Vapor Intrusion:
USEPA & the Burden of Proof

North East Waste Management Officials Assoc./Brown Univ.
Providence, RI & West Boston, MA
Sept. 26-27, 2013

This is a scientific paper and is not intended to communicate EPA policy.

Henry Schuver, DrPH
USEPA – HQ-OSWER-RCRA, Washington, DC

See: http://iavi.rti.org and http://epa.gov/oswer/vaporintrusion

Outline

- An analysis of the Burden of Proof
  - Historical approaches to VI
  - Current evidence
  - Issues related to current approaches
  - Observations from similar exposure pathways
    - Groundwater ingestion
    - Radon (gas) intrusion
- Rationale for changing the Burden of Proof for VI
  - How that could work, &
  - 'Pre-emptive' controls to improve: assessment & protection
- Summary & comments
  - Controlling soil gas/vapor intrusion

Brief History of Soil Vapor Intrusion (chemicals*) at USEPA

- Conceptual extrapolation of radon gas intrusion to chemical VOCs (hypotheses Nazzaroff & others ~ 1988)
- 1992 (USEPA) Air/Superfund guidance
  - ~ *if* evaluated, *assume 'incomplete'* exposure pathway *until shown to be complete*
    - Evaluation of VI apparently optional
      - Before 1999 RCRA Environmental Indicator forms
        - » Pathways table w/ indoor air (based on known petroleum VI)
        - » Footnote Re: Colo. DOT site (Not background & low (MCL) levels)

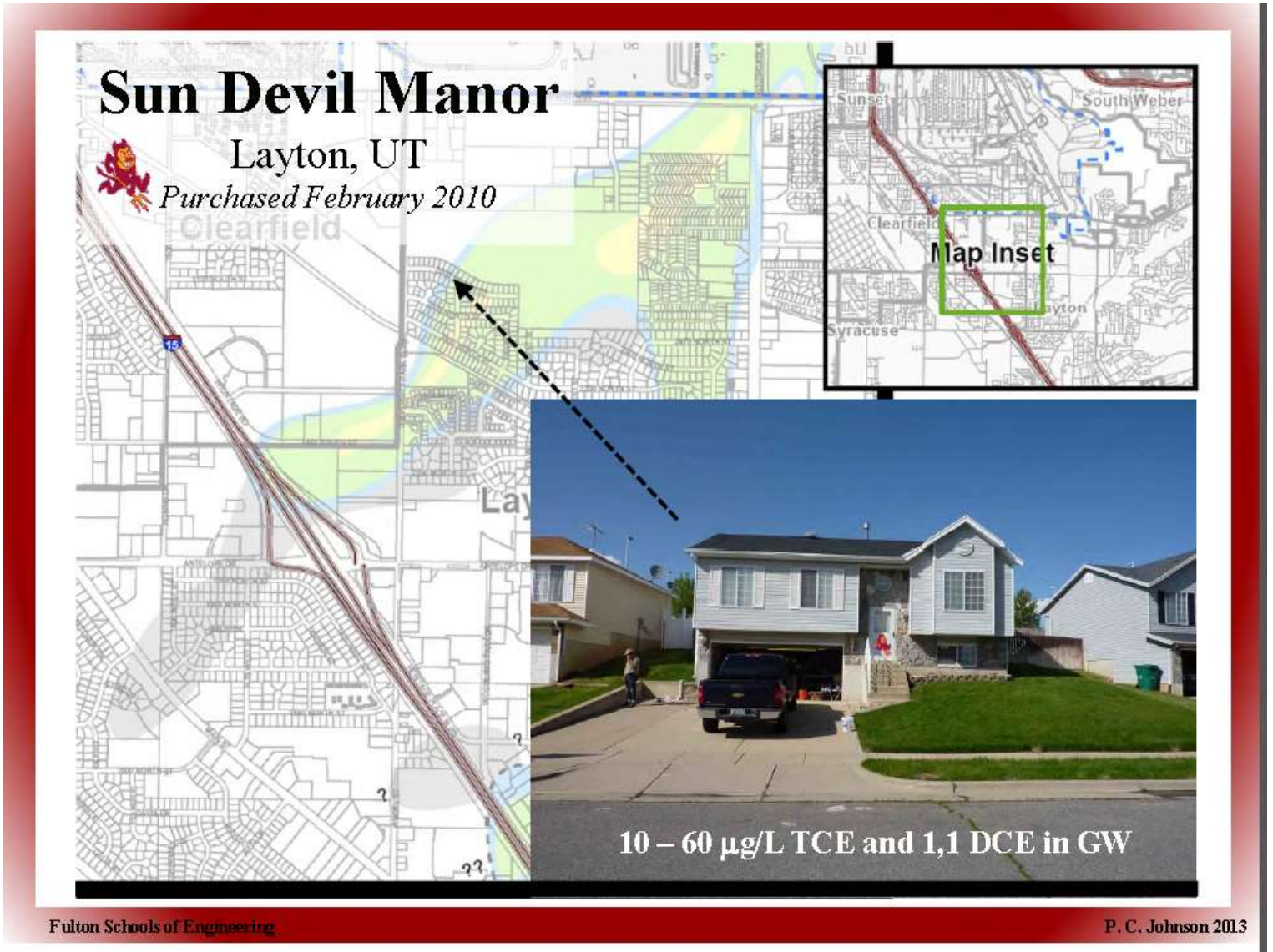
*primarily recalcitrant (e.g., chlorinated), not most petroleum

The Burden of Proof
for Chemical VI (at USEPA)

- Initial Presumptions:
  - VI pathway for human exposure likely incomplete
  - VI *should be* readily observable/predictable
    - E.g., in a 'one-time' assessment (if complete)*
- By 2013 the evidence indicates …
  - After many years of:
    - Modeling - **Groundwater** to est. Indoor Air
    - Grab-Sampling **Exterior Soil Gas** to est. indoor air
    - Grab-Sampling **Sub-Slab Soil Gas** to est. indoor air
    - 24-hr Grab-Sampling **Indoor Air** (& est. indoor sources)

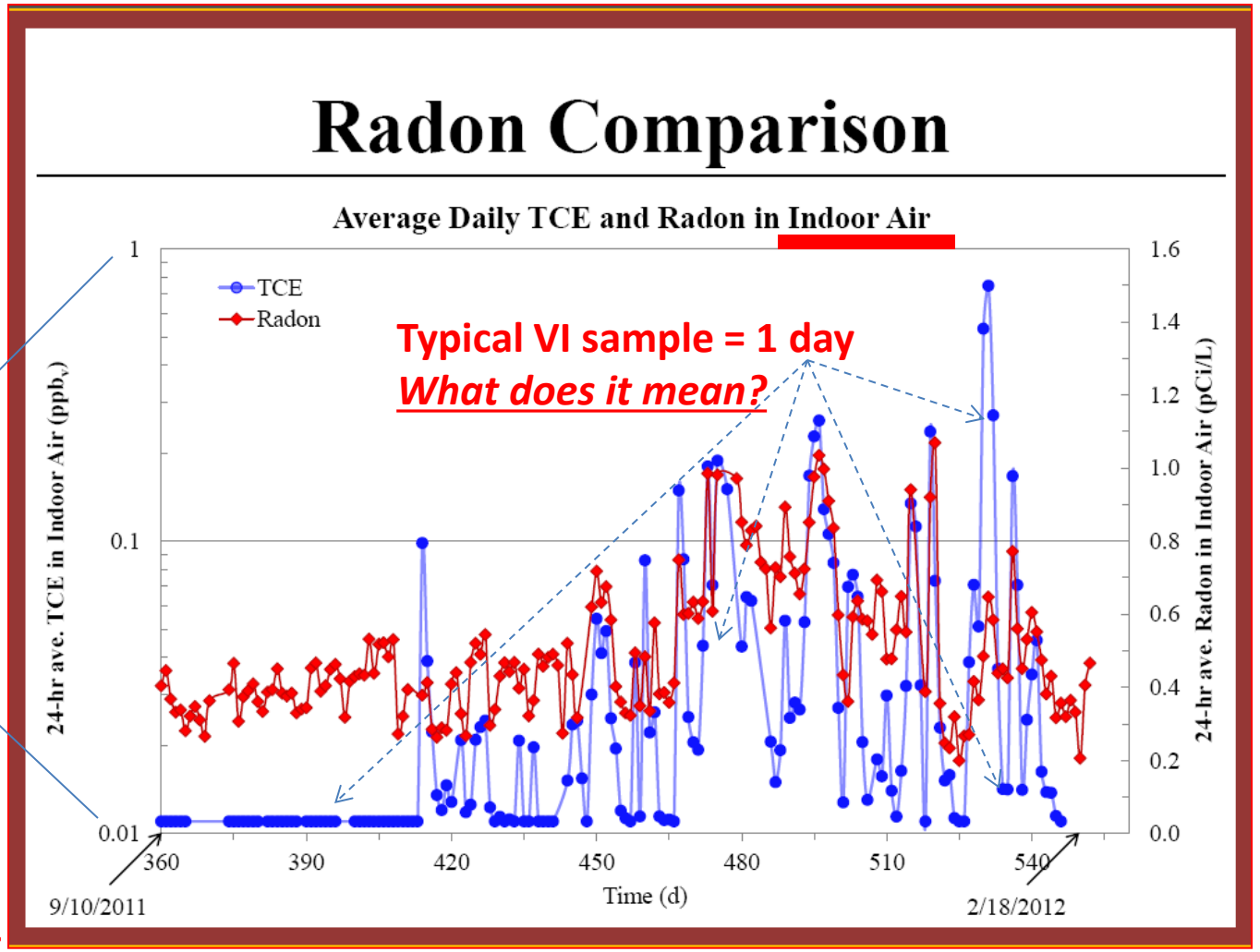
*1992: Air/Superfund guidance: "Assessing Potential Indoor Air Impacts for Superfund Sites"

ASU House presented at AEHS 2013



5 Mo. of Continuous Monitoring (atypical) Shows Soil-Gas/Vapor Intrusion is Variable Across Time

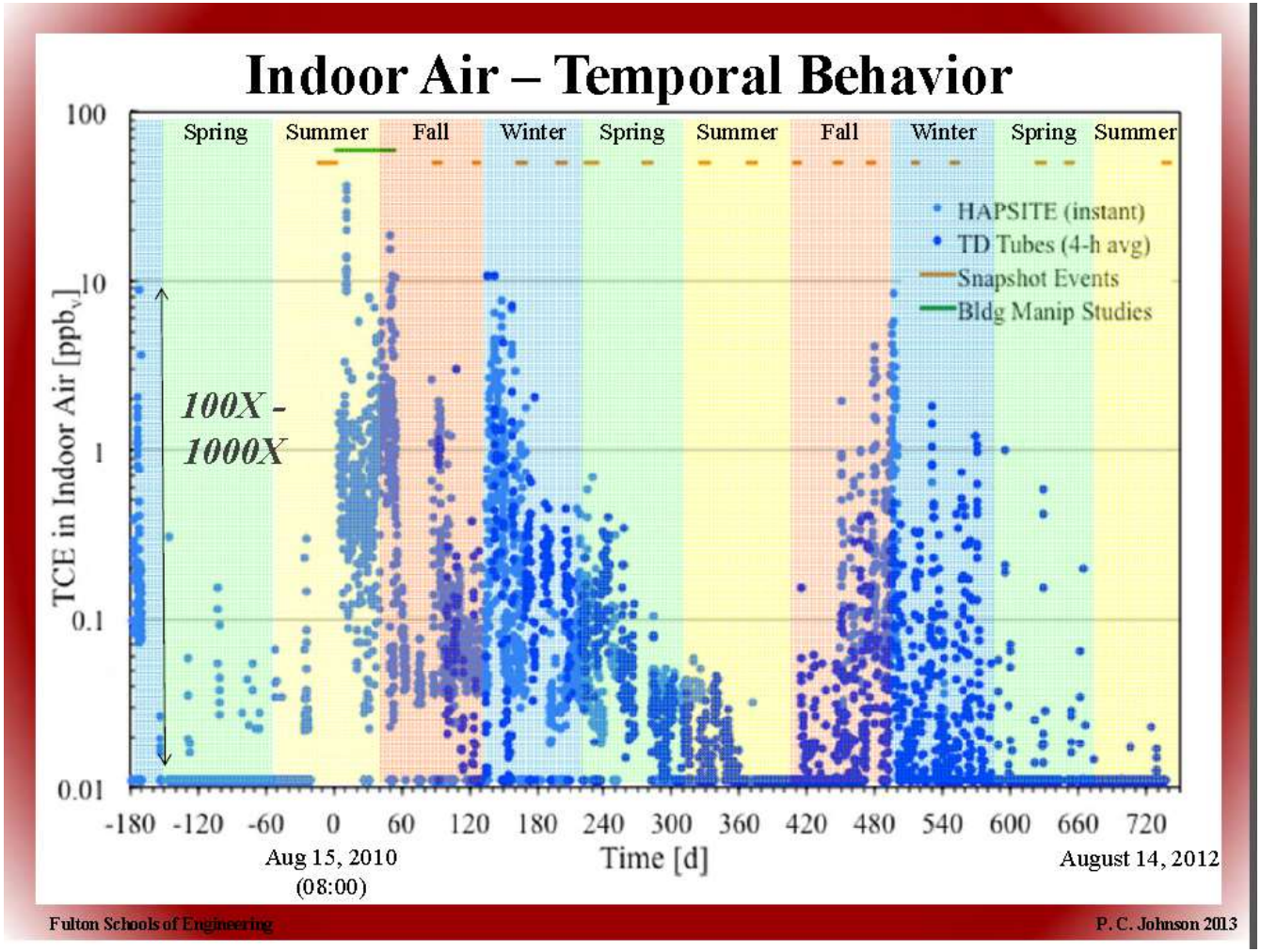
100x (over 5 mon.)



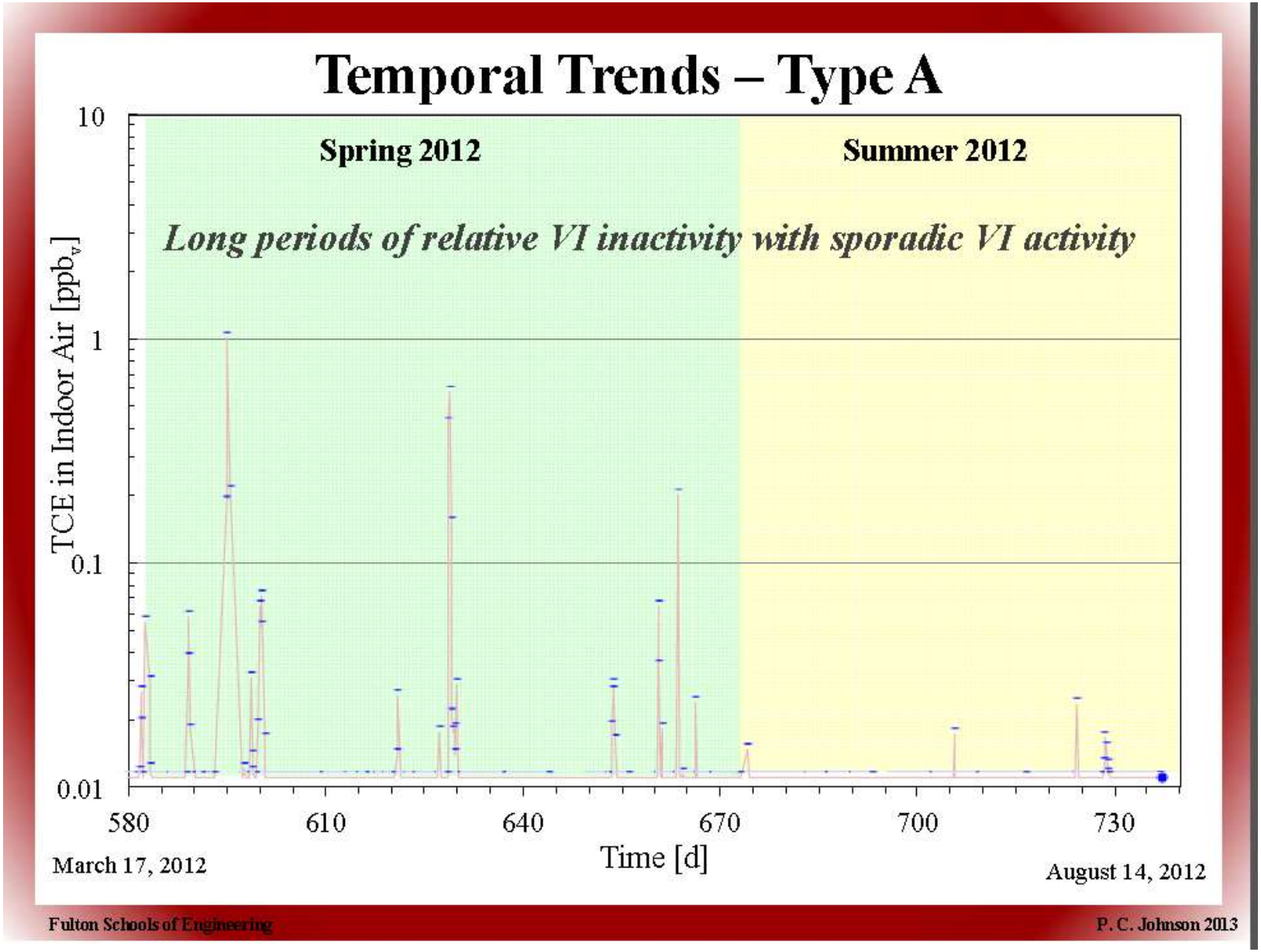
Red text added to:

https://iavi.rti.org/attachments/WorkshopsAndConferences/02_Holton_Weather-Temporal-Variation-3-22-2012.pdf

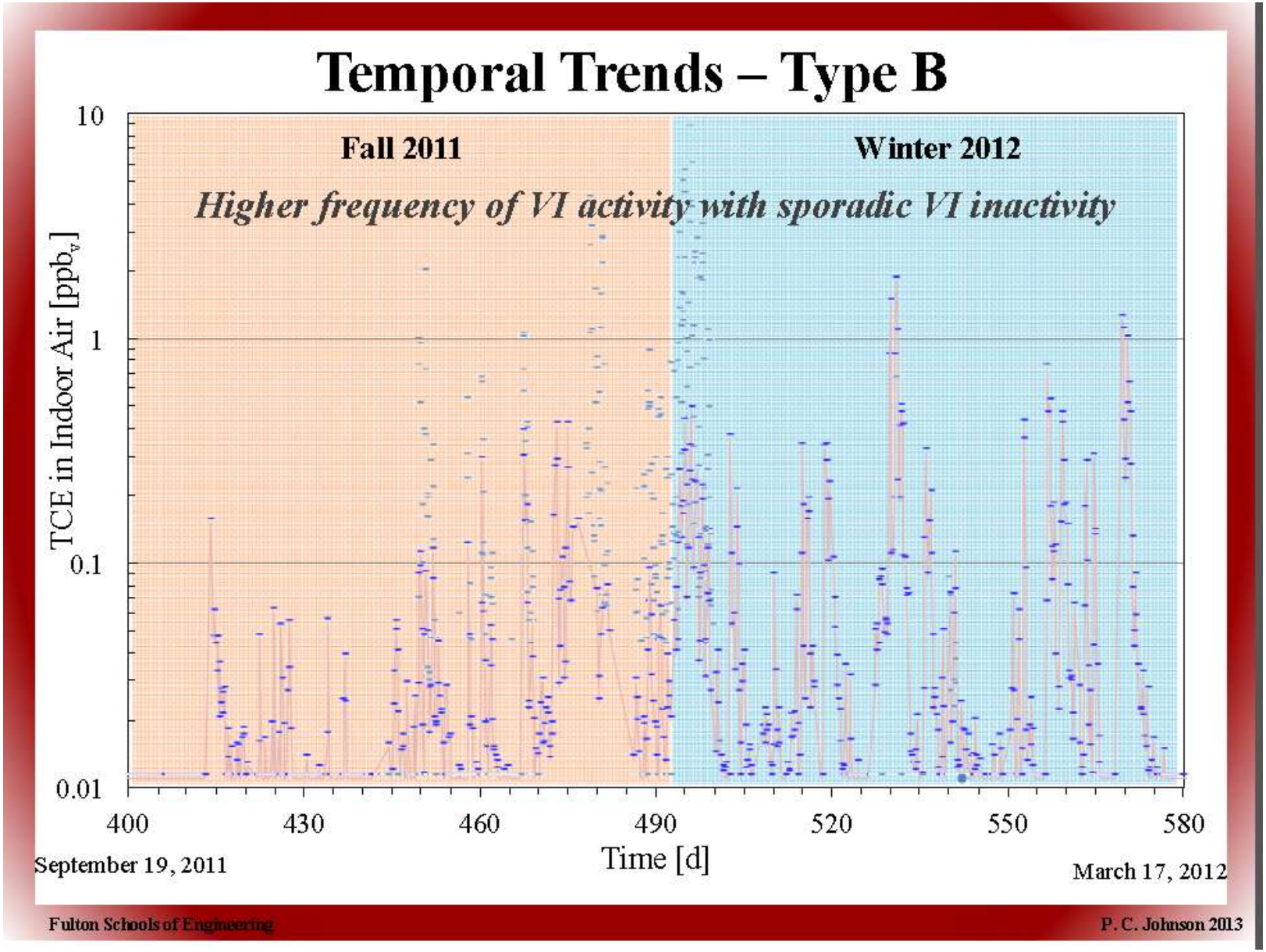
Longer monitoring shows even more Variation in conc. (100-1000x over 2 yr.)



Dr. Paul Johnson's slide 13/48 - Note *audio* recording of presentation also available at: https://iavi.rti.org/attachments/WorkshopsAndConferences/05_Johnson_03-19-13.pdf



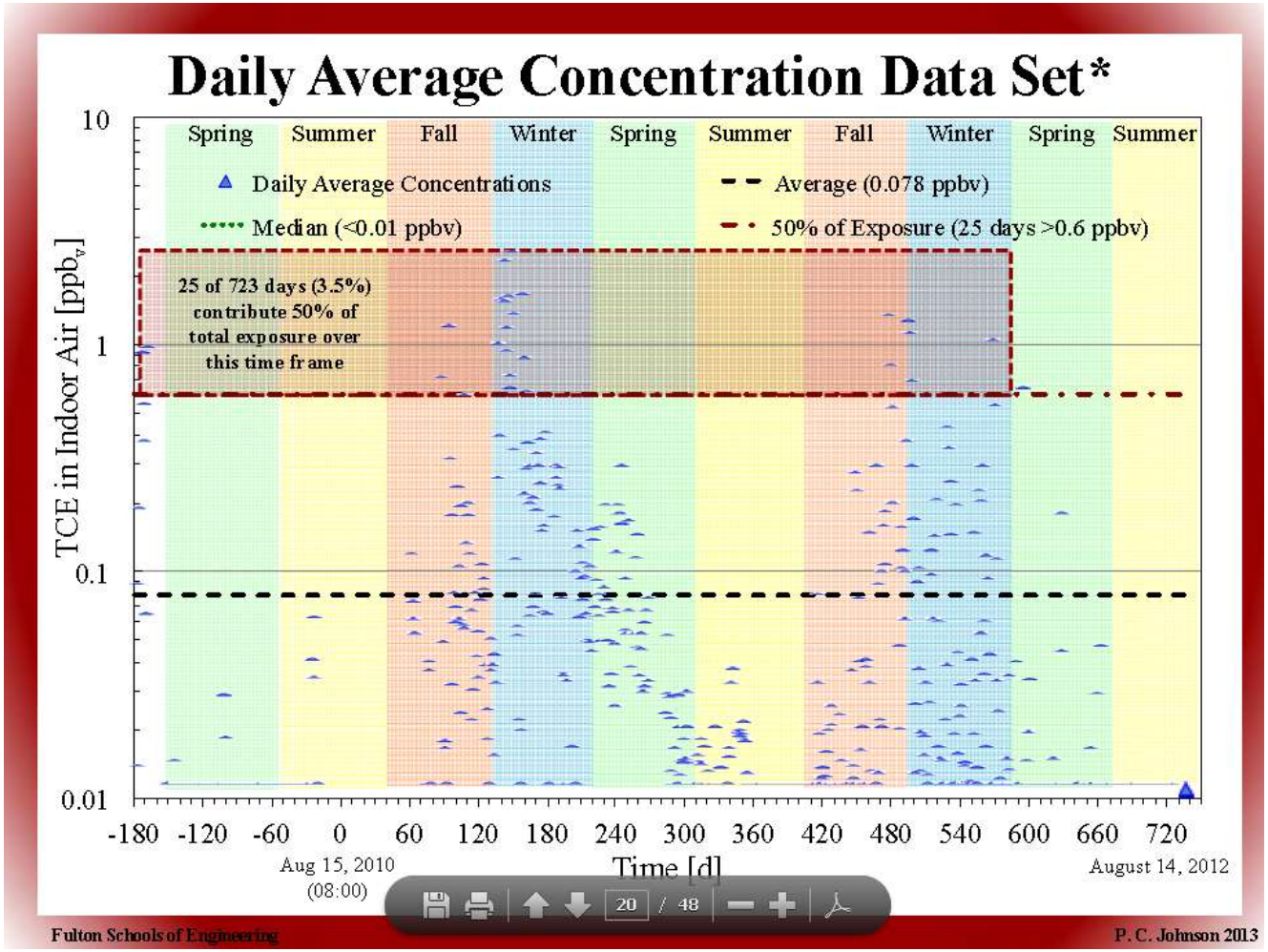
Dr. Paul Johnson's slide 14/48 - Note audio recording of presentation also available at: https://iavi.rti.org/attachments/WorkshopsAndConferences/05_Johnson_03-19-13.pdf



Dr. Paul Johnson's slide 15/48 - Note audio recording of presentation also available at: https://iavi.rti.org/attachments/WorkshopsAndConferences/05_Johnson_03-19-13.pdf

Episodic Peaks Drive Exposure

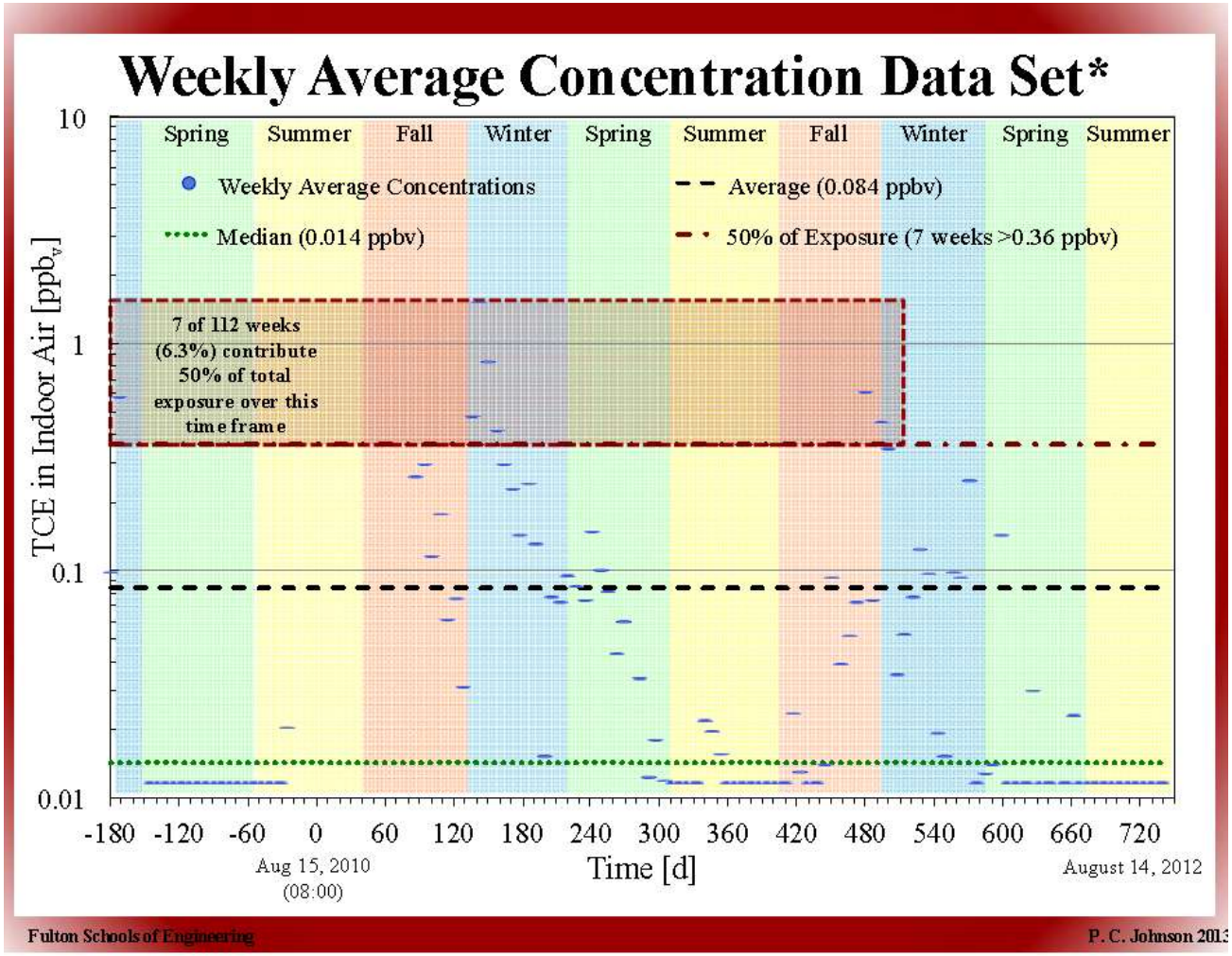
25 days (3.5%) present more exposure than the other 698 days



Dr. Paul Johnson's slide 20/48 - Note audio recording of presentation also available at: https://iavi.rti.org/attachments/WorkshopsAndConferences/05_Johnson_03-19-13.pdf

Episodic Peaks Drive Exposure

7 weeks (6.3%) present *more exposure* than the other 105 *weeks*



Dr. Paul Johnson's slide 22/48 - Note audio recording of presentation also available at: https://iavi.rti.org/attachments/WorkshopsAndConferences/05_Johnson_03-19-13.pdf

Examples of VI in new & old homes

Sun Devil Manor – Layton, UT

- 1991 split level, slab-on-grade, attached garage; 0.29–0.92 ACH
- Suburban residential land use
- Alluvial deposit with interbedded fine-grained layers (silt, sand, clay)
- GW 9 to 10 ft bgs; moderate change
- 10–60 µg/L TCE (GW) primary COC

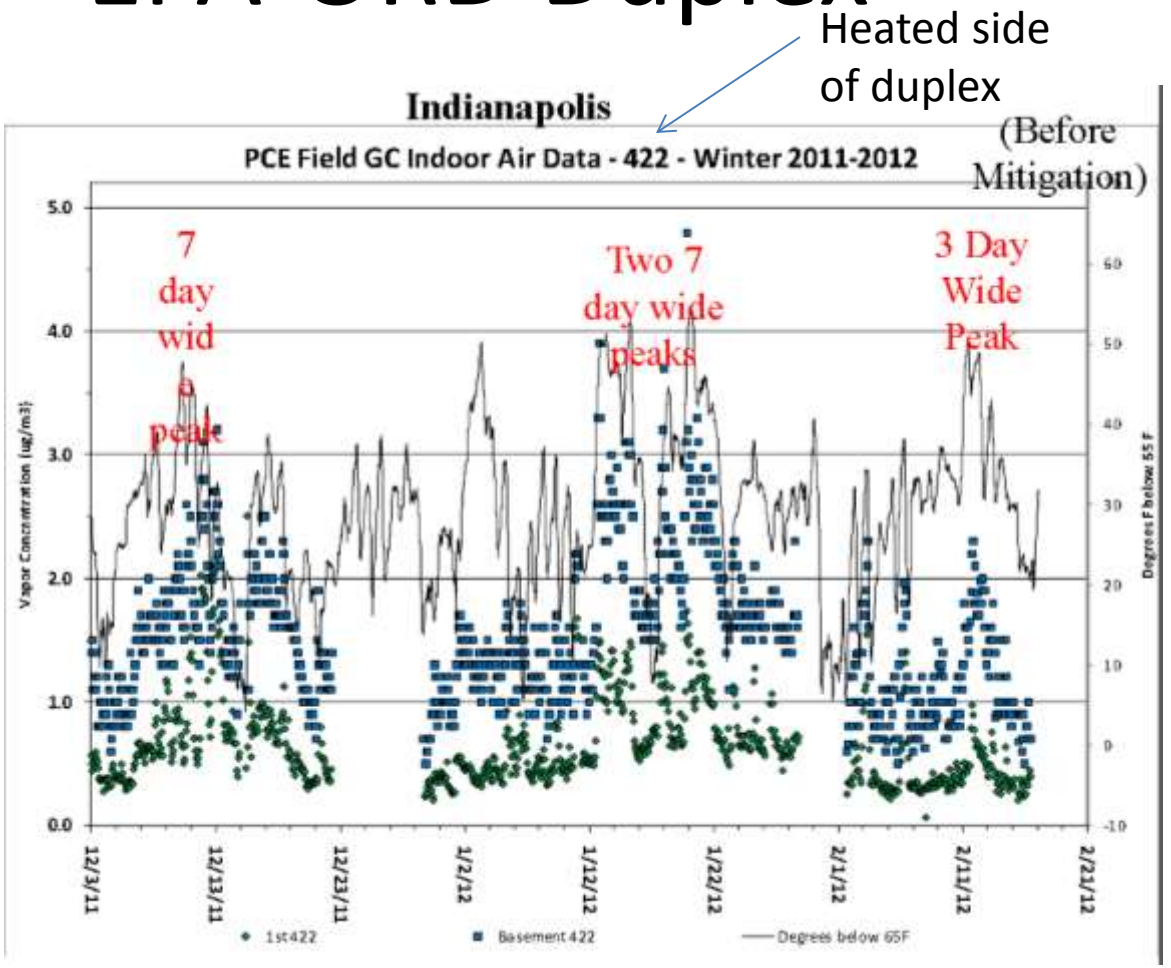
Indianapolis Duplex

- 1917 two story with full basement; 0.53-0.74 ACH
- Mixed urban commercial/ residential
- Glacial till over very coarse outwash (sand, gravel, cobbles)
- GW 10 – 16 ft bgs; rapid change w/ stream flow
- PCE, chloroform, radon main COCs
- PCE <3 µg/l in GW
- deep soil gas PCE ≈ 100 µg/m^3

EPA-ORD Duplex

Summary of ASU & ORD houses

Measurement Periods that Contribute to the **majority** (>50%) of the Total Exposure			
Sampling Interval	**ASU (%)**	**ORD 420 (%)**	**ORD 422 (%)**
1-day	**3**	na	na
1-week	**6**	**4**	12
3-weeks	**8**	**8**	16
Seasonal	**20**	**25**	**25**



Date taken from slides 16-17 AEHS 2013 https://iavi.rti.org/attachments/WorkshopsAndConferences/06_Truesdale_03-19-13.pdf

Slide 7 of 22, audio also available at: https://iavi.rti.org/attachments/WorkshopsAndConferences/06_Truesdale_03-19-13.pdf

In Summary, it appears:

- VI Peaks are episodic: In other words:
  - "made up of separate especially loosely connected episodes"
  - "occurring, appearing, or changing at usually irregular intervals"
    - http://www.merriamwebster.com/dictionary/episodic
  - Because episodic peaks are essentially unpredictable
    - & VI Peaks *determine* the *majority of VI exposure*
- Using conventional one-time assessments, it appears that:
  - The majority of VI (exposure) could be considered unpredictable

In the Words of Dr. Johnson

Now What Do We Do?

Assuming that indoor air measurements will continue to be weighted heavily in future VI pathway assessment…

- evaluate the robustness of practicable combinations of different sampling durations and frequencies (daily, weekly, 3-weeks, seasonal)

What is a "robust" VI sampling plan?

One that produces data that lead to a high probability of correct and confident answers to questions like:

- Is the VI pathway complete?
- Are the indoor air concentrations and resulting exposures over periods of interest likely to exceed thresholds of concern?

Fulton Schools of Engineering P.C. Johnson 201

Are there Scientific Analogies to help us address CVI more efficiently & protectively?

- We have a great deal of experience with:
  - **Ground Water Ingestion** (GWI) exposures
  - **Radon** gas intruding into indoor air

Ground Water Ingestion pathway
The Burden of Proof

- Initial Presumption:
  - Ground Water Ingestion (GWI) pathway 'incomplete'
    - until shown otherwise
- Evidence:
  - Ground Water contamination can be assessed reasonably
  - GW is typically slow moving and can be mapped
  - Tap-water samples can be collected (conc. variations ~1 SD ~1 OoM)
    - Possible to reasonably accurately predict/model GWI exposures
      - w/ reasonable knowledge of subsurface & human use of ground water
      - Allows reasonably protective/preventive action decisions to be made
- Current working hypothesis
  - GWI pathway is assumed incomplete, until shown otherwise
    - Reasonable since it can be assessed
      - Using Ground & Tap Water samples
      - Predicted with reasonable accuracy
      - GW plume is typically monitored through time (w/ or w/o on-going exposures)

Brief History of soil gas/vapor Intrusion for (Radon) at USEPA

- Decade(s) of effort to see phenomenon is real (Watras) & predict
  - Using measures of Rn in soil, soil-gas, in complex models with inputs for:
    - 1-Subsurface factors, 2-building factors, 3-atmospheric factors, and 4-human behavior
  - By ~1993 summary
    - Evidence indicates soil-gas/radon VI is a natural process and the exposure pathway is complete (to some degree) - in all buildings
      - Naturally, & changing through time
      - No assumption of incomplete pathway - Prioritize areas of US into 3 zones (HML)
    - Recommend measuring the degree in individual buildings Indoor Air
      - Primary concerns are for chronic (adult) disease & longer sample durations are better
    - Recommend re-sampling every 2 yr
      - » Changes observed across months, seasons, years, & decades
    - 1993-2004 human evidence for lung c. risk mixed (w/ 'short' <1 yr-long samples)
    - 2005 epidemiology ends debates regarding risks (only using samples $\geq$1yr)
      - Avg. 2.3% lifetime risk of Lung cancer at 4 pCi/L action level (sub-studies suggest 4%)
    - 2009 WHO etc. validate global relevance (measure Rn in all homes world-wide)
      - & lower threshold for concern (to 2.7 pCi/L)

STUDIES ON TEMPORAL VARIATIONS OF RADON IN SWEDISH SINGLE-FAMILY HOUSES

Lynn Marie Hubbard, Hans Mellander, and Gun Astri Swedjemark
Swedish Radiation Protection Institute, S-171 16 Stockholm, Sweden

Environment International, Vol. 22, Suppl. 1, pp. S715–S722, 1996

Rn as Analogy

Indoor Air Samples

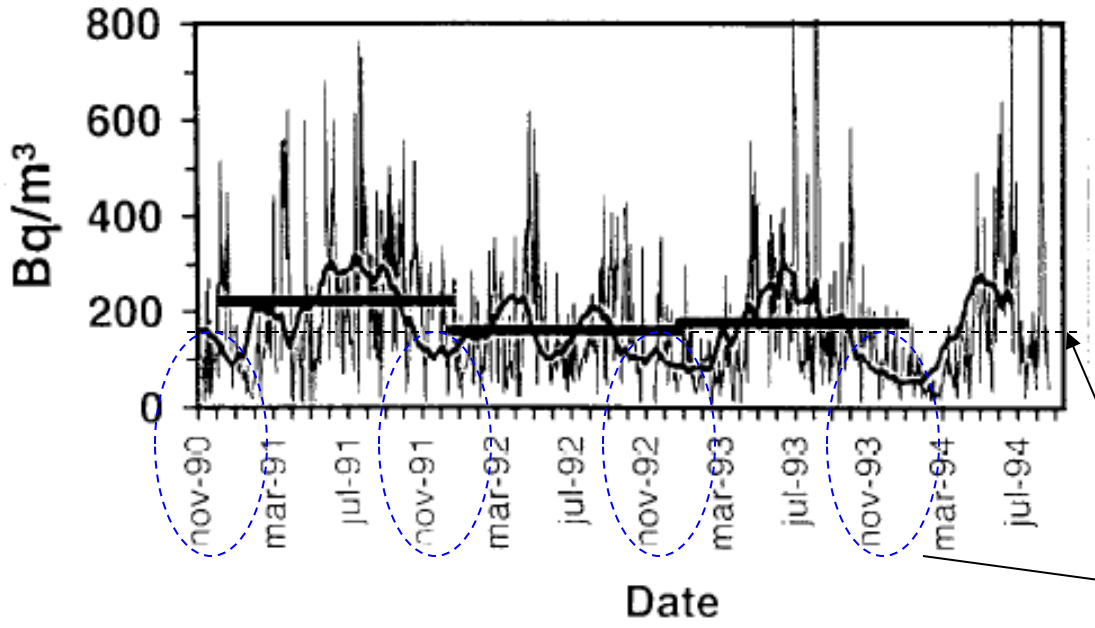


Fig. 1. Daily, bimonthly, and yearly averaged indoor radon concentration.

Typical VOC sample duration

~ 4pCi/L

Note, highest in spring & fall

Scientific Evidence for the Validity of VI Assessment/Screening – Only Example Radon?

- No evidence for VI_{chem} screening effectiveness?
- High radon region analogous to VI_{chem} study areas

Radon Screening Lessons

Steck 2005

- In an area with a high level of radon:
  - "The efficiency of the [2 to 4 day] diagnostic test is … *not much different from a random* … test's efficiency."
    - i.e., **close to *50 – 50***
  - "homeowners who believe based on their single screening [*2 to 4 day long indoor air*] measurement, that they have a house below the action level are *often mistaken*."

Steck 2005

Residential Radon Risk Assessment: How well is it working in a high radon region?

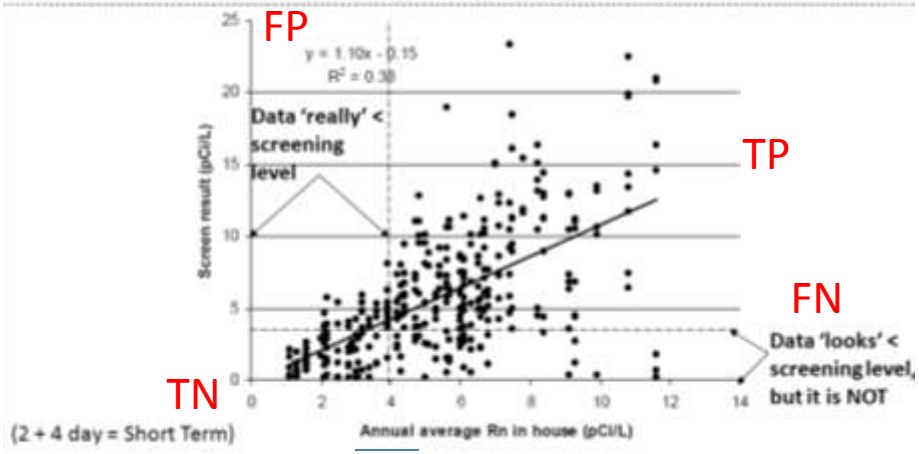
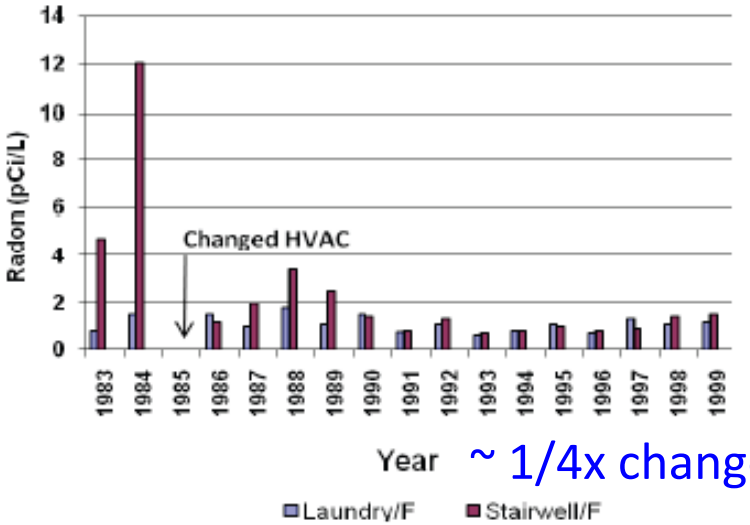


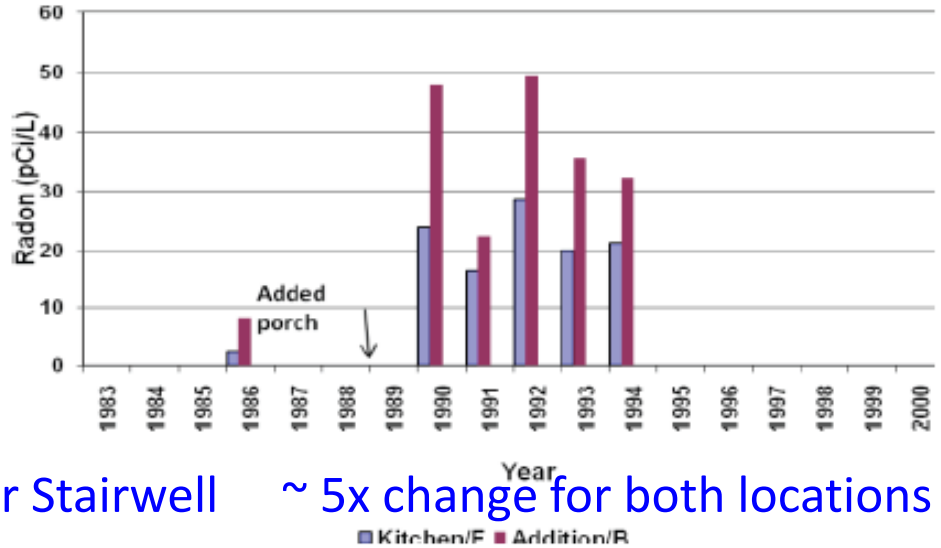
Figure 3. Linear regression between ST screening measurements and the annual average radon in the house (one high radon house is not shown) in the Temporal survey

Radon Studies illustrate the importance of building factor changes through time

American Association of Radon Scientists and Technologists 2007 Proceedings
Of the 2007 AARST International Symposium Jacksonville, FL, 2008©AARST

Both man-made + natural changes: Earthquakes, Settling, Drying soils, Burrowing …





~ 1/4x change for Stairwell ~ 5x change for both locations

Figure 4 Examples of large radon changes created by house modifications

Note, the difficulty of estimating changes in heating or air condition or adding porches; and also impacts to VI.

Steck 2007, see: http://www.aarst.org/proceedings/2007/8-SteckYTYRnvariation07.pdf

Radon Intrusion pathway
The Burden of Proof

- Initial Presumption:
  - Radon intrusion pathway 'incomplete'
    - until shown otherwise
- Evidence:
  - Soil Gas Intrusion – occurs naturally/inevitably
    - with some (varying) amount of Radon
    - Not poss. to predict/model w/o nearly-infinite knowledge
- Current working presumption/hypothesis
  - RI pathway 'complete' to some degree (poss. Signif.)
    - Until shown otherwise: Recommend
      - **Sample every home/bldg.** in US (EPA/SG) [in world, as per WHO]
      - **Through time – every 2 years** (w/ or w/o mitigation)

Open Questions:

- Is the chemical VI community ready to:
  - Consider the radon program's observations from 1993 (& CVI to-date):
    - Evidence indicates soil-gas/radon VI pathway is complete (to some degree) -
      - in all buildings (naturally, & changes through time)
  - Accept - Limited (2+house) but clear evidence - latest CVI
    - that chemical VI can be un-assessable / screening unreliable
      - Using conventional (affordable/feasible) sampling techniques
        - » Particularly given the shorter exposure periods of concern for CVI

Some example Spatially-Associated: **Health Effects**

*Endicott, NY - **TCE** plume (70 block) area:*

- Statistically elevated rates of TCE-assoc.:
- **Cancers** (e.g., Kidney; ATSDR, 2006)
- **Non-**cancer **effects -** (IA = 0.18 - 140 ug/m^3)
  - 1090 births 1978-2002 (~2615 residents)

+ **23%**	Small for gestational age*	117
+ **36%**	Low birth weight**	76
+ **68%**	Term low birth weight	37
+ **215%**	Cardiac defects***	15
+ **240%**	Major cardiac defects	6
+ **491%**	Conotruncal[1] defects	3

Weeks of Pregnancy & Fetal Heart Development

Week 3 15-21 days from fertilization
"Primitive **heart tube** is forming"

Week 4 22-28 days from fertilization
"The heart bulges, further develops, and **begins to beat** in a regular rhythm."

ehp ENVIRONMENTAL HEALTH PERSPECTIVES
ehponline.org

"**Conclusions**: Maternal residence in **both areas** was associated with **cardiac defects**. Residence in the **TCE** area, but *not the PCE area*, was associated with **low birth weight** and **fetal growth restriction**."

Maternal Exposure to Tetrachloroethylene and Trichloroethylene through Soil Vapor Intrusion and Adverse Birth Outcomes in New York State

Steven P. Forand, Elizabeth L. Lewis-Michl, Marta I. Gomez

http://dx.doi.org/10.1289/ehp.1103884

~95% of problem Identified & controlled w/n 6 - 12 **months**

National Institute of Environmental Health Sciences
National Institutes of Health
U.S. Department of Health and Human Services

Similar findings for: *SGA in NC, MA; ** LBW in NJ, AZ; ***CD in NJ, AZ, WI

[1] "abnormal formation of the outflow tracts of the heart"

(RR%) Rate Ratios in percent relative to the rest of NY state (excluding NYC)

The Burden of Proof for VI
IF – THEN Statement

- IF
  - A ‘one-time’ assessment of the exposure is:
    - Easy
    - Quick
    - Low cost
    - Accurate
- THEN
  - We could reasonably safely presume pathway is ‘incomplete’ until assessment shows us otherwise

IF (however) – THEN Statement

- IF (however);
  - A ‘one-time’ assessment of the exposure is:
    - Difficult
    - Lengthy
    - Costly
    - *In*accurate
- THEN
  - It may be more reasonably safe & efficient to begin with (for building overlying a chem. VI source*):
    - A rebuttable *presumption* that the pathway is complete
      - To some degree (and *possibly unacceptably*)
      - Until demonstrated otherwise

*e.g., from EPA databases correlated sub-surf. conc. with unacceptable indoor air > 5% of the time)

Responsible Parties would then have the incentive/option/opportunity to:

- To demonstrate (to regulators/communities) that the VI pathway is 'incomplete' or exposures 'acceptable'
- Either:
  - Without pathway/exposure controls in place
    - With willing occupant/community agreement(s)
      - Thorough assessment with some monitoring as long as 'source' remains
    - Or
  - With preemptive/precautionary pathway/exposure controls to quickly reduce any potential VI exposures
    - While further assessment takes place
      - Allowing *perhaps-more-confident* demonstrations (e.g., slab-wide/vent samples) that controls are not (will no longer be) needed (for chem.);
        - » or are needed (for Chem. VI); &
      - To assess whether source remediation/removal may be appropriate

Communities / Occupants May want to be aware that:

- Without controls in place:
  - Exposures, at whatever episodic intervals and peak conc. levels,
    - Can continue as long as natural conditions are uncontrolled
      - E.g., typically as long a (uncontrolled) investigation-studies cont./a VI 'source'
  - Seeking occupant preferences regarding the timing of prevention vs. further (uncontrolled) study of VI, is important
    - Costs of preventive controls can be lower
      - & can provide much higher confidence levels of protection for CVI, Rn, …
- Improved occupant health vs. average,
  - Could be expected for those with controls preventing soil gas intrusion
  - Volunteer reports (on selected diseases)
    - could improve our understanding of the risks involved (with soil gas in indoor air exposures) and
    - help better protect others in the future

Concepts for Regulators

- Define ‘VI source’ area
- Identify ‘overlying’ buildings*
- Notify current (& future) occupants of:
  - Potential for VI
  - Evidence supports an initial rebuttable-presumption - VI could be occurring
    - Typical/conventional difficult & lengthy assessment, w/ low chance of catching VI
- Request occupant preferences/opinions Re:
  - Expenditures (time & money) for:
    - Further (uncontrolled) Studies (of migration to surf./bldg., & intrusion into Indoor air)
      - vs.
    - Preemptive controls to ~remove potential VI
      - (e.g., ~1/10>100x reductions of all soil gases)
    - While *perhaps-(less frequent/disruptive) but more-confident* demonstrations can be made
  - Consider occupant preferences in making decisions
    - Re: expenditures for rebutting the presumption of a ‘complete’ VI exposure pathway
    - Currently, or in future, for as long as ‘VI-source’ remains

*existing (& potential for future)

Concepts to Rebut presumption of VI (by PRPs):

- Confirm no 'VI source' - in soil-gas, groundwater, soil, etc., or
- Confirm (insure w/ controls) no 'overlying' buildings (now or in the future)*, or
- Notify regulators that:
  - Current (& future) occupants are (will be) aware of:
    - Potential for VI
    - & Accept PRP's option to attempt to rebut presumption of VI, using:
      - Further Studies (migration to surf./bldg., intrusion into Indoor air)
        - » With or w/o exposure controls in place
- & (for un-controlled assessments)
  - Confirms vapors do/will* not reach 'near-surface' in detectable conc. in any location overlying the VI-source area* (or uses VI preventive controls), or
  - Confirms sub-slab/foundation conc. for all (existing & future) building are (will remain*) less than generic conc. of concern* (or uses VI preventive controls) or
  - Confirms indoor air due to VI does not exceed RBC for any relevant exposure period* or (or uses VI preventive controls)
    - Note if unacceptable indoor air conc. due to VI is confirmed - long-term chemical-specific effectiveness indoor air monitoring & source remediation could be expected

*for as long a VI source remains

In Closing - 1

The Burden of Proof for Chemical VI

- Original Presumption:
  - VI pathway incomplete, until shown otherwise
- Evidence (from buildings over VI source areas):
  - Soil Gas Intrusion – occurs in episodic time periods
    - with some varying amount of subsurface chemical vapors
    - Assess. difficult, costly, and can be inaccurate
- Alternative (rebuttable) approach for CVI*
  - VI pathway is ‘complete’ to some degree (poss. Signif.)
    - Until demonstrated otherwise:

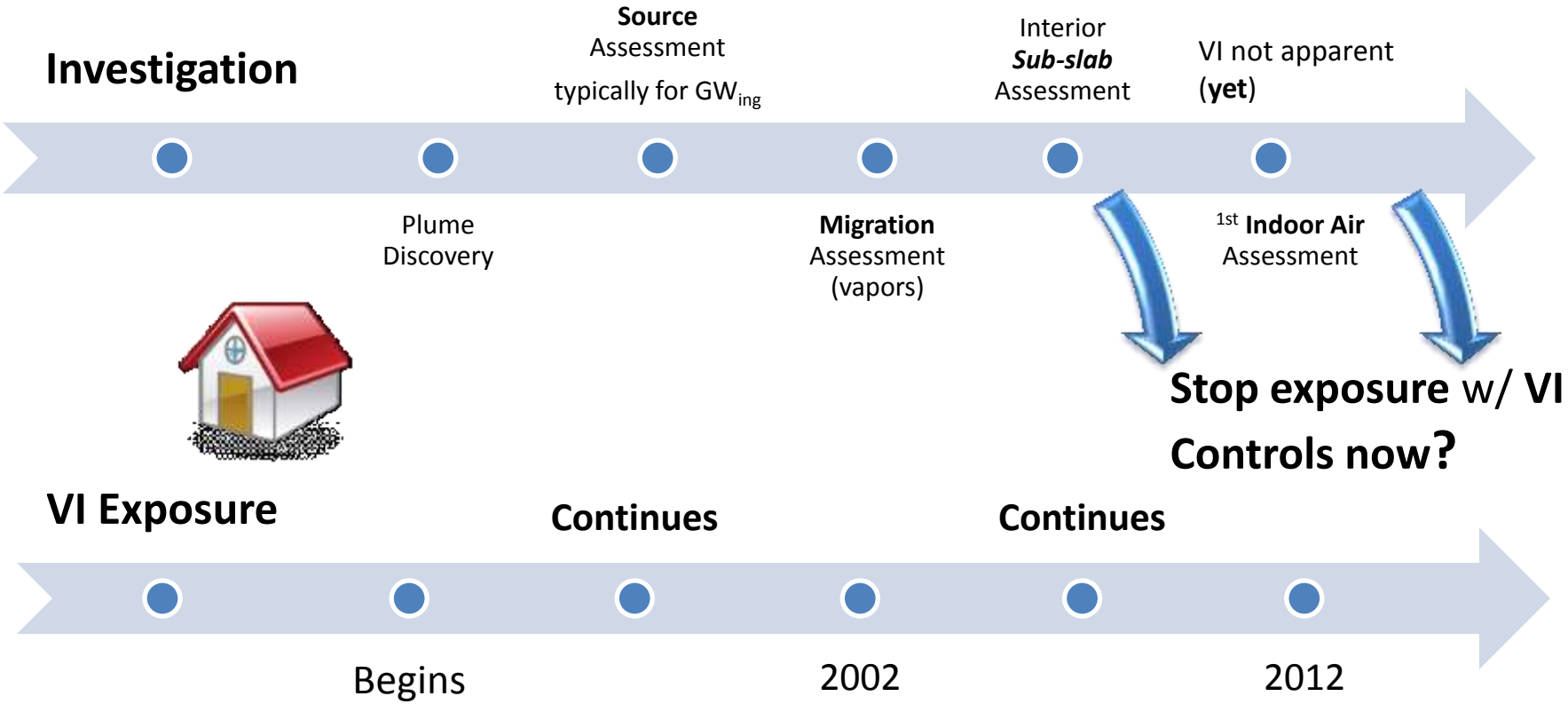
* Similar to that used for Radon intrusion

In Closing - 2

The Burden of Proof for Chemical VI

- If the VI pathway has **not** been demonstrated to be incomplete/insignificant via:
  - No 'VI source' - in soil-gas, groundwater, soil, etc.,
    - » or
  - No 'overlying' buildings (now or in the future)*
  - Then the demonstration needs to be:
    - Surrounding/in occupied home/bldg. (over VI source area)
    - Through time
      - » Maybe for as long a VI source remains
  - However, the question remaining is:
    - Whether the assessment is w/ or w/o VI/exposure controls
      - VI controls that could both:
        - » Protect occupants (from any potential chem.+ exposures), & help
        - » Confidently determine how long VI controls are needed (for chem.)
          - Potentially with fewer samples

Hypothetical (but Typical?) VI Investigation & Exposure Timeline*



* Not to scale

Evidence shows: The duration of exposure matters

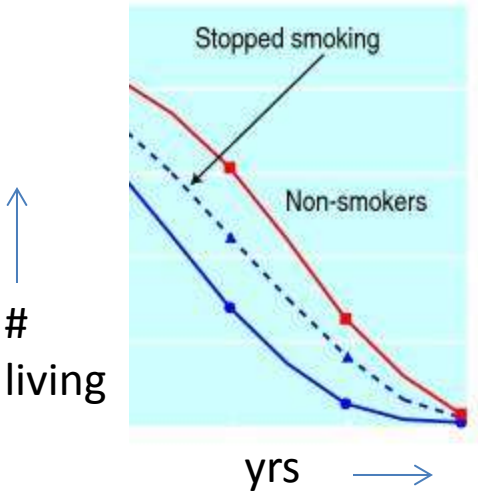
Removal from Exposure Today Reduces Risks Compared to Continued Exposures

(& the sooner the better)

Exposure "cessation at age 50 halved the hazard, and cessation at age 30 avoided almost all of it"

Example: *Mortality in relation to smoking: 50 years' observations on male British doctors*

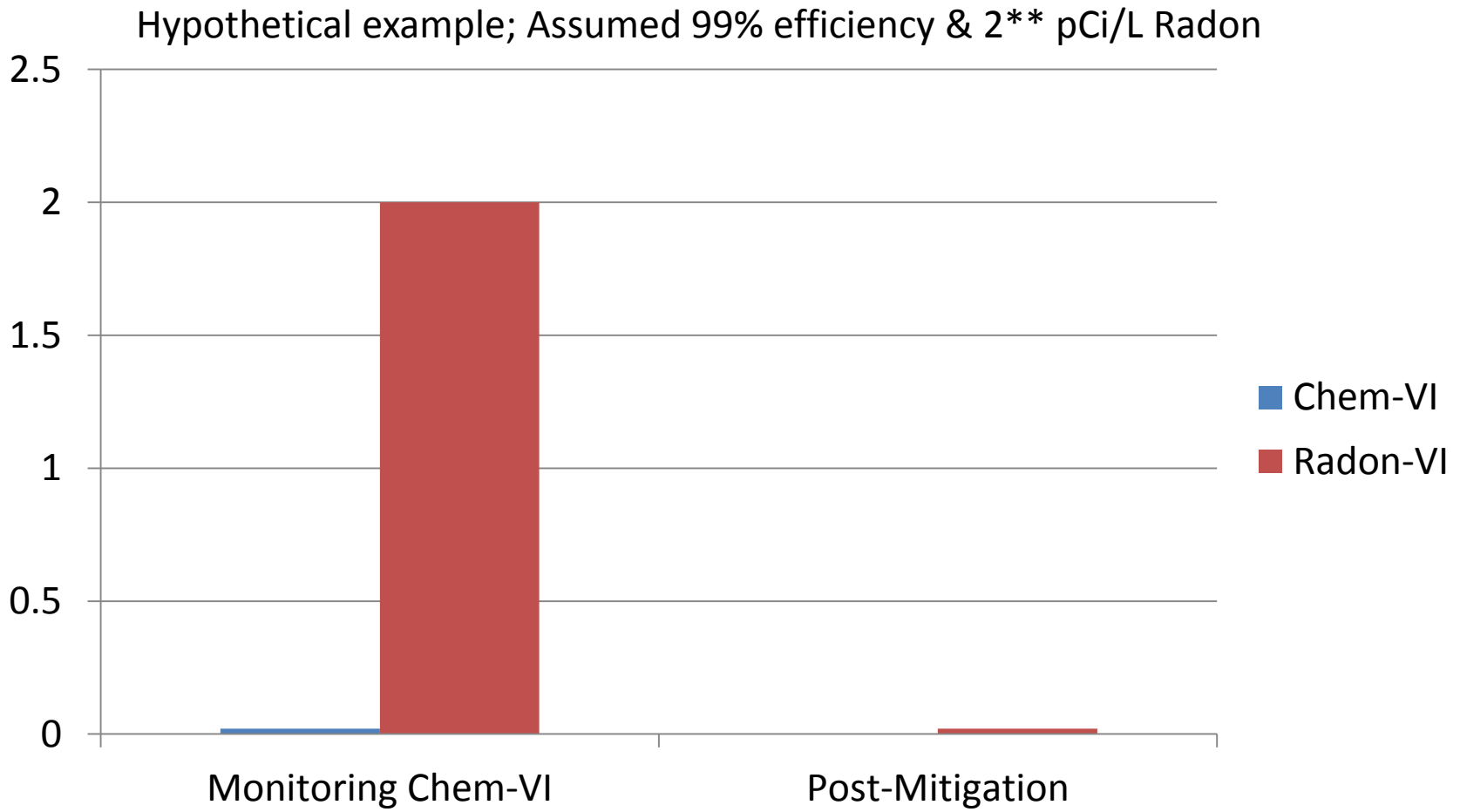
BMJ. 2004 June 26; 328(7455): 1519.
Richard Doll, Richard Peto, Jillian Boreham, and Isabelle Sutherland



Even for Chronic disease, shown here - w/ exposure averaged over decades
Non-cancer disease - 1-day exposures 'of concern' - so it is even *more urgent*

Collateral Benefits of Chem-VI-Protective VI Controls

Reducing Risk-Driving Cancer* Risks (%)



*Only considering Lung cancer (increasing evidence for leukemia (esp. child) & other diseases)

**Assumed typical 2 pCi/L level, & general population risk (based on sub-studies, ~2x bulk), assumed (even though atypical) chemical VI cancer risk = 1x10-4

Documenting Benefits

- Increasingly important to document the benefits of our efforts
  - Current efforts by EPA - OSRE/ORCR/OSWER
    - ORCR recommended - Est. populations (# peo.) protected
    - Possible extension to cases avoided, QALYs/$$ saved
    - Metrics for incentives?
      - » Discussing new '(Chemical) VI Mitigation' credential to add to existing Radon mitigation credential
  - All involved should share the credit for documented public health/environmental benefits

The Health Science is Clear:

*Soil gas intrusion degrades indoor air quality in a number of ways**

Science supports promoting being soil gas safe **-** by keeping soil gas out of indoor air - even if chemical aspect is uncertain.

- LEED credits for:
  - "Enhanced indoor … quality" considering both …
    - "*Radon* and *Ground Contaminants*"
      - Certified for individual buildings
- Communities that are safe from all soil-gas hazards
    - Could be recognized as leaders in understanding & health
      - The science is clear, cultural 'stigma' for soil-gas controls mistaken
  - *Radon mitigation correlated w/ high income & educ. (SES)*
    - What would future occupants want?
    - Pre-const./renovation savings $$ ("128%-400%" (EPA, RRNC))
    - Opportunity grabbed or missed?

* Radon, chemicals (from?), Pesticides, Methane, CO_2, CO, moisture/mold, …

Questions/Comments/Discussion

?