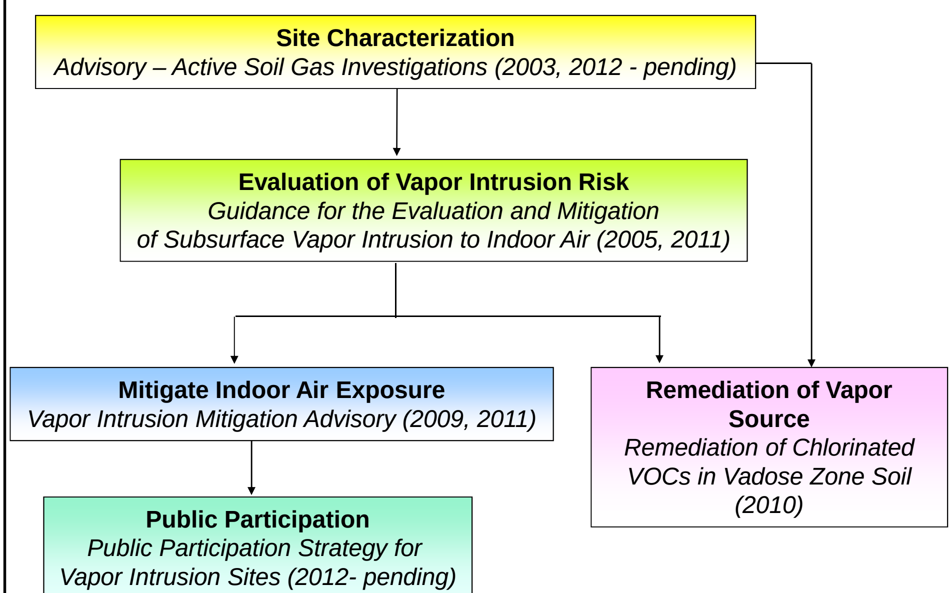
Vapor Intrusion: Decision Framework for Testing Indoor Air and Overview of Sampling Procedures

CUPA Conference

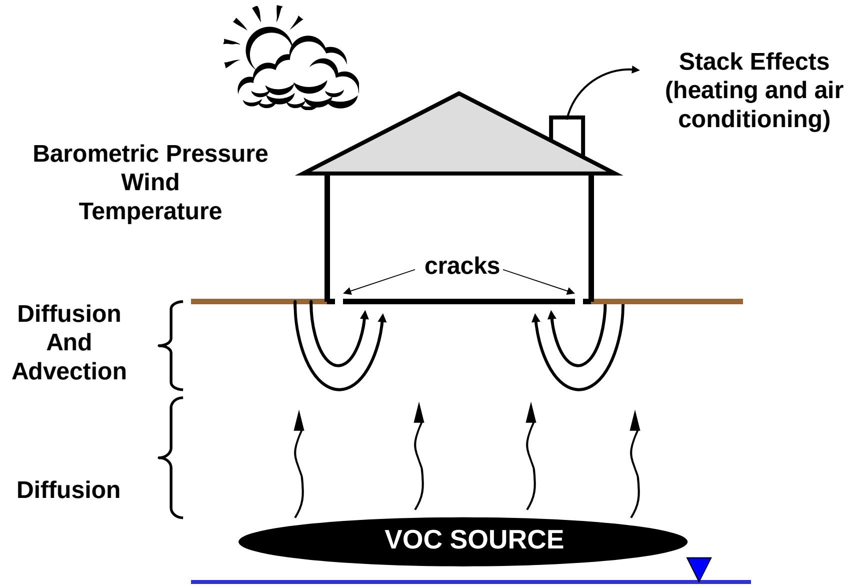
Dan Gallagher
Department of Toxic Substances Control
California Environmental Protection Agency

February 8, 2012

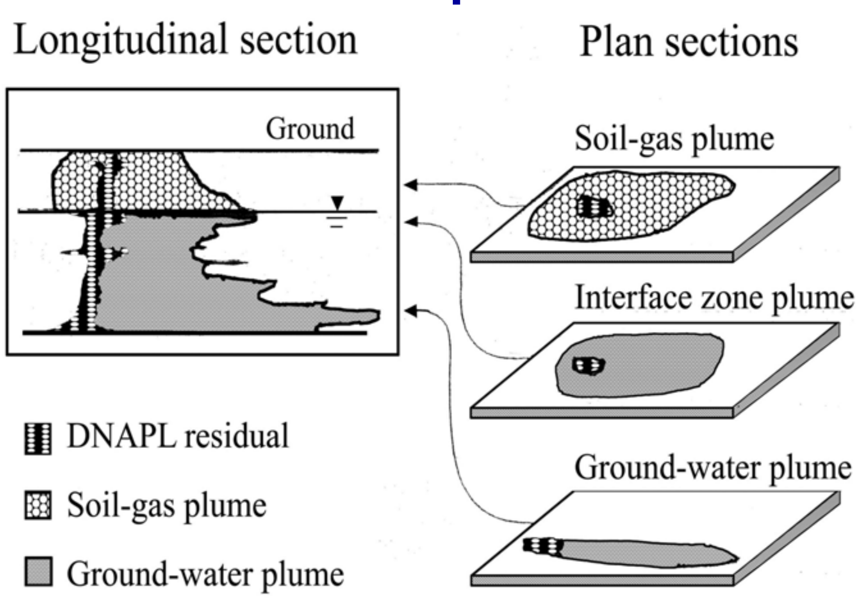
DTSC Guidance Documents



Vapor Intrusion – Conceptual Model



VOC Conceptual Model

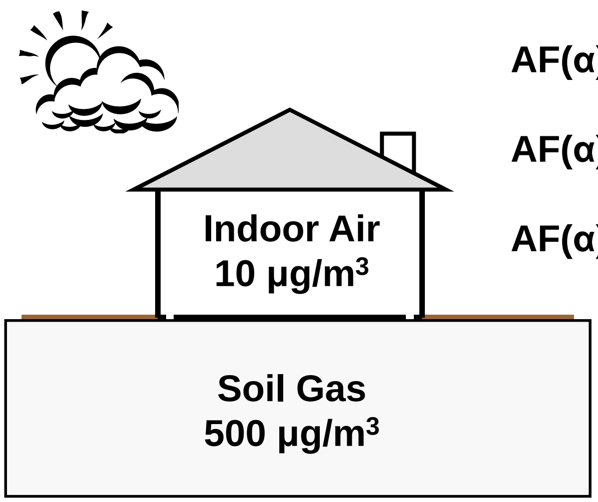


Taken from Rivett (1993)

Components of a CSM

- Underground utilities and pipes
- Contaminant release mechanism
- Existing and future buildings
- Soil stratigraphy
- Hydrogeology and depth to water table
- Nature of vapor source
- Source area locations
- Surface cover description

Attenuation Factor Concept



$AF(\alpha) = C_{indoor}/C_{soil\ gas}$

$AF(\alpha) = 10/500$

$AF(\alpha) = 0.02$

Unit Conversion Table

Soil Gas Unit Comparison		
Units	Convert to	Multiply by
µg/L	mg/m³	1
µg/m³	mg/m³	0.001
ppbv	µg/m³	MW/24
µg/m³	ppbv	24/MW
ppmv	mg/m³	MW/24
ppbv	mg/m³	MW/24,000
µg/L	µg/m³	1000
µg/m³	µg/L	0.001
µg/L	ppbv	24,000/MW
µg/L	ppmv	24/MW
ppbv	ppmv	0.001
ppmv	ppbv	1000

MW - molecular weight
mg/m³ - milligrams per cubic meter
µg/m³ - micrograms per cubic meter
µg/L - micrograms per liter
ppbv - parts per billion by volume
ppmv - parts per million by volume

Converting Analytical Results

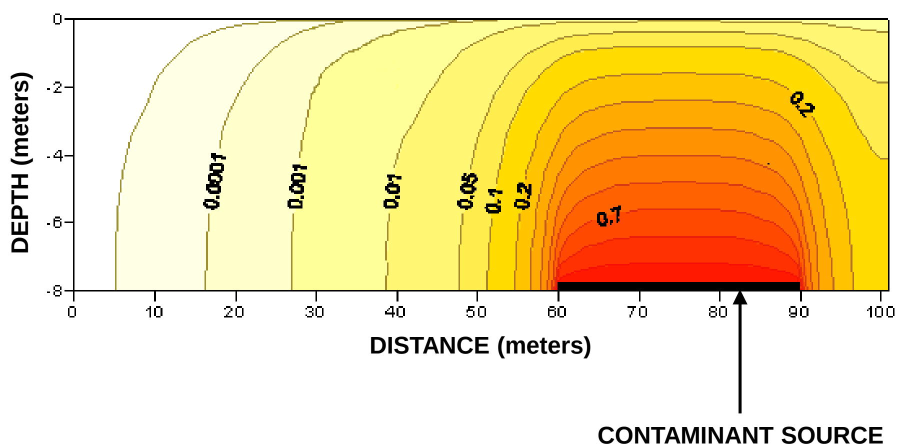
ppbv = (µg/m³ x 24.45) / MW
µg/m³ = (ppbv x MW) / 24.45

Unit Conversion Website
http://www.airtoxics.com/cclasses/unitcalc.html

Soil Gas Modeling

Theoretical Distribution of Soil Gas Above a Subsurface Contaminant Source

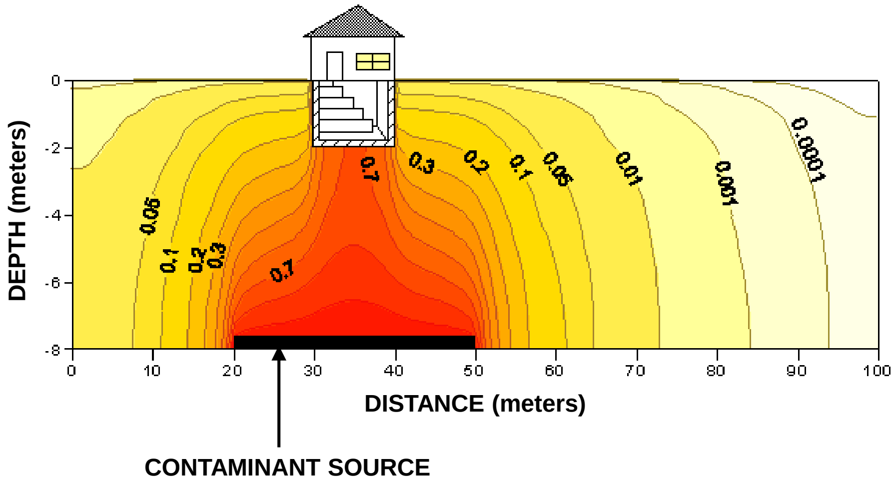
Modified from Johnson and Abreu (AEHS Conference 2005)



Soil Gas Modeling

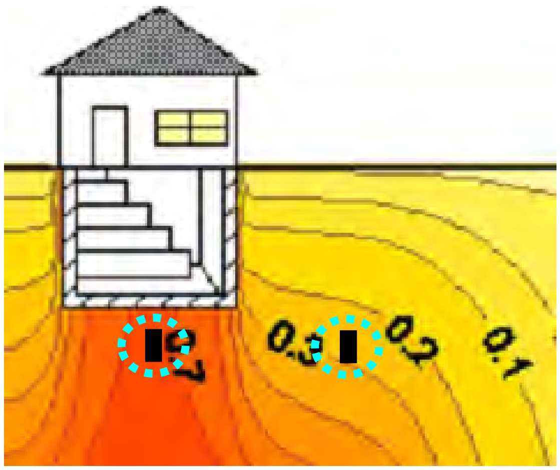
Theoretical Distribution of Soil Gas Above a Subsurface Contaminant Source With a Building

Modified from Johnson and Abreu (AEHS Conference 2005)



Soil Gas Sampling Depths

Differences in "open-field" and "under-building" soil gas concentrations



Higher concentrations are observed under buildings

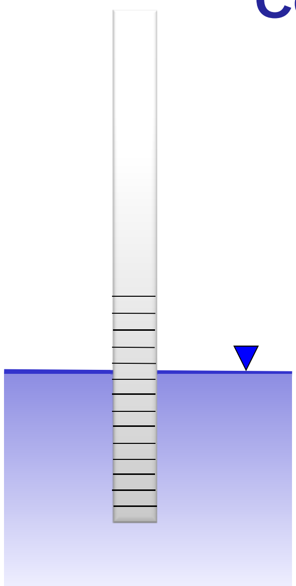
Installation of Permanent Probes

- Evaluate whether contamination has reached steady-state
- Evaluate temporal contaminant trends
- Soil gas grab samples yield an irregular distribution of contamination
- Soil gas plumes have migrated under buildings
- Evaluate the effectiveness of SVE systems

Soil Gas Sampling Collection

Theo Johnson Presentation

Groundwater Sampling Considerations



- Wells must be screened across the water table
- Screen interval should be short (≤ 10 feet)
- Need to establish contaminant trends

Soil Matrix Sampling Considerations

- Volatile loss upon sample collection
- Must use partitioning assumptions

METHOD 5035 SHOULD BE USED FOR SAMPLING

Sampling Resources

- Cal-EPA Advisory – Active Soil Gas Investigations (January 2003; 2012 revision pending)
- DTSC Guidance Manual for Ground Water Investigation; Representative Sampling of Ground Water (February 2008; original dated July 1995)
- USEPA Ground-Water Sampling Guidelines for Superfund and RCRA Project Managers: Ground Water Forum Issue Paper (May 2002)
- DTSC Guidance Document for the Implementation of USEPA Method 5035: Methodologies for Collection, Preservation, Storage, and Preparation of Soils to be Analyzed for VOCs (November 2004)

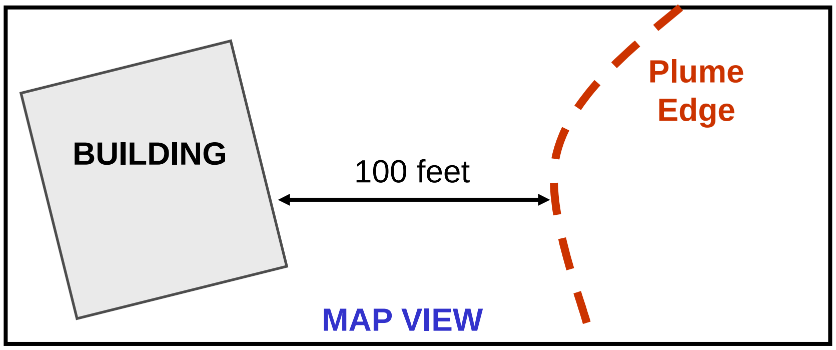
DTSC Tiered Approach

1. Exposure Pathway Complete?
   - Building and volatile chemical present?
2. Preliminary Screening
   - California Human Health Screening Levels
3. Site-Specific Screening
   - Subslab sampling
   - Fate and transport modeling
   - In-situ measurements

Exposure Pathway Complete?

1. 112 chemicals listed in DTSC (2005)

2. Are buildings within 100 feet of the plume?



Preliminary Screening (Soil Gas)

OEHHA generated soil screening levels in 2005 for seventeen volatile chemicals pursuant to SB 32

California Human Health Screening Levels (Existing Building)

Chemical	Protective Soil Gas Concentration (Residential)
Benzene	0.04 µg/L
Trichloroethylene (TCE)	0.5 µg/L
Tetrachloroethylene (PCE)	0.2 µg/L
Vinyl Chloride	0.01 µg/L

Preliminary Screening (Groundwater)

$$C_{groundwater} = C_{soil\ gas} / \text{Henry's law constant}$$

Chemical	Protective Soil Gas Concentration (Residential)	Henry' law constant (unitless)	Protective Groundwater Concentration (Residential)
Benzene	0.04 µg/L	0.2	0.2 µg/L
TCE	0.5 µg/L	0.4	1.25 µg/L
PCE	0.2 µg/L	0.8	0.25 µg/L
Vinyl Chloride	0.01 µg/L	1.1	0.009 µg/L

Preliminary Screening Attenuation Factors

Building Scenario	Building Type	Sample Location	Attenuation Factor
Existing	Residential	Contaminant Source	0.002
		Crawl Space	1.0
		Subslab	0.05
	Commercial	Contaminant Source	0.001
		Subslab	0.05
Future	Residential	Contaminant Source	0.001
	Commercial	Contaminant Source	0.0005

Site-Specific Screening

Johnson and Ettinger (1991) Model

Attenuation Factor (α) Definition

$$\alpha = \frac{\left[\dfrac{D_T^{eff} A_B}{Q_B L_T}\right]\exp\left(\dfrac{Q_{soil} L_{crack}}{D_{crack}^{eff}\eta A_B}\right)}{\exp\left(\dfrac{Q_{soil} L_{crack}}{D_{crack}^{eff}\eta A_B}\right) + \left[\dfrac{D_T^{eff} A_B}{Q_B L_T}\right] + \left[\dfrac{D_T^{eff} A_B}{Q_{soil} L_T}\right]\left(\exp\left(\dfrac{Q_{soil} L_{crack}}{D_{crack}^{eff}\eta A_B}\right) - 1\right)}$$

J/E Model Assumptions

- One-dimensional vertical transport
- Steady state conditions
- No preferential pathways
- No biodegradation of contaminants
- Constant source concentration
- Uniform mixing within building
- Non-fractured vadose zone

NEED TO ENSURE THAT MODEL ASSUMPTIONS AND SITE CONDITIONS ARE CONSISTENT

Soil Effective Diffusion Coefficient (D_{eff})

Millington and Quirk (1961)

$$D_{eff} = D_a \left(\frac{\theta_a^{3.33}}{n^2} \right) + \frac{D_w}{H} \left(\frac{\theta_w^{3.33}}{n^2} \right)$$

- D_a = diffusion coefficient in air
- D_w = diffusion coefficient in water
- θa = volumetric air content
- θw = volumetric water content
- H = Henry's law constant
- n = total porosity

USEPA VI Spreadsheet

SG-SCREEN
A Version 2.0; 04/

Reset to Defaults

DTSC
Vapor Intrusion Guidance
Interim Final 12/04
(last modified 2/4/09)

Soil Gas Concentration Data

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Soil gas conc., C_g ($\mu g/m^3$)	OR	ENTER Soil gas conc., C_g (ppmv)	Chemical
127184	1.00E+03			Tetrachloroethylene

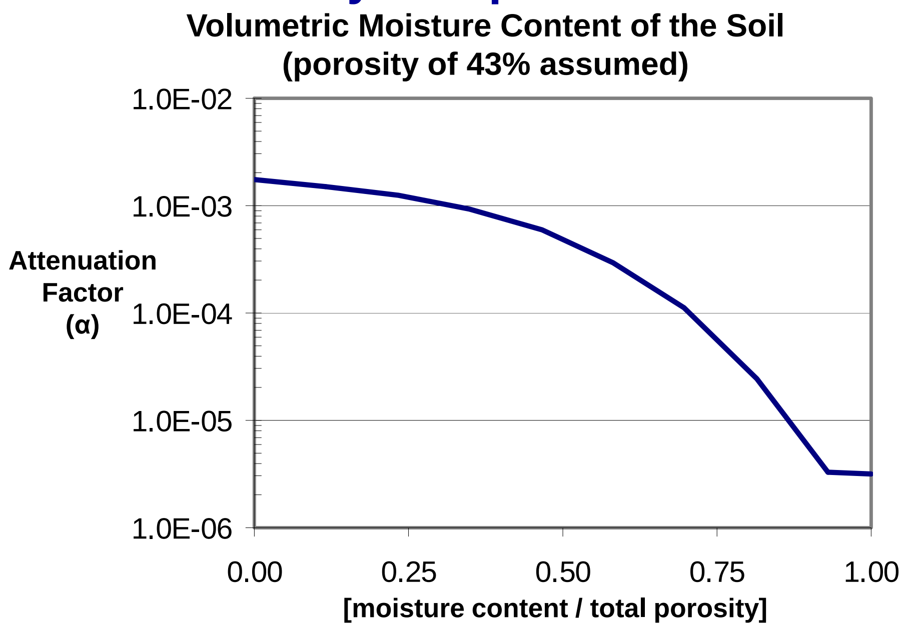
MORE ↓

ENTER Depth below grade to bottom of enclosed space floor, L_F (15 or 200 cm)	ENTER Soil gas sampling depth below grade, L_s (cm)	ENTER Average soil temperature, T_S (^oC)	ENTER Vadose zone SCS soil type (used to estimate soil vapor permeability)	OR	ENTER User-defined vadose zone soil vapor permeability, k_v (cm^2)
15	152.4	24			1.00E-08

MORE ↓

ENTER Vandose zone SCS soil type (Lookup Soil Parameters)	ENTER Vadose zone soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Vadose zone soil total porosity, n^V (unitless)	ENTER Vadose zone soil water-filled porosity, θ_w^V (cm^3/cm^3)	ENTER Average vapor flow rate into bldg. (Leave blank to calculate) Q_{soil} (L/m)
	1.5	0.43	0.15	5

Sensitivity of Input Parameters



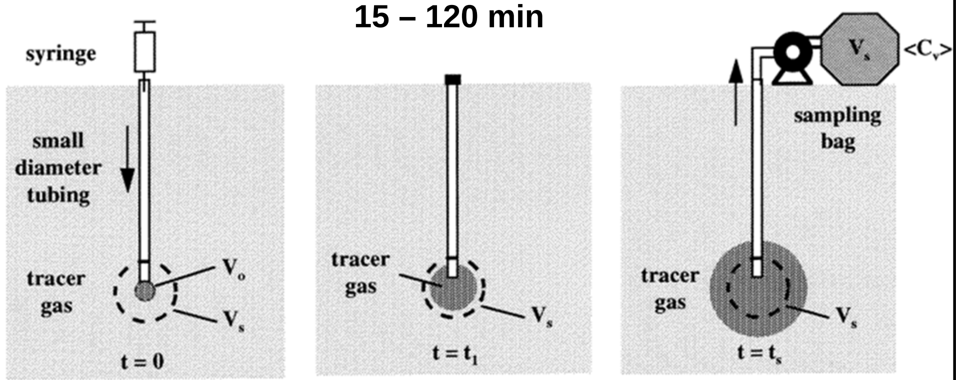
Site-Specific Modeling

Determination of Physical Properties

- Grain Size Distribution
- Geotechnical Laboratory Analysis
- In-Situ Measurements

In-Situ Measurement of Effective Diffusion Coefficient

Step 1	Step 2	Step 3
Tracer Injection	Hold Time 15 – 120 min	Volume Withdrawal



(Johnson et al., 1998)

In-Situ Measurement of Air Permeability

Measure air pressure and air temperature after achieving steady flow into the well (extraction or injection)

$$k = Q_{sc} \frac{\mu \ln \left(L / r_w\right)}{\pi L \left(p^2 - p_o^2\right)} \frac{T p_{sc} Z}{T_{sc}}$$

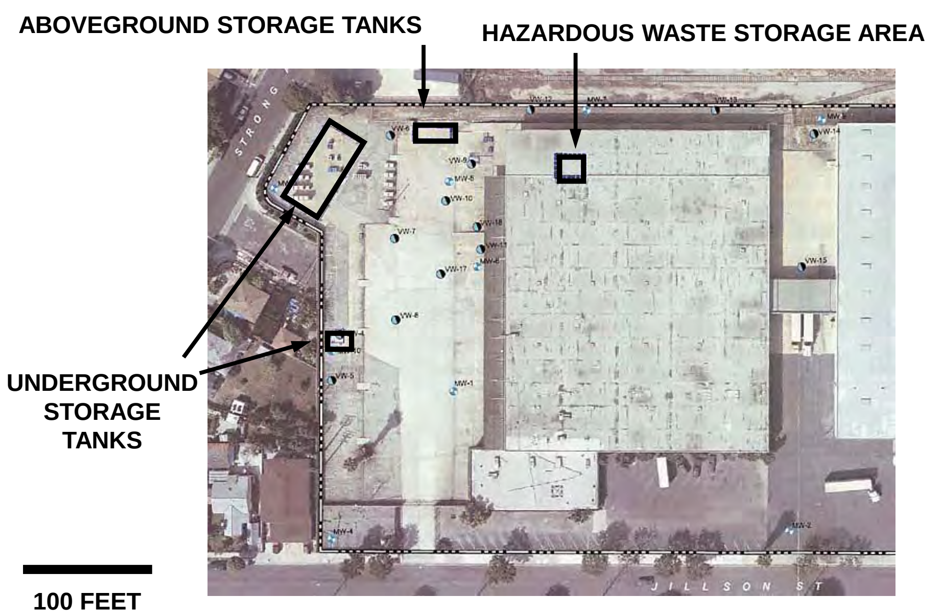
(DTSC 2011)

SUBSLAB SAMPLING

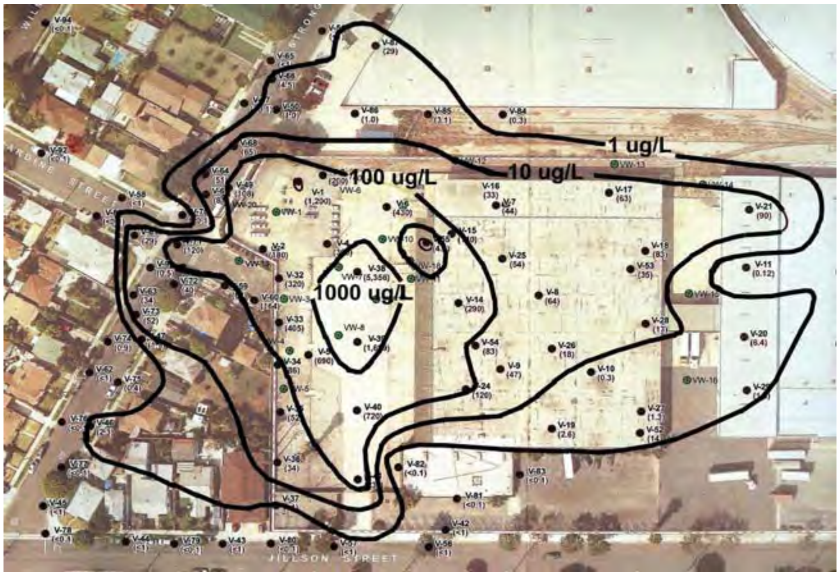
- Soil gas most likely to enter structure
- Sample at base of foundation slab
- Sample away from building edge

(DiGuilio 2004)

Chemical Distribution Center



SHALLOW SOIL GAS PLUME



PCE SOIL GAS CONCENTRATIONS: 5 FEET BELOW SURFACE

Nearest Residential Structure

INDOOR AIR MODELING

13 Laboratory Geotechnical Measurements: 5 - 8 feet below grade

	Median	Conservative
Total Porosity	0.44	0.50
Water-Filled Porosity	0.30	0.19
Permeability (cm^2)	5.8×10^{-9}	1.9×10^{-8}

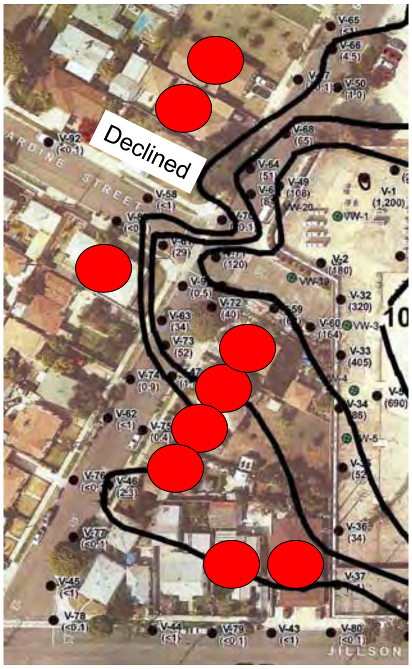
PCE Risk for nearest residence (PCE soil gas = 48 µg/L)

	Median	Conservative
J/E Attenuation Factor	0.00008	0.0005
PCE Cancer Risk	1×10^{-5}	7×10^{-5}
Predicted PCE Indoors (µg/m^3)	4	24

PROTECTIVE SOIL GAS CONCENTATIONS

PCE soil gas concentration at nearest residence = 48 µg/L

	µg/L
Residential CHHSL (PCE)	0.2
Site-Specific Screening Value (PCE)	0.8 – 5.0



Homes Subject to Indoor Air Testing

September 2004

Indoor Air Measurements

Advantages:

- **Actual exposure concentration (no modeling)**
- **Relatively quick (no drilling, minimal equipment)**

Disadvantages:

- **Potential background sources**
- **No control over samplers (leave unattended)**
- **Temporal variability**
- **Requires public access**

Coordination with Laboratory

- Sampling duration (flow regulators)
- MRL vs MDL
- Canister cleanliness
- Gauge and regulator cleanliness
- Pressure gauges (often inaccurate)
- Duplicates
- Trip blanks
- Spare canisters

Indoor Air Sample Collection

- Schedule Test
- Day 1 – Drop Off
  - Conduct survey and screen building
  - Prepare sketch of home
  - Select canister location
  - Open value, record time and pressure
- Day 2 - Pickup
  - Close valve, record time and pressure
  - Conduct post-test interview
  - Ship canister under chain-of-custody

Indoor Air Sample Collection

- 24-hour duration
- Only analyze for subsurface contaminants
- Representative of conservative building conditions
- Canisters should have slight vacuum upon completion

Indoor Air Background

- Household Activities
- Consumer Products
- Building Materials
- Ambient Air

Resource:

Household Products Database (National Institute of Health)
http://householdproducts.nlm.nih.gov/products.htm

Indoor Air Sources

Source	Benzene	Toluene	Ethylbenzene	Xylene	Styrene	Trimethylbenzene	Naphthalene	Trichloroethene	Trichloroethanes	Perchloroethene	Chlorobenzene	Decane
Latex Paints	X	X				X						
Alkyl Paints										X	X	
Carpets	X	X			X	X						
Glued Carpets	X	X			X	X					X	X
Wood Burning		X		X	X	X	X					
Foam Board											X	
Paint Removers		X										
Spray Products				X								
Adhesives/Tapes		X			X			X				X
Room Deodorants											X	
Tobacco Smoke	X	X	X	X	X							
Gasoline/driving	X	X		X	X	X						
Solvents		X	X						X			
Dry Cleaning										X		

From Hers et al., 2001. J. Air & Waste Manage. Assoc., 51:1318-1331

Indoor Air Sampling Considerations

- Instructions to Occupants (48 hours prior to sampling)
  – No smoking
  – No cleaning
  – No painting
  – No indoor hobbies that use solvents
  – No cosmetics use
  – No gasoline storage or use

Outdoor Air Sample Collection

- Upwind of contaminant source
- Six feet off ground
- 10 feet from tree dripline
- Twice height from building

Indoor Response Action

Example Contingency Table

Indoor Air Sampling Results (minimum of 2 sampling events)	Response	Activities
Risk: $<10^{-6}$ HQ: <1.0	No Further Action	None
Risk: 10^{-4} - 10^{-6} HQ: >1.0	Evaluation	• Collect More Data • Monitoring • Mitigation • Source Remediation
Risk: $>10^{-4}$	Action Needed	• Mitigation • Source Remediation

Background Considerations

- Subsurface should be well characterized
- Remove "background" household products
- "Ratio" similarity between soil gas and indoor air
- Indicator compounds: 1,1-DCE, radon
- Collect ambient air samples

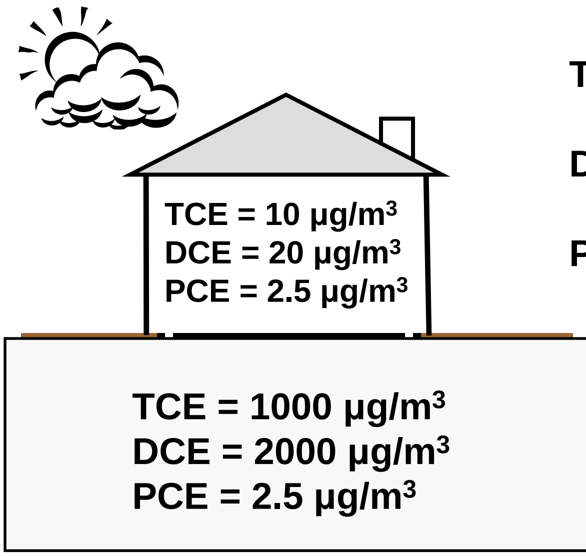
Comparison of Typical Background to CHHSLs

Chemical	CARB Annual Statewide Toxic Summary 2009 (µg/m^3)			Residential Indoor Air CHHSL (µg/m^3)
	Minimum	Median	Maximum	
Benzene	0.079	0.79	7.35	0.085
Carbon Tetrachloride*	0.063	0.59	0.82	0.063
Ethylbenzene	0.43	0.65	3.5	0.97
PCE	0.03	0.21	21.7	0.47
Toluene	0.37	3.47	18.1	317
TCE	0.05	0.08	0.97	1.31
m/p Xylene	0.43	2.08	11.3	740

* 2004 data

http://www.arb.ca.gov/adam/toxics/statesubstance.html#voc

Constituent Ratio Example



TCE AF(α) = 0.01

DCE AF(α) = 0.01

PCE AF(α) = 1.0

CERCLA Approach to Background

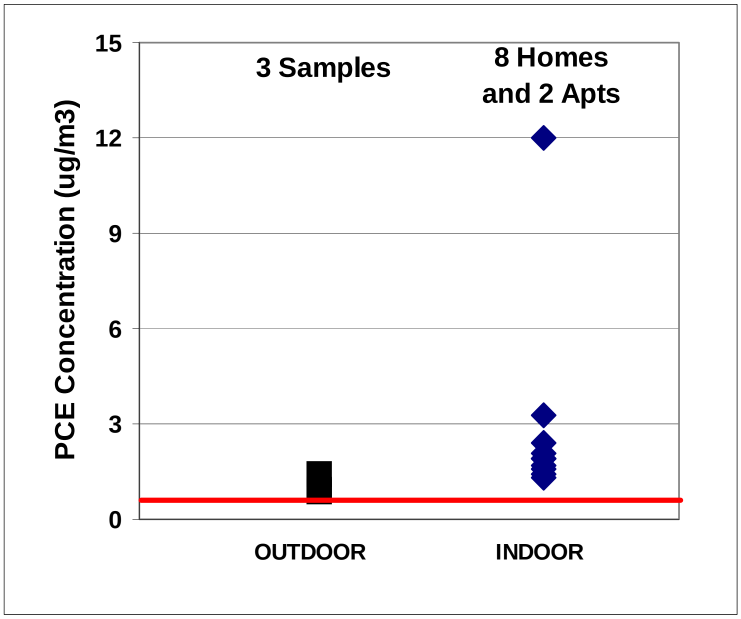
- Background contribution to the concentration of contaminants from a release should be included in the risk assessment

BUT

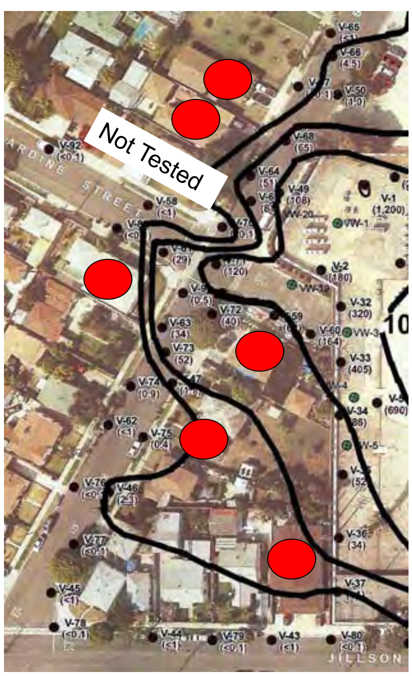
- CERCLA does not generally cleanup to concentrations below background levels

Source: Role of Background in the CERCLA Cleanup Program, OSWER 9285.6-07P, April 2002

Indoor and Outdoor Sampling Results



OEHHA Value for PCE in Indoor Air = 0.47 µg/m³ (risk = 10⁻⁶)



Homes Subject to Vapor Intrusion

Indoor air in homes that tested positive for 1,1-DCE

Tips for Effective Public Outreach

- The “Knock at the Door” should not be your first communication
- Prepare a written outreach strategy
- Learn about stakeholders prior to meetings
- One regulatory point of contact
- Confidentiality
- Community Advisory Groups (CAGs)
- Document Repositories

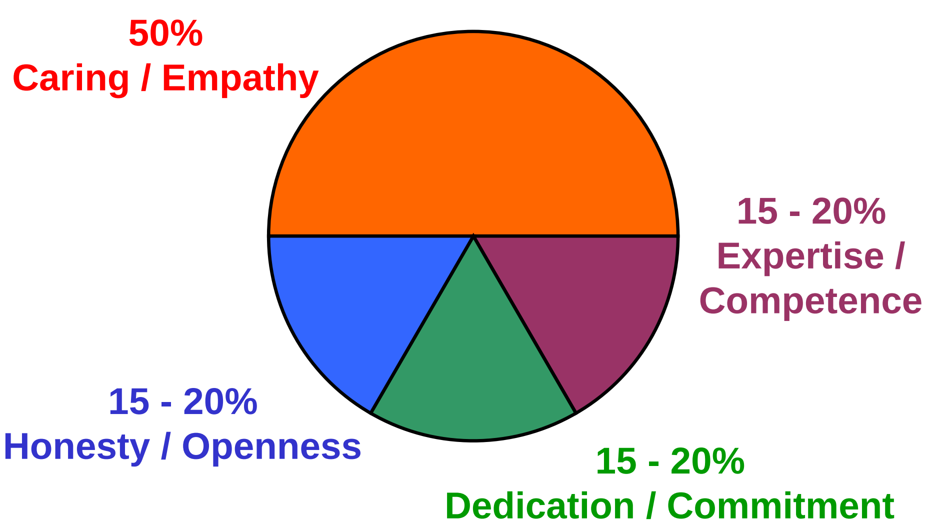
Indoor Air Sampling Steps

1. Fact sheet
   - During site characterization
2. Public meeting
3. “Knock at the Door”
4. Scheduling meeting
   - Sampling instructions, fact sheets
5. Indoor air sampling event
   - Building pre-screening
6. Written notification of results
7. Follow-up public meeting?

Public Meetings

- Plan and rehearse
- Simple presentation slides
- Keep presentations short (< 30 minutes)
- Good facilitator
- Hold meeting near the facility
- Invite everyone (school flyers, mailers, etc)
- Translator needed?
- Crowd management

Factors Critical to Establishing Trust and Credibility



Outreach Resources

- DTSC Public Participation Policy and Procedures Manual (October 2001)
- DTSC Vapor Intrusion Public Participation Advisory (2012 - pending)
- USEPA RCRA Public Participation Manual (1996)
- USEPA Temporary Relocations Implementation Guidance, Superfund Response Action (April 2002)
- USEPA's Technical Assistance Services for Communities (TASC) Program
- Agency for Toxic Substances and Disease Registry's ToxFAQs. Fact Sheets of "Frequently Asked Questions" on over 100 hazardous substances in plain language (www.atsdr.cdc.gov/toxfaq.html)

Active vs Passive Sampling

ACTIVE

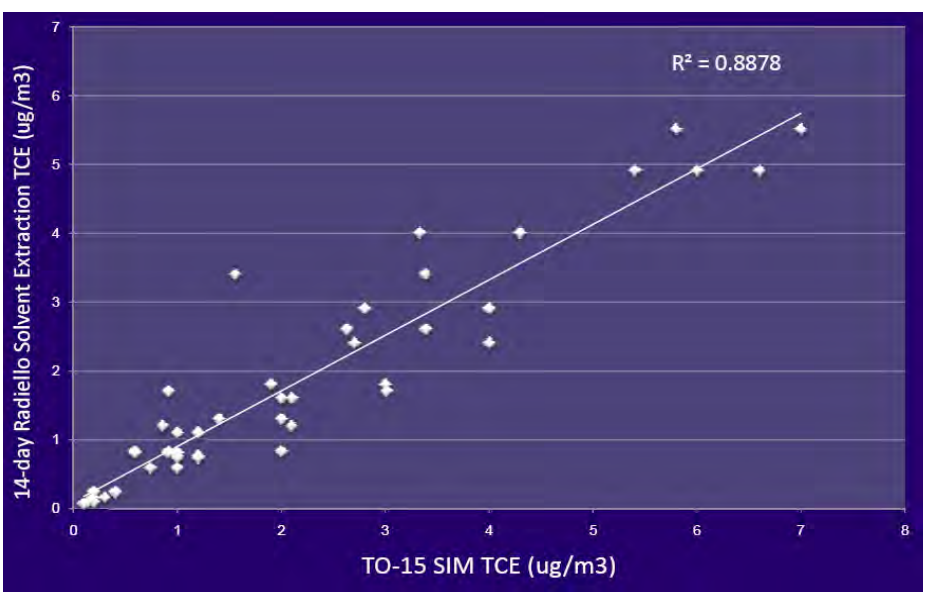
PASSIVE

Sorbent Concentration Calculation

$$C = \left(\frac{M}{Q\,t}\right)$$

C = concentration in air
M = mass of analyte on sorbent
t = exposure time
Q = experimentally measured sampling rate

Sorbent (Solvent-Extract) vs TO-15



(A. Lee, USEPA (2010))

Active vs Passive Sampling

Summa Canister	Passive Sorbent
Used in U. S.	Used in Europe
Specific analyte list and deployment time	Sorbent type, geometry, and deployment chemical specific
Shorter time-integrated sample (8 – 24 hours)	Longer time-integrated sample (2 - 14 days)
Higher cost	Lower cost
Very visible – homeowner cautious	Less intrusive – better acceptance
Bulky – expensive to ship	Small – inexpensive to ship

(A. Lee; USEPA, 2010)