

# **Vapor Intrusion Training Part 2 – Updates & Exercises**

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This presentation is a follow-up to the vapor intrusion training given to COP PMs and consultants.

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.

# Training Overview

- Review of Some Basics & Key Issues
- Update of New EPA & Local Guidances
- Assessment Methods
- Using the DTSC J-E Spreadsheets
- Q&A to COP Issues
- Discussion of Typical Service Station Scenario
- COP Case Histories

This training consists of updates & developments in vapor intrusion since the last training, review of some of the key concepts and issues required to assess the vapor intrusion risk pathway, updates of the newest Federal and State vapor intrusion guidances, with special emphasis on local regulations, working with the J-E spreadsheets, questions and answers to issues raised by COP, and hands-on working of case histories.

# Basics & Key Issues

- Units
- Attenuation Factors
- Risk Based Screening Levels (RBSL & CHHSLs )

To properly conduct a vapor intrusion assessment, a few basics need to be understood.

## Units: 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. For groundwater, the correct answer is (a). Since most consultants are used to working with groundwater, this is the default answer in their minds.

# Attenuation (alpha) Factors

$$\alpha_{sg} = C_{indoor}/C_{sg}$$

$$\alpha_{gw} = C_{indoor}/(C_{gw} * H)$$

- Lower alpha means higher attenuation
- Current DTSC VI guidance  $\alpha_{sg}$ :
  - Existing Res: 0.002 for 5', 0.01 sub-slab
  - Future Res: 0.0009 for 5', 0.01 sub-slab??
  - Existing Comm: 0.001 for 5', 0.005 sub-slab
  - Future Comm: 0.0004 for 5', 0.005 sub-slab?

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 DTSC guidance uses alpha factors at the step 5 level as a screening step. Using alpha factors is LESS stringent than CHHSLs. DTSC has a variety of allowable alpha factors depending upon the type of structure (residential vs. commercial) and whether it is an existing or future building.

# Using Alpha Factors to Calculate Screening Levels

For Soil Gas:

$$C_{sg} = C_{indoor} / \alpha_{sg}$$

For Groundwater:

$$C_{gw} = C_{indoor} / (H * \alpha_{gw})$$

Example:  $C_{in}$  benzene = 0.084 ug/m<sup>3</sup>

$$C_{sg} (5') = 0.084 / 0.002 = 42 \text{ ug/m}^3$$

$$C_{gw} = 0.084 / (0.20 * 0.0005) = 0.84 \text{ ug/L}$$

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

This is the method the EPA & DTSC guidance uses to determine acceptable levels in the soil gas or groundwater.

## What Risk Level?

- 1 in 1 million: Residences, Schools, Hosp
- 1 in 100,000: Commercial Settings (cumulative)
- 1 in 10,000: Acute (mitigate immediately & in some states evacuate premises)

The allowable concentrations in indoor air, and hence in the vadose zone, depend upon the risk level and exposure time. Different agencies use different risk levels.

# Commercial Settings

A target, cumulative excess cancer risk of  $10^{-5}$  and noncancer Hazard Quotient of 1.0 is acceptable provided that a thorough investigation of the site has been completed and all potential contaminants of concern identified. A higher cumulative risk (not to exceed  $10^{-4}$ ) and noncancer Hazard Index (DTSC vapor intrusion guidance lists an upper limit of 3.0). could be acceptable under some circumstances, including background (e.g., arsenic), feasibility of cleanup and the type of contaminant involved.

See also Appendix 1, Section 3.2 of the ESL document:

For carcinogens, the human health screening levels presented are based on a target excess cancer risk of  $10^{-6}$ . This represents the upper end (most stringent) of the potentially acceptable range of  $10^{-4}$  to  $10^{-6}$  recommended by the USEPA (USEPA 1989a,b). As stated in the National Contingency Plan, however, "The  $10^{-6}$  level shall be used as the point of departure for determining remediation goals..." (USEPA 1994). Remediation or risk management is rarely warranted at sites where the estimated cancer risk does not exceed  $10^{-6}$ . Remediation or risk management is almost always warranted at sites where the estimated cancer risk exceeds  $10^{-4}$ . For sites where the estimated risk is between  $10^{-4}$  and  $10^{-6}$ , the need for active remediation or risk management is evaluated on a site-specific basis (i.e., risks within this range are "potentially acceptable", depending on site-specific considerations).

This top text (from a regulatory risk assessor) addresses what risk level is applicable for commercial facilities.

The bottom text excerpted from the San Francisco Water Board risk document addresses the issue of applicable risk ranges.

# Beware The CHHSLs

## How do the CHHSLs differ from cleanup standards?

**The CHHSLs presented in the lookup tables are NOT regulatory "cleanup standards".** Use of the CHHSLs and this document is voluntary on the part of those who choose to use them. At sites where cleanup of contaminated soils to levels at or below the CHHSLs would be costly, the time and effort to develop more site-specific cleanup may be desired. At sites where the extent of contaminated soil is limited or the timeframe available to carry out cleanup actions is very short, use of the CHHSLs as final soil cleanup standards may be cost-beneficial. However, this would require the concurrence of both the responsible party and the overseeing regulatory agency and can only be done after a full evaluation of site conditions and other potential environmental concerns. Regulatory agencies cannot be compelled to use the CHHSLs as final cleanup standards for a contaminated property.

The California Human Health Screening Levels (CHHSLs) were developed by a branch of CA-EPA (OEHHA) using the Johnson-Ettinger model. They are NOT regulatory cleanup standards and they are to be used voluntarily unless BOTH parties concur to use them.

Table 2. California Human Health Screening Levels for Indoor Air and Soil Gas

Chemical	<sup>1</sup> Indoor Air Human Health Screening Levels (µg/m <sup>3</sup> )		<sup>2</sup> Shallow Soil Gas Human Health Screening Levels (Vapor Intrusion) (µg/m <sup>3</sup> )	
	Residential Land Use	Commercial/Industrial Land Use Only	Residential Land Use	Commercial/Industrial Land Use Only
Benzene	8.40 E-02	1.41 E-01	3.62 E+01	1.22 E+02
Carbon Tetrachloride	5.79 E-02	9.73 E-02	2.51 E+01	8.46 E+01
1,2-Dichloroethane	1.16 E-01	1.95 E-01	4.96 E+01	1.67 E+02
<i>cis</i> -1,2-Dichloroethylene	3.65 E+01	5.11 E+01	1.59 E+04	4.44 E+04
<i>trans</i> -1,2-Dichloroethylene	7.30 E+01	1.02 E+02	3.19 E+04	8.87 E+04
Ethylbenzene	Postponed <sup>3</sup>	Postponed <sup>3</sup>	Postponed <sup>3</sup>	Postponed <sup>3</sup>
Mercury, elemental	9.40 E-02	1.31 E-01	4.45 E+01	1.25 E+02
Methyl tert-Butyl Ether	9.35 E+00	1.57 E+01	4.00 E+03	1.34 E+04
Naphthalene	7.20 E-02	1.20 E-01	3.19 E+01	1.06 E+02
Tetrachloroethylene	4.12 E-01	6.93 E-01	1.80 E+02	6.03 E+02
Tetraethyl Lead	3.65 E-04	5.11 E-04	2.06 E-01	5.78 E-01
Toluene	3.13 E+02	4.38 E+02	1.35 E+05	3.78 E+05
1,1,1-Trichloroethane	2.29 E+03	3.21 E+03	9.91 E+05	2.79 E+06
Trichloroethylene	1.22 E+00	2.04 E+00	5.28 E+02	1.77 E+03
Vinyl Chloride	3.11 E-02	5.24 E-02	1.33 E+01	4.48 E+01
<i>m</i> -Xylene	7.30 E+02	1.02 E+03	3.19 E+05	8.87 E+05
<i>o</i> -Xylene	7.30 E+02	1.02 E+03	3.15 E+05 <sup>4</sup>	8.79 E+05 <sup>4</sup>
<i>p</i> -Xylene	7.30 E+02	1.02 E+03	3.17 E+05	8.87 E+05

Reference: Appendix 1, OEHHA Target Indoor Air Concentrations and Soil-Gas Screening Numbers for Existing Buildings under Residential and Industrial/Commercial land uses.

Notes:

1. "Residential Land Use" screening levels generally considered adequate for other sensitive uses (e.g., day-care centers, hospitals, etc.). Commercial/industrial properties should be evaluated using both residential and commercial/industrial CHHSLs. A deed restriction that prohibits use of the property for sensitive purposes may be required at sites that are evaluated and/or remediated under a commercial/industrial land use scenario only.

Calculation of cumulative risk may be required at sites where multiple contaminants with similar health effects are present. Carcinogens: CHHSLs based on target cancer risk of 10<sup>-6</sup>. Cal/EPA cancer slope factors used when available.

Noncarcinogens: CHHSLs based on target hazard quotient of 1.0.

2. Soil Gas: Screening levels based on soil gas data collected <1.5 meters (five feet) below a building foundation or the ground surface. Intended for evaluation of potential vapor intrusion into buildings and subsequent impacts to indoor-air. Soil gas data should be collected and evaluated at all sites with significant areas of VOC-impacted soil. Screening levels also apply to sites that overlie plumes of VOC-impacted groundwater.

3. Calculation of a screening number for the chemical has been postponed (pp) until the toxicity criterion currently being developed by OEHHA is published as a final document.

4. Representative Screening Numbers for mixed xylenes. The representative value for mixed xylenes is based on the calculated lowest one amongst the three isomers.

The infamous CHHSLs. Note, soil gas values are for 5' deep soil gas samples, not for sub-slab samples.

## Reasonable Exposure Times? (Benzene 1e-6 risk, 5' deep SG sample)

Agency	Residential	Workplace	Ratio
OEHHA	36	61*	1.7
DTSC	42	84	2
SF ESLs	85	145*	1.7

All units ug/m3     \* Corrected for ventilation rate

Ratio Should be  $(24/8) * (350/250) * (30/25) = 5.0$

This table gives a summary of the ratio of the allowed soil gas value for benzene for workplace vs. residential settings for three California agencies published RBSLs. The OEHHA & SF ESL values have been reduced by a factor of two to take out the effect of the different ventilation rate between residential and commercial settings that is incorporated in their tabulated values. The ratio assuming workplace exposure times of 8 hours/day, 250 days/year, for 25 years should be 5. The agency values are about 2.5 times too conservative.

## Screen-Out More Sites By:

- Adopting More Realistic Exposure Times
  - Workplace: 8 hrs/day, 250 days/yr, 25 yrs (5x)
  - School: 8 hrs/day, 180 days/yr, 6 yrs (30x)
  - Hospital: 24 hrs/day, 1 yr (30x)
- Adopt More Reasonable Distance Criteria
  - 100' Spatial for HCs Too Far Due to Bio
  - 100' Vertical for Cl Too Far
  - 5-10' Vertical for HC if O2 Present

More sites will be screened out if more realistic screening criteria are used such as more realistic exposure times, especially for schools and hospitals, and adopting more reasonable depth criteria. For State reimbursement funds, reasonable screening of sites will prevent draining the fund balances.

# Review of VI Guidances

- EPA OSWER
- California Agencies

In this part, we will briefly review the latest happenings with the EPA OSWER draft vapor intrusion guidance and the DTSC guidance.

# Overview of Proposed Changes

## EPA Draft VI Guidance

**Nov. 2002**

**Fall 2005**

<ul style="list-style-type: none"><li>• Tier 1: <b><u>Primary</u></b> Screening<ul style="list-style-type: none"><li>- Q1: VOCs present?</li><li>- Q2: Near buildings?</li><li>- Q3: Immediate concern?</li></ul></li><li>• Tier 2: <b><u>Secondary</u></b> Screening<ul style="list-style-type: none"><li>- Q4: Generic screening</li> <li>- Q5: Semi-site specific screening (alphas from charts &amp; tables)</li></ul></li><li>• Tier 3: Site-Specific Pathway Assessment<ul style="list-style-type: none"><li>- Q6: Indoor air (and/or subslab)</li></ul></li></ul>	<ul style="list-style-type: none"><li>• Tier 1: <b><u>Preliminary</u></b> Screening<ul style="list-style-type: none"><li>• Q1: VOCs present?<ul style="list-style-type: none"><li>- Q2: Near buildings?</li><li>- Q3: Immediate concern?</li></ul></li></ul></li><li>• Tier 2: <b><u>Generic</u></b> Screening<ul style="list-style-type: none"><li>- Q4: Generic residential and non-residential screening levels</li></ul></li><li>• Tier 3: <b><u>External Site-Specific</u></b> Screening<ul style="list-style-type: none"><li>- Q5: More site-specific parameters (alpha from spreadsheet)</li></ul></li><li>• <b><u>Tier 4: Internal</u></b> Site-Specific Assessment<ul style="list-style-type: none"><li>- Q6: Indoor air or subslab or both</li><li>- Multiple lines of evidence</li></ul></li></ul>
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In late 2005, the EPA proposed changes to the draft guidance that were supposed to go into effect in the first half of 2006. The same 6 questions exist, but they have been divided into 4 tiers instead of 3 tiers (Q4, Q5, & Q6 all get their own tier). This was primarily done to allow more flexibility under Q5. Q5 now allows more sampling options external to the structure and more freedom in using the J-E model before having to go inside. The changes were never implemented.

(Slide courtesy of Helen Dawson of EPA)

# VI Guidance - Further Changes Being Contemplated by Writers Group (*DRAFT!*)

## **Fall 2005**

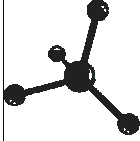
- **Tier 1: Preliminary Screening**
  - Q1: VOCs present?
  - Q2: Near buildings?
  - Q3: Immediate concern?
- **Tier 2: Generic Screening**
  - Q4: Generic residential and non-residential screening levels
- Tier 3: **Exterior Site-Specific Screening**
  - Q5: More site-specific parameters (alpha from **J&E model Spreadsheet- Includes Future Use and commercial settings**)
- **Tier 4: Interior Site-Specific Assessment**
  - Q6: Indoor air or subslab or both
  - Multiple lines of evidence

## **Summer 2006 DRAFT!**

- Tier 1: **Preliminary** Screening (site decision)
  - VOCs present?
  - Near buildings?
  - Immediate concern?
- Tier 2: **Source** Screening (site or subsite decision)
  - Generic residential (and non-residential) screening levels, applied to conservative (near-source) samples (existing or future buildings)
- Tier 3: **Pathway** Assessment (building decisions)
  - Worst-first assessment (inside out)
  - Multiple lines of evidence (pitchfork), including:
    - Near building soil gas and/or groundwater samples
    - Geological and/or biological attenuation
    - Constrained site-specific modeled attenuation, including future use and commercial settings
    - Interior (subslab, indoor air) sampling

In the summer of 2006, the EPA contemplated new changes based upon recent data from sites in Endicott NY and Stratford CT. The exterior site specific screening step will be much more conservative and require multiple lines of evidence. It will be much more difficult to get closure at this Tier. Tier 3 involves indoor assessment and will be much more intrusive and require more time. As of April 2007, these proposed revisions have yet to be implemented and are on indefinite hold.

Slide courtesy of Henry Schuver, USEPA.



# Northern CA Sites

## Agencies with Policy/Guidance:

- CA-DTSC (& LA-RWQCB)
  - Soil Gas & Vapor Intrusion “Advisory”
  - CHHSLs (thanks to OEHHA)
- EPA Region 9
  - Follows the EPA Draft VI Guidance
- SF-RWQCB
  - Has own ESLs (“fail levels”)
- Central Valley Boards
  - Want Residential Criteria Applied  
Regardless of Site Use

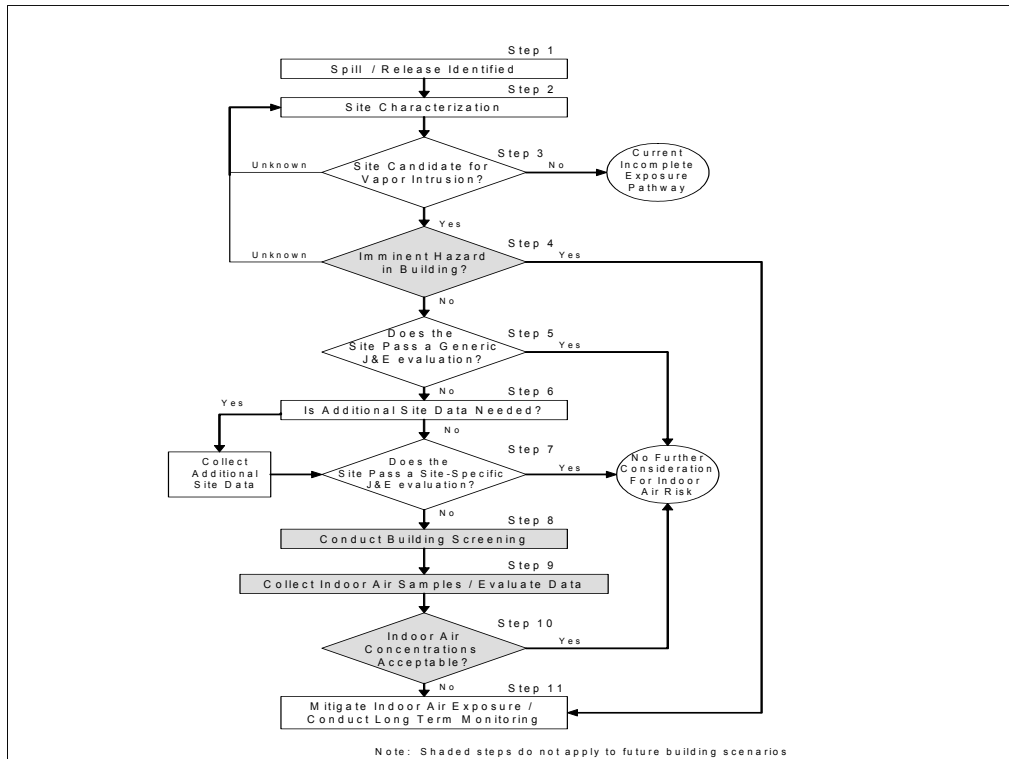


Here is a summary of the vapor intrusion policy/guidances for some California regulatory agencies. DTSC has soil gas collection & analytical guidance and has issued a vapor intrusion guidance document. The San Francisco Water Board has issued their own ESLs (fail levels). The Central Valley & some Bay 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.

# DTSC Guidance

- Step-Wise Approach (11 steps)
- Extensive COC List (VOCs & SVOCs)
  - Naphthalene, dioxane, PCBs, Pb
- Cumulative Risk
  - Drives DLs down to TO-15 levels
- OSHA PELs Given the Boot
- Indoor Air Sampling Very Labor Intensive

The DTSC Draft guidance (posted February 2005) consists of 11 steps. It has an extensive COC list including both VOCs and SVOCs. It requires cumulative risk (addition of risk from all sources and compounds) which in turn drives fail levels lower. In most cases, OSHA PELs do not apply. The indoor air sampling program is very labor intensive.



Here's the flow chart from the DTSC guidance, squeezed to one page.

## DTSC Step-Wise Approach

- Steps 1-4: Is Site VI Candidate?
  - Got Buildings? (If not now, in future?)
  - Got COCs?
  - Got Headaches?
- Step 5: Generic Risk: Alphas or CHHSLs
- Steps 6 & 7: Site Specific Risk Using J-E
  - Soil Gas Data Preferred. Near & Sub-slab.
- Steps 8-10: Indoor Air Sampling
- Step 11: Mitigate

A brief summary of the DTSC guidance goes like this:

Steps 1 through 4 evaluate whether vapor intrusion is a possible concern at a given site. Because the criteria are so conservative, these steps are more like a hopper than a filter, so nearly all sites are “in”.

Step 5 allows you to compare measured values to acceptable levels using DTSC determined alpha factors or tabulated CHHSLs. You must also use the maximum concentration found on the site.

Steps 6 & 7 allow use of the DTSC version of the J-E model to determine whether you pass or fail. You may use an average of the measured data and you have some freedom to change some of the default model parameters. Soil gas data are the preferred type.

Steps 8 through 10 are for indoor air sampling programs and Step 11 describes mitigation.

## DTSC VI Guidance “Issues”

- If GW Contamination, Also Do GW
- Soil Data Not Preferred
  - 5035 required if & when done
- Soil Gas Data from 2 Depths
- 1 Sample per  $\frac{1}{4}$  Acre, 100' Clean Zone
- TO-15 NOT Required
- Passive & Flux Chambers Qualitative
- Bioattenuation “Recognized”
- Finite Source Model Allowed

Some issues in the DTSC guidance that you need to be familiar with when writing a work scope:

\*If groundwater is the contaminant source, you must determine risk from both the soil gas and groundwater, ie., you must measure both.

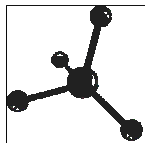
\*If soil gas data can not be obtained, soil phase data can be used but only if analyzed by method 5035.

\*Soil gas data must be collected at 2 depths at a density of 1 sample per quarter acre.

\*Passive soil gas and flux chambers are not considered to give quantitative results and can't be used alone for closure.

\*The document acknowledges that bioattenuation occurs and how to demonstrate it (using vertical profiles), but there is no provision for how to use the data. Flux chambers may be a way to support the bioattenuation argument.

\*The agency allows a finite source model to be used if the contamination zone will be defined. Since all risk calculations assume 20 to 30 year exposure times, this could be a very useful approach to reduce exposure times, and hence decrease the risk.



# Acceptable Soil Gas Levels

(Benzene 1e-6 risk, residential, 5' bgs)

State	Alpha	1/Alpha	Fail Level (ug/m <sup>3</sup> )
CHHSLs			37
DTSC – S5	0.002	500	42
DTSC – S6	Model	1000	95
EPA Q5	0.002	500	155
SD-DEH	Model	11,000	900



This table gives a summary of the acceptable soil gas level (the “fail level”) for a 5 foot deep soil gas sample for different agencies. Note the large difference in the fail levels based upon the agency.

The DTSC – S5 refers to Step 5 in their guidance where a default alpha is used. The DTSC – S6 refers to step 6 where a DTSC custom version of the J-E model is allowed.

San Diego County is likely to “close the gap” in their guidance within the next year.

NJ only allows outside soil gas if no buildings exist and they use a sub-slab alpha. This is so restrictive that soil gas sampling likely not a good alternative especially for non-biodegradable compounds.

# Updates on Assessment Methods

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

Updates on the common assessment methods.

# Indoor Air Measurement

- Mobile TO-15 Now Possible
  - Allows real-time screening of houses
  - Work from inside out?
  - Reduces hardware blanks
  - Can get multiple analyses per day
  - Automated mode possible (run around clock)
  - Are temporal variations significant?

The biggest advance in indoor air measurement is that TO-15 analysis can now be done on-site. This enables better control, reduces blanks from hardware, enables multiple measurements during the day, and allows one to screen houses in real-time.

# Modeling

- Johnson-Ettinger Still Being Used
  - GW, soil, soil gas spreadsheets
  - Screen & advanced versions
  - 2003 and 2001 versions differ in some defaults
  - Hard to compare defaults vs actual values used
- DTSC Has Customized Version
  - Has own defaults
  - Only screen version allowed
- Can Use Soil Gas Spreadsheet for All Data

The most common model currently being used is the Johnson & Ettinger (J-E) model. The EPA has written different spreadsheets for groundwater, or soil, or soil gas data. The spreadsheets were updated in 2003 and are available from the EPA website referenced previously. There are two versions of each: screening and advanced. The primary difference is that the advanced version allows for multiple soil zones of varying lithologies.

DTSC has their own version with their own custom default values. They only allow the screening version to be used.

The soil gas spreadsheet can also be used for groundwater data by calculating the soil gas data from the groundwater data using the Henry's constant.

The soil spreadsheet is helpful for calculating the soil gas concentration from soil data.

## Using the J-E SG Spreadsheet

- Unlock Cells with ABC
- Iterate Conc to get Desired Risk
- Cannot Change Exposure Time
- Default Ventilation Rate is 0.5/hr
- Bldg Size is for a Typical House
- Soil Physical Prop Can be Changed

Here are some of the key steps in using the J-E soil gas spreadsheet. We will walk through these in this training.

# Soil Gas Sampling Methods Updates

- Sampling & Analysis Issues
- Bioattenuation
- Other Tools/Approaches

This part of the training will give an update of any soil gas issues since the last training and also point out errors I am seeing in submitted workplans or from the regulators. We also will address some of the common sampling issues you've raised to me over the past several months.

# Probe Installation Methods

- Sample Through Rod Methods
  - Aka temporary probes
  - Collect sample while probe rod in ground
  - Less disturbance, less parts in the ground
- Vapor Mini-Wells/Tubing Method
  - Aka semipermanent or permanent probes
  - Bury tubing in the ground
  - Better for repeated sampling

There are two common ways for collecting active soil gas samples: collection through a probe or rod driven into the ground or collection through a vapor well buried into the ground.

Collection through the probe rod is advantageous if only one sampling round is required. Also, less materials are emplaced in the ground minimizing disturbance of the in-situ vapor and decreasing the potential for blanks from the materials.

Vapor wells consist of small diameter, inert tubing and offer advantages when vertical profiles are desired or when repeated sampling events are likely.

Both methods can give reliable data if done properly.

# Through Rod Method

- Hand Methods (Rotohammer, Slidehammer)
  - Better access
  - Shallower depths (<6' bgs)
  - Internal tubing already connected
  - Better penetration in cobbles
- Direct Push Methods
  - Access more limited
  - Deeper depths
  - Post-run tubing connector can leak
  - Can smear walls in finer grained materials

Installation of the probe rod is most commonly done by one of two methods: using hand methods or with direct-push systems. Rods can also be installed using rotary, sonic, or percussion drill rigs.

Hand methods are useful in limited access areas for shallow sampling (<6' bgs), but also have a few technical advantages over the direct-push methods. This method can often get better penetration in cobbly soils.

Direct push methods can go deeper, but access is more limited. The post-run tubing can leak at the coupling point inside the rod and smearing of the borehole walls can reduce permeability in finer grained or moist soils.

For either method, seals at the base of the probe at the ground surface are advisable, especially if depths are shallow, soils are coarse grained, and larger volume samples (>1 liter) are collected.

## Mini-Wells/Tubing Method

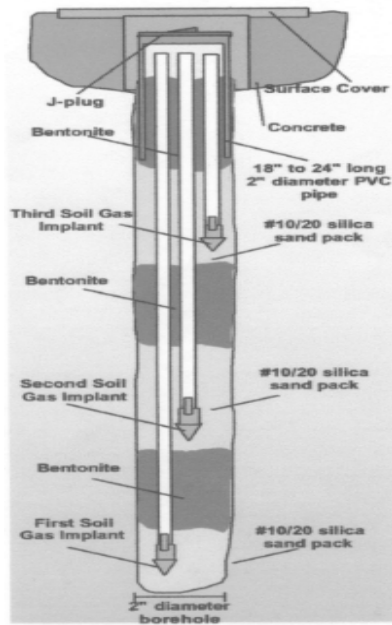
- Inexpensive & easy to install/remove
- Allow repeated sampling
- Can “nest” in same bore hole
- Installed multiple ways (DP, hand, rigs)
- Can be better for low permeability soils
- More disturbance to in-situ soil gas
- More parts in the ground – increases blanks

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. Vapor wells can often times get a sample in low permeability soils when the drive rod methods can not.

Tubes can be installed in a number of ways using simple hand-auger methods, direct-push rigs, or larger drill rigs.

Disadvantages are that more materials are left in the ground increasing the chance for blanks and the burial of the tubes with a sand-pack causes a greater disturbance of the in-situ soil gas.

# Multi-Depth Nested Well



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)
  - Small diameter best (1/8" or 1/4")
- **Probe Tip**
  - Beware metal tips (may have cutting oils)
- **Equilibration Time**
  - Effects by air knife, rotary, air percussion, sonic
- **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.

# Soil Gas Sampling Issues

- Tracer/Leak Compound
  - Gaseous (He) or Liquid (IPA, Freons)
  - Imp for sub-slab & larger sample volumes
- Pumps
  - Collect on upstream side. Watch vacuum applied
- Rain
  - How long to wait after a rain event?
- Time-Integrated Samples?
  - Existing data does not show large variations

Tracer/leak compounds are required to ensure sample integrity. Both gaseous (He) and liquid tracers are used. The liquid tracers are operationally simpler and can cover more locations.

If pumps are used, samples should be collected upstream of pump and the applied vacuum should be minimized to avoid leaks.

Does rain influence soil gas concentrations? Probably not for depths greater than 3' and certainly not under paved surfaces.

Are time-integrated samples required ala indoor air samples? Most data do not show large temporal variations in soil gas concentrations.

# Soil Gas Sampling Issues

- Sample Size
  - Greater the volume, greater the uncertainty
  - Smaller volumes faster & easier to collect
  - Large purge vols require pumps & control
- Containers (Don't Chill!!)
  - Canisters: More blank potential. Higher cost.
  - Do NOT need to certify clean if  $> 10 \text{ ug/m}^3$
  - Tedlars: Good for  $\sim 2$  days. Easier to collect
- Flow Rate
  - Really not imp. But most agencies  $< 200 \text{ ml/min}$

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.

Larger purge volumes require pumps and flow control which requires more effort and increases chance of errors. Three dead volumes should extract 88% or original air in the system volume, but what about sand pack and surrounding formation?

A variety of sample containers can be used depending upon volume required and storage time. All must be inert, tested clean, and handled properly (no cooling or heat).

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  $\sim 2$  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.

# Liquid Method

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

OK Method if Lab On-site

Liquid tracers are readily available, easy to use, and can be applied to many points along the sampling train at the same time. However, they are qualitative and don't allow real-time feedback. So, if you do not have on-site analysis, you are taking a chance that the collected sample is leak-free.

## Typical Liquids

- Isopropanol – adsorb onto skin
- Shaving Cream (butane) - partitions into skin
- Freons – readily available
- Pentane, hexane: not readily available

Isopropanol (rubbing alcohol) & shaving cream have been commonly used as they are readily available. However, they adsorb on the fingers and then are easily transferred to subsequent samples when the hardware is handled. Commercially available freons offer advantages as they don't adsorb onto skin.

# Gas Method

- Pros
  - Quantitative
  - Real-time results with portable meters
- Cons
  - More complicated and slower. Increases costs
  - Harder to cover multiple locations, esp with DP

Best Method if No Lab On-site

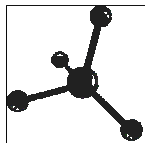
Use of gases is quantitative and enables real-time feedback with portable meters. However, the procedure requires more hardware and time. Also, it is more difficult to cover the entire sampling train especially is sampling through a direct-push rod.

## Typical Gaseous Tracers

- Helium – meter exp, low MW
- Carbon dioxide – not in areas of high bio
- Isobutylene – can use hand-held PID
- SF<sub>6</sub> – meter & gas exp

Have to Ensure Gases Clean!

A number of gases can be used, each with advantages and disadvantages.  
Isobutylene can be measured with the commonly used hand-held PID



# Soil Gas Analysis Issues

(TO-14/15 or 8260 or 8021)

- All Methods Give Reliable Results
- Some States Require TO-15
- Detection Level Discriminator:
  - TO Methods: 1 to 10  $\mu\text{g}/\text{m}^3$
  - 8260 SIM: 10  $\mu\text{g}/\text{m}^3$
  - 8260: 50  $\mu\text{g}/\text{m}^3$
- 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  $\mu\text{g}/\text{m}^3$ . 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.

## Coming Attractions: On-site TO-15 Scan/SIM

- Simultaneous Scan/SIM mode enables  
<10 ug/m<sup>3</sup> for All VOCs &  
< 2 ug/m<sup>3</sup> for subset of compounds.
- Only 2cc of Sample. Eliminates Hardware
- Real-time Analysis in Structures: Control!
- Already in CA

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/m<sup>3</sup> while simultaneously measuring for a subset of compounds at lower detection levels (<2 ug/m<sup>3</sup>). 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.

## Not All TO-15s Are Alike

- Standard Method QA/QC Poor & Does Not Meet Many CA Requirements
  - Can use standard for a year!!
  - No second source standard
  - No surrogates
  - Wider calibration acceptance windows
- Beware the “Wal-Mart TO-15”
  - Only use labs that have upgraded method
  - Only use lab that has a certification

The TO-15 analytical method has been advertised as the “Gold Standard”, but actually, the QA/QC is very poor and does not match the requirements of many State agencies. Further, it may have difficulty meeting the legal challenge. Incredibly, most State regulatory personnel don’t realize this. Some States, like NJ, have published a more exacting method than the standard method.

The higher-quality labs have upgraded the method to meet more exacting requirements required by the EPA SW-846 methods or any specific State regulatory requirements, such as second source standards & surrogates.

Beware the “Wal-Mart TO-15”. To ensure that you are getting a quality analysis, only use labs that can show they have upgraded the method QA/QC and have a certification from some NELAC or a State agency.

## Other Analytical Issues

- Pb
  - NIOSH method
  - Requires lots of sample volume & time
- Total TPH Alkanes
  - 8015m, 8260, TO-15, TO-3
- Naphthalene
  - 8260 or TO-15
- Oxygen & CO<sub>2</sub>
  - Portable meter ok
  - Use to find bioattenuation zone

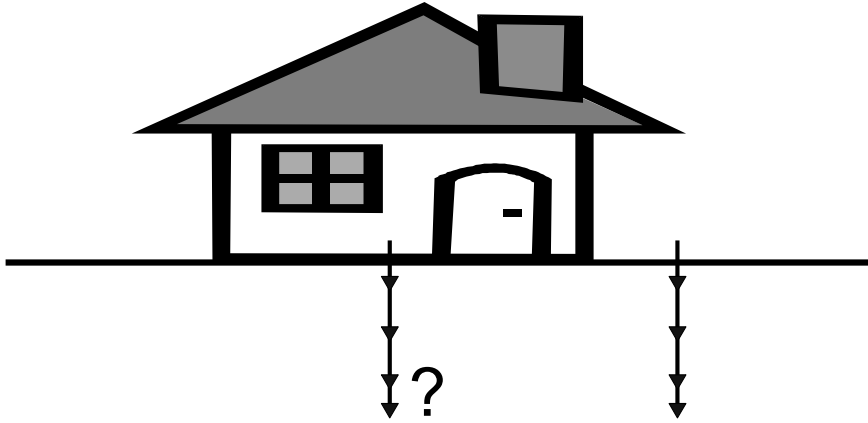
Some CA agencies are requiring tetramethyl-lead and tetraethyl-lead to be analyzed. This is done by a NIOSH adsorbant method and requires large volumes of sample. And hence time.

Total TPH alkanes can be analyzed by a series of methods. If only gasoline range required, then it can be determined from the same VOC analysis for a small incremental cost and save considerable money over TO-3.

Naphthalene is part of the standard 8260 analysis but is not part of the standard TO-15 analysis. 8260 DL is about 100 ug/m<sup>3</sup>. For commercial settings, RBSL is 470 ug/m<sup>3</sup> for 5' soil gas.

Oxygen and carbon dioxide can be done with portable meters. These compounds can help identify the bioattenuation zone while on-site.

# Sub-Slab vs. Near-Slab Samples

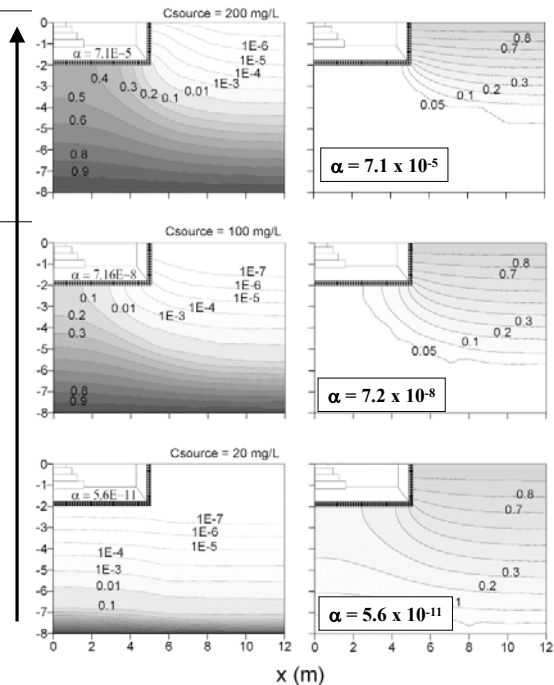


Are sub-slab samples necessary to collect?

# Effect of Source Concentration

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

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) and Dr. Paul Johnson (Arizona State University) 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 & Dr. Paul Johnson

# How Often to Sample?

- Closer to Surface, More Variability
  - 3' to 5' bgs generally considered stable
  - Upper few feet likely variable
  - Recent data show repeatability <5' bgs
- Seasonal Effects
  - Most studies show less than 5x
  - Heating/cooling of structure more imp
  - Heavy periods of rain
  - Fluctuation groundwater

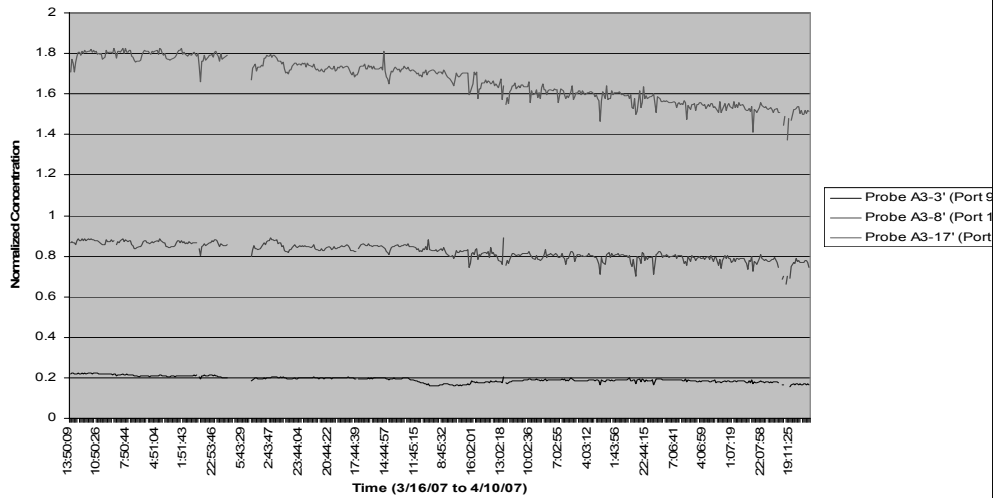
The closer to the surface, the more the potential temporal variation. Depths of 3' to 5' below the surface are generally considered stable and repeatable. Recent studies imply soil gas concentrations are stable at depths shallower than 5' bgs.

Temporal variations have been shown to be less than a factor of 5 even in colder environments. Larger variations may be seen due to effects caused when heating or ventilation systems are operative, during heavy periods of precipitation, and if the groundwater levels fluctuate.

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

Probe A3 (TCE - Normalized)



This is a plot of data recently collected by an automated instrument at a Vandenberg AFB site from three probes at the same location but at different depth (3', 8, & 17' bgs). This plot consists of over 500 points per probe collected once per hour over a 4 week period from mid March to mid April. The soil gas concentrations varied by less than 10% over these four days even for probes only 3 feet below the surface.

# Where to Sample Spatially

- Source Not Immediately Below
  - Collect on side towards source
  - Collect on other sides of structure
  - Preferential pathways at edges & conduits
- Source Below
  - If inside access ok, collect sub-slab
  - Collect around structure if access a problem
  - Get decent coverage
- Representativeness
  - Need enough points

There is currently much debate on where to collect samples and no existing protocols or guidance. So, common sense comes into play. If source not directly below, collect samples between the structure and the source at a depth that is deep enough to give repeatable results. Collect in any known preferential pathways, such as utility lines.

If the source is below, for legal issues, it is often times preferred to collect around the structure before going inside the structure.

Spatial averaging allows a better representation of what's below the structure. One approach is to collect samples on all sides of the house and use an averaging method to get a value under the structure footprint.

If real-time data exist, add additional points depending upon the results. If not, collect extra samples spatially and analyze if necessary.

## Where to Sample Vertically

- Initially Deep Enough for “Stable Data”
  - For HCs, 5’ below structure
  - For Cl-HCs, at GW or mid-way to GW
- Shallower Samples (<5’ bgs)
  - Zone of bioattenuation
  - Zone of surface reaeration
- Vertical Profiles
  - Determine direction of source
  - Can aid in documenting bioattenuation

The closer you get to the surface, the greater the chance that surface processes such as atmospheric pumping, precipitation, & advective flow from structures will affect the soil gas. So, initially, sample 5’ bgs to get below this zone if the source is below.

In some cases, collect samples shallower than 5 feet to document that the concentrations are attenuating due to bioattenuation in the uppermost vadose zone.

Vertical profiles also will aid in determining the direction of the source.

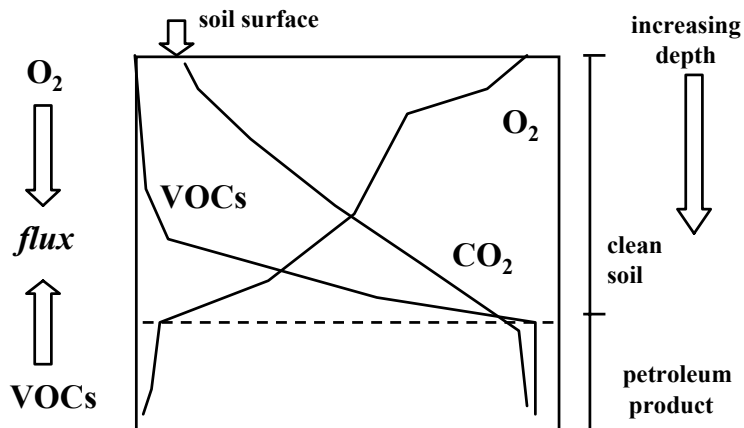
## Bioattenuation of HCs

- Existing data suggest O<sub>2</sub> effective barrier
- 98% effective if O<sub>2</sub>>5% and 3'-5' clean soil
- Document by vertical profiles of COC & O<sub>2</sub>
- Request 10x attenuation from agency

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 5% or greater and 3 to 5 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 ( $\alpha = 0.0001$ ).

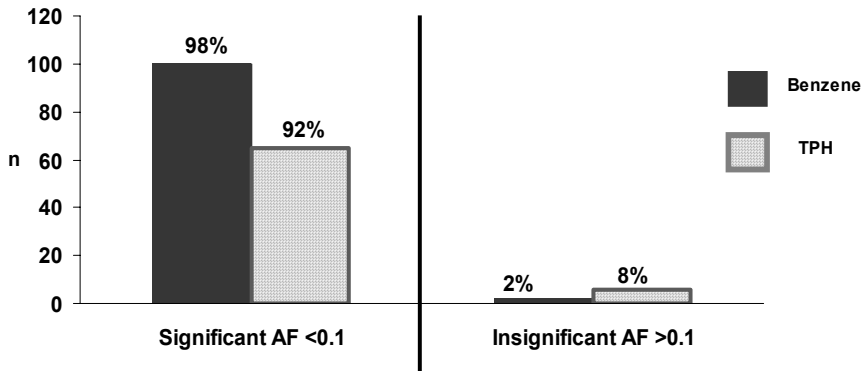
Documentation that this process is occurring is done by collecting vertical profiles of the soil gas for the hydrocarbons, oxygen, and carbon dioxide. If shown to occur, many agencies are conservatively allowing a factor of 10 to 100 reduction in the alpha factor.

# Theoretical Bio Profile



This is the theoretical profile for hydrocarbon VOCs, CO<sub>2</sub>, and oxygen in the soil gas with depth where bioattenuation is active. Without on-site analysis, you don't know where the depth of this zone is. Either use oxygen to find it or collect additional samples.

Sample Events and % Attenuation of  
Benzene and TPH  
Study Data Set Events: 102 Benzene, 71 TPH  
n=# vapor sample events



**SIGNATURE CHARACTERISTICS OF BIO-ATTENUATION**

- 5 feet clean coarse-grained or 2 feet of fine-grained soil overlies contaminant source
- Vapor concentrations decrease significantly vertically away from source
- O<sub>2</sub> depleted and CO<sub>2</sub> enriched near the source, O<sub>2</sub> enriched and CO<sub>2</sub> depleted with increasing distance from the source
- O<sub>2</sub> minimum range 3% to 5%

An analysis of hydrocarbon sites from around the country has been performed by Robin Davis of the Utah DEP. Her analysis shows that 92% of TPH contaminated sites and 98% of benzene contamination have significant (>100 times) reduction in concentration due to bioattenuation.

Slide courtesy of Robin Davis of Utah DEP

# Supplemental Tools/Data

- Site Specific Alpha Using Radon
  - Factor of 10 to 100. \$100/sample
  - Agency acceptance growing
- Indoor Air Ventilation Rate
  - Factor of 2 to 10. <\$1,000 per determination.
- Real-Time, Continuous Analyzers
  - Can sort out noise/scatter
- Forensics
  - Still in infancy

If the soil gas levels exceed the fail levels, there are some other inexpensive tools/data that can be applied to better evaluate some of the default model parameters. 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.

For HCs, vertical profiles of the soil gas can demonstrate bioattenuation. In some States, the agencies allow for a 10 times reduction in risk if bioattenuation is demonstrated. Although the DTSC guidance recognizes bioattenuation, it currently gives no indication as to how the data will be interpreted.

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.

Pressure measurements are helpful with indoor air data to possibly show a background source.

# Practical Strategies

(Things to Do)

- Stay Within EPA Q5 (DTSC Step 6&7)
- Collect Enough Data to Get Average
- Use On-site Data to:
  - Make Real-time Decisions
  - Confirm TO-15 Hits
- HCs: Sub-slab or Vertical Profiles for Bio
- Use Radon for Slab-Specific Alpha
- Measure Ventilation Rate
- Check Your Units!!!!!!!!!!!!!!!

Some things you want to do to minimize your pain when you are assessing this risk pathway.

# Practical Strategies

## (Things Not to Do)

- Don't Trust Regulator for SG RBSLs
- Don't Chase the CHHSLs
- Don't Report at TO-15 DLs
- Don't Report Any & All Compounds
- Beware DTSC Step 8 (Interior Air)
- Don't Spend Much \$ on Soil Properties
- Don't Assume  $1 \text{ ppbv} = 1 \text{ ug/L}$

Some things you don't want to do if you want to minimize you and your client's pain.

# Existing Documents & Training

(Available at [www.handpmg.com](http://www.handpmg.com))

- Overview of SV Methods
  - 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
- Regulatory Guidance
  - CA-EPA Collection Protocols
  - San Diego County Collection/Analytical Protocols

A summary of some existing documents on the VI pathway and soil gas methods can be found at these locations:

# Existing Documents & Training

- Soil Gas Sampling SOPs
  - Soil Gas Sampling, Sub-slab Sampling, Vapor Monitoring Wells/Implants, Flux Chambers ([www.handpmg.com](http://www.handpmg.com))
- Other
  - ITRC VI Guidance ([www.itrcweb.org](http://www.itrcweb.org))
  - API Soil Gas Document ([www.api.org/bulletins](http://www.api.org/bulletins))
  - Robin Davis Lustline Article on Bioattenuation (Lustline March 2006, [www.neiwpcc.org](http://www.neiwpcc.org))

More documents.

# Exercises & Case Histories

- Typical Service Station Scenario
- COP Sites
  - Roseville
  - Corcoran
  - Placerville
  - Terminal Site

Now we will apply the information we learned to a common service station scenario and to specific sites that COP is dealing with.