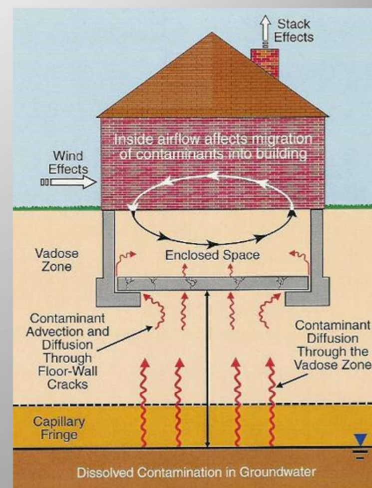
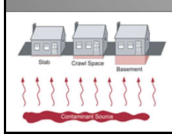
Part 3 – Fundamentals

- Units
- Contaminant Partitioning
- Vapor Migration
- Site Conceptual Model
- Attenuation (alpha) Factors
- Risk/Screening Levels



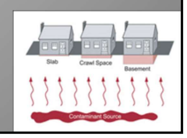


In this part of the training, we will cover some of the fundamental principles you need to know if you are going to get involved with the vapor intrusion pathway. These basic principles need to be understood in order to understand and effectively manage the vapor intrusion pathway. Some of these principles you may not have had in school or have never really used them, so you are rusty. We will be using them throughout the rest of this training so we will review them in detail now.

Most Common VI Bloopers

- Unit Confusion
  - Assuming ug/L equivalent to ppbv
  - Assuming ug/m3 equivalent to ppbv
- Screening Levels
  - Comparing to generic screening levels
  - Not calculating correct levels
- Sampling & Analysis Errors
  - Program design: Which method?
  - Wrong hardware, wrong analysis

Unit Converter: www.hartmaneg.com



The most common mistakes made by inexperienced practitioners conducting vapor intrusion assessments.

The Most Common Goof

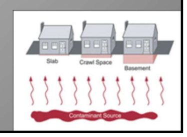
1 ug/L Benzene equals:

a) 1 ppbv

b) 1 ppmv

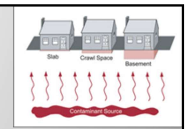
c) 320 ppbv

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:

Quiz Solution



Ug/L = mass/volume

ppbv = volume/volume

How to go from volume to mass?

PV=nRT

For gases, there are ~24 liters/mole at 20C.

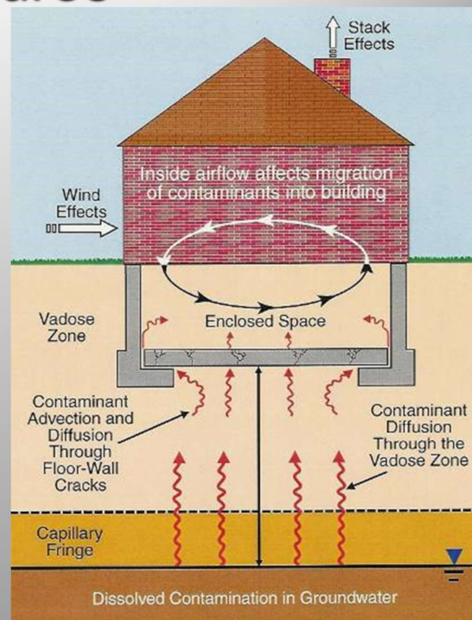
1 mole =mass/MW

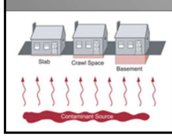
Ug/L = (MW/24)*1000 = 78/24 =325 ppbv

Contaminant Pathway into Structures

Steps:

- Partitioning from gw
- Diffusion through vadose zone
- Advection near building
- Dilution in building





These are the paths contaminants must take to get from the groundwater or deep vadose zone into an overlying structure. We will cover these pathways now.

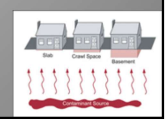
Contaminant Partitioning

Groundwater to Soil Gas (Henry's Constant):

$$H = Csg/Cw, \quad so, \quad Csg = Cw * H$$

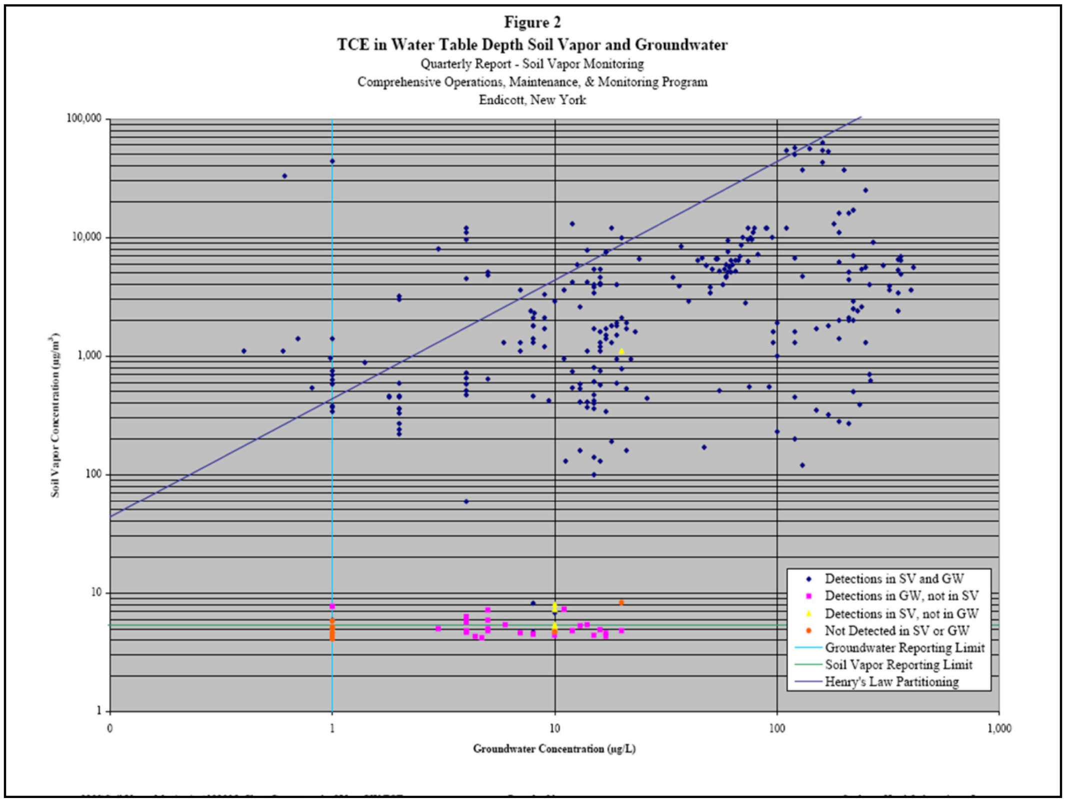
Example: $H_{benzene} = 0.25$ (dimensionless)
For GW Conc = 10 ug/L
$Csg = 10 * 0.25 = 2.5$ ug/L

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

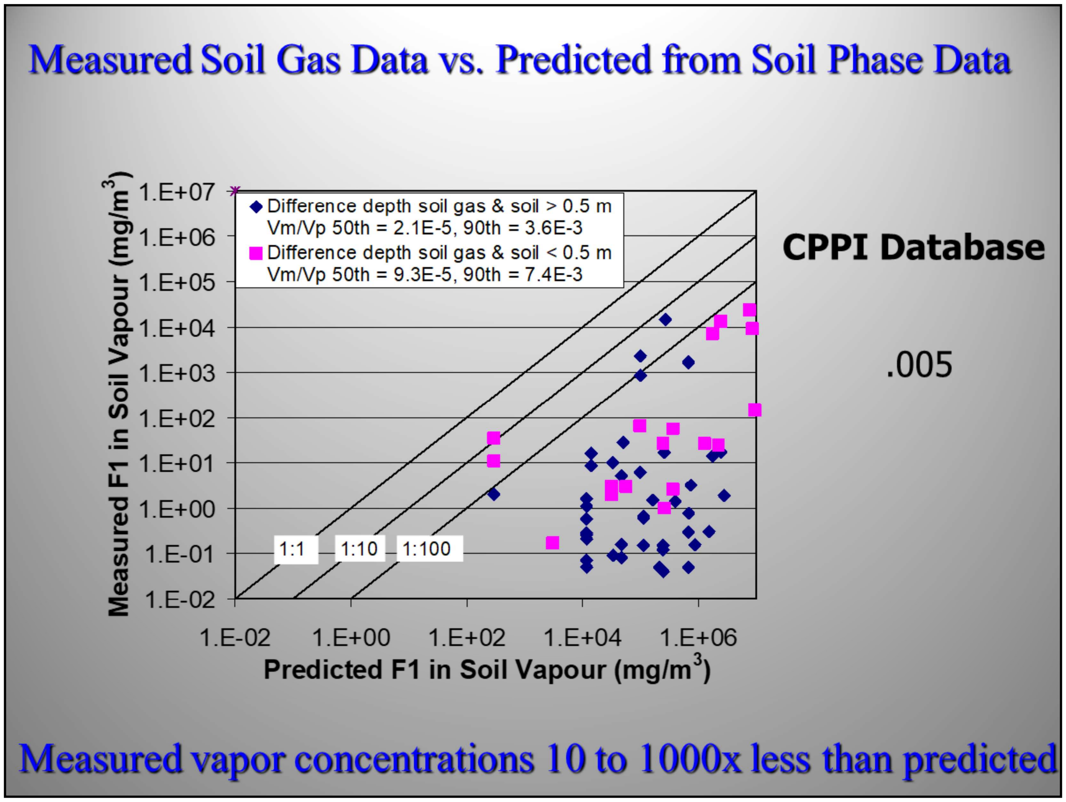


Partitioning refers to the distribution of molecules between different phases. Partition coefficients are determined empirically by laboratory measurement. The partition coefficient for water to air partitioning (e.g., groundwater to soil gas) is called the Henry's Constant or Henry's Law. It simply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

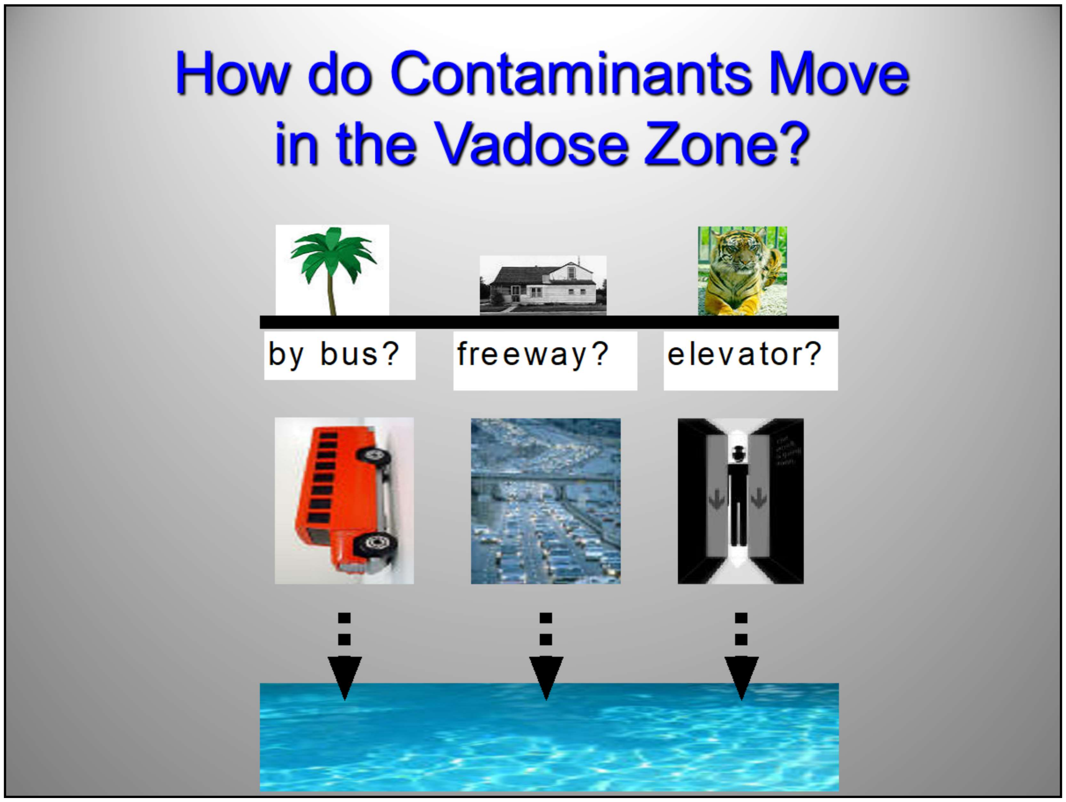


This slide shows data from the NY Endicott site comparing measured soil gas concentrations near groundwater to groundwater concentrations. The line shows the predicted values based upon equilibrium partitioning using the Henry's constant. You can see that the vast majority of points fall orders of magnitude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



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.

Slide courtesy of Ian Hers, Golder and Associates.



So how do contaminants move in the vadose zone? There are no buses, or freeways, or elevators moving vapors around. There's no wind. Vapors do not exhaust themselves like Old Faithful geyser.

The principle mechanism is by molecular diffusion. In molecular diffusion, the vapor itself is stagnant and the contaminants move through the stagnant vapor phase. This concept is crucial to understand because it arises in all facets of the vapor intrusion process including sampling techniques and data interpretation.

How Do Contaminants Move?
(Molecular Diffusion)

Movement (Flux) = K d?/dx

where: K is a proportionality constant
d?/dx is a gradient

Property	Equation	Constant
Momentum:	Flux = K dH/dx	hydraulic cond
Heat (Fourier's):	Flux = Φ 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.

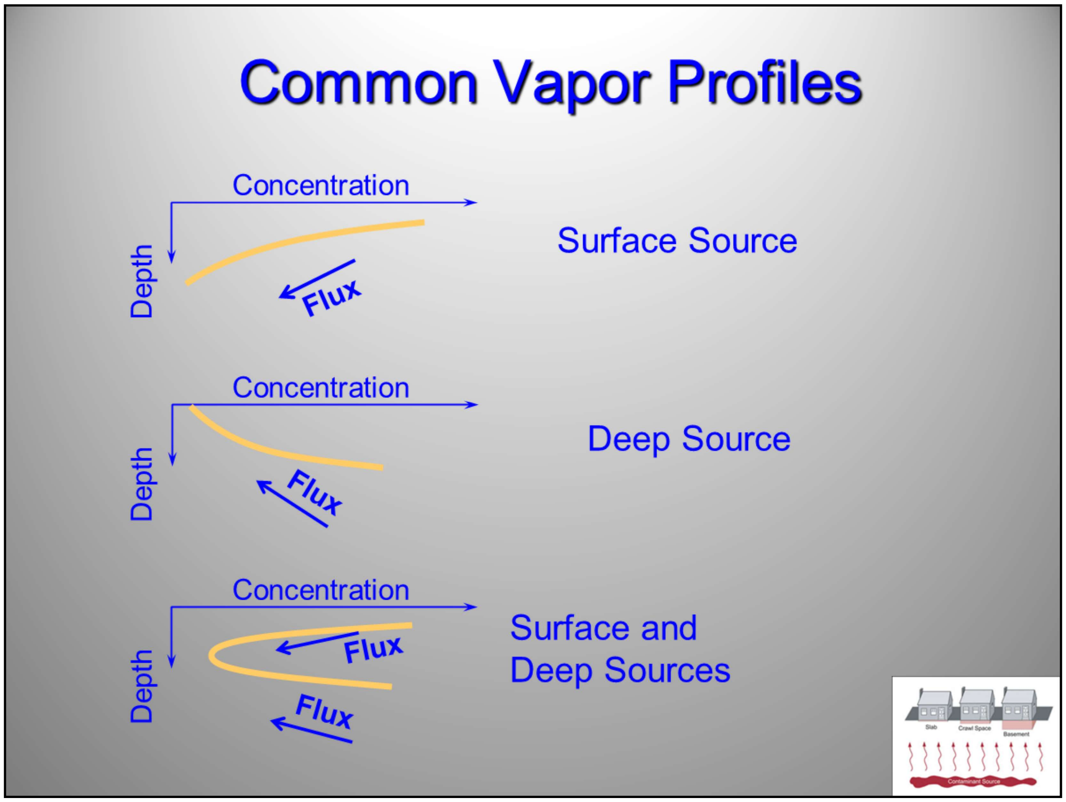
How Do Contaminants Move? (Advection)

Advection - Air Itself Moves, Caused by:

- Pressure Gradients
  - Wind speed (only if high)
  - Barometric pressure changes – not great
  - Building Effects (heating, ventilation, air conditioning) and fan operations
- Methane Gas Generation

Not Much Advection in Vadose Zone Except Close to Surface

Advective flow is movement of the entire air body which carries the contaminant molecules along with it. This process is much faster than diffusion, but there must be a driving force to cause the air to move. In the vadose zone, there is little advective flow except close to the surface or close to a building.



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?

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

where: D_e is effective diffusivity, t is time

Vapors through the Vadose Zone:

$D_e \sim 0.01\ cm^2/sec$

Distance = (2*0.01*31,000,000) = **800 cm/yr**

Vapors through Liquid (into/out of GW):

$D_e \sim 0.000001\ cm^2/sec$

Distance = (2*0.000001*31,000,000) = **8 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.

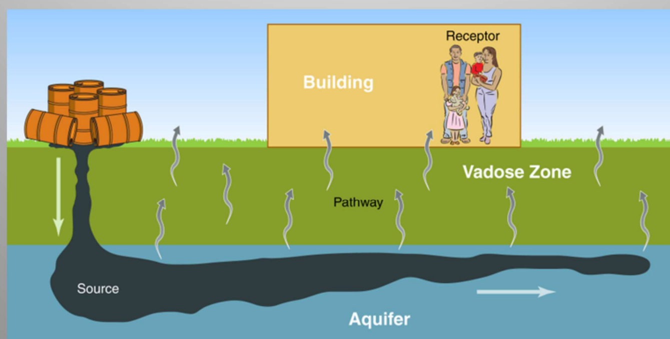
Contaminants move through the vadose zone by molecular diffusion at a rate of 800 cm/yr, which is 8 m/yr, or approx. 25 ft/yr, or 1 inch a day.

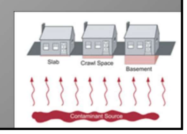
Contaminants move through liquid (into or out of) 100 times slower because the diffusion coefficient for liquids is 10,000 times lower. Thus, volatilization of contaminants out of an undisturbed water interface (e.g., groundwater) is glacially slow and typically orders of magnitude below equilibrium.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

Conceptual Site Model
(or Site Conceptual Model)

DEFINITION:

A Conceptual Site Model (CSM) is a simplified version (pictures and/or descriptions) of a complex real-world system that approximates its relationships





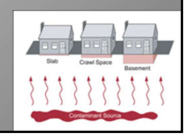
A site conceptual model is a basic picture of the site.

Key information required:

- What types of contaminants at what concentrations in what media?
- Is contamination well defined?
- What types of receptors (houses, retail, commercial industrial) and what structure type (slab, basement, crawlspace)?
- What is location of contaminant relative to structure?
- Is the Risk Acute?

Components of a CSM

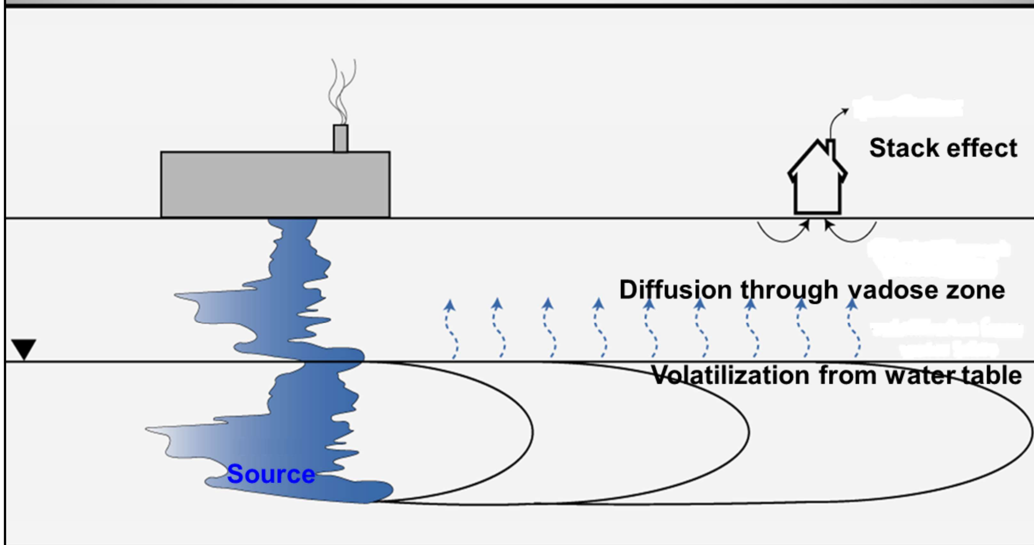
- Underground utilities & pipes
- Existing & potential future buildings
- Construction of buildings
- Type of HVAC system
- Soil stratigraphy
- Hydrogeology & depth to water table
- Receptors present (sensitive?)
- Nature of vapor source
- Vadose Zone characteristics
- Limits of source area & contaminants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



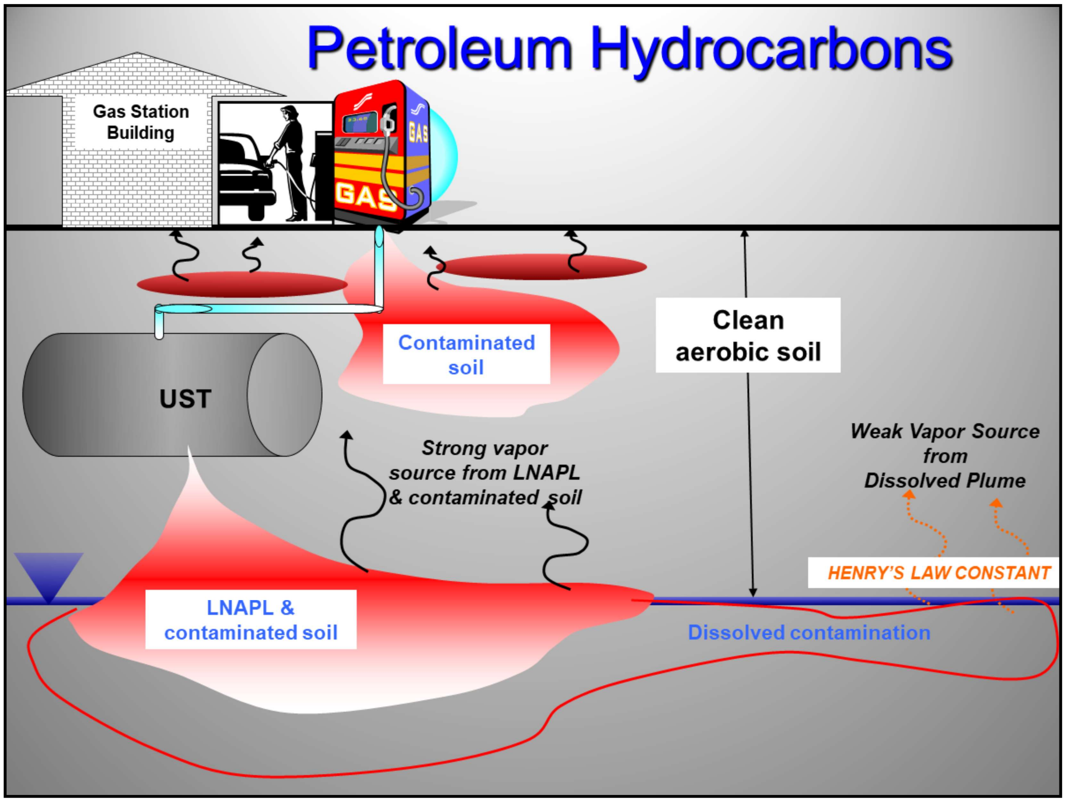
ITRC VI Guidance Appendix B

Some of the components of a SCM. Go to the ITRC guidance for a complete checklist.

Chlorinated VOCs in GW



Here is the typical conceptual model for chlorinated VOCs in groundwater moving under a receptor.



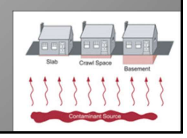
The conceptual model for hydrocarbon contamination differs greatly from chlorinated solvents because of bioattenuation in the vadose zone.

Volatile compounds associated with LNAPL, contaminated soil, and very high dissolved contaminant concentrations can generate very high vapor concentrations that, when in close proximity to buildings or utilities, can cause PVI. Those conditions are the only known cases of petroleum vapor intrusion. There are no known or reported cases of petroleum vapor intrusion associated with low dissolved-phase concentrations at or near buildings or utilities.

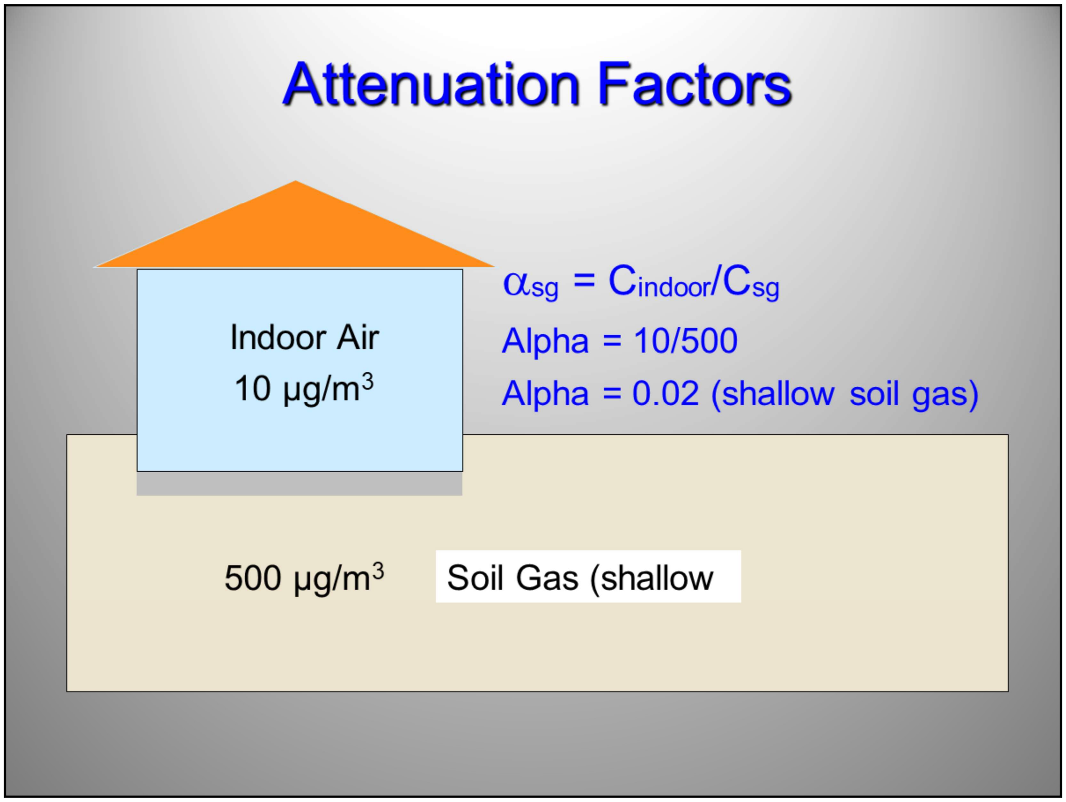
Definition of "Clean" Soil

Typically one of:

- Soil Phase TPH (<100 mg/kg)
- Oxygen in Vadose Zone (>2% - 4%)
- Soil Headspace PID Data (<100 ppmv)

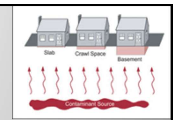


Clean soils are soils capable of bioattenuating hydrocarbons. The criteria for defining clean soil are typically one of the three listed on this slide. The actual values depend upon the oversight agency.



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.

Attenuation (alpha) Factors



Soil Gas: $\alpha_{sg} = C_{indoor}/C_{sg}$

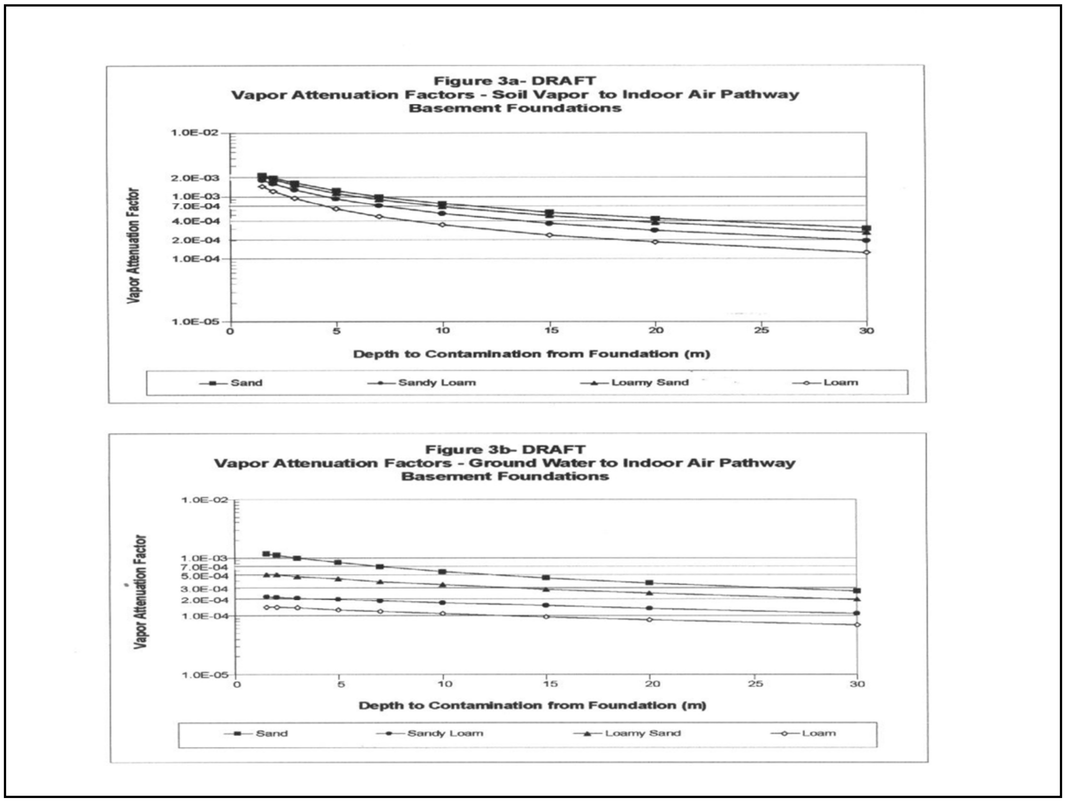
Groundwater: $\alpha_{gw} = C_{indoor}/(C_{gw}*H)$

- Lower alpha factor means higher attenuation

- EPA Guidance attenuation factors:
  - 2002: Soil Gas 0.002 for 5' bgs, 0.1 for sub-slab
  - 2013: Soil Gas 0.1 for 5' bgs, 0.01- 0.03 for sub-slab
  - Groundwater = 0.001 for 5'bgs
  - Hydrocarbon αsg likely <0.00001

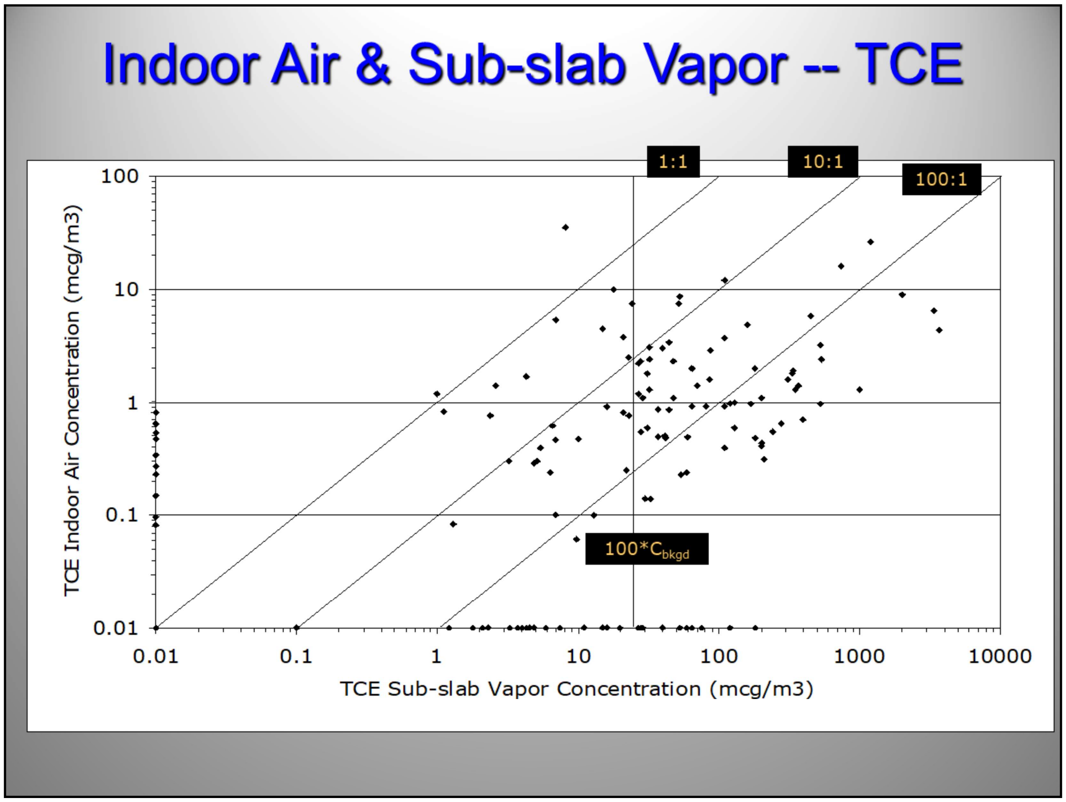
Since indoor air values are lower than subsurface values, alpha factors tend to be less than 1, hence lower numbers mean greater attenuation. Thus, inverse alpha factors are often easier to understand.

The 2002 EPA draft guidance proposes alpha factors, determined from modeling. In March 2012, EPA released a white paper giving an analysis of attenuation factors from empirical data (actual site data). The proposed attenuation factors went up for shallow soil gas (less attenuation by 50x) and went down for sub-slab soil gas (more attenuation by 3.3x to 10x).



In the EPA VI guidance, alpha factors are summarized vs. depth in Figure 3. As you can see in Figure 3a, the highest soil gas alpha is 0.002 at 5 feet below the structure. The inverse is 500.

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



Attenuation factors from the NY Endicott site show large variation from 1 to 0.001 further complicating what value to use in interpreting sub-slab soil gas results.

Further, the data points show no correlation with each other, implying that sub-slab values are not a good predictor of indoor air values.

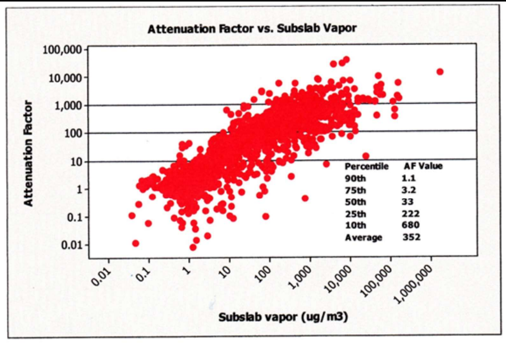


Figure A-3: Attenuation Factor vs. Sub-Slab Vapor

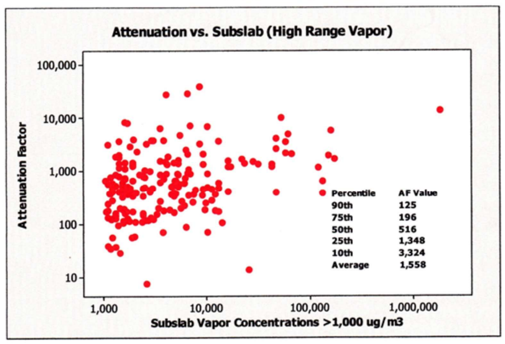


Figure A-4: Attenuation vs. Sub-Slab (High Range Vapor)

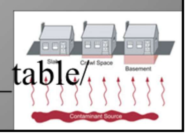
Oregon DEQ did their own analysis of the EPA attenuation factor data base and concluded that the more reasonable sub-slab attenuation factor to use is 0.005 (200x). This is 6 times more attenuation that the EPA value of 0.03.

RISK 101: Screening Level Acronyms

- RBSL: Risk Base Screening Level
- RBC (from ASTM): Risk Based Concentration
- RSL: Region 3 Screening Levels
- RBTL: Risk Based Target Level (MO)
- PEL: OSHA Permissible Exposure Limits

Need to Know When & How to Use

http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/



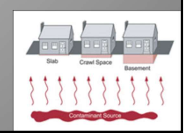
Risk based screening levels (RBSL) vary from state to state and guidance to guidance. Acronyms are plentiful. The VI professional needs to know what they are, where they come from, and how and when to use them.

The most updated screening levels being used in the US can be found at: http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm

RISK 101:
Why Are Indoor Air RSLs So Low?

- Benzene: EPA: 0.31 ug/m3 (1e-6)
- TCE: EPA: 0.43 ug/m3 (1e-6)
- Values Assume Exposure Times of:
  - 24 hr, 350 days/yr, 30 years

Ultra Conservative Assumptions Lower Allowed Levels and Bring in More Sites

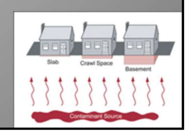


Allowable indoor air concentrations are so low because of the ultra conservative assumptions that are used, especially in regards to exposure time.

Factors Affecting Indoor Air Screening Levels

- Risk levels
  - 10^{-4} to 10^{-6} cancer risk levels
  - Non-Cancer risks (hazard quotients, HQ)
  - Individual vs. cumulative risks
- Receptors
  - Residential and non-residential receptors
- Exposure Times

ITRC VI Guideline Appendix H



The main factors determining screening levels are the risk level you are concerned with, the type of receptor, and the exposure time.

Inhalation Exposure Parameters

20 m^3/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

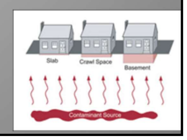
$$\left(\frac{Residential}{Comm-Ind}\right)=\left(\frac{30\ years}{25\ years}\right)x\left(\frac{350\ days/year}{250\ days/\ year}\right)x\left(\frac{24\ hours/day}{8\ hours/day}\right)=5.1\cong\mathbf{5}$$

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.

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

Final Risk Points

- Risk Reported to only 1 Significant Figure
  - RAGS, 1989, Ch 8 (EPA/540/1-89/002)
  - 1.49e-5 = 1e-5;   1.51e-5 = 2e-5
- RAGS Part F (2009)
  - Eliminated body weight/inhalation rate issue
  - Commercial RBLs 5x greater than residential



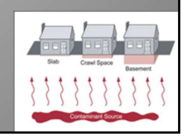
Some final points re risk

Determining Screening Levels

- From Lookup Tables (EPA Table 3)
- From Attenuation Factors
- From J-E Model/Spreadsheets

Higher SLs

Levels increase from top to bottom (less conservative)



Three methods are typically used to determine screening levels. The first method listed gives the lowest (most conservative) levels. The J-E Model gives the highest (least conservative) levels.

Screening Levels from Lookup Tables

- Often Very Conservative
- Considered for "Generic Site"
- Often Derived by Predictive Model
- Used for Preexisting Data

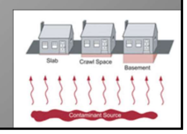


Table 2. California Human Health Screening Levels for Indoor Air and Soil Gas

Chemical	[1]Indoor Air Human Health Screening Levels ($\mu g/m^3$)		[2]Shallow Soil Gas Human Health Screening Levels (Vapor Intrusion) ($\mu g/m^3$)	
	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
cis-1,2-Dichloroethylene	3.65 E+01	5.11 E+01	1.59 E+04	4.44 E+04
trans-1,2-Dichloroethylene	7.30 E+01	1.02 E+02	3.19 E+04	8.87 E+04
Ethylbenzene	Postponed[3]	Postponed[3]	Postponed[3]	Postponed[3]
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
m-Xylene	7.30 E+02	1.02 E+03	3.19 E+05	8.87 E+05
o-Xylene	7.30 E+02	1.02 E+03	3.15 E+05[4]	8.79 E+05[4]
p-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 10-6. 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.

An example of generic lookup tables used in California.

Screening Levels From Attenuation Factors

For Soil Gas:

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

For Groundwater:

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

Example: C_{indoor} benzene = 3.1 ug/m3 (1e-5)

C_{sg} (5’) = 3.1/0.002 = 1550 ug/m3

C_{gw} = 3.1/(0.20* 0.001) = 15,500 ug/m3 = 15.5 ug/L

By using attenuation factors, one can calculate target levels for soil gas and groundwater starting from the acceptable indoor air concentration.

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

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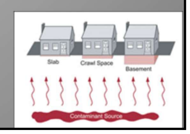
Example: Benzene in Soil Gas Commercial Receptor

- Allowable indoor air residential level: 3.1 $\mu g/m^3$
- Adjust for 5 times less exposure time for commercial, allowable indoor air commercial: 5*3.1 = 15.5 $\mu g/m^3$
- Default attenuation factors for soil gas 0.1 for ss & 0.002 for 5’ sg, hence soil gas screening levels:

Css = 15.5/0.1 = 155 ug/m3

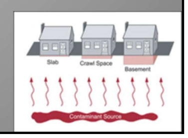
Csg= 15.5/0.002 = 7,750 $\mu g/m^3$



Calculation of benzene screening levels for sub-slab and exterior soil gas for a commercial receptor.

Screening Levels from Models

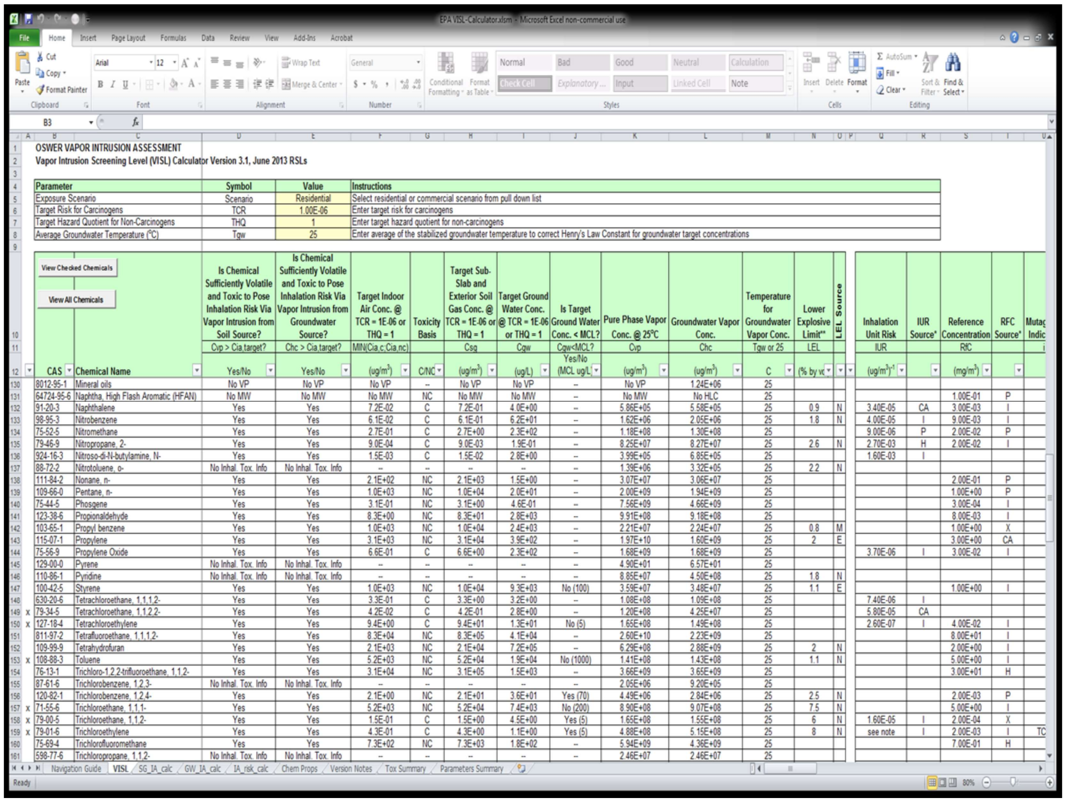
- Johnson-Ettinger Still Being Used
  - GW, soil, soil gas spreadsheets
  - Screen & advanced versions
  - 2003 and 2001 versions differ in some defaults
- Calculators
  - Vapor Intrusion Screening Level Calculator (VISL)
- Biovapor for HC
- PVI-Screen for HCs?
  - Supposed to be out in 2014 by EPA



Models are also allowed in most guidances to calculate screening levels. The most common model currently being used is the Johnson & Ettinger (J-E) model. The EPA has written different Excel spreadsheets for groundwater, or soil, or soil gas data. The spreadsheets were updated in 2003 and are available from the EPA website referenced previously.

Calculators (spreadsheets) also exist. The 2 most common are the EPA-Athens Learn2model calculator and the EPA-OSWER vapor intrusion screening level (VISL) calculator released in March 2012. Neither of these incorporate bioattenuation.

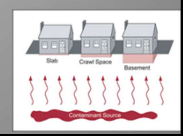
One model incorporating bioattenuation is Biobapor written by API. EPA is supposed to come out with their version of Biovapor in 2014 called Bioscreen.



This on-line calculator is a handy way to calculate screening values without getting into the J-E spreadsheets. It uses EPA Federal default parameters for toxicity info, ventilation rates, etc. It can be found at http://www.epa.gov/athens/learn2model/index.html.

Comparison: TCE in Soil Gas, Residential Receptor, 1-5 Risk

2012	Method	Alpha	RBSL (ug/m^3)
EPA Q4	lookup	0.1	21
EPA Q5	Att factor	.002	1050
EPA Q6	Model	.001	2100
EPA 2014?	lookup	0.1	21



A comparison of the different screening levels for TCE from the different approaches.