Vapor Intrusion: The Science

Navigating the Vapor Intrusion Landscape
Missouri Waste Control Coalition Seminar
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Vapor Intrusion: The Science

- What is vapor intrusion and why do we care?
- What physical, chemical, and biological factors influence vapor migration from source to building?
- How can our understanding of the key factors influencing vapor intrusion improve site investigation and mitigation planning?
What is Vapor Intrusion?

- Vapor intrusion occurs when a hazardous or toxic volatile chemical migrates, in vapor phase, from a subsurface contamination source into an overlying building.
Why Do We Care?

- Vapor intrusion can impact a broad range of land use settings and buildings of any foundation type
- Vapor accumulations may pose:
  - Near-term safety hazards
  - Acute/chronic health effects
  - Aesthetic problems
Why Do We Care?

- Vapor intrusion concerns may impact property values (ASTM E1527-13 and ASTM E2600-15)
- Vapor intrusion potential may drive target groundwater concentrations below EPA maximum contaminant levels
- Vapor- or water-intrusion contamination may be the sole driver for placing a contaminated site on the Superfund National Priorities List (notice of proposed rulemaking anticipated 01/2016)
What Influences Vapor Migration?

- Physical, chemical, and biological factors influence vapor migration
  - From the source
  - Through the subsurface
  - Into buildings
Source Factors

- Volatility
- Toxicity
- Phase
- Amount
- Location
Source Factor: Volatility

- Must have sufficient vapor pressure or Henry’s Law constant to contribute to vapor transport in the unsaturated zone
- May include:
  - Volatile organic compounds
  - Semivolatile organic compounds
  - Some inorganic analytes
- Higher volatility increases vapor intrusion potential
Source Factor: Toxicity

- Vapor concentration of pure component exceeds indoor air target risk level (soil source)
- Saturated vapor concentration exceeds target indoor air risk level (groundwater source)
- Indicator compounds and other hazards (e.g., cis-1,2-DCE, methane, radon)
Source Factor: Phase
Source Factor: Phase

- **ALL** phases can contribute to vapor intrusion
  - Non-aqueous phase liquid: light, dense, residual
  - Aqueous: dissolved
  - Solid: adhered or adsorbed
  - Vapor: volatilized

- Volatile compounds responsible for a large number of contamination sites include both LNAPLs (petroleum hydrocarbon) and DNAPLs (chlorinated solvents)
Source Factor: Amount

- Vapor intrusion potential increases with the volume and concentration of the source.
Source Factor: Location

- Vapor intrusion potential increases with proximity to receiving buildings or structures;
- Identification and location of all sources is key.
Subsurface Factors

- Fate and Transport Processes
  - Diffusion
  - Advection
  - Sorption
  - Biodegradation
- Environmental Conditions
  - Structure
  - Moisture content
  - Other
Subsurface Factor: Diffusion

- Vapors migrate from areas of high concentration to areas of low concentration
Subsurface Factor: Diffusion

- Important vapor intrusion considerations:
  - More rapid in gaseous than aqueous phase; slowed by water or high moisture
  - Proceeds quickly along preferential pathways, geologic or engineered
  - Slowed or redirected by low permeability zones
  - Consistent within the confines of a well defined conceptual site model
Subsurface Factor: Advection

Vapors migrate from areas of high pressure to areas of low pressure
Subsurface Factor: Advection

- Important vapor intrusion considerations:
  - May draw vapors from soil into lower pressure buildings
  - Proceeds quickly along preferential pathways, geologic or engineered
  - Slowed or redirected by low permeability zones
  - Varies temporally as drivers change (e.g., building conditions, temperature, barometric pressure, wind load, methane generation)
Subsurface Factor: Sorption

- Vapors partition onto the solid phase
- Important vapor intrusion consideration:
  - Volatile organic compounds tend to preferentially adsorb to organic matter in soil
  - Phase partitioning will retard contaminant vapor transport under transient conditions, but not under steady-state transport conditions, when the mass transfer between phases approaches equilibrium
**Subsurface Factor: Biodegradation**

- Chemical compounds are converted to other chemicals through the biological activity of microorganisms in the subsurface.

- Important vapor intrusion consideration:
  - Biodegradation products may be toxic or hazardous

![Chemical reactions and structures](image)
Subsurface Factor: Biodegradation

- Important vapor intrusion consideration:
  - Rates are chemical, site, and location specific
  - Chlorinated solvents degrade best in anaerobic conditions
  - Petroleum hydrocarbons degrade best in aerobic conditions (e.g., vadose zone, water table interface)
Subsurface Factor: Geology/Structure

- Vapors do not migrate readily through horizontal, laterally extensive, fine-grained layers
- Important vapor intrusion consideration:
  - Vapors may accumulate below impermeable layers

Low permeability layers may limit oxygen for anaerobic biodegradation
Subsurface Factor: Geology/Structure

- Vapors will migrate readily through vertical fractures or openings, or through coarse-grained media.
- Important vapor intrusion consideration:
  - Chemical transport (via diffusion, advection) may be faster and farther along preferential pathways.
Subsurface Factor: Moisture Content

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- Important vapor intrusion consideration:
  - Chemical transport (via diffusion, advection) may be faster and farther along preferential pathways.
Subsurface Factor: Others

Many other environmental conditions may influence vapor migration in the subsurface, including but not limited to:

- Factors impacting chemical biodegradation:
  - Microbiome
  - Oxygenation
  - Carbon content
  - Temperature
- Steady windloads influencing subslab concentration distribution
Building Factors

- Openings
- Pressure differentials
- Entry rates
- Air exchange
- Mixing
Building Factors: Openings

- Vapors may enter buildings through “adventitious” or intentional openings.
- Even small pressure differences may cause advective flow of soil gas into or out of openings.
Building Factors: Pressure Differentials, Entry Rates

- Subslab-to-building pressure differentials fluctuate with daily and seasonal changes in air temperature, pressure, wind, and HVAC building conditions.

- As such, entry rates vary temporally and geographically.
Building Factors: Air Exchange, Mixing

- Air exchange and mixing are influenced by building use, room size/location, partitions, ventilation, etc.
- However, most models are predicated on well mixed spaces with uniform concentration distribution
Building Factors: Air Exchange, Mixing

- Mixing with clean air dilutes concentrations
- Mixing with impacted air complicates source attribution
- Published background levels of volatile chemicals in indoor air are useful but should not substitute for representative site-specific data
A Few Key Concepts to Carry into VI Investigation and Mitigation Planning

- Vapor concentrations vary *spatially and temporally* in the:
  - Subsurface (e.g., plume migration, geologic heterogeneity, moisture content)
  - Subslab (e.g., seasonal shifts in temperature and pressure, entry points, wind load)
  - Indoors (e.g., HVAC use, room size/location)
Indoor air concentrations are influenced by a complex *combination* of source, subsurface, and building-specific factors.
A Few Key Concepts to Carry into VI Investigation and Mitigation Planning

- So ...
  - Recognize that one size does not fit all
  - Collect multiple samples (and rounds of samples) as necessary to adequately represent site spatial and temporal variability
  - Assess and demonstrate concordance among multiple lines of evidence to confidently support decision-making
Additional Information


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Questions?