U.S. EPA "State of VI Science" Workshop

Selecting Sampling Strategies for Efficient & Economical Vapor Intrusion Site Assessment & Long-Term Management – forming Soil Gas Safe Communities

Sampling Strategy Performance: Daily and Weekly Durations: Comparing Random, Seasonal and Indicator- & Tracer-Guided

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Presentation archived
at https://iavi.rti.org/

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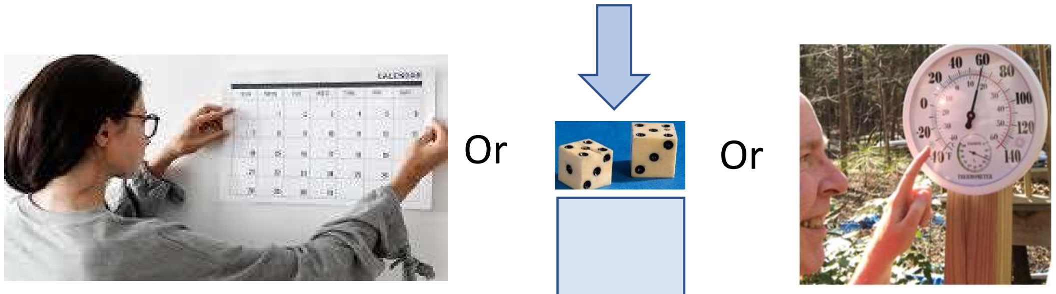
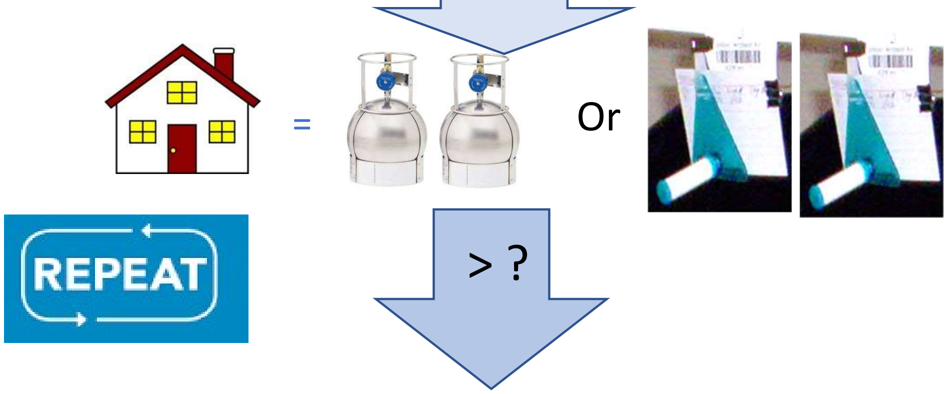
Preview: In This Presentation We Will Show Using a Sampling Analysis

- A method for analyzing the performance of realistic sampling strategies using rich research datasets.
- In each individual case analyzed, an Indicator and Tracer (I&T) based sampling rule and/or a seasonal based sampling rule can be identified that substantially outperforms random sampling.
- However, the top performing I&T based rule is not the same across all sampling zones, so additional mechanistic insight is needed to select *a priori* the optimum sampling rule for a given sampling zone.
- An *a priori* selection of sampling rule would need to be based on the information generally available before initiating sampling at a given building: climate zone, building type, and a conceptual site model describing the primary source of contamination (groundwater vs. soil).
- Making decisions based on four randomly or convenience based short term samples will not likely characterize the 90th or higher percentile of the concentration distribution.
- At some sites with highly skewed concentration distributions, making decisions based on four randomly or convenience based short term samples will underestimate the mean long-term concentration, because a small percentage of the samples contribute >50% of the total exposure.
- Extending sample durations to weekly provides in many cases a modest incremental benefit in increasing the probability of reaching a performance goal for a sampling approach.

Sampling Performance Analysis Approach: Did I&T Increase the odds of seeing upper end concentration?





p90 of distribution, 95 % UCL of Mean or p50 of cumulative total exposure

Long Term Indoor Concentration Data Sets ≈real concentration distribution ≈ Approximation of Reality

Apply Sample Scheduling Rule

Test many 2 or 4 possible sample events – either day long or week long

Compare Subsample Mean or Max To

Performance Goal= VI Screening Level, True Distribution Mean or Percentile

Evaluate Whether Confident and Accurate Enough

Metric, Probability or Odds

Data Sets Tested in This Study (n is # sampling events for VOCs)

- Sun Devil Manor (Residential); unoccupied, with land drain open, without blower door, n=342 daily averages
- Indianapolis Duplex (Residential) – unoccupied, data from two floors; without mitigation; n=58 weeklong samples or 49 weeklong with high time resolution radon ; n=136 daily averages
- Moffett Field Building 15 (Commercial) – normal operating conditions; n =156 daily averages
- Gaffney Alaska (Commercial) – normal operating conditions, n= 27 days of sampling
- Virginia Site A (Industrial) – two locations – normal operating conditions n=589 daily averages

Sample Scheduling Approaches Tested in this Study

- One sample per calendar season (Winter = Dec 1 to Feb 28, Spring March 1 to May 31…..) – either winter/summer or four quarterly samples
- Half the samples in heating season (November 1 to March 31st), half not in heating season
- All samples in heating season.
- All samples in winter; all samples in summer etc.
- OR sampling event begun based on:
  - a decrease in temperature day over day of 5 F (in either daily low or daily average)
  - indoor/outdoor differential temperature of 15 F
  - a negative differential pressure of 0.01 inches of water or 2.49 Pa or more negative
  - a day over day increase in radon concentration of 0.5 pCi/l
  - a threshold Level of > 2 pCi/l in radon
  - exceeding the 90th percentile of radon levels expected for the structure either based on heating season or the full data set.
- 24 hr duration samples or week duration samples

Comparing Daylong and Weeklong Sample Durations

- One week or longer duration samples can be done with passive sampling or capillary controller Summa canisters (Rossner, 2020, 2023)
- The sampling and analysis costs for daylong and weeklong are similar, so longer, more representative observation periods may be preferred (EPA, 2015).
- One week duration samples are expected to exhibit less temporal variability then 24-hour (daily) samples and thus yield estimates closer to the midpoint of the long-term exposure distribution.
- Fewer weeklong samples will be needed to confidently observe goals around the mean.
- But will it then be more difficult to directly observe the concentrations towards the upper end of the distribution of daily average concentrations (i.e. 90th or 95th percentile) using weekly samples?

Alan Rossner , David P Wick, Christopher Lutes, Benjamin Stone, Michelle Crimi; "Evaluation of Long-Term Flow Controller for Monitoring Gases and Vapors in Buildings Impacted by Vapor Intrusion" International Journal of Environmental Research and Public Health, March 2023 Int. J. Environ. Res. Public Health 2023, 20, 4811. https://doi.org/10.3390/ijerph20064811.

Goals for a Sampling Strategy

- Is a >90% confidence in making the assessment decision about an individual structure required? (<10% false negative?)
- Sampling strategies should be applicable to a wide variety of buildings, using a minimum of easily available preexisting information.
- Sampling strategies should be significantly better than random sampling, while still allowing a reasonable number of potential sampling days per year.
- Sampling strategies should be robust – perform well across a variety of situations (building types, climates, climate change)

Sampling Performance Analysis Assumptions

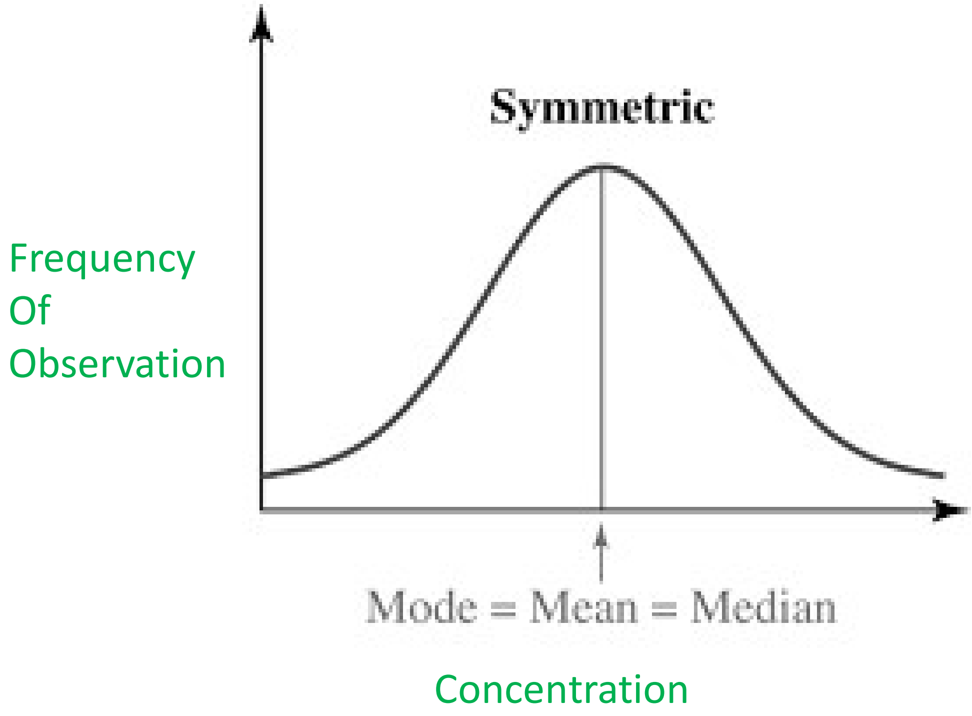
Key Question: Will the proposed strategies help achieve better odds of observing upper end concentrations than random sampling?

- Most Scheduling Approaches Tested with 2 vs. 4 Sampling events
- Assumed computer or person would “evaluate” previous data at midnight to decide whether to sample that day or week (starting in theory at 12:01 AM).
- Evaluation could be automated/triggered sampling; human in the decision loop, weather forecast, or calendar based.
- All allowable combinations of sampling days based on scheduling approach considered equally likely.
- Days to be sampled will be defined as 24-hour block averages. Either one Summa sample or a daily block average GC result.
- Week samples defined as 7 day block averages, or the actual result of a 6 to 8 day passive sample.

Metrics, Probabilities, Tested (more tested and will be published, but only these two in this presentation)

- At least one of the two or four samples will exceed the 90th percentile of the underlying distribution
- At least one of the two or four samples taken will come from above the 50% of total cumulative exposure point.

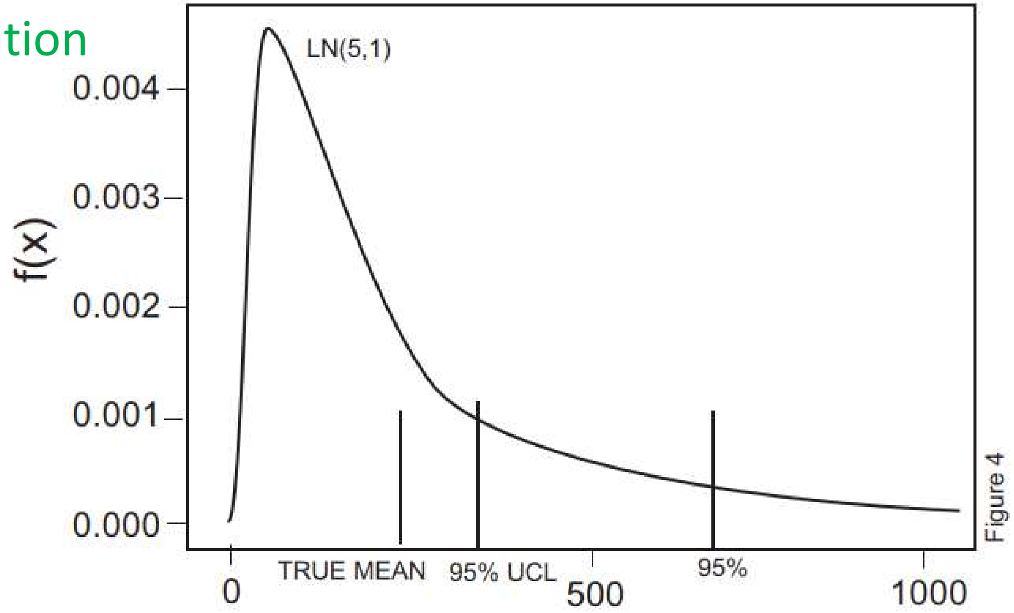
If The Distribution is Symmetrical (or Normal) It is Relatively Easy to See the Mean (cancer risk criteria) With a Few Samples



With a symmetrical distribution you have a 50% chance to be above the mean with at least one sample and a 75% chance to be above the mean with at least one of two samples. The median is the most common sample (highest frequency).

But: It is Much Harder to Observe the True Mean With a Small Number of Samples When the Distribution is Skewed - as it Often Is in Environmental Samples

Frequency
Of
Observation



Concentration

Figure Reprinted from EPA/600/R-97/006

The Performance of Purely Random Sampling Can Be Determined Mathematically if the Metric is the 90th Percentile of the Distribution (a noncancer criteria assumption)

- You have a 10% chance with one random sample of observing the >90th percentile of any distribution.
- You have a 19% chance with two random samples of observing the >90th percentile of any distribution.
- You have a 34% chance with **four** random samples of observing the >90th percentile
- You have a **90%** chance with **22** random samples of observing the 90th percentile at least once

Image from https://wi101.wisc.edu/2020/09/09/object-history-a-twenty-sided-die/

Explaining the Concept of 50% Cumulative Exposure With an Invented, Simplified Ten Sample Example

(Note: cumulative inhalation exposure is **only a simple sum to show what daily samples represented the most inhalation exposure** and does not account for processes in the human body)

Day (Sequential Number)	**duration (days)**	**Concentration ($\mu g/m^3$)**	**Percentile of the underlying distribution**	**Inhalation rate (m^3/day)**	**Exposure (µg/day)**	**Cumulative Exposure (µg)**	**Percent of cumulative exposure from individual sample**	**Percent of cumulative exposure**
1	1	1	0	16	16	16	1.1%	1.1%
2	1	1	0	16	16	32	1.1%	2.3%
3	1	2	22.2	16	32	64	2.3%	4.6%
4	1	2	22.2	16	32	96	2.3%	6.9%
5	1	2	22.2	16	32	128	2.3%	9.2%
6	1	3	55.5	16	48	176	3.4%	12.6%
7	1	5	66.6	16	80	256	5.7%	18.4%
8	1	11	77.7	16	176	432	12.6%	31.0%
9	1	20	88.8	16	320	752	23.0%	54.0%
10	1	40	100	16	640	1392	46.0%	100.0%
				Sum Total Exposure	**1392**	µg		
				50th percentile of cumulative	696	µg		

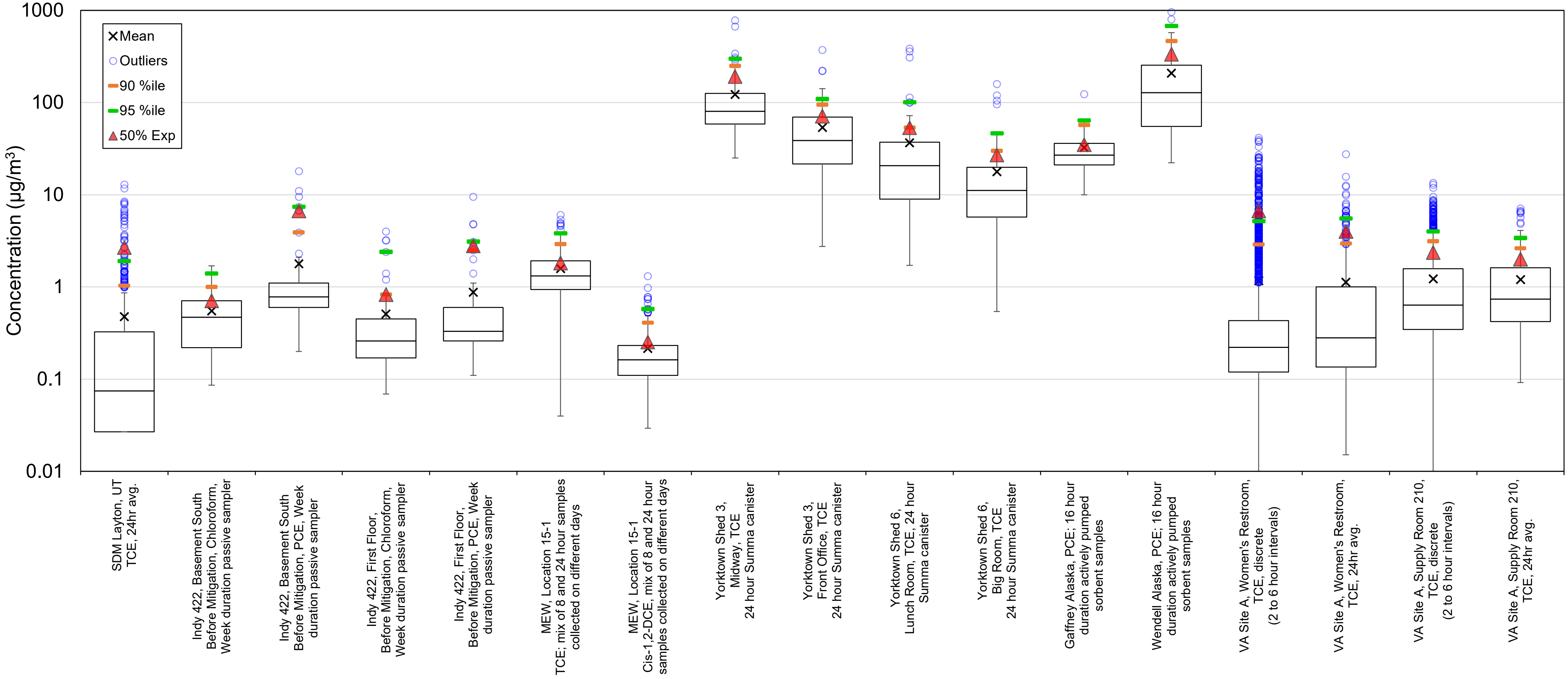
Median Concentration 2.5 $\mu g/m^3$

Mean Concentration 8.7 $\mu g/m^3$ (95th UCL is 8.96)
Mean Exposure 139.2 µg/day.

50th Percent of the cumulative exposure 696 µg

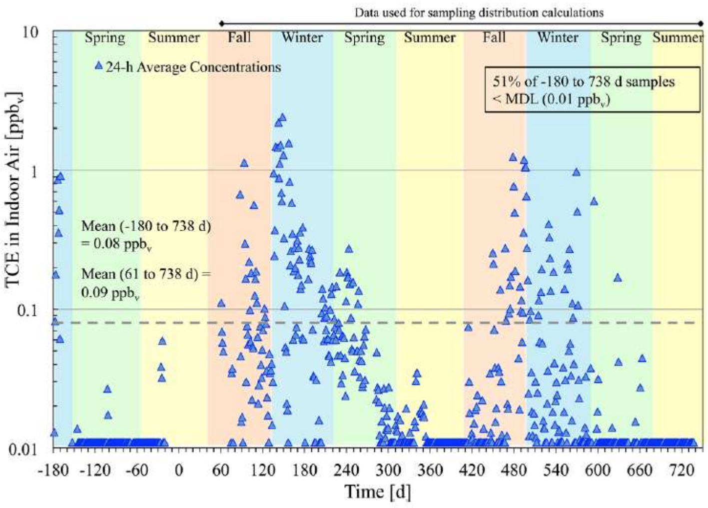
90th and 95th percentiles of underlying distribution

Temporal Variability of Indoor Air Concentrations Across 7 Sites



Key point: Degrees of temporal variability across sites compared. Various upper end measures in skewed distributions are shown.

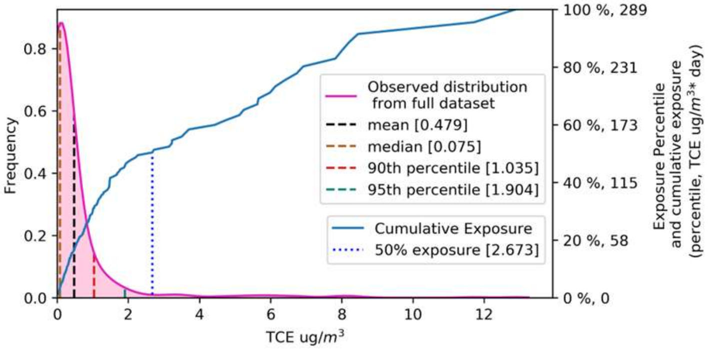
Sampling Performance With a Highly Skewed Distribution? (Sun Devil Manor 603 days)



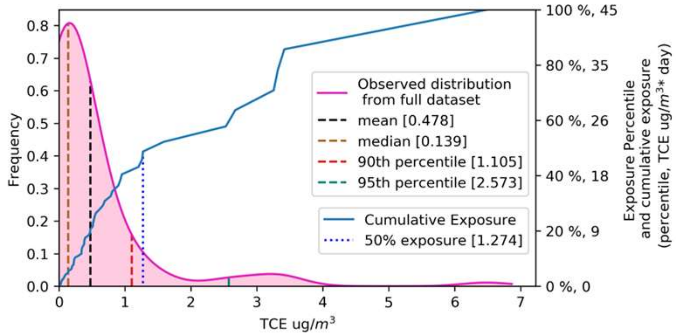
Your chances of once

- ➢ Seeing TCE sample over the 90th percentile with four daily samples (vs four weekly):
  - Random = 35% (36%)
  - Only in heating season = 62% (68%), In winter only = 74% (80%)
  - When radon >90th of full radon dataset = 95% (100%)
  - When radon >90th of heating season radon = 99% (95%)
- ➢ Seeing TCE over the 50th percentile of cumulative VOCs with four daily samples (vs four weekly):
  - Random = 16% (30%)
  - Only in heating season =31% (59%), in winter only = 40% (68%)
  - When radon >90th of full radon dataset = 60% (100%)
  - When radon >90th of heating season radon = 81% (100%)

Sun Devil Manor, Layton Utah, Daily Data Exposure Curve
Date range: 2010-08-15 to 2012-08-21
Sample Count: 603



Sun Devil Manor, Layton Utah, Weekly Static Data Exposure Curve
Date range: 2010-08-15 to 2012-08-21
Sample Count: 95

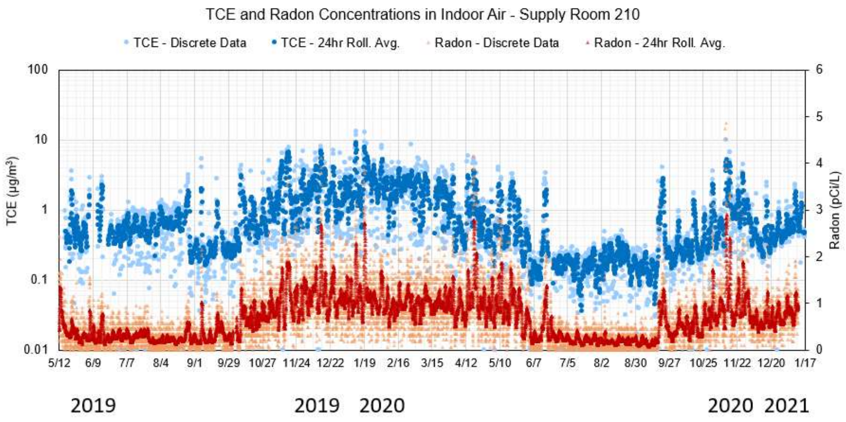


Key Points: Weeklong sampling compared to upper end of weeklong distribution has better odds than day long sampling compared to upper ends of daily distribution.

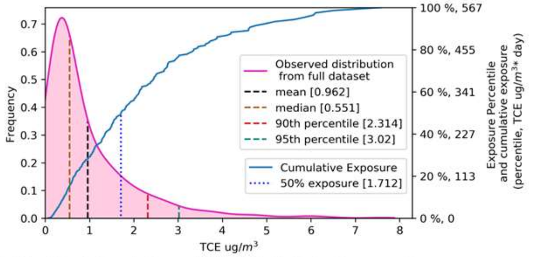
The 90th percentiles are almost identical for the daily and weekly distributions, but the 50th percentile of cumulative are quite different.

Preferential pathway case.

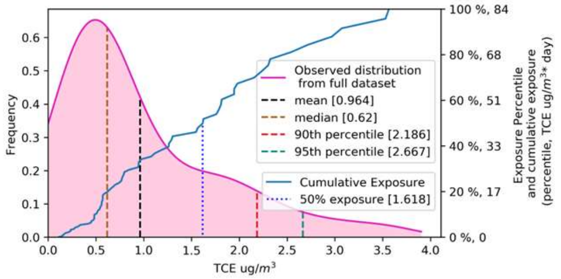
Sampling Performance With Moderate Skew: VA Site A: Supply Room (589 days)



Virginia Site A, Supply Room Daily Data Exposure Curve
Date range: 2019-05-17 to 2021-01-10
Sample Count: 589



Virginia Site A, Supply Room Weekly Static Data Exposure Curve
Date range: 2019-05-17 to 2021-01-10
Sample Count: 87



Your chances of

- Seeing a TCE sample over the 90th percentile once with four daily (four weekly) samples:
    - Random: 34% (36%)
    - Only in heating season: 67% (74%), only winter: 71% (87%)
    - Radon >90th full radon dataset: 77% (95%)
    - Radon >90% heating season radon and heating season: 84% (100%)
    - Radon >2 pCi/l: 100% (100%)

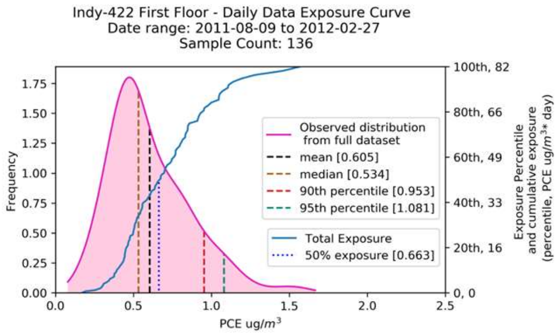
- Seeing TCE over the 50th percentile of cumulative VOCs once with one of four daily (four weekly) samples
    - Random: 49% (63%)
    - Only in heating season: 86% (97%); Only winter: 90% (99%)
    - Radon >90% of full radon dataset: 93% (100%)
    - Radon >90% heating season radon and heating season: 97% (100%)
    - Radon >2 pCi/l: 100% (100%)

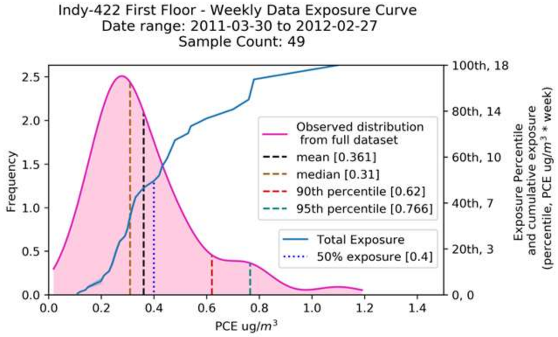
Key Points: Weeklong sampling compared to weeklong distribution performed better than day long sampling compared to daily distribution.
Note in this case the characteristics of the weekly and daily distributions were quite similar for both the 90th percentile and 50th percentile cumulative exposure.
This case has "classic" stack effect behavior from a source directly under building.

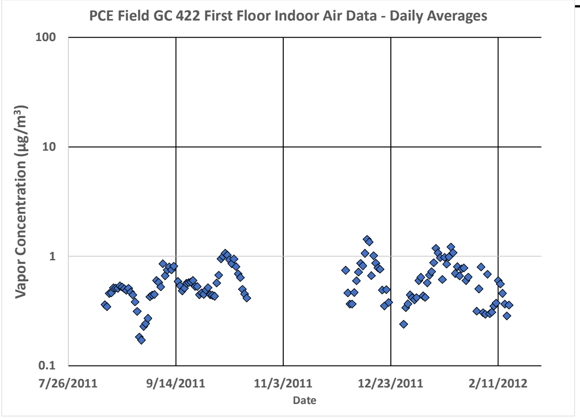
Sampling Performance With Little Skew – Indianapolis First Floor: Daily (8/9/11 – 2/27/12) Weekly (3/30/11 -2/27/12)

Your chances of once

- Seeing PCE sample over the 90th percentile with four daily (four weekly) samples:
  - Random = 37% (36%)
  - Only in heating season= 51% (39%) or in winter only = 51% (31%)
  - When radon >90th of full radon dataset = 58 % (80%)
  - When radon >90th of heating season Rn, in heating season= 85% (80%)
- Seeing PCE over the 50th percentile of cumulative VOCs with four daily (four weekly) samples:
  - Random = 81% (81%)
  - In winter only = 91% (95%)
  - When radon >90th of full radon dataset = 99% (100%)
  - When radon >90th of heating season Rn, in heating season=100% (93%)





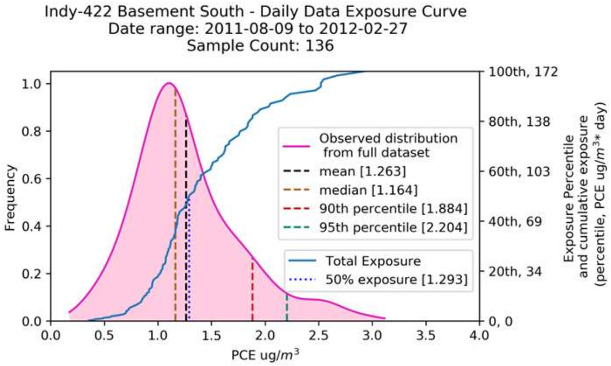


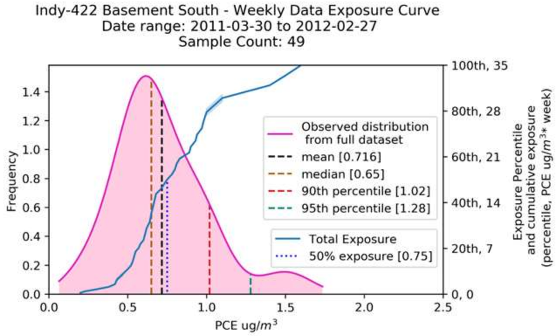
Key Points: Weeklong sampling compared to weeklong distribution sometimes better than daylong sample compared to daily distribution.

Daily and Weekly distributions are different time periods here.

This case is at a distance from source, preferential pathway influenced on neighborhood scale.

Sampling Performance in a Case With Little Skew and Weaker Radon/VOC Correlation – Indianapolis South Basement:
Daily Data 8/9/11- 2/27/12
Weekly Data: 3/30/11 – 2/27/12


Indy-422 Basement South - Daily Data Exposure Curve
Date range: 2011-08-09 to 2012-02-27
Sample Count: 136


Indy-422 Basement South - Weekly Data Exposure Curve
Date range: 2011-03-30 to 2012-02-27
Sample Count: 49

Your chances of once:

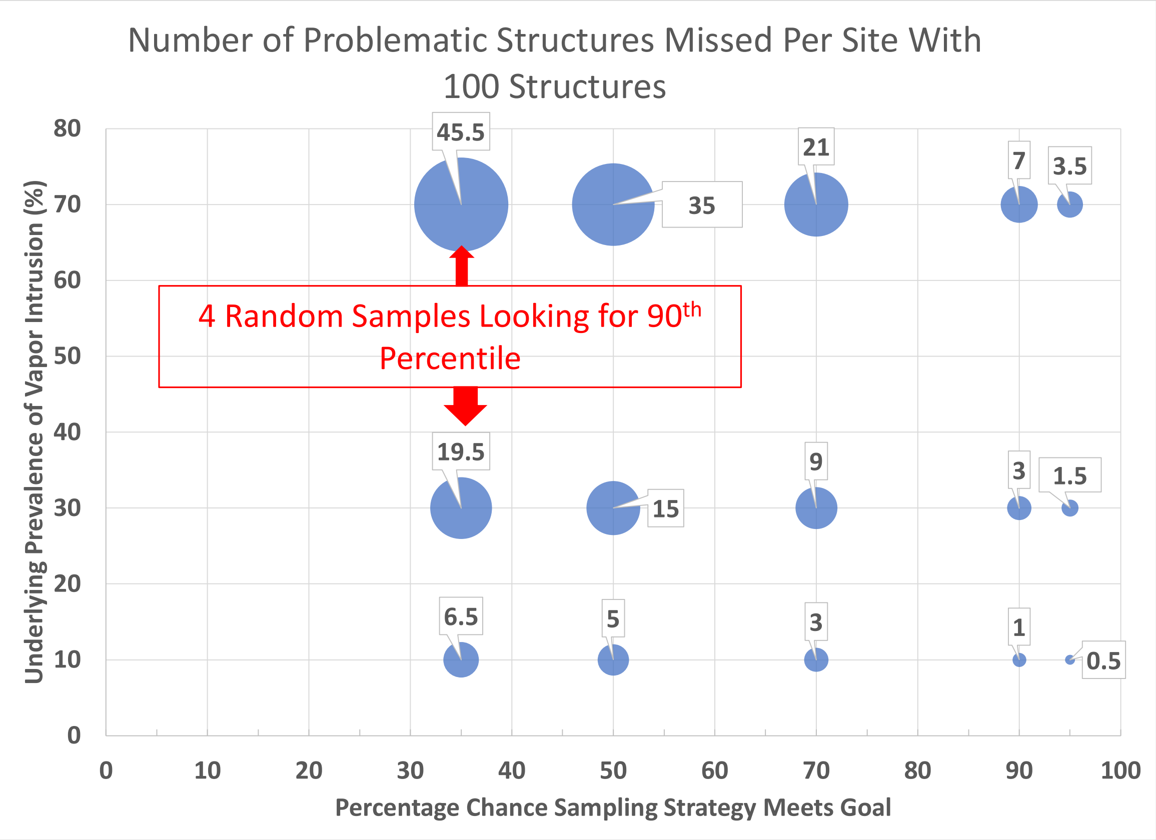
- Seeing PCE sample over the 90th percentile with four daily (weekly) samples:
  - Random 36% (36%)
  - Only in heating season 61% (53%), in winter only 61% (54%)
  - When radon >90th of full radon dataset 48% (0%)
  - When radon >90th of heating season radon and during heating season : 93% (0%)
  - Radon >2 pCI/l: 37% (33%)
- Seeing PCE over the 50th percentile of cumulative VOCs with four daily (weekly) samples:
  - Random: 84% (85%)
  - Only in heating season 98% (91%), in winter only 98% (90%)
  - When radon >90th of full radon dataset 64% (0%)
  - When radon >90th of heating season radon and heating season 99% (0%)
  - Radon >2 pCI/l: 86% (87%)

Key Point: Weeklong sampling compared to weeklong sample distribution was not better in this case than comparing daylong sampling estimated daily distribution. Available datasets were of different durations.
This case was influenced by a preferential pathway on neighborhood scale

How Many Buildings with Problematic VI Would We Miss Per Site Sampling Strategy is Weak?

Scenarios analyzed:

- Percentage chance that sampling strategy meets the performance goal (i.e. sees the 90th percentile with at least one of foursamples) = 35%, 50%, 70%, 90% or 95%
- Number of structures evaluated: 10, 30, or 100
- True underlying percentage of unacceptable VI in the population of structures (prevalence): 10%, 30% or 70%
- **Answers range from:** 0.05 buildings to 35 buildings missed



Number of Problematic Structures Missed Per Site With 100 Structures

Key Point: If your sampling strategy is weak, and VI is common, you miss a lot of problematic structures.

Summary Across Multiple Sites – Sampling Analysis

- In each individual case analyzed, an I&T based sampling rule and/or a seasonal based sampling rule can be identified that substantially outperforms random sampling.
- However, the top performing I&T based rule is not the same across all sampling zones, so additional mechanistic insight is needed to select *a priori* the optimum sampling rule for a given sampling zone.
- An *a priori* selection of sampling rule would need to be based on the information generally available before initiating sampling at a given building: climate zone, building type, and a conceptual site model describing the primary source of contamination (groundwater vs. soil).
- Making decisions based on four randomly or convenience based short term samples will not likely characterize the 90th or higher percentile of the concentration distribution.
- At some sites with highly skewed concentration distributions, making decisions based on four randomly or convenience based short term samples will underestimate the mean long-term concentration, because a small percentage of the dates contribute >50% of the total exposure.
- Extending sample durations to weekly provides in many cases a modest incremental benefit in increasing the probability of reaching a performance goal for a sampling timing approach.

For further Information

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Jacobs

Challenging today.
Reinventing tomorrow.

The Performance of Purely Random Sampling Can Be Determined Mathematically if the Metric is the 95th Percentile of the Distribution (a noncancer criteria assumption)

- You have a 5% chance with one random sample of observing the >95th percentile of any distribution.
- You have a 9.7% chance with two random samples of observing the >95th percentile of any distribution.
- You have a **18.5%** chance with **four** random samples of observing the >95th percentile
- You have a **95%** chance with **58** random samples of observing the 95th percentile once

Image from https://wi101.wisc.edu/2020/09/09/object-history-a-twenty-sided-die/