Long term radon predicted from shorter term measurements

Implications for long term stewardship of contaminated sites

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Critical Question

How can we generalize the predictive chemical vapor (CV) concentration variation models generated by the intensive data from two houses to other houses covering long periods of time?
Issues with VI temporal variation model extensions to other houses

- Site and regional factors influence VI variation
- Individual building characteristics cause variation
- Validating CV variation at several hundred homes has technical and resource limits ($ and time)
Outline

• Temporal radon (Rn) research results for potential insight to CV variation
  – Clarification of temporal terms ST, LT, VL
  – Show sample of intensive Rn databases to illustrate similarities to recent CV variation modeling work
  – Short-term measurements predictions for long term Rn
  – Long term measurements predictions for very long term Rn

• Possible implications for CV models and protocols
Terms for VI temporal measurements used for exposure assessment

<table>
<thead>
<tr>
<th>Short-Term (ST)</th>
<th>Typical averaging Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly</td>
<td>1 – 12 hours</td>
</tr>
<tr>
<td>Daily</td>
<td>1 – 90 days</td>
</tr>
</tbody>
</table>

Long-Term (LT)

| Seasonal       | 3 – 6 months              |
| Annual (AA)    | 1 year                    |

Very long term(VL): Stewardship –grade

| 5 – >60 years |
Insights from existing radon research into CV variation

• Elevated indoor Rn is an indicator of soil gas intrusion

• Temporal Rn variation has been studied in hundreds of houses in different climates

• Modelling “stewardship-grade” Rn for cumulative exposure assessment
  – For stewardship we need years-long average Rn (VL)
    • Three studies on multi-year variation of annual average Rn about VL
  – Most current Rn measurements are ST (two days)
    • Four studies of modeling annual average Rn from short term measurement

• Start with ST intensive Rn data from the IN and a MN house
Models from short-term intensive data sets

• Temporal aggregate variation analysis for model development:
  – Hourly .. Daily .. Weekly....Annual Average
  – Favorite Statistics: RANGE or 95%CI range or COV
    • CV: temporal aggregate analysis in SDM (Layton UT house)
    • Rn: Temporal variation of soil gas intrusion and retention AEHS 2013
      – https://iavi.rti.org/WorkshopsAndConferences.cfm?PageID=documentDetails&AttachID=580

• Time series analysis for model development:
  – Variation frequencies and amplitude
  – Need about a total time span that is about six periods before you can estimate the variation
    • Example quarterly variation requires more than a year of hourly data
    • Rn: Temporal variation of soil gas intrusion and retention AEHS 2013
      – https://iavi.rti.org/WorkshopsAndConferences.cfm?PageID=documentDetails&AttachID=580

• Examples : IN and MN houses
Hourly Rn and aggregates in
Indianapolis IN and Collegeville MN houses

3/30/2011 - 3/26/2012 (Indianapolis)

6/29/2003 - 7/22/2005 (Minnesota)

Rn Range (max/min) in Collegeville house during 2 y; hourly ~ 100  daily ~ 10  quarterly ~3  annual ~1.5
Time Series Analysis:
Temporal variation spectra in two houses

IN (1 year)
- Basement: Quarterly +
- First floor: Quarterly +

MN (2 years)
- Walkout basement: Quarterly+

Conclusions:
- temporal behavior of two houses is similar
- Strong monthly and seasonal components
Variation of predictive models based on short and long term measurements

IS THIS VARIATION TYPICAL OF A BROAD SAMPLE OF HOUSES OVER LONGER TIME PERIODS?
## Predicting long term Rn (AA) from ST measurements in broad samples of houses

Regression model statistic $R^2$ (fraction of variation predicted by model)

<table>
<thead>
<tr>
<th>Study</th>
<th>Region homes</th>
<th>Floor</th>
<th>Median Rn (pCi/L)</th>
<th>AA from 2d ST</th>
<th>AA from 7d ST</th>
<th>AA from two 2d ST seasonal</th>
<th>AA from four 2d ST seasonal</th>
</tr>
</thead>
<tbody>
<tr>
<td>White 1994</td>
<td>US 480</td>
<td>LL B &amp; FF</td>
<td>0.8 (US SRRS)</td>
<td>0.61</td>
<td></td>
<td>0.72</td>
<td>0.78</td>
</tr>
<tr>
<td>Barros 2014</td>
<td>IA 189</td>
<td>B</td>
<td>5.1</td>
<td></td>
<td>0.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steck 2005</td>
<td>MN 80</td>
<td>B&amp;FF</td>
<td>4.5</td>
<td>0.41</td>
<td></td>
<td>0.65</td>
<td>0.78</td>
</tr>
</tbody>
</table>

White SB, Alexander BV, Rodman NF. Predicting the annual concentration of indoor 222Rn from one or more short-term measurements. Health Phys. 66:55-62; 1994


Very long term Rn variation in houses
Multiyear AA Rn variation about VL

<table>
<thead>
<tr>
<th>Study Area Reference</th>
<th>Homes</th>
<th>Measured Floors (N)</th>
<th>Years Spanned</th>
<th>AA COV Median (Range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grand Junction CO Martz 1991</td>
<td>25</td>
<td>Basement (13) First Floor (12)</td>
<td>6</td>
<td>25%* (8%-51%)</td>
</tr>
<tr>
<td>Iowa statewide Zhang 2007</td>
<td>61</td>
<td>Basement (47) First Floor (60)</td>
<td>7</td>
<td>19% (0%-110%)</td>
</tr>
<tr>
<td>Minnesota statewide Steck 2009</td>
<td>98</td>
<td>Basement (94) First Floor(99)</td>
<td>6-17</td>
<td>26% 27% (3% -110%)</td>
</tr>
</tbody>
</table>

* Equivalent to a factor of 1.6


About 20% of the MN houses showed persistent increasing or decreasing trends.
In some houses discontinuities occurred when changes were made to the structure, HVAC,...
Summary: year-to-year AA variation

• The median Annual Average radon concentration has a 25% variation about the decade long average radon concentration
  – 25% COV equivalent to a 95%CI factor of 1.6

• Slow trends in source term, climate or building and major changes in structure, HVAC, occupants indicate a need for periodic AA retesting
## Predicting very long (VL)term Rn

Regression statistic \( R^2 \) (percent of variation predicted by model)

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<tr>
<th>Study</th>
<th>Region</th>
<th>Homes</th>
<th>Floor</th>
<th>AA from 2d ST</th>
<th>AA from 7d ST</th>
<th>AA from two 2d ST seasonal</th>
<th>AA from four 2d ST seasonal</th>
<th>VL from 2d ST</th>
<th>VL from AA LT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steck 2009</td>
<td>MN</td>
<td>43</td>
<td>B&amp;FF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>0.49</strong>* (factor of 2.9)</td>
</tr>
<tr>
<td>White 1994</td>
<td>US</td>
<td>480</td>
<td>LL B or FF</td>
<td><strong>0.61</strong></td>
<td><strong>0.72</strong></td>
<td><strong>0.78</strong></td>
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<td>80</td>
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<td></td>
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<td><strong>0.78</strong></td>
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*Measured in 1988

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Temporal Rn variation modelling summary

- VL Rn can be predicted to around 25% in unmodified houses with the same occupants using AA measurements
  - Periodic AA retesting is needed every few years and when changes are made to the building, HVAC, and occupants
  - VL Rn can only be predicted to within a factor of about 3 from ST measurements
  - AA Rn can be predicted from multiple ST measurements only to within a factor of about 2
Issues for using temporal Rn variation as a surrogate for CV variation

• Possible source term differences
  – Parent source concentration relatively stable for Rn, probably not for CV
  – Vapor surface transport variation may differ

• Entry and exchange terms
  – Building structural changes may tap into different “new” pockets depending on source distribution
  – Outdoor air has substantial Rn (~10% to 25% of threshold value) which dampens temporal swings

• Occupant and operation terms
  – Little is known about long term effects of change of occupants or HVAC
Evaluation of temporal measurements for stewardship (VL) exposure assessment

<table>
<thead>
<tr>
<th>Measurement Interval</th>
<th>Useful* for Rn?</th>
<th>Useful* for CV?</th>
</tr>
</thead>
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<tr>
<td><strong>Short-Term (ST)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hourly</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Daily</td>
<td>No</td>
<td>Probably not</td>
</tr>
<tr>
<td>Daily in multiple seasons</td>
<td>Probably not poor correlation</td>
<td>Maybe not? **</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Insufficient research</td>
</tr>
<tr>
<td><strong>Long-Term (LT)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Average</td>
<td>Yes with periodic retests</td>
<td>? Insufficient research</td>
</tr>
</tbody>
</table>

* Useful, if VL exposure risk can be estimated (modeled) well enough to satisfy decision criteria