This training focuses on some of the basic principles that need to be understood in order to understand and effectively manage the vapor intrusion pathway.

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.
Some Fundamentals

- Units
- Fick’s Law
- Contaminant Partitioning
- Attenuation (alpha) Factors
- Site Conceptual Model (SCM, CSM)
- Risk Based Screening Levels
- Bioattenuation

This is a summary of the topics we will cover. 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:
Another Common One:

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

Another one.
How do Contaminants Move?

**Movement (Flux) = K d?/dx**

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

<table>
<thead>
<tr>
<th>Property</th>
<th>Equation</th>
<th>Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Momentum:</td>
<td>Flux = K dH/dx</td>
<td>hydraulic cond</td>
</tr>
<tr>
<td>Heat (Poisson’s):</td>
<td>Flux = Φ dT/dx</td>
<td>thermal cond</td>
</tr>
<tr>
<td>Mass (Fick’s):</td>
<td>Flux = D dC/dx</td>
<td>diffusivity</td>
</tr>
</tbody>
</table>

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.
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.
Contaminant Partitioning

Groundwater to Soil Gas (Henry’s Constant):

\[ H = \frac{C_{sg}}{C_w}, \text{ so, } C_{sg} = C_w \times H \]

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

For GW Conc = 10 ug/L

\[ C_{sg} = 10 \times 0.25 = 2.5 \text{ ug/L} \]

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

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?
Some of the components of a SCM. Go to the ITRC guidance for a complete checklist.
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.
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.
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 text from the US EPA gives direction on when to take action for different exceedances of risk levels.
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

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

Typical parameters used in calculations of RBSLs
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 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.
There are 3 common ways to determine screening levels. Lookup tables are typically the most conservative; spreadsheets the least conservative.
Lookup tables are offered in the EPA-OSWER guidance and by many State agencies. They are typically the most conservative screening levels
The California Human Health Screening Levels (CHHSLs) were developed by a branch of CA-EPA (OEHHA) using the Johnson-Ettinger model. Note, soil gas values are for 5’ deep soil gas samples, not for sub-slab samples.
**Using Alpha Factors to Calculate Screening Levels**

For Soil Gas:

\[ C_{sg} = \frac{C_{\text{indoor}}}{\alpha_{sg}} \]

For Groundwater:

\[ C_{gw} = \frac{C_{\text{indoor}}}{(H \times \alpha_{gw})} \]

Example: \( C_{in} \) benzene = 0.3 ug/m3

\[ C_{sg} (5') = 0.3/0.002 = 150 \text{ ug/m3} \]

\[ C_{gw} = 0.3/(0.20 \times 0.0005) = 30 \text{ ug/L} \]

By using attenuation (alpha factors) one can calculate screening levels for soil gas and groundwater by knowledge of the acceptable indoor air concentration.

Many consultants are not familiar with using alphas and calculate incorrect target values.
Several models are available that allow you to calculate screening values for groundwater, soil gas, and even soil phase data. The Johnson-Ettinger model/spreadsheet is the most common. API is releasing a version that includes bioattenuation.
This on-line calculator is a handy way to get a feel for “fail levels” 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.
A comparison of the different screening levels from the different approaches.

### Comparison: Benzene in Soil Gas, Residential Receptor, 1-6 Risk

<table>
<thead>
<tr>
<th></th>
<th>Alpha</th>
<th>1/Alpha</th>
<th>RBSL (ug/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHHSL</td>
<td>0.002</td>
<td></td>
<td>37</td>
</tr>
<tr>
<td>DTSC – S5</td>
<td>0.002</td>
<td>500</td>
<td>42</td>
</tr>
<tr>
<td>DTSC – S6</td>
<td>Model</td>
<td>1000</td>
<td>95</td>
</tr>
<tr>
<td>EPA Q5</td>
<td>0.002</td>
<td>500</td>
<td>155</td>
</tr>
</tbody>
</table>
Example: RBC for Benzene in Soil Gas, Commercial Receptor

Allowable indoor air residential level: 0.084µg/m³

- For commercial receptors use 100,000 risk, hence allowable indoor commercial level = 0.84 µg/m³
- Adjust for 5 times less exposure time for commercial:
  \[ 5 \times 0.84 = 4.2 \text{ µg/m}^3 \]
- Adjust for 2 times higher exchange rate for commercial,
  \[ 2 \times 4.2 = 8.4 \text{ µg/m}^3 \]

Default attenuation factor for soil gas from 5’ bgs= 0.002, hence allowable soil gas conc:

\[ C_{sg} = \frac{8.4}{0.002} = 4200 \text{ µg/m}^3 = 4.2 \text{ µg/L} \]

Calculating a soil gas screening level from allowed indoor air level.
Other Considerations

- Toxicity of Compounds
  - TCE: 0.017 or 1.0 µg/m³ (50x)
  - Benzene: 0.084 or 0.31 µg/m³ (~4x)

- Cumulative Risk – Required by some Agencies
  - Lowers RBSLs for each compound
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 CI 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.
Bioattenuation of HCs

- Existing data suggest O₂ effective barrier
- Attenuation > 10,000 times
- Vertical profiles of COC & O₂
- How to Account for it?

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

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.
This is the theoretical profile for hydrocarbon VOCs, CO2, 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.
Conceptual model of the API Biovapor model/spreadsheet