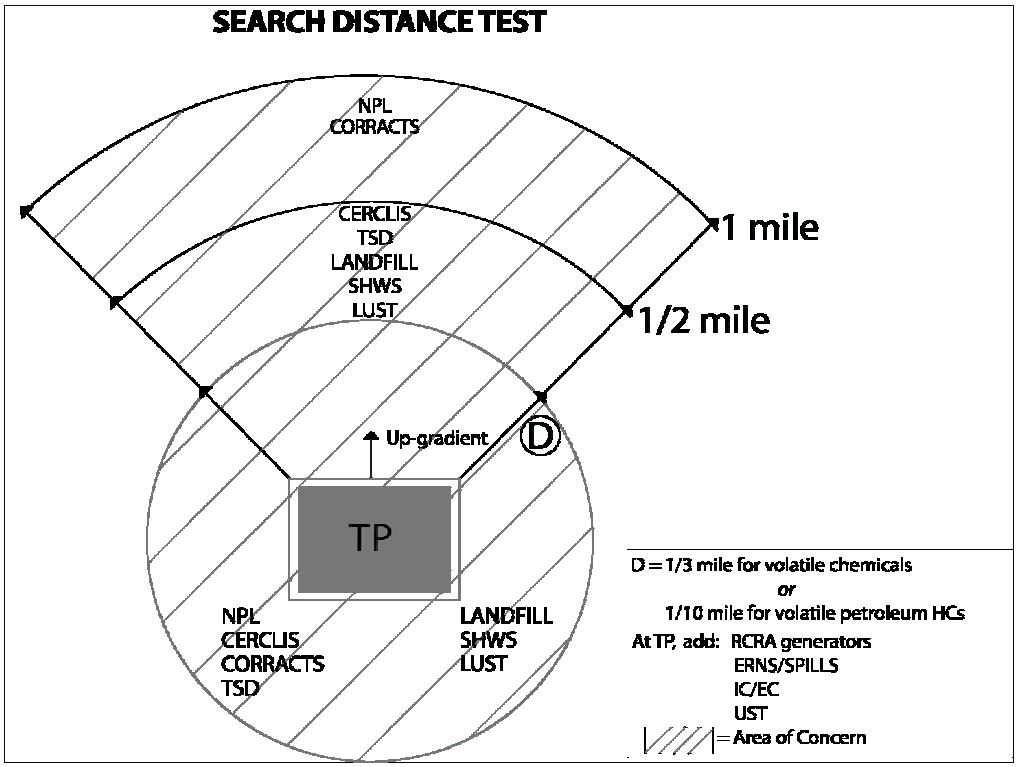
ASTM convened a technical workgroup in 2005 to write a standard for vapor intrusion as it applies to property transactions. The standard was released on March 3, 2008.

ASTM VI Standard

Vapor Intrusion Condition (VIC) *is defined as* ***"****the presence or likely presence of any volatile chemical of concern in existing or planned structures on a property resulting from an existing release or a past release from contaminated soil or groundwater on the property or within close proximity to the property,* ***at a concentration that presents or may present a human health risk****."*

The Standard defines a new term/arconym: the Vapor Intrusion Condition.

Slide courtesy of Anthony Buonicore, Chairman ASTM VI Task Group



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

- Range of Regulatory Approaches:
  - USEPA: 2002 Guidance not recommended for UST sites
  - ASTM – Critical distance reduced from 100’ to 30’
  - Some regulatory agencies include a 10X biodegradation factor
  - ITRC: Use vertical profile to demonstrate
- Evidence 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 simpoly 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

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.

Ingredients for Effective VI Assessments

- Investigatory Approach
- Determine Correct Screening Levels
- Sample & Analyze Properly
- Know & Use Supplemental Tools
- Demonstrating Bioattenuation

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.

Some Key VI Assessment Issues

- 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
  - Laborious Protocols, no control
  - 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).

Indoor Air

Consumer Products Containing PCE

Product	PCE Concentration
ARAMCO Art and Crafts Goop	Not Specified
Aleenes Patio & Garden Adhesive	70%
Gumout Brake Cleaner	50 - 90%
Liquid Wrench Lubricant w/ Teflon	65 - 80%
Plumbers Goop Adhesive	67.5%
Hagerty Silversmith Spray Polish	30.5%
Champion Spot it Gone	20 - 25%

KEY POINT: **Wide variety of consumer products still contain high concentrations of PCE.**

Contaninants in indoor air may be from household products, not vapor intrusion.

Slide courtesy of Dr. Tom McHugh, GSI, Houston, TX

Groundwater Data

- Preexisting Data Often Exist
  - Over proper well screen interval?
  - Coverage typically limited; interpolation
- Gather New Data
  - Well location, construction, sampling
- Perched/clean water layer?
- Likely Will Over-Predict VI Risk

At many sites, groundwater data already exist. But, it may not be from a well screened across the interface. Plus, coverage often is limited so you have to interpolate the data.

Some States prefer groundwater data. Or if groundwater is very shallow, it may be the only option. If you are going to collect new groundwater data, be sure that the well locations and construction are correct.

Also, be sure that you aren't sampling perched water infiltrating from the surface.

Soil Phase Data

- Soil Data Generally Not Acceptable in VI Assessment
- Existing Soil Data – Line of Evidence
  - Can "screen in" sites
  - Cannot be used alone to "screen out" sites
- Convert to Soil Gas Concentrations
  - Partitioning equations exist. Likely overestimate.

Soil phase data are generally not acceptable for VI investigations by most States. This is because equilibrium partitioning is rarely achieved so it is difficult to predict soil vapor concentrations from soil phase data, and hence in turn, the vapor intrusion risk.

- Soil data can be used to "screen in" sites, but cannot be used alone to "screen out" sites

- Soil data may have elevated reporting limits or volatilization losses, therefore non detect (ND) in soil does not mean "no potential for VI"

- One can convert soil data to soil gas concentrations using partitioning equations. This result provides an estimate of the soil gas concentration in the vadose zone.

Modeling

- Pros:
  - Can Use GW, Soil (?), Soil Gas Data
  - Relatively Easy
- Cons:
  - Not All States Allow
  - Which Version to Use?
  - Often Too Restrictive

The use of models to calculate an indoor air concentration, and in turn a health risk, is commonplace. Existing models use groundwater, soil, or soil gas data and are relatively easy to use. In general, if default parameters are used, they tend to over calculate the risk for most situations.

Several versions currently exist with different default values for various parameters, so one must be careful to know what version they are using. Regulators must be careful with using modeling results for a number of reasons, one being that it is easy to try and change the values of some of the variables to get a passing value. As a result, some States will let you use the models as a screening tool, but not give complete closure.

Modeling

- Johnson-Ettinger Most Common
  - GW, soil, soil gas spreadsheets
  - Screen & advanced versions
- Variables You Can Change
  - GW or soil gas concentration
  - Soil type & diffusivity
  - Ventilation rate
  - Exposure time
  - Building size

Soil Gas Measurement

- Pros:
  - Representative of Subsurface Processes
  - Higher Fail Levels
  - Relatively Inexpensive
  - Can Give Real-time Results
- Cons:
  - Mass Transfer Coefficient Unknown
  - Spatial Variability
  - Protocols still debated

Measurement of soil gas is by far the most preferred 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 fail 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.

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.

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.

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. More discussion on these methods follows.

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.

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

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.

Real-time analyzers can be used to locate problem houses, preferential pathways into structures, or sort out background scatter. Pressure measurements are helpful with indoor air data to possibly show a background source.

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

Automated continuous analyzers exist that run unattended enabling analysis around the clock. They can sample from multiple rooms or probes and can send data over the internet in real time. Both gas chromatographs (GC) running 8021 and mass spectrometer (GC/MS) instruments running TO-15 are currently available.

Issues of Contention

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

Issues currently being debated.

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

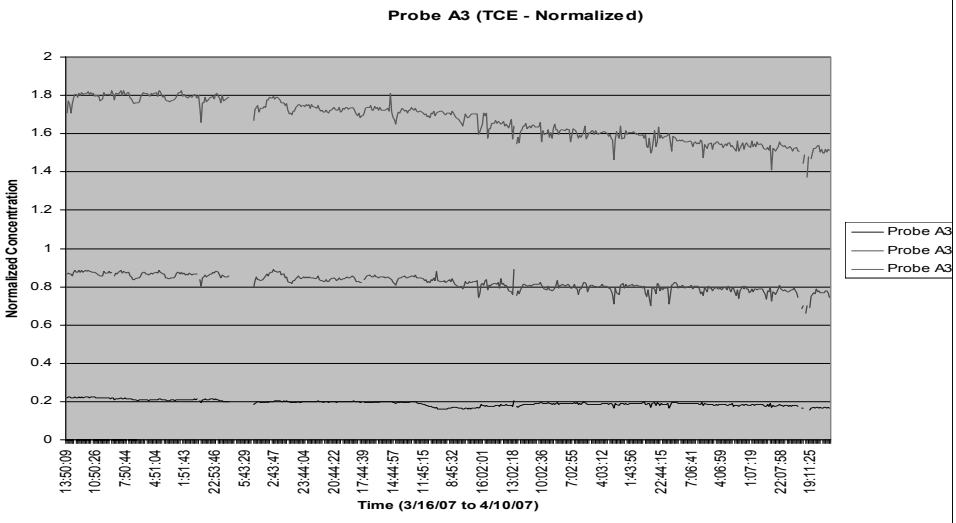
The closer to the surface, the more the potential temporal variation. Depths of 3’ to 5’ below the surface are generally considered deep enough to get repeatable data and resampling is not required by most agencies.

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.

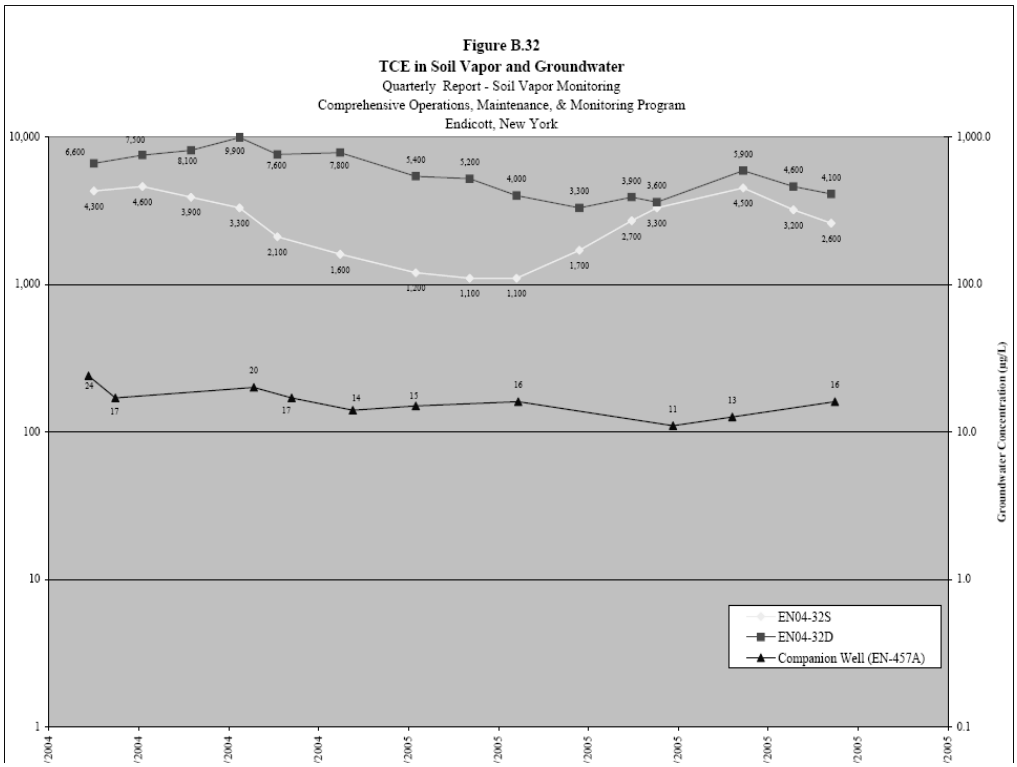
In general, if the soil gas concentrations are below allowed levels by a factor of 10, there should be no need to repeat sampling.

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



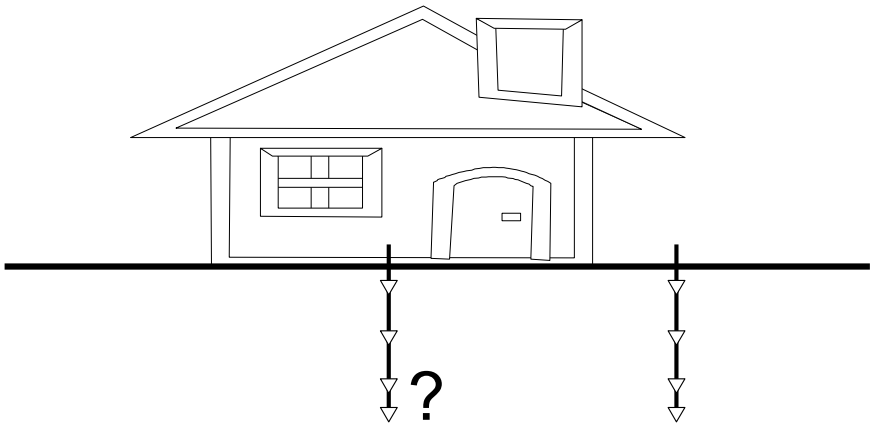
This is an enlargement of the data from three probes at the same location but at different depth (3', 8, & 17' bgs). This plot consists of over 600 points per probe collected once per hour over a 4 week period from mid March to mid April 2007. The soil gas concentrations varied by less than 10% over 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 meteological variations.



Recent data collected over 15 months from Endicott NY show very low variations in deep soil gas (max variation less than factor of 2) and sub-slab soil gas concentrations (max variation less than factor of 4). Hence, in most cases, it is not necessary to collect samples more than once.

Slide courtesy of Dr. William Wertz, NY-DEC

Sub-Slab vs. Near-Slab Samples?

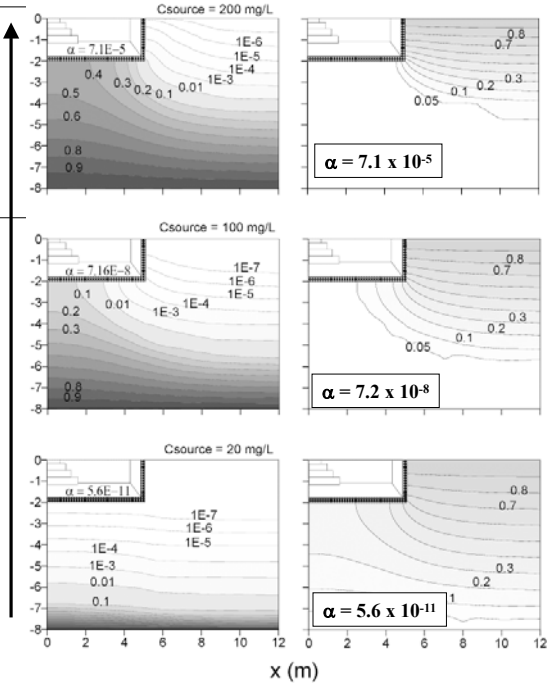


Are sub-slab samples the best to collect?

Effect of Source Concentration

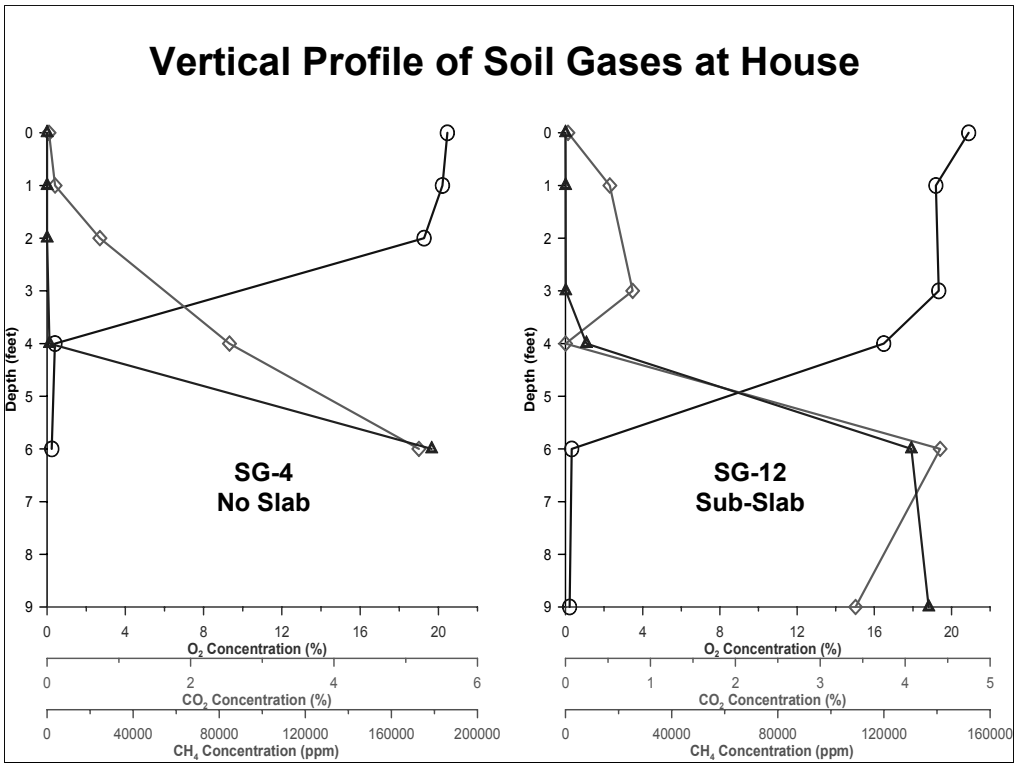
[$\lambda = 0.18\ h^{-1}$]

Results suggest that there may be source vapor concentrations that are of little concern if soil gas beneath the foundation is well-oxygenated (e.g., groundwater plume sources)



Recent modeling by Dr. Lilian Abreau (Geosyntec Consultants) has shown that for hydrocarbons sources in the soil vapor less than 20 mg/L, there is unlikely to be any vapor intrusion risk. The benzene vapor concentration in equilibrium with gasoline is only 7.8 mg/L and data from 100 sites show maximum benzene vapor concentrations of less than 1 mg/l! So, unless the source very close to the receptor, there is no need to worry.

Slide courtesy of Dr. Lilian Abreau



A study comparing exterior soil gas values to sub-slab soil gas values under a single story residence showed no differences in the profiles, presumably due to bioattenuation.

Slide courtesy of Todd Ririe, BP/Arco.

Bioattenuation of HCs

- Existing data suggest O_2 effective barrier
- Attenuation > 10,000 times
- Vertical profiles of COC & O_2
- How to Account for it?

A vast number of studies have been performed clearly demonstrating that the bioattenuation of hydrocarbon vapors occurs in aerobic soils. In general, the studies show that when oxygen levels are 10% or greater (a published study by NJDEP suggested oxygen levels as low as 6% are sufficient), and a couple feet of vadose zone exist between the source and receptor, that the hydrocarbons aren't escaping into the receptor. Attenuation factors can be as high as 10,000 times (alpha = 0.0001).

Documention that this process is occurring is done by collecting vertical profiles of the soil gas for the hydrocarbons, oxygen, and carbon dioxide. If shown to occur, many agencies are conservatively allowing a factor of 10 to 100 reduction in the alpha factor.

Effect of Vapor Source Concentration and Depth

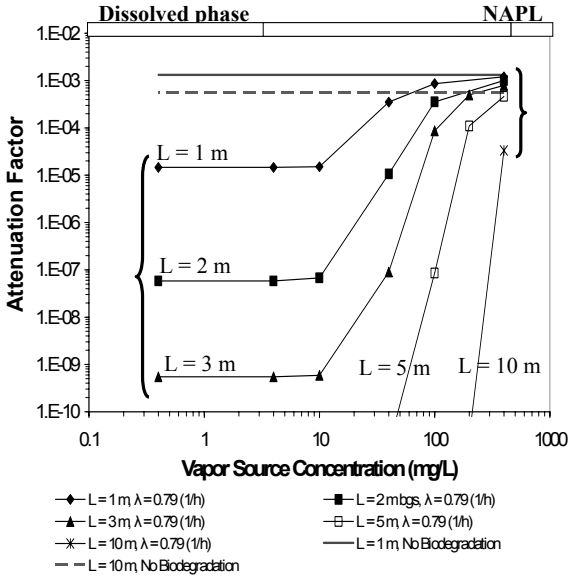
Modeling Assumptions:

- **Benzene source**
- **Sand soil**
- **Basement scenario**
- **$\lambda = 0.79\ h^{-1}$**

Biodegradation is likely to have a significant effect on α for non-NAPL sources

For NAPL sources, effect of biodegradation on α may be minimal due to oxygen depletion

L: source-foundation distance



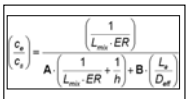
The end result of the recent modeling by Dr. Lilian Abreau (Geosyntec Consultants) is that one can now estimate the bioattenuation attenuation factor based upon depth to source and source strength. Note that for all concentrations below 10,000 ug/L, the attenuation factor is no higher than 1e-5. This is 4 orders of magnitude lower than the EPA VI guidance default value! Unless the source is within 3 feet of the receptor, the attenuation factor never exceeds 1e-3, still 2 orders of magnitude lower than the EPA default value.

Slide courtesy of Dr. Lilian Abreau, Geosyntec Consultants, and API.

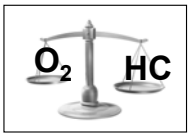
Conceptual Model

What is BioVapor?

1-D Analytical Model	**Version of Johnson & Ettinger vapor intrusion model modified to include aerobic biodegradation (DeVaull, 2007).**
Oxygen Mass Balance	**Uses iterative calculation method to account for limited availability of oxygen in vadose zone.**
User-Friendly	**Simple interface intended to facilitate use by wide range of environmental professionals.**



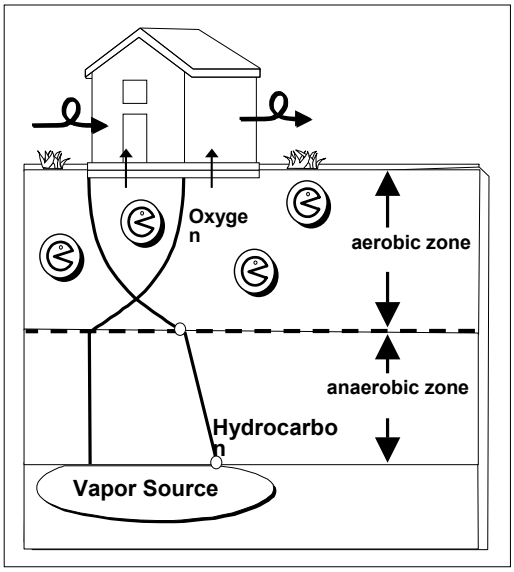
SIMPLE MATH



KEY POINT:	**Free, easy-to-use vapor intrusion model that accounts for oxygen-limited aerobic vapor intrusion.**

API has developed a new spreadsheet based upon the J-E model which includes bioattenuation. The spreadsheet is now being beta tested and is due to be released for free this summer.

BioVapor – API 1-D Steady State VI Model



3. **Advection, diffusion, and dilution through building foundation**

2. **Diffusion & 1st order biodegradation in aerobic zone**

1. **Diffusion only in anaerobic zone**

Algebra Solution for:

Oxygen demand = Oxygen Supply

Conceptual model of the API Biovapor model/spreadsheet

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 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?

- Indy Risk Conference, Nov 2009
- ITRC half-day VI Training, New Orleans, November 17 (Brownfields Conf)
- ITRC 2-day VI Training - 2010

Upcoming vapor intrusion conferences & training

VI Sampling 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 – More Q&A, Summer 2006
- Regulatory Guidance
  - ITRC toolkit (www.itrcweb.org)
  - CA/DTSC soil gas sampling guidance revised 8/08

A summary of existing documents on soil gas methods can be found at these locations:

VI Websites & Links

- www.handpmg.com
  - Soil Gas Information
  - Other Site Assessment Methods
- www.itrcweb.org
- www.api.org
- http:iavi.rti.org

Useful vapor intrusion websites.

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ENVIRONMENTAL GEOSCIENCE

Blayne Hartman
Hartman Environmental Geoscience
H&P Mobile Geochemistry
858-925-7206
www.handpmg.com

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