Quantitative Decision Framework for Vapor Intrusion Evaluation in DoD Industrial Buildings - Based on an Empirical Database

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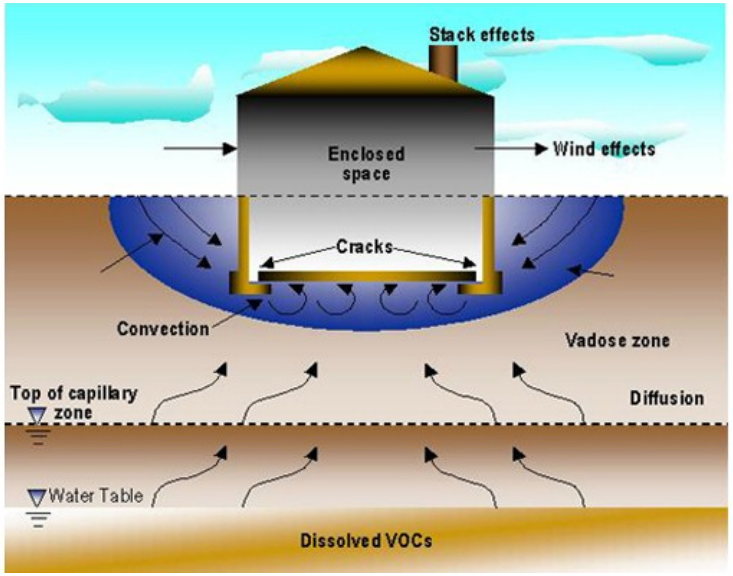
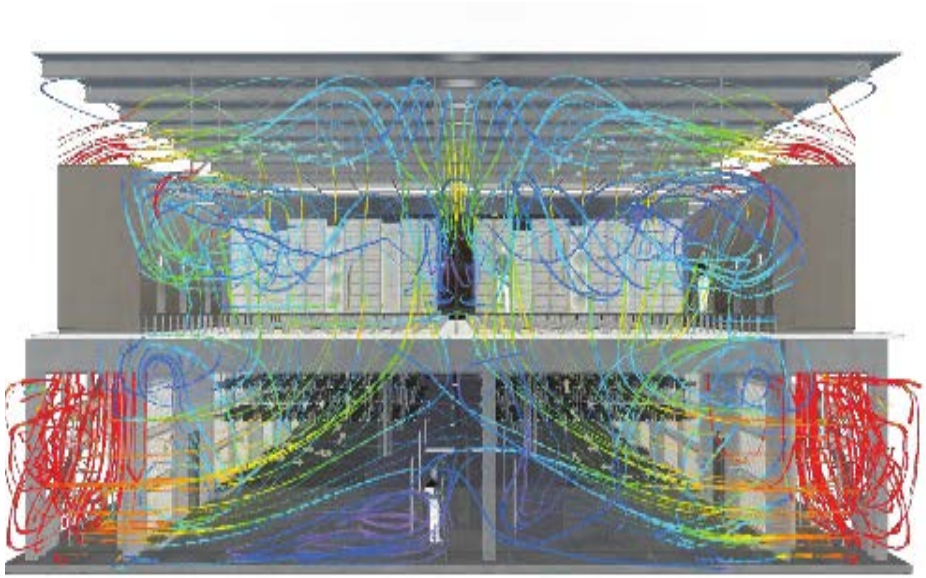
Innovation that Provides Sustainable Solutions to Complex Local Challenges, Worldwide

Outline

- Vapor intrusion (VI) basics, key points from EPA 2015 VI Guide
- Navy database contents
- Methods of data analysis used
- Comparison of DoD industrial buildings to EPA residential dataset
- Key individual factors controlling indoor air concentrations
- Quantitative decision framework and its applications
- Ideas for the future



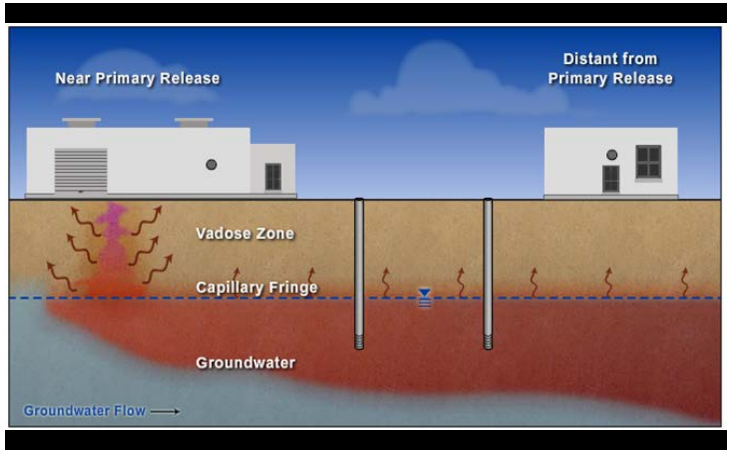


Introduction to Vapor Intrusion (VI)

- What is Vapor Intrusion?

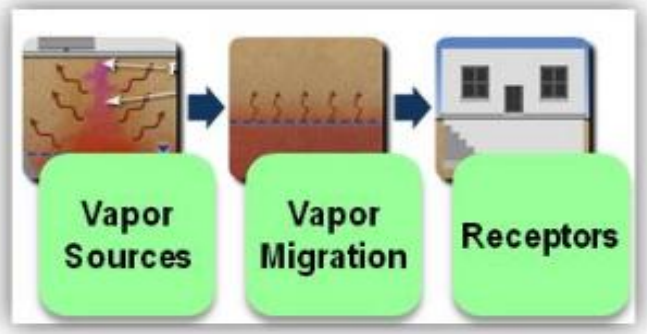
  Migration of volatile chemicals from subsurface into indoor air (EPA, 2015).

- **VI Pathway**
  - **Volatilization from soil/groundwater**
  - **Diffusion and attenuation in deep vadose zone**
  - **Advection and attenuation in shallow vadose zone**
  - **Transport and attenuation across building foundation**
  - **Mixing with indoor air**

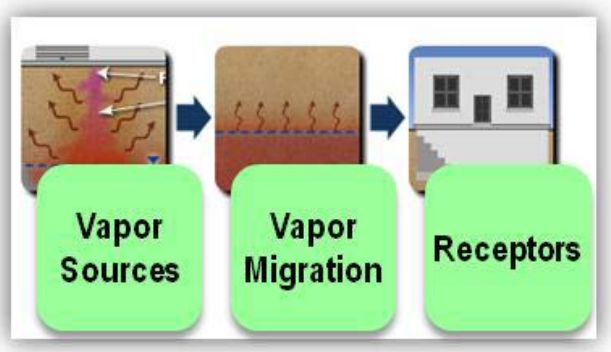


Navy Message

VI Tool in NIRIS provides good introduction to science of VI

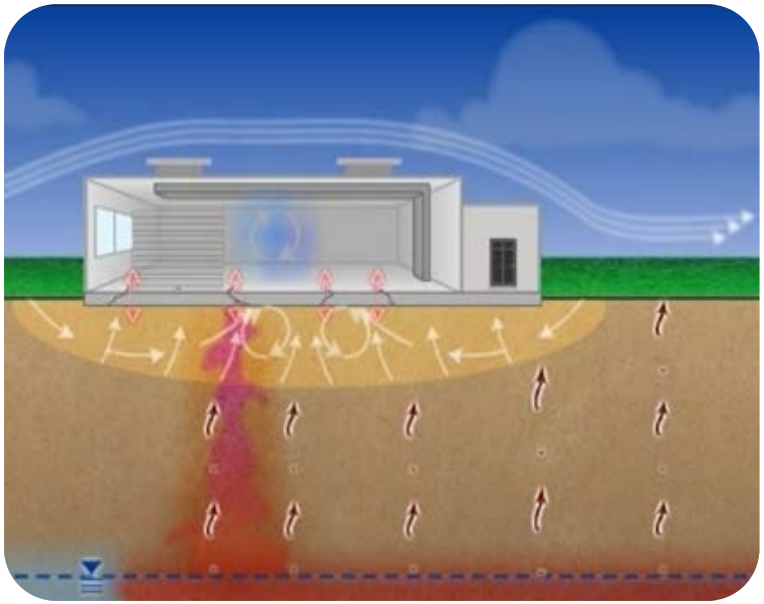


VI Conceptual Site Model (CSM)



EPA Message

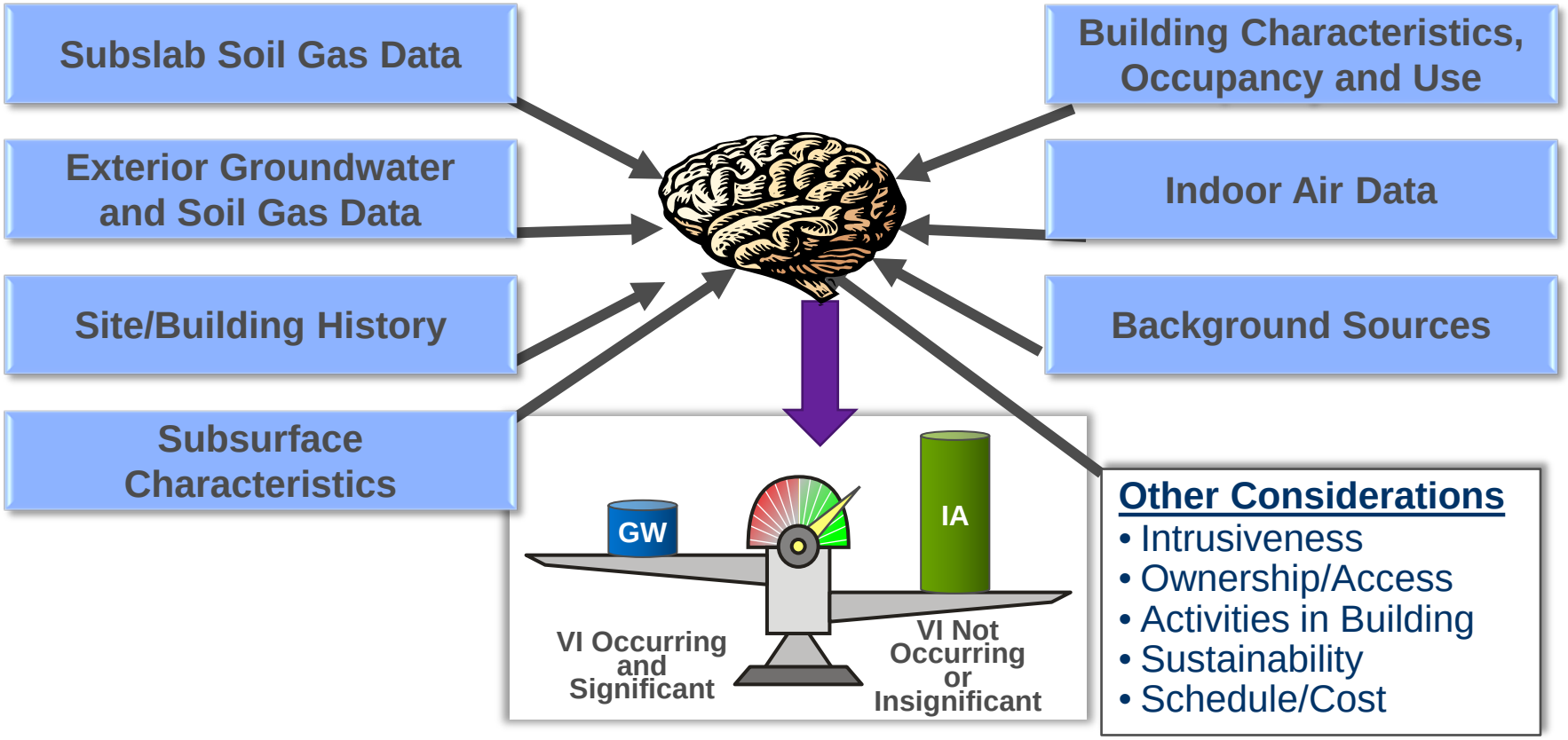
"…building specific information…"
"…consider a hypothetical building…"



1. **Multiple lines of evidence (MLE) required**
2. **Not all lines of evidence are equal**
3. **Strength of evidence depends on CSM**
4. **Not all buildings are the same**

Weighing Multiple Lines of Evidence

- **Simultaneously weigh *multiple lines of evidence***
- **Understand evidence strengths and limitations**
- **Focus on CSM and building characteristics**



EPA 2015 VI Guide

EPA Message

"Several rounds of sampling are recommended to develop an understanding of temporal variability…"

"More advanced methods of distinguishing the various potential contributions to indoor air might be utilized…"

"…provides a flexible science-based approach to assessment…"

Challenge

- Complex pathway
- Variability of many pathway elements
- Stakeholder agreement on level of resolution

Navy Message

- Leverage current research and focus on CERCLA chemicals of concern
- Apply site-specific CSM information to depart from conservative defaults
- Plan before sampling and consider exit strategies

Risk Assessment and Management Framework

EPA Message

"… 'background' contributions to indoor air…";
"EPA does not clean up to concentrations below…background levels…"

"…chemicals that exceed the VISL…would not automatically trigger mitigation…are not offered as response action levels or cleanup levels"

"…a complete exposure pathway does not necessarily mean that an unacceptable human risk exists due to vapor intrusion."

"…the inhalation reference concentration…is defined as an estimate (with uncertainty spanning perhaps an order of magnitude)…"

Final Report NESDI Project #476 Available

Naval Facilities Engineering Command
ENGINEERING AND EXPEDITIONARY WARFARE CENTER

TECHNICAL REPORT
TR-NAVFAC-EXWC-EV-1603
JUNE 2015

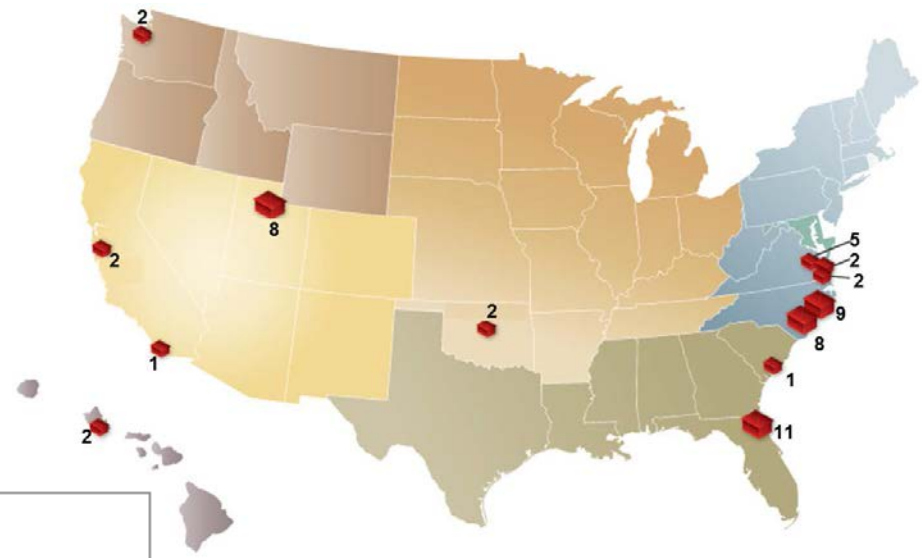
A Quantitative Decision Framework for Assessing Navy Vapor Intrusion Sites

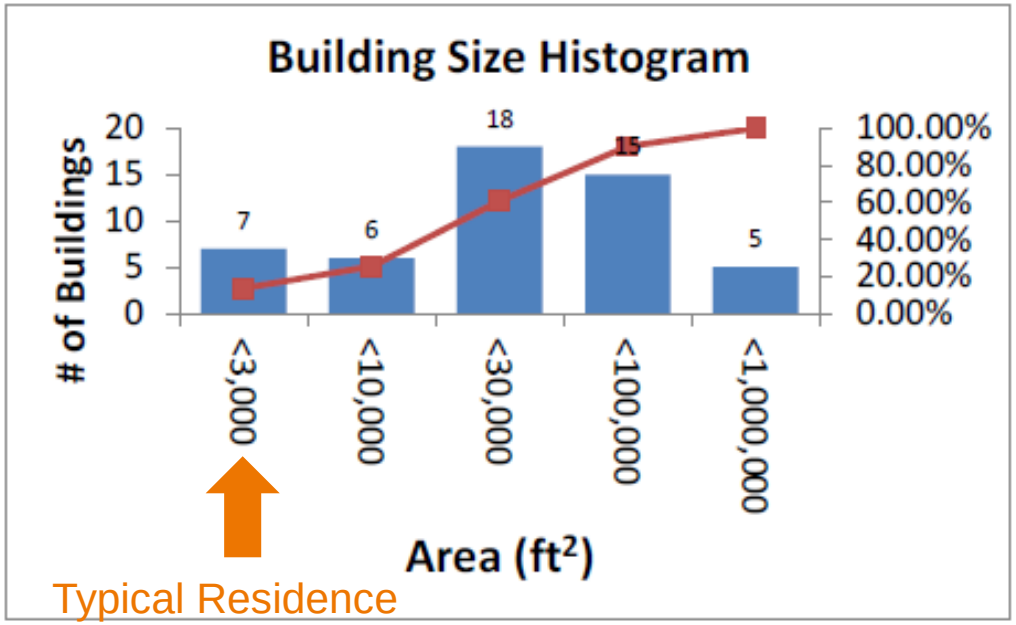
http://www.nesdi.navy.mil/Files/FinalReports/FR_476.pdf

Appendix H
Quantitative Decision Framework – User's Quick Start Guide

Database of DoD Buildings with Chlorinated VOCs

- 12 installations, 13 sites, and 49 commercial/industrial/institutional buildings
- Average age of buildings in the database is 55 years
- Majority of sites have depths to water less than 10 feet (<3 m)

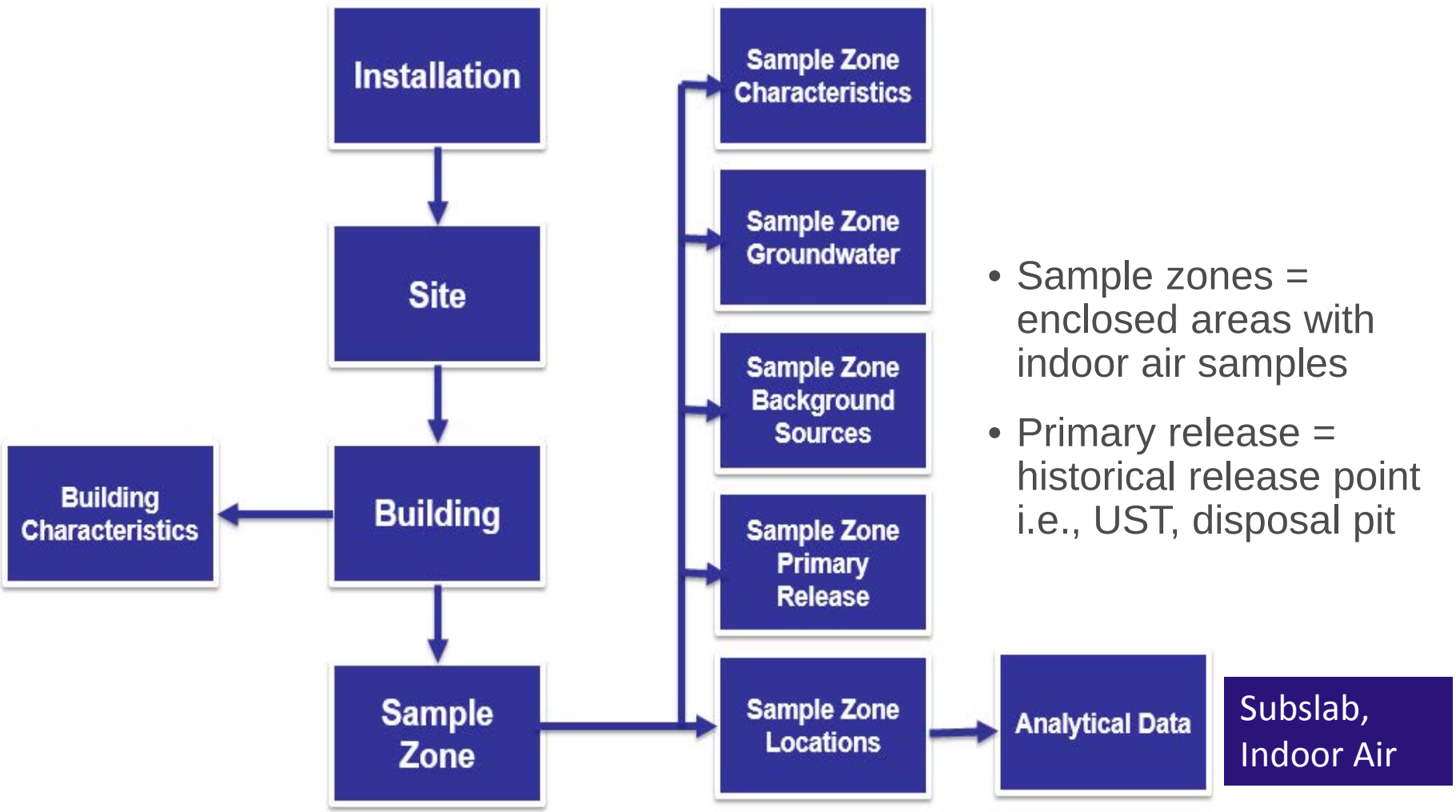




Project conducted under Navy Environmental Sustainability Development to Integration (NESDI) Project #476

10 Navy sites, 2 Air Force sites

Research Database Structure
(NIRIS not yet customized for VI data like this)

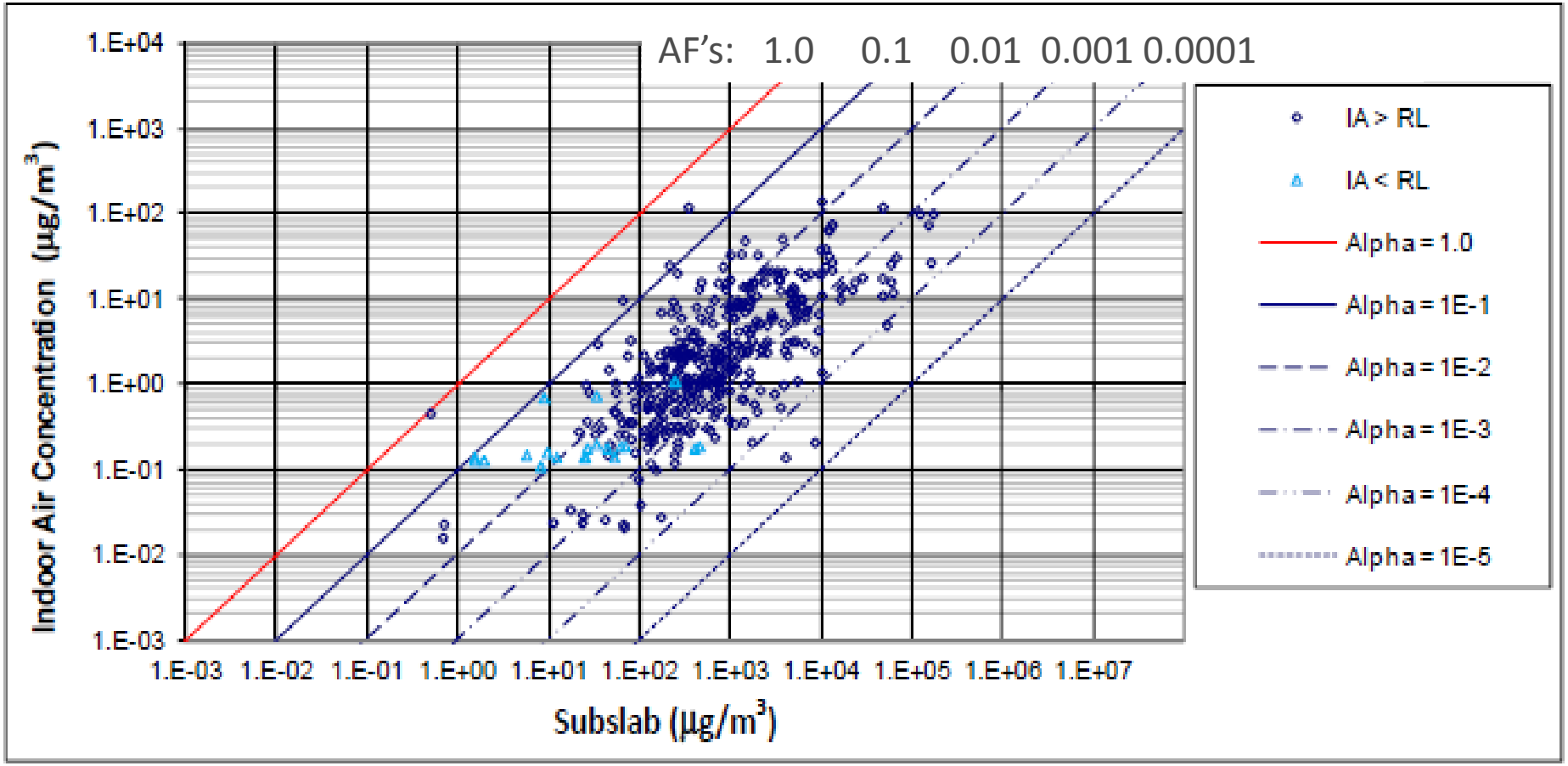


- Sample zones = enclosed areas with indoor air samples
- Primary release = historical release point i.e., UST, disposal pit

DoD Data Analysis Methods

- Example database fields: building footprint area, sample zone use, soil type, subgrade structures
- Analysis showed nondetects had little effect on dataset
- Screening approach paralleled EPA residential study
- Results presented here screened to remove indoor sources based on source strength screen
- Data also filtered to remove atypical preferential pathways
- Subslab and indoor data paired by sample zones
- Deep soil gas concentration calculated using Henry's Law = groundwater vapor concentration
- Single and multivariate regression analyses conducted

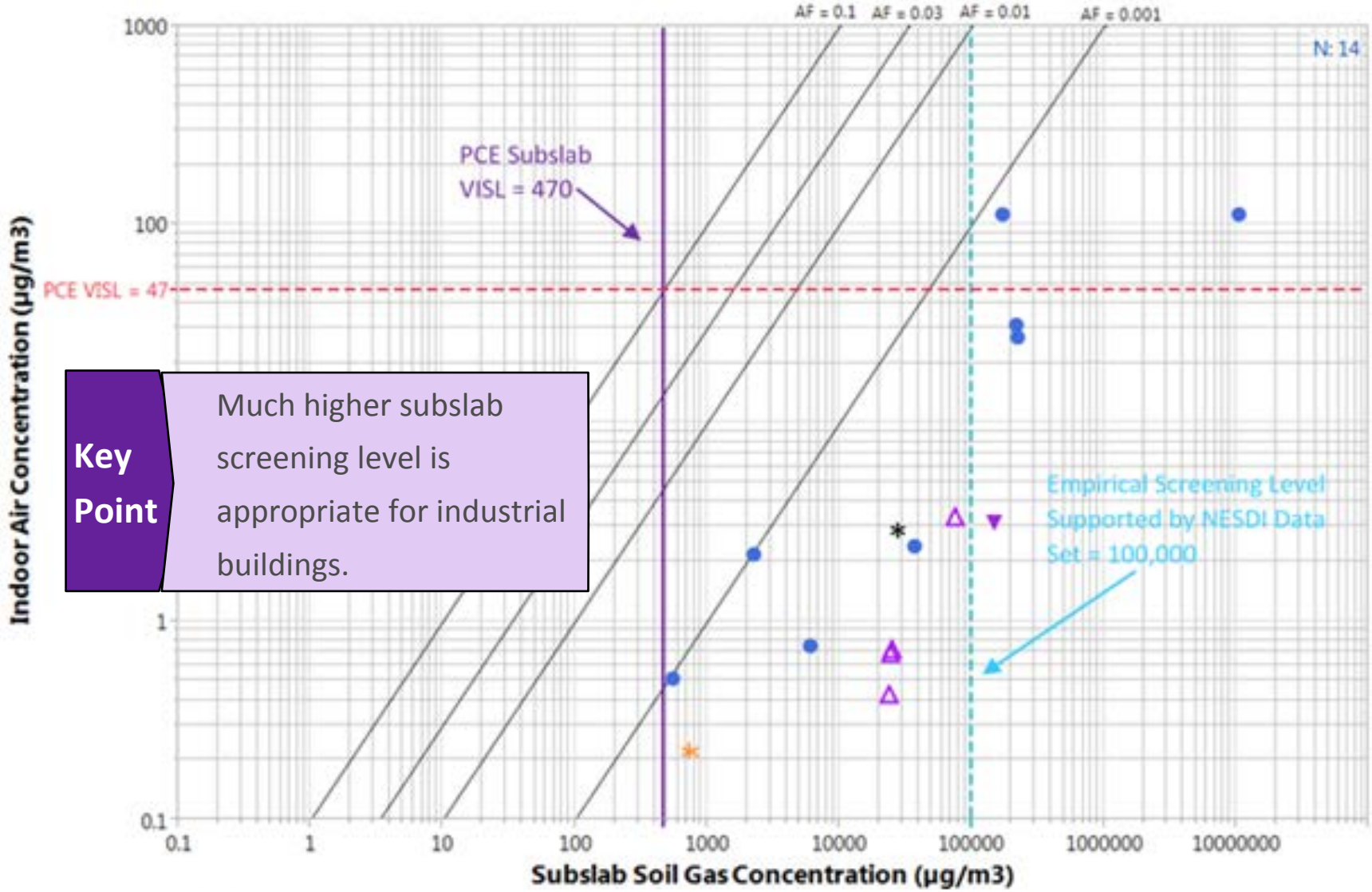
Basis for Comparison – EPA Residential Database



- Attenuation factor definition: $$AF_{VI} = \frac{C_{IA-VI}}{C_{SV}}$$

- EPA database multiple compounds, 13 sites, 532 data points

PCE Concentration in Subslab vs. Indoor Air (DoD)



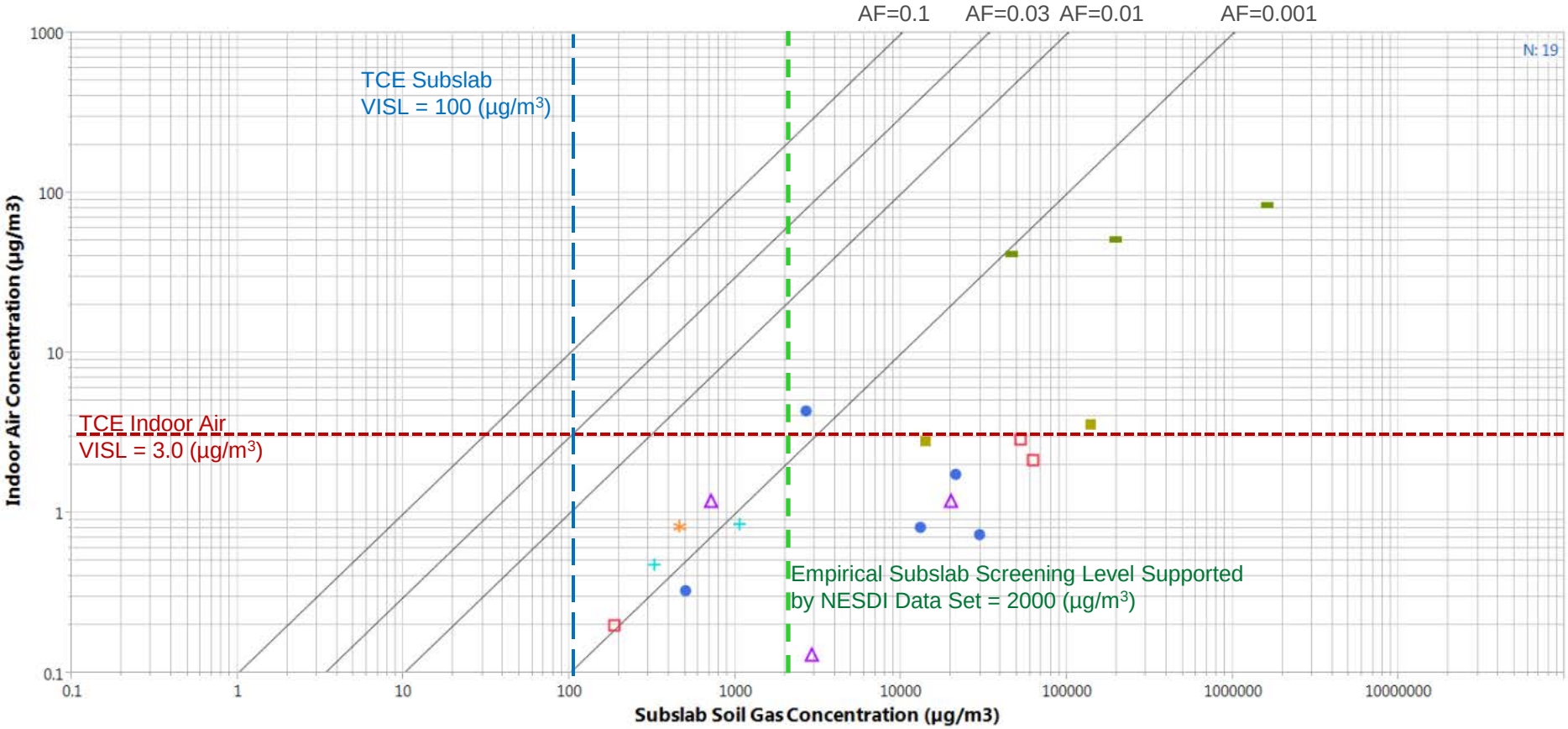
Key Point

Much higher subslab screening level is appropriate for industrial buildings.

Shapes denote bases

Note: asterisk indicates sample zone where max subslab soil gas concentration/min subslab soil gas concentration > 1000

TCE Concentration in Subslab vs. Indoor Air (DoD)

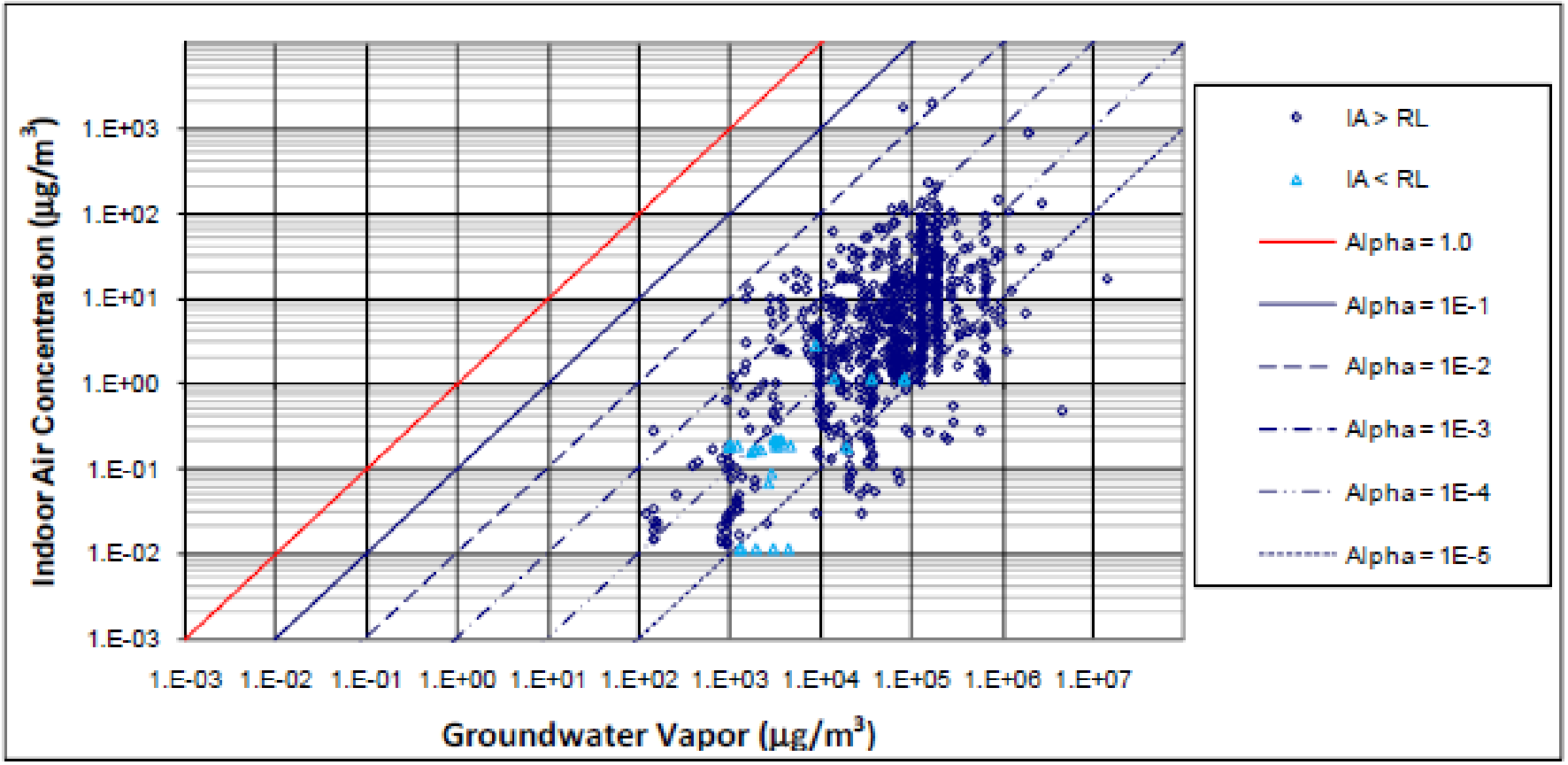


Shapes Denote Bases

TCE Concentration in Sub-slab Soil Gas vs. Indoor Air

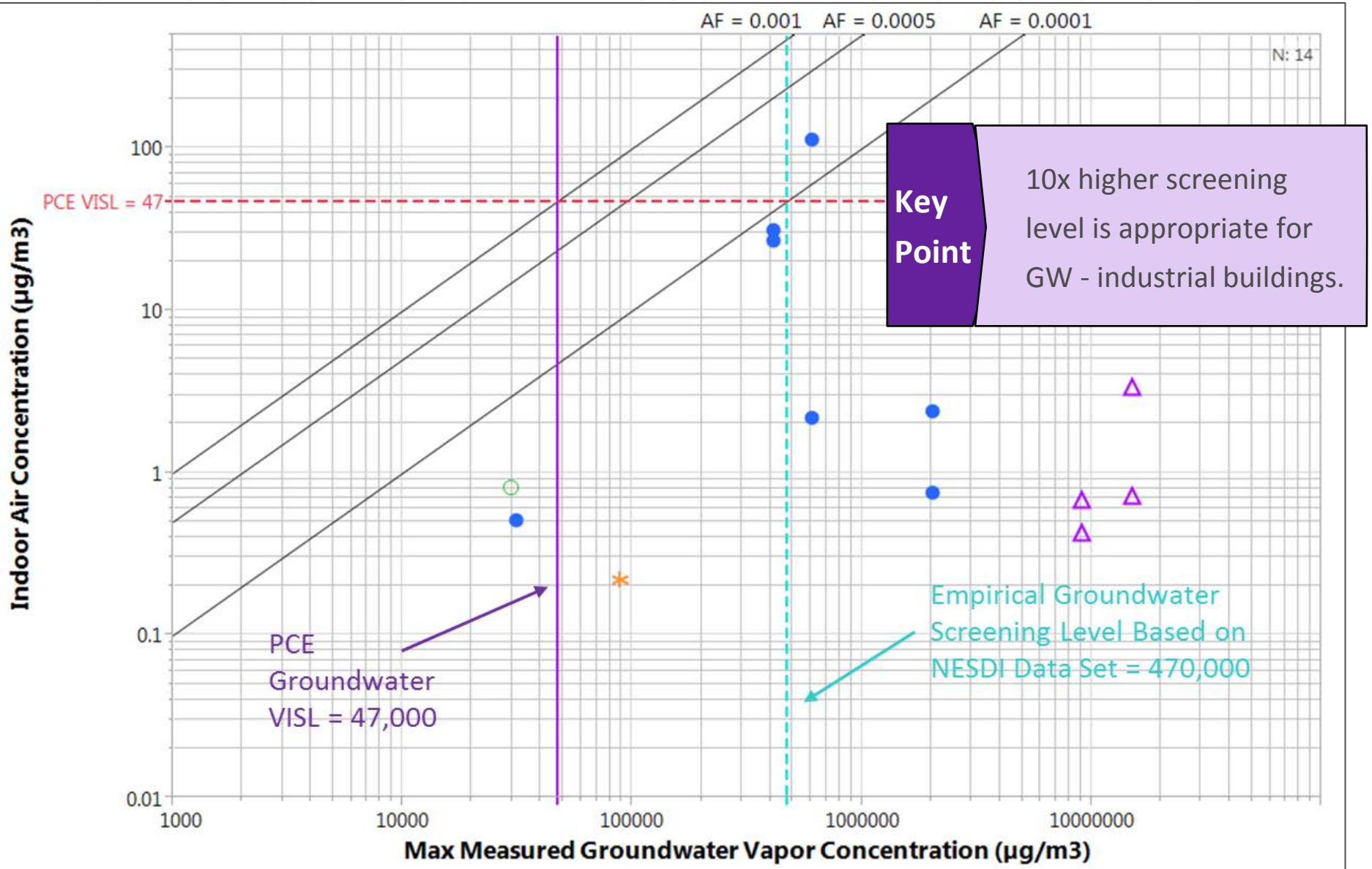
Sample Zone Averages; Detectable Data Only Included

Basis for Comparison – Groundwater to Indoor Air: EPA Residential Database



EPA recommends a 95th percentile attenuation factor = 0.001 for groundwater vapor on the basis of this analysis.
EPA dataset has 24 sites and 774 data point pairs

PCE Concentration in Indoor Air vs. Groundwater

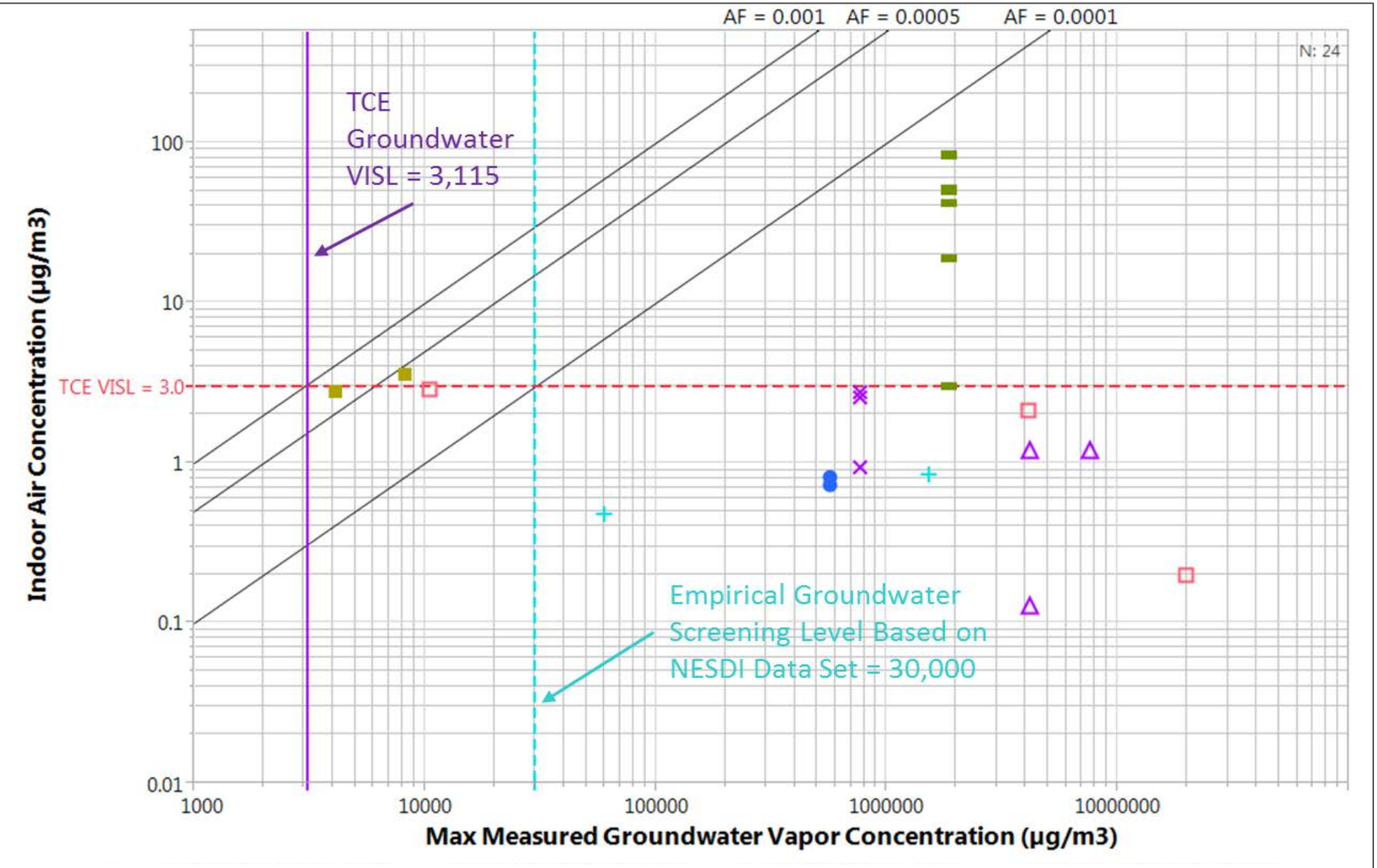


Key Point

10x higher screening level is appropriate for GW - industrial buildings.

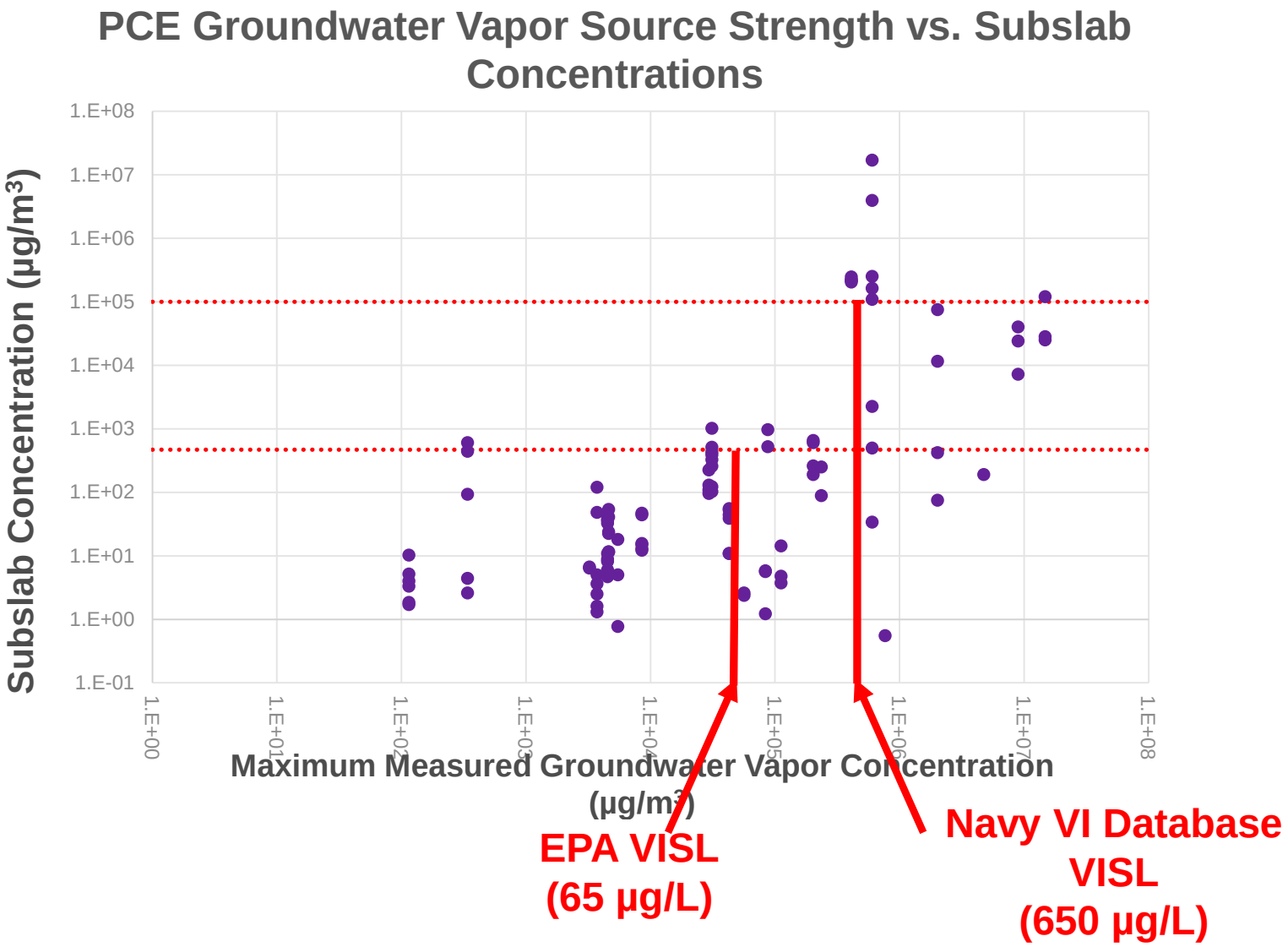
Shapes denote bases

TCE Concentration in Indoor Air vs. Groundwater



Shapes denote bases

Example of Navy VI Database Findings (cont.)



Why Do Vapor Intrusion Plots Have Scatter? Many Variables Involved – Radon Experience

"This paper identified about thirteen factors that can affect radon: …soil moisture content, soil permeability, wind, temperature, barometric pressure, rainfall, frozen ground, snow cover, earth tides, atmospheric tides, occupancy factors, season and time of day.

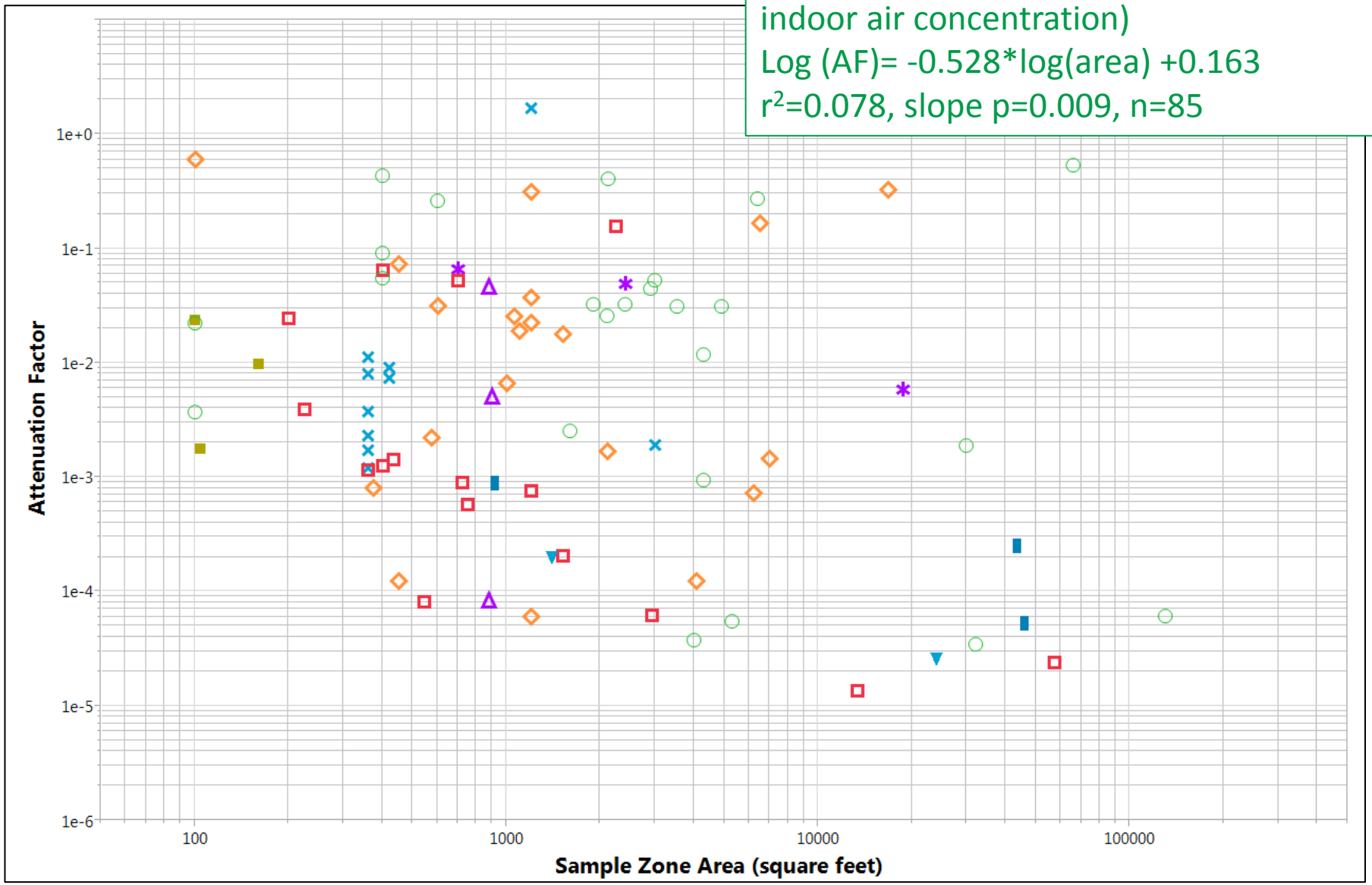
….. Four factors that influence radon concentrations indoors are properties of the building material and ground; building construction; meteorological conditions; and occupant activities."

Lewis & Houle, A Living Radon Reference Manual (2009)

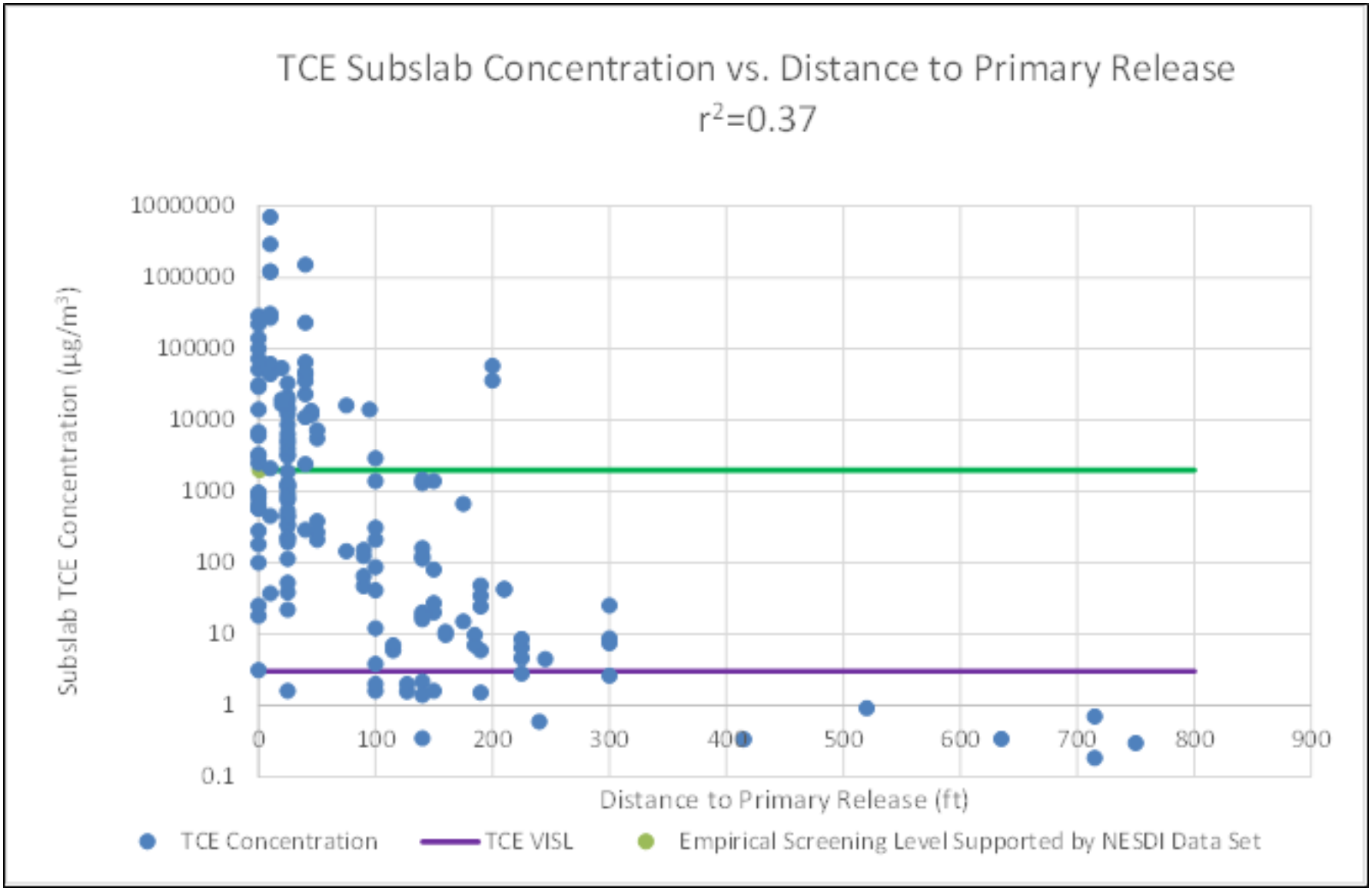
- EPA and NESDI plots have scatter for this reason.
- We analyzed which variables mattered in our dataset with multiple statistical techniques, including hypothesis testing and multiple regression.

Key Difference in Commercial/Industrial Buildings: Sample Zone Size Effects

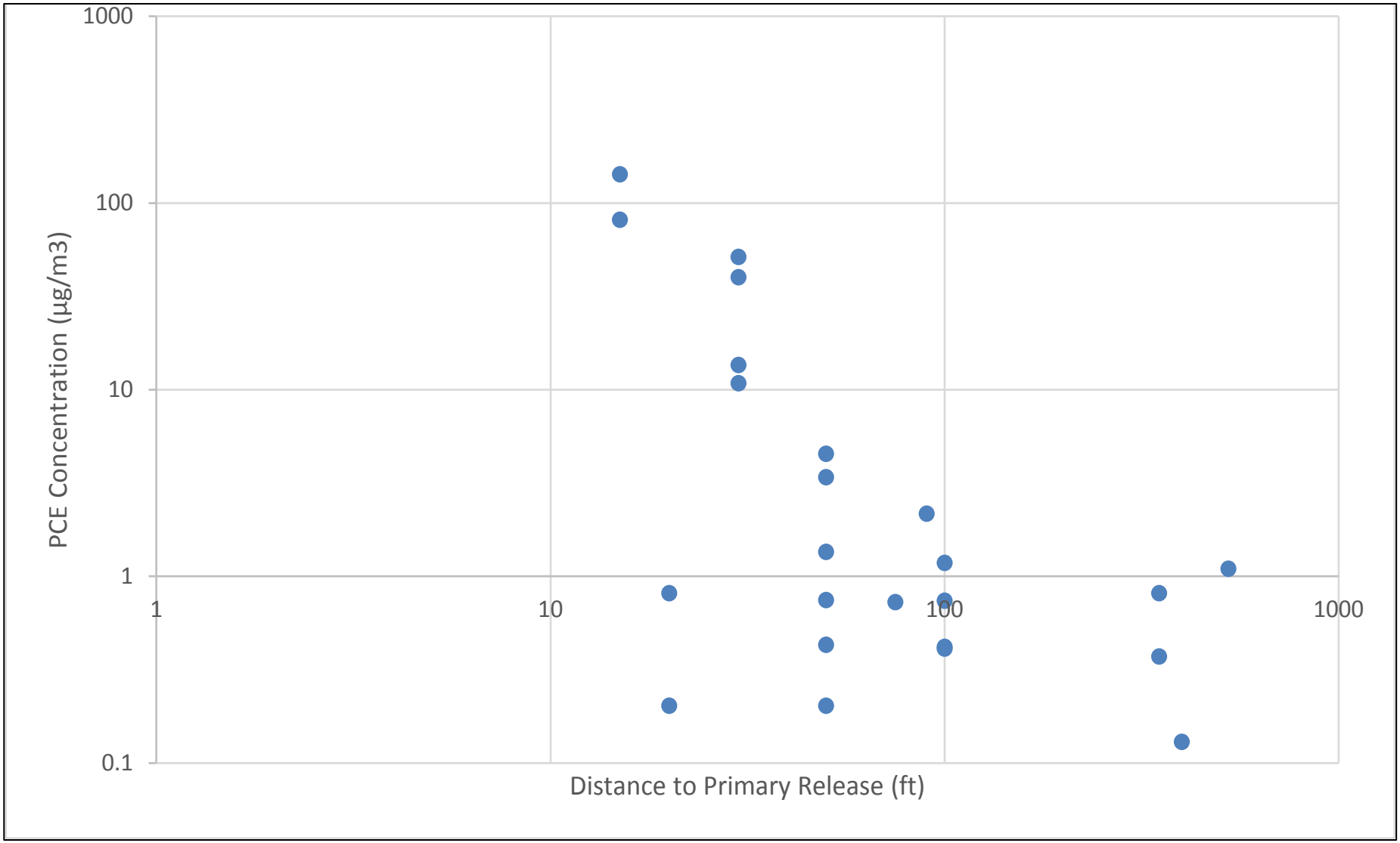
AF = Attenuation Factor (normalized indoor air concentration)
Log (AF)= -0.528*log(area) +0.163
r^2=0.078, slope p=0.009, n=85



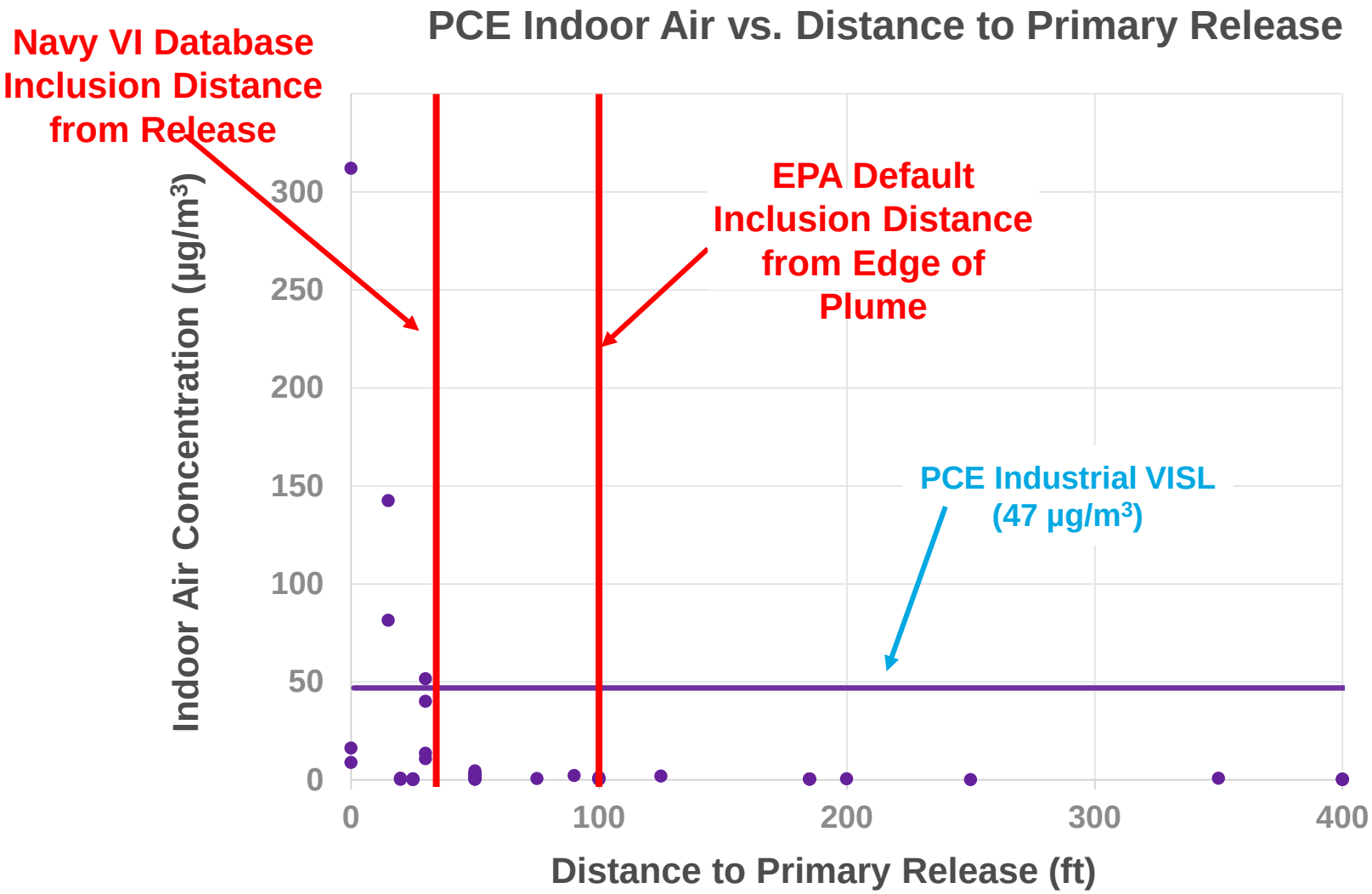
Key Difference in Commercial/Industrial Buildings: Rapid Drop-off in Subslab with Distance from Release



Key Difference in Commercial/Industrial Buildings: Rapid Drop-off in Indoor Air with Distance from Release PCE $r^2 = 0.337$



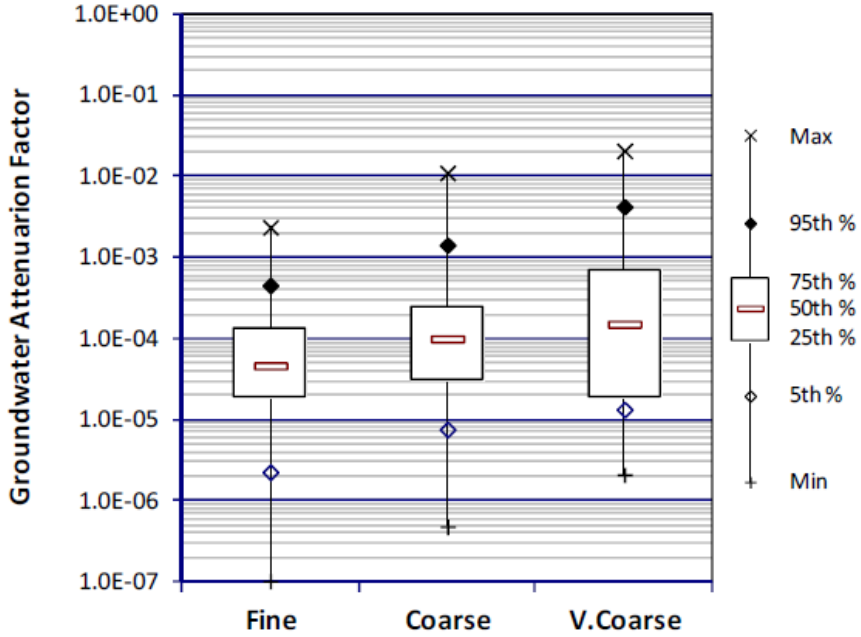
Example of Navy VI Database Findings

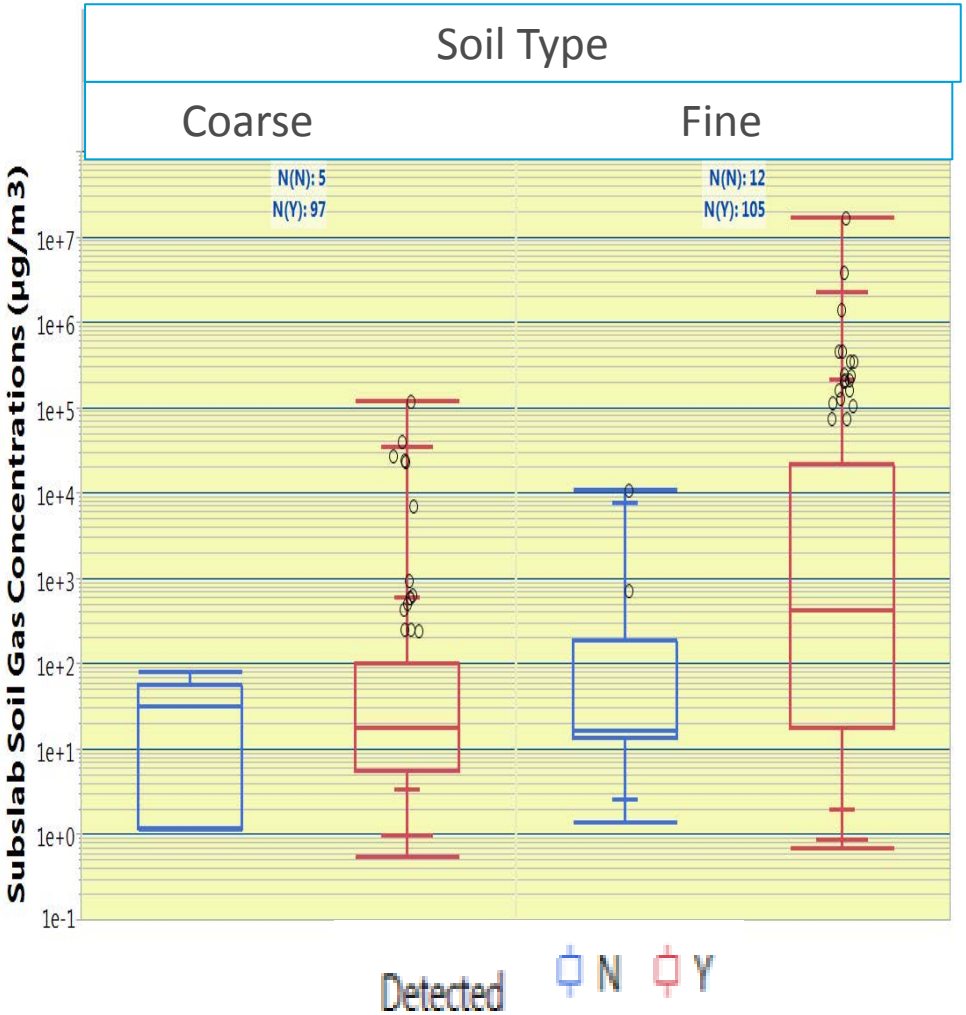


Key Difference in Commercial/Industrial Buildings: Role of Soil Type

DoD Buildings – Fine Soil – Higher Concentration: p value, 2 tailed = 8E-6

Residential – EPA Database – Fine Soil Slightly Lower Normalized Concentration





Multiple Regression Analysis Results

- Winter sampling is single strongest variable (stack effect)
- Multivariate analyses explained majority of variance in indoor air concentration using a small number of variables:
  - Sampling season
  - Sample zone area
  - Subslab soil gas concentration
  - Groundwater concentration
  - Depth to groundwater
  - Distance to primary release
- That is, TCE indoor (subset of winter data (n=19)) modeled with only four terms adjusted $r^2 = 0.86$; each $p < 0.000001$
- Models require confirmation; not enough data available to have separate training and test datasets

Results Provide a Basis to Benefit from Flexibilities Added in EPA 2015 VI Guide

EPA Message

"EPA's recommended approaches…aim to be flexible and adaptable …are not intended to be prescriptive…"

"…VISL Calculator…including input of alternative attenuation factor(s) based upon site- or building-specific information…"

"…necessitates site-specific approaches to scoping investigations and sequencing investigation…"

Industrial vs. Residential Buildings

Industrial Buildings Different

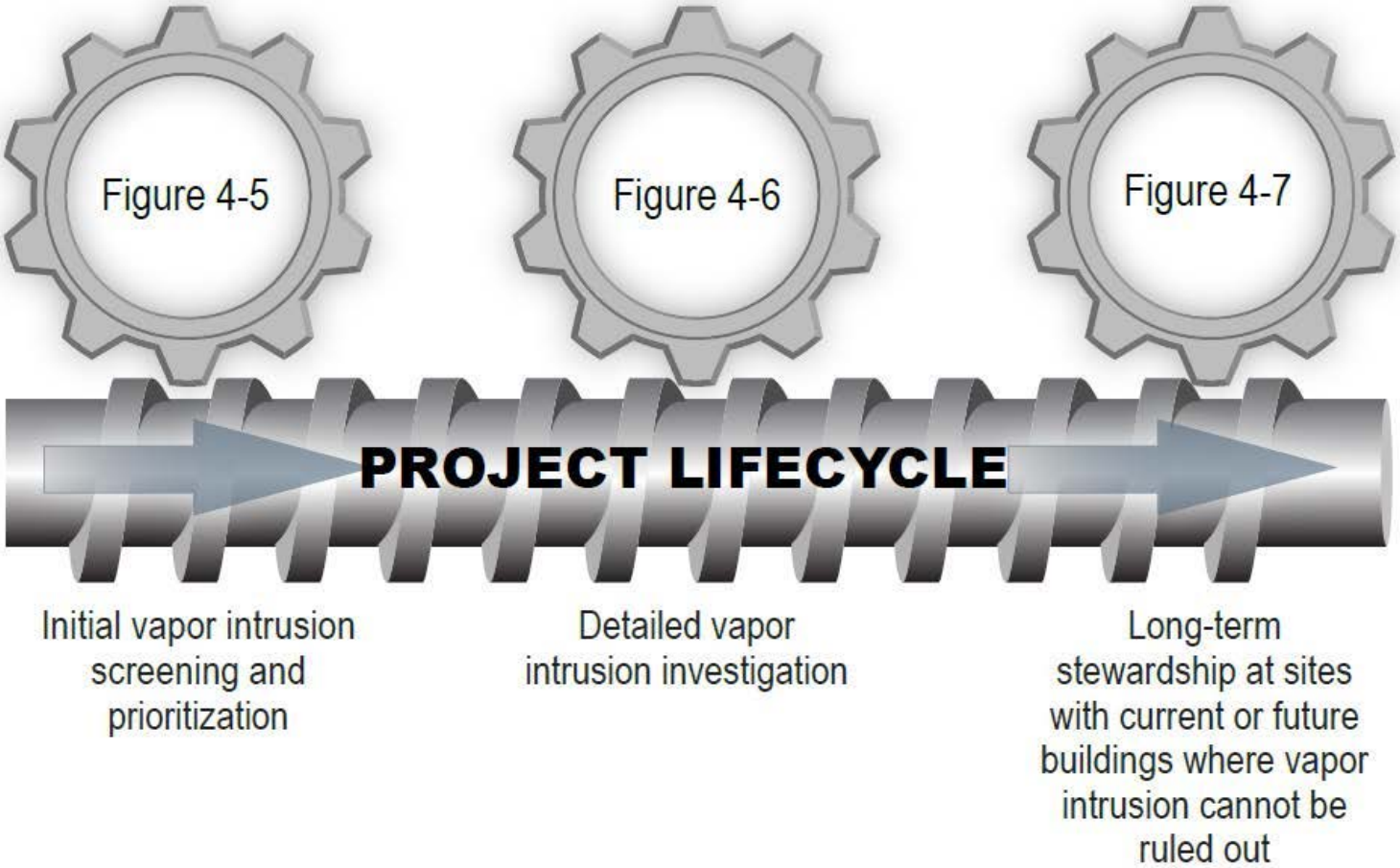
- AF's at least an order of magnitude less conservative
- More likely to contain background indoor air sources
- Larger indoor air volume
- Open work bays

Navy Message

Incorporate site-specific CSM information that supports departure from default residential values:

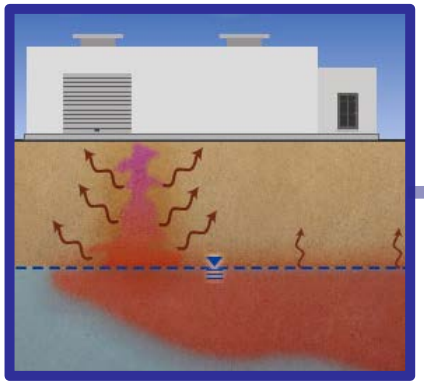
- Attenuation factors, risk thresholds, hydrogeology, building characteristics

Decision Framework to Help at Three Project Stages



** This scoring can be used through the lifecycle of the project*

Navy VI Database Decision Framework (cont.)



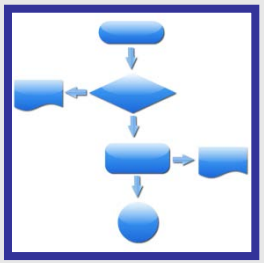
Navy VI Database (Site, Building, Zone Characteristics)

Data Analysis

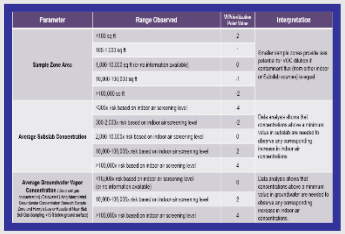
Key Influencing Factors/Empirical Relationships, e.g.,

- Dimensions
- Exterior Wall
- Soil Type
- Distance to Source
- Source Concentration
- Preferential Pathways

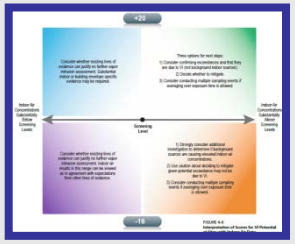
Data Interpretation



Flow Charts

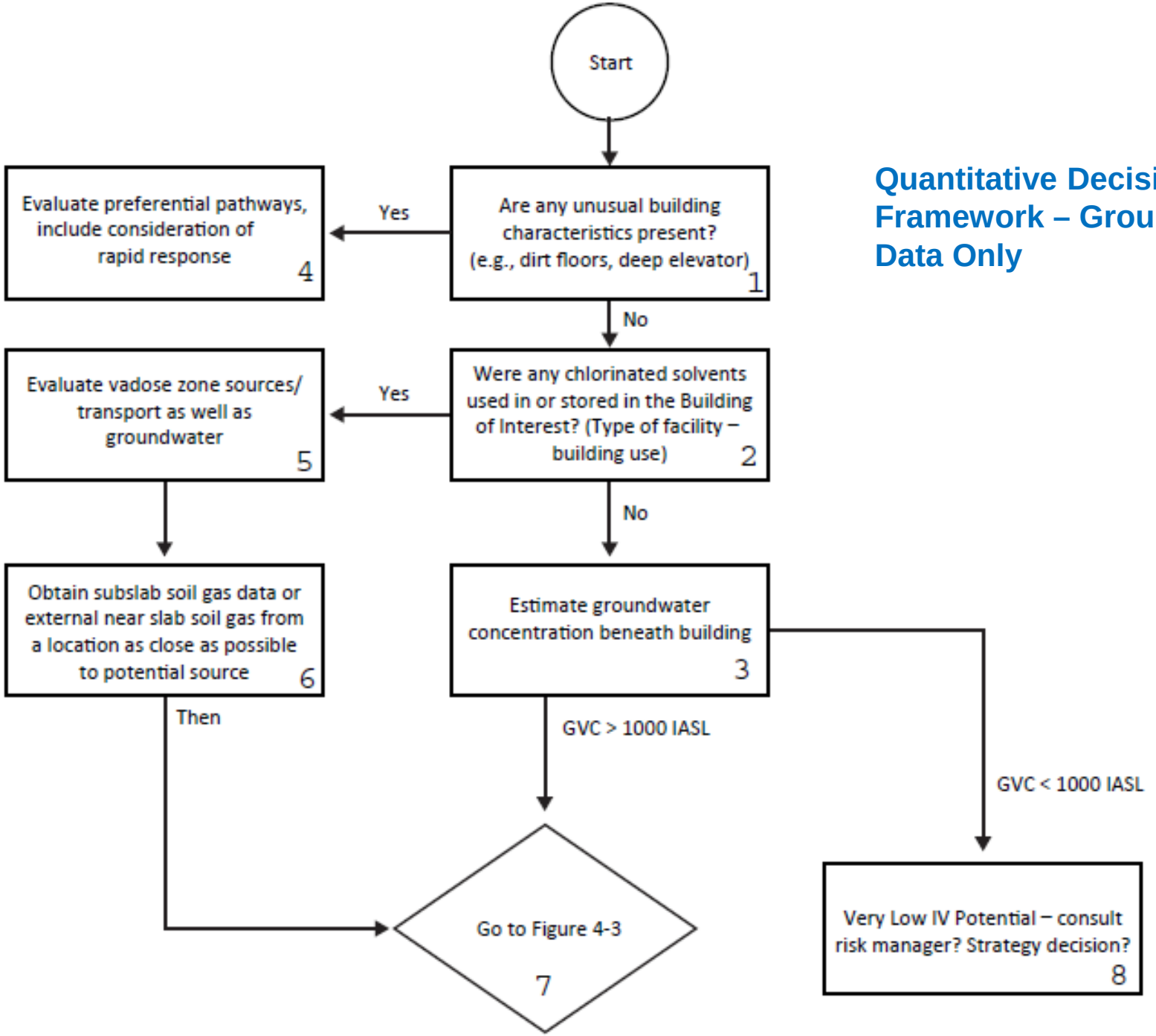


Score Card



Decision Matrix

Quantitative Decision Framework – Groundwater Data Only



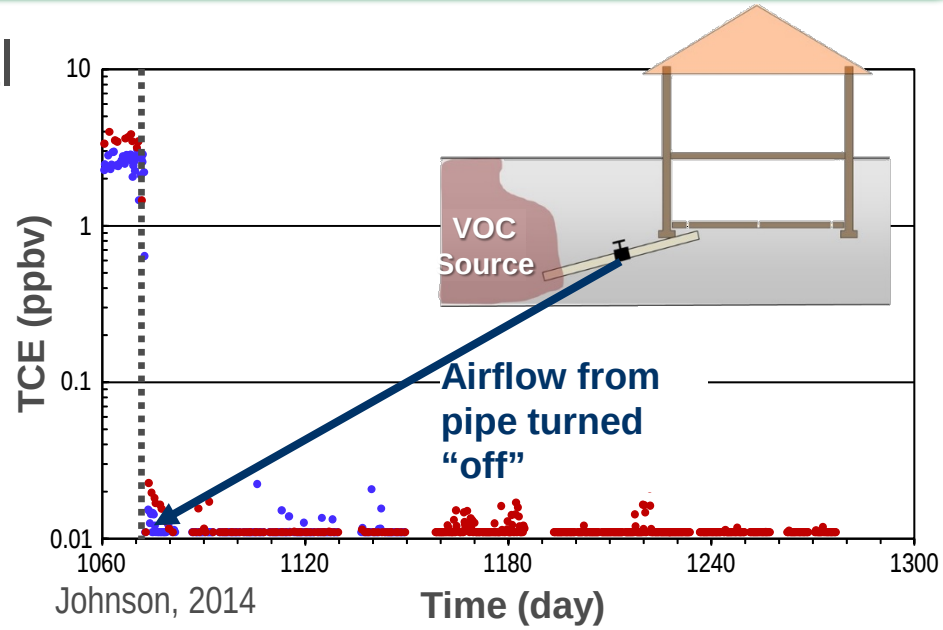
Atypical Preferential Pathways

EPA Message

"…and demonstrate the absence of preferential migration routes…"

Identifying Atypical Preferential Pathways

- Maps
- Building Surveys
- Interviews
- Field Instruments
- Tracer Studies



Johnson, 2014

Navy Message

- Intercepts source with little resistance to vapor flow
- Evaluate when unacceptable indoor air risk because of VI
- Generally only significant when intercepts VOC source area
- Need to consider for future construction

VI Decision Framework Score Card – Part 1

Paramater	Range Observed	VI Prioritization Point Value
Sample zone Area	<100 sq ft	2
	100-1000 sq ft	1
	1000-10,000 sq ft (or no information available)	0
	10,000-100,000 sq ft	-1
	>100,000 sq ft	-2
Average Subslab concentration	<300X risk based on indoor air screening level	-4
	300-2000X risk based on indoor air screening level	-2
	2000-10,000x risk based on indoor air screening level (or no information available)	0
	10,000 - 100,000x risk based indoor air screening level	2
	>100,000X risk based indoor air screening level	4
Average Groundwater Vapor Concentration (Deep soil gas concentration) (Calcualted Using Interpolated Groundwater Concentration Beneath Sample Zone and Henry's Law or Results of Near Slab Soil Gas Sampling >15 ft below ground surface)	<10,000x risk based indoor air screening level (or no information available)	0
	10,000 - 100,000x risk based indoor air screening level	2
	>100,000X risk based indoor air screening level	4

VI Decision Framework Score Card – Part 2

Soil Type and Solvent Use/Disposal History	Potentially contributing solvent activities and fine soil type	2
	Potentially contributing solvent activities and coarse soil type (or insufficient information)	0
	No potentially contributing solvent activities occurred in the building	-1
Sample zone on exterior wall of building?	Yes	1
	No	-1
Presence of *atypical* preferential pathway? (elevator shaft, tunnel, open soil visible beneath pit or wall etc.)	yes	3
	insufficient information	1
	known to be absent	0
Distance to Primary release point (from closest point within sample zone)	<10 ft	4
	10-30 ft	2
	30-100 ft	0
	100-200 ft	-2
	>200 ft	-4

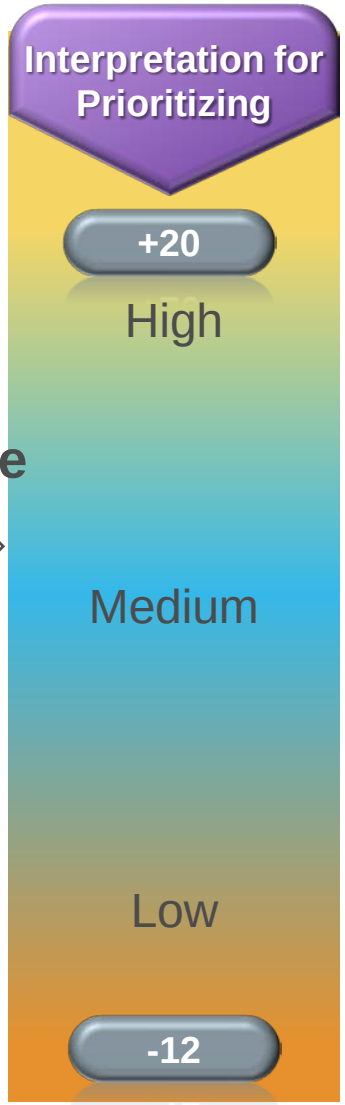
Uncertainty Rating for each paramater above not known +1

.

Prioritization – Using the Decision Framework

Decision Inputs	Input Range	Weight of Importance
Dimensions	<100 to >100,000 sq ft	2 to -2
Exterior Wall	Yes/No	1 to -1
Soil Type	Fine/Coarse	2 to 0
Distance to Source	<10 ft to >200 ft	4 to -4
Source Concentration	>100,000x SL to <20x SL	4 to -4
Preferential Pathways	Yes/Unknown/No	3 to 0

Cumulative Score



Prioritization

Prioritization for 167 Buildings

- Source strength
- Building features
- Distance

130 Bldgs. — No VI

25 Medium Priority

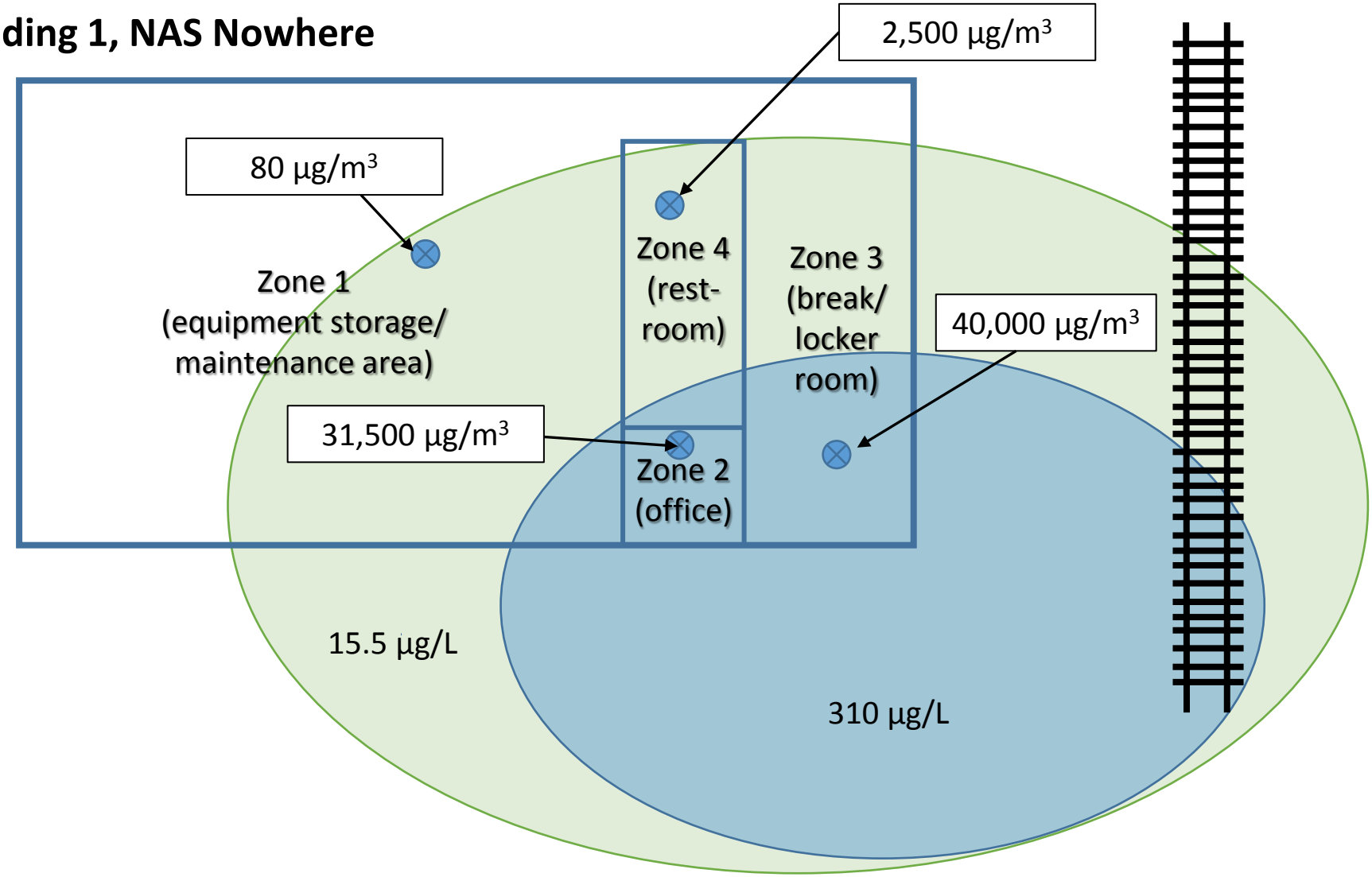
12 High Priority

Highest priority buildings

Saved >$1M by limiting investigation to only a few buildings

Application of Navy VI Decision Framework with Subslab and Groundwater Data

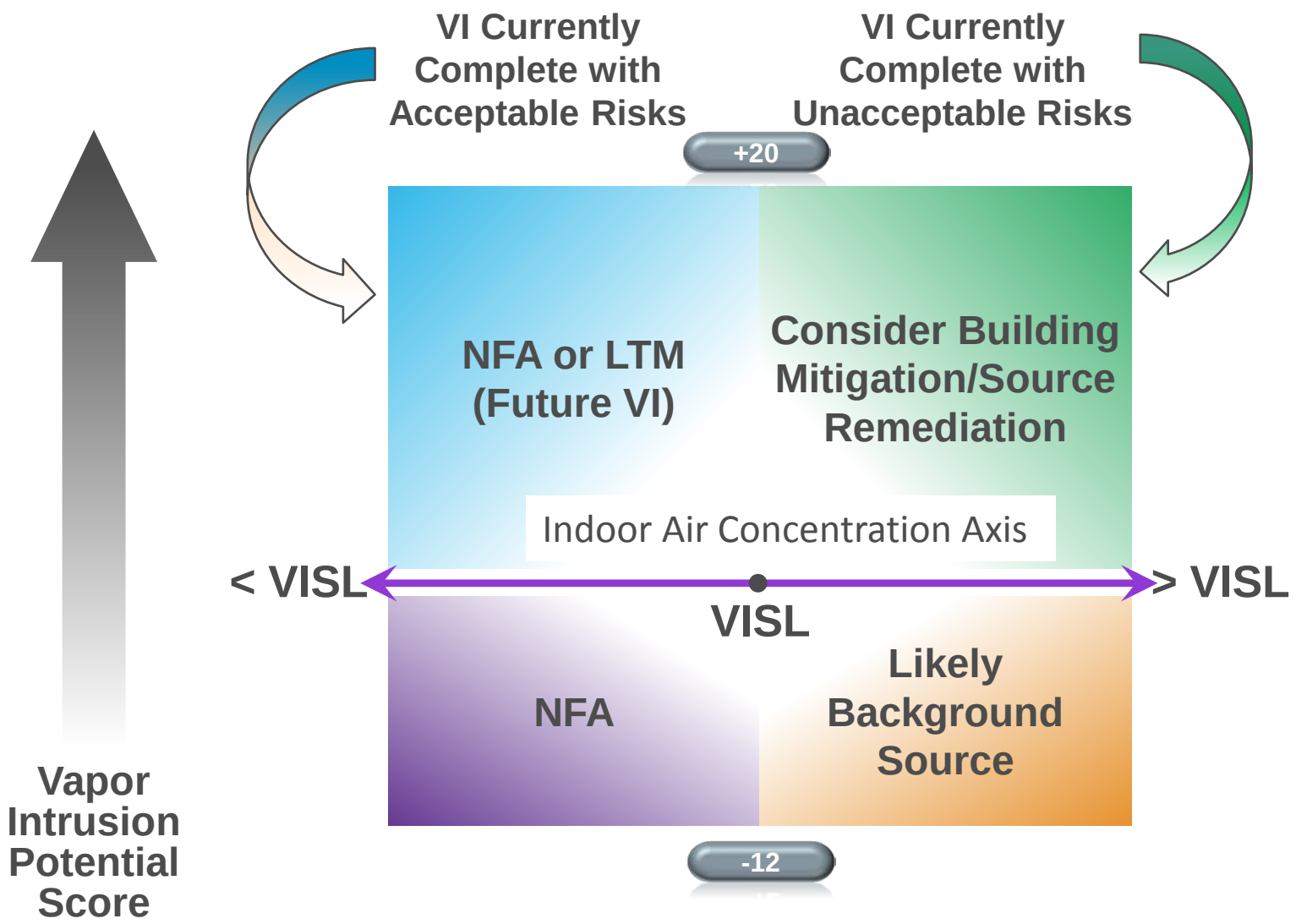
Building 1, NAS Nowhere



Application of Navy VI Decision Framework

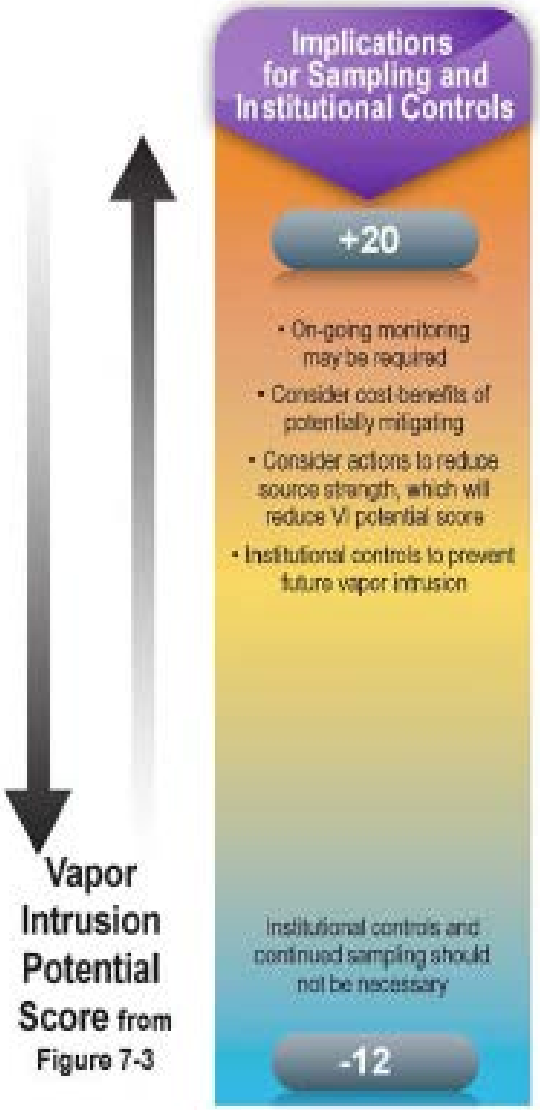
PARAMETER	ZONE 1 (Equip Area)	ZONE 2 (Office)	ZONE 3 (Break Room)	ZONE 4 (Restroom)
Initial Screening	Value	Value	Value	Value
Chemical of Concern	TCE	TCE	TCE	TCE
IASL	3 µg/m^3	3 µg/m^3	3 µg/m^3	3 µg/m^3
Max GW Concentration (µg/L)	15.5	310	310	15.5
Max GW Vapor Concentration (µg/m^3)	3,191	63,800	63,800	3,191
GW VC >1,000x IASL? (3,000 µg/m^3)	Yes	Yes	Yes	Yes
Highest SS SG Concentration (µg/m^3)	80 (27x IASL)	31,500 (10,500x IASL)	40,000 (13,300x IASL)	2,500 (833x IASL)
SS SG >33x IASL?	No	Yes	Yes	Yes
Very Low VI Potential?	Yes	No	No	No

Decision Matrix after Collecting Indoor Air



Interpretation for Long-term Stewardship

- The greater the VI potential and the closer to action levels indoor air concentrations are, the greater the frequency of ongoing monitoring that will likely be required in an existing building.
- In situations with frequent monitoring requirements, cost-benefit analysis can be applied to determine whether mitigation for the purpose of reducing monitoring costs is merited.
- Can also support MLE analysis for future buildings – VI resistant construction, monitoring requirements.



Future Vision

- Current DoD database structure does not smoothly support VI data analysis at the base or programmatic level. Made recommendations for a vapor intrusion specific NEDD.
- Add more sites to database; expand number of buildings and geographic spread.
- Gather more data about temporal variability in industrial buildings (expected side benefit of Clarkson ESTCP project).
- Refine database coverage of key building variables such as HVAC type and foundation systems.
- Tool for program management and applied research.
- Analysis platform using strengths of GIS, NIRIS analytical data, and INFADS building information.

Work in Progress on Prototype GIS Implementation

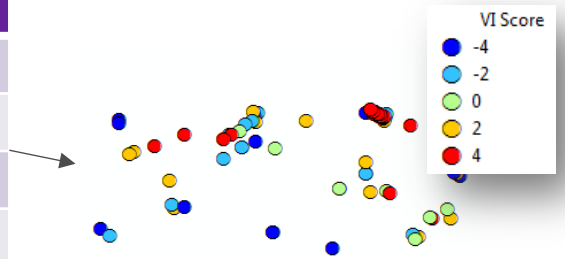
Process

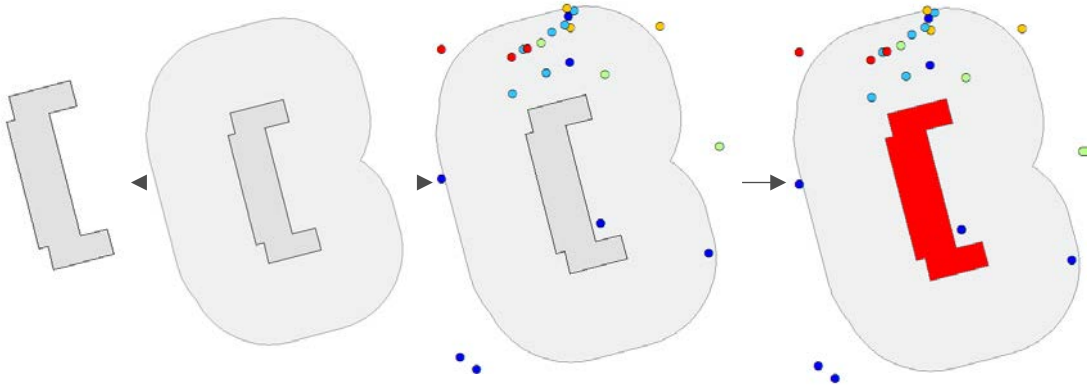
- Sample Locations to GIS Points Layer
  - Sample location table spatially enabled using XY coordinate information
- Building Buffer and Spatial Join
  - Buildings buffered by 100 feet
  - Sample points intersected with building buffers
  - Data joined between intersecting features
- VI Score Attribution
  - Max VI score from all intersecting samples attributed to building

Output

- GIS Buildings Layer Attributed with VI Scores

Sample ID	VI Score	X	Y
1234	-4	1234567.9	34567891.2
1235	0	1236809.4	34579701.1
1236	2	1246940.5	45769202.2
1237	4	2759382.7	34586058.9
1238	-2	1758937.1	34587694.3





Conclusions

- Commercial, industrial, and institutional buildings are different from single family residences in VI behavior.
- EPA's Vapor Intrusion Screening Level (VISL) calculator likely overestimates concentrations in indoor air for these buildings by a factor of 100x for subslab and 10x for groundwater.
- DoD data suggest GW screening level 70 µg/l TCE and 650 µg/l PCE.
- Normalized indoor air concentrations decrease with increasing sample zone size (square footage).
- Subslab (and indoor) concentrations fall off rapidly with distance to point of primary release.
- Soil type affects large buildings differently from single family residences.
- Results were used to develop a quantitative decision framework that can be used for prioritization, evaluation of indoor air data, and long-term stewardship decision making.

Thank You

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Innovation that Provides Sustainable Solutions to Complex Local Challenges, Worldwide