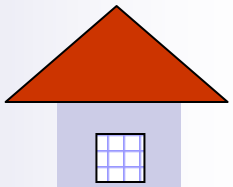


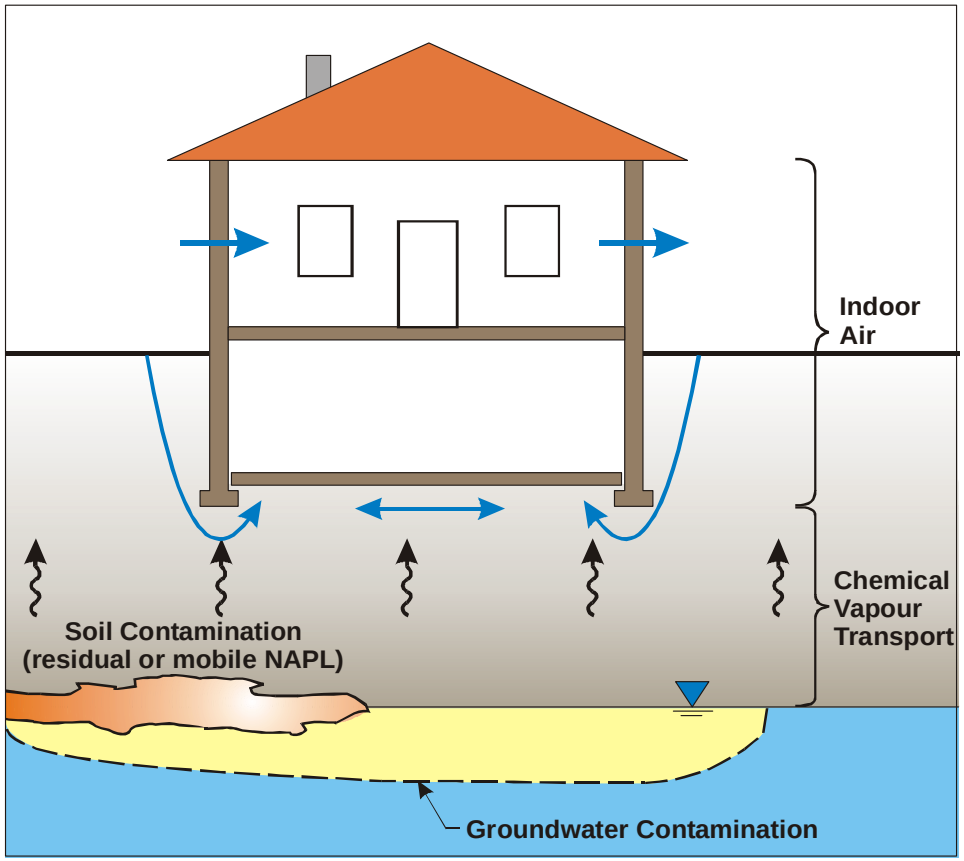
Vapor Intrusion - Site Characterization and Screening

NEWMOA Workshop on Vapor Intrusion
Chelmsford, MA – April 12, 2006

David J. Folkes P.E. EnviroGroup Limited

What is Vapor Intrusion?

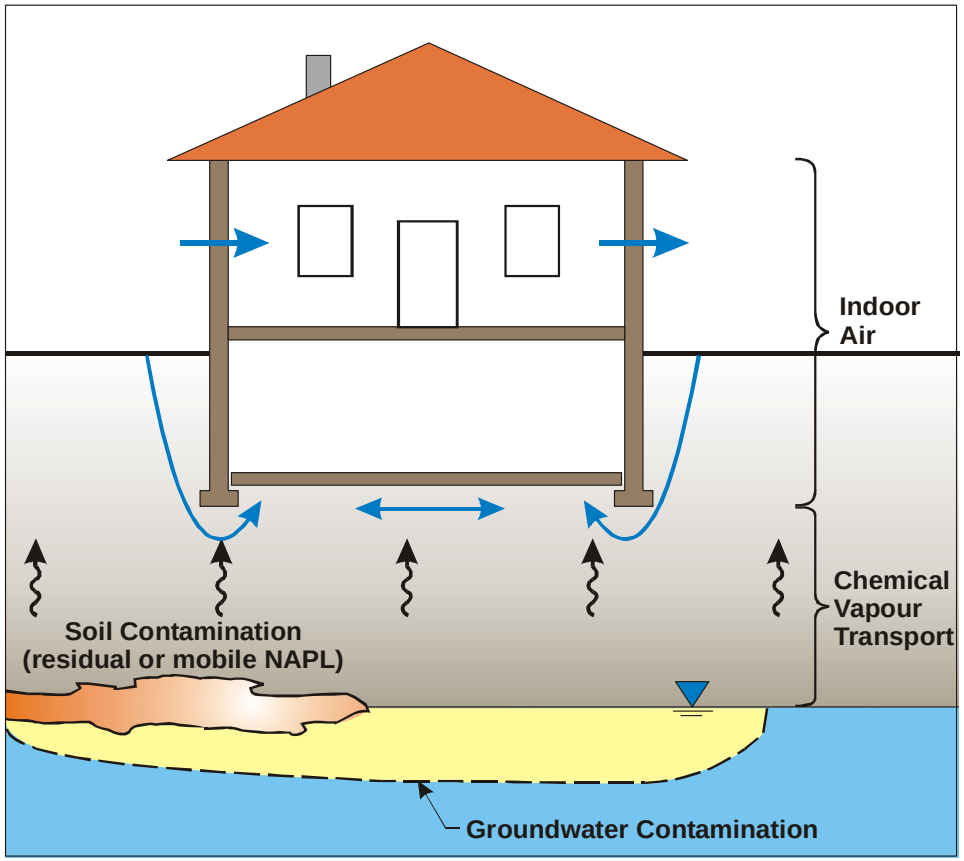
- Compounds of Concern
  - Volatile Organics
  - Naphthalene
  - Mercury
  - Possibly other compounds



Courtesy Ian Hers, Golder Associates

What is Vapor Intrusion?

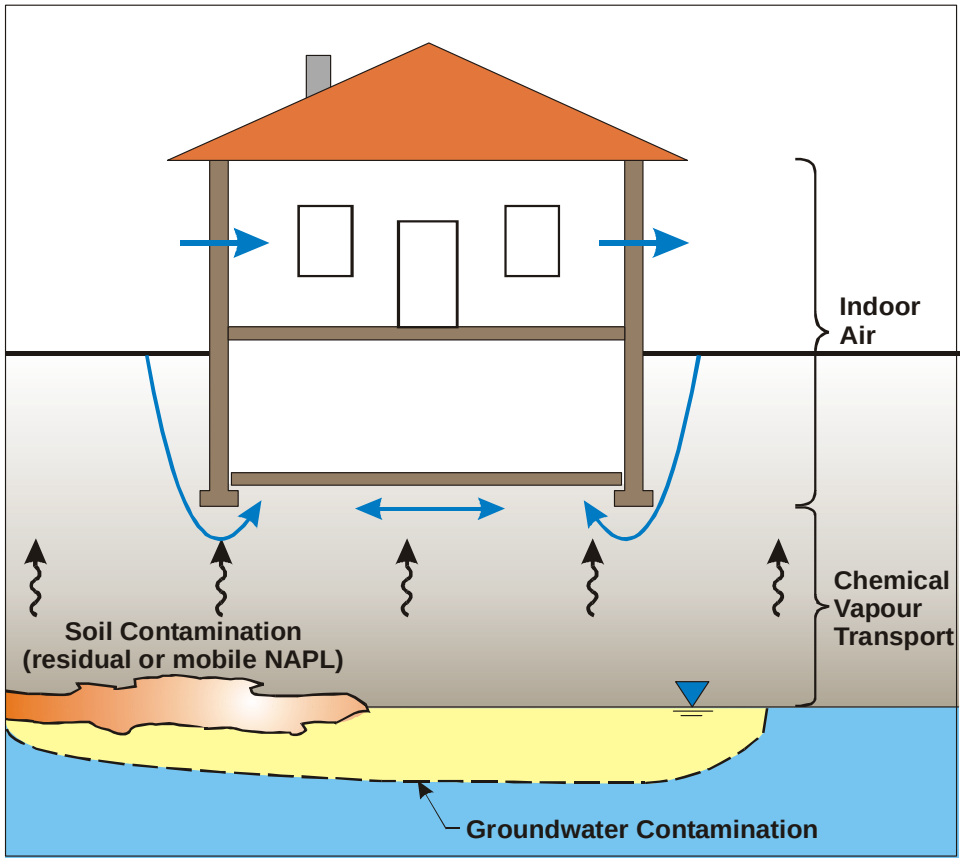
- Sources
  - Soil Contamination
  - NAPL
  - Groundwater Plumes



Courtesy Ian Hers, Golder Associates

What is Vapor Intrusion?

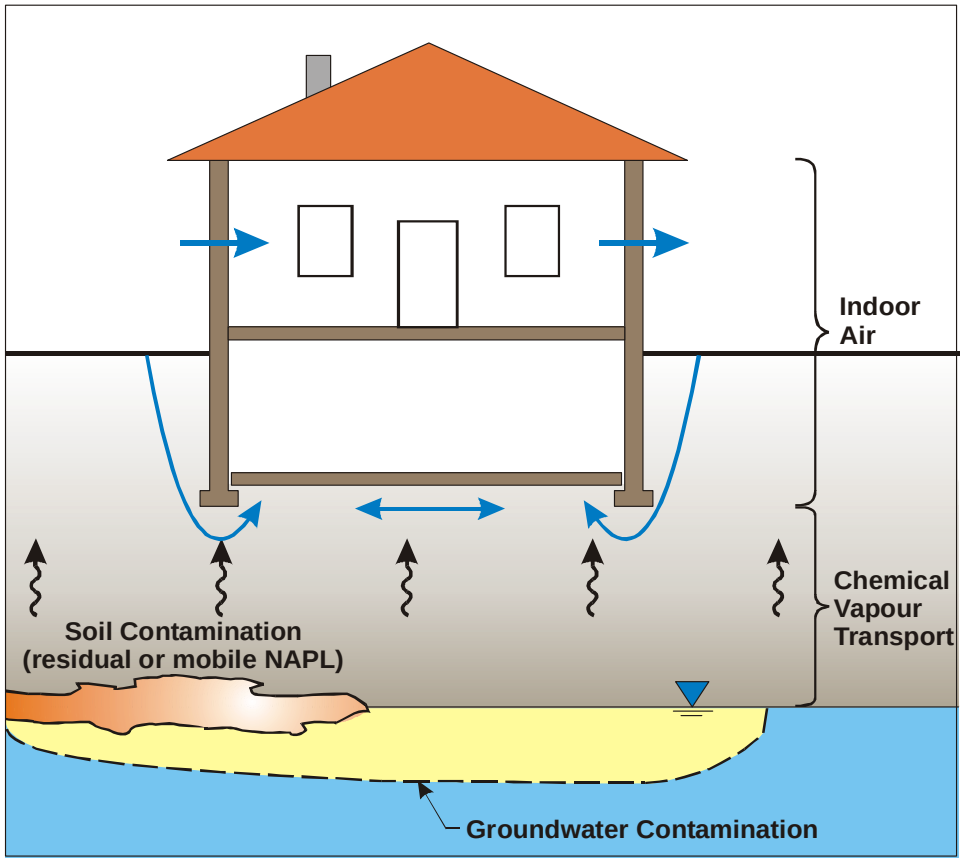
- Pathway
  - Partitioning to Vapor Phase
  - Diffusion in Vadose Zone
  - Advection near Building
  - Dilution in Building



Courtesy Ian Hers, Golder Associates

What is Vapor Intrusion?

- Receptors
  - Building occupants

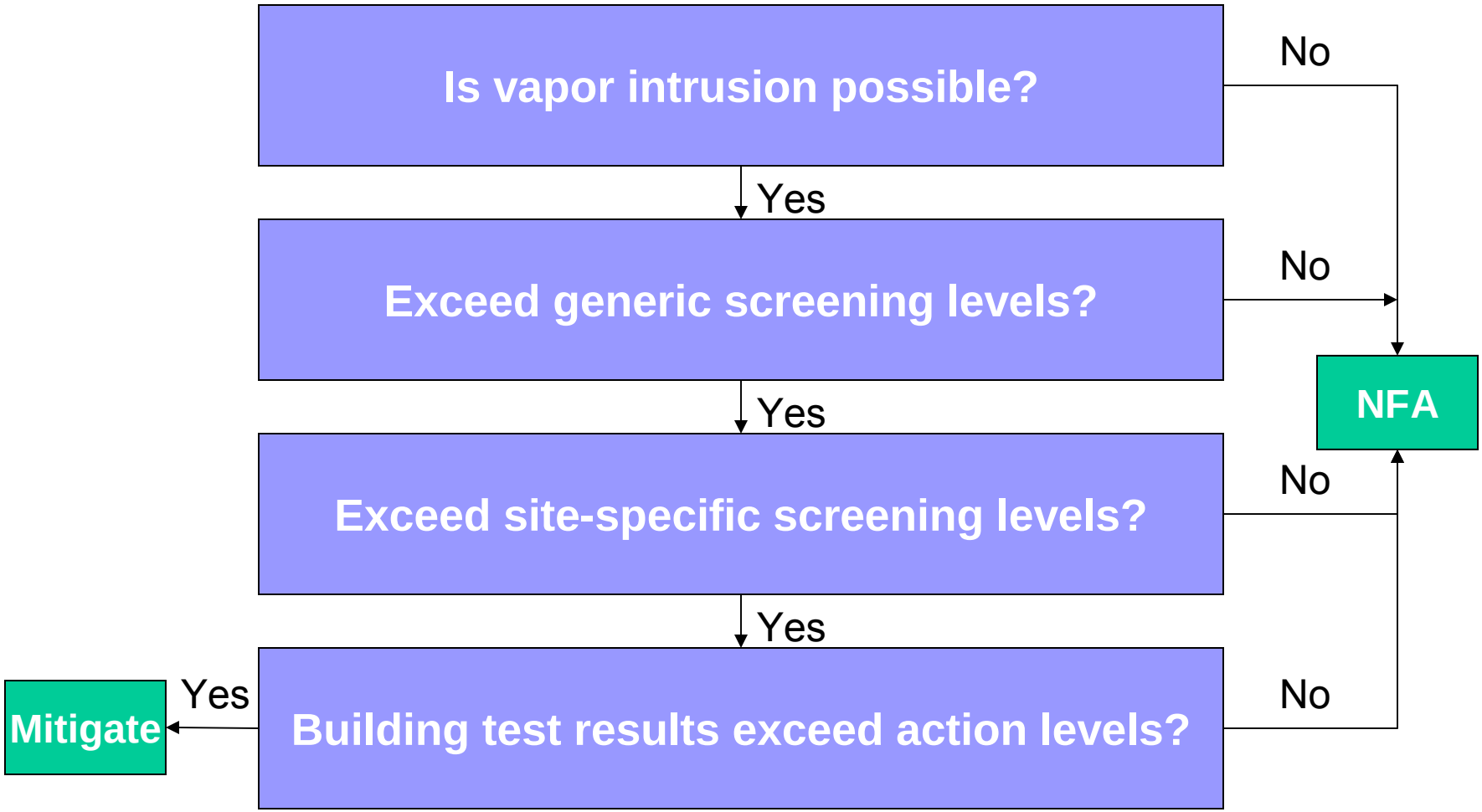


Courtesy Ian Hers, Golder Associates

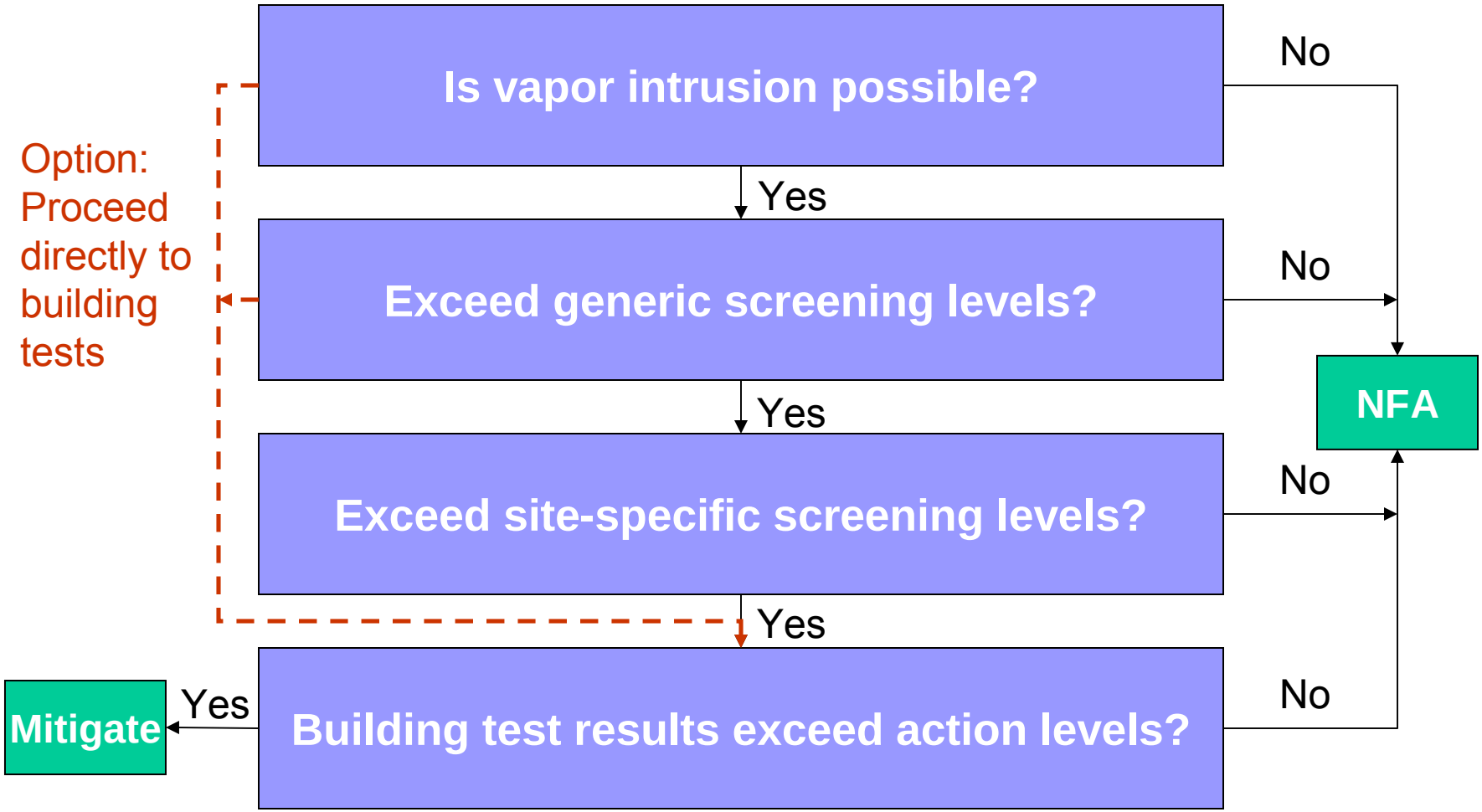
Why Evaluate Vapor Intrusion?

- Screening existing and new sites under regulatory programs
- Voluntary cleanup sites
- Real estate transactions
- Brownfield sites

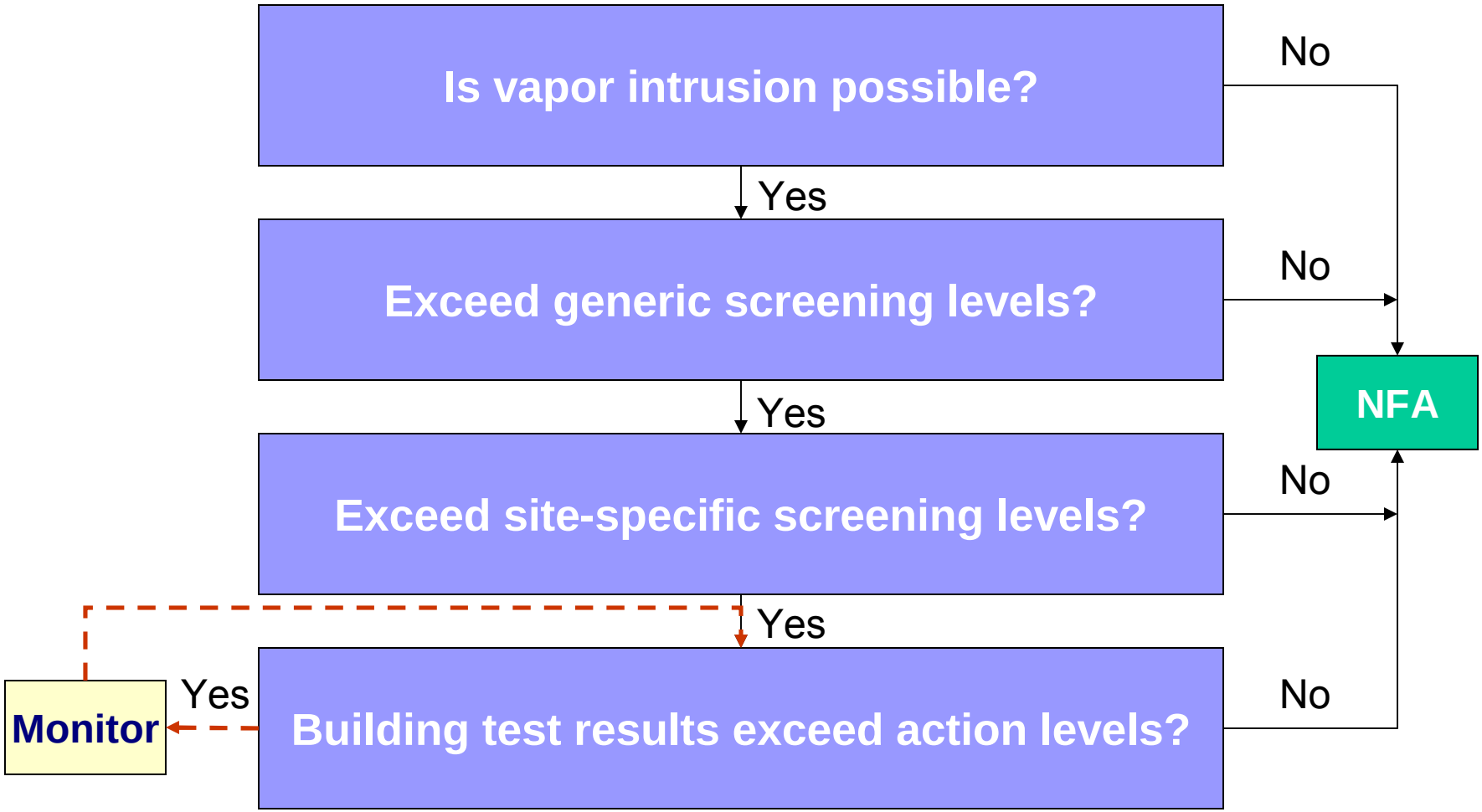
Typical VI Evaluation Process



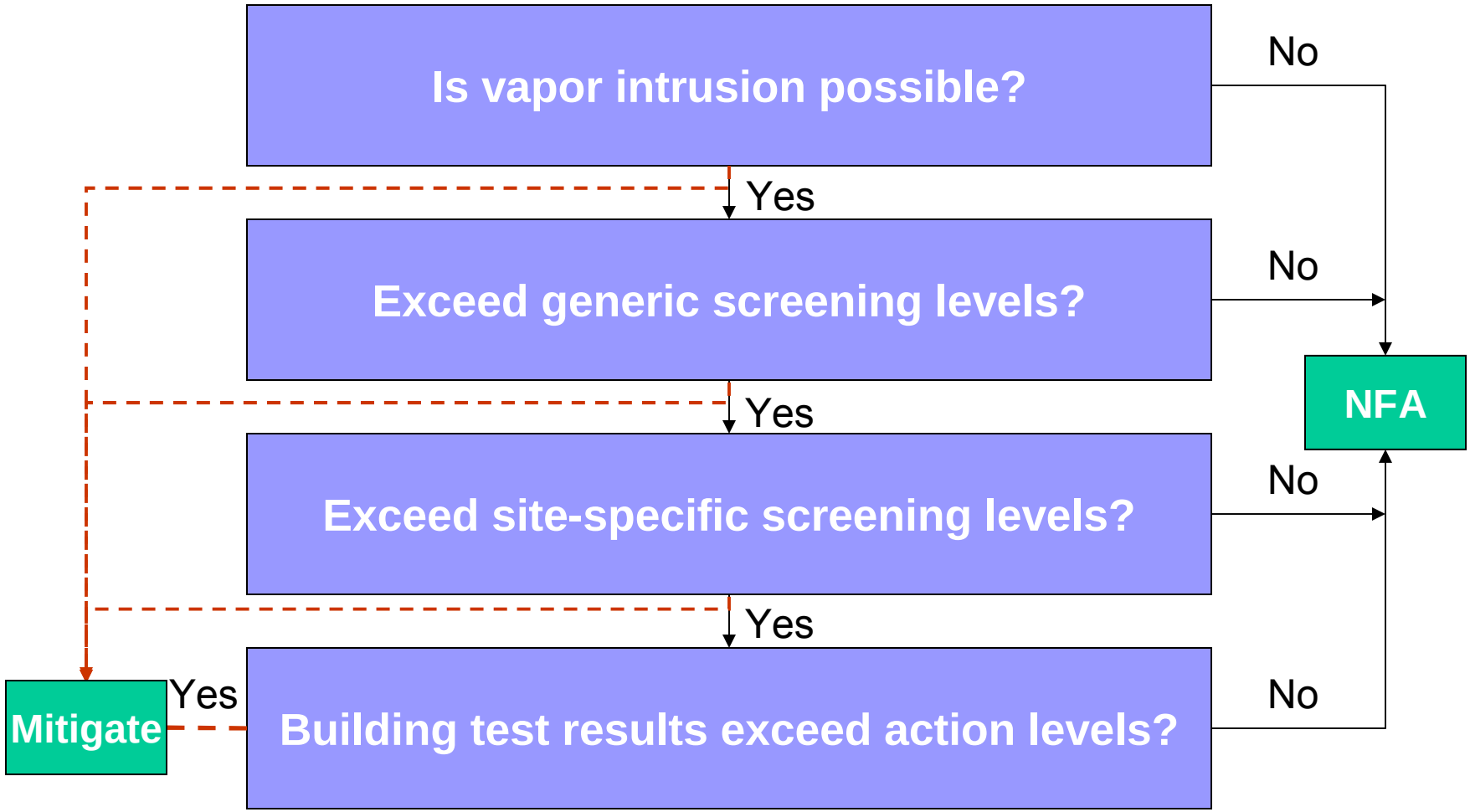
Skip Screening Option



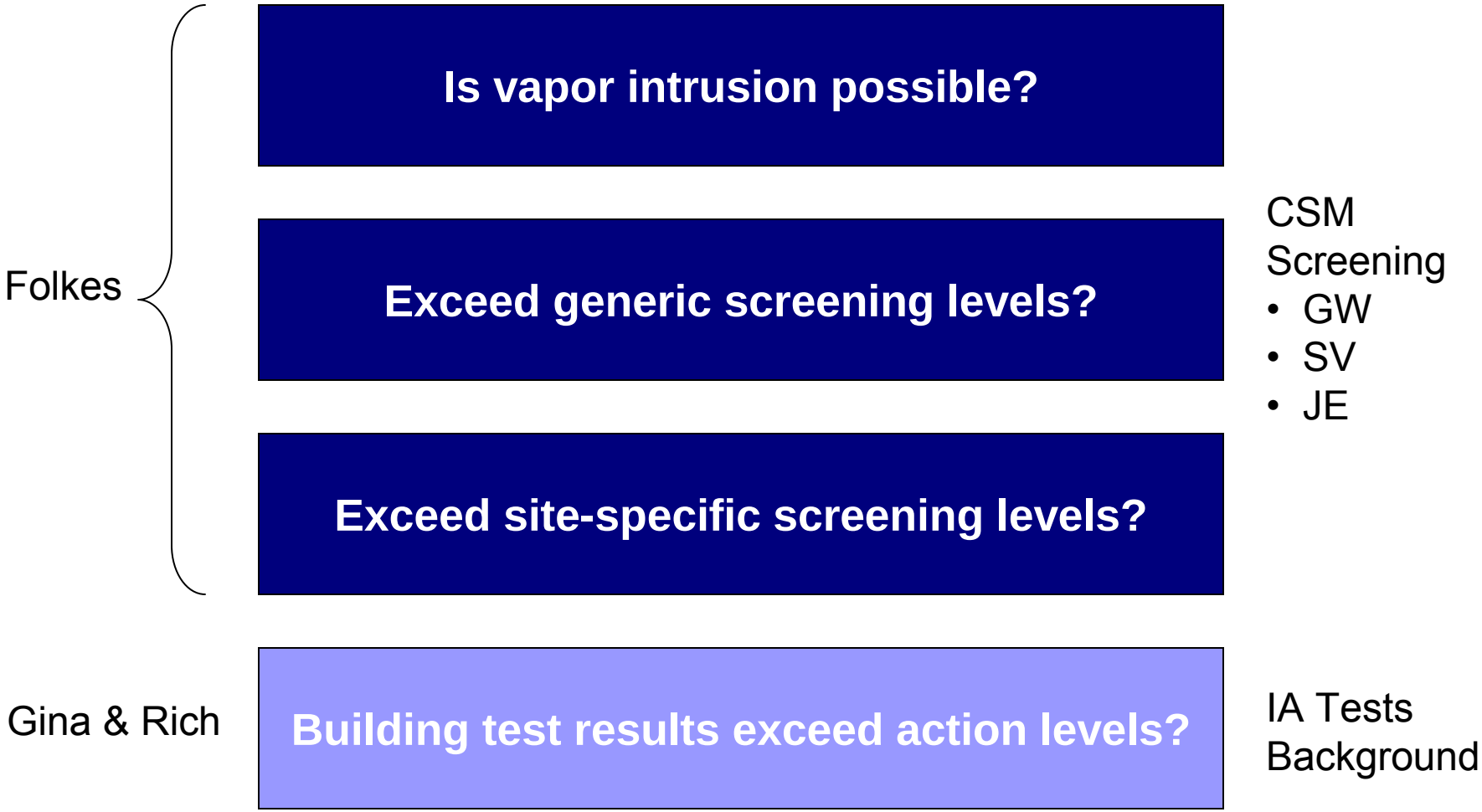
Indoor Air Monitoring Option



Pre-emptive Mitigation Option



Focus of Presentations

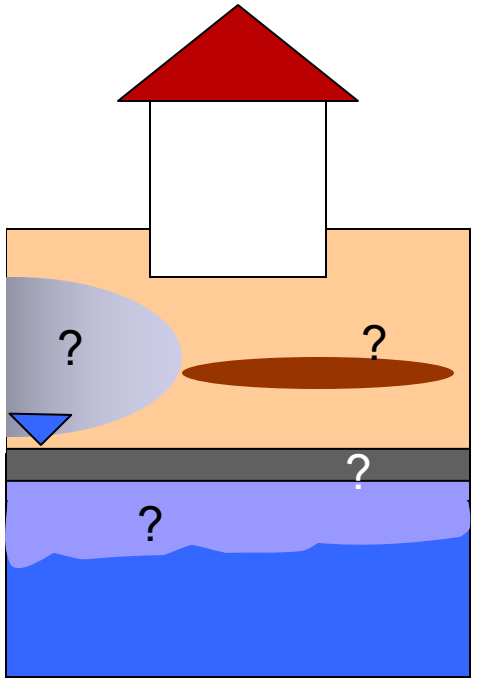


Getting Started …
Site Conceptual Model

- Minimum information needed to begin the screening and evaluation process

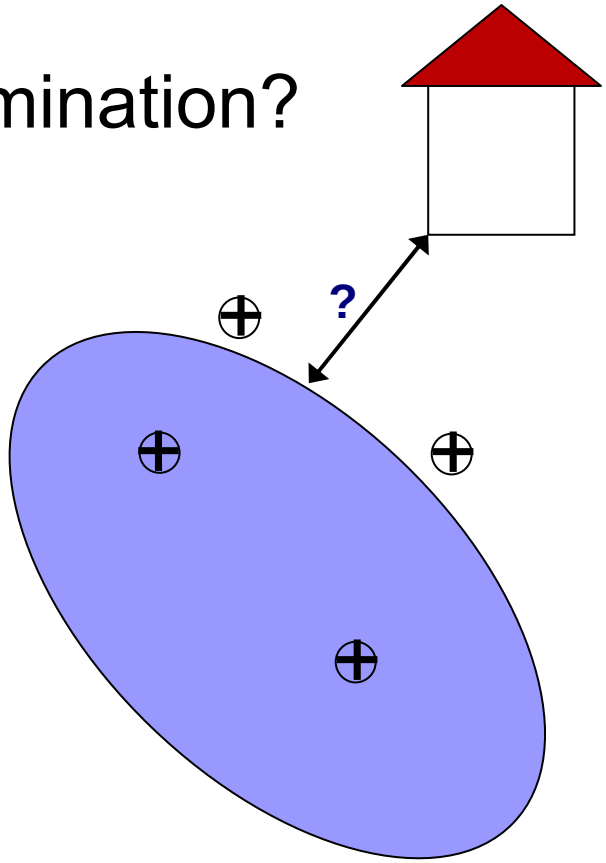
Getting Started …
Site Conceptual Model

- Nature of Vapor Source(s)
  - Dissolved plume?
  - LNAPL?
  - Contaminated soil?
  - Vapor cloud?



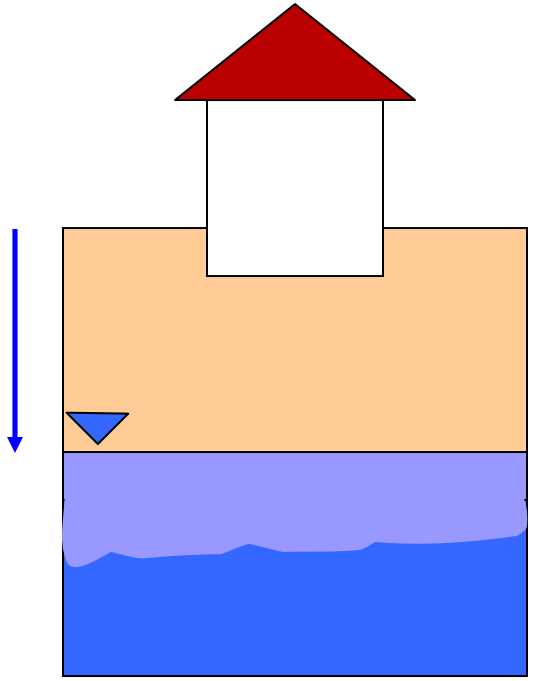
Getting Started …
Site Conceptual Model

- Nature of Vapor Sources
  - Horizontal extent of contamination?
  - Distance from buildings?
  - Sufficient delineation?



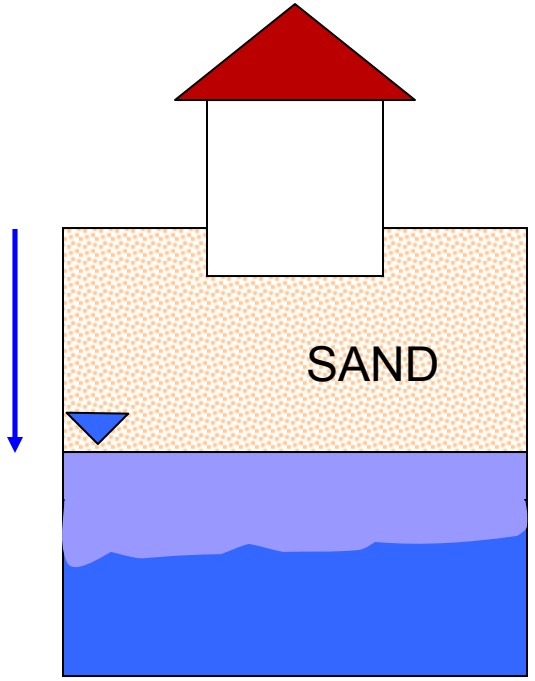
Getting Started …
Site Conceptual Model

- Vadose Zone Characteristics
  - Depth to source



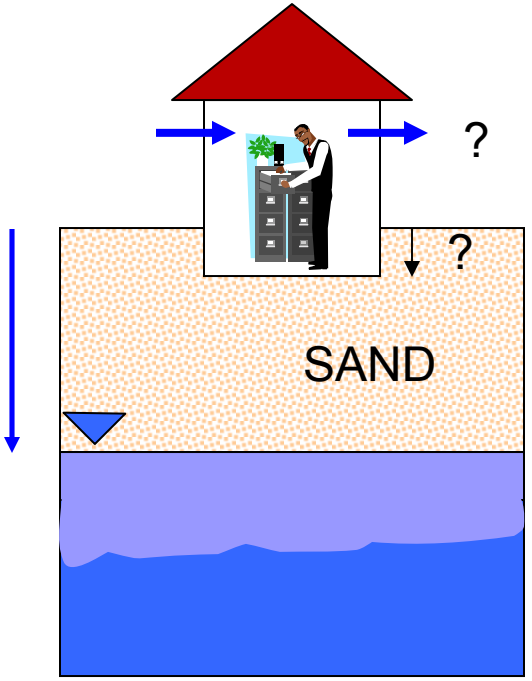
Getting Started …
Site Conceptual Model

- Vadose Zone Characteristics
  - Depth to source
  - Soil type



Getting Started …
Site Conceptual Model

- Building Information
  - Occupants?
  - Foundation type?
  - Leaky or tight?



Next Step – Generic Screening

- Objectives:
  - Minimize amount of information needed for screening
  - Eliminate sites that do not warrant further action
  - Focus efforts on sites with higher potential for vapor intrusion

Next Step – Generic Screening

- Issues:
  - Screening criteria must be conservative
  - Screening levels are very low
  - Most people agree conservative enough, but…
  - Very few sites are being screened out

Next Step – Generic Screening

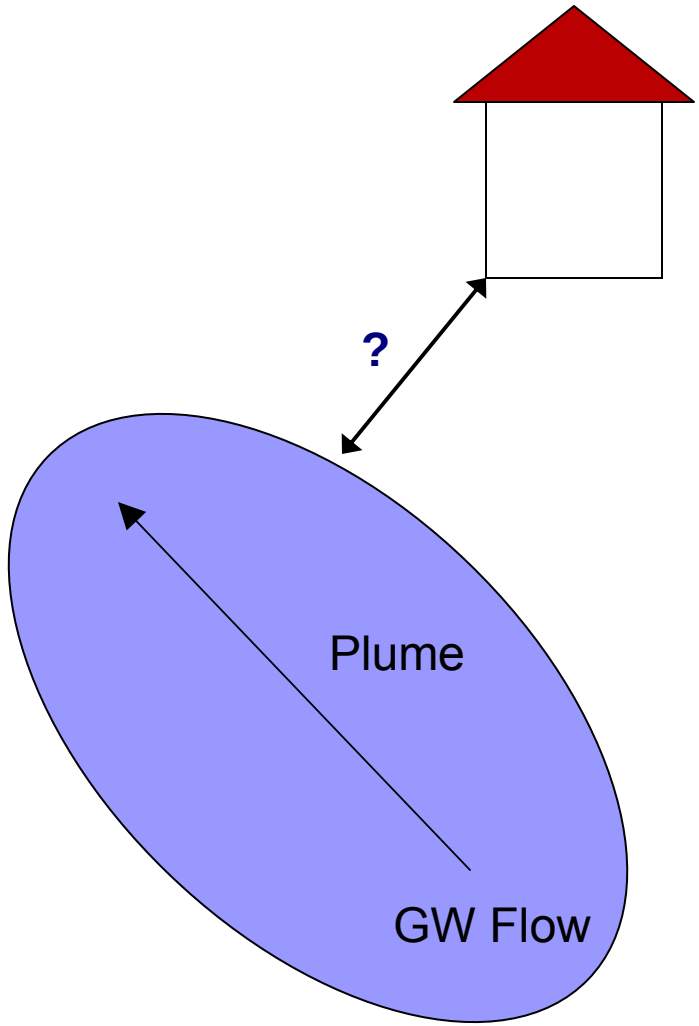
- Choices:
  - Try to increase screening levels, if warranted
  - Accept that more site-specific data will be needed at most sites

Generic Screening Process - "Qualitative" Criteria

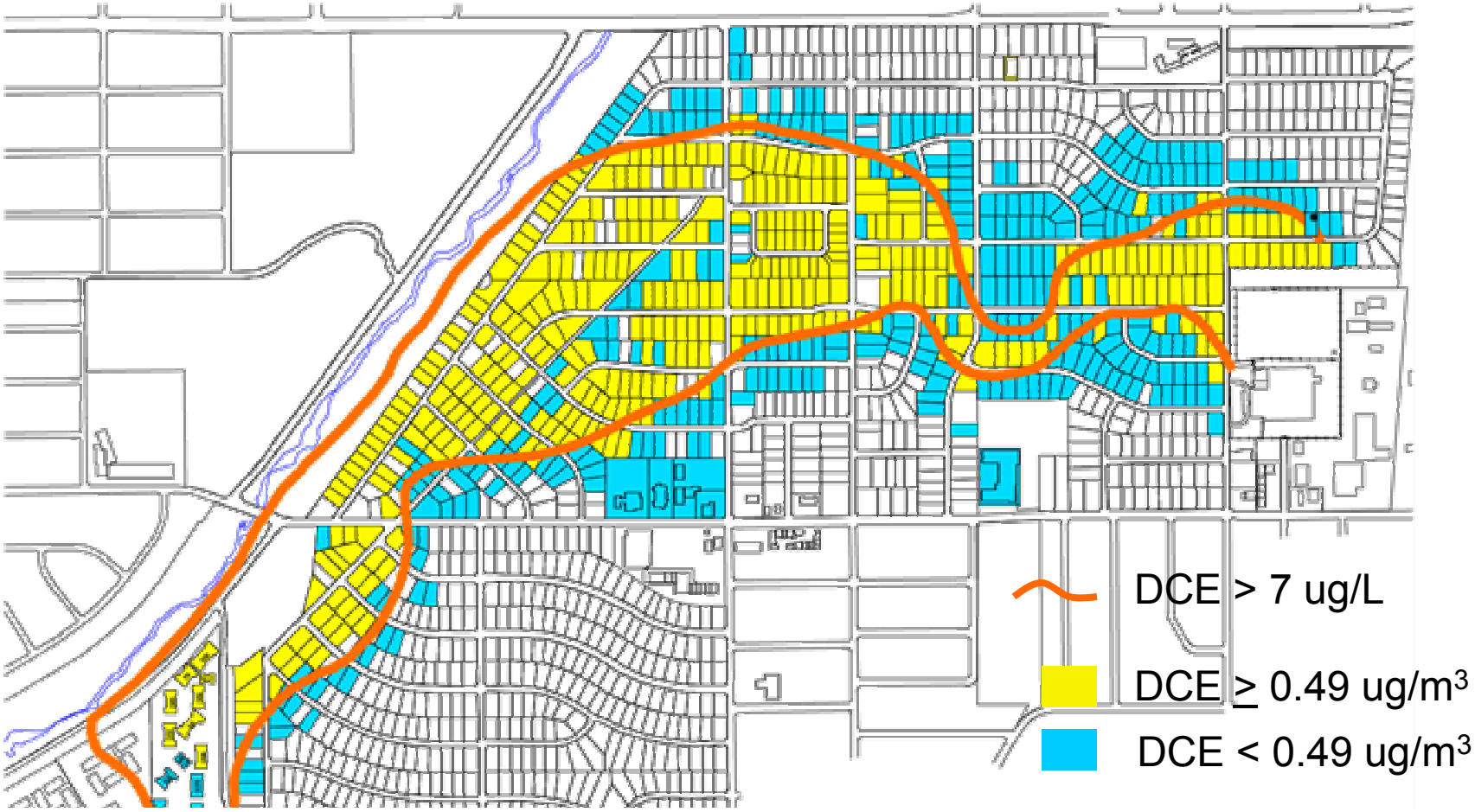
- Is vapor intrusion possible (reasonably)?
  - Are volatile compounds present?
  - Are occupied buildings present (now or in future)?
- If no, no further action
- If yes, compare to "quantitative" criteria (generic screening levels)

How far is far enough?

- EPA (2002) – 100’
- Empirical data supports ~100’ (e.g., Colorado sites)
- Theory supports ~100’
- Preferential pathways may increase distance (relatively rare)



Correlation with GW Plume



From Folkes, 2005

Generic Screening Process

- Compare site data to look-up table values
- Available for groundwater and soil vapor
- Concentration < screening level – NFA
- Concentration > screening level
  - Cannot screen out
  - Does not mean vapor intrusion is occurring
  - Need more information

Generic Screening Process

- EPA (2002) commonly referenced
- Based on target indoor air concentration
  - Toxicity criteria
  - Risk level (10-4, 10-5, 10-6)
- Provides “equivalent” soil vapor and groundwater concentrations

Generic Screening Process

- EPA (2002) 10-4 screening table excerpt

Table 2a: Question 4 Generic Screening Levels and Summary Sheet [1]

Risk = 1 x 10^{-4}

CAS No.	Chemical	Compounds with Provisional Toxicity Data Extrapolated From Oral Sources	Basis of Target Concentration C=cancer risk NC=noncancer risk	Target Indoor Air Concentration to Satisfy Both the Prescribed Risk Level and the Target Hazard Index (R=10^{-4}, HI=1) C_{target} (ug/m^3)	(ppbv)	Measured or Reasonably Estimated Indoor Air Concentration [if available] (specify units)	Target Shallow Soil Gas Concentration Corresponding to Target Indoor Air Concentration Where the Soil Gas to Indoor Air Attenuation Factor=0.1 $C_{soil\text{-}gas}$ (ug/m^3)	(ppbv)	Measured or Reasonably Estimated Shallow Soil Gas Concentration [if available] (specify units)	Target Deep Soil Gas Concentration Corresponding to Target Indoor Air Concentration Where the Soil Gas to Indoor Air Attenuation Factor=0.01 $C_{soil\text{-}gas}$ (ug/m^3)	(ppbv)	Measured or Reasonably Estimated Deep Soil Gas Concentration [if available] (specify units)	Target Groundwater Concentration Corresponding to Target Indoor Air Concentration Where the Soil Gas to Indoor Air Attenuation Factor = 0.001 and Partitioning Across the Water Table Obeys Henry's Law C_{gw} (ug/L)	Measured or Reasonably Estimated Groundwater Concentration [if available] (specify units)
83329	Acenaphthene	X	NC	2.1E+02	3.3E+01		2.1E+03	3.3E+02		2.1E+04	3.3E+03		**	
75070	Acetaldehyde		NC	9.0E+00	5.0E+00		9.0E+01	5.0E+01		9.0E+02	5.0E+02		2.8E+03	
67641	Acetone	X	NC	3.5E+02	1.5E+02		3.5E+03	1.5E+03		3.5E+04	1.5E+04		2.2E+05	
75058	Acetonitrile		NC	6.0E+01	3.6E+01		6.0E+02	3.6E+02		6.0E+03	3.6E+03		4.2E+04	
98862	Acetophenone	X	NC	3.5E+02			[illegible]				7.1E+0[illegible]			
107028	Acrolein		NC	2.0E-02			[illegible]E-01				8.7E-0[illegible]			
107131	Acrylonitrile		NC	2.0E+00			[illegible]E+01				9.2E+0[illegible]			
309002	Aldrin		C	5.0E-02			[illegible]E-01				3.3E-0[illegible]			
319846	alpha-HCH (alpha-BHC)		C	1.4E-01	1.1E-02		1.4E+00	1.1E-01		1.4E+01	1.1E+00		3.1E+02	
100527	Benzaldehyde	X	NC	7.5E+02	8.1E+01		3.5E+03	8.1E+02		3.5E+04	8.1E+03		3.6E+05	
71432	Benzene		C	3.1E+01	9.8E+00		3.1E+02	9.8E+01		3.1E+03	9.8E+02		1.4E+02	
205992	Benzo(b)fluoranthene	X	C	1.2E+00	1.1E-01		**	**		**	**		**	
100447	Benzylchloride	X	C	5.0E+00	9.7E-01		5.0E+01	9.7E+00		5.0E+02	9.7E+01		3.0E+02	
91587	beta-Chloronaphthalene	X	NC	2.8E+02	4.2E+01		2.8E+03	4.2E+02					**	

Benzene

Indoor Air 31 ug/m^3

Shallow SV 310 ug/m^3

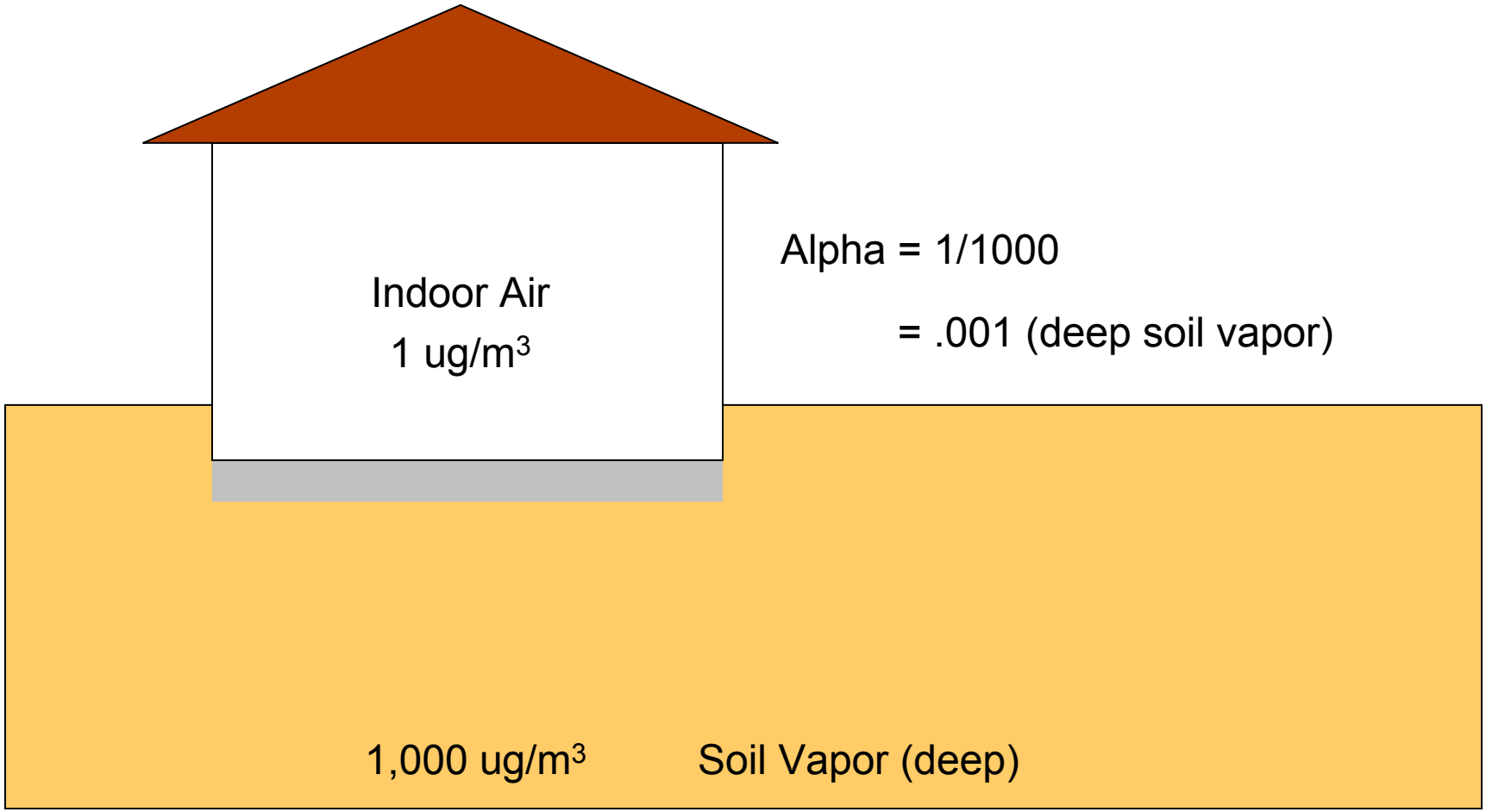
Deep SV 3100 ug/m^3

Groundwater 140 ug/L

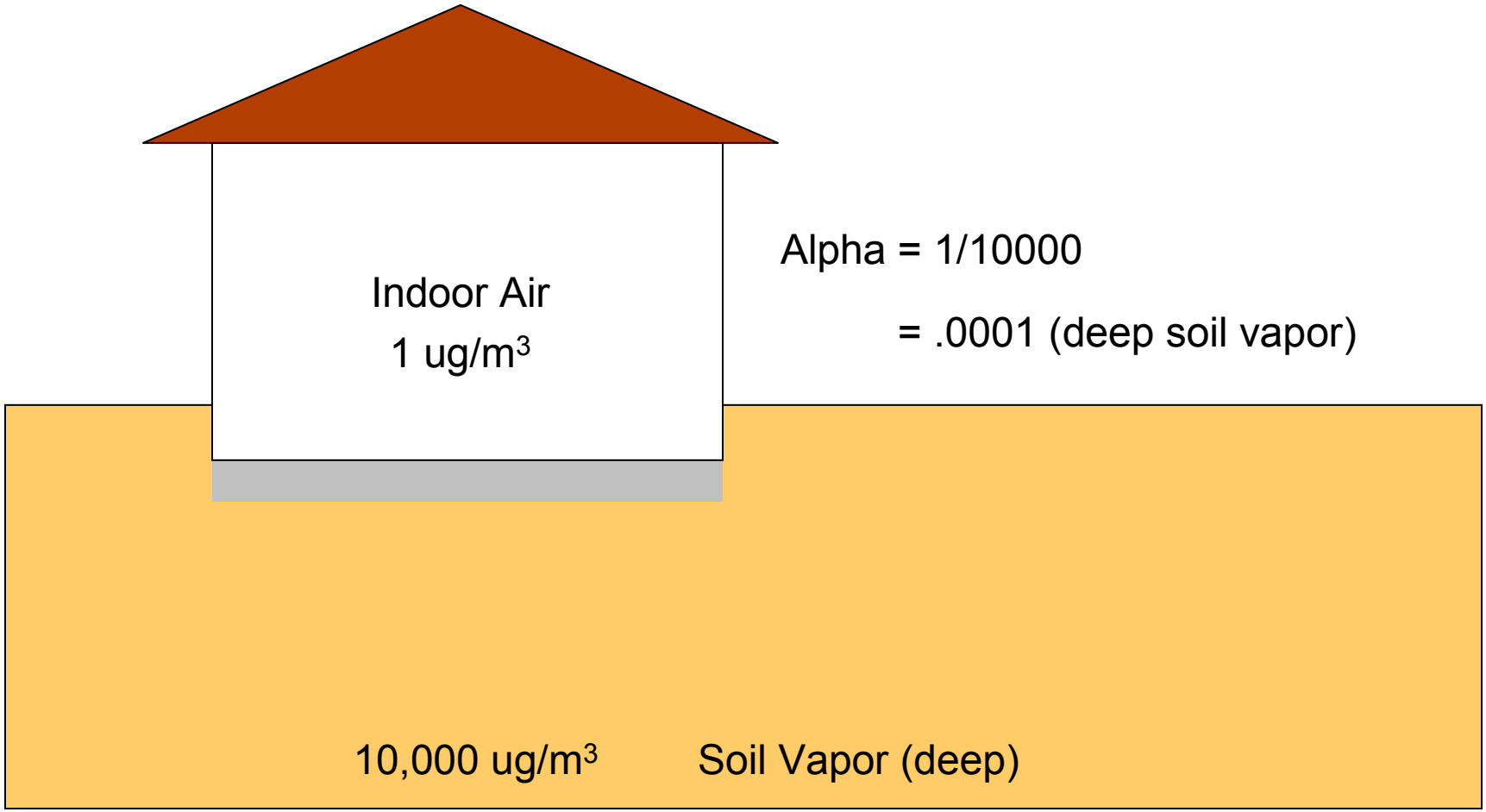
Derivation of Generic Screening Levels

- Based on assumed attenuation between "source" vapors and indoor air
- Attenuation factors deliberately conservative ("reasonable worst-case")
  - Low probability of false negative
  - High probability of false positive, therefore
    - Should NOT trigger mitigation
    - But continued evaluation warranted

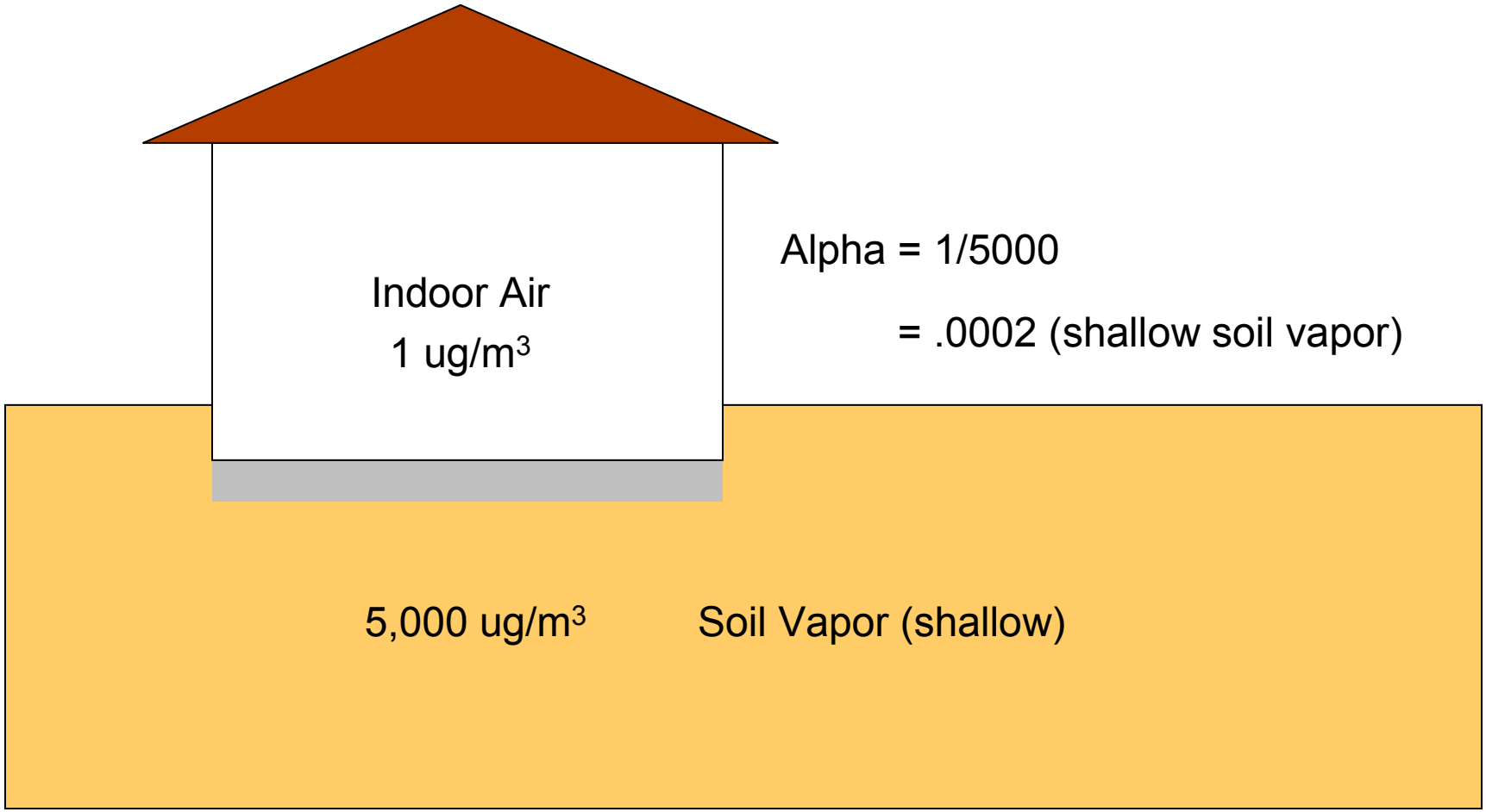
Attenuation Factor Concept



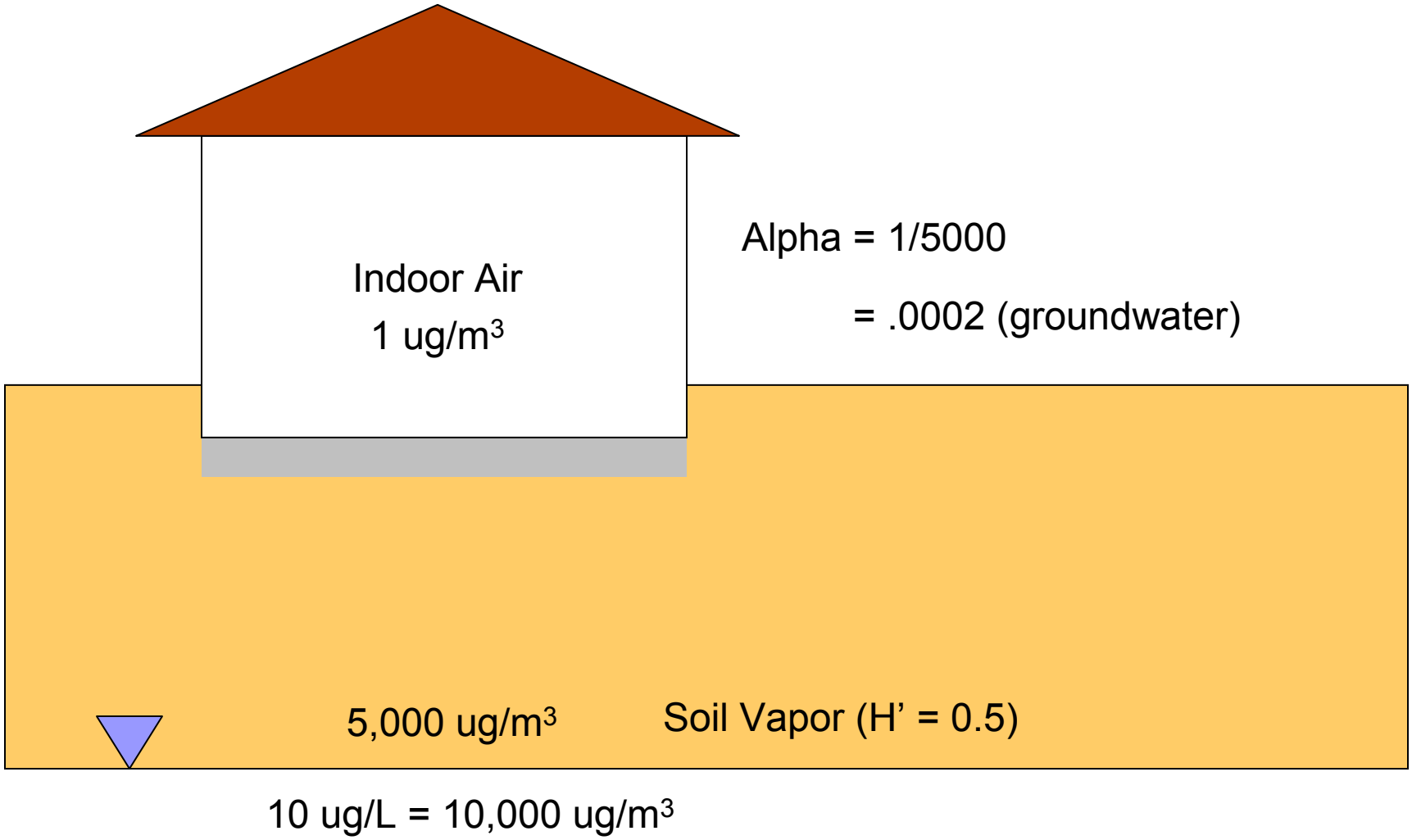
Attenuation Factor Concept



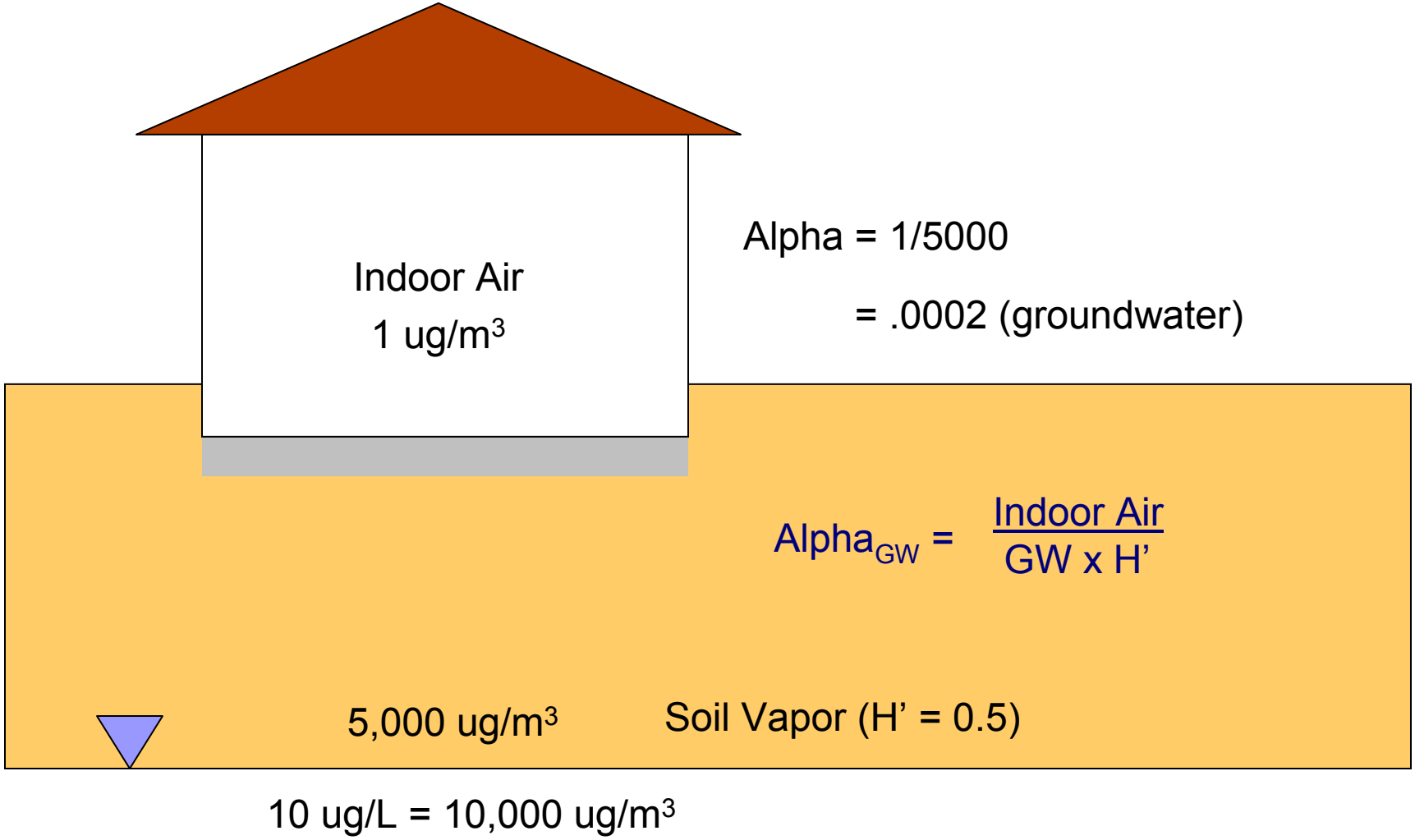
Attenuation Factor Concept



Attenuation Factor Concept

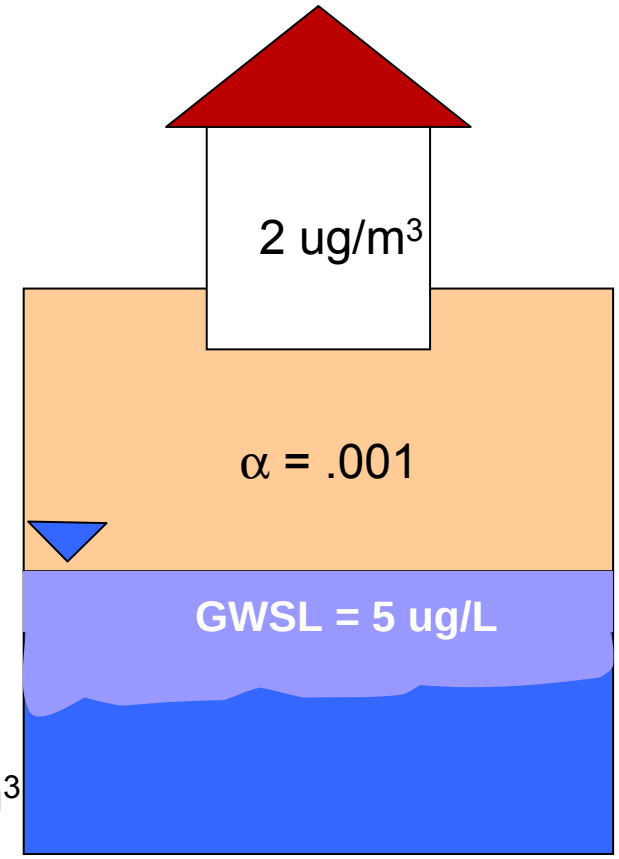


Attenuation Factor Concept



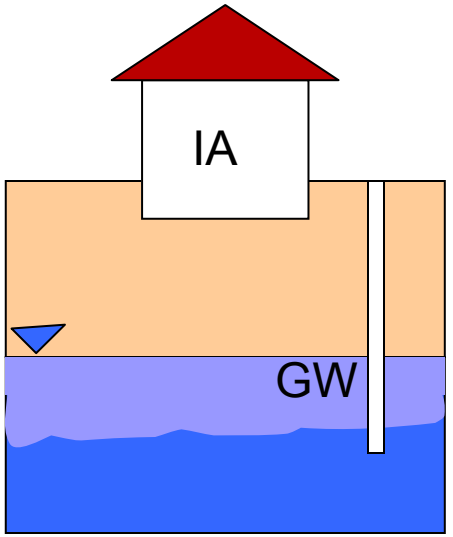
Calculation of Generic Screening Levels

- Begin with target indoor air concentration
- Select alpha for media of interest, e.g., groundwater
- Calculate media concentration (example only)
  - SV = IA / α = 2 ug/m^3 / 0.001 = 2000 ug/m^3
  - Therefore, GWSL = 2000 ug/m^3 / H'
  - Assume H' = 0.4
  - Therefore, GWSL = 2000 ug/m^3 / 0.4 = 5000 ug/m3 = 5 ug/L



EPA GW Screening Levels

- How conservative are they?
- Based on observed groundwater to indoor air attenuation factors
- Upper bound value (0.001) selected to develop generic screening levels



IA/GW*H' = alpha

Observed Groundwater to Indoor Air Attenuation Factors

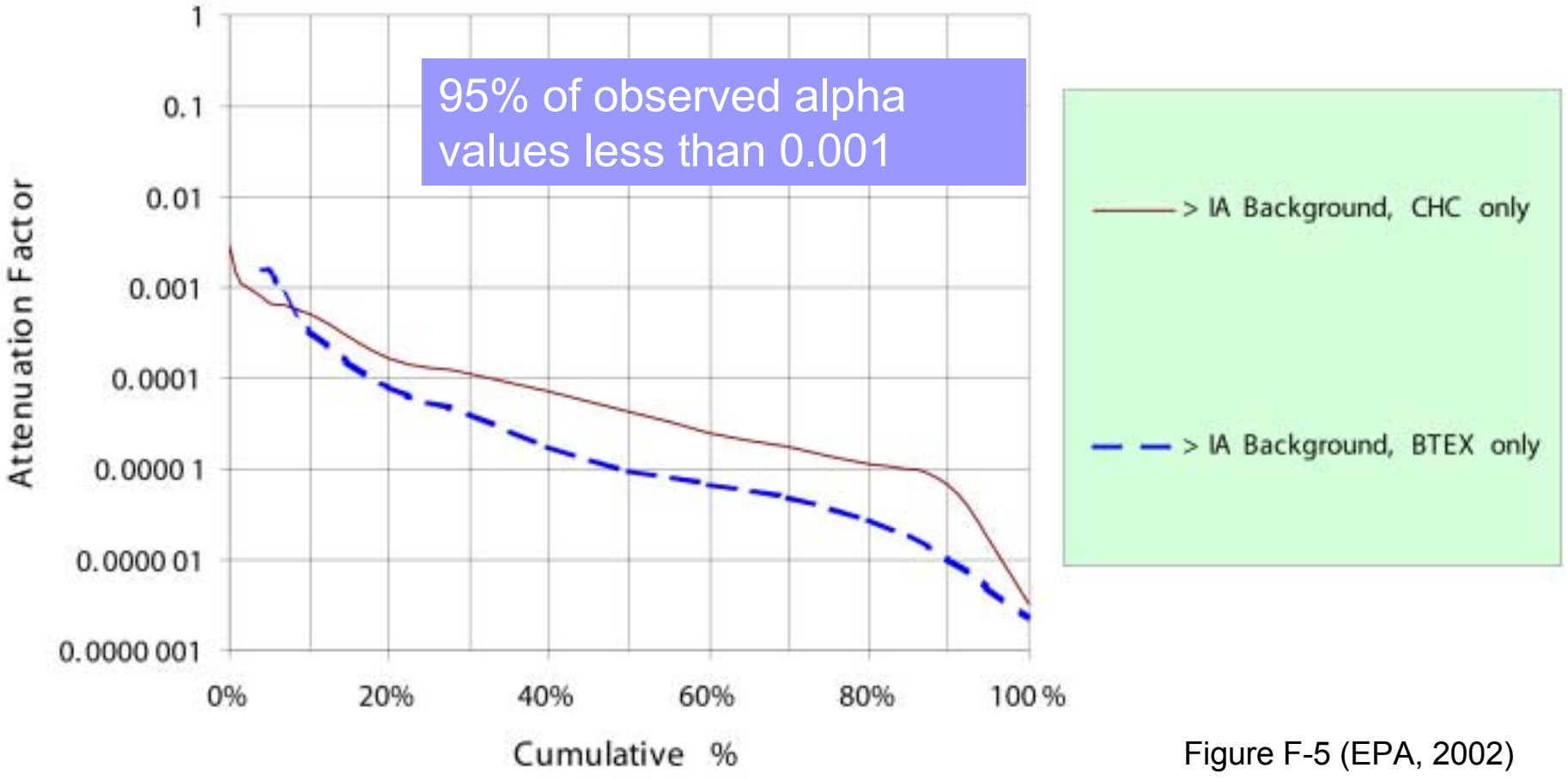
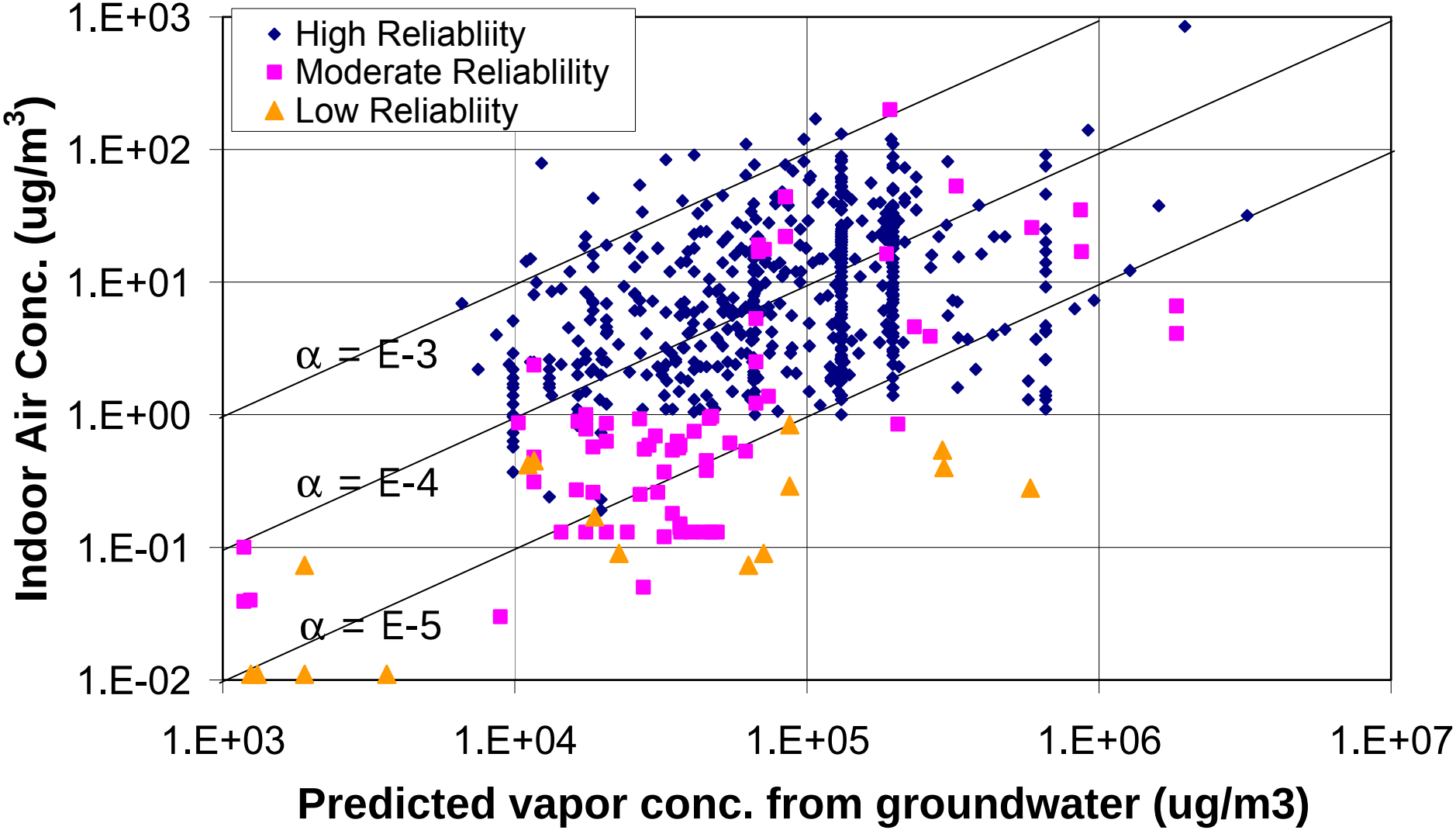


Figure F-5 (EPA, 2002)

EPA Groundwater Alpha Values

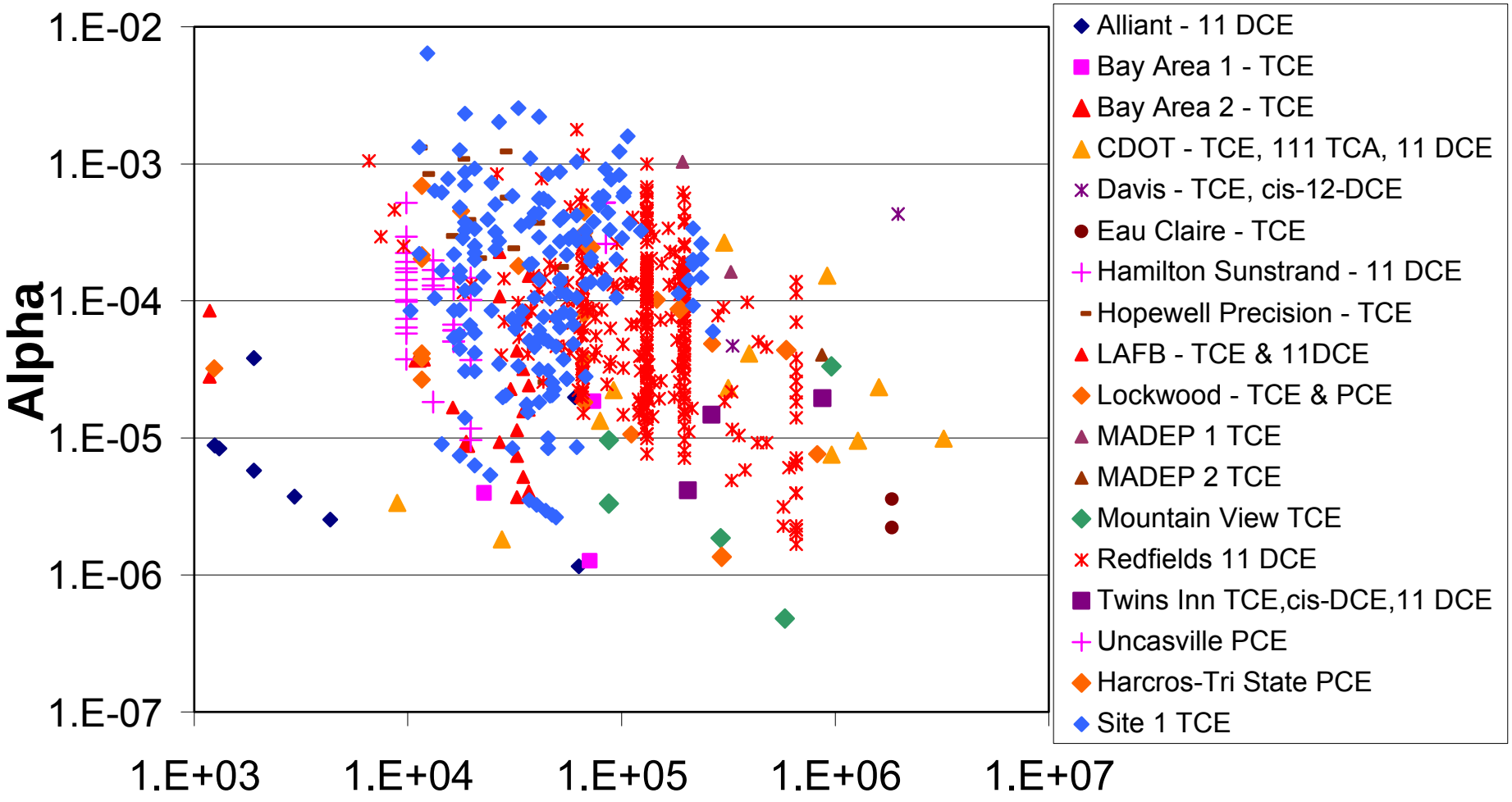
- Groundwater Screening Levels based on alpha of 0.001
- Should over-estimate indoor air concentrations 95% of the time
- Since 2002, additional empirical data have confirmed alpha of 0.001 is conservative

Groundwater Alpha - Residential - Chlorinated Solvent - Filtered



Courtesy Ian Hers, Golder Associates

All Site Data
Gdw Alpha - CS - Residential



Courtesy Ian Hers, Golder Associates

Observed GW Alpha Statistics

	Juniper TCE	Hamilton 11DCE	Lowry 11DCE	Lowry TCE	Redfield 11DCE	Lockwood TCE	Lockwood PCE	Lockwood cis-12-DCE	CDOT 11DCE	CDOT TCE	CDOT 111 TCA
N	54	32	11	13	65	19	18	17	6	4	4
10th	2.4E-05	2.3E-05	5.7E-06	1.1E-06	8.4E-07	7.3E-06	8.9E-06	8.4E-07	1.6E-06	6.1E-06	1.1E-05
25th	5.4E-05	3.7E-05	6.6E-06	3.2E-06	2.4E-06	1.4E-05	1.6E-05	1.4E-06	2.7E-06	6.6E-06	1.2E-05
50th	1.3E-04	6.9E-05	1.9E-05	8.7E-06	1.1E-05	6.1E-05	5.0E-05	5.5E-06	5.3E-06	9.2E-06	1.7E-05
75th	3.0E-04	9.3E-05	7.6E-05	3.1E-05	3.3E-05	1.4E-04	8.4E-05	4.8E-05	6.0E-06	4.3E-05	3.8E-05
90th	7.6E-04	1.2E-04	4.7E-04	2.8E-04	1.5E-04	2.3E-04	1.3E-04	7.1E-05	1.0E-05	1.0E-04	6.5E-05

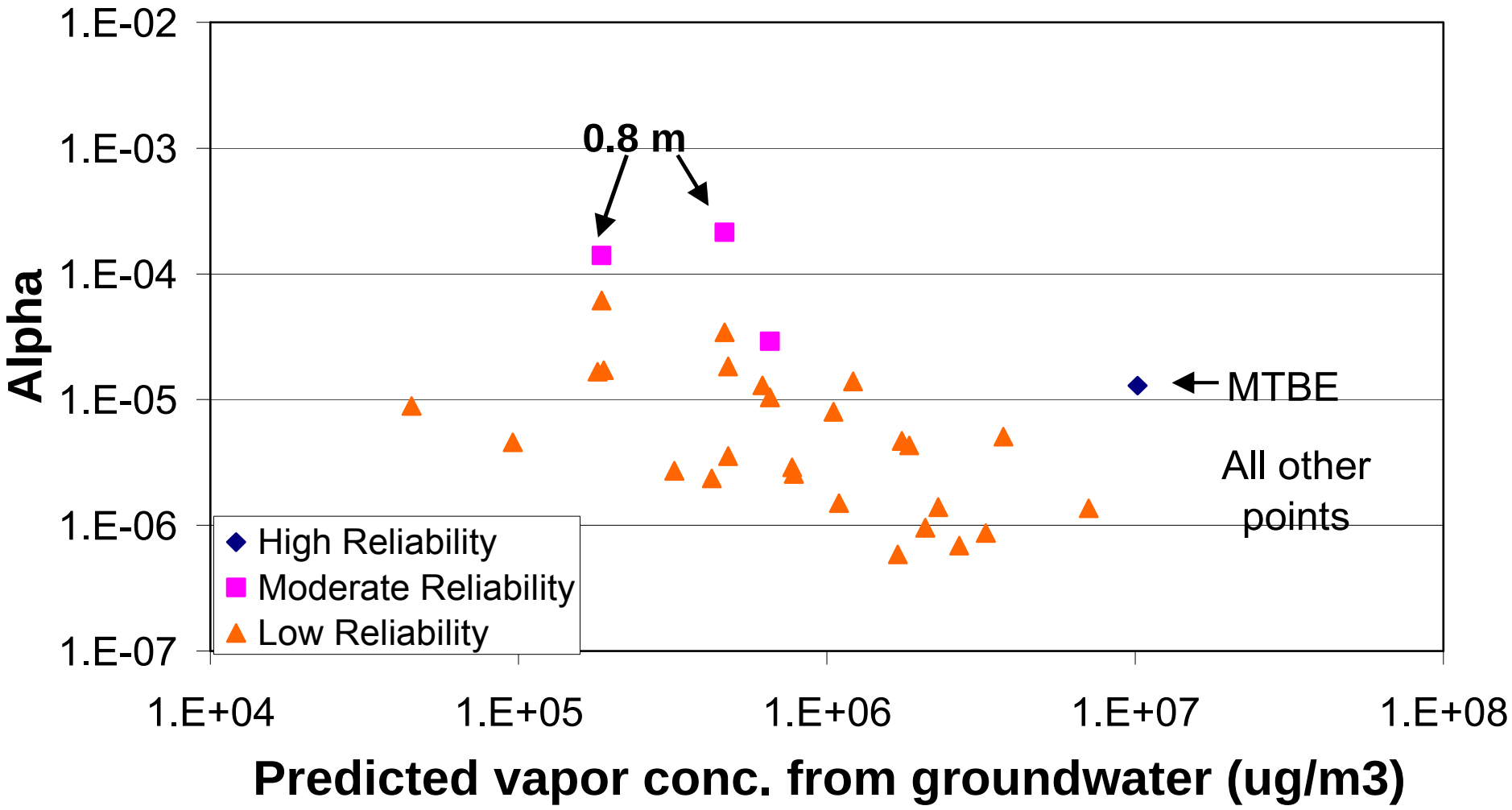
USEPA Generic Gdw Alpha = 1E-03

Semi-site Specific Alpha = 7E-05 to 1.1E-3

Note: CDOT data median of mean for multiple buildings

From Hers et al., 2005

Groundwater Alpha - Residential - Petroleum Hydrocarbon- Filtered



Courtesy Ian Hers, Golder Associates

Groundwater Screening Issues

- EPA (2002) screening levels very low
  - Not much is screened out
- Risk level is key
  - Mitigation at 10-5 common
- EPA does not go below MCLs
  - Some states do

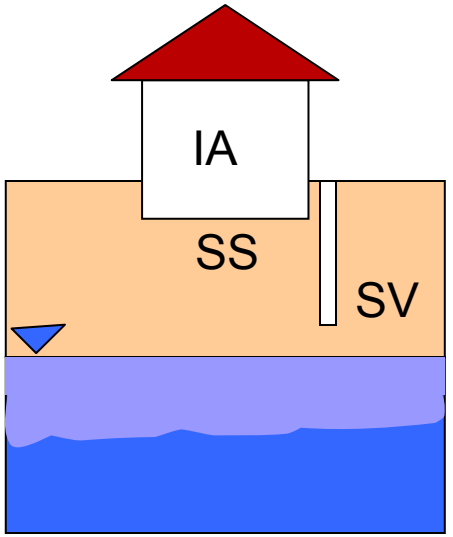
EPA GW Screening Levels (ug/l)

Compound	10-6 Risk	10-5 Risk	10-4 Risk
TCE	5*	5*	5.3
PCE	5*	11	110
Benzene	5*	14	140

* Defaults to MCL

EPA SV Screening Levels

- Shallow SV (< 5 ft below foundation) - alpha = 0.1
- Shallow = Sub-Slab (SS)
- Deep SV alpha = 0.01



IA/GW*H' = alpha

Groundwater
140 ug/L

Generic Screening Process

- EPA (2002) 10-4 screening table excerpt

Table 2a: Question 4 Generic Screening Levels and Summary Sheet [1]

Risk = 1 x 10^{-4}

CAS No.	Chemical	Compounds with Provisional Toxicity Data Extrapolated From Oral Sources	Basis of Target Concentration C=cancer risk NC=noncancer risk	Target Indoor Air Concentration to Satisfy Both the Prescribed Risk Level and the Target Hazard Index (R=10^{-4}, HI=1) C_{target} (ug/m^3)	(ppbv)	Measured or Reasonably Estimated Indoor Air Concentration (If available) (specify units)	Target Shallow Soil Gas Concentration Corresponding to Target Indoor Air Concentration Where the Soil Gas to Indoor Air Attenuation Factor=0.1 $C_{soil\text{-}gas}$ (ug/m^3)	(ppbv)	Measured or Reasonably Estimated Shallow Soil Gas Concentration (If available) (specify units)	Target Deep Soil Gas Concentration Corresponding to Target Indoor Air Concentration Where the Soil Gas to Indoor Air Attenuation Factor=0.01 $C_{soil\text{-}gas}$ (ug/m^3)	(ppbv)	Measured or Reasonably Estimated Deep Soil Gas Concentration (If available) (specify units)	Target Groundwater Concentration Corresponding to Target Indoor Air Concentration Where the Soil Gas to Indoor Air Attenuation Factor = 0.001 and Partitioning Across the Water Table Obeys Henry's Law C_{gw} (ug/L)	Measured or Reasonably Estimated Groundwater Concentration (If available) (specify units)
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75070	Acetaldehyde		NC	9.0E+00	5.0E+00		9.0E+01	5.0E+01		9.0E+02	5.0E+02		2.8E+03	
67641	Acetone	X	NC	3.5E+02	1.5E+02		3.5E+03	1.5E+03		3.5E+04	1.5E+04		2.2E+05	
75058	Acetonitrile		NC	6.0E+01	3.6E+01		6.0E+02	3.6E+02		6.0E+03	3.6E+03		4.2E+04	
98862	Acetophenone	X	NC	3.5E+02			[illegible]+03				7.1E+0[illegible]			
107028	Acrolein		NC	2.0E-02			[illegible]-01				8.7E-0[illegible]			
107131	Acrylonitrile		NC	2.0E+00			[illegible]+01				9.2E+0[illegible]			
309002	Aldrin		C	5.0E-02			[illegible]-01				3.3E-0[illegible]			
319846	alpha-HCH (alpha-BHC)		C	1.4E-01	1.1E-02		1.4E+00	1.1E-01		1.4E+01	1.1E+00		3.1E+02	
100527	Benzaldehyde	X	NC	7.5E+02	8.1E+01		3.5E+03	8.1E+02		3.5E+04	8.1E+03		3.6E+05	
71432	Benzene		C	3.1E+01	9.8E+00		3.1E+02	9.8E+01		3.1E+03	9.8E+02		1.4E+02	
205992	Benzo(b)fluoranthene	X	C	1.2E+00	1.1E-01		**	**		**	**		**	
100447	Benzylchloride	X	C	5.0E+00	9.7E-01		5.0E+01	9.7E+00		5.0E+02	9.7E+01		3.0E+02	
91587	beta-Chloronaphthalene	X	NC	2.8E+02	4.2E+01		2.8E+03	4.2E+02		2.8E+04	4.2E+03		**	

Benzene

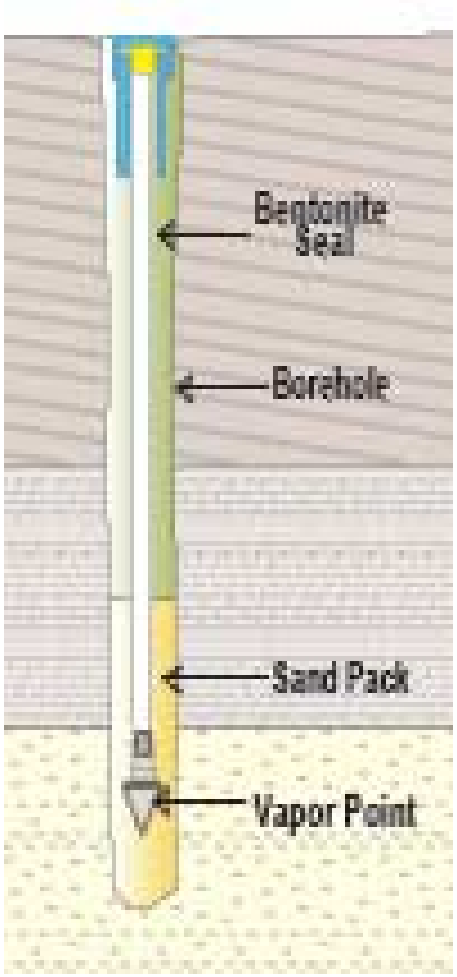
Indoor Air 31 ug/m^3

Shallow SV 310 ug/m^3

Deep SV 3100 ug/m^3

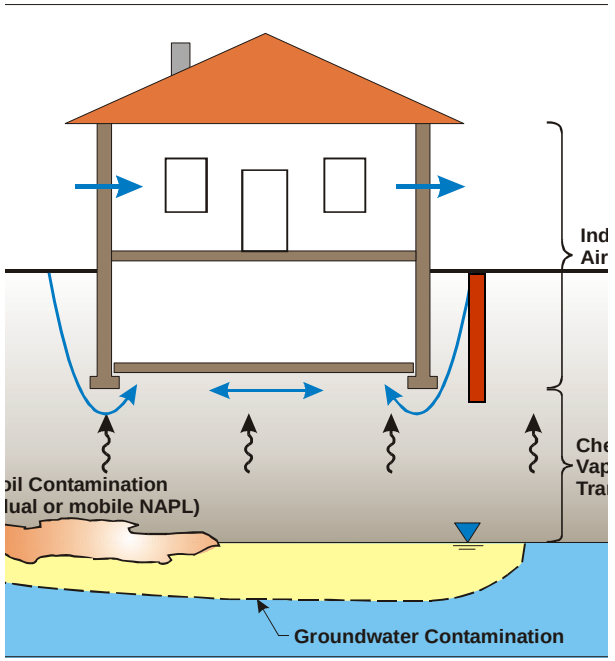
Soil Gas Sampling Procedures

- Implants preferred
- Tracer gas to demonstrate good seals
- Purging of probe and tubes
- Slow gas collection rates (100 – 200 ml/minute)
- References
  - API 4741 (November 2005)
  - NYDOH (2005)

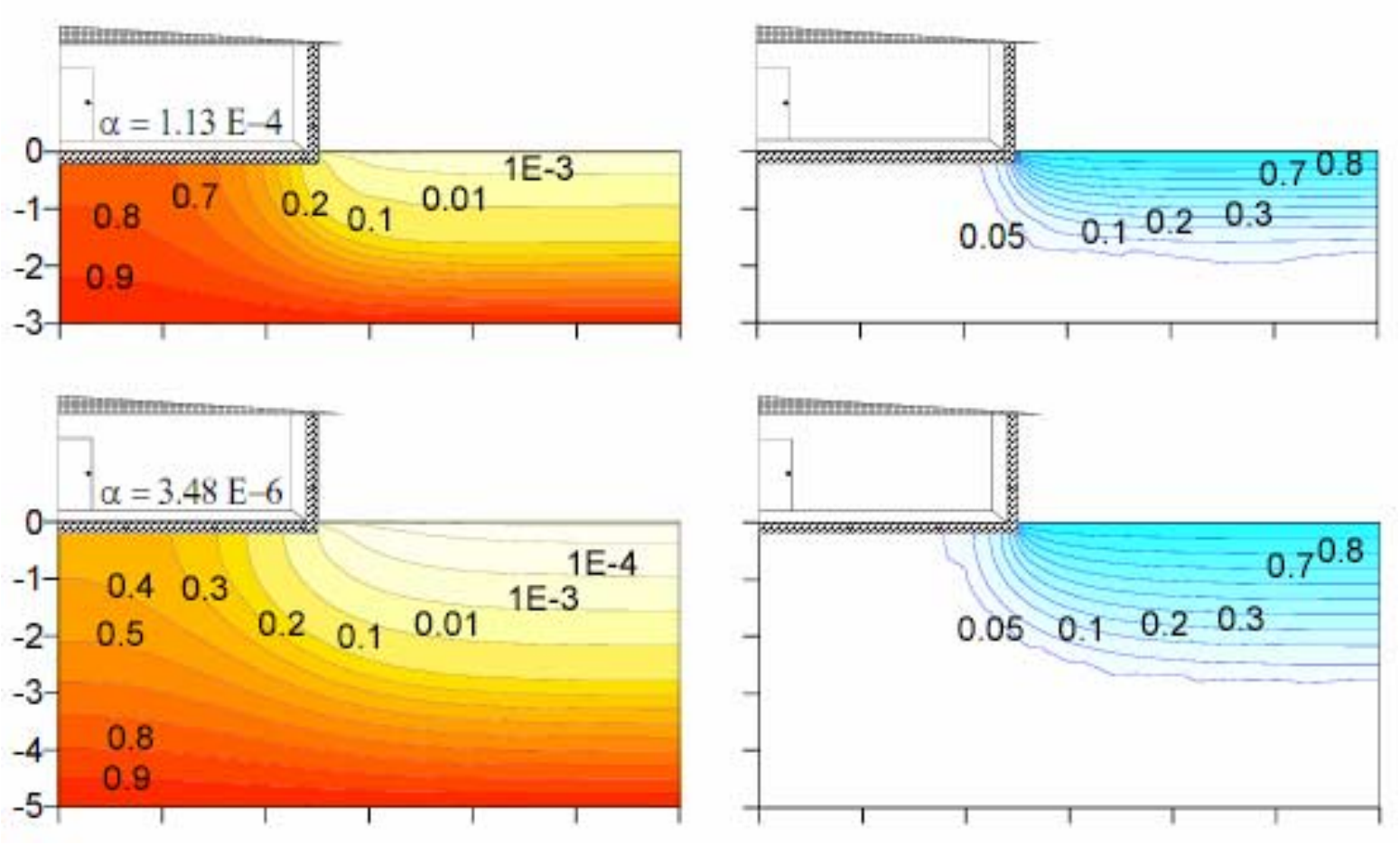


EPA SV Screening Levels

- Shallow, exterior SV samples may under-estimate potential
- Exacerbated with petroleum hydrocarbons
  - Oxygen may be depleted below buildings



Effect of Buildings on Petroleum HC Vapors

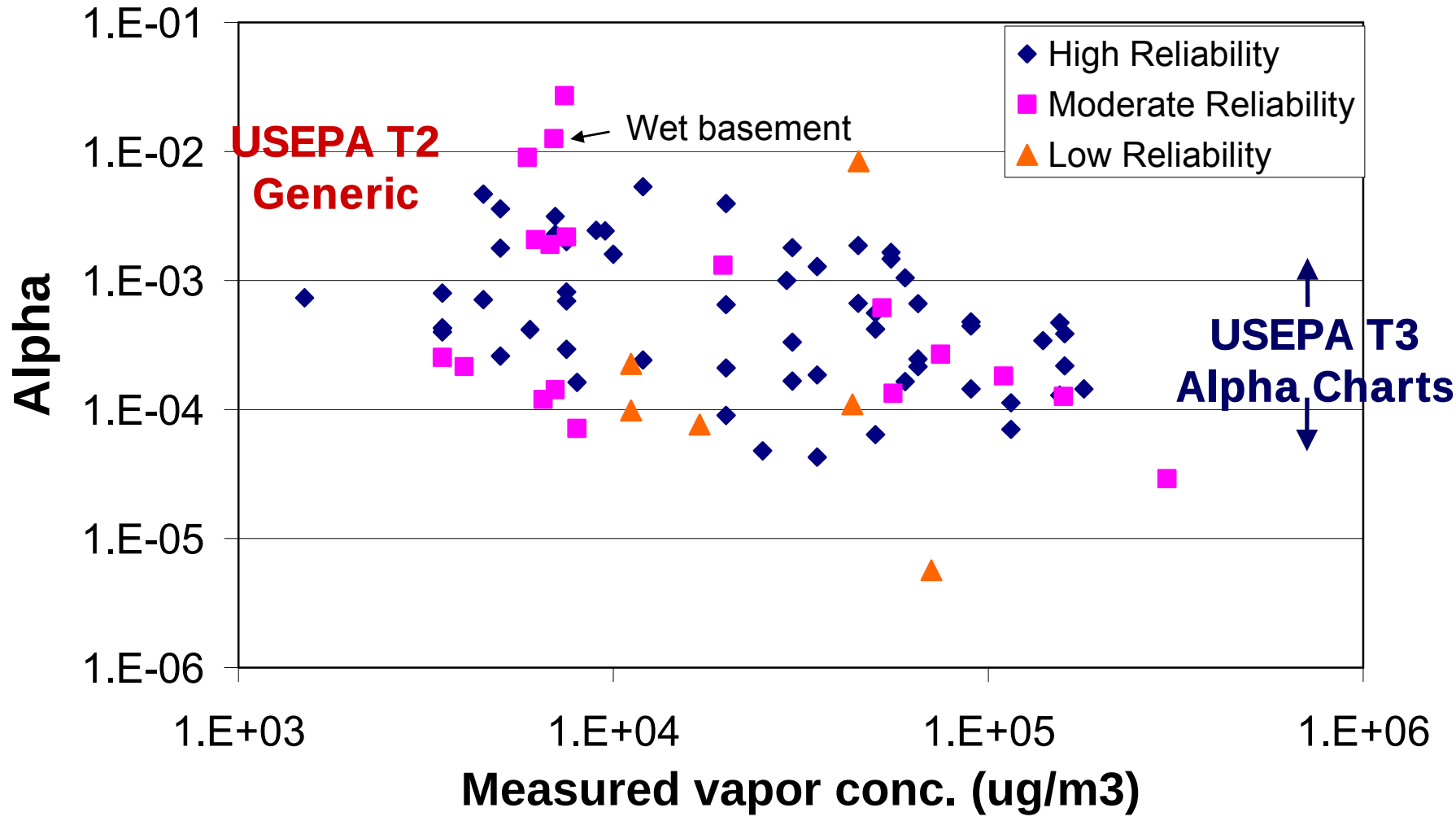


Attenuation Factor

Oxygen Level

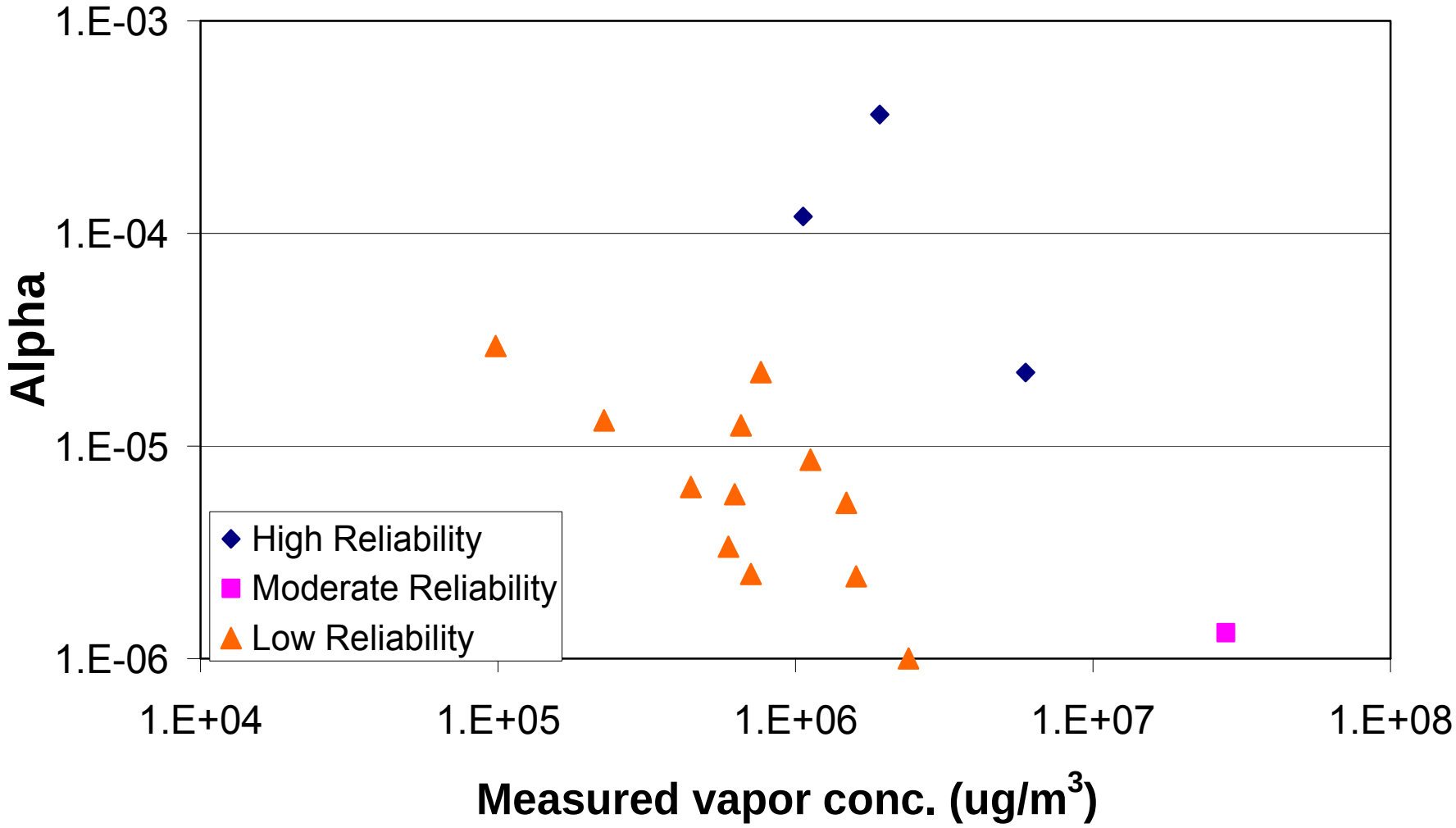
Abreu (2005), Abreu and Johnson (2005)

Soil Vapor Alpha - Residential - Chlorinated Solvents - Filtered



Courtesy Ian Hers, Golder Associates

Soil Vapor Alpha - Residential - Petroleum Hydrocarbon - Filtered



Courtesy Ian Hers, Golder Associates

Soil Vapor Screening Issues

- EPA (2002) alpha of 0.1 conservative for Sub-Slab samples
- Empirical data suggest Sub-Slab alpha of 0.01
- EPA likely to reduce shallow SS alpha
- Deep soil gas samples (alpha 0.01) may be more reliable for exterior samples

Next Step - Site-Specific Screening

- Next step if exceed generic screening levels for GW or SV
- (May also proceed to indoor tests)

Next Step - Site-Specific Screening

- Objectives:
  - Eliminate sites where further evaluation is not warranted
  - Collect additional data to allow less conservative screening levels (alpha values)
  - Still rely on exterior (rather than indoor) data

Next Step - Site-Specific Screening

- Issues:
  - Can additional data reduce uncertainty (and, therefore, need for conservatism)?
  - Which are more reliable, soil vapor or groundwater data?
  - Are models (e.g., JE model) reliable?

Next Step - Site-Specific Screening

- Choices:
  - Collect high quality data to reduce uncertainty

  and

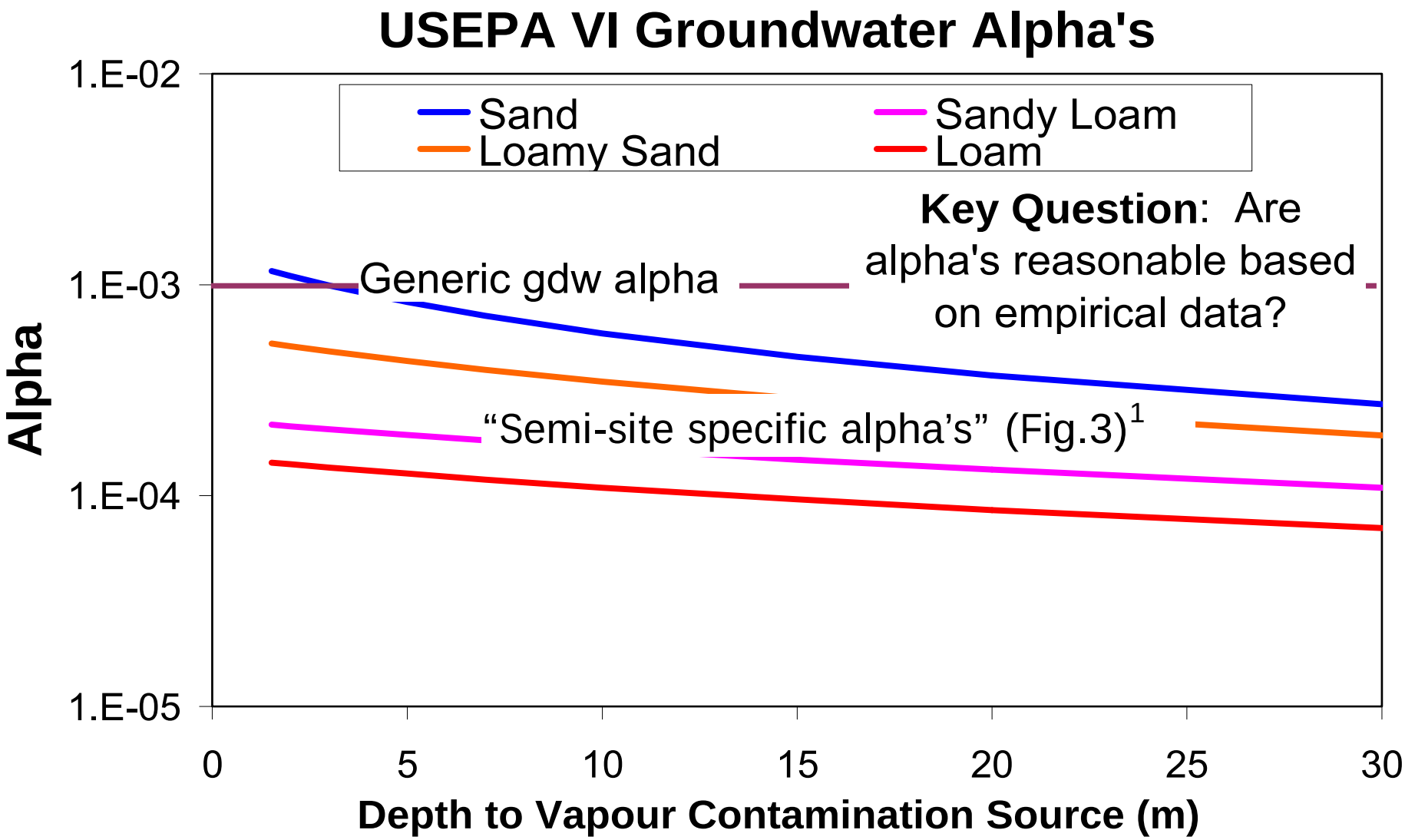
  - Improve our ability to predict vapor intrusion based on exterior data

  or

  - Go directly to indoor testing

Site-Specific Screening Options

- Select less conservative attenuation factors based on observed correlations with site-specific conditions
  - Depth to groundwater
  - Soil type
  - Other (building conditions)
- Use models to predict indoor air levels

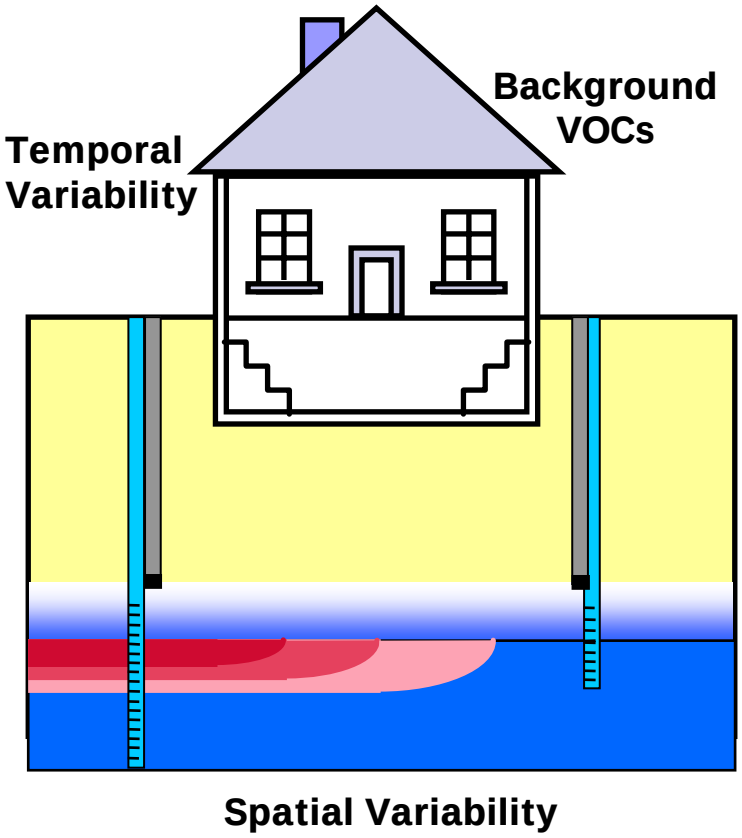


"Alpha Charts" to be replaced with "Constrained" Use of J&E Model, however concept similar

Courtesy Ian Hers, Golder Associates

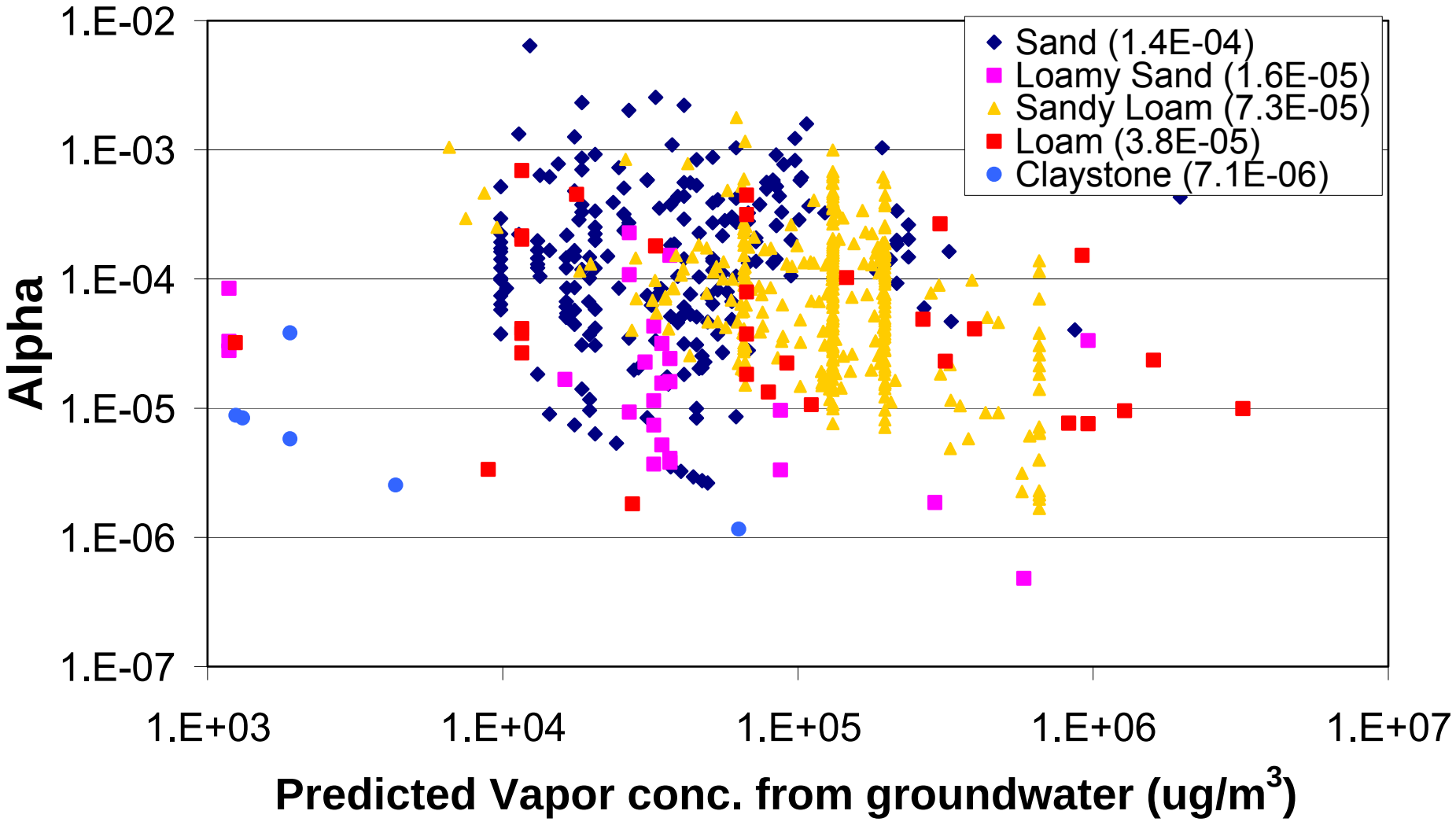
Challenges Correlating Vapor Intrusion with Various Factors

- Large number of factors control VI
- Significant data uncertainty
  - Groundwater and soil vapor concentrations interpolated
  - Data quality uncertain
- Concentrations vary over time (particularly indoor air)
- Background contributions to indoor air concentrations



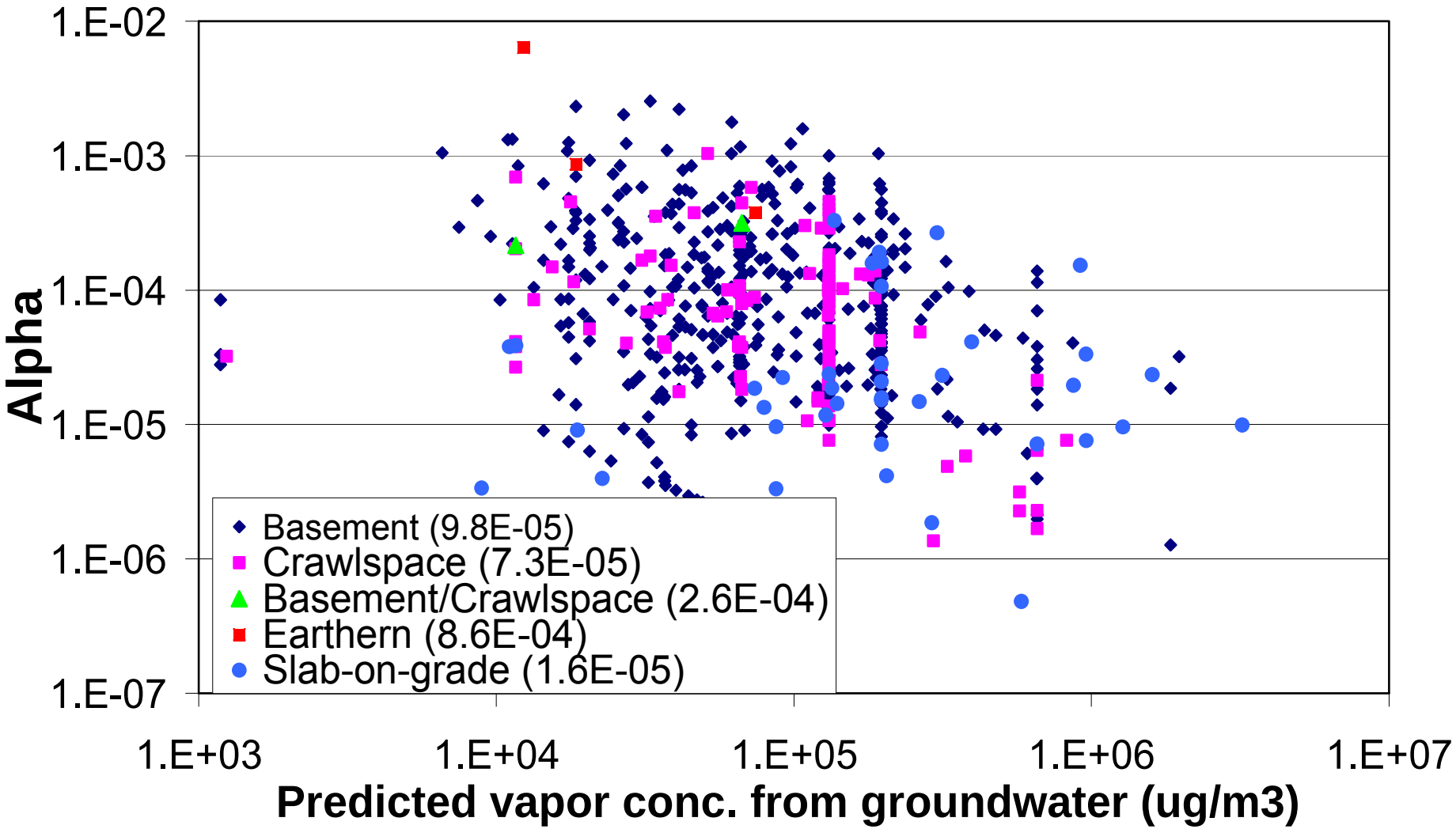
Courtesy Ian Hers, Golder Associates

Influence of Soil Type
Gdw Alpha - CS - Residential



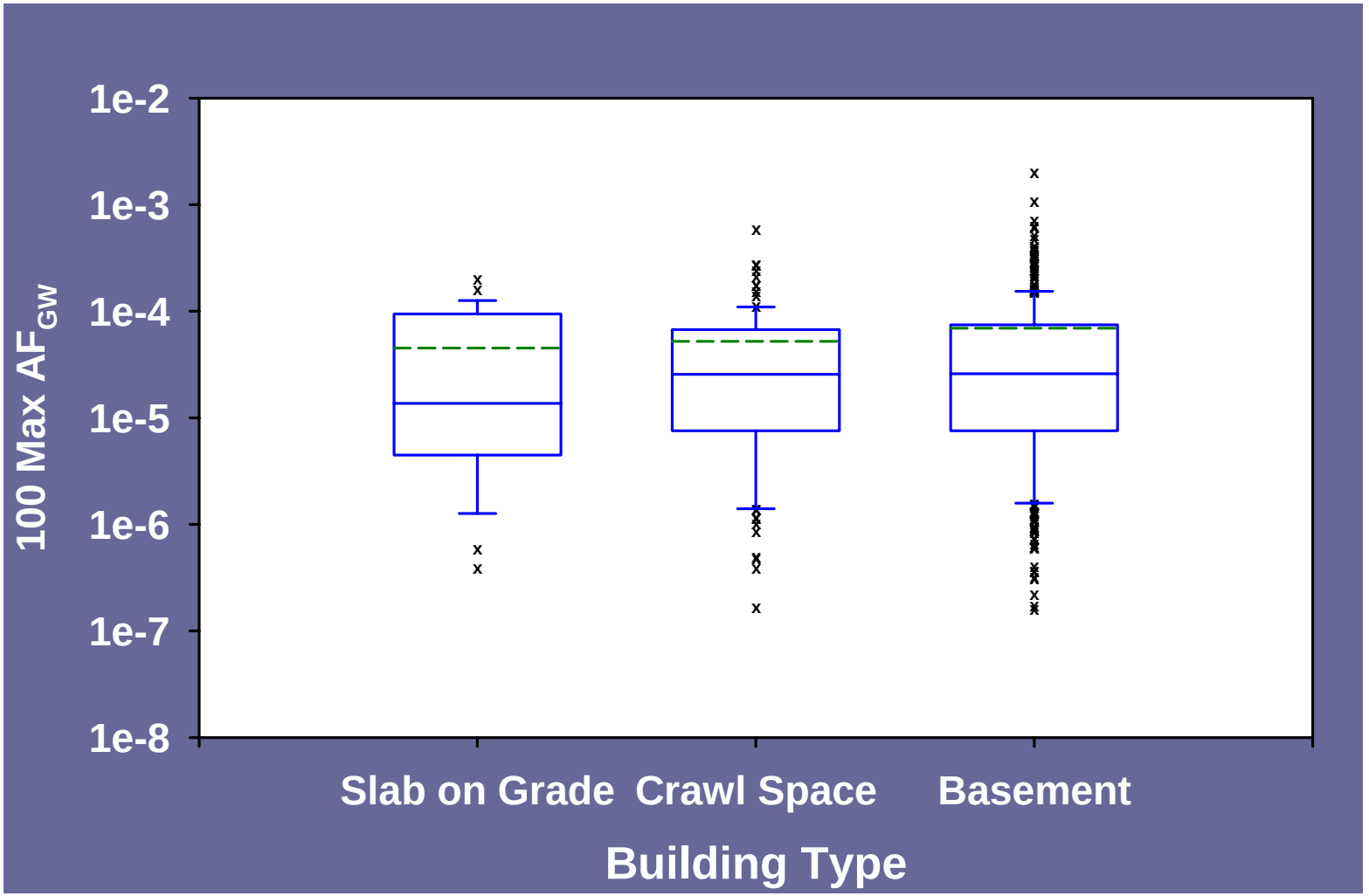
Courtesy Ian Hers, Golder Associates

Influence of Foundation
Gdw Alpha - CS - Residential



Courtesy Ian Hers, Golder Associates

GW Alpha vs Foundation Type

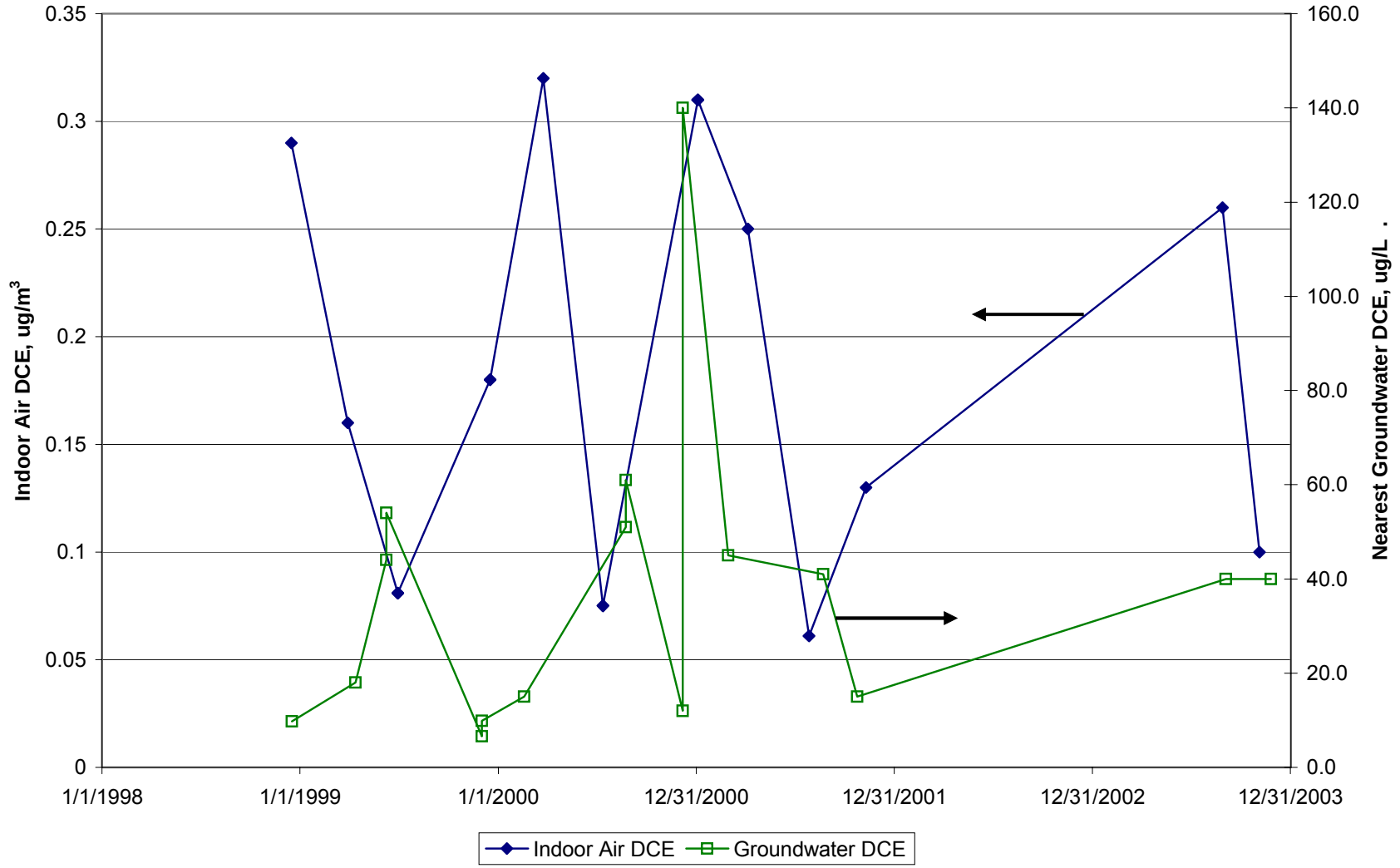


Folkes et al., 2004

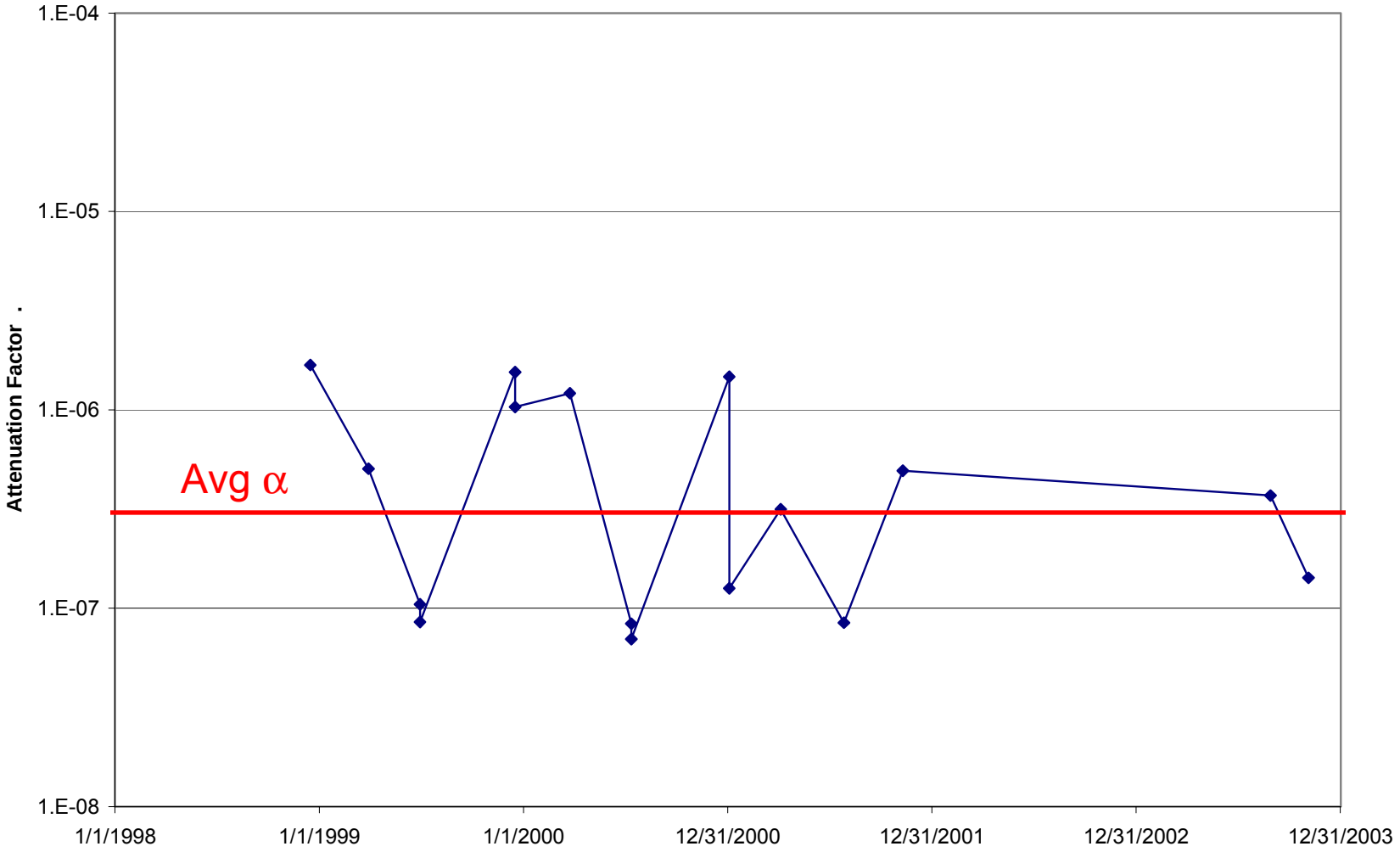
Site-Specific Screening Options

- Observed groundwater alpha values
  - Medium values correlate with soil type
  - Do not correlate well with foundation type
- Variations in indoor air concentration over time contribute to data scatter
- Alphas based on long term average concentrations show less scatter

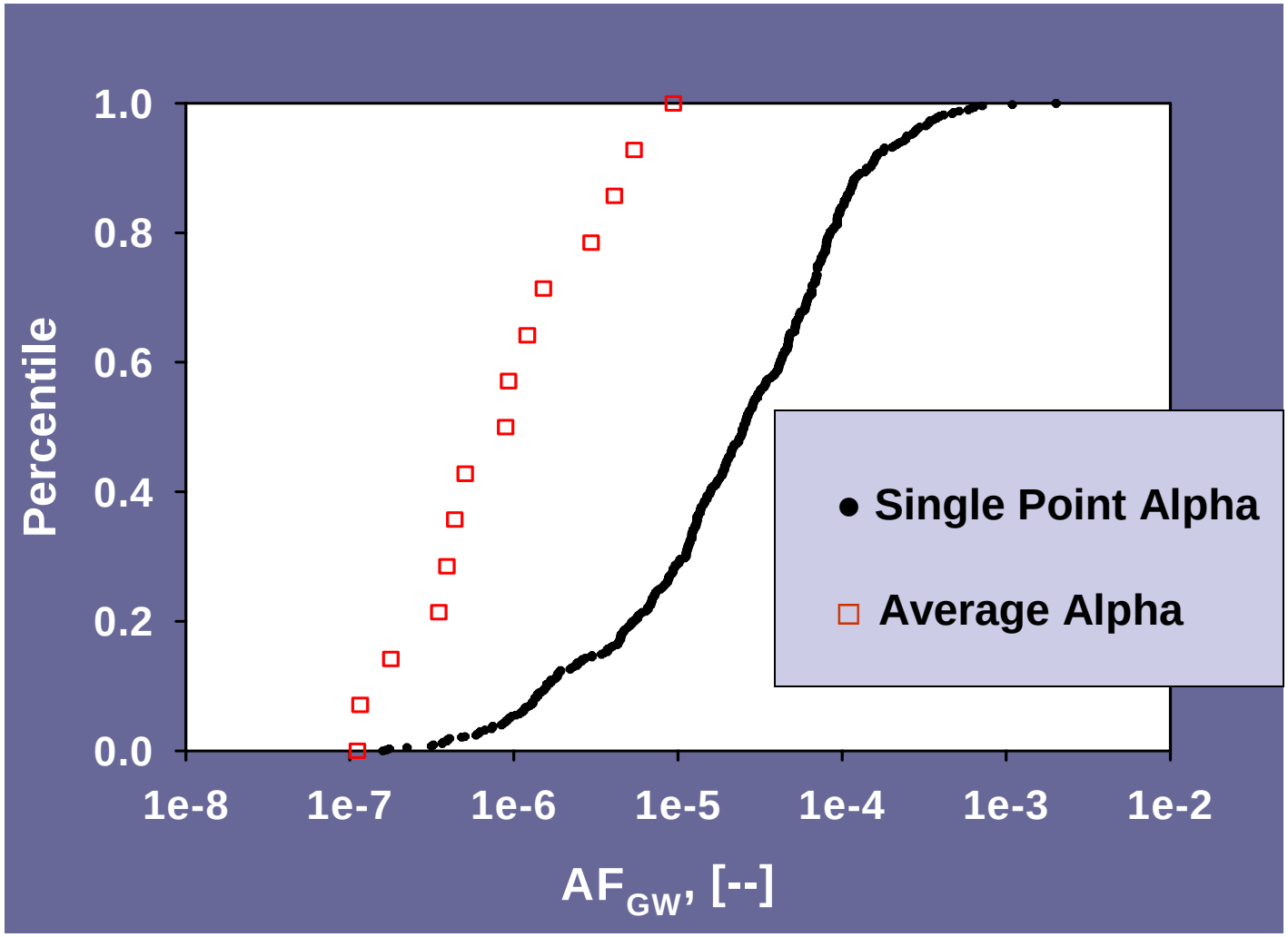
IA Concentrations Over Time



Alpha Variations Over Time

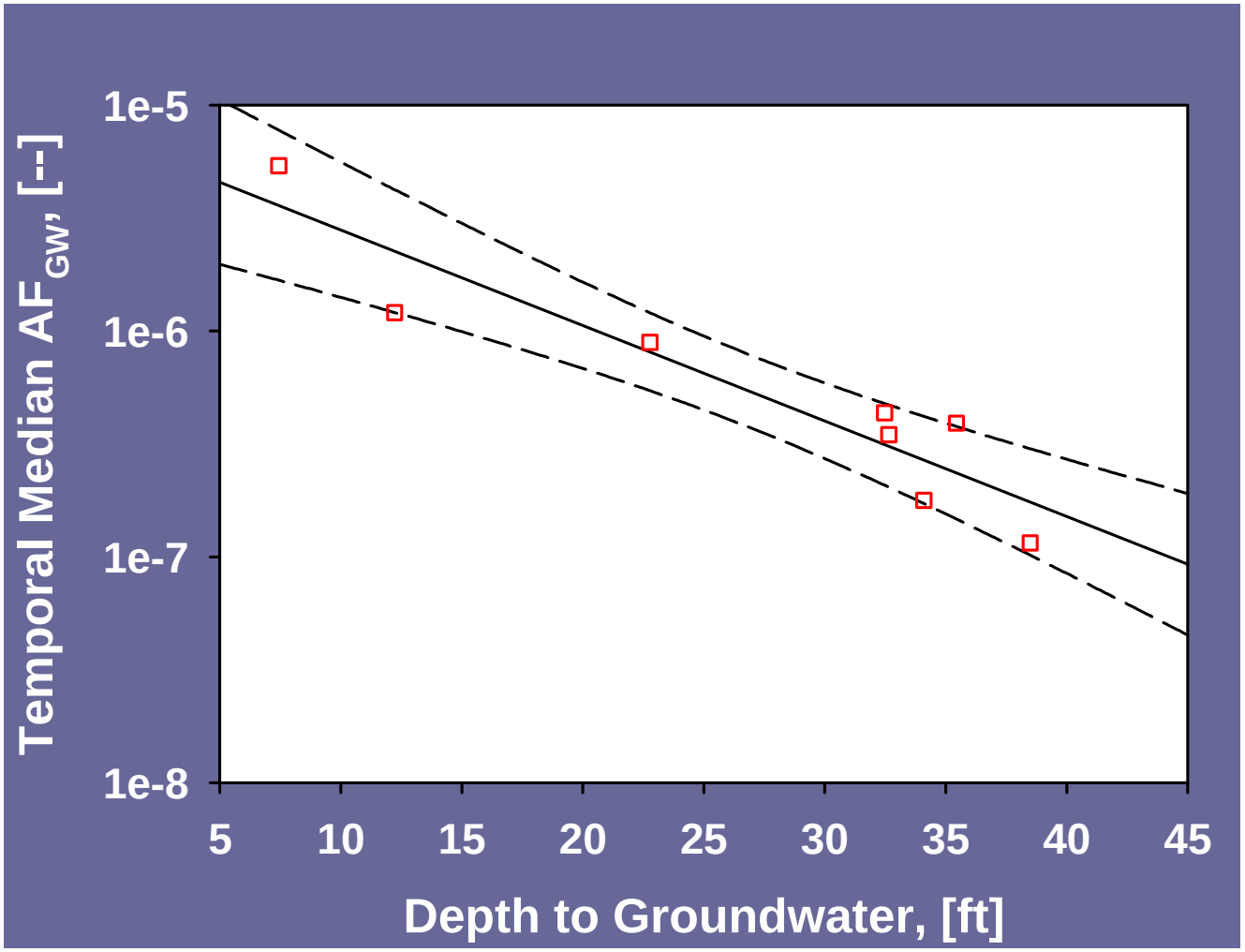


Average vs Single Point Alphas



Folkes et al., 2004

Alpha (Avg) vs Depth to GW



Folkes et al., 2004

JE Model

- Order magnitude precision (EPA 2004)
- Accuracy depends on input data
- Determine critical parameters
  - Johnson 2002 (API 17)
- Conduct sensitivity analyses
- Results may correlate best with average indoor air concentrations

Summary: Conceptual Site Model

- Need one to understand pathway

Summary: Generic Screening

- EPA generic screening alphas validated by empirical data, but conservative due to data scatter
- Not much is screened out
- Petroleum hydrocarbons may warrant lower alphas (based on oxygen levels)

Summary: Site-Specific Screening

- Needed to avoid unnecessary indoor tests
- Empirical data support modest decreases in alpha based on soil type
- JE models should be applied conservatively to account for imprecision
  - EPA proposed “constrained” JE model?

Summary: Possible Options

- Develop empirical alphas based on long term (average) data to reduce data scatter
- Improve data collection procedures
- Validate models based on above
- Rely more on indoor air and/or sub-slab testing