

# Some Basics

- Units
- Fick's Law
- Contaminant Partitioning
- Attenuation (alpha) Factors
- Risk Based Screening Levels (RBSL, RBC, CHHSLs )

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 seminar so we will review them now.

# 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:

# The Most Common Goof

**Sent:** Wednesday, November 20, 2007 11:36 AM

**Subject:** VI Question

Blayne,

I have a technical question for you. I'm worried that some deep soil gas data I just collected might have been compromised by ambient air leakage from the surface. The measured oxygen level was 44% much higher than we expected in deeper soil gas. The data are attached. What is your opinion?

An e-mail regarding units. See if you can spot the error.

# How do Vapors Move?

$$\text{Movement (Flux)} = K d\phi/dx$$

where:      K is a proportionality constant  
               $d\phi/dx$  is a gradient

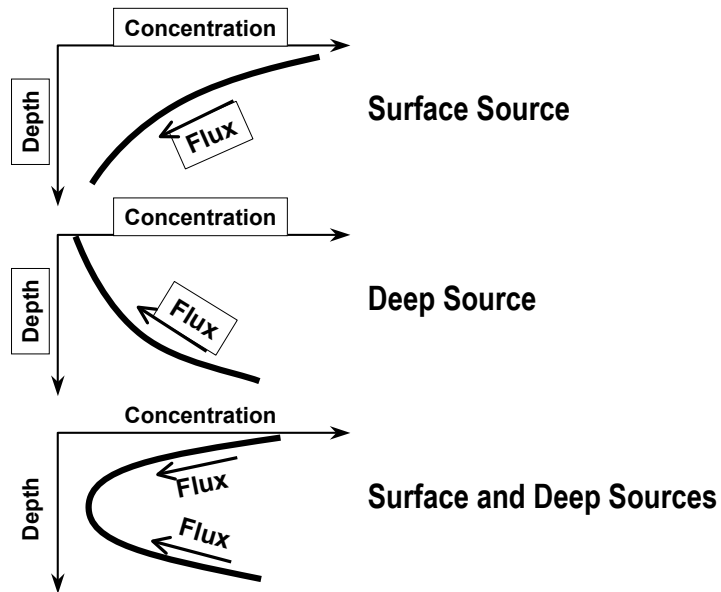
<u>Property</u>	<u>Equation</u>	<u>Constant</u>
Momentum:	Flux = K dH/dx	hydraulic cond
Heat (Poisson's):	Flux = $\Phi$ dT/dx	thermal cond
Mass (Fick's):	Flux = D dC/dx	diffusivity

Momentum, Heat, Mass ALL Move from High to Low

The fundamental equation describing momentum, heat, and mass movement is the same. Movement or flux is equal to a proportionality constant times a gradient. For momentum (groundwater or balls), the equation is known as Darcy's Law. For heat, the equation is known as Poisson's Law. For mass, it is known as Fick's Law. The proportionality constant is known as the diffusivity or diffusion coefficient (D).

Balls, heat, and mass all move the same way: downhill, hot to cold, high to low concentration. As you will see, people often tend to forget this fundamental concept and make incorrect decisions.

# Common Vapor Profiles



Knowledge of Fick's Law enables one to determine the direction of soil gas movement, and hence the direction of the source, from vertical gradients of the soil gas. Three types of common profiles are shown for sources at different locations in the vadose zone. Note that the flux is down the concentration gradient even when the flux is going "uphill" with respect to depth in the vadose zone.

# How Fast do Things Move?

$$\text{Distance} = (2 * D_e * t)^{1/2}$$

where:  $D_e$  is effective diffusivity,  $t$  is time

Vapors through the Vadose Zone:

$$D_e = 0.01 \text{ cm}^2/\text{sec}$$

$$\text{Distance} = (2 * 0.01 * 31,000,000) = 800 \text{ cm/yr}$$

Vapors through Liquid (into/out of GW):

$$D_e = 0.000001 \text{ cm}^2/\text{sec}$$

$$\text{Distance} = (2 * 0.000001 * 31,000,000) = 8 \text{ cm/yr}$$

**Transport in Vadose Zone 100 times faster than in GW**

An estimate of how fast contaminants move in the vadose zone can be obtained by a simple calculation based upon the diffusivity.

Contaminants move through the vadose zone by molecular diffusion at a rate of 800 cm/yr, which is 8 m/yr, or approx. 25 ft/yr, or 1 inch a day.

Contaminants move through liquid (into or out of) 100 times slower because the diffusion coefficient for liquids is 10,000 times lower. Thus, volatilization of contaminants out of an undisturbed water interface (e.g., groundwater) is glacially slow and typically orders of magnitude below equilibrium. This is a crucial concept when using groundwater data to calculate soil gas concentrations. Calculated soil gas values will always be over estimated.

# Contaminant Partitioning

## Groundwater to Soil Gas (Henry's Constant):

$$H = C_{sg}/C_w, \text{ so, } C_{sg} = C_w * H$$

Example:  $H_{\text{benzene}} = 0.25$  (dimensionless)

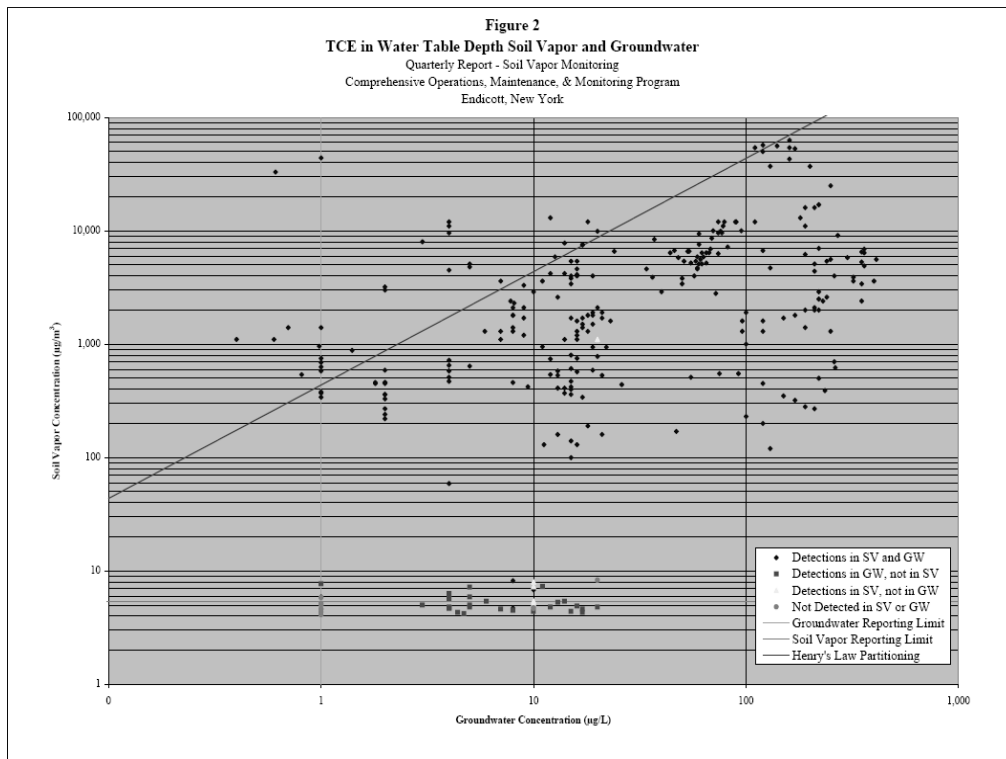
For GW Conc = 10 ug/L

$$C_{sg} = 10 * 0.25 = 2.5 \text{ ug/L}$$

**Assumes Equilibrium. Very Rarely Achieved  
(no mixers or blenders in the subsurface)**

Partitioning refers to the distribution of molecules between different phases. Partition coefficients are determined empirically by laboratory measurement. The partition coefficient for water to air partitioning (e.g., groundwater to soil gas) is called the Henry's Constant or Henry's Law. It simply is a ratio of the concentration in the air to the concentration in the water. It is simple to calculate the soil gas concentration from groundwater data or the reverse from the dimensionless Henry's constant.

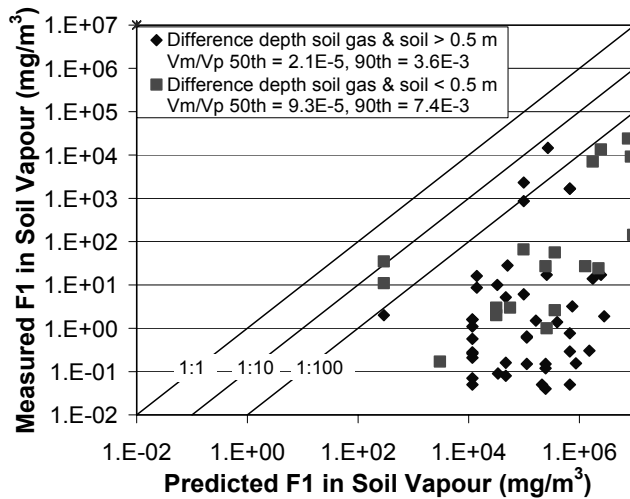
Henry's constants are based upon equilibrium being reached. The container was vigorously mixed. Mixers do not exist in the subsurface so equilibrium not reached and actual soil gas concentrations are far below calculated ones.



This slide shows data from the NY Endicott site comparing measured soil gas concentrations near groundwater to groundwater concentrations. The line shows the predicted values based upon equilibrium partitioning using the Henry's constant. You can see that the vast majority of points fall orders of magnitude below the calculated values. This proves that soil gas values predicted by groundwater are over-estimated.

Slide courtesy of Dr. William Wertz, NYDEC

# Measured Soil Gas Data vs. Predicted from Soil Phase Data



CPPI Database

.005

**Key  
point:**

Measured vapor concentrations 10 to 1000x less than predicted

This slide compares measured soil gas concentrations to soil gas concentrations predicted from co-located soil phase data for petroleum hydrocarbons. You can see that the vast majority of measured values fall orders of magnitude below the calculated values. This proves that soil gas values for hydrocarbons predicted from soil data are likely to be over-estimated. The same is not necessarily true for chlorinated solvents.

## Attenuation (alpha) Factors

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

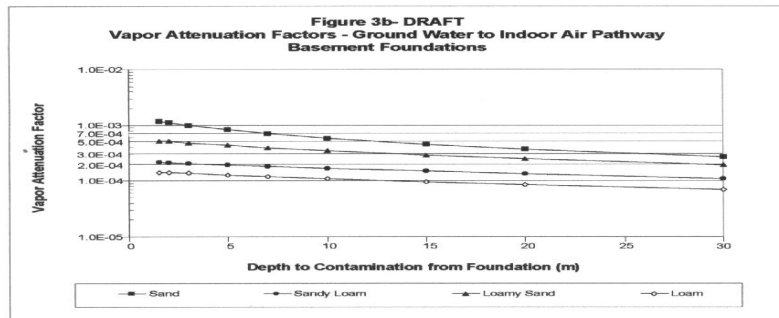
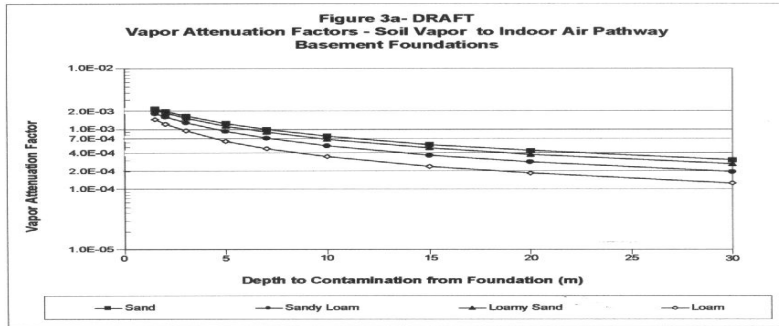
$$\alpha_{gw} = C_{indoor}/(C_{gw} * H)$$

- Lower alpha means higher attenuation
- Current VI guidances:
  - EPA  $\alpha_{sg} = 0.002$  for 5', 0.1 for sub-slab
  - CA  $\alpha_{sg} = 0.002$  for 5', 0.01 for sub-slab
  - NY State Data Shows  $\alpha_{sg} < 0.01$
  - Hydrocarbon  $\alpha_{sg}$  likely  $< 0.0001$

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. More recent and larger data bases (IBM Endicott) are showing that the alphas should be orders of magnitude lower, especially for petroleum hydrocarbons.



In the draft VI guidance, alpha factors can be 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.

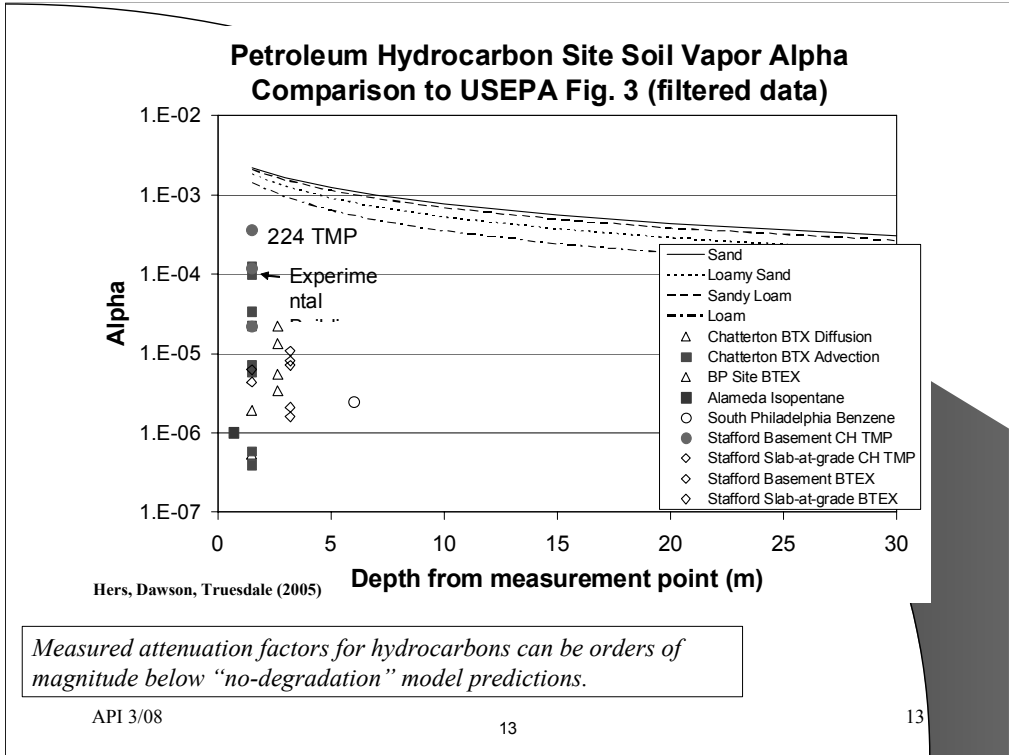
For groundwater, Figure 3b shows the highest alpha is ~.001. The inverse is 1000.

# Johnson and Ettinger Model

$$\alpha = \frac{C_{indoor}}{C_{vs}} = \frac{\left[ \frac{D_T^{eff} A_B}{Q_B L_T} \right] \exp\left( \frac{Q_{soil} L_{crack}}{D_{crack}^{eff} \eta A_B} \right)}{\exp\left( \frac{Q_{soil} L_{crack}}{D_{crack}^{eff} \eta A_B} \right) + \left[ \frac{D_T^{eff} A_B}{Q_B L_T} \right] + \left[ \frac{D_T^{eff} A_B}{Q_{soil} L_T} \right] \left( \exp\left( \frac{Q_{soil} L_{crack}}{D_{crack}^{eff} \eta A_B} \right) - 1 \right)}$$

- $D_T^{eff}$  = "overall" effective diffusion coefficient [cm<sup>2</sup>/s]
- $D_{crack}^{eff}$  = effective diffusion coefficient through cracks in foundation [cm<sup>2</sup>/s]
- $C_{vs}$  = vapor concentration at the source [g/cm<sup>3</sup>]
- $C_{indoor}$  = indoor air concentration [g/cm<sup>3</sup>]
- $L_T$  = distance from source to basement [cm]
- $A_B$  = cross-sectional area of foundation available for vapor flux [cm<sup>2</sup>]
- $Q_{soil}$  = volumetric flow rate of soil gas into the building [cm<sup>3</sup>/s]
- $L_{crack}$  = thickness of the foundation [cm]
- $A_{crack}$  = area of cracks or openings through which vapors enter building [cm<sup>2</sup>]
- $Q_B$  = building ventilation rate [m<sup>3</sup>/s]
- $\eta$  = the "crack factor":  $A_{crack}/A_B$  so that  $0 < \eta < 1$

While this equation is in terms of an alpha factor, in reality, what the the J-E model is trying to do is estimate a value for the effective diffusivity, the proportionality constant in Fick's Law that we talked about previously. There is no easy way to do this because too many factors influence this term. As you can see, there are many variables, some of which can not be directly measured or easily measured.



Measured attenuation factors for hydrocarbons can be orders of magnitude below “no-degradation” model predictions.

Slide compliments of Robbie Ettinger, Geosyntec

## 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 = 0.3 ug/m<sup>3</sup>

$$C_{sg} (5') = 0.3 / 0.002 = 150 \text{ ug/m}^3$$

$$C_{gw} = 0.3 / (0.20 * 0.0005) = 30 \text{ ug/L}$$

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

By allowable level, I mean the concentration of a contaminant in the indoor air, soil gas, groundwater, or soil that fails the upward vapor risk calculation. It also is referred to as risk based screening level (RBSL), target level, ESL, PRG, acceptable value, look-up value, screening level, etc. This term will be used quite frequently throughout the remainder of this seminar.

Many consultants are not familiar with using alphas and calculate incorrect target values.

## Acceptable Soil Gas Levels (Benzene 1e-6 Risk)

State	Alpha	1/Alpha	Fail Level (ug/m <sup>3</sup> )
NH	0.002	500	150
CA-DTSC	0.002	500	42
CT	0.0013	770	192
NJ (Subslab)	0.05	200	60
EPA Q4	0.1	10	3.1
EPA Q5	0.002	500	155
EPA Q6	0.1	10	3.1

A summary of the alpha factor and corresponding acceptable soil gas levels for various States and the EPA draft guidance shows large variation and illustrates the main point: the levels are variable from State to State.

Notice the difference in fail values for the different EPA VI guidance questions.

## **RISK 101: Screening Levels**

- RBSL: Risk Base Screening Level
- RBC (from ASTM): Risk Based Concentration
- CHHSL: CA Human Health Screening Level
- ESL (from SF RWQCB): Environmental Screening Levels

### **Need to Know When & How to Use**

Risk based screening levels vary from state to state and guidance to guidance. Acronyms are plentiful. The VI professional needs to know what they are, where they come from, and how and when to use them.

## RISK 101:

### Why Are Indoor Air RBSLs So Low?

- Benzene: EPA: 0.30 ug/m<sup>3</sup>
- TCE: EPA: 0.022 or 1.0 ug/m<sup>3</sup>
- PCE: EPA: 0.41 ug/m<sup>3</sup>
- Values Assume Exposure Times of:
  - 24 hr, 350 days/yr, 30 years

**Ultra Conservative Assumptions Lower Allowed Levels and Bring in More Sites**

Allowable indoor air concentrations are so low because of the ultra conservative assumptions that are used, especially in regards to exposure time.

## Example Exposure Parameters

Parameter	Symbol	Typical Value	Units
Target Risk	TR	1E-6, 1E-5	unitless
Body Weight	BW	70	kg
Averaging Time-cancer	AT <sub>C</sub>	25,550	days
Averaging Time-noncancer	AT <sub>NC</sub>	ED x 365	days
Conversion Factor	CF	1,000	μg/mg
Exposure Duration	ED	25	years
Exposure Frequency	EF	250	days/year
Intake Rate	IR	20	m <sup>3</sup> /day
Attenuation Factor	α	.01-.0001	unitless

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**Exposure parameters may be set by EPA policy or guidance; state policy, legislation, regulation, or guidance; or even County or local requirements. Federal facilities are likely to have their own exposure factors because of the shorter military-specific tours of duty at any one base or facility. Be sure to check the requirements of the applicable agency for your case.**

**It is usually difficult to get alternate exposure factors accepted by regulatory agencies, except for federal facilities where controls on human activities and land use are more comprehensive.**

**It's probably not advisable to prepare a VIA based on alternate exposure factors, different than those in guidance documents, unless it is a building-specific slab factor or a building-specific ventilation rate. Keep in mind that the VIA must be able to be accepted if it were brought to the attention of the applicable government agency.**

# Inhalation Exposure Parameters

20 m <sup>3</sup> /day for Res. vs Comm.-Ind. Exposure				
Parameter	Symbol	Res.	Comm-Ind.	Units
Exposure Duration	ED	30	25	years
Exposure Frequency	EF	350	250	days/year
Exposure Time	ET	24	8	hours/day

$$\left( \frac{\text{Residential}}{\text{Comm-Ind}} \right) = \left( \frac{30 \text{ years}}{25 \text{ years}} \right) \times \left( \frac{350 \text{ days/year}}{250 \text{ days/year}} \right) \times \left( \frac{24 \text{ hours/day}}{8 \text{ hours/day}} \right) = 5.1 \approx 5$$

**Exposure parameters may be set by EPA policy or guidance; state policy, legislation, regulation, or guidance; or even County or local requirements. Federal facilities are likely to have their own exposure factors because of the shorter military-specific tours of duty at any one base or facility. Be sure to check the requirements of the applicable agency for your case.**

**It is usually difficult to get alternate exposure factors accepted by regulatory agencies, except for federal facilities where controls on human activities and land use are more comprehensive.**

**The ratio of inhalation exposure factors for residential and commercial-industrial exposure scenarios has a "standard" ratio of 5. To convert an RBSL for a residential scenario to one for a commercial-industrial scenario, the residential RBSL would be multiplied by a factor of 5 to obtain the RBSL for a Commercial-Industrial exposure scenario.**

# 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

\* Corrected for ventilation rate

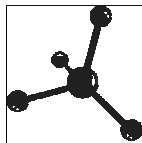
**Note: Ratio Should be 5**

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.

# Methods for RBC Determination

- From Lookup Tables
- From Attenuation Factor
- From Spreadsheet/Model

**Method Often Agency Specific**



# 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.

## Screen Out More Sites By:

- Using Correct Risk Level
  - 1 in 1 million: Residences, Schools, Hosp
  - 1 in 100,000: Commercial Settings (cumulative)
  - 1 in 10,000: Mitigation Required
- 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)
- Accounting for Bioattenuation

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 risk criteria. For State reimbursement funds, reasonable screening of sites will prevent draining the fund balances.