Improving Risk-Based Decision Making at Vapor Intrusion Sites

Presented by

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Disclaimer

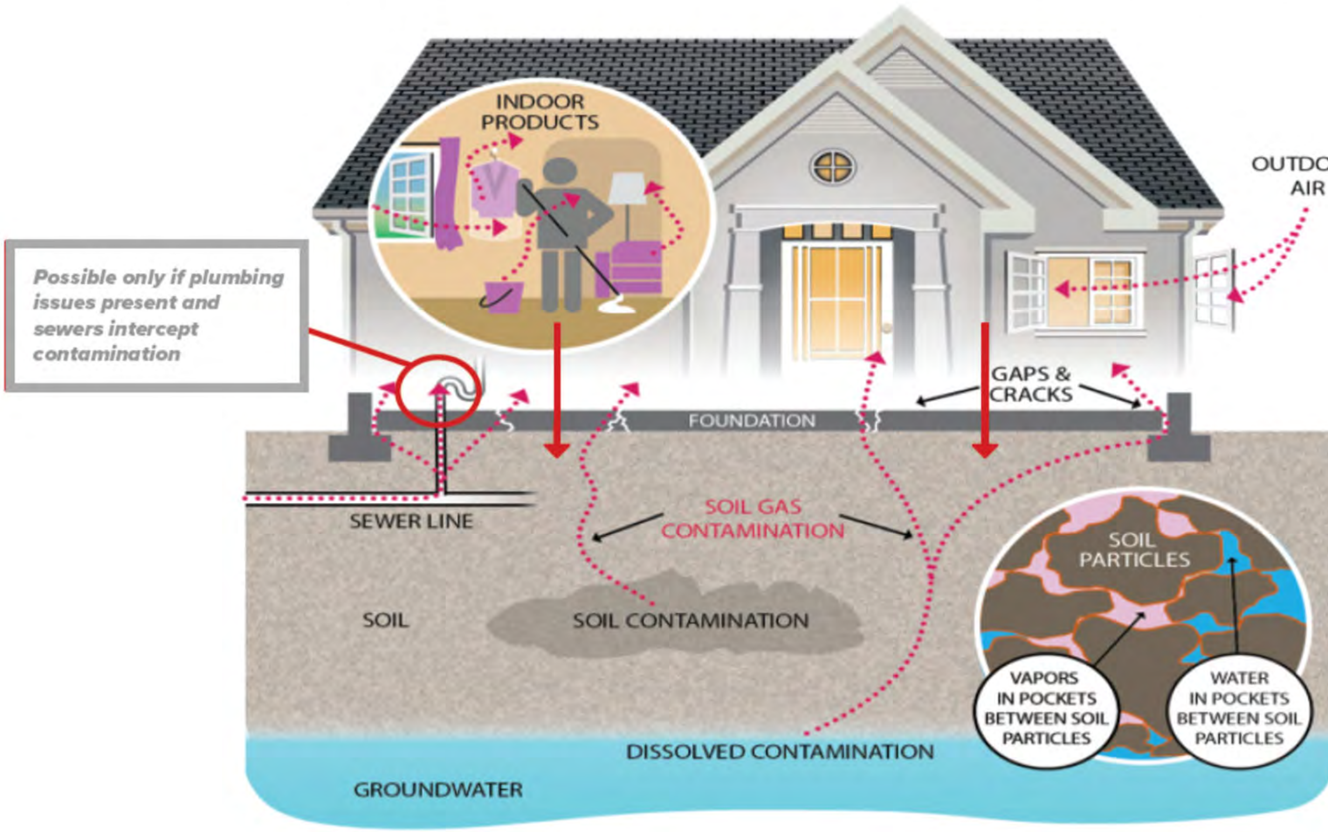
The views expressed herein are not those of the SF Bay Regional Water Board, State Board, Governor Newsom, the Pope, Dalai Lama, or even all three presenters

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



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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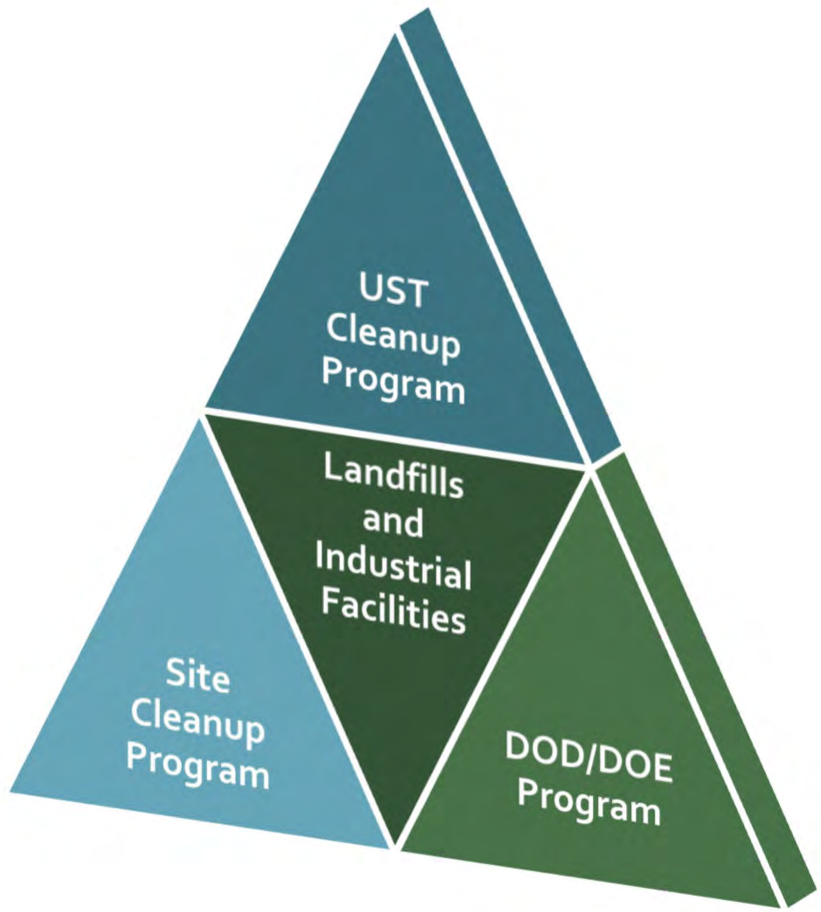
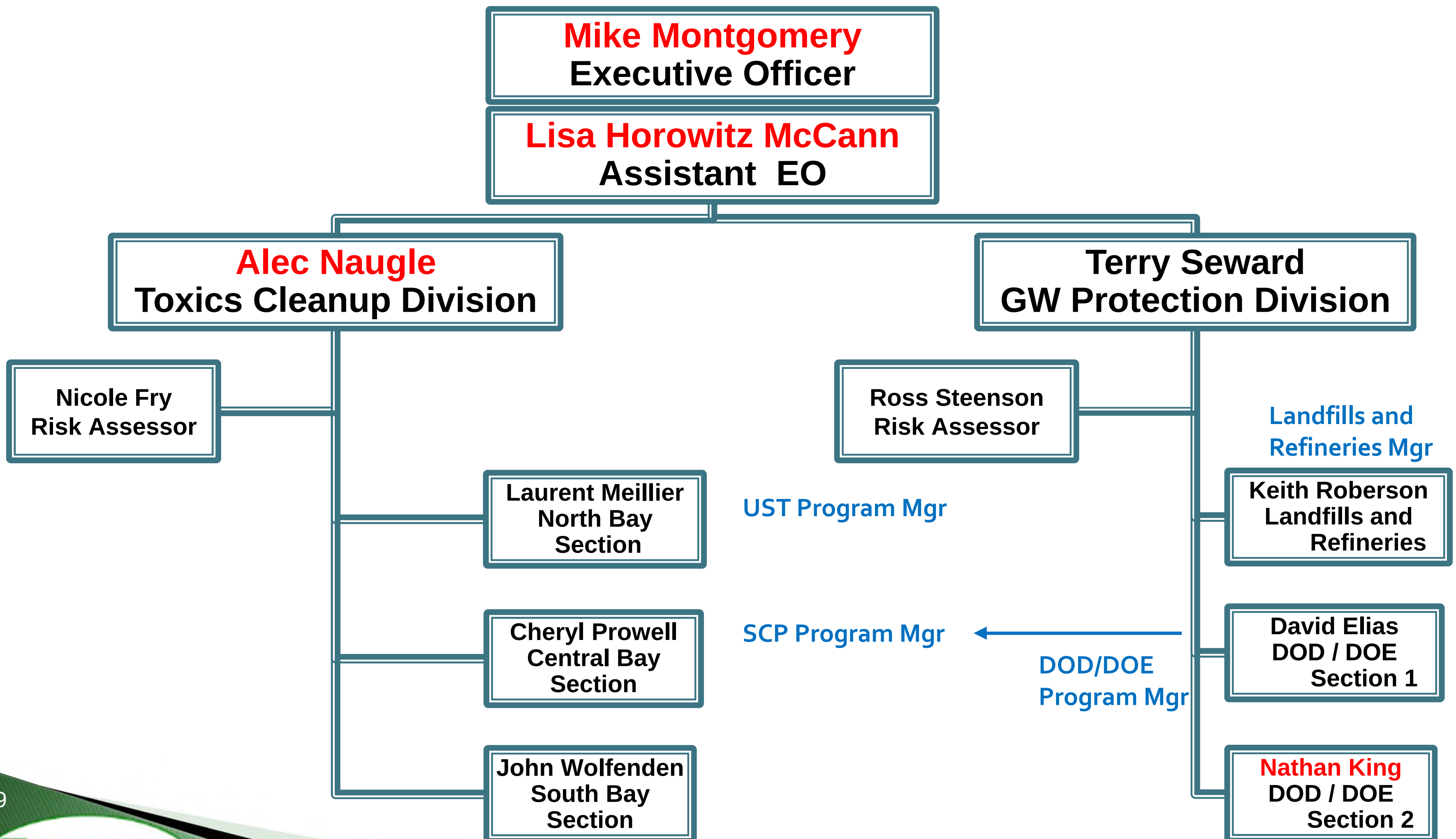
Water Board Groundwater Programs



SF Bay Regional Water Board (R2): Groundwater Divisions Update



R2 Evolving Approach to Vapor Intrusion: 2010-2020

— from "Model & Trust" to "Model but Verify"—

2010

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

2013

ESL update
- JEM-based AFs
- SG only (0.002)

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

2016

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

2019

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

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

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)

	J&E Model	USEPA	CA (2018)
Subslab	**0.002 (1/500)**	**0.03 (~1/30)** **218 buildings**	**0.01 (~1/100)*** **26 buildings**
Correct Value	Unknown	Unlikely May be conservative	Maybe Need more data
Protective	Not all cases Not RME	Yes	Maybe Need more data

** 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:

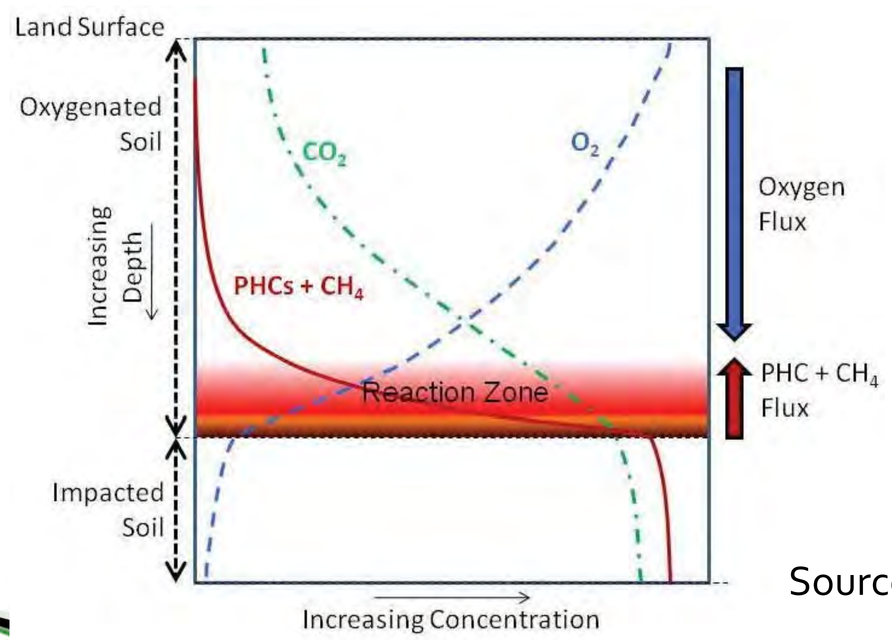
- Vapor and groundwater plumes:
  - Stable/decreasing (not spreading/ discharging)
  - Subsurface cleanup levels met in reasonable timeframe
- Indoor air: exposure controls not needed

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**

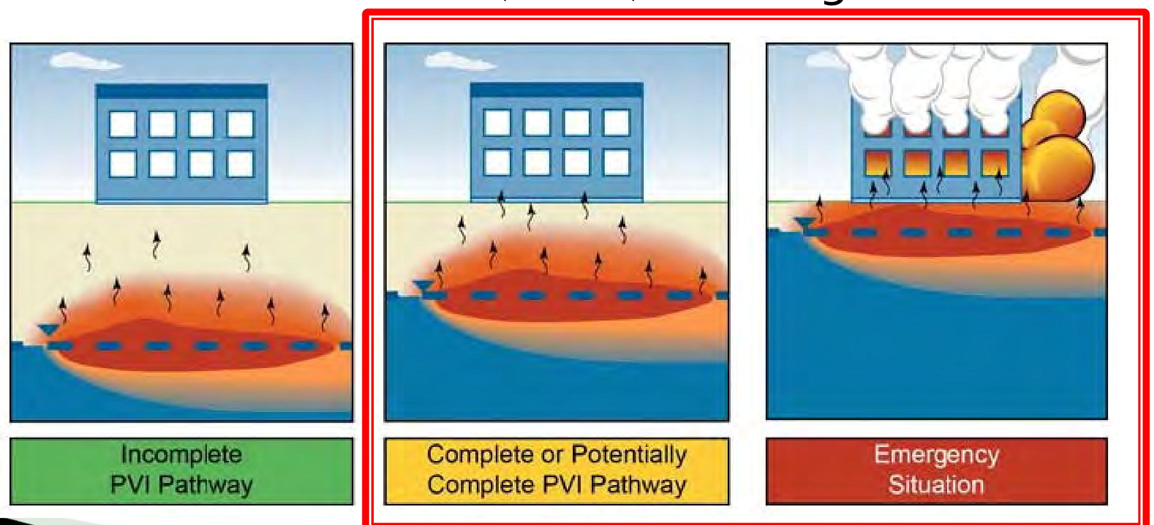


PHC – petroleum hydrocarbon
CH_4 – methane
O_2 – oxygen
CO_2 – carbon dioxide

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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USEPA developed VI database from sites across nation to assess empirical attenuation factors

USEPA, 2012. EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Compounds and Residential Buildings

- 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 sub-surface data used to calculate empirical attenuation factors
- Filtered data to screen out results likely impacted by background sources

Uncertainties and limitations to USEPA study need to be considered for VI screening and risk-based decision making

- 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

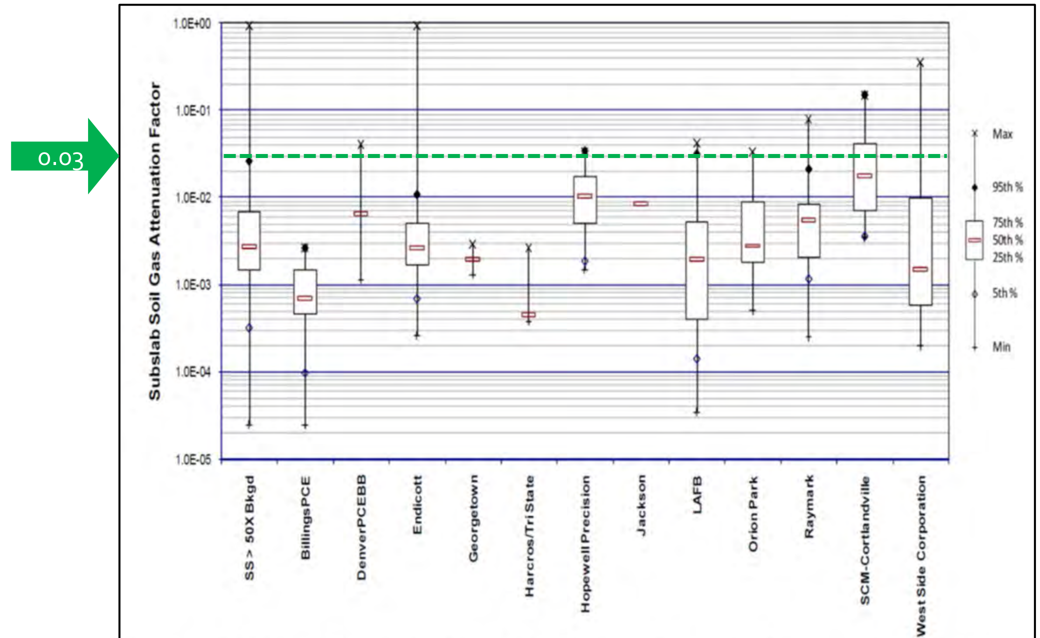
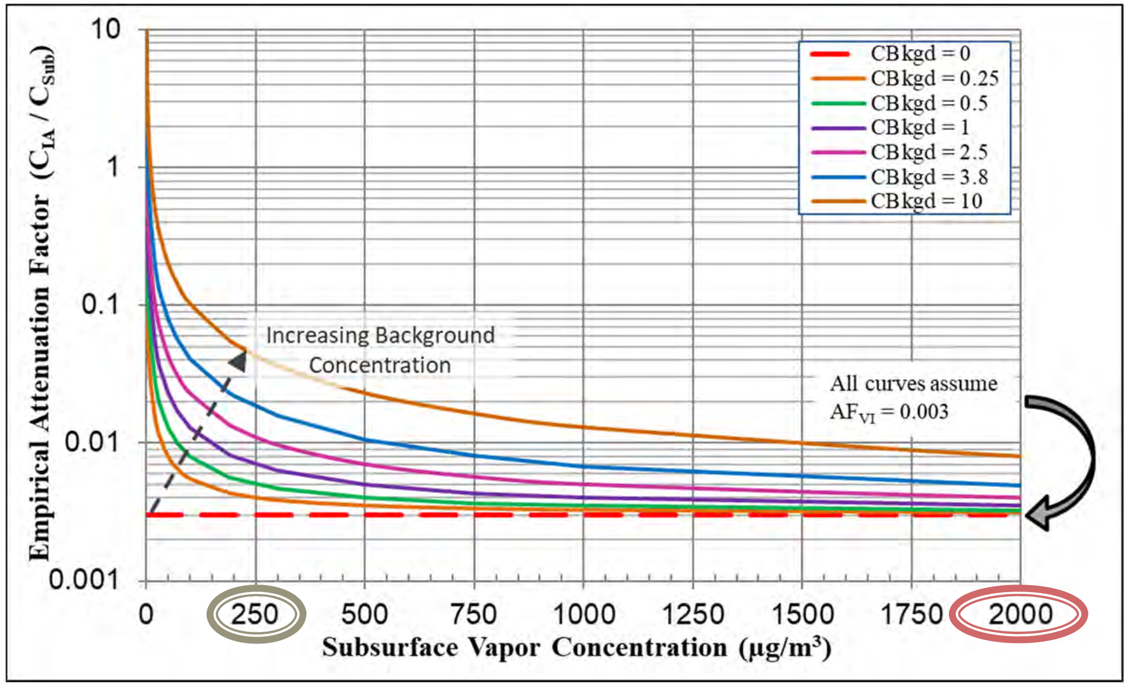


Figure 25. Box-and-whisker plots summarizing subslab soil gas attenuation factor distributions for individual sites after Source Strength Screen (subslab soil gas concentrations > 50 times "background").

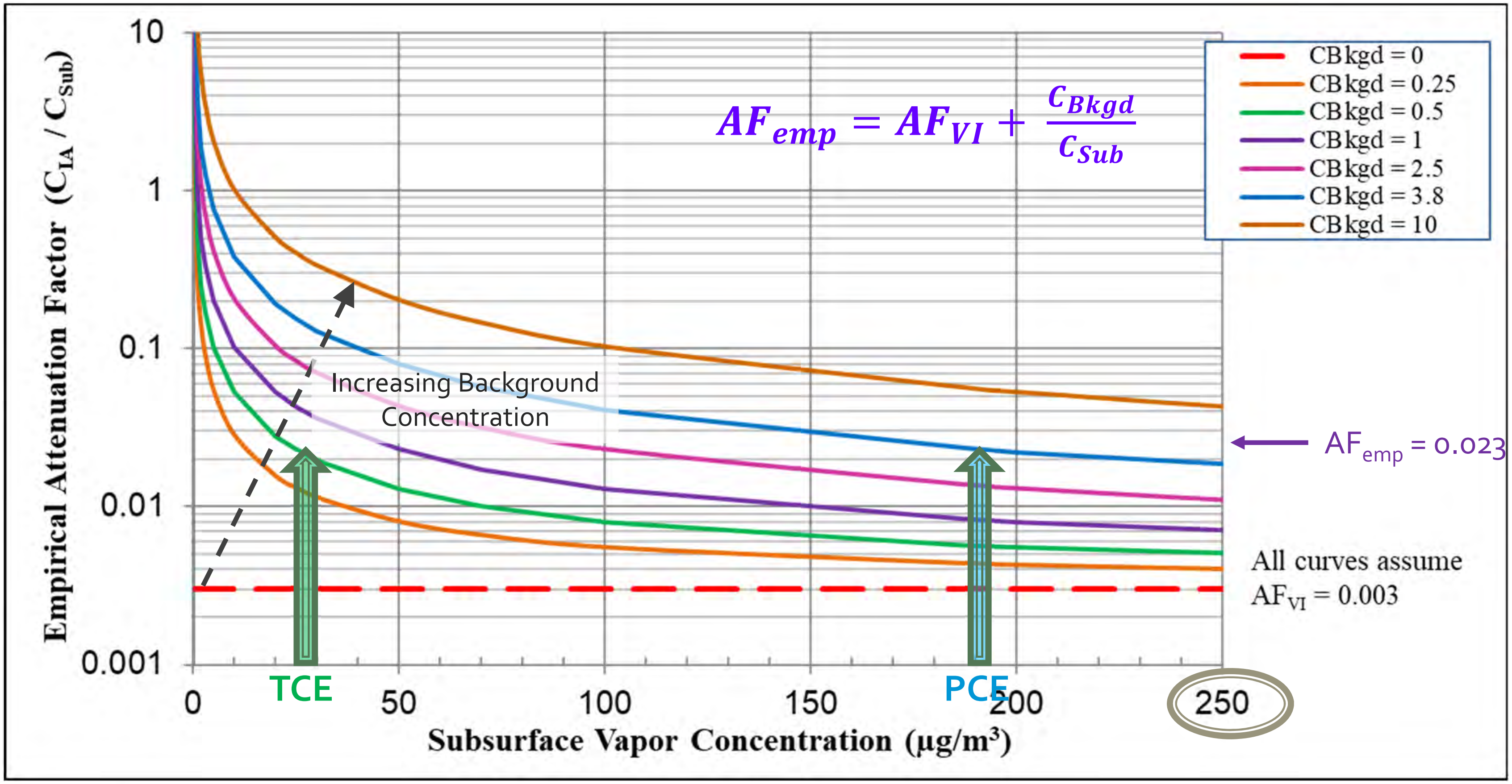
USEPA study recognized background sources can result in positive bias on empirical AFs

- 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

$$AF_{emp} = \frac{C_{IA}}{C_{Sub}} = AF_{VI} + \frac{C_{Bkgd}}{C_{Sub}}$$



Effect of background sources on empirical AF can be significant even for low to moderate source concentrations



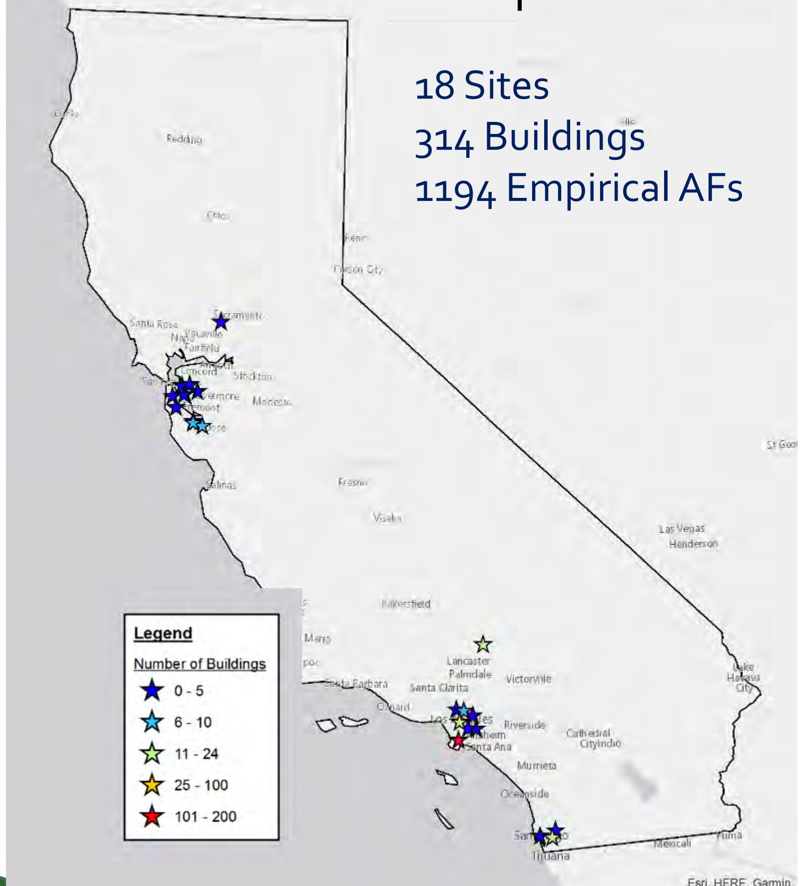
VI Database to Assess California-Specific Empirical AF

- 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

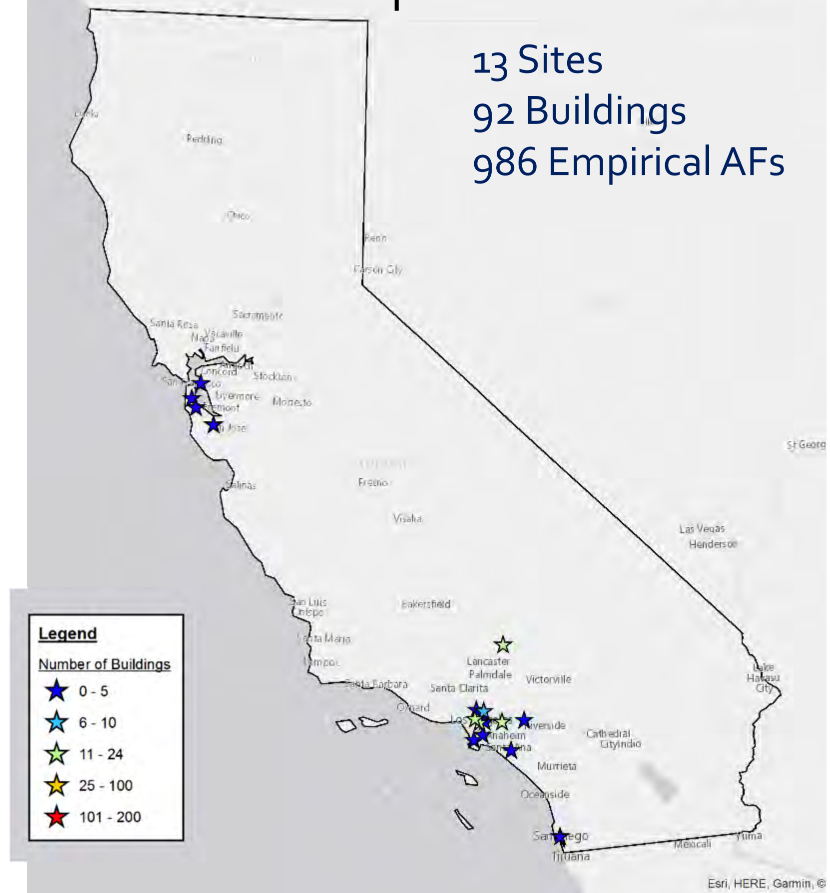
Sub-Slab Vapor

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/m^3 filtered from analysis

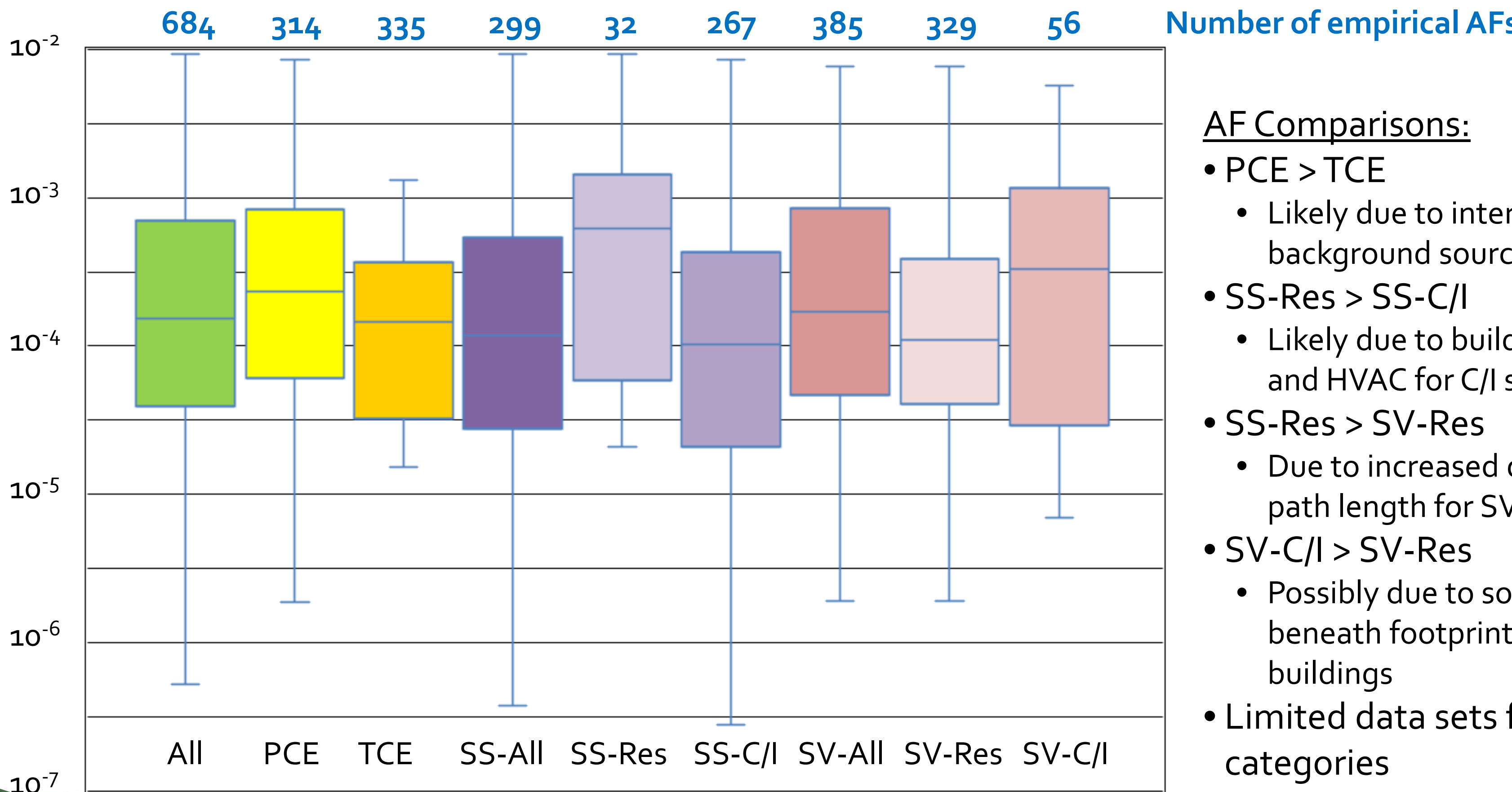
California empirical AF results are substantially lower than USEPA results

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

Note:

- Sub-slab 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



<u>AF Comparisons:</u>

- 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

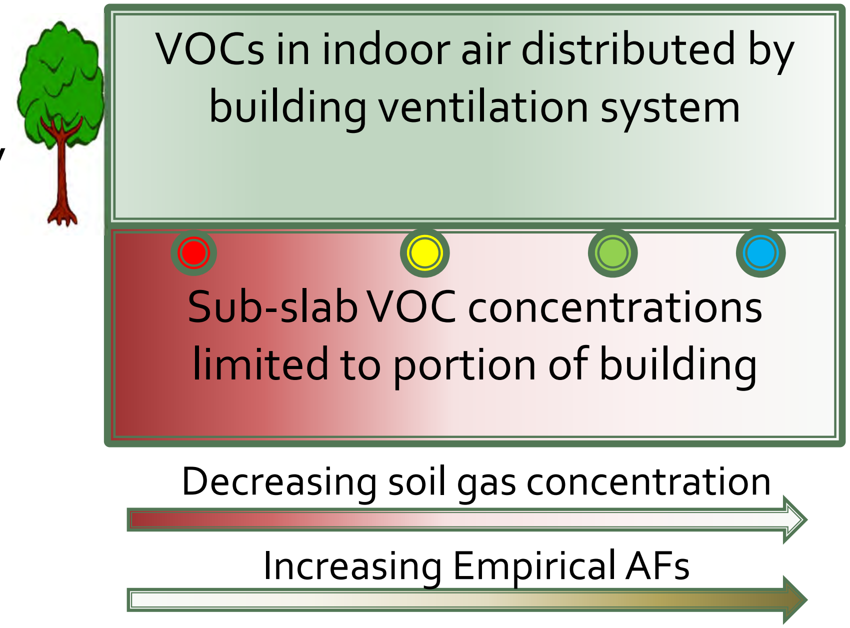
Data can be further evaluated to assess impact of site conditions on AFs

	AF Statistics								
Media	All	All	All	Sub-Slab			Soil Vapor		
Bldg Type	All	All	All	All	Res.	Comm / Indust.	All	Res.	Comm. / Indust.
Analyte	All	PCE	TCE	All	All	All	All	All	All
# AFs	686	314	335	299	32	267	385	329	56
95%	2.0E-03	2.5E-03	1.4E-03	2.6E-03	5.6E-03	2.1E-03	1.6E-03	1.1E-03	3.1E-03
90%	1.2E-03	1.5E-03	8.5E-04	1.5E-03	3.0E-03	1.3E-03	9.6E-04	8.5E-04	1.9E-03
75%	5.1E-04	6.9E-04	3.2E-04	5.3E-04	1.4E-03	4.2E-04	4.7E-04	3.9E-04	1.1E-03
50%	1.2E-04	1.9E-04	8.0E-05	1.2E-04	6.3E-04	1.0E-04	1.2E-04	1.1E-04	3.3E-04
25%	3.5E-05	5.8E-05	1.8E-05	2.8E-05	6.2E-05	2.1E-05	4.0E-05	4.1E-05	3.5E-05

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

Cross Sectional View



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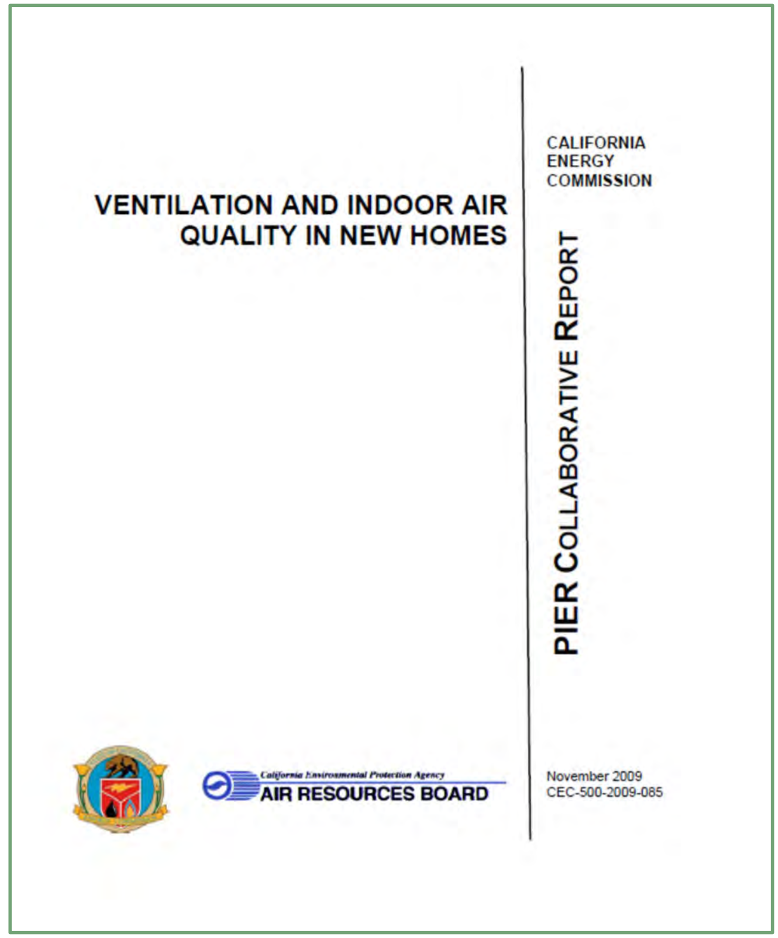
Typical Indoor Air Concentrations

- 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*



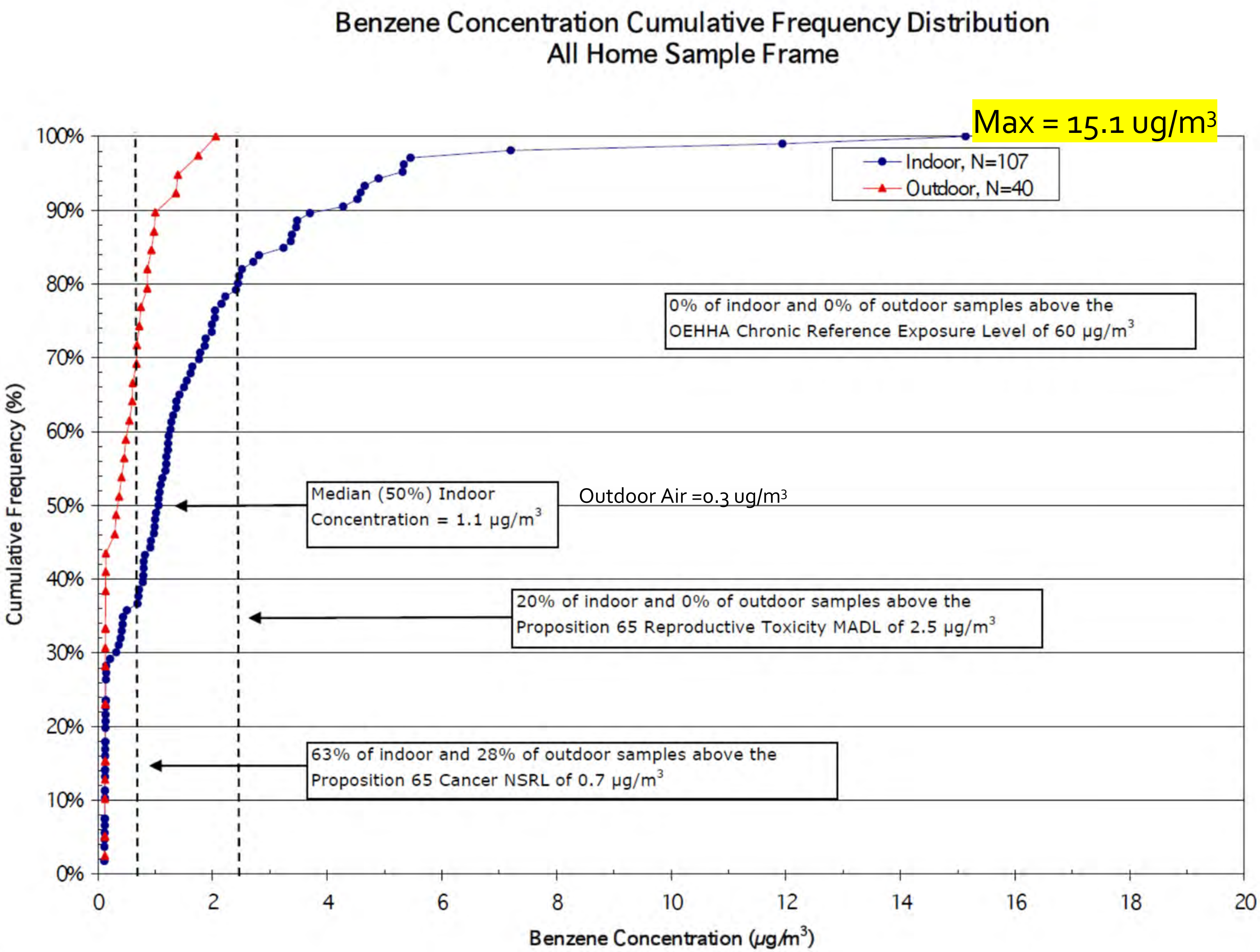


Figure 13. Benzene concentration cumulative frequency distribution – All Home Sample Frame.

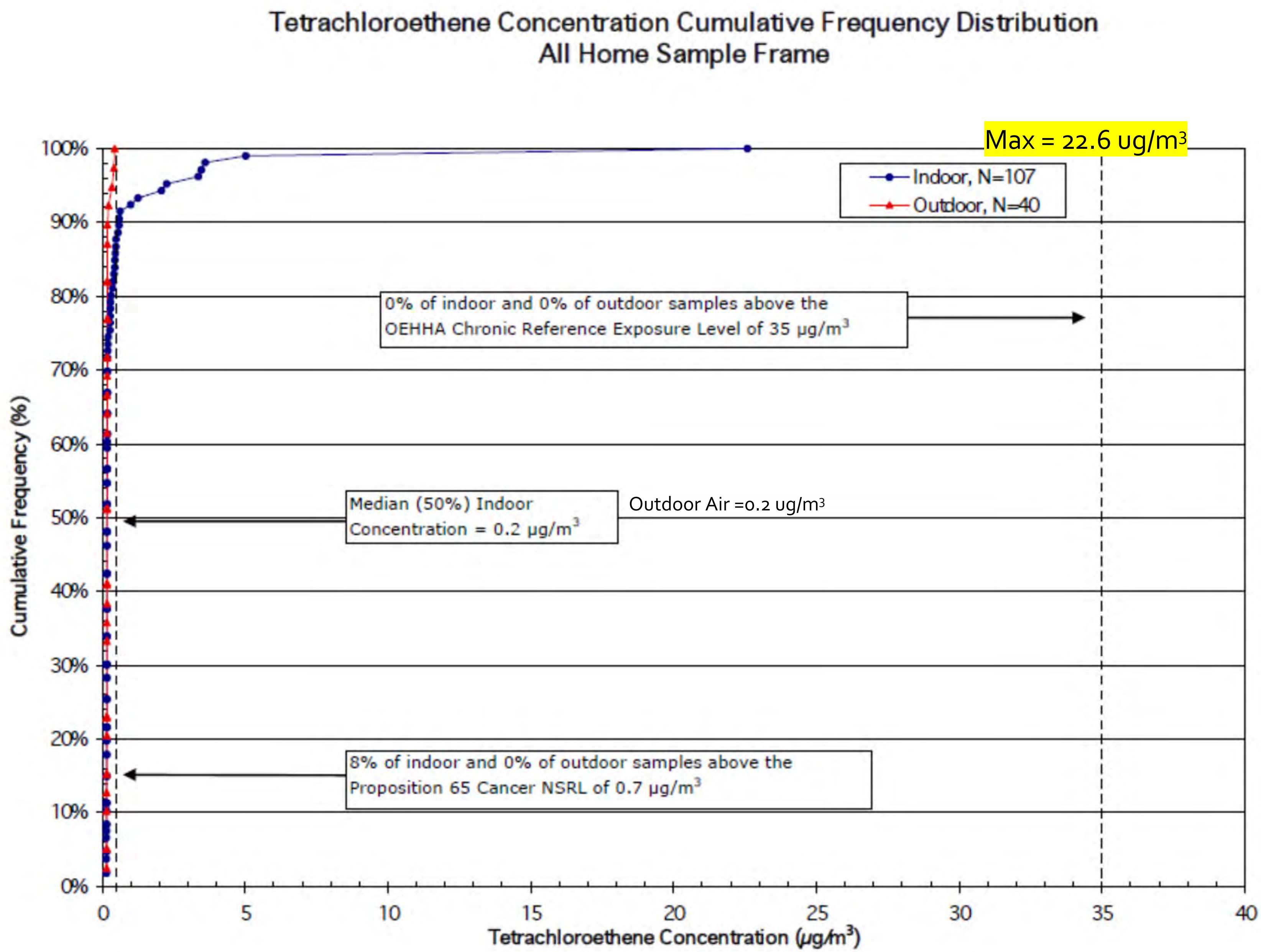


Figure 20. Tetrachloroethene concentration cumulative frequency distribution – All Home Sample Frame.

Background Indoor Air Considered in Developing EPA Vapor Intrusion Database

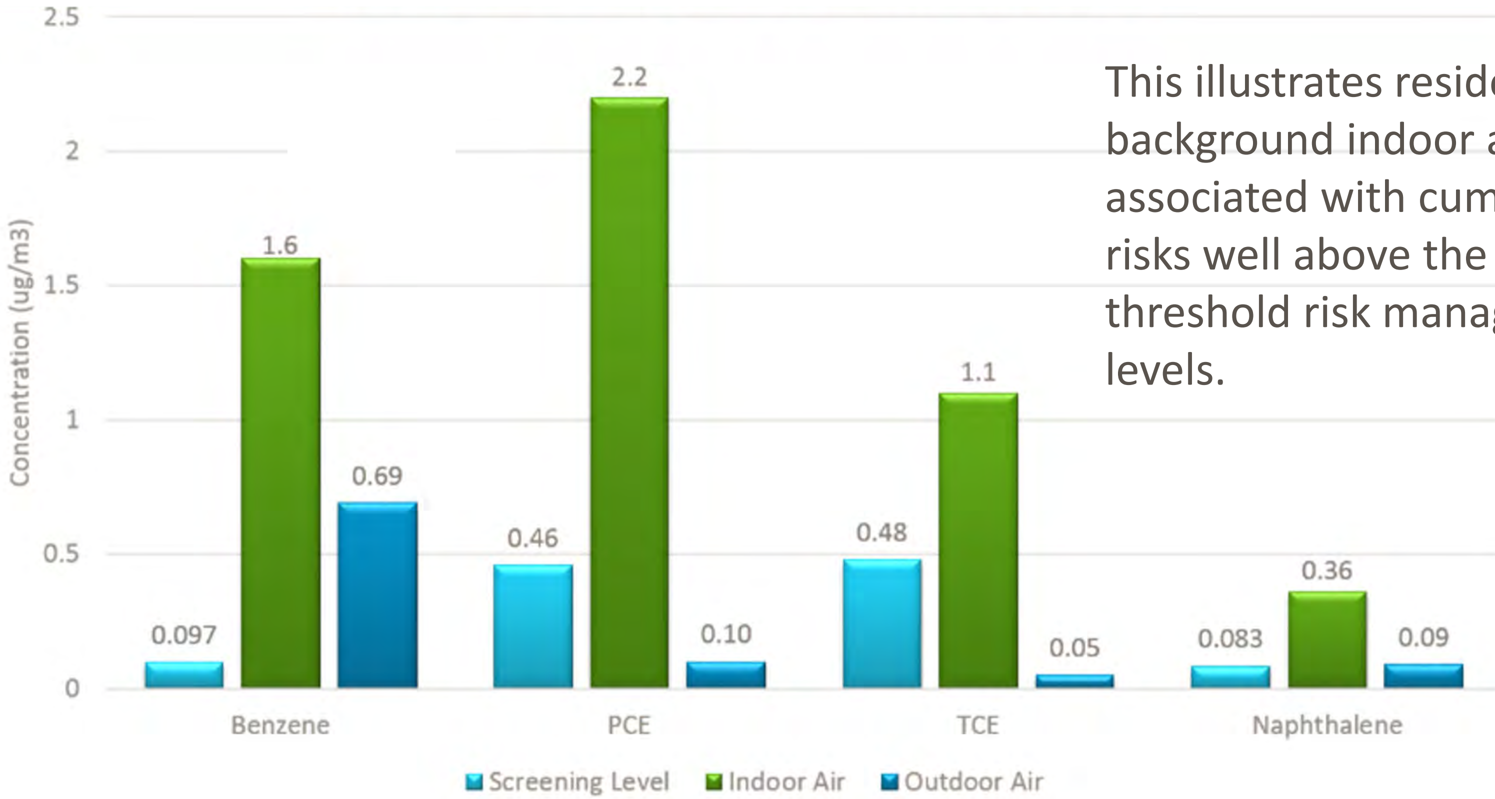
Table 5. Upper-end background indoor air concentrations of common VOCs measured in North American residences between 1990 and 2005 used to screen EPA's vapor intrusion database.

Compound	Median of 90th Percentile Conc.[a] ($\mu g/m^3$)	N[b]
Benzene	9.5	11
Carbon tetrachloride	0.8	5
Chloroform	4.0	9
Dichloroethane, 1,1-	<RL	2
Dichloroethane, 1,2-	0.1	7
Dichloroethylene, 1,1-	0.8	2
Dichloroethylene, cis 1,2-	<RL	3
Ethylbenzene	8.9	7
Methyl tert-butyl ether (MTBE)	38	4
Methylene chloride	10.5	8
Tetrachloroethylene	3.8	10
Toluene	54	9
Trichloro-1,2,2-trifluoroethane, 1,1,2- (Freon 113)	1.8	3
Trichloroethane, 1,1,1-	3.1	8
Trichloroethylene	0.5	9
Vinyl chloride	0.01	4
Xylene, m/p-	21	9
Xylene, o-	10.8	9

[a] Data source is the Background Indoor Air Report (EPA, 2011a).

[b] N = Number of studies reporting the 90th percentile.

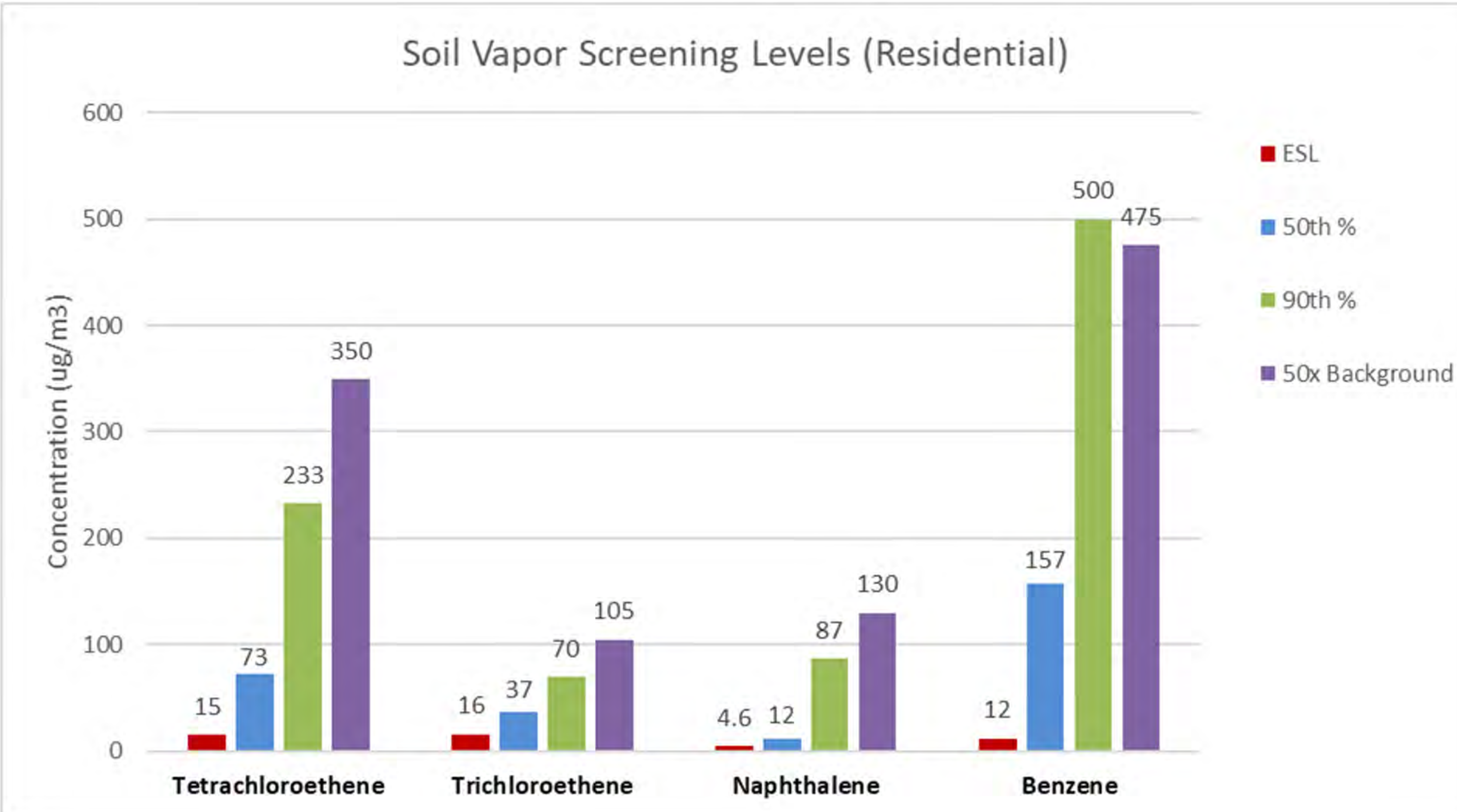
Residential Indoor Air Screening Levels vs. Typical Background (50th percentile)



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.
3. USEPA Air Quality System, California monitoring stations, 2010-2017 (2010-2015 Naphthalene). https://www.epa.gov/outdoor-air-quality-data

Generic Soil Vapor Screening Levels Based on Range of Background & Compared to EPA AF Source Screen



1. SFRWQCB Environmental Screening Levels, 2019. Residential Use.
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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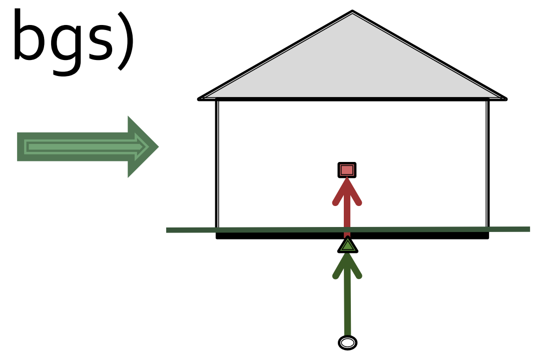
R2: Context for Calculating Soil Vapor Clean-Up Goals

- 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

- <u>Source to Slab AFs (Site-Specific)</u>
  - Johnson & Ettinger model
  - Multi-depth soil gas samples
- <u>Slab to Indoor Air AFs* (Building-Specific)</u>
  - Paired subslab and indoor air samples
  - Mass flux/mass loading (ESTCP/McAlary 2018)
  - Vapor flux model for ventilated garages

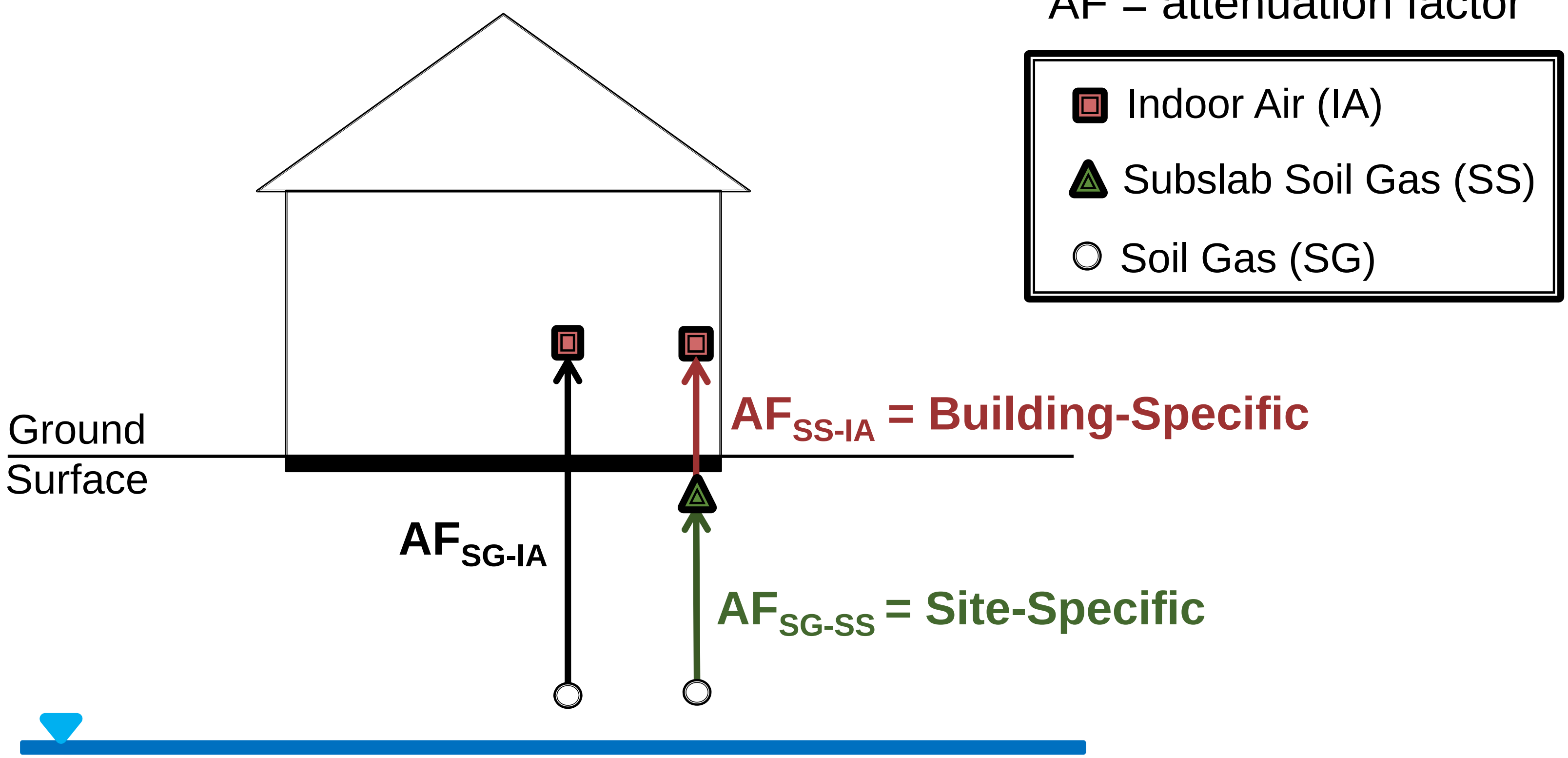
** R2 Perspective on Building-Specific AFs:*

- *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

$$(AF_{SG\text{-}IA}) = (AF_{SG\text{-}SS}) \times (AF_{SS\text{-}IA})$$

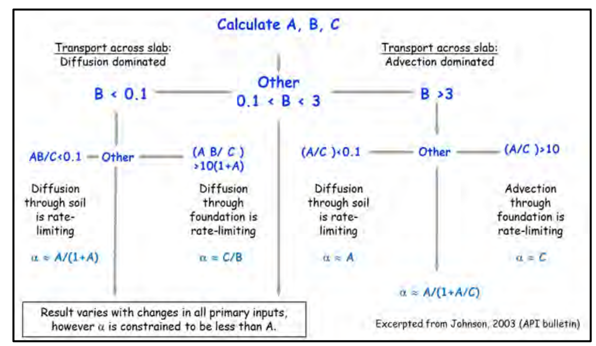
AF = attenuation factor



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

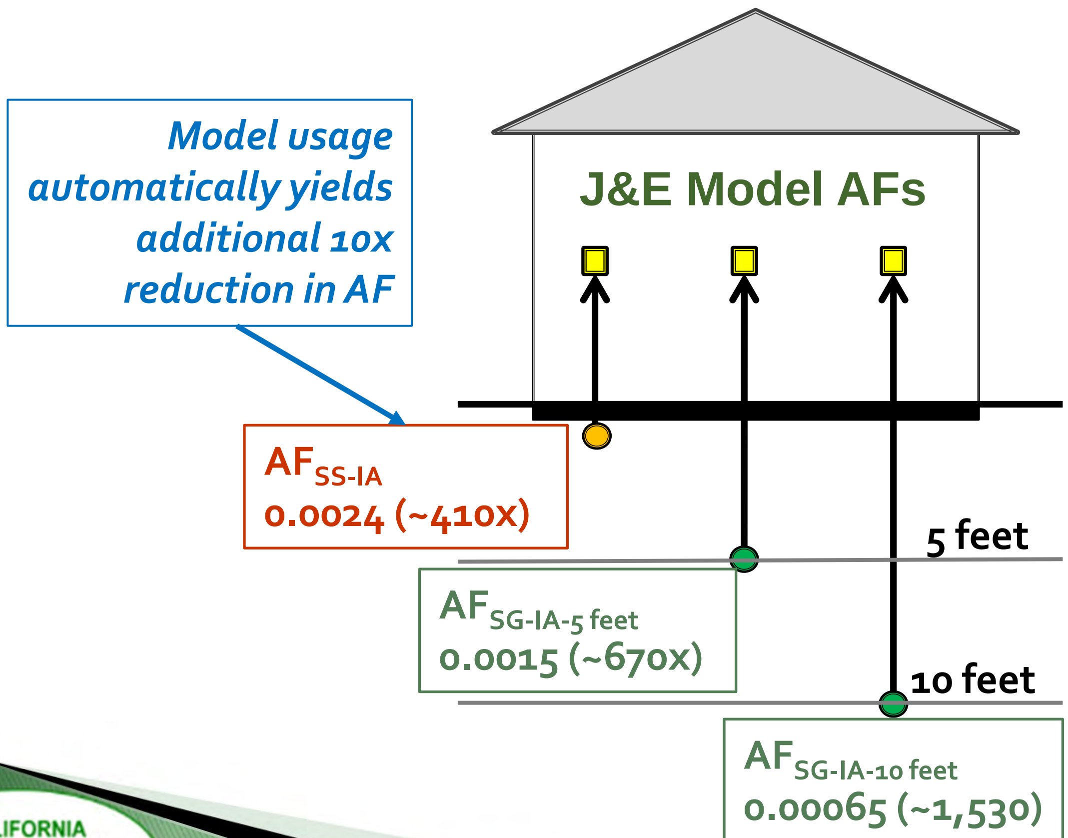


R2: J&E Model Use Recommendations

- 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 $AF_{SS\text{-}IA}$ (0.03)
  - Separately calculate risk/hazards
  - Follow Model Checklist in ESL User's Guide/webpage
  - R2 may require calibration and/or verification monitoring

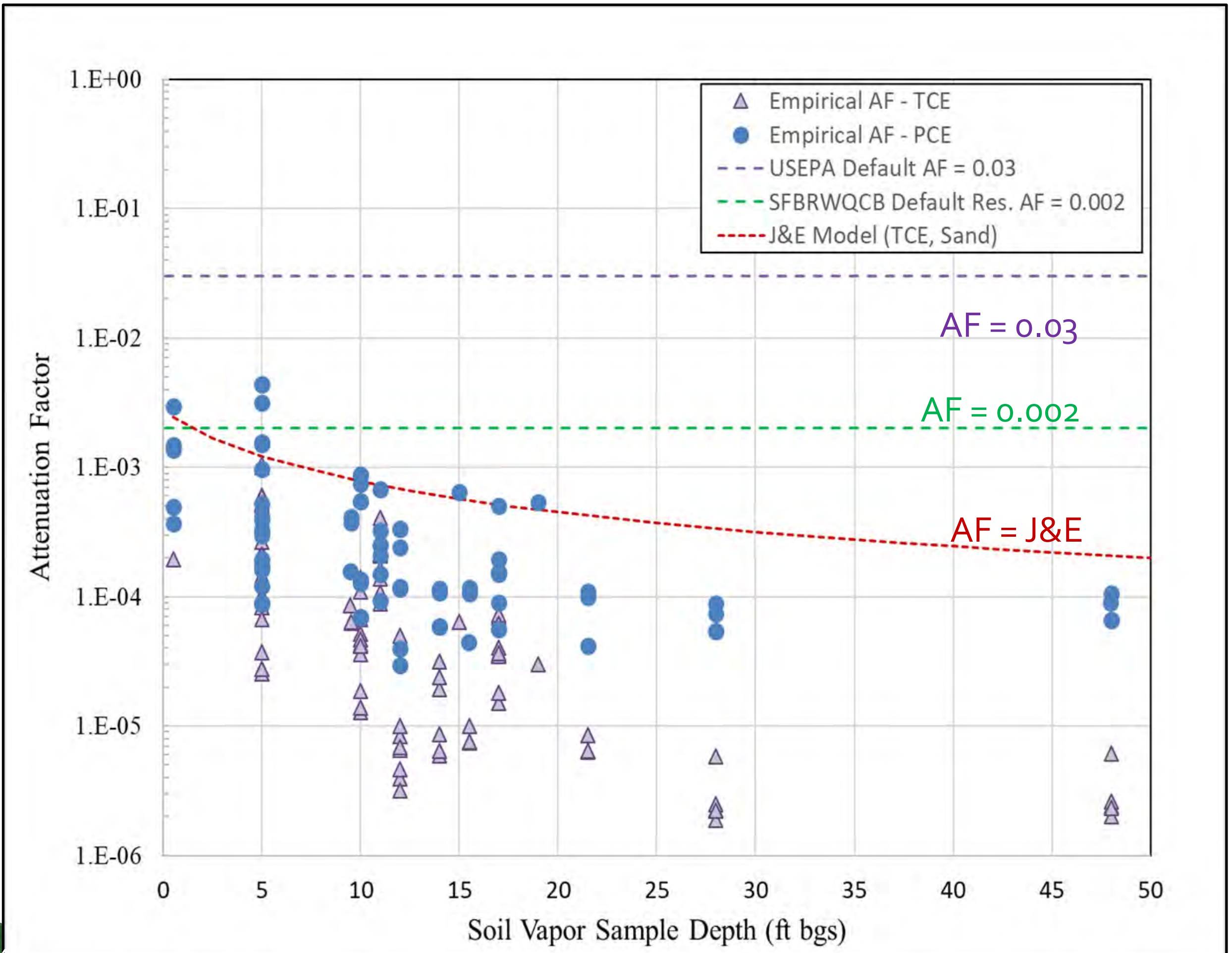
R2: 2004 J&E Model Limitations

- Many assumptions, most parameters not measured
- Accuracy: about an order of magnitude (Hers et al. 2003)



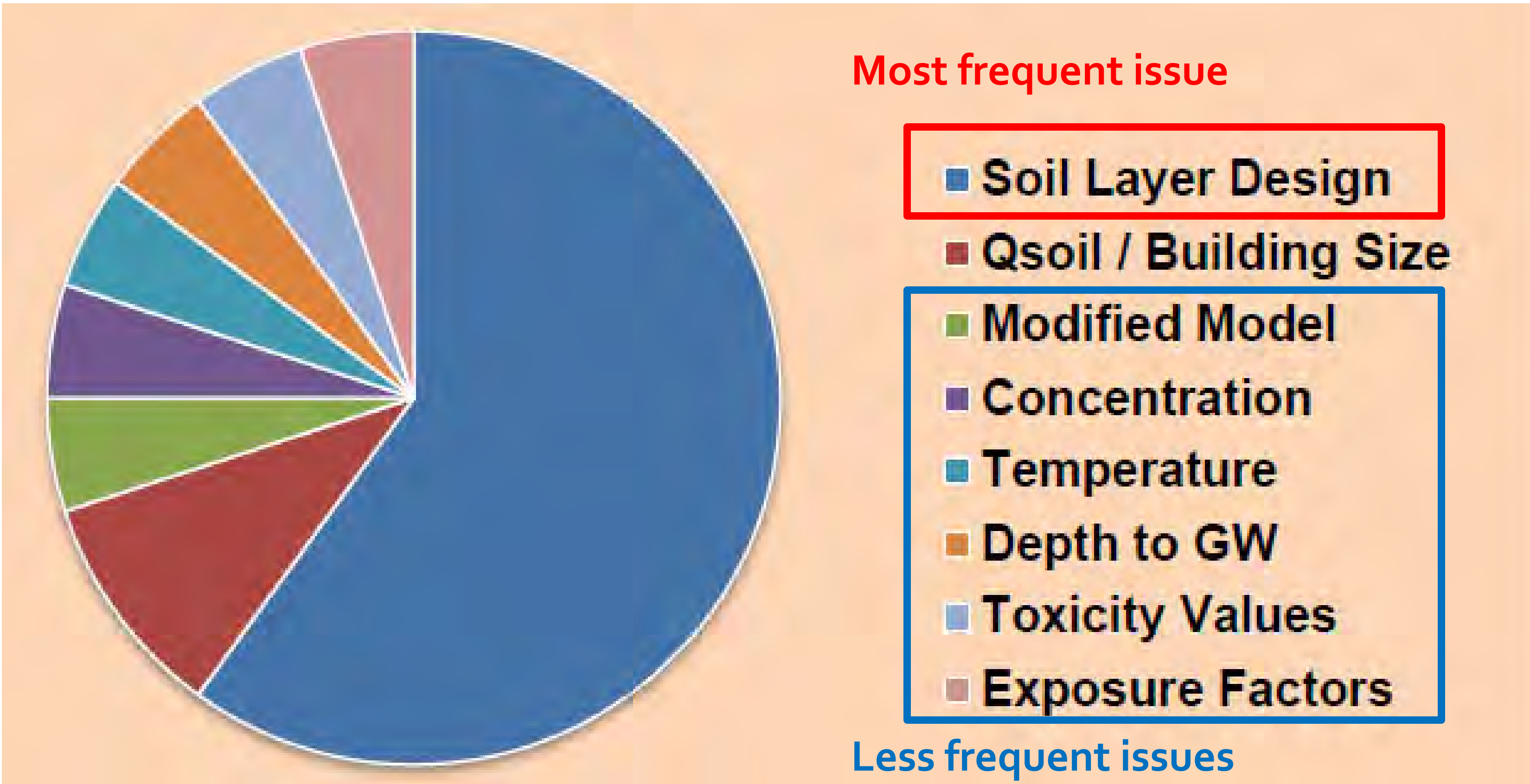
Assumptions:
Default building
Sand (default values)
Default soil parameters

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

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)

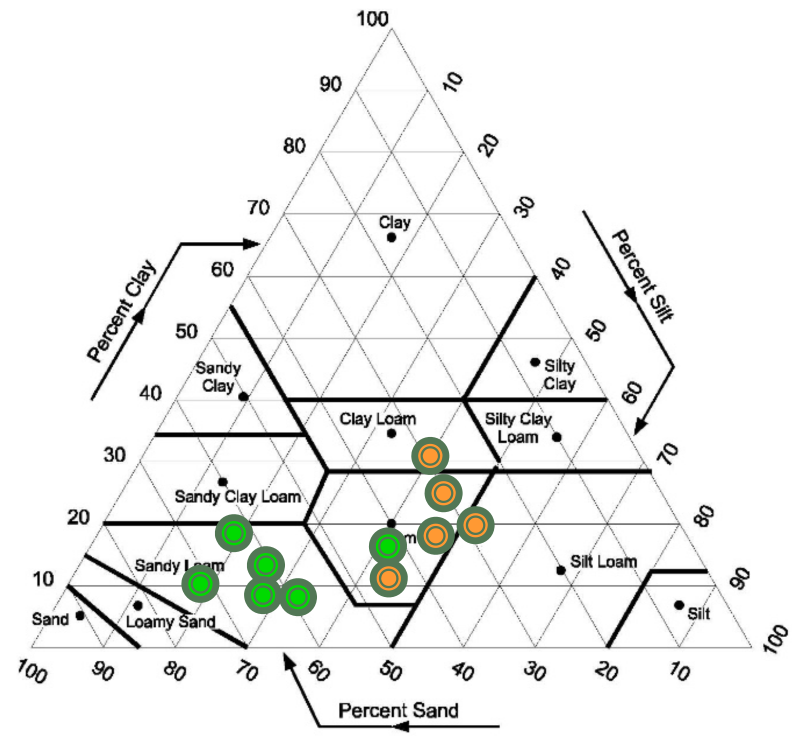


Figure 3. U.S. Soil Conservation Service Classification Chart Showing Centroid Compositions (Solid Circles)

https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054167

Using Site-Specific Soil Data

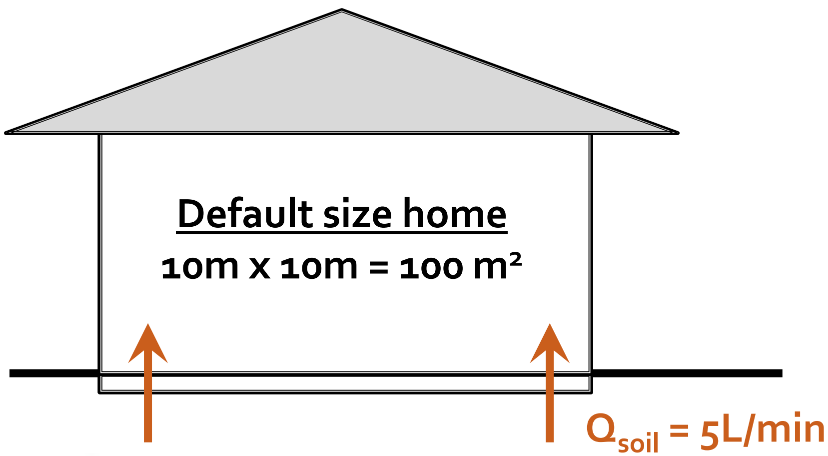
- Historically, statistics on soil properties used for model inputs
- Alternate approach is to base input on evaluation of calculated effective diffusion coefficient for different samples

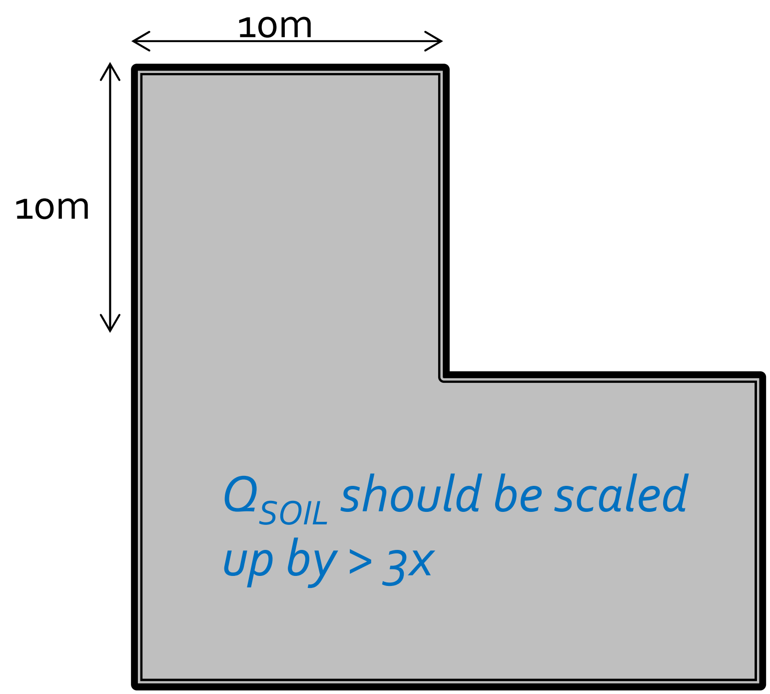
Sample ID	Depth (ft bgs)	Soil Stratum	Total Porosity (Vb)	Water-Filled Porosity (Vb)	Air-Filled Porosity (Vb)	TCE Calculated Deff (cm^2/s)
ASVP-2	5	A	0.410	0.253	0.158	0.00088
BSVP-3	5	A	0.392	0.286	0.106	0.00026
VE-2	5	A	0.382	0.232	0.151	0.00087
SVMP-1D	5	A	0.405	0.241	0.164	0.00102
ASVP-3	20	B	0.381	0.304	0.078	0.00010
ASVP-5	20	B	0.459	0.322	0.138	0.00045
BSVP-1	20	B	0.414	0.307	0.107	0.00024

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)

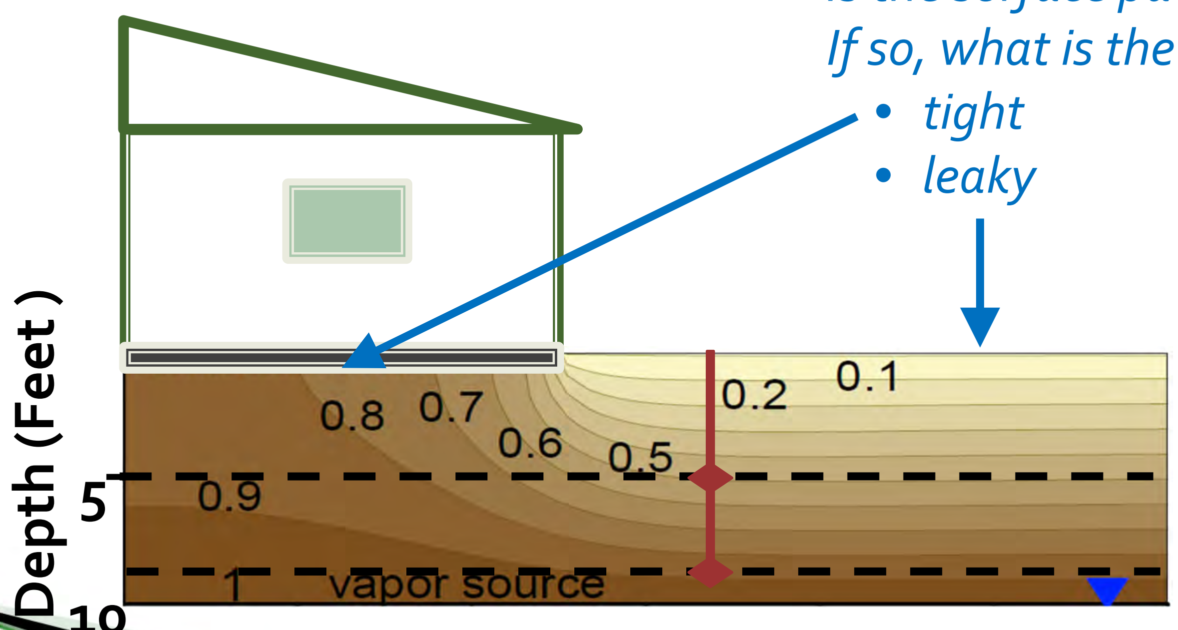




R2: Multi-Depth Soil Vapor Samples

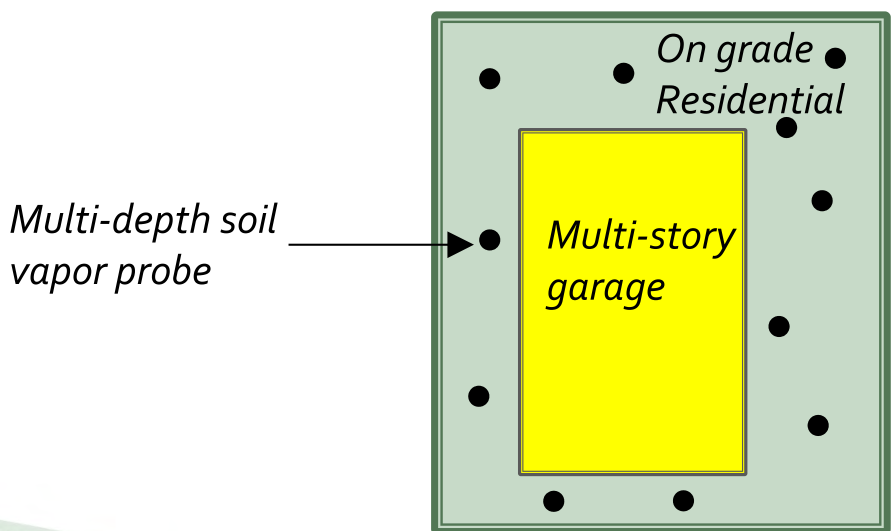
- Use actual soil vapor data to calculate AF_{SG-SS}
- Most applicable away from release areas
- Key issue: surface conditions at time of sampling
- Seasonable variability

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



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

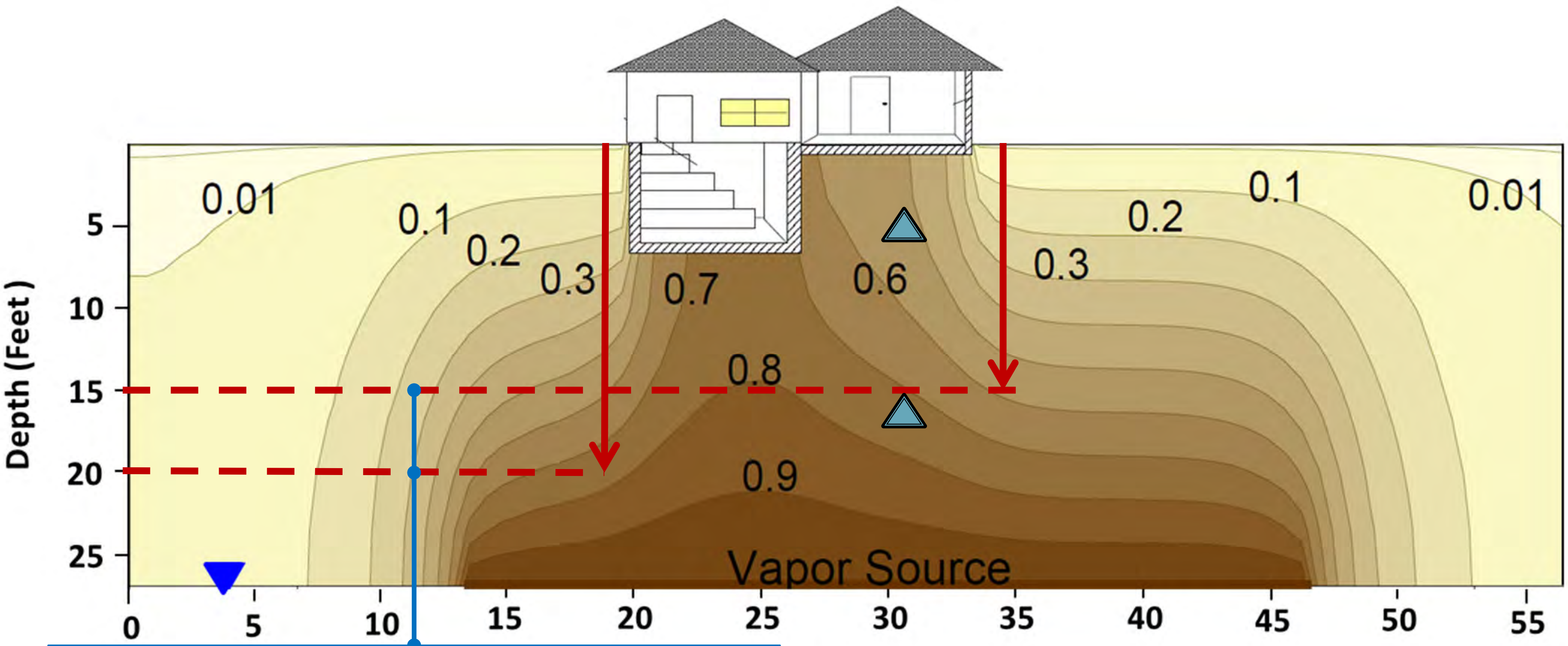


R2 Case Study 1: Conceptual Site Model

- **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

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22nd Annual California CUPA Training Conference
February 2020

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
  - **$AF_{SG\text{-}IA}$ = 0.0011 (~900x)**
- **Adjustment for generic SG-SS AF (0.03)**
  - Model subslab AF – 0.0021 (~480x)
  - $AF_{JE\text{-}SG\text{-}SS} = (AF_{JE\text{-}SG\text{-}IA} / AF_{JE\text{-}SS\text{-}IA}) = 0.0011/0.0021 = 0.52$
  - **$AF_{ADJ\text{-}SG\text{-}IA}$** = $AF_{JE\text{-}SG\text{-}SS}$ [0.5] x $AF_{Generic\text{-}SS\text{-}IA}$ [0.03] = **0.015 (~70x)**
  - Note: $AF_{ADJ\text{-}SG\text{-}IA}$ 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 $AF_{EMP\text{-}SG\text{-}SS}$ values from 0.3 (3x) to 0.5 (2x)

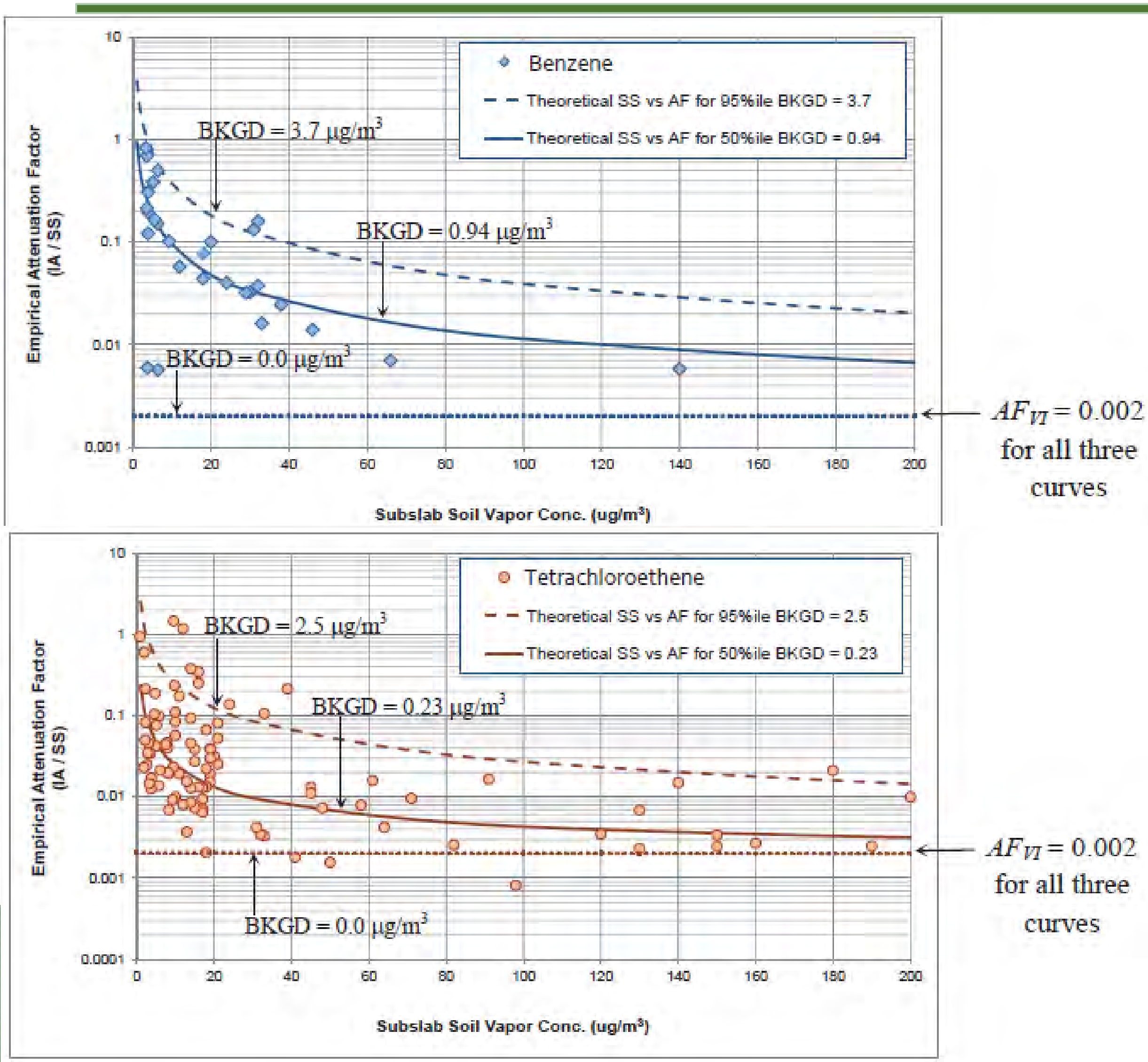
Soil Vapor (SV) Samples	Arithmetic Mean (µg/m^3)	95UCL (µg/m^3)
Shallow SV	282	910
Deep SV	842	1,762
$AF_{SG\text{-}SS}$ (source to slab)	0.33 (3x)	0.52 (2x)

  - $AF_{EMP\text{-}SG\text{-}IA}$ = 0.5 x 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

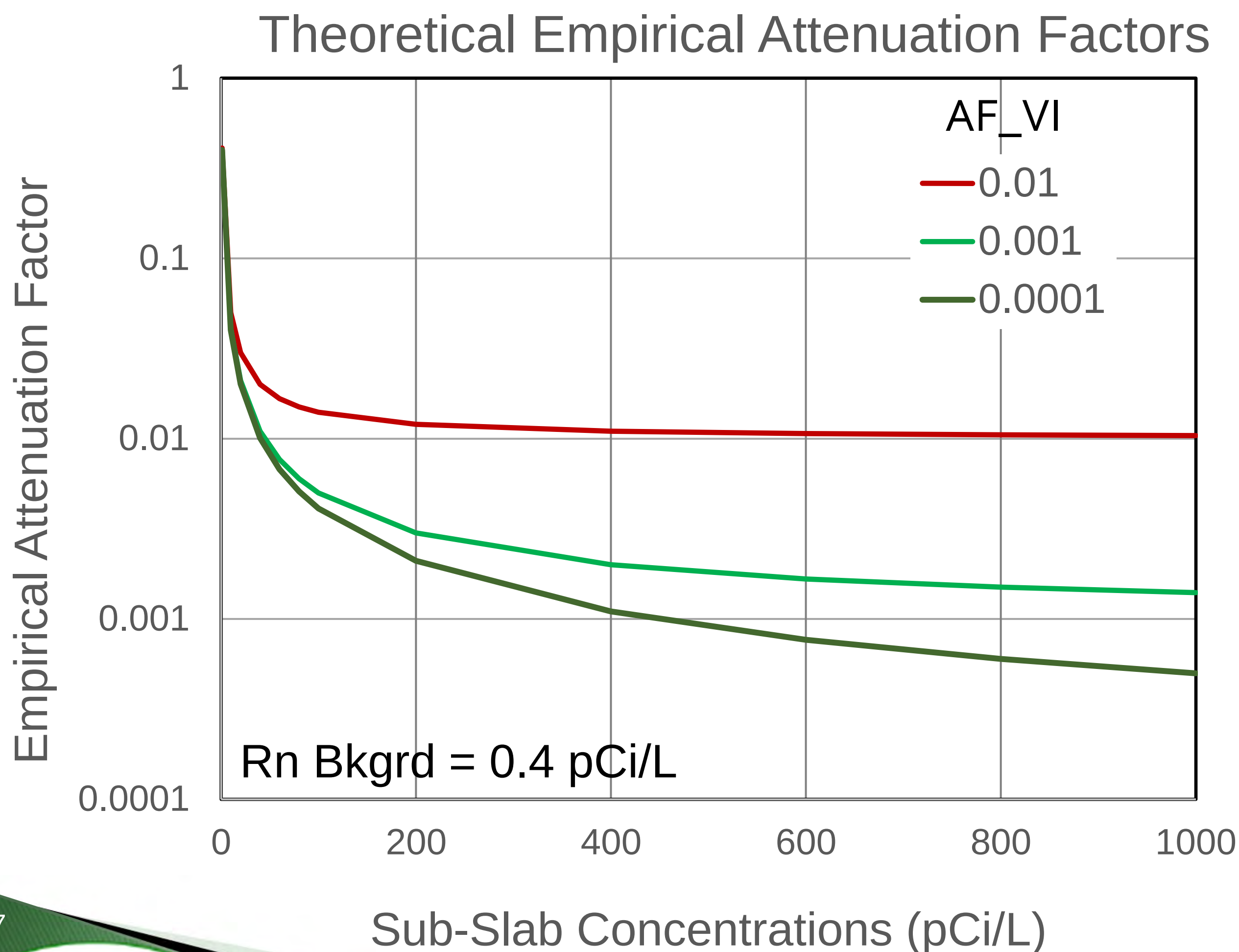


- Data indicate back-ground sources have significant impact on indoor air quality and empirical AFs
- Due to relatively low sub-slab concentrations, it is impractical to estimate building-specific AFs
- Sub-slab to indoor air attenuation factor of 0.002 provides upper-bound estimate for Site-specific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

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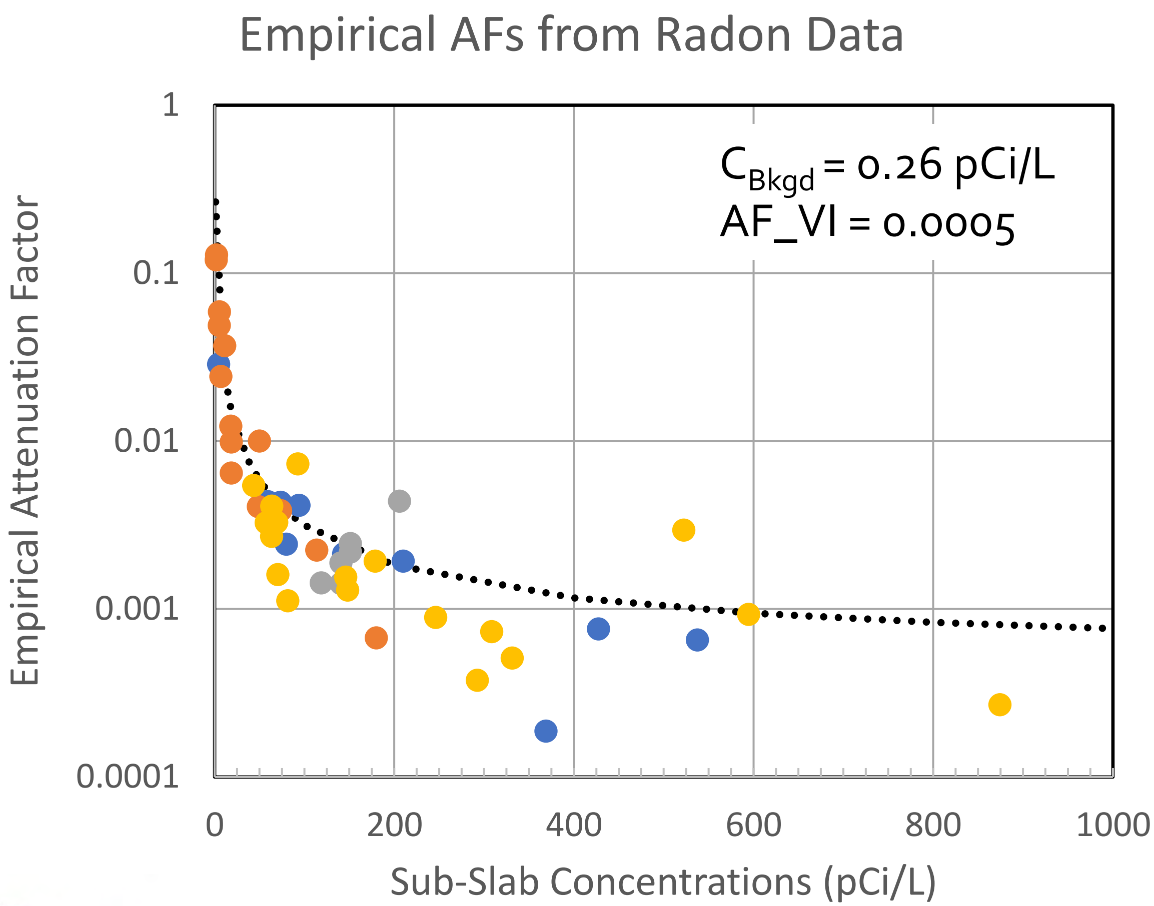
Case Study: Radon measurements used to assess VI attenuation factors for new construction with vapor barriers

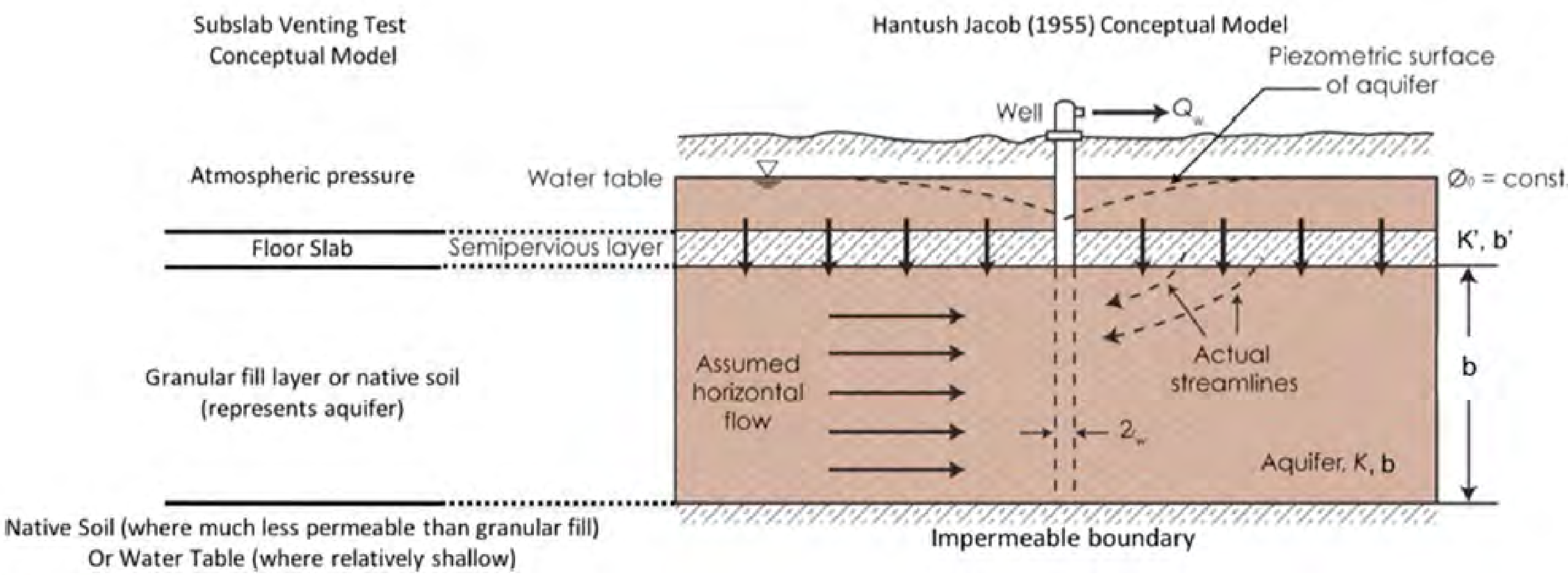


- Radon data collected at 41 structures constructed with vapor barriers
- Median outdoor air radon concentration = 0.26 pCi/L
- Range of empirical AFs observed,
- When background contribution considered, AF_VI is approximately 0.0005

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)

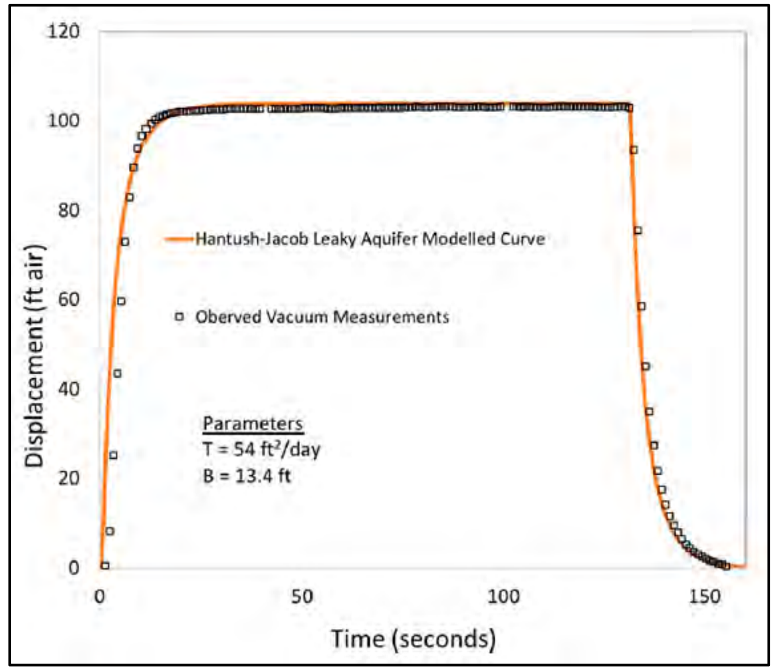
Pneumatic-Based Attenuation Factors Mathematical Basis

- Extraction test data evaluated following Hantush-Jacob analysis to identify:
  - Leakage Factor, B:

$$B = \sqrt{\frac{K\ b\ b'}{K'}}$$

  - Sub-slab transmissivity, T:

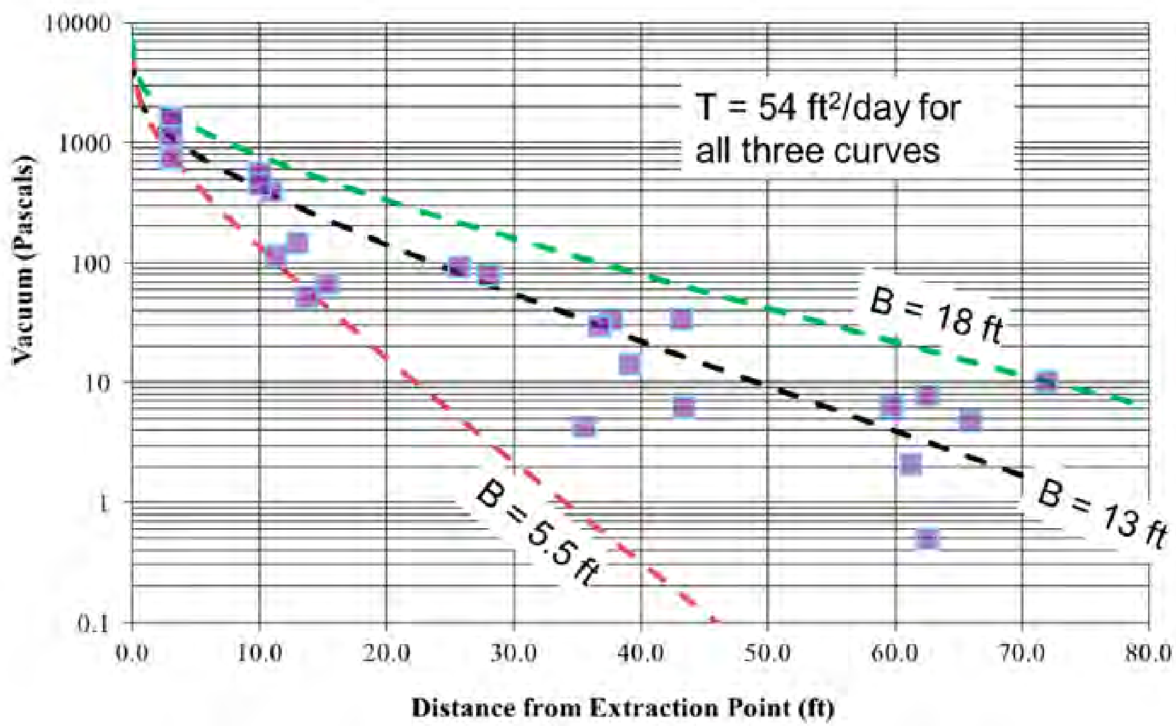
$$T = K\ b$$



- 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 ft^2/d
- B = 5.5 - 18 ft
- ΔP = 2 Pa
- h = 15 ft
- AER = 0.8 hr^{-1}

Pneumatic-based AF

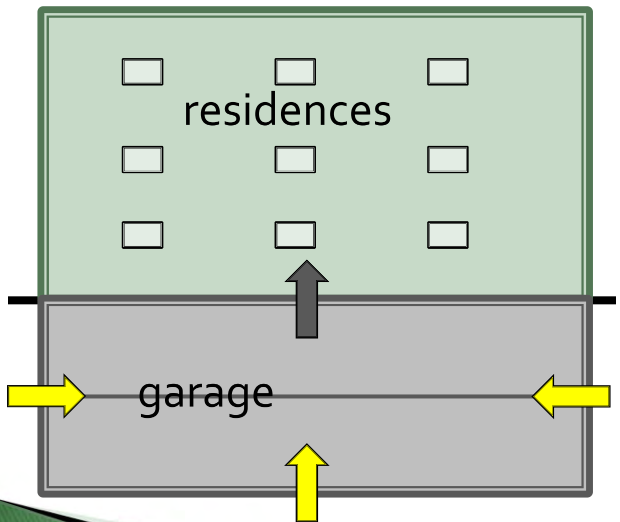
- 0.003 – 0.00003
- Best estimate = 0.0003 (based on B = 13 ft)

- 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 ($AF_{SS\text{-}GARAGE}$)

- Assume $AF_{GENERIC\text{-}SS\text{-}IA}$ = 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
- **$AF_{SS\text{-}GARAGE}$ = 0.03 / (2/0.5) = 0.0075 (130x)**



Step 2 ($AF_{SS\text{-}RES\ IA}$)

- Use 0.1 from garage air to residences IA
- Basis: 2004 Minnesota tobacco study
- **$AF_{SS\text{-}RES\ IA}$ = 0.0075 x 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 $AF_{SG\text{-}IA}$ (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 $AF_{SG\text{-}IA}$ 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*

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

(concentrations in ug/m^3)

Case Study (cont.): Improvement of Assessment Approach

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

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

(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/m^3.
- Trigger to active VIMS is currently 85 ug/m^3 (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

AF	Risk	PCE (ug/m3)
0.001	10^{-6}	460
0.0001	10^{-5}	4600
0.00001	10^{-4}	46,000

- 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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Discussion

References

1. Adgate, J.L, et. Al. "Outdoor, Indoor, and Personal Exposure to VOCs in Children,". Environmental Health Perspectives. Vol. 112, No. 14, p. 423, 2004.

2. Ettinger, R.A. et. al. "Empirical Analysis of Vapor Intrusion Attenuation Factors for Sub-Slab and Soil Vapor –An Updated Assessment for California Sites". Paper VI22, Presented at the Vapor Intrusion, Remediation, and Site Closure Conference December 5 -6, 2018 Phoenix, AZ.

3. Hodgson, A.T., A.F. Rudd, D. Beal and S. Chandra. "Volatile Organic Compound Concentrations and Emission Rates in New Manufactured and Site-built Houses," Indoor Air 10: 178-192. Report No. LBNL-43519, 2000.

4. Jia, Chunrong and Batterman, Stuart, "A Critical Review of Naphthalene Sources and Exposures Relevant to Indoor and Outdoor Air," International Journal of Environmental Research and Public Health, ISSN 1660-1601, July 2010 .

5. Montana Department of Environmental Quality, Typical Indoor Air Concentrations of Volatile Organic Compounds in Non-Smoking Montana Residences Not Impacted by Vapor Intrusion, August 2012.

6. U.S. Environmental Protection Agency, Atmospheric Sciences Research Laboratory. National Ambient Volatile Organic Compounds (VOCs) Data Base Update. EPA/600/3-88/010(a). Research Triangle Park, NC, 1988.

7. U.S. Environmental Protection Agency, "Background Indoor Air Concentrations of Volatile Organic Compounds in North American Residences (1990–2005): A Compilation of Statistics for Assessing Vapor Intrusion", EPA 530-R-10-001, June 2011.

8. Weisel, C.P., J. Zhang, B.J. Turpin, M.T. Morandi, S. Colome, T.H. Stock, D.M Spektor, et al. Relationships of Indoor, Outdoor, and Personal Air (RIOPA): Part 1. Collection Methods and Descriptive Analyses. HEI Research Report 130; NUATRC Research Report 7. Health Effects Institute, Boston, MA; Mickey Leland National Urban Toxics Research Center, Houston, TX, 2005. Available at http://pubs.healtheffects.org/view.php?id=31

9. Weisel, C.P. Investigation of Indoor Air Sources of VOC Contamination. Final Report, Year 2, SR03-033. New Jersey Department of Environmental Protection. October 2006.