Vapor Intrusion in North Carolina

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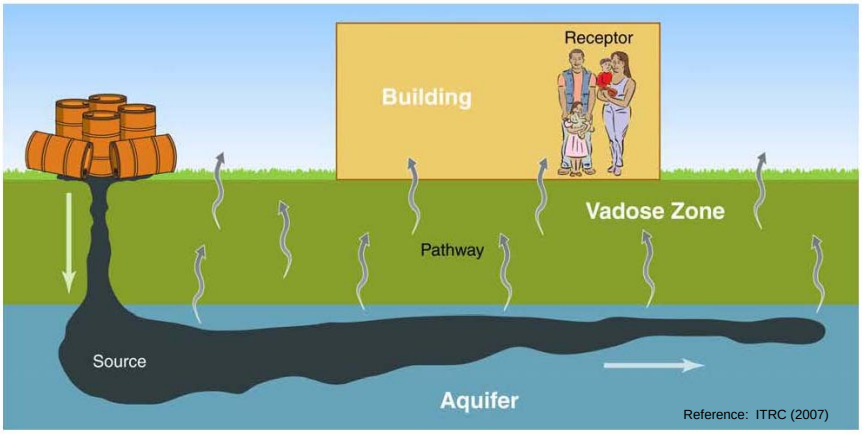
Cardno ATC

Prepared for:
NCDOT Geo3T2 Conference
April 9, 2015

TOPICS OF DISCUSSION

I. Vapor Intrusion Basics and Complications
II. NC Vapor Intrusion Guidance
III. Case Studies

What is vapor intrusion (VI)?



VI is the migration of volatile chemicals from the subsurface into overlying buildings (USEPA 2002).

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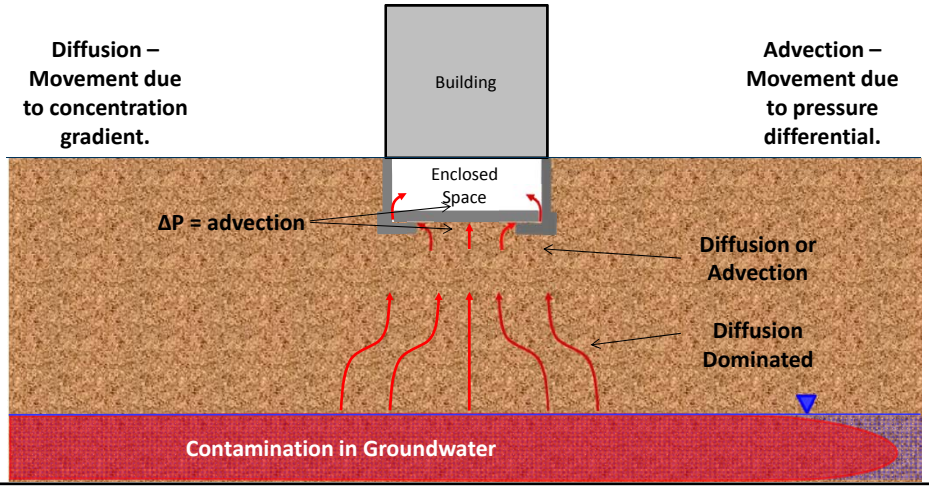
The Basics of VI

Chemicals with potential for VI:

- Chemicals with sufficient volatility (Henry's Law Constant > 10^{-5} atm m^3/mol) and toxicity
- Chlorinated solvents and petroleum most common
- Commonly more risk for chlorinated solvents because petroleum constituents tend to degrade aerobically

The Basics of VI

Simplistic View of Vapor Migration



The Basics of VI

Factors affecting VI

- **Vapor source**
- **Geology**
- **Biochemistry**
- **Weather**
- **Building Factors**

What do all these influences mean? Modeling can be problematic due to uncertainty in input parameters. Temporal and spatial variability (changes in concentrations at different times or locations) are also a big concern.

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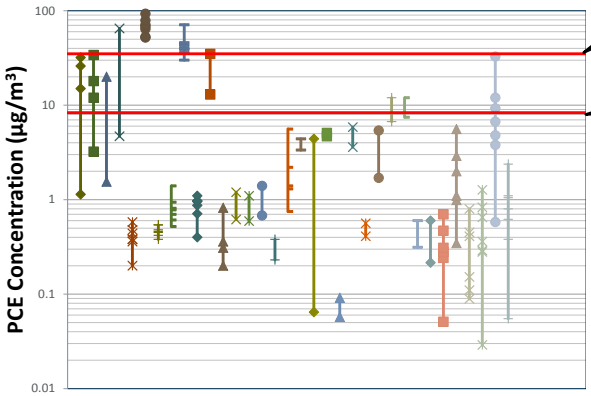
Complications and Emerging Research



Temporal Variability! How many sampling events needed? How long?

Each vertical line represents a different sampling location

Reference: Data collected by Cardno ATC and the NCDENR DSCA Program at NC drycleaning solvent release sites.

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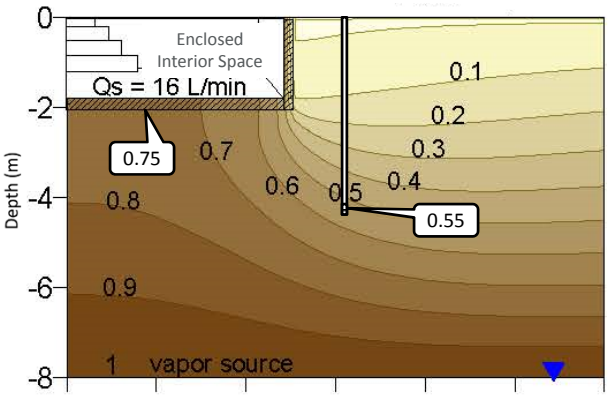
Complications and Emerging Research



Spatial Variability!

Soil gas sample collected outside the building may not be representative of soil gas concentrations entering the building

Simulated VOC isoconcentration contours shown

Reference: Conceptual Model Scenarios for the Vapor Intrusion Pathway, USEPA, February 2012

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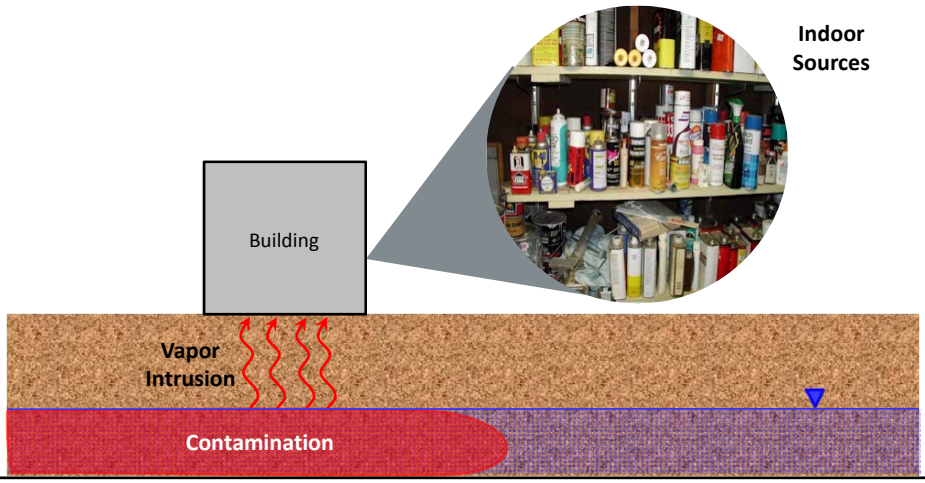
Beware of Background Indoor Air Sources

Where is indoor air contamination coming from?



Beware of Background Indoor Sources

Product	Constituent	Concentration (µg/m^3)	NCDENR Residential IASL (µg/m^3)	NCDENR Non-Residential IASL (µg/m^3)
Silly String	Benzene	23,000	0.36	1.57
Candle Wax		7,100		
Shaving Cream		389		
Pumice Hand Cleanser		27		
Baby Wipes		21		
Fish Oil Vitamins		19		
Modeling Clay	PCE	430	8.34	35
Shoe Polish/Waterproofing	TCE	55	0.417	1.75

Data courtesy of H&P Mobile Geochemistry.

Beware of Background Indoor Air Sources

Was it the tequila or the silly string???

Complications and Emerging Research

2011 EPA Revised Human Health Risk Assessment for TCE

- Concluded potential risk of cardiac birth defects for pregnant women with exposure to very low levels of TCE (2 $\mu g/m^3$) over a time period as short as 24 hours
- Lots of criticisms - controversial short-term oral rat study, results could not be repeated

Questionable toxicity data

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Complications in evaluating health risk

What is risk? What is acceptable? Says who?

OHSA PEL
547,500 ug/m^3

NC Residential IASL
0.41 ug/m^3

Action levels for TCE may vary by as much as 8 orders of magnitude depending on the receptor. What is "right"?

Complications and Emerging Research

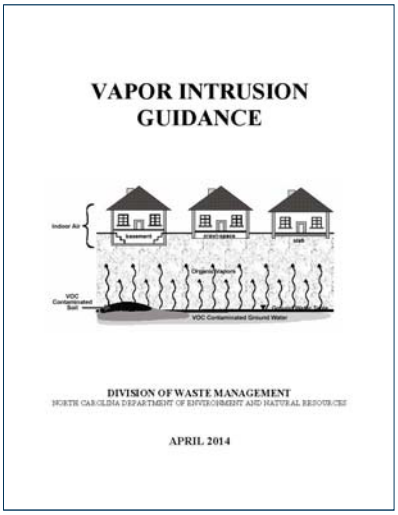
KEY TAKEAWAYS

- **VI is an emerging science**
- **There are still many unknowns**
- **Expect changes in investigation approaches in the future as the science advances**

Is it any wonder that EPA and many state agencies have had trouble finalizing VI guidance?

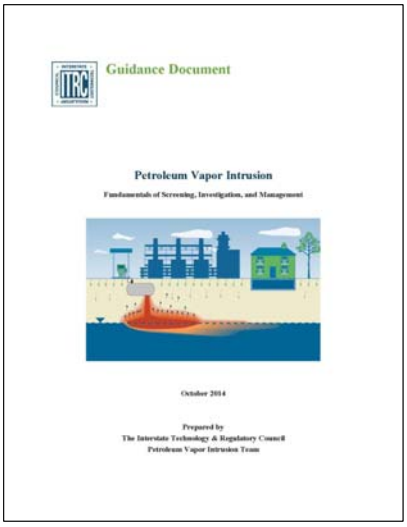
VI Investigation in NC

Division of Waste Management VI Guidance Document



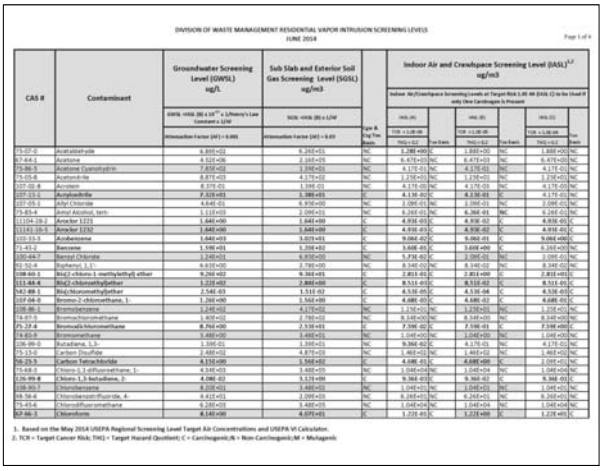
- Addresses VI issues at sites under cleanup programs in the DWM
- Always work with the DWM program with oversight, may be supplemental guidance
- UST Section developing separate guidance
- http://portal.ncdenr.org/web/wm/dwm-new-vapor-guidance

ITRC Petroleum VI Guidance Document



- UST Section expected to adopt methodology similar to that detailed in ITRC Petroleum VI
- http://www.itrcweb.org/Guidance/ListDocuments?TopicID=28&SubTopicId=48

DWM VI Screening Levels


DIVISION OF WASTE MANAGEMENT RESIDENTIAL VAPOR INTRUSION SCREENING LEVELS
JUNE 2014

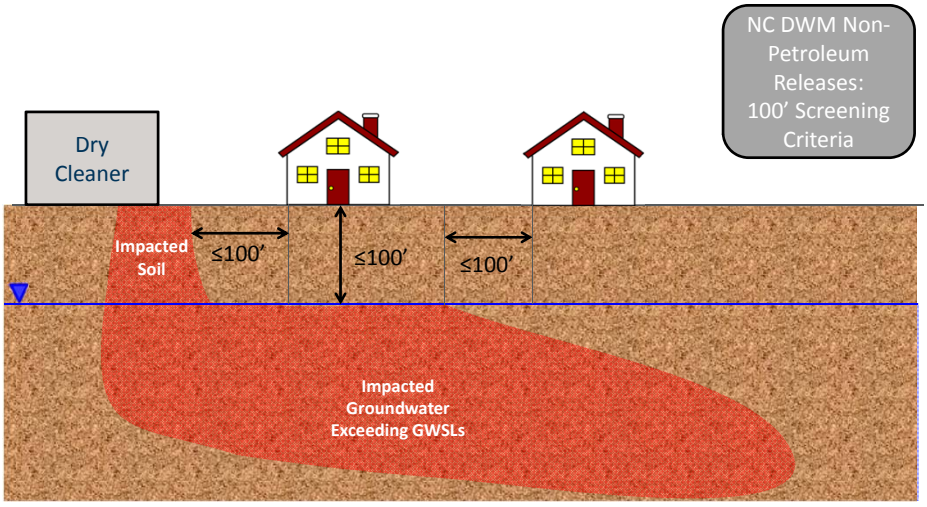
CAS #	Contaminant	Groundwater Screening Level (GWSL) ug/L	Sub Slab and Exterior Soil Gas Screening Level (SGSL) ug/m3	Type A, Type B, Type C	Indoor Air and Crawlspace Screening Level (IASL)[1,2] ug/m3					
		Attenuation Factor (AF) = 0.001	Attenuation Factor (AF) = 0.03							
75-07-0	Acetaldehyde	6.80E+02	6.26E+01	NC	1.28E+00	C	1.86E+00	NC	1.86E+00	NC
67-64-1	Acetone	4.52E+06	2.16E+05	NC	6.47E+03	NC	6.47E+03	NC	6.47E+03	NC
75-86-5	Acetone Cyanohydrin	7.85E+02	3.39E+01	NC	4.17E-01	NC	4.17E-01	NC	4.17E-01	NC
75-05-8	Acetonitrile	8.87E+03	4.17E+02	NC	1.27E+01	NC	1.27E+01	NC	1.27E+01	NC
107-02-8	Acrolein	8.37E-01	1.19E-01	NC	4.17E-03	NC	4.17E-03	NC	4.17E-03	NC
107-13-1	Acrylonitrile	7.32E+01	1.38E+01	C	4.13E-02	C	4.17E-02	NC	4.17E-02	NC
107-05-1	Allyl Chloride	4.64E-01	6.85E+00	NC	2.09E-01	NC	2.09E-01	NC	2.09E-01	NC
75-85-4	Amyl Alcohol, tert-	1.11E+03	2.09E+01	NC	6.26E-01	NC	6.26E-01	NC	6.26E-01	NC
11104-28-2	Aroclor 1221	1.64E+00	1.64E+00	C	4.93E-03	C	4.93E-03	C	4.93E-03	C
11141-16-5	Aroclor 1232	1.64E+00	1.64E+00	C	4.93E-03	C	4.93E-03	C	4.93E-03	C
103-33-3	Azobenzene	1.64E+03	3.02E+01	C	9.06E-02	C	9.06E-01	C	9.06E+00	C
71-43-2	Benzene	1.59E+03	3.20E+02	C	3.60E-01	C	3.60E+00	C	6.26E+00	NC
100-44-7	Benzyl Chloride	3.24E+01	6.85E+00	NC	5.73E-02	C	2.09E-01	NC	2.09E-01	NC
92-52-4	Biphenyl, 1,1-	6.81E+00	1.78E+00	NC	8.34E-02	NC	8.34E-02	NC	8.34E-02	NC
108-60-1	Bis(2-chloro-1-methylethyl) ether	9.26E+02	9.36E+01	C	2.81E-01	C	2.81E+00	C	2.81E+01	C
111-44-4	Bis(2-chloroethyl)ether	1.22E+02	2.86E+00	C	8.51E-03	C	8.51E-02	C	8.51E-01	C
542-88-1	Bis(chloromethyl)ether	2.54E-03	1.51E-02	C	4.53E-05	C	4.53E-04	C	4.53E-03	C
107-04-0	Bromo-2-chloroethane, 1-	1.26E+00	1.56E+00	C	4.68E-03	C	4.68E-03	C	4.68E-03	C
108-86-1	Bromobenzene	1.24E+02	4.17E+02	NC	1.25E+01	NC	3.23E+01	NC	1.25E+01	NC
74-97-5	Bromochloromethane	1.82E+02	2.78E+02	NC	8.34E+00	NC	8.34E+00	NC	8.34E+00	NC
75-27-4	Bromodichloromethane	8.76E+00	2.53E+01	C	7.59E-02	C	7.59E-01	C	7.59E+00	C
74-83-9	Bromomethane	3.48E+00	3.48E+01	NC	1.04E+00	NC	1.04E+00	NC	1.04E+00	NC
106-99-0	Butadiene, 1,3-	1.59E-01	1.59E+01	NC	9.36E-02	C	4.17E-01	NC	4.17E-01	NC
75-15-0	Carbon Disulfide	2.48E+02	4.87E+03	NC	1.46E+02	NC	1.46E+02	NC	1.46E+02	NC
56-23-5	Carbon Tetrachloride	4.15E+00	1.56E+02	C	4.68E-01	C	4.68E+00	C	1.09E+01	NC
75-68-3	Chloro-1,1-difluoroethane, 1-	4.54E+03	3.48E+03	NC	1.04E+04	NC	1.04E+04	NC	1.04E+04	NC
106-99-0	Chloro-1,3-butadiene, 2-	4.08E-03	3.12E+00	C	9.36E-03	C	9.36E-02	C	9.36E-03	C
108-90-7	Chlorobenzene	8.20E+01	3.48E+02	NC	1.04E+01	NC	1.04E+01	NC	1.04E+01	NC
69-34-4	Chlorodanitrifluoride, 4-	4.41E+01	2.09E+03	NC	6.26E+01	NC	6.26E+01	NC	6.26E+01	NC
75-45-6	Chlorodifluoromethane	6.28E+03	3.48E+05	NC	1.04E+04	NC	1.04E+04	NC	1.04E+04	NC
67-66-3	Chloroform	8.14E+00	4.07E+01	C	1.22E+00	C	1.22E+00	C	1.22E+01	C

1. Based on the May 2014 USEPA Regional Screening Level Target Air Concentrations and USEPA VI Calculator.
2. TCR = Target Cancer Risk; THQ = Target Hazard Quotient; C = Carcinogenic; N = Non-Carcinogenic; M = Mutagenic

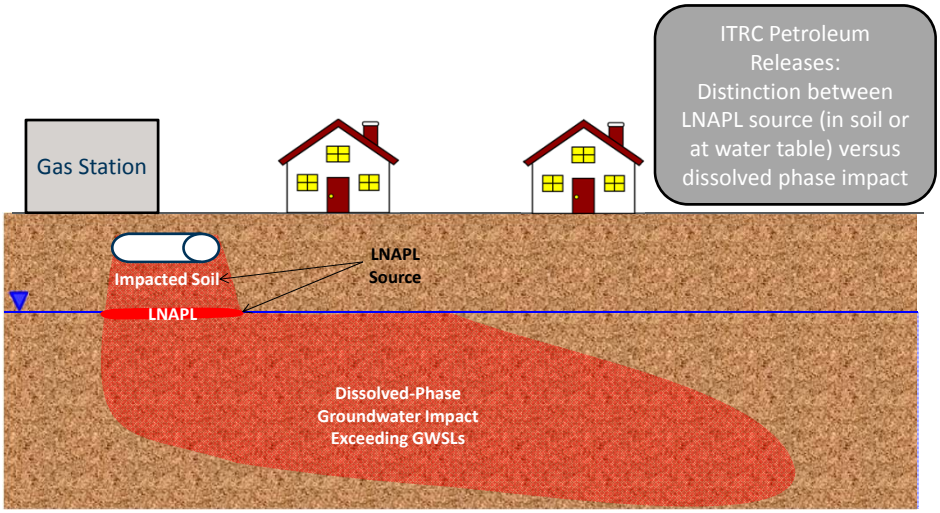
- Two tables – residential and non-residential
- Screening levels for groundwater, soil gas, and indoor air, but <u>not soil</u>

Screening levels updated periodically and posted at http://portal.ncdenr.org/web/wm/dwm-new-vapor-guidance

Is the VI pathway complete for non-petroleum releases?

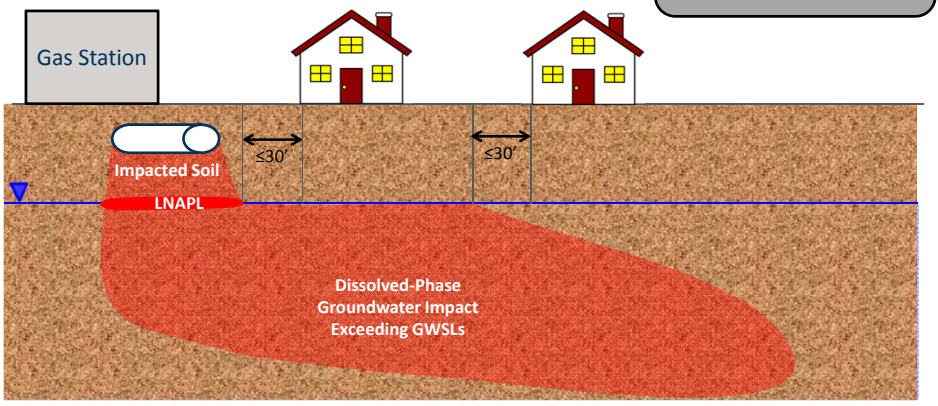


Is the VI pathway complete for petroleum releases?



Is the VI pathway complete for petroleum releases?

ITRC Petroleum Releases:
Lateral Inclusion Zone =
30′

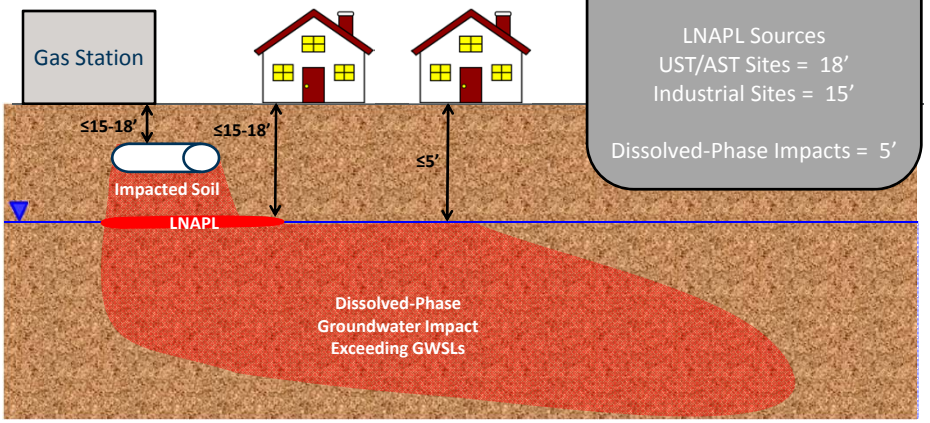


Is the VI pathway complete for petroleum releases?

ITRC Petroleum Releases
Vertical Separation Distance

LNAPL Sources
UST/AST Sites = 18′
Industrial Sites = 15′

Dissolved-Phase Impacts = 5′



How do we assess VI?

Compare groundwater concentrations to GWSLs

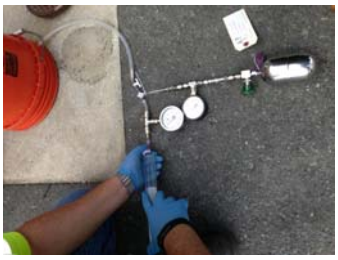
↓

Compare exterior soil gas directly above capillary fringe to SGSLs

→ Compare interior sub-slab gas to SGSLs or crawl space air to IASLs

→ Indoor air sampling as a last resort

An outside-in approach is recommended to avoid concerns with indoor sources and spatial/temporal variability.



How do we assess VI?

Proper sampling protocol is essential for "defensible data"

Soil gas sampling:
- Purge volume
- Purge rate and vacuum
- Tracer gas testing
- Shut-in test

Indoor air sampling:
- Sampling timeframe
- Pre-sampling site recon

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Data Evaluation & Risk Assessment

Carcinogenic Risks

TCR = Individual Excess Lifetime Cancer Risk = Increase over background in an individual's probability of getting cancer over a lifetime due to exposure to a chemical

TCR = 10^{-6} = 1/1,000,000 increased risk of cancer
TCR = 10^{-5} = 1/100,000 increased risk of cancer
TCR = 10^{-4} = 1/10,000 increased risk of cancer

Non-Carcinogenic Risks

HQ = Hazard quotient means the ratio of level of exposure to a chemical of concern over a specified time period to a reference dose for that chemical of concern derived for a similar exposure period

HQ > 1 = Adverse health effects possible
HQ < 1 = Adverse health effects not possible

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Data Evaluation & Risk Assessment

DIVISION OF WASTE MANAGEMENT RESIDENTIAL VAPOR INTRUSION SCREENING LEVELS
JUNE 2014

Page 1 of 4

CAS #	Contaminant	Groundwater Screening Level (GWSL) ug/L	Sub Slab and Exterior Soil Gas Screening Level (SGSL) ug/m3		Indoor Air and Crawlspace Screening Level (IASL)[1,2] ug/m3					
					Indoor Air/Crawlspace Screening Levels at Target Risk 1.0E-04 (IASL C) to be Used if only One Carcinogen is Present					
		GWSL =IASL (B) x 10^{-3} x 1/Henry's Law Constant x 1/AF	SGSL =IASL (B) x 1/AF		IASL (A)		IASL (B)		IASL (C)	
		Attenuation Factor (AF) = 0.001	Attenuation Factor (AF) = 0.03	Cnc & Cng Tox Basis	TCR = 1.0E-06 THQ = 0.2	Tox Basis	TCR = 1.0E-05 THQ = 0.2	Tox Basis	TCR = 1.0E-04 THQ = 0.2	Tox Basis
75-07-0	Acetaldehyde	6.89E+02	6.26E+01	NC	[illegible]	C	[illegible]	NC	[illegible]	NC
67-64-1	Acetone	4.52E+06	2.16E+05	NC	[illegible]	NC	[illegible]	NC	[illegible]	NC
75-86-5	Acetone Cyanohydrin	7.85E+02	1.39E+01	NC	4.17E-01	NC	4.17E-01	NC	4.17E-01	NC
75-05-8	Acetonitrile	8.87E+03	4.17E+02	NC	1.25E+01	NC	1.25E+01	NC	1.25E+01	NC
107-02-8	Acrolein	8.37E-01	1.39E-01	NC	4.17E-03	NC	4.17E-03	NC	4.17E-03	NC
107-13-1	Acrylonitrile	7.32E+01	1.38E+01	C	4.13E-02	C	4.13E-01	C	4.17E-01	NC
[illegible]	[illegible]	[illegible]	[illegible]	NC	[illegible]	NC	[illegible]	NC	[illegible]	NC

NCDENR calculates a IASLs for carcinogenic and non-carcinogenic risks then the lower of the two is listed in the table.

TCR = 10^{-6} THQ = 0.2

TCR = 10^{-5} THQ = 0.2

TCR = 10^{-4} THQ = 0.2

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Data Evaluation & Risk Assessment

NCDENR Acceptable Risk Levels

- **Most programs use the IASLs in the table as a "Tier 1" screening for individual constituents**
- **Refer to your specific program to determine which IASLs are appropriate**
- **Higher levels are acceptable based on a cumulative risk evaluation**

Data Evaluation & Risk Assessment

Indoor Air Screening Levels
Residential Non-Carcinogenic Equation

Indoor Air Screening Level OR Concentration

Target Hazard Quotient OR Calculated Risk

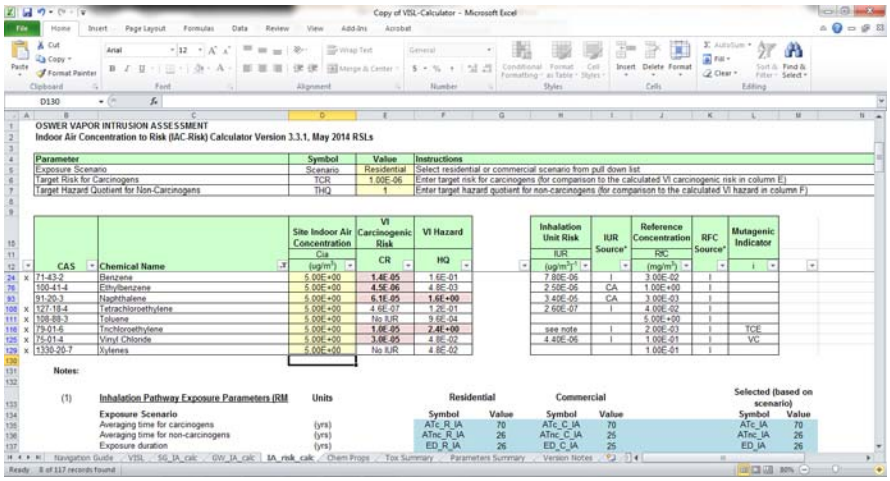
$$IASLnc = \frac{THQ \times ED}{EF \times ED \times ET \times \frac{1}{RfC}}$$

ET = Exposure Time = 26 yrs
ED = Exposure Duration = 350 days/yr
EF = Exposure Frequency = 24 hrs/day

RfC = Reference Concentration = Chemical specific toxicity value

Data Evaluation & Risk Assessment

EPA VI Calculator -
http://www.epa.gov/oswer/vaporintrusion/guidance.html



OSWER VAPOR INTRUSION ASSESSMENT
Indoor Air Concentration to Risk (IAC-Risk) Calculator Version 3.3.1, May 2014 RSLs

Parameter	Symbol	Value	Instructions
Exposure Scenario	Scenario	Residential	Select residential or commercial scenario from pull down list
Target Risk for Carcinogens	TCR	1.00E-06	Enter target risk for carcinogens (for comparison to the calculated VI carcinogenic risk in column E)
Target Hazard Quotient for Non-Carcinogens	THQ	1	Enter target hazard quotient for non-carcinogens (for comparison to the calculated VI hazard in column F)

CAS	Chemical Name	Site Indoor Air Concentration Cia (ug/m³)	VI Carcinogenic Risk CR	VI Hazard HQ	Inhalation Unit Risk IUR (ug/m³)⁻¹	IUR Source*	Reference Concentration RfC (mg/m³)	RFC Source*	Mutagenic Indicator I
71-43-2	Benzene	5.00E+00	1.4E-05	1.6E-01	7.80E-06	I	3.00E-02	I	
100-41-4	Ethylbenzene	5.00E+00	4.5E-06	4.8E-03	2.50E-06	CA	1.00E+00	I	
91-20-3	Naphthalene	5.00E+00	6.1E-05	1.6E+00	3.40E-05	CA	3.00E-03	I	
127-18-4	Tetrachloroethylene	5.00E+00	4.6E-07	1.2E-01	2.60E-07	I	4.00E-02	I	
108-88-3	Toluene	5.00E+00	No IUR	9.6E-04			5.00E+00	I	
79-01-6	Trichloroethylene	5.00E+00	1.0E-05	2.4E+00	see note	I	2.00E-03	I	TCE
75-01-4	Vinyl Chloride	5.00E+00	3.0E-05	4.8E-02	4.40E-06	I	1.00E-01	I	VC
1330-20-7	Xylenes	5.00E+00	No IUR	4.8E-02			1.00E-01	I	

Notes:

(1) Inhalation Pathway Exposure Parameters (RM)

Exposure Scenario	Units	Residential Symbol	Residential Value	Commercial Symbol	Commercial Value	Selected (based on scenario) Symbol	Selected (based on scenario) Value
Averaging time for carcinogens	(yrs)	ATc_R_IA	70	ATc_C_IA	70	ATc_IA	70
Averaging time for non-carcinogens	(yrs)	ATnc_R_IA	26	ATnc_C_IA	25	ATnc_IA	26
Exposure duration	(yrs)	ED_R_IA	26	ED_C_IA	25	ED_IA	26

Data Evaluation & Risk Assessment

Cumulative Carcinogenic Risk

Carcinogenic risk ≥ 10^{-4} or Hazard index ≥ 1	Mitigate Immediately
Carcinogenic risk 10^{-4} to 10^{-6} or Hazard index 0.2 to 1	More monitoring, depends on regulatory program and professional judgment
Carcinogenic risk ≤10^{-6} or Hazard index < 0.2	Usually NFA

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Data Evaluation & Risk Assessment

When to mitigate?

How many sampling events to conclude VI is not a concern?

Professional judgment is key. Use multiple lines of evidence approach.

How do we mitigate VI?

For existing structures, most common mitigation methods include:

- Sub-slab or submembrane depressurization
- HVAC system adjustments
- Sealing floor cracks and penetrations

For many structures, mitigation systems similar to those used to address radon concerns are effective and inexpensive.

How do we mitigate VI?

For new construction, most common mitigation methods include:

- Vapor barrier
- Active or passive venting in combination with vapor barrier
- Vapor barriers may be geomembrane or spray-on.

The vapor barriers used for VI mitigation are thicker than traditional vapor barriers and sealing of all penetrations is crucial.

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Case Studies
$2.50 Krystal Cleaners, Winston-Salem, NC

Use of Radon to Evaluate VI Vs Indoor Sources

Spices of India	$2.50 Krystal Cleaners (drop-off/pick-up)	Kim's Alterations
IA PCE IA: 20 µg/m³ SS PCE: 540 µg/m³ PCE SAF: 0.04	IA PCE IA: 76 µg/m³ SS PCE: 270 µg/m³ PCE SAF: 0.3	IA PCE IA: 110 µg/m³ SS PCE: 38 µg/m³ PCE SAF: 3

SAF = Slab Attenuation Factor = Indoor Air Concentration ÷ Sub-Slab Soil Gas Concentration
IA = Indoor Air, SS = Sub Slab Soil Gas, Lower SAF = More VI, Higher SAF = Less VI

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IA Radon: 129 pCi/L SS Radon: 0.23 pCi/L Radon SAF: 0.002	IA Radon: 131 pCi/L SS Radon: 0.15 pCi/L Radon SAF: 0.001	IA Radon: 97 pCi/L SS Radon: 0.73 pCi/L Radon SAF: 0.008

SAF = Slab Attenuation Factor = Indoor Air Concentration ÷ Sub-Slab Soil Gas Concentration
IA = Indoor Air, SS = Sub Slab Soil Gas, Lower SAF = More VI, Higher SAF = Less VI

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$2.50 Krystal Cleaners, Winston-Salem, NC

Use of Radon to Evaluate VI Vs Indoor Sources

Spices of India	$2.50 Krystal Cleaners (drop-off/pick-up)	Kim's Alterations
IA PCE IA: 20 µg/m³ SS PCE: 540 µg/m³ PCE SAF: 0.04	IA PCE IA: 76 µg/m³ SS PCE: 270 µg/m³ PCE SAF: 0.3	IA PCE IA: 38 µg/m³ SS PCE: 110 µg/m³ PCE SAF: 3
IA Radon: 129 pCi/L SS Radon: 0.23 pCi/L Radon SAF: 0.002	IA Radon: 131 pCi/L SS Radon: 0.15 pCi/L Radon SAF: 0.001	IA Radon: 97 pCi/L SS Radon: 0.73 pCi/L Radon SAF: 0.008
SS PCE x Radon SAF = Predicted PCE Associated with VI = 1.08 µg/m³	SS PCE x Radon SAF = Predicted PCE Associated with VI = 0.27 µg/m³	SS PCE x Radon SAF = Predicted PCE Associated with VI = 0.88 µg/m³

SAF = Slab Attenuation Factor = Indoor Air Concentration ÷ Sub-Slab Soil Gas Concentration
IA = Indoor Air, SS = Sub Slab Soil Gas, Lower SAF = More VI, Higher SAF = Less VI

Case Studies
WP Ballard, Durham, NC

Former Solvent Distribution Facility/ Current Auto Repair Shop

Clearly indoor sources…

Case Studies
WP Ballard, Durham, NC

But also clearly substantial VI…including in office space.

Concentrations in µg/m³

Max Indoor Air
PCE 870
TCE 5.4
cis-1,2-DCE 2.1
VC 0.339

Max Sub-Slab
PCE 9,200,000
TCE 87,000
cis-1,2-DCE 43,000
VC 3,300

Cis-1,2-dichloroethylene (DCE) is uncommon in indoor sources and can be used to evaluate slab attenuation factor similar to radon.

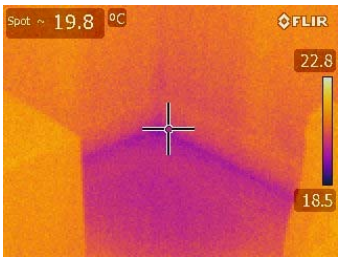
Slab Attenuation Factors
PCE 9E-05
TCE 6E-05
cis-1,2-DCE 5E-05
VC 1E-04

Case Studies
WP Ballard, Durham, NC

Mitigation difficult due to absence of gravel sub base under slab

Installed sub-slab extraction points and collected vacuum radius of influence measurements in the field until achieved negative vacuum throughout building. Also sealed cracks in concrete floor slab. Attributed any remaining impacts to indoor sources.

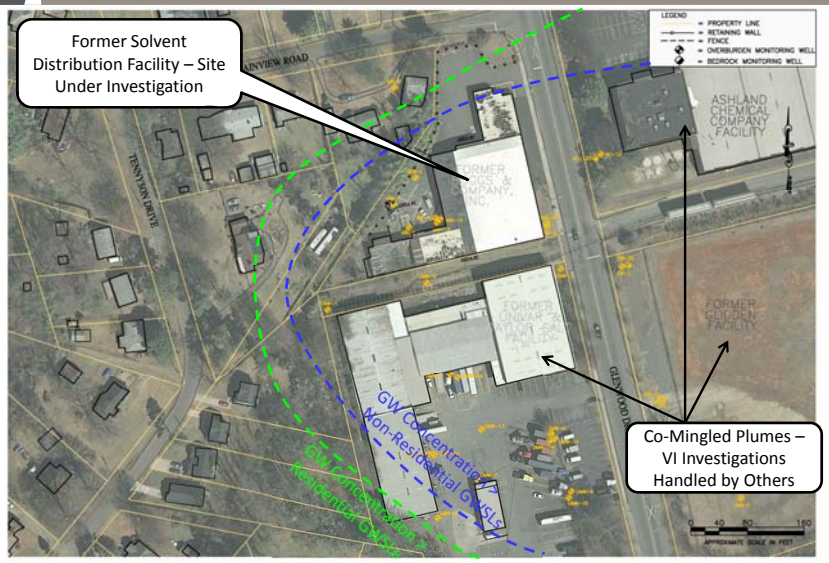
Case Studies
A Cleaner World, Jamestown, NC



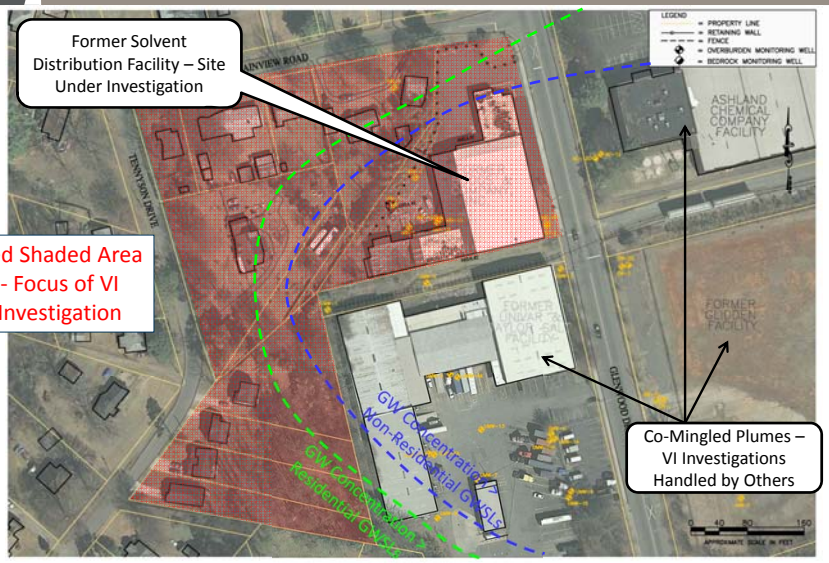
Thermographic camera can be used to identify points of air exchange between building spaces so these points can then be sealed off.

Cardno
Shaping the Future

Case Studies
Boggs & Company, Charlotte, NC

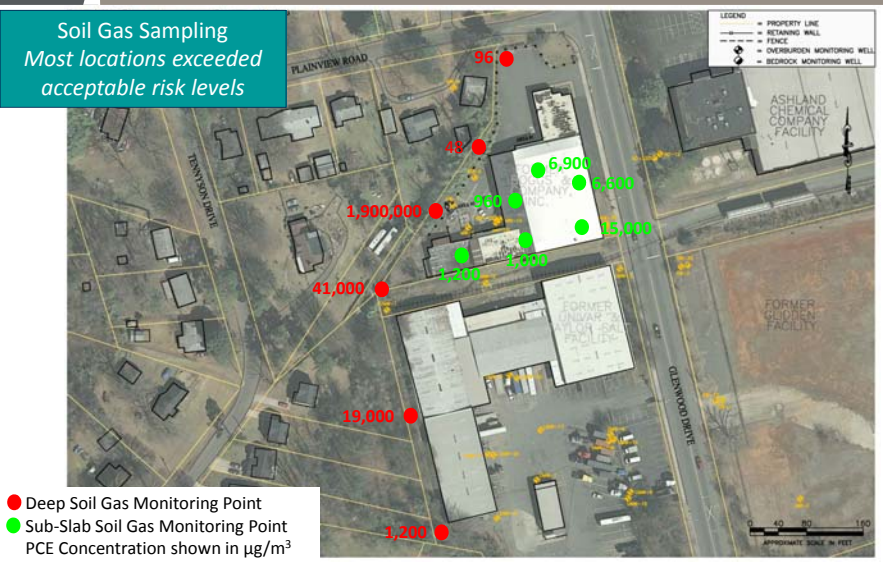


Case Studies
Boggs & Company, Charlotte, NC



Case Studies
Boggs & Company, Charlotte, NC

Soil Gas Sampling
Most locations exceeded acceptable risk levels

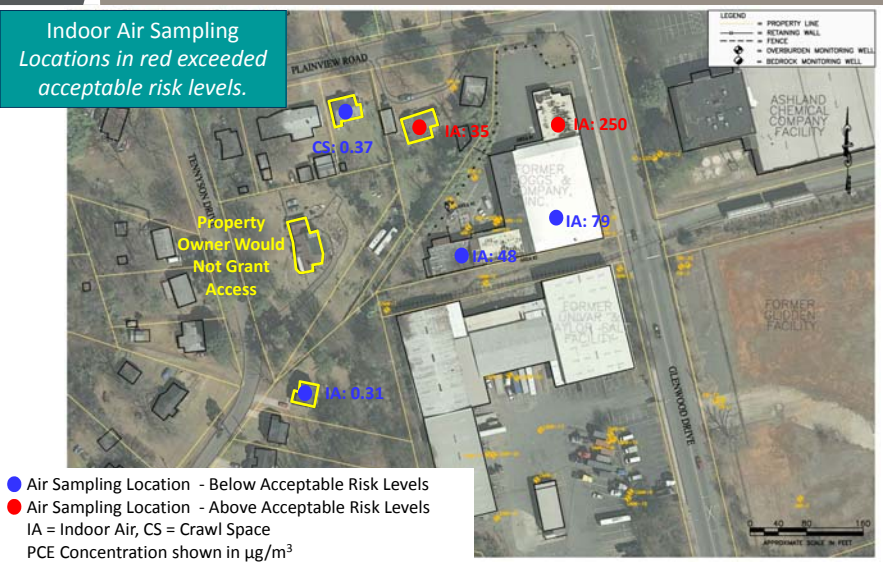


- Deep Soil Gas Monitoring Point
- Sub-Slab Soil Gas Monitoring Point

PCE Concentration shown in µg/m³

Case Studies
Boggs & Company, Charlotte, NC

Indoor Air Sampling
Locations in red exceeded acceptable risk levels.

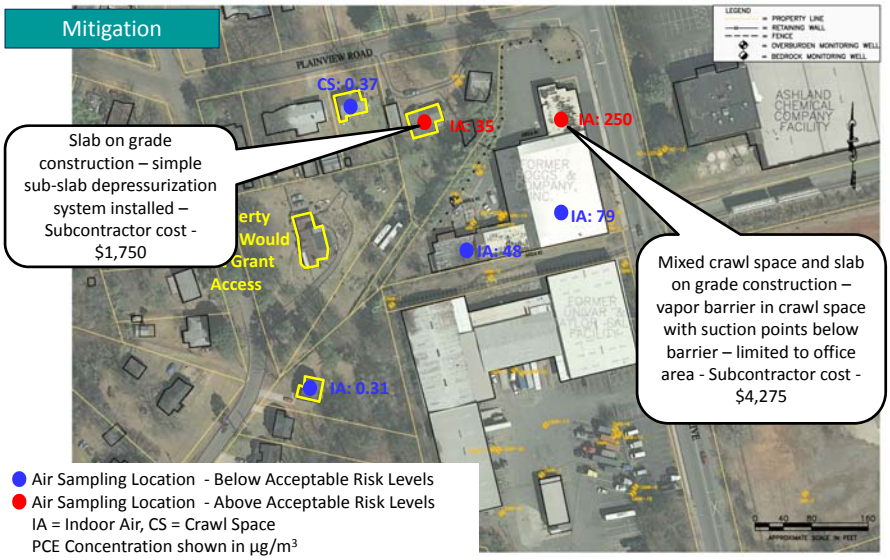


- Air Sampling Location - Below Acceptable Risk Levels
- Air Sampling Location - Above Acceptable Risk Levels

IA = Indoor Air, CS = Crawl Space
PCE Concentration shown in µg/m³

Case Studies
Boggs & Company, Charlotte, NC

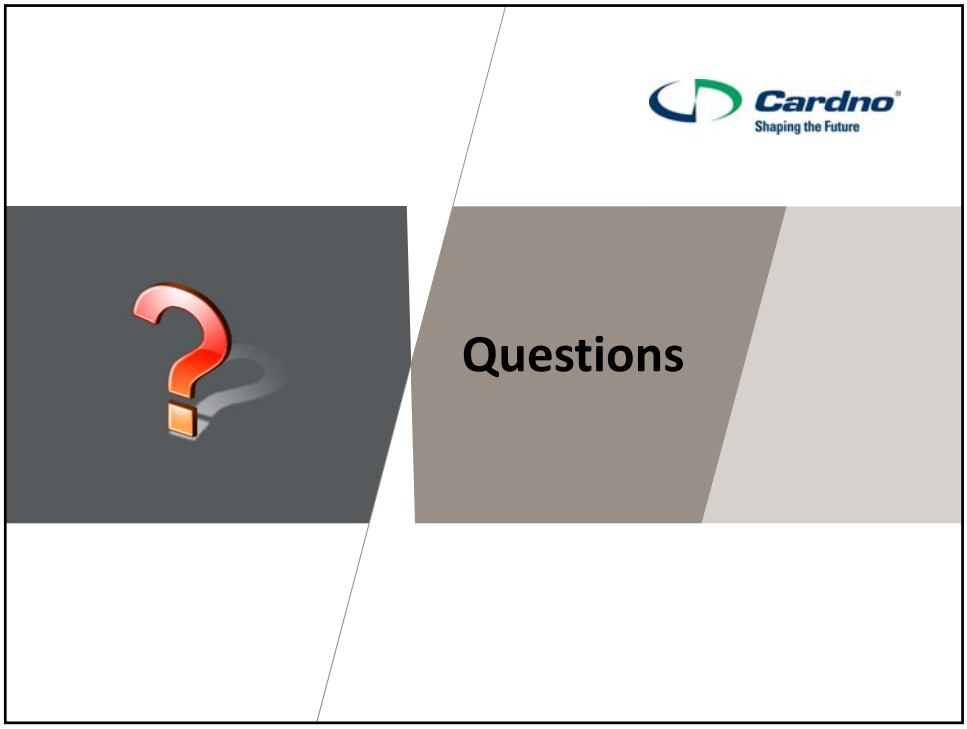
Mitigation



Case Studies
Boggs & Company, Charlotte, NC

View of vapor mitigation system in on-site building.

Post-mitigation indoor air samples indicated concentrations reduced to below acceptable risk levels. Semiannual (summer/winter) indoor air sampling to monitor concentrations.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Questions