Four Winters of Continuous Vapor Intrusion Monitoring In Indianapolis – Temporal Variability in Indoor Air

Presented at EPA 2014 workshop on Vapor Intrusion (VI) Exposures – The Challenges, Need for, & Benefits of Long-Term Stewardship

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- ARCADIS Inc.
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- US EPA National Exposure Research Laboratory
Robert Truesdale and Robert Norberg
- RTI International
Specific Questions

(1) On what time scales does indoor air (and soil gas) temporal variability occur and how does this affect long term stewardship? Sampling strategies?

(2) How can we best characterize the upper tail of the temporal distribution for short term exposure and risk management? Are there cost-effective surrogates?

(3) Is temporal variability controlled by subslab depressurization systems?

(4) Do we understand why temporal variability happens? (which would allow us to pick worst case sampling dates)
Study Design

Indoor and Ambient Air, Passive Samples

- 7 locations: 1 ambient; 2 basement, 1 first floor on each side of 1915 duplex
- 95+ weeks of VOC sampling: (Jan 2011-Jan 2014): VOCs by Radiellos, radon by electrets (7-day);

Subslab and Soil Gas, Active Samples

- Five internal soil gas locations, 4 depths each (6, 9, 13, 16.5 ft).
- Five conventional sub-slab locations.
- Four basement wall ports.
- Weekly sampling for VOCs, TO-17 at 45+ locations; Alphaguard radon @ shallow ports
Only very recently has chloroform been detected in groundwater at concentrations equivalent through Henry’s law to some of our highest deep soil gas concentrations.

There may be fresh/intermittent sources of chloroform; combined sewers, drinking water mains or chloroform mass stored in the vadose zone from a historic release.

Chloroform levels observed in GW lower then those in Indianapolis drinking water.

For PCE, the results indicate a relatively constant groundwater source, so groundwater variation doesn’t explain indoor air variability.

Tracer tests show advective movement from 13’ bls exterior to subslab (6’ bls) in a few days.
Why Might Temporal Variability Occur? Meteorology

- Indoor/Outdoor T Differential 0°C to >40°C
- Diurnal, seasonal and climatological cycles
- Wind loads on building walls can be up to 50 Pa

Sources: www.city-data.com http://mesonet.agron.iastate.edu
Why Might Temporal Variability Occur? Hydrogeology

Duplex’s depth to water is 10.5 to 18.5 ft, with variations depending on Fall Creek discharge. Major Floods can occur in Winter or Spring.
How Much Temporal Variability Did We Experience?

**Indoor Air Radon**
- Radon Concentration (pCi/L)
- Data from Jan-11 to Jan-14
- Symbols represent different sources:
  - 422 First Rn
  - 422 Base S Rn
  - 422 Base N Rn
- Ambient Rn

**Indoor Air PCE**
- PCE Concentration (µg/m³)
- Data from Jan-11 to Jan-14
- Symbols represent different sources:
  - 422 First PCE
  - 422 Base S PCE
  - 422 Base N PCE
- Ambient PCE
**Subslab Port PCE**

<table>
<thead>
<tr>
<th>Date</th>
<th>SSP-1 PCE</th>
<th>SSP-2 PCE</th>
<th>SSP-3 PCE</th>
<th>SSP-4 PCE</th>
<th>SSP-5 PCE</th>
<th>SSP-6 PCE</th>
<th>SSP-7 PCE</th>
<th>SSP-8 PCE</th>
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Concentration (µg/m³)
Subslab Port Chloroform

<table>
<thead>
<tr>
<th>Date</th>
<th>Concentration (µg/m³)</th>
<th>SSP-1 CHCl3</th>
<th>SSP-2 CHCl3</th>
<th>SSP-3 CHCl3</th>
<th>SSP-4 CHCl3</th>
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Mitigation On
Mitigation Passive
## Winter to Winter Comparison

### Indoor Air

#### 422 Basement South - January

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<tr>
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<th>Screening Level</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
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</thead>
<tbody>
<tr>
<td>Radon (pCi/L)</td>
<td>4</td>
<td>9.4</td>
<td>8.8</td>
<td>9.5/3.6**</td>
<td>9.35</td>
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<tr>
<td>PCE (µg/m³)</td>
<td>4.2</td>
<td>11.4</td>
<td>0.89</td>
<td>2.1/0.7**</td>
<td>0.606</td>
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<td>Chloroform (µg/m³)</td>
<td>0.11</td>
<td>1.2</td>
<td>0.7</td>
<td>0.69/0.29**</td>
<td>0.798</td>
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#### 422 First Floor - January

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<th>2013</th>
<th>2014</th>
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<tbody>
<tr>
<td>Radon (pCi/L)</td>
<td>4</td>
<td>5.3</td>
<td>4.4</td>
<td>4.1/1.6**</td>
<td>4.56</td>
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<tr>
<td>PCE (µg/m³)</td>
<td>4.2</td>
<td>5.8</td>
<td>0.43</td>
<td>0.94/0.3**</td>
<td>0.314</td>
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<tr>
<td>Chloroform (µg/m³)</td>
<td>0.11</td>
<td>0.65</td>
<td>0.3</td>
<td>0.38/0.22**</td>
<td>0.404</td>
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**VOCs - residential RSL 10-6 Nov 2013**

**Mitigation Off/On**
## Winter to Winter Comparison Sub-slab

### 422 Sub-Slab - December

<table>
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<tr>
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<th>2010</th>
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<th>2012</th>
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<tr>
<td>Chloroform</td>
<td>27</td>
<td>180</td>
<td>NA/207**</td>
<td>49</td>
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<tr>
<td>Radon</td>
<td>1265</td>
<td>1253/569**</td>
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<td>Tetrachloroethene</td>
<td>90</td>
<td>202</td>
<td>NA/493**</td>
<td>131</td>
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### 422 Sub-Slab - January

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<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
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</thead>
<tbody>
<tr>
<td>Chloroform</td>
<td>105</td>
<td>133</td>
<td>71</td>
<td>49</td>
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<tr>
<td>Radon</td>
<td>1179</td>
<td>1184</td>
<td>1240</td>
<td>1212</td>
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<tr>
<td>Tetrachloroethene</td>
<td>591</td>
<td>230</td>
<td>341</td>
<td>36</td>
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How Different Were These Winters?
How Different Were These Winters?

Indianapolis International Airport - Monthly Temperature Summaries for January in Successive Years

- Extreme maximum temperature for month (°F)
- Extreme minimum temperature for month (°F)
- Mean monthly maximum temperature, degree F
- Monthly Mean Minimum Temperature, degree F
- Monthly Mean Temperature, degree F
If sampled once in every season, 63% chance of getting at least one sample above true mean. 96% chance that sample mean would be between 0.5 and 5.2 \( \mu g/m^3 \).

If sampled twice in winter, 65% chance of getting one sample above the true mean. 82% chance that sample mean would be between 0.5 and 5.2 \( \mu g/m^3 \).
Distribution of Week Long Chloroform Indoor Air Data Set – 422 Basement South

- If sampled once in every season, 88% chance of getting at least one sample above true mean. 99.7% chance that sample mean would be between 0.17 and 1.68 µg/m³.
- If sampled twice in winter, 91% chance of getting one sample above the true mean. 100% chance that sample mean would be between 0.17 and 1.68 µg/m³.

102 samples, only 2 ND

Current RSL 0.11 µg/m³
Diagnostics with all four suction pits activated, ten temporary pressure ports, in October:
1) -.092” (22 Pa), 2) -.089”, 3) -.046”, 4) -.046” (11 Pa), 5) -.009”, 6) -.065”, 7) -.066”, 8) -.040”, 9) -.035”, 10) -.006” (1.4 Pa)

Radon Away RP265 fan:
91-129 Watts (≈0.15 HP)
Max. Pressure 2.3” WC Fan
Curve:
247 CFM at 0.5” (124 Pa)
176 CFM at 1” (249 Pa)
50 CFM at 2” (498 Pa)
Effect of Mitigation on Indoor VOCs

- For the 7 months of on/off mitigation system testing
- Radon reduced 91%
- Radon consistently below 2 pCi/l
- Chloroform reduction 68%
- PCE reduced 61%
The Degree of Temporal/Spatial Variability Varies with Depth of Sample
## Effect Of Mitigation at Wall Port-3 PCE

<table>
<thead>
<tr>
<th>Mitigation</th>
<th>Heating</th>
<th>Number Samples</th>
<th>Mean</th>
<th>SD</th>
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</thead>
<tbody>
<tr>
<td>Not Installed</td>
<td>Off</td>
<td>14</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Not Installed</td>
<td>On</td>
<td>36</td>
<td>38</td>
<td>88</td>
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<tr>
<td>On</td>
<td>On</td>
<td>6</td>
<td>178</td>
<td>228</td>
</tr>
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</table>

- Limited pressure data suggests that SSD beneath the floor did not provide depressurization at WP-3.
- SSD did depressurize three other wall ports at the same depth.
- WP-3 has the highest PCE concentration of the wall ports.
Differential Pressure and PCE Show Snow/High Wind Effect With SSD On

420 Differential Pressure Data

420 1st Floor Indoor Air

Differential Pressure and PCE Show Snow/High Wind Effect With SSD On

420 Differential Pressure Data

420 1st Floor Indoor Air

Differential Pressure and PCE Show Snow/High Wind Effect With SSD On
How Much Variability on Short Time Scales With and Without Mitigation?

Data Collected Every 3 Hours with Mitigation Off, On and Passive (many locations)
Mitigation Conclusions

- The mitigation system met conventional depressurization tests and worked well for Radon.
- Immediate VOC reductions in indoor air were observed and were significant overall, but the system only achieved a reduction of just over 60% of VOC.
- During these periods of mitigation system operation, the system was also observed to increase soil gas levels below the slab, behind the basement walls and at depth below the duplex, suggesting that VOCs are being redistributed by mitigation.
- Flux estimates with mitigation on = 114 mg PCE per day for the whole duplex. Much higher then without.
Methods Used to Analyze Data To Determine Drivers for Temporal Variability

- Visual examination of the shape of temporal trends in stacked plots of indoor air and certain soil gas ports over the full project period
- Detailed examination of temporal trends on stacked plots during unusual differential pressure events
- Visual examination of XY graphs and
- Quantitative time series methods.
FROG Field GC (Defiant Technologies, Inc.)

- Multifunctional handheld instrument, tested for routine indoor air monitoring, soil gas, and groundwater.
- Rapid runs (8 min) – one location
- Quick change between media (water/air)
422 South Basement Radon vs. PCE (Alphaguard vs. FROG)

Date

Rn Concentration (pCi/L)

PCE Concentration (µg/m³)

422 Base S PCE
422 Base S Rn

0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

1/31/2014
2/5/2014
2/10/2014
2/15/2014
2/20/2014
2/25/2014
3/2/2014
3/7/2014
FROG GC PCE Data vs. Pressure and Weather Conditions

Pressure (in Hg)
Date
FROG PCE
WP-3 Diff P
Outdoor Pressure
Wind Speed
Wind Direction

PCE (µg/m³)

Wind (degrees)

Wind Speed (mph)

WP-3 DP (Pa)

Date
2/3/2014
2/8/2014
2/13/2014
2/18/2014
2/23/2014
2/28/2014
3/5/2014

FROG PCE
WP-3 Diff P
Outdoor Pressure
Wind Speed
Wind Direction
Effect of Outside Temperature on VOCs is Consistent Across Compounds and Data Sets

Comparing Two Data Sets

PCE Daily Resolution – Field GC Data, Dec 2011 – Feb 2012

PCE Weekly Time Resolution – Passive Sampler Data, Jan 2011 – April 2013
PCE Concentration as a Function of Indoor Humidity
Soil Moisture at 6 ft below land surface – Just below floor

**Chloroform**

**Tetrachloroethene**
Weekly Average Wind Direction vs. PCE Concentration (Radiello)
422 Base South, Mitigation Off or Not Installed Data Only
GC Phase 3 PCE and Chloroform at WP-3 Compared with Wind Speed

Wind Speed (mph)

Chloroform Concentration (µg/m³)

PCE Concentration (µg/m³)

Date

01/14/12
01/24/12
01/03/13
01/13/13
01/23/13
02/02/13
02/12/13
02/22/13
03/04/13
03/14/13

WP-3 GC PCE
WP-3 GC CHCl3
Wind Speed
Mitigation On
Mitigation Passive
a axis
Temporal Variability- Multiple Causes

• Cold temperatures definitely contribute to greater vapor intrusion in this duplex
• Both snowfall and snow/ice accumulation can increase VOC vapor intrusion, although this is complex for VOCs.
• Little evidence of rain effects on VOCs
• Barometric pressure change appears to have effects on radon and probably VOCs, the interactions are complex
• Association between winds from westerly directions with vapor intrusion in the 422 portion of the duplex
• Some of the effects are nonlinear
How Can We Provide Long Term Stewardship Despite Temporal Variability?

• Measure chronic risks with cost effective long-term passive samples? Our results (presented previously) say this has promise for PCE over up to one year sampling durations with a single sample. Current results suggest that just saying “sample in winter for worst case” is too simplistic – long term samples increase the odds of catching the worst case.

• Use mechanistic understandings to select near worst case conditions? Our results say that while there are many factors that cause temporal variability, at least some such as differential temperature are well enough understood to guide the selection of sampling dates.

• Force worst case conditions with fans? Our results say that a fan isn’t always more powerful than mother nature, especially mother nature acting on subsurface conditions over longer time periods then the fan test.
So What Else Can We Do About Temporal Variability?

- Place weight on the least variable lines of evidence (i.e. deeper soil gas?) Suggestion by Johnson, has merit, but requires knowing at what depth the source is and doesn’t fully account for unusual building envelope conditions. Variable water tables can also make deep soil gas variable.

- Use short term monitoring methods (field GCs?) (has promise but the cost needs to come down further)

- Use surrogates (differential pressure? Radon?) to get a handle on the degree of variability for short term risk? Our results suggest that these may be indicative of attenuation across the building envelope but underestimate the total variability.

- Manage buildings differently based on design Buildings without gravel layers beneath floor and behind walls likely display the most complex behavior.
Where Can I Get More Information?

• EPA/600/R-13/241 *Assessment of Mitigation Systems on Vapor Intrusion*, 2013 (release pending)
• EPA/600/R-12/673 *Fluctuation of Indoor Radon and VOC Concentrations Due to Seasonal Variations*, 2012
• Numerous conference presentations on this and other projects at: https://iavi.rti.org/WorkshopsAndConferences.cfm
Acknowledgements

U.S. EPA ORD National Exposure Research Laboratory (NERL)
Blayne Hartman, Hartman Environmental Geosciences
Patrick Lewis, Defiant Technologies Inc.
Leigh Evans, Doressa Breitfield, and Nate Lichti; Mapleton-Fall Creek Development Corporation
Dale Greenwell; EPA NRMRL and Ron Mosley (retired)
Heidi Hayes and Ausha Scott; Air Toxics Ltd.
Rebecca Forbort and Valerie Kull, database; ARCADIS
Breda Munoz, data analysis; RTI
Mike Brenneman, Chris Jordan; Radon Environmental
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919-541-6152

Report of work through Feb 2012 data is available on line:
Radon as a Tool To Estimate Attenuation Factors

- Radon estimates of attenuation factor are generally reasonably accurate across the building envelope.
- Radon predicts poorly from deeper soil gas.
422 Differential Pressure (Deep vs. Shallow and Subslab vs. Basement)

Pressure (Pa)

-60
-40
-20
0
20
40
60
10/13/12
10/23/12
11/2/12
11/12/12
11/22/12
12/2/12
12/12/12
12/22/12
1/1/13
1/11/13
1/21/13
1/31/13
2/10/13
2/20/13

Mitigation On
Passive
Snow
Snow Max 7"
Snow Max 1/4"

- 422 svb (Pa)
- 422 dsgssg (Pa)
Sub-slab and Soil Gas Port Locations – 422 (heated) Side

- **SSP** = conventional sub-slab port (ports installed similarly in basement wall below ground)
- **SGP** = multi-depth soil gas port
  - 6, 9, 13, 16.5 ft bls
  - 6 ft just below basement slab
- **TC** = thermocouple
- **MW** = Monitoring Well
- **MS** = Moisture Sensor
Sub-slab and Soil Gas Port Locations – 420 (unheated) Side

- **SSP** = conventional sub-slab port (ports installed similarly in basement wall below ground)
- **SGP** = multi-depth soil gas port
  - 6, 9, 13, 16.5 ft bls
  - 6 ft just below basement slab
- **TC** = thermocouple
- **MW** = Monitoring Well
- **MS** = Moisture Sensor
Mitigation System-Performance Verification

<table>
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<tr>
<th>Port</th>
<th># of Readings, Dec 29th, 2012</th>
<th>Differential Pressure Range</th>
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<tbody>
<tr>
<td>SSP-1</td>
<td>3</td>
<td>-0.212” to -0.215”</td>
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<tr>
<td>SSP-2</td>
<td>3</td>
<td>-0.029 to -0.032</td>
</tr>
<tr>
<td>SSP-4</td>
<td>3</td>
<td>-0.029 to -0.045</td>
</tr>
<tr>
<td>SSP-5</td>
<td>3</td>
<td>-0.018 to -0.033</td>
</tr>
<tr>
<td>SSP-6</td>
<td>3</td>
<td>-0.035 to -0.038</td>
</tr>
<tr>
<td>SSP-7</td>
<td>7</td>
<td>+0.19 to -0.10</td>
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Building Tested

- Study duplex on 1915 Sanborn Map
- Basement +2 overlying floors
- Unoccupied, unfurnished
- Heated and unheated sides
- Adjacent commercial building - since 1930 – pharmacy, beauty supply, radio, fur, and detector companies

Cracks in basement concrete floor and brick walls

420 Not Heated
422 Heated
Site Setting - Indianapolis

- Temperate climate
- 10 dry cleaners within ¼ mile
- Snow/ice pack varies by winter
- Top 7-8 ft: topsoil, cinders (fill); sandy silty clay loam (till).
- 8-25 ft: sand, gravel, cobbles (very coarse outwash).
- Depth to water (10.5 to 18.5 ft) rapidly fluctuates with nearby creek
Overlay of Log Files 408 (Outdoor Blank), 424 (422Cistern Crack), and 426 (422 Corner Crack)

Blue- Outdoor Sample taken at curb, tailgate of truck
Red- FROG detects 0.9ppbv at 422 Basement Corner Crack S/N=270 (entry point)
Green- FROG detects 0.36ppbv at 422 Basement Cistern Crack S/N=52

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<th>Time (seconds)</th>
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<td>190</td>
<td>325000</td>
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<td>195</td>
<td>330000</td>
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<td>200 (Retention Time and Window)</td>
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<td>350000</td>
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<tr>
<td>220</td>
<td>355000</td>
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How Much Variability Occurs on Short Time Scales?

An Example of VOC Indoor Temporal Variability: Data Points Every 3 Hours vs. Data Averaged over a Week