Prioritizing Buildings/Zones Using a Quantitative Decision Framework and Incorporating Indicators/Tracers into Vapor Intrusion Building Assessments

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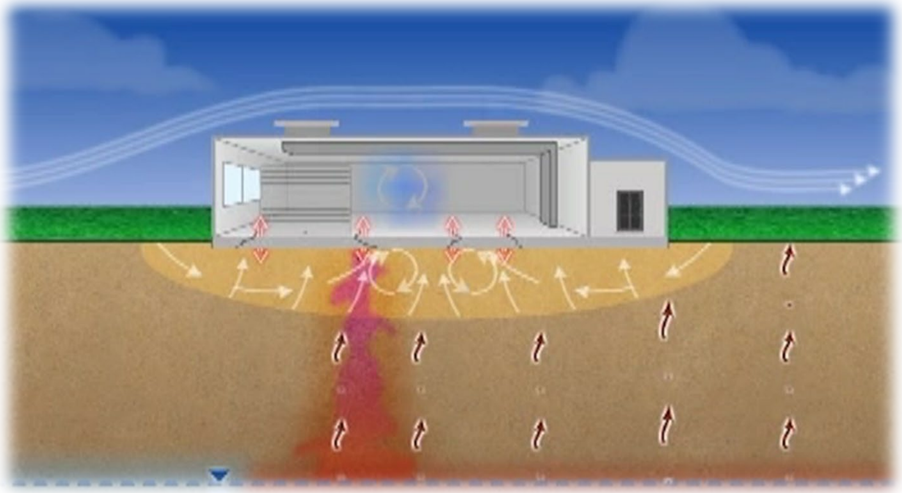
Jacobs

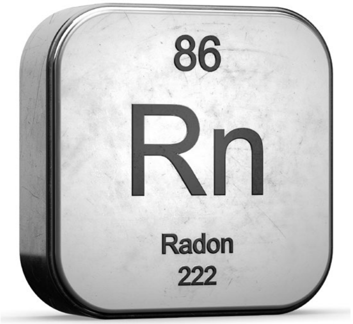
Challenging today.
Reinventing tomorrow.

Agenda

- Introduction
- DoD Industrial Building VI Database
  - Background
  - Types of data
  - Data Analysis
- Quantitative Decision Framework
- Practical Indicator & Tracer Protocol
- VI Matrix of Technologies
- Conclusions
- Q&A

DoD = Department of Defense





DoD Industrial Building Vapor Intrusion Database

DoD Industrial Building VI Database

- Objectives
  - Create DoD-specific VI database for industrial/commercial buildings
  - Evaluate relationships between factors affecting VI
  - Use data analysis to create framework to assist in VI decision-making
- Initially created in 2015 under NESDI Project #476
  - 12 installations 13 sites, and 49 buildings
- Updated in 2018
  - 22 installations, 27 sites and 79 buildings
    - Number of VOC indoor air results increased from 1,870 to 5,323
      - 2,989 VOC results in EPA (2012) database
  - Large (47%), medium (37%), small (16%) buildings

NESDI Project #476: Quantitative Decision Framework for Assessing Navy Vapor Intrusion Sites
http://www.nesdi.navy.mil/Files/FinalReports/FR_476.pdf

NESDI = Navy Environmental Sustainability Development to Integration

Types of Data

- Chlorinated VOCs concentrations
  - GW, SSSG, IA/OA
- HVAC type
- Area and volume of sampling zones/buildings
- Building/Zone Use
- Flooring type
- Presence of exterior wall

- Preferential pathways
- Soil type
- Depth to groundwater
- Distance to primary release
- Open/closed doors
- Construction Date

GW = Groundwater
SSSG =Subslab Soil Gas
IA = indoor air
OA =outdoor air

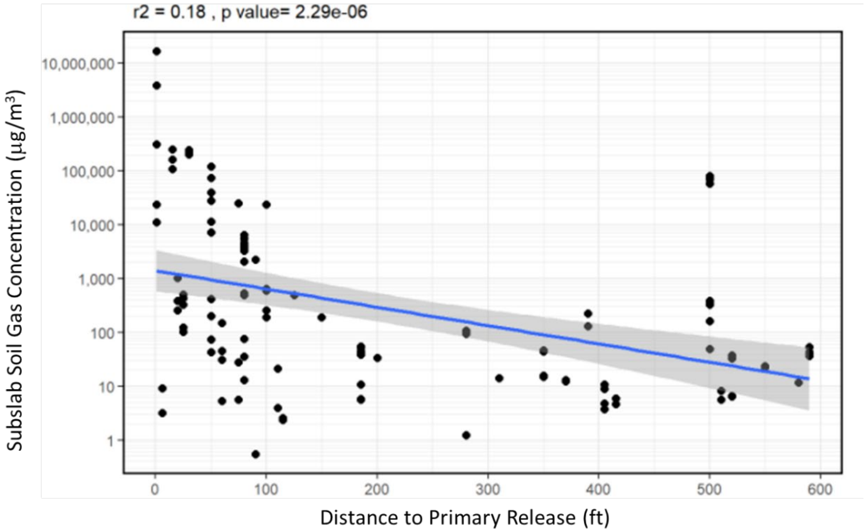
Data Analysis

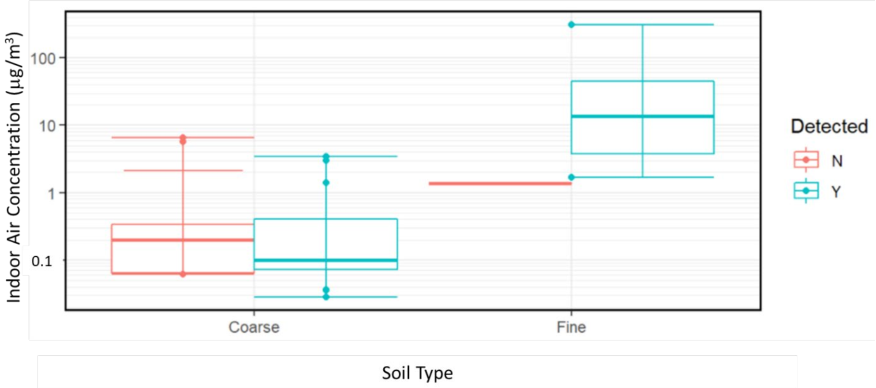
- Conducted statistical analysis using screening methods consistent with USEPA (2012) in analysis of their (primarily residential) database.

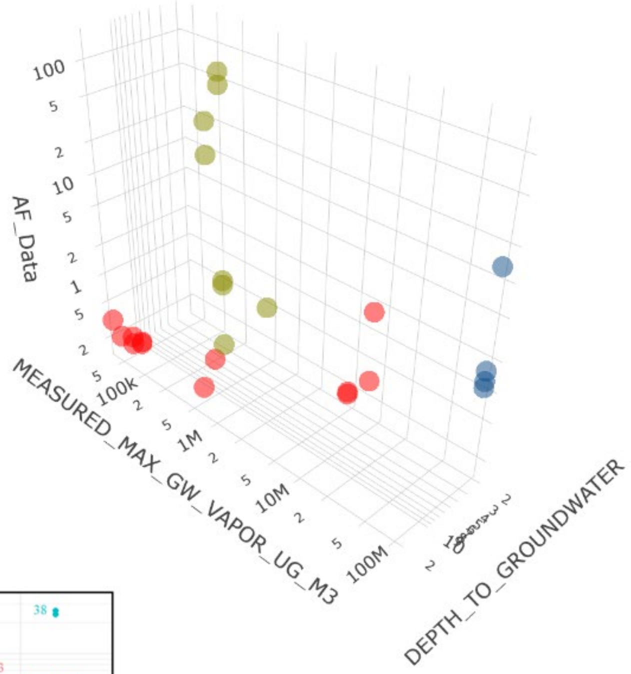
- Single Variate Analysis
  - GW Concentration
  - SSSG Concentration
  - Building Area
  - Soil Type
  - Distance to Primary Release
  - Depth to GW
  - Exterior Wall Presence
  - Building Characteristics
    - Building/Zone Use
    - HVAC presence
    - Flooring type
    - Construction date
- Multivariate Analysis
  - Transport from GW to IA
    - Soil Type and GW Depth
  - Transport from GW to SSSG
    - Soil Type and GW Depth
  - Transport and Dilution from SSSG to IA
    - Sample Zone Area and Presumed Open Doors
  - Transport and Dilution from SSSG to IA
    - Sample Zone Area and Zone Use
  - Transport and Dilution from SSSG to IA
    - Building Area and Building Use
  - Transport and Dilution from SSSG
    - Building Volume and Building Use
- Atypical Preferential Pathway

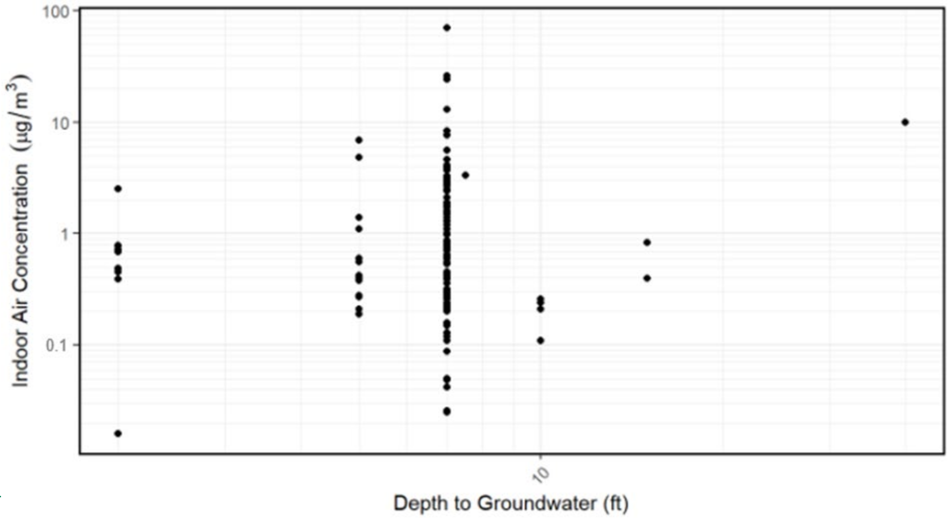
https://exwc.navfac.navy.mil/Portals/88/Documents/EXWC/Restoration/er_pdfs/v/Reanalysis_of_DOD_VI_Database_of_Comm_Ind_Buildings_Final_NOV21/Reanalysis%20of%20DOD%20VI%20Database%20of%20Comm%20Ind%20Buildings%20Final%20NOV21.pdf?ver=ujOoxNHDndzSmKvGzP-Q3w%3d%3d&timestamp=1652983111487

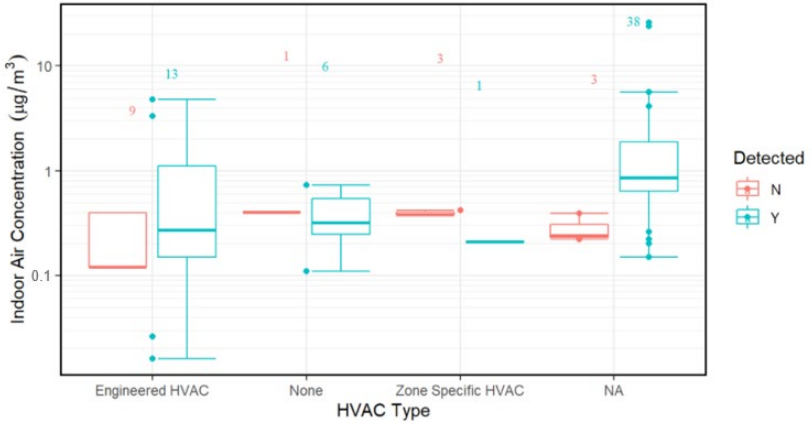
Data Analysis







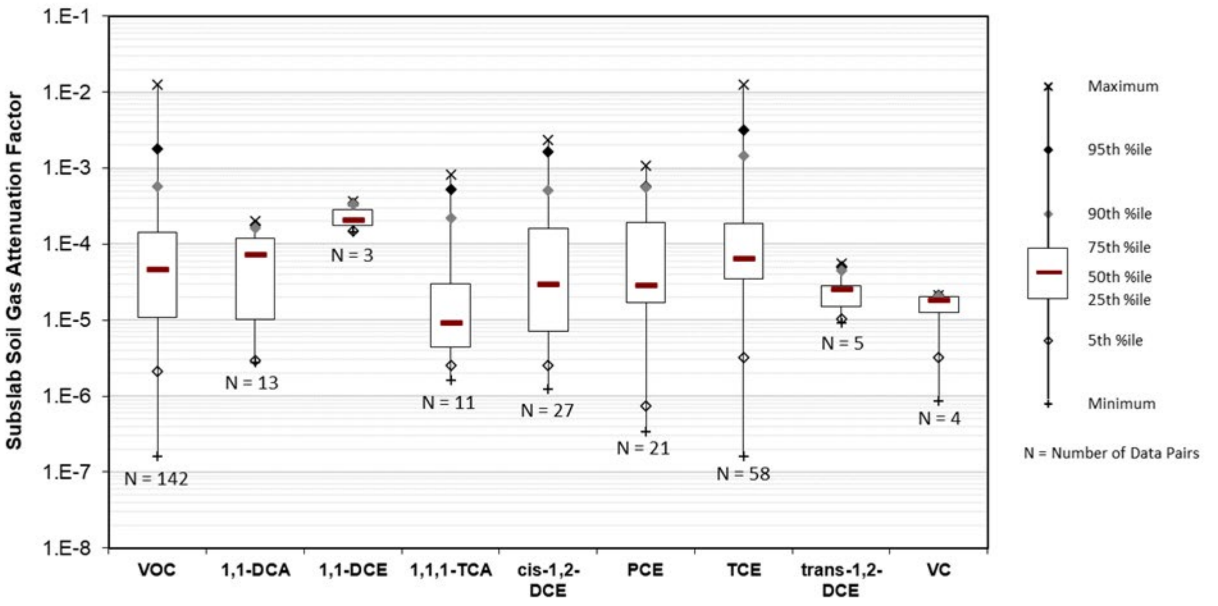


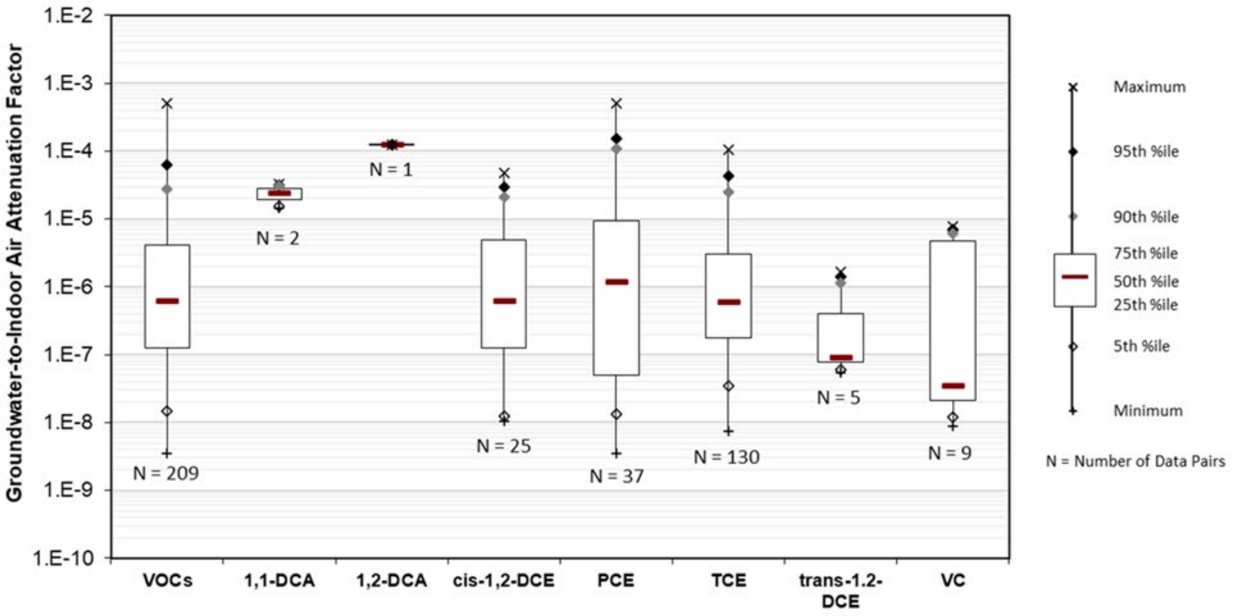



```
## ANOVA Table (type II tests)
##
##      Effect DFn DFd    F     p p<.05   ges
## 1 HVAC_TYPE   2  30 0.41 0.668       0.027
## # A tibble: 3 x 9
##   term   group1 group2 null.value estimate conf.low conf.high p.adj p.adj.signif
## * <chr>  <chr>  <chr>       <dbl>    <dbl>    <dbl>     <dbl> <dbl> <chr>
## 1 HVAC_~ Engin~ None            0  -0.330     -1.44     0.778 0.746 ns
## 2 HVAC_~ Engin~ Zone ~          0  -0.372     -1.76     1.02  0.787 ns
## 3 HVAC_~ None   Zone ~          0  -0.0425    -1.64     1.56  0.998 ns
```

Significant Findings

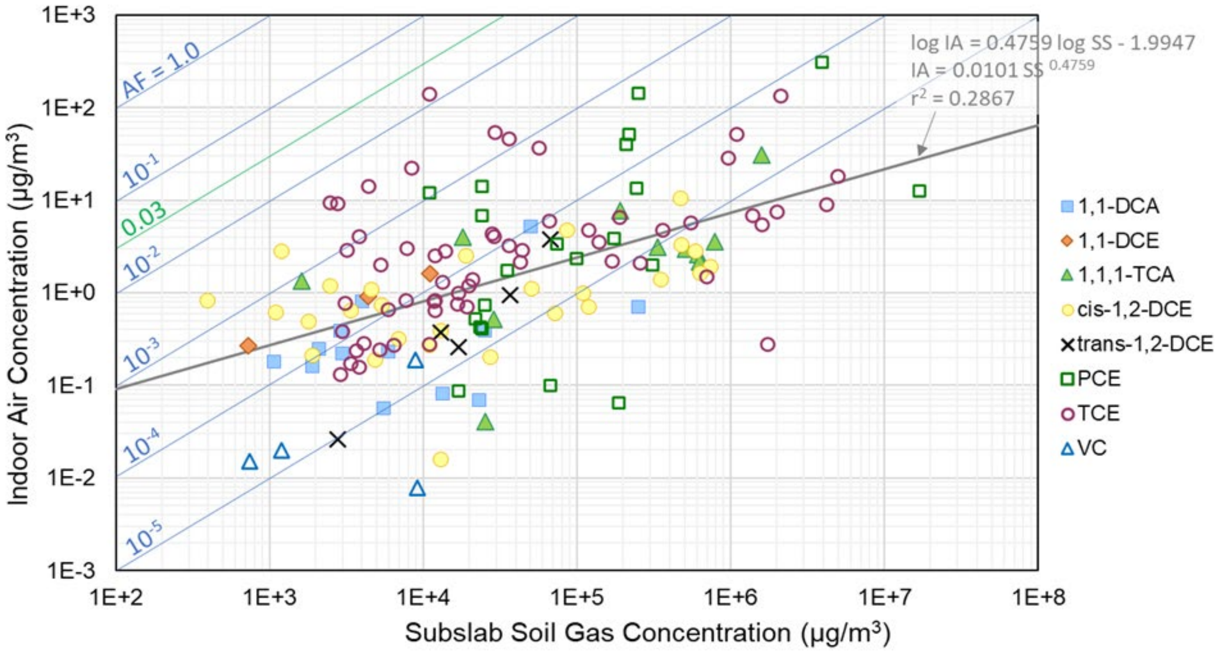
- USEPA Default AFs of 0.03 for SSSG and 0.001 for GW not appropriate for commercial/industrial buildings
- 95th Percentile for DoD Industrial Buildings:
  - SSSG to IA = 0.001
  - GW to IA = 0.0001
- Journal of the Air & Waste Management Association:
  - "An Alternative Generic Groundwater-to-Indoor Air Attenuation Factor for Application in Commercial, Industrial, and Other Nonresidential Settings" (2023) https://doi.org/10.1080/10962247.2023.2175740
  - "An Alternative Generic Subslab Soil Gas-to-Indoor Air Attenuation Factor for Application in Commercial, Industrial Other Nonresidential Settings" (2021) https://doi.org/10.1080/10962247.2021.1930286

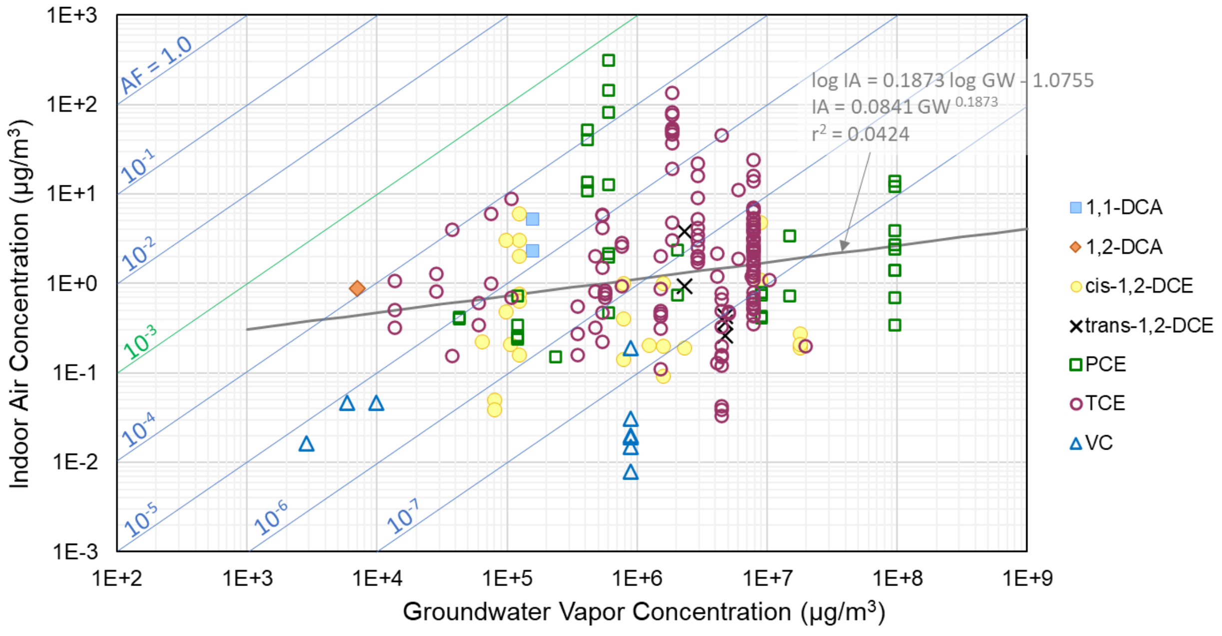




Significant Findings (cont)

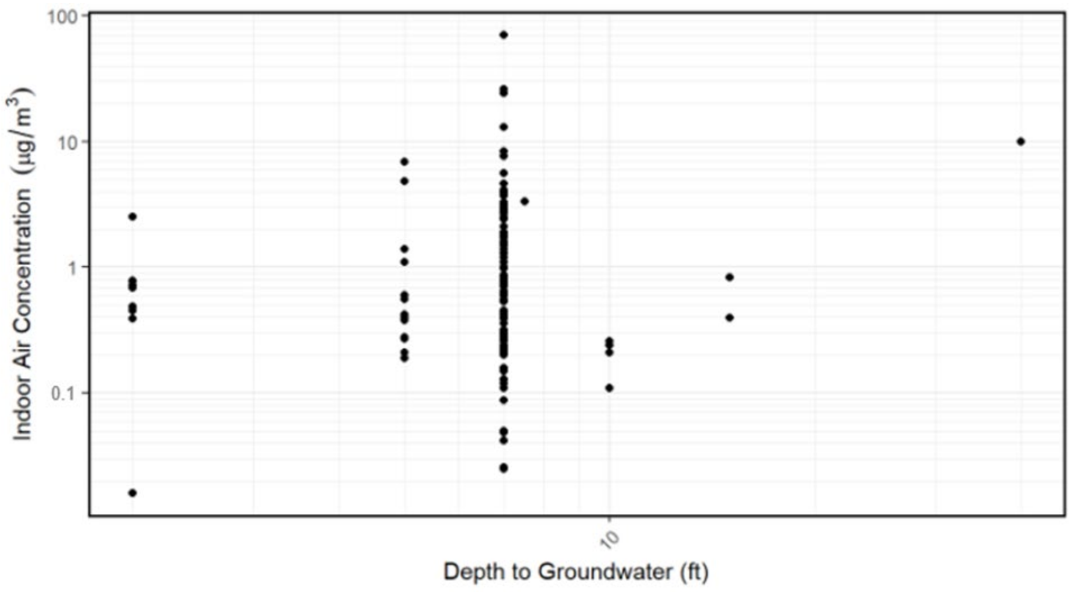
- Analysis indicated IA concentration does not rise linearly with the SSSG or GW vapor concentration
- For SSSG, the slope or exponent is 0.4759 (versus 1 if the increase was linear)
- For groundwater vapor, the slope or exponent is 0.1873 (versus 1)
- Linkage between GW concentrations and SSSG concentrations found to be relatively weak

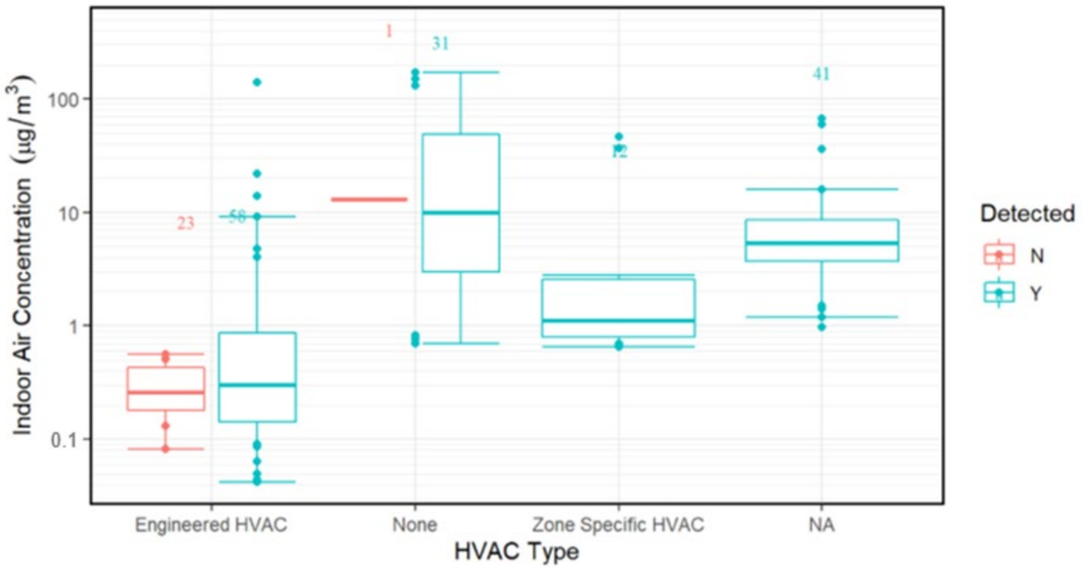


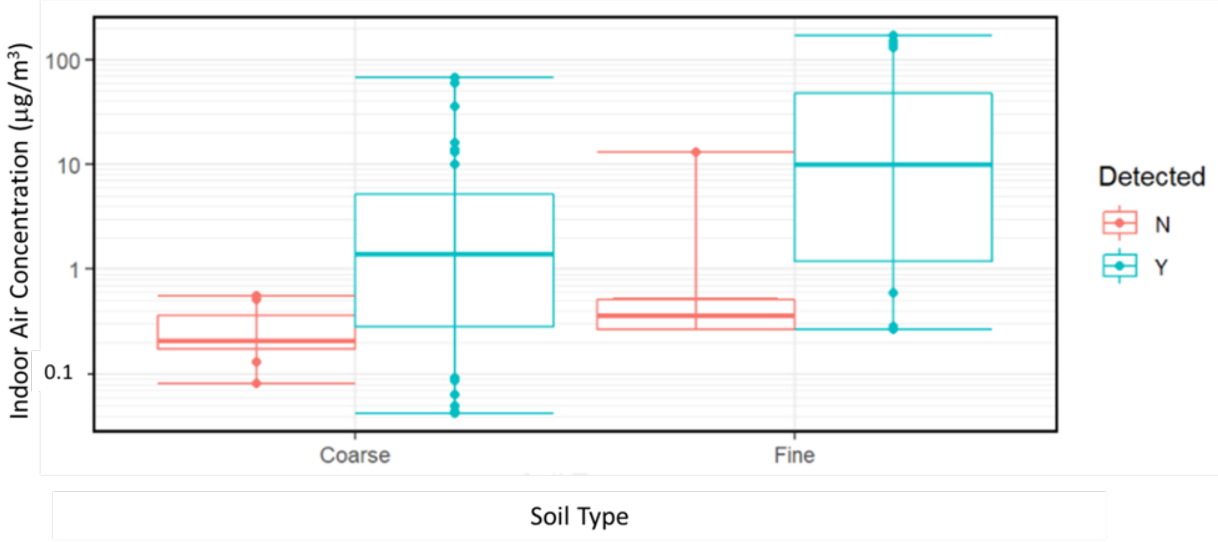


Significant Findings (cont)

- Other statistically significant factors influencing VI:
  - Soil Type and Solvent Use History
  - Atypical Preferential Pathways
  - Distance to Primary Release Point*
  - Depth to Impacted Groundwater
  - Presence of Engineered HVAC System
  - Year of Building's Original Construction







Quantitative Decision Framework

Quantitative Decision Framework (QDF)

- QDF developed based on the results of the analysis of the DoD Industrial Building VI database
- Designed to assist project team in prioritizing and evaluating VI at industrial/commercial buildings
  - Multiple lines of evidence (MLE) (analytical and non-analytical)

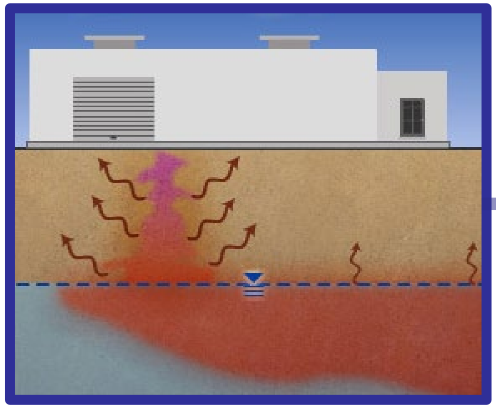
- Considers multiple factors
- Decision science to weight importance
- Facilitates systematically evaluating MLE
- Peer-reviewed and validated

QDF (cont)

- QDF (flowchart/scoring system) has similar format to ITRC 2014 petroleum VI guidance:
  - Provides “off ramps” for clear-cut cases
  - Harder cases lead to scoring
- Allows more in-depth evaluation using MLE leading to a VI prioritization score
- Range of weights emphasize the importance of predictor variables
- Separate scorecards available for groundwater only and groundwater/subslab soil gas data

ITRC = Interstate Technology and Regulatory Council
MLE = Multiple lines of Evidence

QDF (cont)



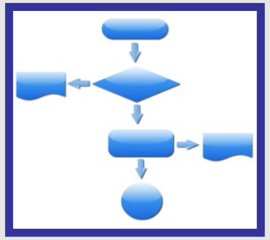
DoD Industrial Building VI Data Base (Site, Building, Zone Characteristics)

Data Analysis

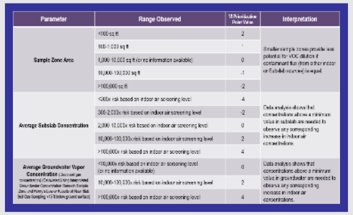
Key Influencing Factors/Empirical Relationships, e.g.,

- Construction Date
- Vadose Source
- GW Depth and Soil Type
- Distance to Source
- Source Concentration
- Preferential Pathways
- HVAC Presence

Data Interpretation



Flowcharts



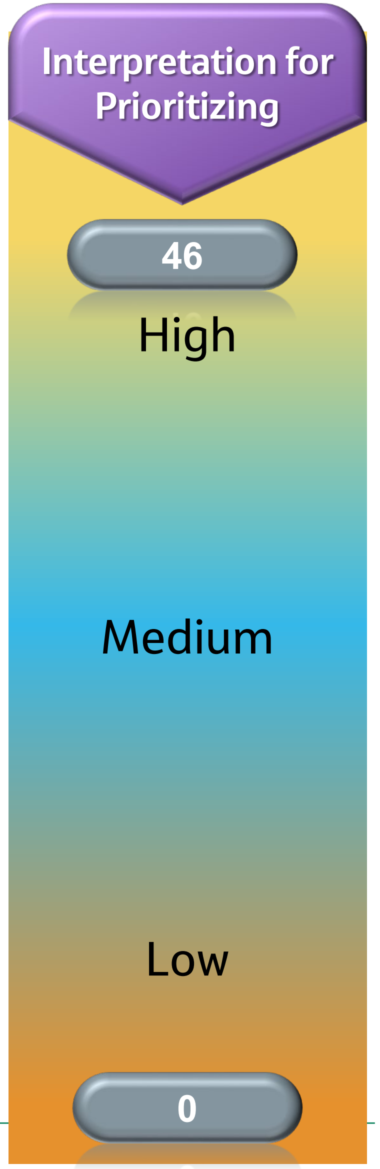
Scorecard

Decision Matrix

Applying the QDF - Prioritization

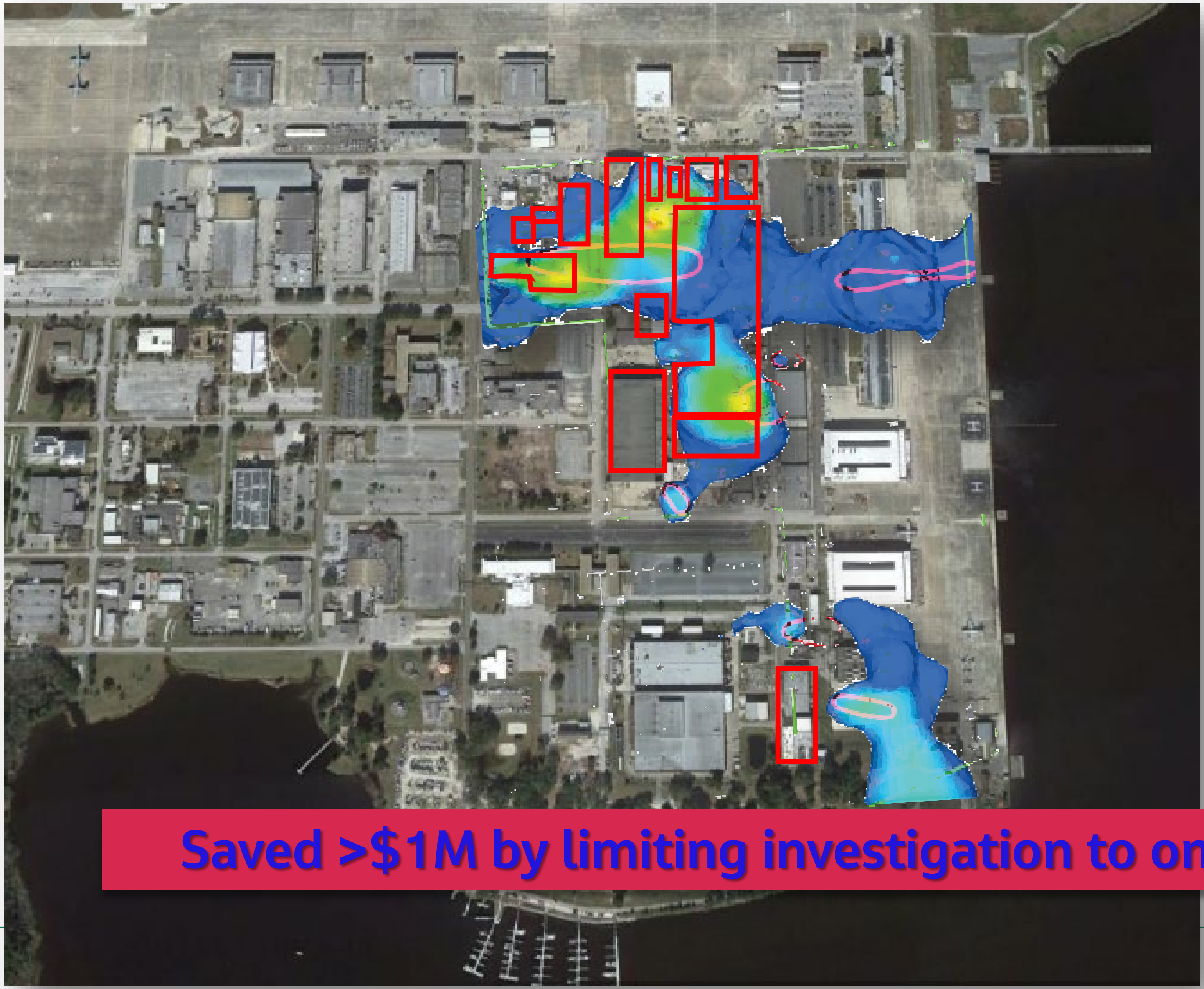
Decision Inputs*	Input Range	Weight of Importance
Construction Date	(1939-1959)/ all other dates	4 to 0
Vadose Source	<200 ft fine/<200 ft coarse/None	0 to 8
GW Depth and Soil Type	>4.9 ft, fine to <4.9 ft, coarse	0 to 4
Distance to Source	<10 ft to >200 ft	12 to 0
Source Concentration	GWVC < [1,000 x IA VISL] to GWVC > [1,500,000 x IA VISL]	0 to 12
Preferential Pathways	Present/Unknown/Absent	4 to 0
HVAC Presence	Yes/Unknown/No	3 to 0

Cumulative Score



*Based on groundwater data only

Prioritization



Prioritization for 167 buildings

- Source strength
- Building features
- Distance

130 Bldgs.

No VI

25 Medium Priority

12 High Priority

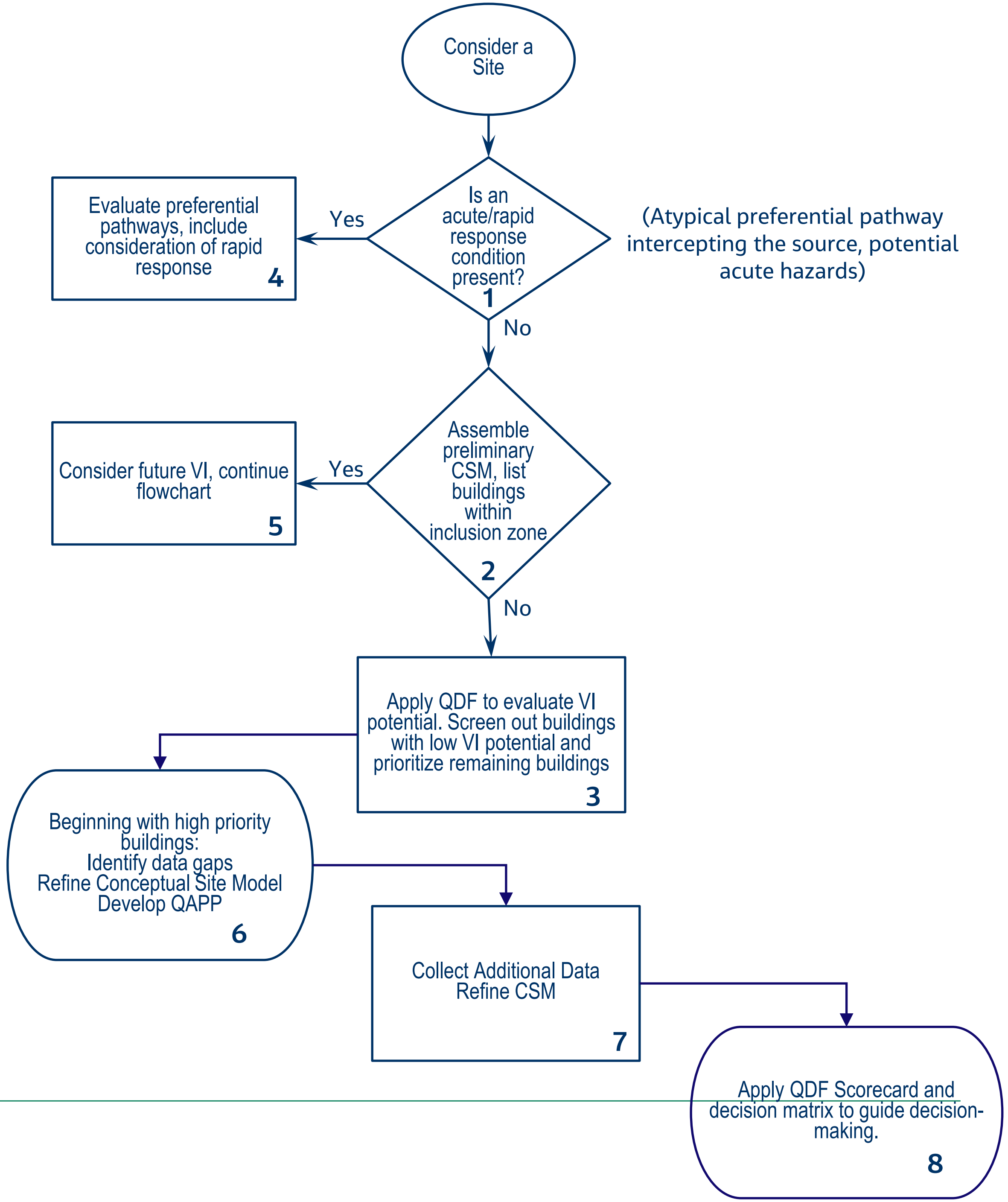
Highest priority buildings

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

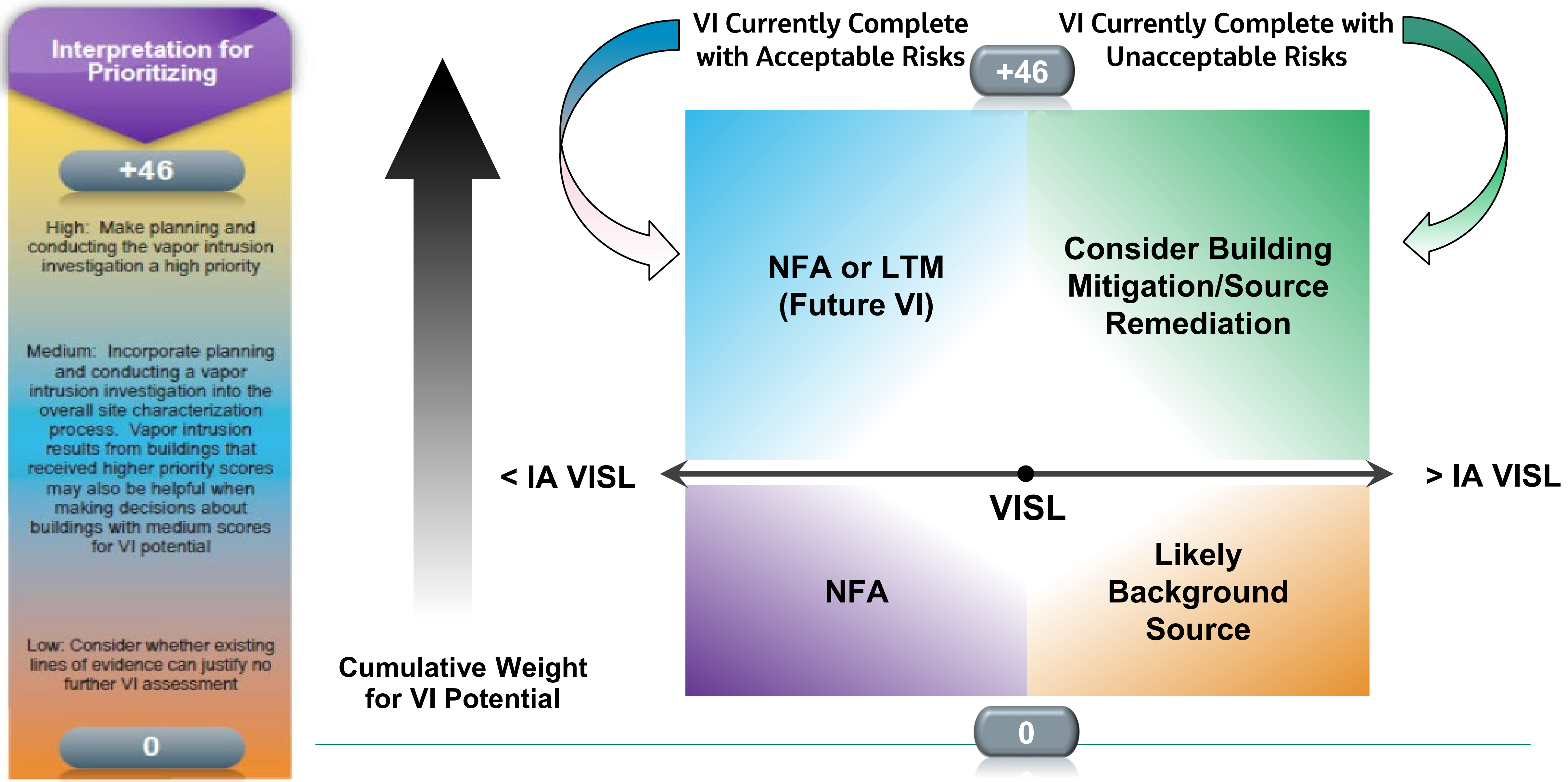
Applying the QDF – Project Lifecycle

Steps for applying the QDF:

- Identify presence of known atypical preferential pathways
- Screen out buildings with very low VI potential using GW Vapor Concentrations and/or SSSG Concentrations
- Calculate VI prioritization scores using multiple lines of evidence
- Interpret VI prioritization scores
- Collect additional data and refine the CSM
- Update the QDF Scorecard and use the decision matrix



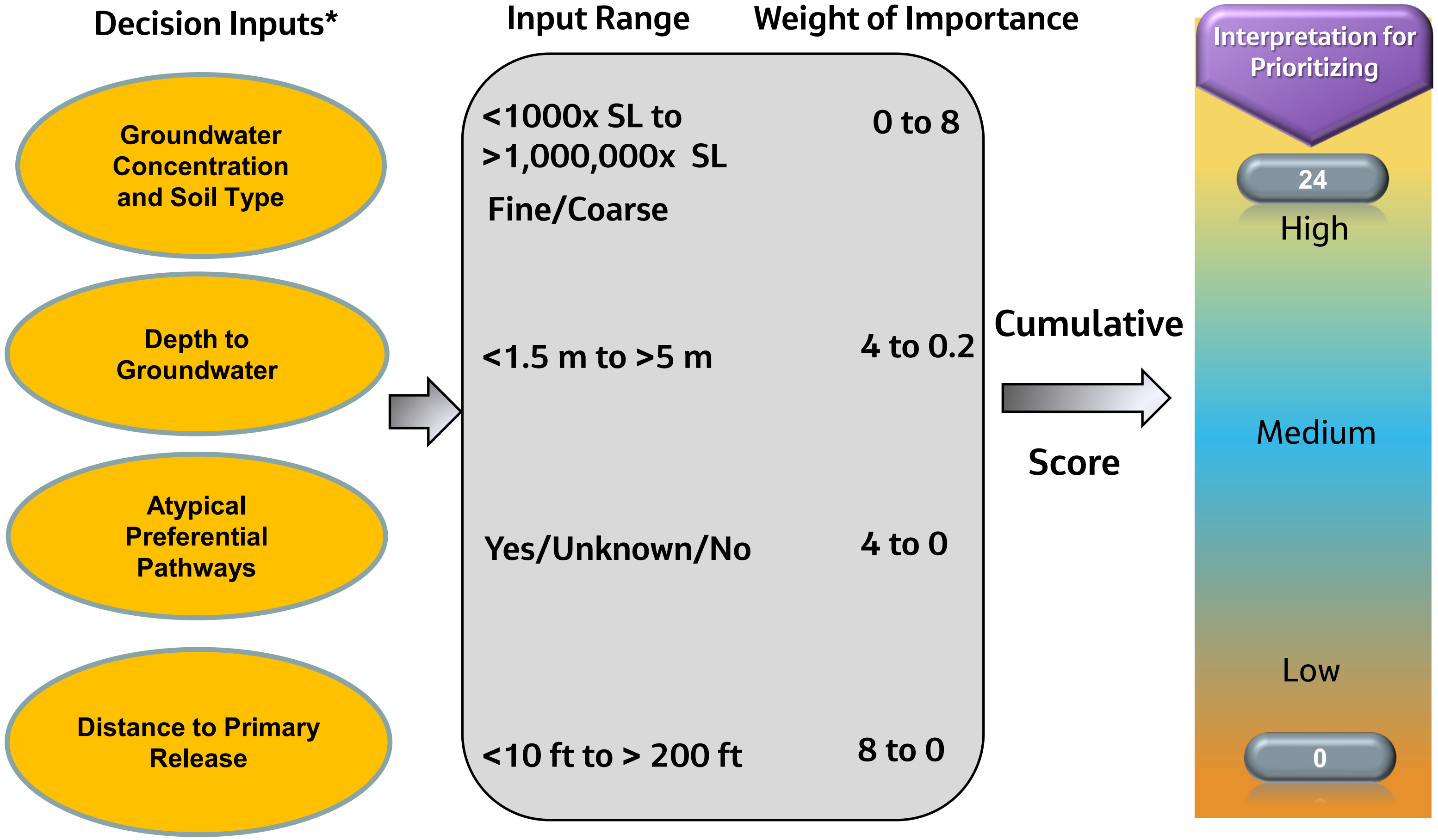
Interpreting Industrial QDF Cumulative Weights & Indoor Air Data



IA = Indoor Air NFA = No Further Action VISL = Vapor Intrusion Screening Level

Residential QDF

- Residential Version of the QDF developed in 2018
- Based on literature review
- Designed to be used with 1 to 4 family detached residential housing for chlorinated solvents
- Additional materials available upon request



*Based on groundwater data only

Incorporating Indicators and Tracers into VI Assessments

Indicators and Tracers (I&T)

I&T = Non-VOC metric used to assess/predict VI

- Following prioritization, I&T can be used to reduce uncertainties in VI investigations and should be incorporated into planning.

Potential I&Ts:
- Radon
- Pressure
- Temperature

VI uncertainties can be reduced using I&T measurements

(Schuver, USEPA, March 2021 VI Workshop)

Objective

Present an evidence-based practical protocol for integrating I&T data collection/analyses into VI assessments

Practical I&T Protocol Development

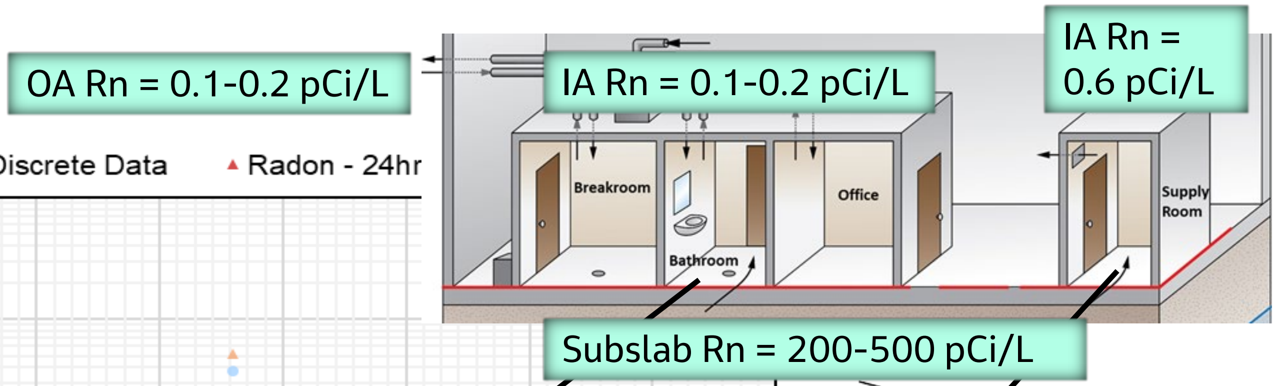
- Results from NESDI Project 554 used to help develop I&T practical protocol
- Building located in Mid-Atlantic region
  - Subsurface source & documented VI
  - ~120,000 ft^2 slab-on-grade & 3 large bays
  - Steam heat & overhead fans
  - No centralized cooling; bay doors open in summer
  - Interior office areas with separate HVACs
    - "Enclosed spaces within larger building"

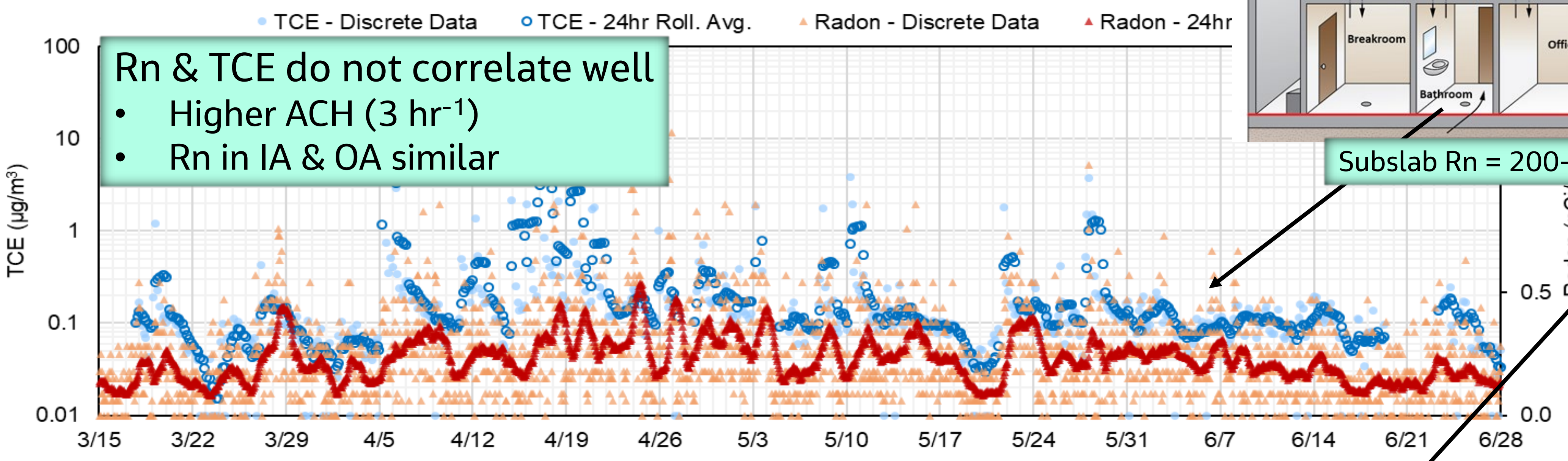
Beneath/Near Building

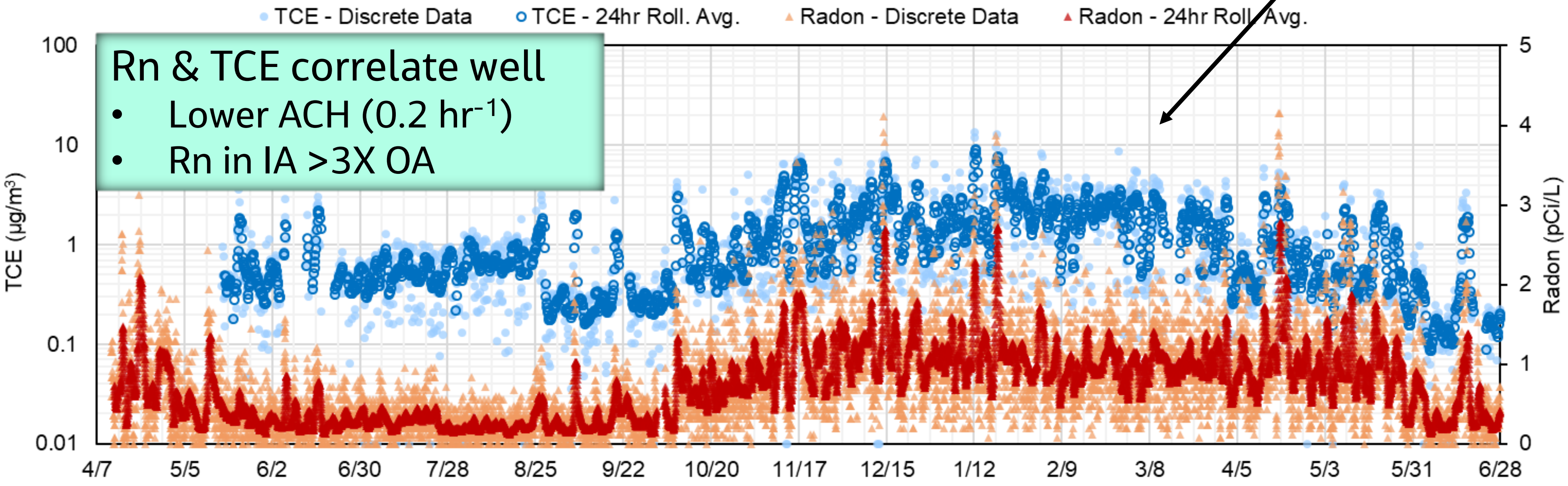
CVOC	Max GW (µg/L)
1,1-DCE	644
1,2-dichloroethane	7.4
Cis-1,2-DCE	474,000
Trans-1,2-DCE	67,700
TCE	898,000
VC	639,000

CVOC = chlorinated VOC GW=groundwater

TCE and Radon





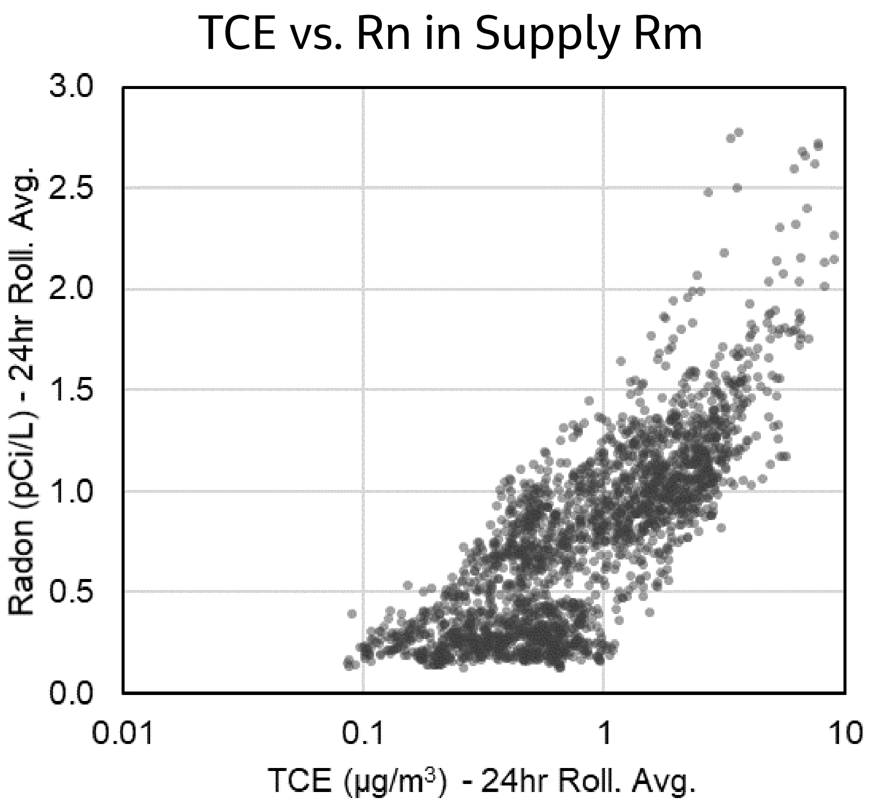


Radon as a Predictor of VI

Radon is good predictor of VI when:

- IA radon is >2-3X OA
- Air exchange rate is low (e.g., <1 hr^{-1})

- Note:
  - Need to understand subslab radon and VOC levels
  - Rn was best I&T for predicting VI



Practical I&T Protocol for VI Investigations

- **Step 1:** Identify, prioritize, & select indoor sampling zones, using:
  - QDF
  - Information about areas with significant VOC subsurface sources
  - Bldg drawings & surveys for areas more susceptible to vapor entry
  - Zones with lower ACH rates &/or high negative dP potential
- **Step 2:** Collect continuous IA & OA radon data for at least one week prior to VOC sampling
  - Consider collecting other I&T data (e.g., dP & dT) as supplemental
- **Step 3:** Continue collecting radon/I&T data and collect subslab, IA, and OA VOC samples (during heating season)
  - Collect subslab radon samples

Practical I&T Protocol for VI Investigations (Cont'd)

- **Step 4:** Evaluate data to assess if I&T can predict VI
  - Radon is best I&T predictor of VI when:
    - IA radon is >2-3X OA
    - Air exchange rate is low (e.g., <1 hr-1)
  - Effectiveness depends on Rn source strength and dilution upon entry
- **Step 5:** Continue monitoring radon in place of VOCs, unless
    - Indoor Rn increases significantly; and
    - Subsurface VOC x bldg-specific AF suggests VI may be potential concern

Note: Building pressure control (BPC) testing can be considered when:

- Radon is not a suitable tracer for monitoring VI
- Long-term radon monitoring is not feasible
- VI investigation is time-sensitive & needs to be expedited

AF = attenuation factor

I&T Protocol Advantages

- Radon as I&T to greatly increase defensibility of VI assessments at most buildings
  - Return to "status quo" if Rn not effective and opt not to use BPC
- Uses and benefits of radon as an I&T* include:
  - Prioritizing & selecting indoor sampling locations
  - Predicting VI of VOCs
  - Guiding when to sample for VOCs and better estimating exposure
  - Minimizing VOC sampling (saves money)
  - Increasing confidence when assessing VI multiple lines of evidence

*Need information about IA/OA (Rn) and subslab (Rn & VOC) levels to decide

Matrix of Technologies for VI Investigations

- DoD Vapor Intrusion Handbook Fact Sheet Update No: 007, titled "Matrix for Selecting Vapor Intrusion Investigation Technologies"
  - Matrix created to provide a tool to select the most effective technologies for investigating VI, broken down by study question
  - Includes technologies for investigating soil sources, soil vapor, and indoor air, I&T, and forensic tools
  - Publicly available at: https://www.denix.osd.mil/irp/denix-files/sites/48/2019/09/Matrix-of-VI-Technologies-Fact-Sheet_Revised-Final-July-2019.pdf

			Soil Screening			Soil Vapor & Indoor Air Field Screening				Soil Vapor & Indoor Air Sampling				Forensic Tools					
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
																Indicators, Surrogates & Tracers			
VI Pathway Assessment	Investigation Objective	Sub-objectives	Discrete soil samples for VOC analysis with microwave extraction	Continuous coring or profiling (MIP, Dye LIF)	Soil Physical Properties (core logging, geotech analysis)	Handheld PID (VOCs)	Portable GC/PID (Tedlar bags)	Mobile GC/ECD (Tedlar bags, glass syringes, Teflon tubing)	Portable GC/MS (HAPSITE) & MS/MS (TAGA)	Evacuated Canister with analysis by EPA Method TO-15	Active Sorbent Sampler with analysis by EPA Method TO-17	Passive Sorbent Sampler	Flux Chambers	Compound Ratio Analysis	Compound Specific Isotope Analysis	Building Pressure Differential Monitoring	Other R= Radon, TD = Temperature Differential; Tr= Introduced Tracers	Building Pressure Cycling	High Volume Soil Gas Sampling
Are VOCs/SVOCs associated with subsurface sources underneath or near the building(s) present at concentrations above screening levels?	Characterize vapor sources	Delineate vadose zone vapor sources	+++	+++ (LIF and MIP)	-	++	+++	+++	+++	+++	+++	++	-	+	++	-	-	-	+
	Characterize near source vapor concentrations	Characterize spatial distribution	+	++ (MIP)	-	++	+++	+++	+++	+++	+++	++	-	-	-	-	-	-	-
		Characterize temporal variability	-	-	-	-	+++	+++	+++	+++	+++	++	-	-	-	-	-	-	-
Are VOC/SVOC vapors migrating from the source towards the building?	Identify vapor migration pathways in the subsurface	Characterize soil migration pathways	-	+ (MIP)	+++	+	++	+++	+++	+++	+++	++	-	-	-	-	++[b]	-	+
		Characterize utility conduits pathways	-	-	-	+	++	++	++	+++	+++	+++	-	+	++	-	+++[b]	++	+
	Characterize near foundation vapor concentrations	Characterize spatial distribution	-	-	-	++	++	+++	+++	+++	+++	++	+	-	-	-	+	-	+++

Conclusions

- Commercial/Industrial AFs derived from robust statistical analysis of the DoD Industrial Building VI database
  - More representative than USEPA defaults based on analysis of primarily residential buildings
- Use QDF to prioritize buildings/sampling zones for data collection
  - Based on analysis of the DoD Industrial Building VI database
  - Can also be used through the project life-cycle to interpret data and evaluate MLE
- Matrix of Technologies can assist in selecting investigation strategy
- VI practice will significantly benefit if use radon as I&T

Thank You!

Q&A

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