An update on the draft of
LESSONS FROM RADON FOR VAPOR INTRUSION
RESEARCH AND PROGRAMS

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From an ancient deposit of knowledge, a roughly hewn message emerges.
Two illustrations of tasks where radon may be useful for CVOC programs

• Accurately predicting long-term average indoor gas concentrations for health risk analysis
  – It is easier and less costly to measure radon than CVOCs over a wide range of time periods

• Making good action decisions for effective intrusion control
  – Estimating temporal variation using radon as an intrusion surrogate
  – Collateral benefit of substantial health risks reduction from mitigation in marginal CVOC houses when indoor radon poses a ~1% or greater lifetime risk
Gold standards for radon

- **Health risk:** lifetime average radon gas concentration in occupied spaces
  - Annual average accepted as practical estimate but
  - Even though radon source term is relatively steady, building and occupant factors can change so periodic retesting is advised

- **Intrusion control action:** annual average radon gas concentration in living spaces
  - Decisions are allowed based on shorter term measurements at a single location
The dilemma of spatial and temporal inhomogeneity:
Predicting long term average indoor gas concentrations

BUILDING SPECIFIC ESTIMATES
Production and transport into a building: Spatial and temporal variation

Radon source

- Radium in soil grain decays to Rn
  - Soil moisture: Rn recoil into pore water or re-implanted
  - Temperature: Rn escapes from pore fluid to soil gas

Horizontal and vertical transport towards surface and house

- Concentration driven: Deposit tortuosity
- Pressure driven: Deposit permeability

Entry through soil contact surfaces

- Diffusion through solids
- Flow through voids _ holes

Reference: Nazaroff and Nero 1988

entry, and retention factors

Entry through ground contact surfaces

- Diffusion
  - Bulk concrete (low) Block (high)
  - Cracks, voids, and holes
- Advection
  - Stack, wind, barometric, mechanical imbalance

Distribution within house

- Active (mechanical) and passive (thermal) flow
- Indoor sources (concrete, granite, rocks)

Egress of indoor radon and ingress of outdoor radon

- Neutral pressure plane location variation
- Lifestyle ventilation choices
A gallery of temporal radon variation in my (typical) house

Hourly

Daily

Seasonally

Yearly

Quarterly-average Rn concentration
COV=35%

Year after construction

Annual-average radon concentration
COV=26%
Possible roles for radon as a surrogate for CVOCI

• Potential surrogate for building specific soil gas intrusion
  – Previous Rn_CVOCI research provides *a priori* basis
  – Investigate relationships with simultaneous time-interval matched short-term tracking

• Cost-effective soil gas entry and retention monitoring over a variety of periods:
  – Days: unusual departure periods
  – Months: seasonal effects
  – Years: Structural or inhabitant changes that affect soil entry along CVOC sub-slab monitoring
Lognormal distributions: variation and terminology

- Lognormal distributions
  - Geometric mean (GM) rather than arithmetic mean
  - Geometric Standard Deviation (GSD) is “multiplicative” rather than additive
  - The variation is multiplicative so the 95% confidence interval (CI) spans from GM divided by \((GSD^2)\) to GM multiplied by \((GSD^2)\)

- “Factor of” is used in text and speech to report the GSD

- For the example distribution where GM=0.01 and GSD = 3.2, the text could be:”The attenuation factor varies by a factor of 3.2. or The 95% CI spans two orders of magnitude from 0.001 to 0.1”.

Example Lognormal Distribution with a GM=0.01 and GSD=3.2

AF = Indoor Rn / Subsurface Rn

\(AF = \text{Indoor Rn} / \text{Subsurface Rn}\)
Multiplicative variation factors for building specific predictions of the annual average radon concentrations in living spaces.

<table>
<thead>
<tr>
<th>Prediction for indoor radon based on</th>
<th>Geometric Standard Deviation</th>
<th>95% CI span</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site soil gas</td>
<td>3.2</td>
<td>100X</td>
</tr>
<tr>
<td>Site soil potential</td>
<td>2.4</td>
<td>30X</td>
</tr>
<tr>
<td>Rn in nearby houses</td>
<td>1.7</td>
<td>8X</td>
</tr>
<tr>
<td>Lowest living level Rn measurement</td>
<td>1.6</td>
<td>6X</td>
</tr>
<tr>
<td>Seasonal Rn measurement in home</td>
<td>1.4</td>
<td>4X</td>
</tr>
<tr>
<td>Rn screening measurement in home (2 to 4 days in lowest living level)</td>
<td>1.8</td>
<td>10X</td>
</tr>
</tbody>
</table>
Intrusion control triggers and effective indoor gas concentration reduction

ACTION DECISIONS BASED ON THRESHOLD VALUES AND SHORT TERM MEASUREMENTS
Radon mitigation action

• Action level = 4 pCi/L
  – Decision usually based on short-term screening measurements
  – Lifetime risk at action level ~ 2% lung cancer death

• Diagnostic test performance of decision protocol is poor in radon prone regions
  – Predictive value of a negative test result can be as low as 50%
  – Screening tests results in the range from 1 to 5 pCi/L were inconclusive
Mitigation system effectiveness


- Independent radon measurements of ~140 mitigated homes in Minnesota of mitigation systems 0.5 to 7 years old
- Reduction of about a factor of 10
  - Self reported pre-mitigation average radon = 10 pCi/L
  - Average post-mitigation radon concentration in the living spaces was 0.8 pCi/L (regional outdoor average)
  - only 9% > 2 pCi/L
- Less temporal variation in post-mitigation radon may mean less monitoring needed for CVOCs?
Pre- and Post- mitigation daily average radon variation in my house

Variation of daily- average Rn concentrations
December to July 03-04; 04-05 and 10-11

Notes:
- Daily Rn precision ~3%, 4% and 7%
- COV
  - Pre-mitigation 54% 38%
  - Post-mitigation 14%
- Post-mitigation "events"
  - A: House unoccupied soil thaw with heavy rain
  - B: Heavy rain and tornados
  - C: Hot 90-100F, no vent AC

Mitigation 12/14/2010
Cost effectiveness of lung cancer prevention by radon mitigation

• Mitigation is a cost-effective alternative to medical treatment
  – High risk in radon prone region and widespread exposure leads to large numbers of radon-related lung cancers
  – Roughly half of those deaths could be prevented by mitigation (~1000 per year for the 6 million in IA and MN)
  – The cost per year of life extension using mitigation is only 10% of the direct lung cancer treatment medical costs per year of life extension

• Preemptive mitigation for inconclusive CVOCIs buildings carries a potential health benefit for buildings with elevated radon
Significant revisions to the 2011 draft are underway

Questions please
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