Improving Risk-Based Decision Making at Vapor Intrusion Sites

Presented by

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Presenters

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Disclaimer

The views expressed herein are not those of the SF Bay Regional Water Board, State Board, Governor Newsom, the Pope, Dalai Lama, or even all three presenters
Presentation Agenda

- **Introduction**  
  *Gina*

- **Regulatory Update**  
  *Ross*

- **VI Empirical Attenuation Factors**  
  *Robbie*

- **Impact of Background on VI Assessments**  
  *Gina*

- **Site-Specific VI Cleanup Goals**  
  *Ross, Robbie*

- **Strategies for Sites with VI Mitigation**  
  *Gina*

- **Questions / Discussion**  
  *All*
Vapor Intrusion Conceptual Model

Vapor Intrusion (VI) is the migration of volatile chemicals from groundwater or soil into overlying buildings.

Possible only if plumbing issues present and sewers intercept contamination.

Adapted from SFRWQCB, 2019
Screening Levels vs. Clean-up Goals

- Screening levels are not clean-up goals
- **Screening levels** are based on default assumptions and assist with making decisions about investigation findings (i.e. is more data needed to determine a path forward)
- **Clean-up goals** should be based on site-specific information, including risk and feasibility evaluations
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- Strategies for Sites with VI Mitigation
- Questions / Discussion

Gina

Ross

Robbie

Gina

Ross, Robbie

Gina

All
Water Board Groundwater Programs

- UST Cleanup Program
- Landfills and Industrial Facilities
- Site Cleanup Program
- DOD/DOE Program
SF Bay Regional Water Board (R2): Groundwater Divisions Update

Mike Montgomery
Executive Officer

Lisa Horowitz McCann
Assistant EO

Alec Naugle
Toxics Cleanup Division

Nicole Fry
Risk Assessor

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Cheryl Prowell
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22nd Annual California CUPA Training Conference
February 2020
R2 Evolving Approach to Vapor Intrusion: 2010-2020
— from “Model & Trust” to “Model but Verify”—

ESL update (never issued)
- Empirical SS/SG AF (0.05)
- SS/SG ESLs 50x lower
- DTSC and OEHHA input
- Advisory group

TCE VI Framework
- Assessment
- Indoor air action levels
- SG and GW trigger levels
- Mitigation approach

VI Framework update
- Assessment
- Remediation
- Mitigation
- Low threat closure or long-term management

ESL update
- JEM-based AFs
- SS/SG (0.002)
- TCE action and trigger levels

ESL update
- Empirical SS/SG AF (0.03)
- SS/SG ESLs 30x lower
- CalEPA VI workgroup

AF – attenuation factor
ESL – env’l screening level
SS – subslab soil gas
SG – soil gas
VI – vapor intrusion
R2: 2019 ESL Update: 
USEPA Empirical VI Attenuation Factors (AFs)

<table>
<thead>
<tr>
<th>Subslab</th>
<th>J&amp;E Model</th>
<th>USEPA</th>
<th>CA (2018)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct Value</td>
<td>Unknown</td>
<td>Unlikely May be conservative</td>
<td>Maybe Need more data</td>
</tr>
<tr>
<td>Protective</td>
<td>Not all cases Not RME</td>
<td>Yes</td>
<td>Maybe Need more data</td>
</tr>
</tbody>
</table>

* R2 filtered the CA 2018 database using USEPA’s filtering protocol

RME – reasonable maximum exposure (Water Code sec 13304.2)
R2: Site Cleanup Approach

- Characterize the site – nature, distribution, extent
- Remediate to extent feasible
  - Default cleanup level is background
  - Feasibility study – justify alternative cleanup levels
  - Point of compliance is “upstream” of biological receptor
  - Basis: State Board Resolution 92-49 points to CCR Title 23 sec 2550.4 for setting cleanup levels
- Mitigate if significant risks remain after remediation

Modification for redevelopment sites: acceptable to mitigate once remediation is well underway (parallel track)
R2: Approach to Low Threat Closure for VI

Assuming site characterized and remediated to extent feasible, low threat closure considered when:

- Vapor and groundwater plumes:
  - Stable/decreasing (not spreading/discharging)
  - Subsurface cleanup levels met in reasonable timeframe

- Indoor air: exposure controls not needed

**Otherwise:**
- Use new GeoTracker case status: Open-Long Term Management
- Verification monitoring, contingency plan, financial assurance
- Ongoing regulatory oversight
R2: Petroleum Vapor Intrusion (PVI) Differs from Chlorinated Vapor Intrusion (CVI)

- Vapor-phase hydrocarbons in the subsurface attenuate sharply in presence of oxygen
  - Levels can decrease **orders of magnitude within a few feet**
  - Petroleum vapor “plumes” typically are **thin zones around source media**

Source: USEPA 2012
R2: Approach to PVI

- Petroleum UST cases must follow the State Board Low-Threat UST Case Closure Policy
- For non-UST cases, R2’s approach aligns with the Policy:
  - Site-specific biodegradation assessment (e.g., clean soil, oxygen, hydrocarbon concentrations decreasing upward)
  - Use bioattenuation factor (0.001) if biodegradation demonstrated

Source: ITRC 2014
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- Introduction  Gina
- Regulatory Update  Ross
- **VI Empirical Attenuation Factors**  Robbie
- Impact of Background on VI Assessments  Gina
- Site-Specific VI Cleanup Goals  Ross, Robbie
- Strategies for Sites with VI Mitigation  Gina
- Questions / Discussion  All
USEPA developed VI database from sites across nation to assess empirical attenuation factors

- Empirical data from over 900 buildings at over 40 sites from across the country
  - Majority of data from a few sites
  - Predominantly CVOCs
  - Very limited data set from California sites
- Paired indoor air and subsurface data used to calculate empirical attenuation factors
- Filtered data to screen out results likely impacted by background sources

Variability in empirical AFs evident in USEPA database
- 95 %ile = 0.03
- Median = 0.003

USEPA analysis skewed by data from a few sites
- Mostly residential properties with basements
- Very limited data set for non-residential properties
- Cold weather climates

EPA guidance recommends the 95th percentile value for screening levels
- Based on sub-slab results – soil vapor results were inconclusive
USEPA study recognized background sources can result in positive bias on empirical AFs

- Background sources in indoor air will affect empirical AF analysis
- USEPA study took steps to reduce potential bias of background sources on results
  - Filtered out data with subsurface concentrations 50 times literature-based indoor air background level
- More detailed assessment of effects of background sources on empirical AF is warranted

\[
AF_{\text{emp}} = \frac{C_{IA}}{C_{Sub}} = AF_{VI} + \frac{C_{Bkgd}}{C_{Sub}}
\]
Effect of background sources on empirical AF can be significant even for low to moderate source concentrations.

\[
AF_{emp} = AF_{v1} + \frac{C_{Bkgd}}{C_{Sub}}
\]

All curves assume \( AF_{v1} = 0.003 \)
VI Database to Assess California-Specific Empirical AF

- 31 Sites
  - 27 sites from study team
  - 4 from EPA DB
- Over 400 buildings
- Foundation construction: slab on grade and crawl space
  - No sites with basements available for sites included in study
- Land Use: residential, school, commercial, industrial, military
- COPCs: mostly TCE & PCE, but some other analytes included
- Paired indoor air and sub-slab / soil gas concentrations
Geographic distribution of California empirical VI data set covers major urban areas of the State

Sub-Slab Vapor

18 Sites
314 Buildings
1194 Empirical AFs

Soil Vapor

13 Sites
92 Buildings
986 Empirical AFs
Data analysis approach is similar to USEPA evaluation

- Calculate empirical AF for each indoor air / subsurface data pair (AF = $C_{ia}/C_{ss}$ or $C_{ia}/C_{sv}$)
  - Only include pre-mitigation sample results
  - Manually identify nearest subsurface data point
  - Exclude data if background source previously identified by source screening or multiple-lines of evidence evaluation (e.g., concentration ratio analysis)
  - Apply “Subsurface Concentration Screening” process to address background bias of empirical results
    - Subsurface concentrations less than 250 µg/m³ filtered from analysis
California empirical AF results are substantially lower than USEPA results

<table>
<thead>
<tr>
<th>Statistic</th>
<th>USEPA Database (Sub-slab)</th>
<th>California Database (Sub-Slab Vapor)</th>
<th>California Database (Soil Vapor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Emp AFs</td>
<td></td>
<td>299</td>
<td>385</td>
</tr>
<tr>
<td>Maximum</td>
<td>9.4E-1</td>
<td>9.3E-3</td>
<td>7.6E-3</td>
</tr>
<tr>
<td>95th %ile</td>
<td>2.6E-2</td>
<td>2.6E-3</td>
<td>1.6E-3</td>
</tr>
<tr>
<td>75th %ile</td>
<td>6.8E-3</td>
<td>5.3E-4</td>
<td>4.7E-4</td>
</tr>
<tr>
<td>50th %ile</td>
<td>2.7E-3</td>
<td>1.2E-4</td>
<td>1.2E-4</td>
</tr>
<tr>
<td>25th %ile</td>
<td>1.5E-3</td>
<td>2.8E-5</td>
<td>4.0E-5</td>
</tr>
<tr>
<td>Minimum</td>
<td>2.5E-5</td>
<td>1.0E-7</td>
<td>1.9E-6</td>
</tr>
</tbody>
</table>

Note:
- Sub-slub dataset is predominantly comprised on non-residential structures
- Soil vapor dataset is predominantly residential structures with crawl space construction
Data can be further evaluated to assess impact of site conditions on AFs

AF Comparisons:
• PCE > TCE
  • Likely due to interior background sources of PCE
• SS-Res > SS-C/I
  • Likely due to building size and HVAC for C/I structures
• SS-Res > SV-Res
  • Due to increased diffusion path length for SV samples
• SV-C/I > SV-Res
  • Possibly due to sources beneath footprint of C/I buildings
• Limited data sets for some categories
Data can be further evaluated to assess impact of site conditions on AFs

<table>
<thead>
<tr>
<th>Media</th>
<th>AF Statistics</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>All</td>
</tr>
<tr>
<td>Bldg Type</td>
<td>All</td>
</tr>
<tr>
<td>Analyte</td>
<td>All</td>
</tr>
<tr>
<td># AFs</td>
<td>686</td>
</tr>
<tr>
<td>95%</td>
<td>2.0E-03</td>
</tr>
<tr>
<td>90%</td>
<td>1.2E-03</td>
</tr>
<tr>
<td>75%</td>
<td>5.1E-04</td>
</tr>
<tr>
<td>50%</td>
<td>1.2E-04</td>
</tr>
<tr>
<td>25%</td>
<td>3.5E-05</td>
</tr>
</tbody>
</table>
Similarity in residential/non-residential AFs is due to differences in source depth and mixing of VOCs in indoor air for large buildings

- Non-residential AFs largely from sub-slab data and residential AFs largely from deeper soil vapor data
  - AF reduction due to higher ventilation rate for non-residential buildings is balanced by AF increase due to sub-slab source
- For large buildings, AF in low-source concentration areas may be biased high by vapor intrusion in other parts of the building due to mixing in indoor air
  - Averaging of concentrations may be more informative than point-by-point ratios
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Typical Indoor Air Concentrations

- Many VOCs are present in indoor air due to our livelihood and products we bring into our homes and workspace
  - *Some at levels which can exceed regulatory screening levels*
  - *Many chlorinated VOCs also common and commercially available*

- Multiple publications on background indoor air concentrations and ambient sources (see reference slide)
  - Will focus on USEPA 2011 and CARB 2009 (new buildings)
Indoor air quality in new, residential homes

- 108 new, single family detached homes in Northern and Southern California
- Objective was to assess homeowner use of windows, exhaust fans and other mechanical ventilation to remove indoor air contaminants
  - Multi-season sampling in 2007-2008
Figure 13. Benzene concentration cumulative frequency distribution – All Home Sample Frame.

Max = 15.1 μg/m³

Median (50%) Indoor Concentration = 1.1 μg/m³

Outdoor Air = 0.3 μg/m³

20% of indoor and 0% of outdoor samples above the Proposition 65 Reproductive Toxicity MADL of 2.5 μg/m³

63% of indoor and 28% of outdoor samples above the Proposition 65 Cancer NSRL of 0.7 μg/m³

0% of indoor and 0% of outdoor samples above the OEHHA Chronic Reference Exposure Level of 60 μg/m³
Figure 20. Tetrachloroethene concentration cumulative frequency distribution – All Home Sample Frame.
Background Indoor Air Considered in Developing EPA Vapor Intrusion Database

Table 5. Upper-end background indoor air concentrations of common VOCs measured in North American residences between 1990 and 2005 used to screen EPA’s vapor intrusion database.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Median of 90th Percentile Conc. (µg/m³)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>9.5</td>
<td>11</td>
</tr>
<tr>
<td>Carbon tetrachloride</td>
<td>0.8</td>
<td>5</td>
</tr>
<tr>
<td>Chloroform</td>
<td>4.0</td>
<td>9</td>
</tr>
<tr>
<td>Dichloroethane, 1,1-</td>
<td>&lt;RL</td>
<td>2</td>
</tr>
<tr>
<td>Dichloroethane, 1,2-</td>
<td>0.1</td>
<td>7</td>
</tr>
<tr>
<td>Dichloroethylene, 1,1-</td>
<td>0.8</td>
<td>2</td>
</tr>
<tr>
<td>Dichloroethylene, cis 1,2-</td>
<td>&lt;RL</td>
<td>3</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>8.9</td>
<td>7</td>
</tr>
<tr>
<td>Methyl tert-butyl ether (MTBE)</td>
<td>38</td>
<td>4</td>
</tr>
<tr>
<td>Methylene chloride</td>
<td>10.5</td>
<td>8</td>
</tr>
<tr>
<td>Tetrachloroethylene</td>
<td>3.8</td>
<td>10</td>
</tr>
<tr>
<td>Toluene</td>
<td>54</td>
<td>9</td>
</tr>
<tr>
<td>Trichloro-1,2,2-trifluoroethane, 1,1,2- (Freon 113)</td>
<td>1.8</td>
<td>3</td>
</tr>
<tr>
<td>Trichloroethane, 1,1,1-</td>
<td>3.1</td>
<td>8</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>0.5</td>
<td>9</td>
</tr>
<tr>
<td>Vinyl chloride</td>
<td>0.01</td>
<td>4</td>
</tr>
<tr>
<td>Xylene, m/p-</td>
<td>21</td>
<td>9</td>
</tr>
<tr>
<td>Xylene, o-</td>
<td>10.8</td>
<td>9</td>
</tr>
</tbody>
</table>

aData source is the Background Indoor Air Report (EPA, 2011a).

bN = Number of studies reporting the 90th percentile.
Residential Indoor Air Screening Levels vs. Typical Background (50th percentile)

This illustrates residential background indoor air is associated with cumulative risks well above the threshold risk management levels.

1. Residential Air Screening Levels: HERO HRRA Note 3, 2018; Note 5, 2014
2. Indoor Air Background: benzene, PCE and TCE from USEPA, 2011 (max 50th%), naphthalene from Rago et al. 2017.
2. Percentiles calculated by applying 0.03 AF to max of indoor air ranges from USEPA, 2011.
3. 50x background from max of 90th %, USEPA, 2011.
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R2: Context for Calculating Soil Vapor Clean-Up Goals

- **Multiple Lines of Evidence (MLE) –** Understand pros and cons of each line of evidence (LOE)
- **Applicability of Generic Subslab/Soil Vapor AF (0.03) –** Most applicable to slab-on-grade residences and subslab soil vapor
- **Alternative Levels –** Most appropriate for commercial/industrial buildings and deeper vapor sources (e.g., groundwater ≥ 20 feet bgs)
- **Site-Specific vs Building-Specific AF**
Example LOEs for Site-Specific or Building-Specific Soil Vapor Levels

- **Source to Slab AFs (Site-Specific)**
  - Johnson & Ettinger model
  - Multi-depth soil gas samples

- **Slab to Indoor Air AFs* (Building-Specific)**
  - Paired subslab and indoor air samples
  - Mass flux/mass loading (ESTCP/McAlary 2018)
  - Vapor flux model for ventilated garages

*R2 Perspective on Building-Specific AFs:*
- Building-specific AFs vary over time due to different HVAC operation, remodeling, or damage
- Cannot effectively restrict how buildings are used
R2: Conceptual Model for Soil Vapor Intrusion

\[(AF_{SG-IA}) = (AF_{SG-SS}) \times (AF_{SS-IA})\]

AF = attenuation factor

- Indoor Air (IA)
- Subslab Soil Gas (SS)
- Soil Gas (SG)

Ground Surface

AF_{SS-IA} = Building-Specific

AF_{SG-IA} = Site-Specific

ESL User’s Guide Figure 5-4
2017 EPA J&E Spreadsheet

- **The Good:**
  - Multi-chemical analysis
  - Informative and helpful updated User’s Guide

- **The Bad**
  - Error in TCE risk calculation for commercial workers
  - Awkward conceptual model for crawl space scenario

- **The Ugly**
  - New “default” input values and typical ranges create confusion on recommended assumptions
  - Uncertainty analysis results are limited
  - Output includes unnecessary details for VI pathway interpretation

- USEPA is planning to update workbook in future
R2: J&E Model Use Recommendations

- R2 recommends using the 2004 J&E due to errors in 2017 J&E – recent communications with USEPA

- 2004 USEPA J&E Soil Gas or Groundwater (1- or 3-layer)
  - Use only for AFs after updating chemical properties
  - Adjust for generic $A_{SS-IA}$ (0.03)
  - Separately calculate risk/hazards
  - Follow Model Checklist in ESL User’s Guide/webpage
  - R2 may require calibration and/or verification monitoring
Many assumptions, most parameters not measured

Accuracy: about an order of magnitude (Hers et al. 2003)
Detailed data evaluation shows AF dependence on depth and demonstrates that modeling can provide conservative estimates

- Empirical data based on soil vapor and indoor air data collected at 27 LA-area residences
- USEPA and SFBRWQCB default AFs are conservative
- J&E Model with typical input assumptions provides conservative estimate
- Difference between PCE and TCE AFs likely due to background bias
R2: Common J&E Trouble Spots (2013-2016)

Pie chart reads clockwise

- Most frequent issue
  - Soil Layer Design
  - Qsoil / Building Size
- Less frequent issues
  - Modified Model
  - Concentration
  - Temperature
  - Depth to GW
  - Toxicity Values
  - Exposure Factors
Soil Physical Properties

- EPA spreadsheets include default soil physical properties for 12 USCS soil types
- Collect soil samples for grain-size distribution analysis for site-specific characterization
- Plot results on USCS soil classification chart to support soil type selection
- Develop CSM to support continuity of stratigraphic diffusive barriers (i.e., low-perm zones)

https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054167
Using Site-Specific Soil Data

- Historically, statistics on soil properties used for model inputs
- Alternate approach is to base input on evaluation of calculated effective diffusion coefficient for different samples

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Depth (ft bgs)</th>
<th>Soil Stratum</th>
<th>Total Porosity (Vb)</th>
<th>Water-Filled Porosity (Vb)</th>
<th>Air-Filled Porosity (Vb)</th>
<th>TCE Calculated Deff (cm²/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASVP-2</td>
<td>5</td>
<td>A</td>
<td>0.410</td>
<td>0.253</td>
<td>0.158</td>
<td>0.00088</td>
</tr>
<tr>
<td>BSVP-3</td>
<td>5</td>
<td>A</td>
<td>0.392</td>
<td>0.286</td>
<td>0.106</td>
<td>0.00026</td>
</tr>
<tr>
<td>VE-2</td>
<td>5</td>
<td>A</td>
<td>0.382</td>
<td>0.232</td>
<td>0.151</td>
<td>0.00087</td>
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<tr>
<td>SVMP-1D</td>
<td>5</td>
<td>A</td>
<td>0.405</td>
<td>0.241</td>
<td>0.164</td>
<td>0.00102</td>
</tr>
<tr>
<td>ASVP-3</td>
<td>20</td>
<td>B</td>
<td>0.381</td>
<td>0.304</td>
<td>0.078</td>
<td>0.00010</td>
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<tr>
<td>ASVP-5</td>
<td>20</td>
<td>B</td>
<td>0.459</td>
<td>0.322</td>
<td>0.138</td>
<td>0.00045</td>
</tr>
<tr>
<td>BSVP-1</td>
<td>20</td>
<td>B</td>
<td>0.414</td>
<td>0.307</td>
<td>0.107</td>
<td>0.00024</td>
</tr>
</tbody>
</table>
R2: Soil Vapor Entry Rate ($Q_{SOIL}$)

- Typical error with $Q_{SOIL}$ is failing to scale up the value for non-default size buildings.

$Q_{SOIL}$ should be 5 liters per minute per 100 square meters of footprint (DTSC VIG Table 3)

$Q_{SOIL}$ should be scaled up by $>3x$
R2: Multi-Depth Soil Vapor Samples

- Use actual soil vapor data to calculate $AF_{SG-SS}$
- Most applicable away from release areas
- Key issue: surface conditions at time of sampling
- Seasonable variability

Is the surface paved? If so, what is the condition:
- tight
- leaky

Depth (Feet)

- 0.8
- 0.7
- 0.6
- 0.5
- 0.2
- 0.1
- 0.9
R2 Case Study 1: Background

- PCE groundwater plume migrating onto site
- Redevelopment into multi-unit residential (on grade)
- Two LOEs developed:
  - J&E model
  - multi-depth soil vapor samples
Site hydrogeology

- Mostly coarse alluvial soils, discontinuous layers
- Depth to groundwater about 25 feet bgs

Soil vapor sampling

- 2019 sampling round
  - 11 locations beneath footprint of future residential building
  - Two depths: shallow (3 to 5 ft bgs), deep (17 ft bgs)
- Surface conditions: paved or covered with existing buildings. Inspection results indicated good condition (treated as tight)
R2: Case Study 1: Soil Vapor Sample Depths

15 feet beneath foundation
Deepest SV sample for VI evaluation

Case study SV samples
R2 Case Study 1: J&E Model LOE

- Used 2004 J&E 3-layer soil gas model
  - Two sand layers, with default values
  - Modeled from 152 cm bgs (5 feet bgs)
  - Building size and $Q_{SOIL}$ scaled from defaults
  - $AF_{SG-IA} = 0.0011$ (~900x)

- Adjustment for generic SG-SS AF (0.03)
  - Model subslab AF – 0.0021 (~480x)
  - $AF_{JE-SG-SS} = (AF_{JE-SG-IA} / AF_{JE-SS-IA}) = 0.0011/0.0021 = 0.52$
  - $AF_{ADJ-SG-IA} = AF_{JE-SG-SS} [0.5] \times AF_{Generic-SS-IA} [0.03] = 0.015$ (~70x)
  - Note: $AF_{ADJ-SG-IA}$ is from 5-feet bgs
R2 Case Study 1: Multi-Depth Soil Vapor Sample LOE

- Multi-depth soil vapor data (single round)
  - Treated shallow SV samples as subslab equivalent
  - Estimated $AF_{EMP-SG-SS}$ values from 0.3 (3x) to 0.5 (2x)

<table>
<thead>
<tr>
<th>Soil Vapor (SV) Samples</th>
<th>Arithmetic Mean ($\mu g/m^3$)</th>
<th>95UCL ($\mu g/m^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow SV</td>
<td>282</td>
<td>910</td>
</tr>
<tr>
<td>Deep SV</td>
<td>842</td>
<td>1,762</td>
</tr>
</tbody>
</table>

- $AF_{SG-SS}$ (source to slab) = $0.33 (3x)$
- $AF_{EMP-SG-IA} = 0.5 \times 0.03 = 0.015 (70x)$ from 17-feet bgs
Case Study: Site-specific empirical attenuation factors from paired sub-slab and indoor air samples

- Collected paired sub-slab and indoor air samples from over 200 single family homes in residential neighborhood
  - 3 sub-slab sample locations per home
  - 2 indoor air sample locations per home
  - 2 sampling events to assess temporal variability
  - Sampling conducted over multiple years which aids in temporal variability assessment

- Estimated site-specific background indoor air concentrations based on properties with target analytes not detected in subsurface
Case Study: Empirical data analysis demonstrates that sub-slab AF = 0.002 is protective

- Data indicate background sources have significant impact on indoor air quality and empirical AFs
- Due to relatively low sub-slab concentrations, it is impractical to estimate building-specific AFs
- Sub-slab to indoor air attenuation factor of 0.002 provides upper-bound estimate for Site-specific assessment
Radon-Based Empirical Attenuation Factors

- Interest in using radon measurements to assess building-specific attenuation factors
- Small incremental cost to typical VI studies
- Limited interior sources make radon a good tracer to assess VI
  - But need to consider outdoor air contributions
  - Typical outdoor air radon concentrations are 0.2 to 0.4 pCi/L
Outdoor air radon concentrations will impact interpretation of empirical attenuation factor data

- Outdoor air radon will make empirical AF higher than VI attenuation factor
- Bias may be present when sub-slab radon concentrations less than 400 – 1000 pCi/L
- Include outdoor air measurements in data collection and interpretation
Case Study: Radon measurements used to assess VI attenuation factors for new construction with vapor barriers

- Radon data collected at 41 structures constructed with vapor barriers
- Median outdoor air radon concentration = 0.26 pCi/L
- Range of empirical AFs observed,
- When background contribution considered, AF_VI is approximately 0.0005

Data courtesy of Glenn Tofani, GeoKinetics
Pneumatic-Based Attenuation Factors

- Sub-slab extraction with flow and vacuum measurements used to calculate building-specific sub-slab to indoor air attenuation factors
- Analysis not affected by background sources of chemicals

McAlary, et al., 2018. Fluid Flow Model for Predicting the Intrusion Rate of Subsurface Contaminant Vapors into Building. ES&T. 52(15)
Pneumatic-Based Attenuation Factors
Mathematical Basis

- Extraction test data evaluated following Hantush-Jacob analysis to identify:
  - Leakage Factor, $B$: 
    $$B = \sqrt{\frac{K b b'}{K'}}$$
  - Sub-slab transmissivity, $T$:
    $$T = K b$$

- Results used to calculate AF
  $$AF = \frac{Q_{soil}}{Q_{Bldg}} = \frac{T \Delta P}{B^2 h AER}$$
Pneumatic-Based Attenuation Factors Example Results

Measured values:
- $T = 54 \text{ ft}^2/\text{d}$
- $B = 5.5 - 18 \text{ ft}$
- $\Delta P = 2 \text{ Pa}$
- $h = 15 \text{ ft}$
- $\text{AER} = 0.8 \text{ hr}^{-1}$

Pneumatic-based AF:
- $0.003 - 0.00003$
- Best estimate = $0.0003$
  (based on $B = 13 \text{ ft}$)

Concentration-based AF:
- $0.006 - 0.00002$
- Avg value = $0.0002$
R2: Case Study 2: Vapor Flux Model for Ventilated Garages with Overlying Residences

**Step 1 (AF\textsubscript{SS-GARAGE})**

- Assume AF\textsubscript{GENERIC-SS-IA} = 0.03 corresponds to default Air Exchange Rate (AER) of 0.5 changes/hour (DTSC VIG Table 3)
- Building code minimum AER: 2 changes/hour for garages
- \( AF\textsubscript{SS-GARAGE} = \frac{0.03}{2/0.5} = 0.0075 \) (130x)

**Step 2 (AF\textsubscript{SS-RES IA})**

- Use 0.1 from garage air to residences IA
- Basis: 2004 Minnesota tobacco study
- \( AF\textsubscript{SS-RES IA} = 0.0075 \times 0.1 = 0.00075 \) (1,300x)
Presentation Agenda

- Introduction
  Gina

- Regulatory Update
  Ross

- VI Empirical Attenuation Factors
  Robbie

- Impact of Background on VI Assessments
  Gina

- Site-Specific VI Cleanup Goals
  Ross, Robbie

- Strategies for Sites with VI Mitigation
  Gina

- Questions / Discussion
  All
Common Gaps in Assessment of Vapor Intrusion Mitigation System (VIMS) Effectiveness

- Screening Levels (SLs) are commonly being used for evaluation of VIMS effectiveness
- The EPA generic $AF_{SG-IA} (0.03)$ was calculated from homes without mitigation, so using SLs based on $0.03$ AF for VIMS action levels is not appropriate
- Further, without considering typical indoor air concentrations, evaluation of any $AF_{SG-IA}$ will lead to incorrect assumptions regarding effectiveness of VIMS
Case Study: Assessment of VIMS Effectiveness

- Chlorinated solvent GW plume with soil vapor impacts across property to be developed for residential use
- Soil vapor RAO = residential SLs (HERO Note 3) using 0.03 AF - which is not technically justified or appropriate

<table>
<thead>
<tr>
<th>COPC</th>
<th>Indoor Air RAO</th>
<th>Soil Vapor RAO (AF=0.03)</th>
<th>Soil Vapor RAO (AF=0.001)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trichloroethene (TCE)</td>
<td>0.48</td>
<td>16</td>
<td>480</td>
</tr>
<tr>
<td>Tetrachloroethene (PCE)</td>
<td>0.46</td>
<td>15</td>
<td>460</td>
</tr>
<tr>
<td>cis-1,2-dichloroethene</td>
<td>8.3</td>
<td>277</td>
<td>8300</td>
</tr>
<tr>
<td>trans-1,2-dichloroethane</td>
<td>83</td>
<td>2767</td>
<td>83,000</td>
</tr>
<tr>
<td>Vinyl chloride</td>
<td>0.0095</td>
<td>0.32</td>
<td>10</td>
</tr>
</tbody>
</table>

(concentrations in ug/m³)
Case Study (cont.): Improvement of Assessment Approach

- Two rounds of indoor air/vapor/outdoor air with VIMS in passive mode

<table>
<thead>
<tr>
<th>COPC</th>
<th>Indoor Air RAO</th>
<th>USEPA 50th percentile</th>
<th>Highest Indoor Air Concentration Reported</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trichloroethene (TCE)</td>
<td>0.48</td>
<td>1.1</td>
<td>0.305</td>
</tr>
<tr>
<td>Tetrachloroethene (PCE)</td>
<td>0.46</td>
<td>2.2</td>
<td>0.881</td>
</tr>
<tr>
<td>cis-1,2-dichloroethene</td>
<td>8.3</td>
<td>1.2</td>
<td>0.206</td>
</tr>
<tr>
<td>trans-1,2-dichloroethene</td>
<td>83</td>
<td>1.2</td>
<td>0.079</td>
</tr>
<tr>
<td>Vinyl chloride</td>
<td>0.0095</td>
<td>0.17</td>
<td>0.056</td>
</tr>
</tbody>
</table>

(concentrations in ug/m³)

- PCE is driver
- Only 9 of 50 samples had IA>AA; max = 0.29
Case Study (cont.): Improvement of Assessment Approach

- Building-specific AFs calculated
  - *Most conservative for buildings with lowest vapor concentrations*
- Typical indoor air concentrations not considered
- All detections in indoor air > outdoor air assumed to be from VI
  - *Does this make sense based on site conditions?*
    - Robust VIMS in-place
    - Indoor air concentrations are all within the range of typical indoor air concentrations
Case Study (cont.): Improvement of Assessment Approach

- Calculating AFs may not be technically appropriate or feasible
- Recommend using MLEs to support assessment
  - Existing subsurface data
  - Range of typical indoor air concentrations
  - COPC ratio analysis
  - Radon data as potential tracer
Case Study (cont.): Confirming Effectiveness

- Data supports VI is not occurring with VIMS in passive mode and with PCE vapor concentrations up to **11,000 ug/m³**.
- Trigger to active VIMS is currently **85 ug/m³** (PCE)-based on incorrect assumptions in calculating AFs.
- Site-specific empirical data supports that passive VIMS is effective and protective at more than **100X** the current trigger level.
Case Study (cont.): Developing Trigger Levels for VIMS

- Using the generic AFs from DTSC 2011, PCE vapor concentration of 11,000 ug/m³ = 4.2x10⁻⁴ risk

<table>
<thead>
<tr>
<th>AF</th>
<th>Risk</th>
<th>PCE (ug/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001</td>
<td>10⁻⁶</td>
<td>460</td>
</tr>
<tr>
<td>0.0001</td>
<td>10⁻⁵</td>
<td>4600</td>
</tr>
<tr>
<td>0.00001</td>
<td>10⁻⁴</td>
<td>46,000</td>
</tr>
</tbody>
</table>

- Empirical data supports passive VIMS is protective
- Building-specific empirical data can and should be used to develop appropriate active system trigger level
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Gina
Ross
Robbie
Gina
Ross, Robbie
Gina
All
Discussion
References


