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

How Vapor Intrusion Data Measured by Communities and Supported by Regulators Can Create "Soil Gas Safe Communities"

Results and Interpretation of Sampling Strategy and Equivalent Protection Cost Effectiveness Analyses

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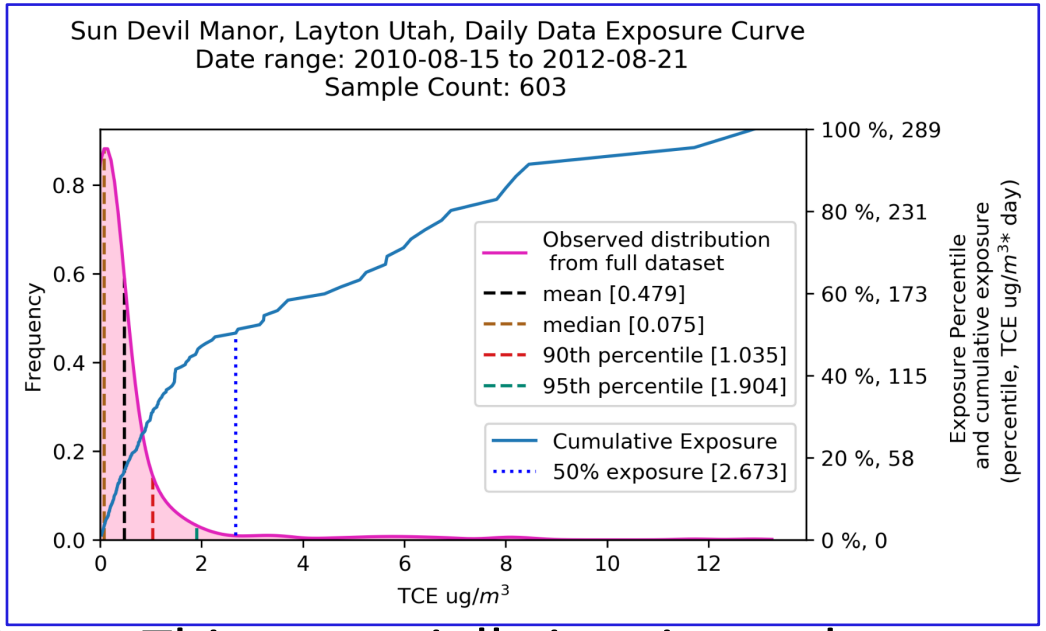
Presentation archived at https://iavi.rti.org/

Presentation Outline

- How the effectiveness of various sampling scheduling approaches were tested. (Assuming that all of the sites are inclusion zone).
- How the various sampling scheduling approaches performed at specific sites
- How easy is it to observe various metrics (indicators RME)
  - mean concentration, 95th UCL on mean,
  - 90th percentile, 95th percentile,
  - 50% total exposure point?



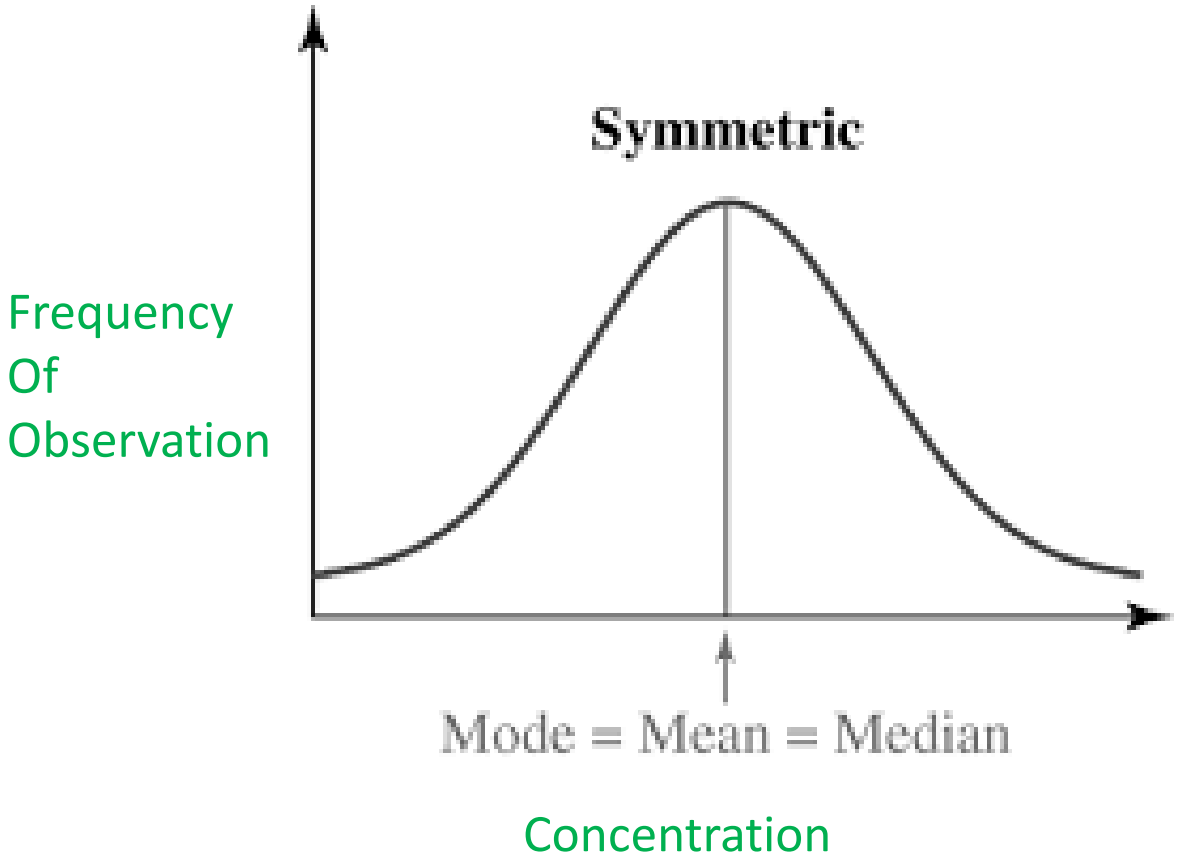
- Relative costs of equivalent protection:
  - Random sampling
  - Seasonal sampling
  - I&T (radon in this case) guided sampling
  - Radon only vapor control (mitigation) decisions. This essentially is using radon as a surrogate.

The Performance of Purely Random Sampling Can Be Determined Mathematically if the Metric is the 95th Percentile of the Distribution (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/

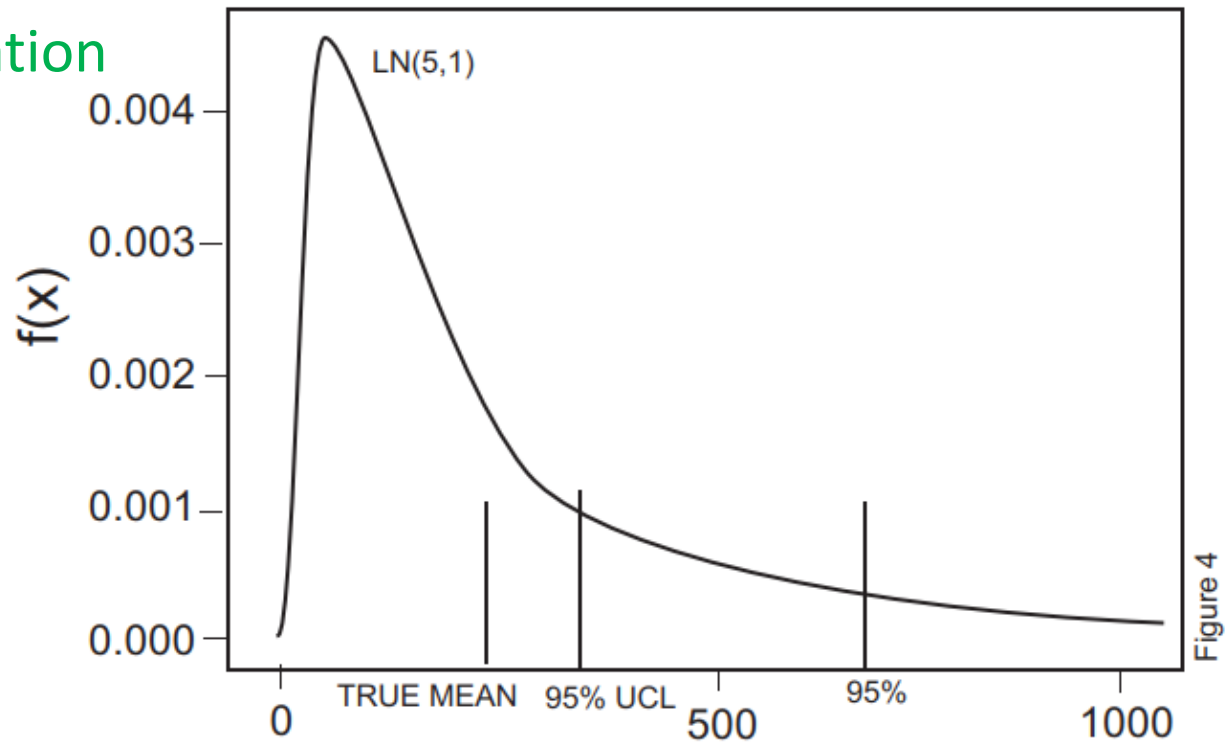
If The Distribution is Symmetrical (or Normal) It is Relatively Easy to See the Mean (cancer risk criteria) With a Few Samples



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.

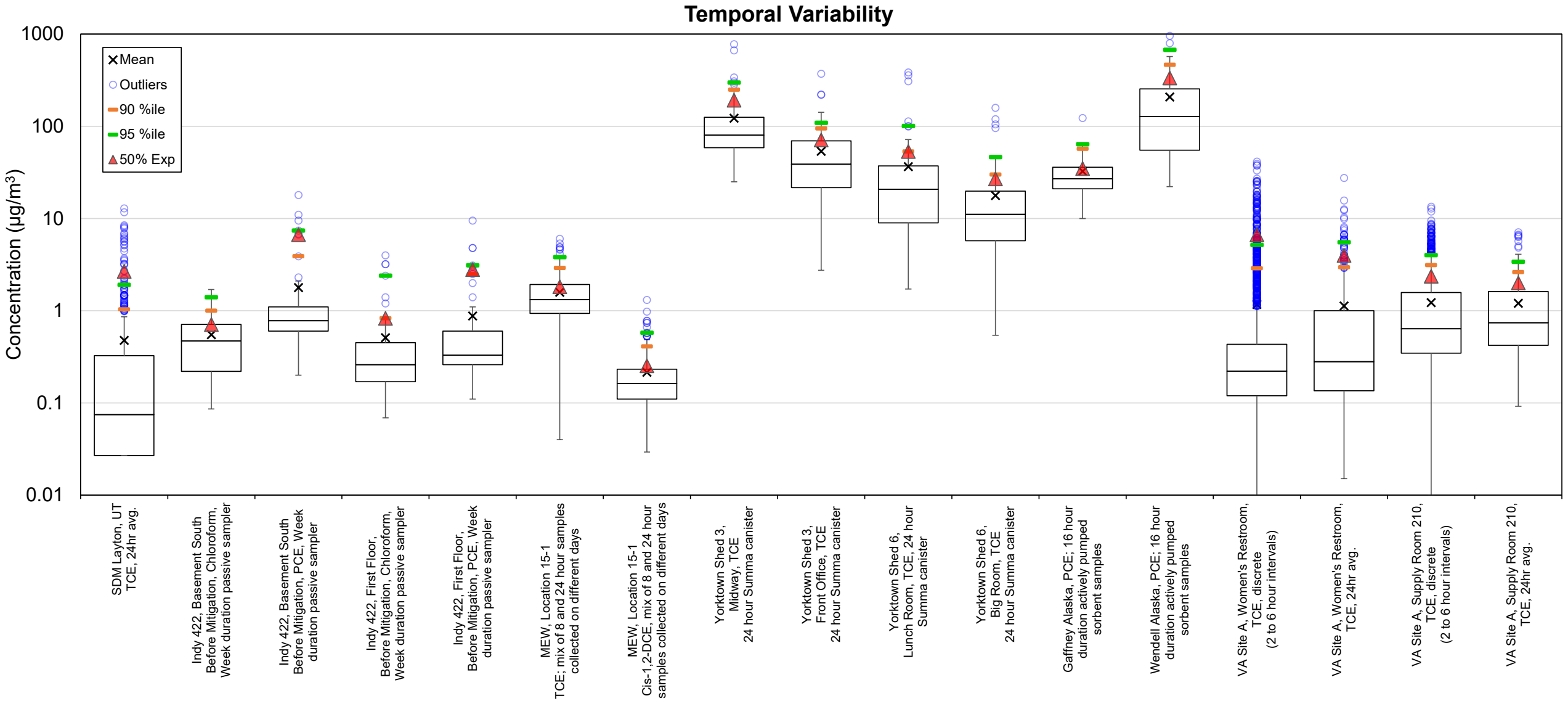
But: It is Much Harder to Observe the True Mean With a Small Number of Samples When the Distribution is Skewed - as it Often Is in Environmental Samples

Frequency Of Observation



Concentration

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



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

Results – Sampling Analysis

- These are results from a recently completed analysis, that have not been peer reviewed
- The sampling analysis results are expressed as the percentage chance that each sampling approach provides of observing the target metric in a particular dataset.
- Results are presented by building after a brief summary of the building characteristics

Results – Equal Protection Analysis

- Four strategies are compared: Random sampling, Seasonal sampling, ITS Driven Sampling and Mitigation based solely on Radon > ambient.
- Recall from AJ's presentation that assessment stops when mitigation is required OR when
  - For cancer a set of at least 12 samples shows 95% UCL on mean below action level.
  - 58 samples for noncancer show no exceedance (random sampling 95th percentile)
- Currently the results of decision making for cancer and noncancer risks are presented separately. In reality the same data is used for both determinations, so the assessment will stop when either criteria requires mitigation.

Data Sets Analyzed

(Sun Devil Manor and VA Site A TCE, and Indianapolis PCE all µg/m^3)

Site/Averaging Duration	Mean	95th UCL on Mean	50th Percentile of Cumulative Total Exposure Curve	95th Percentile of Dataset	Date start	Date end	Number of samples
Sun Devil Manor Daily	0.48	0.58	2.67	1.90	8/15/10	8/21/12	603
Sun Devil Manor Weekly	0.48	0.67	1.27	2.57	8/15/10	8/21/12	95
Indy Base N Week	0.49	0.54	0.53	0.77	3/30/11	2/27/12	45
Indy Base S Day	1.26	1.34	1.29	2.20	8/9/11	2/27/12	136
Indy Base S Week	0.72	0.80	0.75	1.28	3/30/11	2/27/12	49
Indy First Floor Daily	0.61	0.65	0.66	1.08	8/9/11	2/27/12	136
Indy First Floor Weekly	0.36	0.42	0.40	0.77	3/30/11	2/27/12	49
VA Site A Daily Womens BR	0.91	1.08	3.66	4.42	5/17/19	1/10/21	589
VA Site A Weekly Womens BR	0.90	1.15	2.02	3.08	5/17/19	1/10/21	87
VA Site A Daily Supply Room	0.96	1.05	1.71	3.02	5/17/19	1/10/21	589
VA Site A Weekly Supply Room	0.96	1.13	1.62	2.67	5/17/19	1/10/21	87
VA Site A Daily Location 08	1.27	1.46	2.61	5.31	4/19/19	2/3/20	230

VA Site A – Building Characteristics

- ~120,000 ft^2 building constructed of brick with a poured concrete slab and divided into three large bays. The slab is generally 6 to 8 inches thick.
- Heat provided by steam-fired unit heaters with overhead fans in the warehouse/storage bays.
- No centralized cooling system within the warehouse space. During Summer, bay doors are kept open and portable fans provide airflow.
- Various wood-framed office areas constructed separately within the bays with separate ceilings and HVAC units.
  - Separate spaces operate as ”zones within larger zones”
- 18 months of frequent GC Concentration observations used.
- Soil Source

VA Site A – One Daily Sample In Supply Room

Concentrations µg/m³:	*0.96*	*1.05*	*1.71*	*3.02*
Rule Description	one sample ≥ true mean	one sample will be ≥ 95% UCL of the mean	one sample > the 50th percentile of the cumulative exposure curve	one sample ≥ the 95th percentile of underlying distribution
Only sample outside of heating season	12%	11%	4%	1%
Random sampling	**33%**	**31%**	**17%**	**5%**
Indoor outdoor differential temperature of 15F or more	35%	33%	18%	6%
Only sample in heating season	67%	64%	39%	13%
Radon greater than 90th percentile of heating season radon data	79%	75%	50%	25%
Radon concentration greater than 2 pCi/L radon	100%	83%	50%	50%

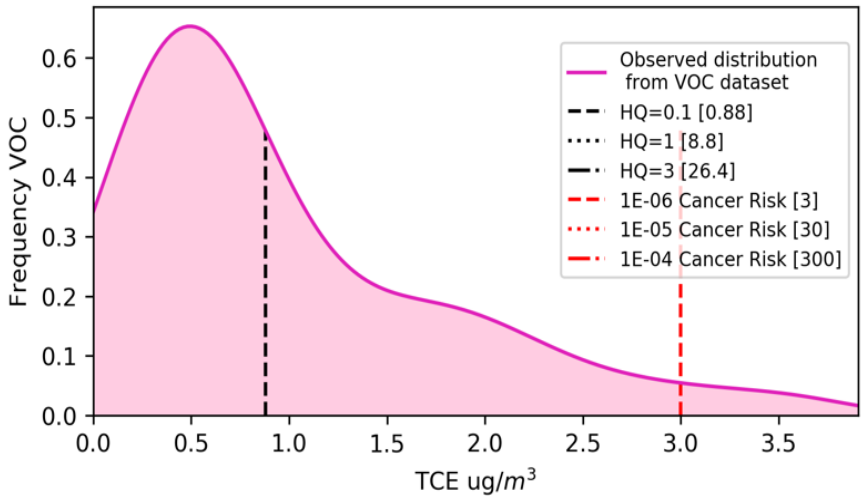
- This zone has "classical stack effect" behavior – thus our temperature, seasonal and radon sampling approaches generally perform better here than at other locations/sites.
- Sampling approaches calling for sampling only during the heating season OR with> 2 pCI/l or >90% radon performed well

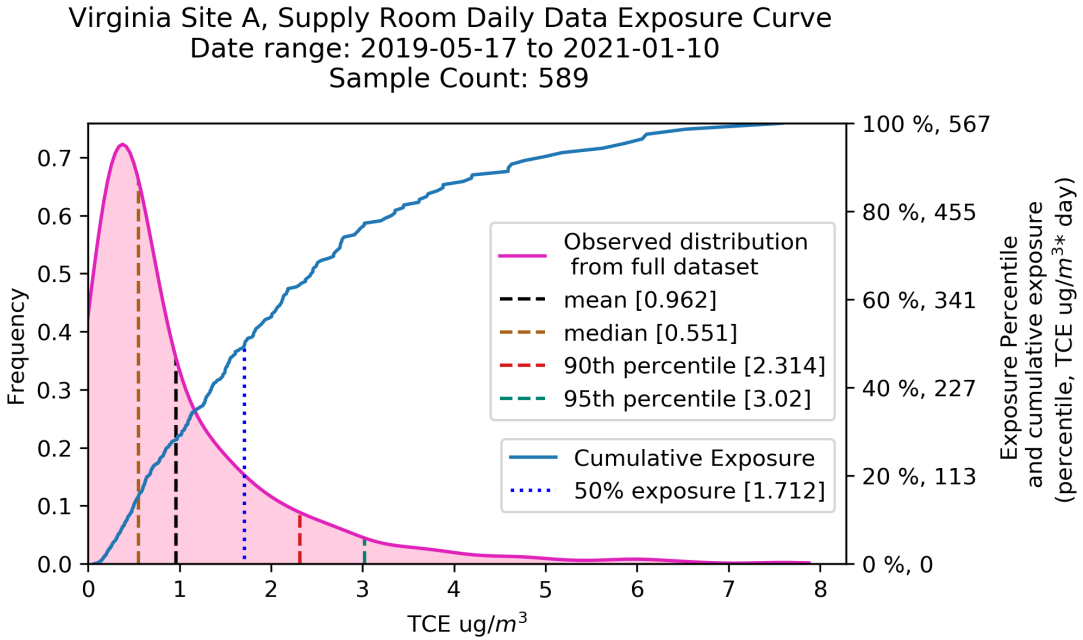
VA Site A – Four Daily Samples In Supply Room

Concentrations µg/m³:	*0.96*	*1.05*	*1.71*	*1.71*	*3.02*
Rule Description	At least one sample of the four samples taken ≥ true mean	At least one of the four samples taken ≥ the 95% UCL of the mean	At least one of 4 samples > the 50th percentile of the cumulative exposure curve	The mean of 4 drawn samples > 50% exposure value of the underlying distribution	At least one of the four samples > the 95th percentile of the underlying distribution
1 sample in heating season, 1 outside of heating season	77%	73%	39%	39%	19%
Random sampling	**80%**	**77%**	**52%**	**10%**	**19%**
Only sample in heating season	99%	98%	86%	44%	42%
Avg temp decrease of 5F or more	76%	72%	42%	6%	14%
Low temp decrease of 5F or more	78%	75%	46%	7%	15%
Indoor outdoor differential temperature of 15F or more	82%	80%	55%	11%	20%
Day over day radon concentration change of +0.5 pCi/L or more	99%	98%	78%	60%	71%
Radon greater than 90th percentile of full radon dataset	100%	99%	93%	61%	63%

- Four random samples provides reasonable performance with regard to the true mean but not 50% cumulative exposure.
- Radon guided and heating season driven strategies most beneficial.

VA Site A Supply Room : Distribution and Mitigation Decision Making





- Industrial screening levels for TCE used
- The majority of individual measurements are below the 10^{-6} TCR screening level and many of the individual measurements are near the HQ=0.1 screening level
- The mean is well below the 10^{-6} TCR screening level
- The 95th percentile daily concentration lies between HQ=0.1 and HQ=1
- Thus, if the full dataset was available mitigation would only be performed if the HQ=0.1 noncancer screening level was used as an action level

VA Site A Supply Room- Economic Analysis Results

Risk Screening Metric	Sampling Rule	Samples	Sample Cost	Mitigate?	Mitigation	Total Cost
1e-4canrisk	ITS Triggered	12	$137,584	No	$0	$137,584
1e-4canrisk	Random	12	$134,784	No	$0	$134,784
1e-4canrisk	Seas	96	$1,078,272	No	$0	$1,078,272
1e-5canrisk	ITS Triggered	12	$137,584	No	$0	$137,584
1e-5canrisk	Random	12	$134,784	No	$0	$134,784
1e-5canrisk	Seas	96	$1,078,272	No	$0	$1,078,272
1e-6canrisk	ITS Triggered	12	$137,584	No	$0	$137,584
1e-6canrisk	Random	12	$134,784	No	$0	$134,784
1e-6canrisk	Seas	96	$1,078,272	No	$0	$1,078,272
HQ=0.1	ITS Triggered	1	$14,032	Yes	$76,939	$90,971
HQ=0.1	Random	2	$22,464	Yes	$76,939	$99,403
HQ=0.1	Seas	2	$22,464	Yes	$76,939	$99,403
HQ=1	ITS Triggered	58	$654,256	No	$0	$654,256
HQ=1	Random	58	$651,456	No	$0	$651,456
HQ=1	Seas	58	$651,456	No	$0	$651,456
HQ=3	ITS Triggered	58	$654,256	No	$0	$654,256
HQ=3	Random	58	$651,456	No	$0	$651,456
HQ=3	Seas	58	$651,456	No	$0	$651,456
Radon Over Ambient	Radon Over Am	2	$2,800	Yes	$76,939	$79,739

- Random and ITS guided sampling approaches are considerably less expensive than the seasonal based sampling.
- The three sampling approaches that include active VOC sampling produce the “correct” result of mitigating only when HQ=0.1 is the action level.
- Radon only decision making led to mitigation, which was conservative but low cost.

Seas = Seasonal

Note: costs are for the 7,200 square foot building that has data like VA site A – not for this actual building or room.

VA Site A – One Daily Sample in Women's Bathroom

Concentrations µg/m³:	*0.91*	*1.08*	*3.66*	*4.42*
Rule Description	one sample ≥ true mean	one sample will be ≥ 95% UCL of the mean	one sample > the 50th percentile of the cumulative exposure curve	one sample ≥ the 95th percentile of underlying distribution
Only sample outside of heating season	9%	8%	2%	2%
Radon greater than 90th percentile of heating season radon data	10%	10%	4%	4%
Random sampling	**20%**	**19%**	**7%**	**5%**
Indoor outdoor differential temperature of 15F or more	23%	21%	7%	6%
Only sample in heating season	40%	36%	14%	10%
Differential pressure >2.49 Pa into the building	47%	44%	17%	13%

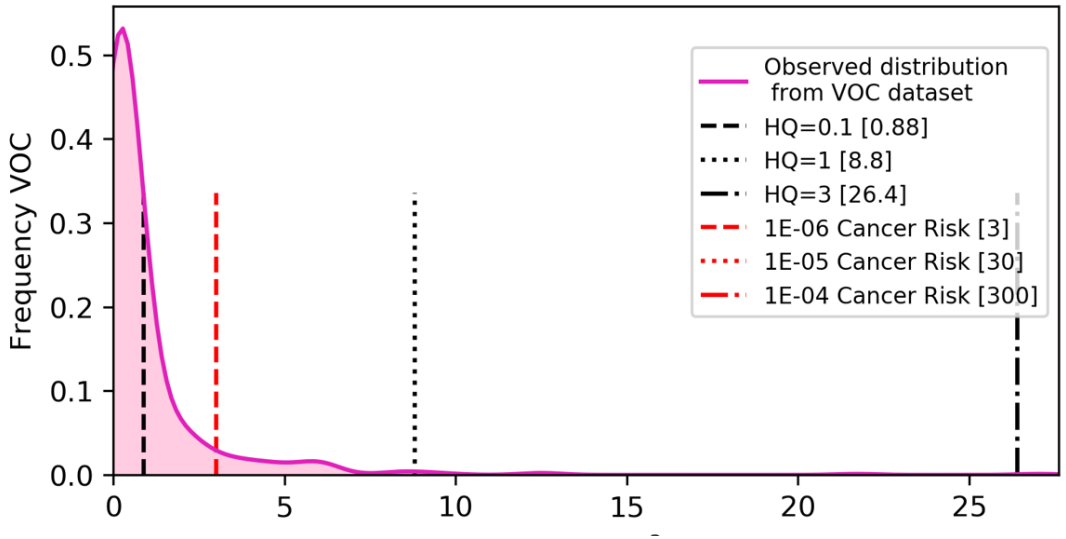
- Nontypical seasonal pattern – possible preferential pathway case
- Heating season and differential pressure outperform random
- No strategy gives good odds of getting over 50th percentile total exposure or 95th percentile of distribution
- Radon performed poorly in this portion of the dataset

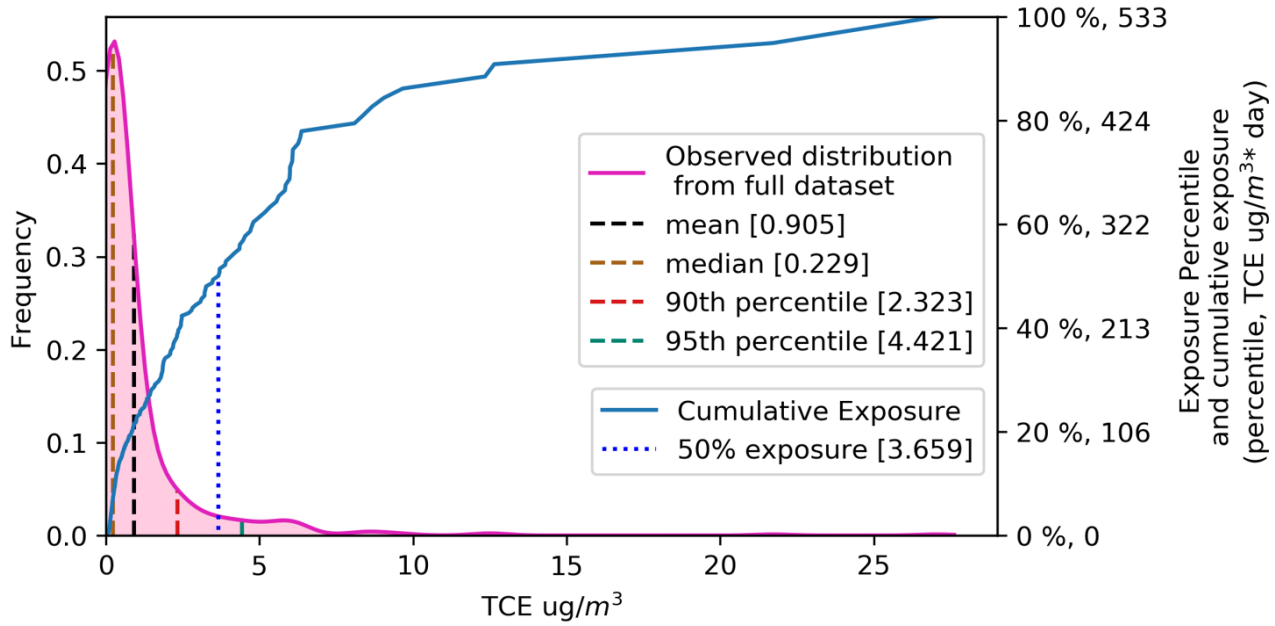
VA Site A –Four Daily Samples in Women's Bathroom

Concentrations µg/m³:	*0.91*	*1.08*	*3.66*	*3.66*	*4.42*
Rule Description	At least one sample of the four samples taken will equal or exceed the true mean concentration	At least one of the four samples taken will be equal to or exceed the 95% UCL of the mean of the VOC distribution	At least one of 4 samples will exceed the 50th percentile of the cumulative exposure curve	The mean of 4 drawn samples will exceed the 50% exposure value of the underlying distribution (simulated 10,000 4 sample draws)	At least one of the four samples will exceed the 95th percentile of the underlying distribution
Radon greater than 90th percentile of full radon dataset	26%	26%	9%	0%	9%
1 sample in heating season, 1 outside of heating season	66%	55%	27%	46%	16%
Random sampling	**60%**	**56%**	**24%**	**2%**	**19%**
Indoor outdoor differential temperature of 15F or more	64%	61%	26%	3%	20%
Only sample in heating season	87%	84%	46%	8%	36%
Differential pressure >2.49 Pa into the building	92%	91%	53%	13%	43%

- Nontypical seasonal pattern – possible preferential pathway case
- Heating season and differential pressure outperform random
- No strategies give good odds of getting over 50th percentile total exposure or 95th percentile of distribution
- Radon performed poorly in this portion of the dataset

VA Site Women's Restroom Distribution and Mitigation Decision Making





- Industrial screening levels for TCE used
- The mean of the full distribution is below 10^{-6} so mitigation is not needed for cancer.
- The 95th percentile is above HQ= 0.1 but below HQ=1.
- Thus if the full data set was available mitigation is only needed for noncancer if HQ=0.1 is used as the action level.

VA Site Women's Restroom – Economics Results

Risk Screening Metric	Sampling Rule	Samples	Sample Cost	Mitigate?	Mitigation Cost $	Total Cost
1e-4canrisk	ITS Triggered	12	$137,584	No	$0	$137,584
1e-4canrisk	Random	12	$134,784	No	$0	$134,784
1e-4canrisk	Seas	96	$1,078,272	No	$0	$1,078,272
1e-5canrisk	ITS Triggered	12	$137,584	No	$0	$137,584
1e-5canrisk	Random	12	$134,784	No	$0	$134,784
1e-5canrisk	Seas	96	$1,078,272	No	$0	$1,078,272
1e-6canrisk	ITS Triggered	12	$137,584	No	$0	$137,584
1e-6canrisk	Random	12	$134,784	No	$0	$134,784
1e-6canrisk	Seas	96	$1,078,272	No	$0	$1,078,272
HQ=0.1	ITS Triggered	10	$115,120	Yes	$76,939	$192,059
HQ=0.1	Random	3	$33,696	Yes	$76,939	$110,635
HQ=0.1	Seas	3	$33,696	Yes	$76,939	$110,635
HQ=1	ITS Triggered	58	$654,256	No	$0	$654,256
HQ=1	Random	58	$651,456	No	$0	$651,456
HQ=1	Seas	56	$628,992	No	$0	$628,992
HQ=3	ITS Triggered	58	$654,256	No	$0	$654,256
HQ=3	Random	58	$651,456	No	$0	$651,456
HQ=3	Seas	58	$651,456	No	$0	$651,456
Radon Over Ambier	Radon Over Ambient	58	$651,456	No	$0	$2,800

Note: costs are for the 7,200 square foot building that has data like VA site A – not for this actual building or room.

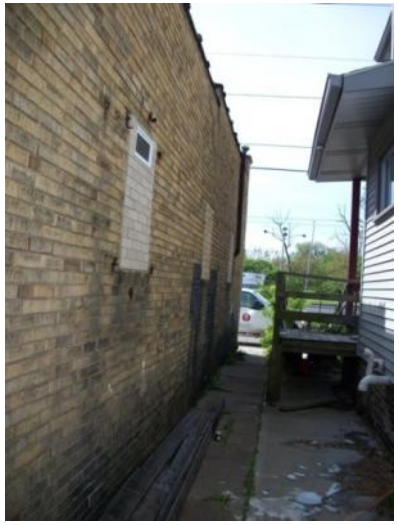
- Either ITS triggered or random sampling gets to the conclusion that cancer risk is not a concern in the minimum number of rounds assessed.
- Costs are similar for the noncancer.
- But radon only is by far lowest cost.

Seas = Seasonal

Indianapolis Duplex

- Study duplex on 1915 Sanborn Map
- Basement +2 overlying floors
- Unoccupied, unfurnished
- Heated and unheated sides
- 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
- Year long weekly passive sampling campaign
- Selected periods of high frequency GC Data

Cracks in basement concrete floor and brick walls



Indianapolis Basement South Single Daily Sample

Concentrations µg/m³:	*1.26*	*1.34*	*1.29*	*2.20*
Rule Description	one sample ≥ true mean (1.26 µg/m³)	one sample will be ≥ 95% UCL of the mean	one sample > the 50th percentile of the cumulative exposure curve	one sample ≥ the 95th percentile of underlying distribution
Only sample outside of heating season	18%	9%	10%	0%
Radon greater than 90th percentile of heating season radon data	24%	19%	19%	10%
Random sampling	**40%**	**33%**	**36%**	**5%**
Differential pressure >2.49 Pa into the building	47%	47%	47%	7%
DT of 15F or more AND DP >2.49 Pa into the building	50%	50%	50%	10%
Day over day radon concentration change of +0.5 pCi/L or more	48%	38%	40%	7%
Only sample in heating season	61%	57%	61%	10%
Radon greater than 90th percentile of heating season radon and heating season	50%	50%	50%	25%

- Many metrics here provided some benefit over random
- Suggests a stack effect mechanism. Evidence suggests preferential pathway to subslab plenum.
- Increasing radon significantly outperformed 90th percentile radon in this case.

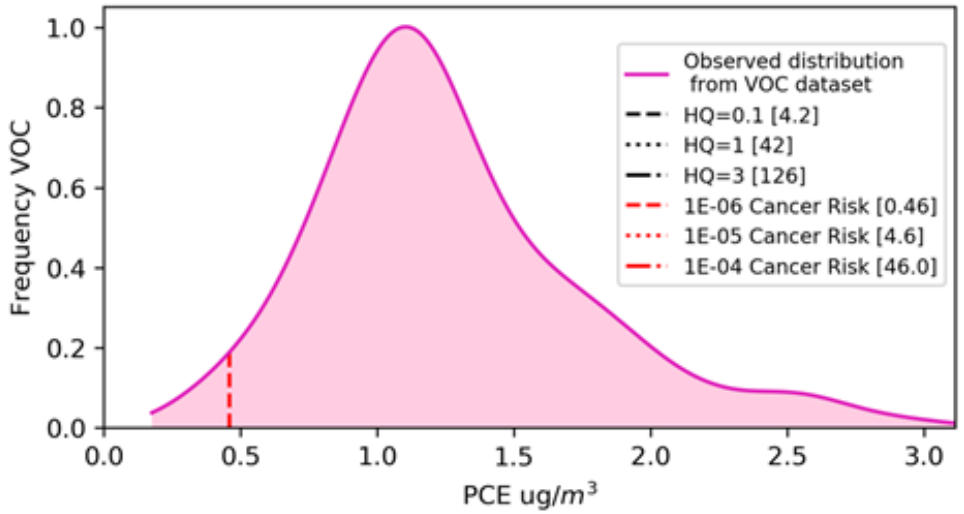
Indianapolis Basement South – 4 Daily Samples

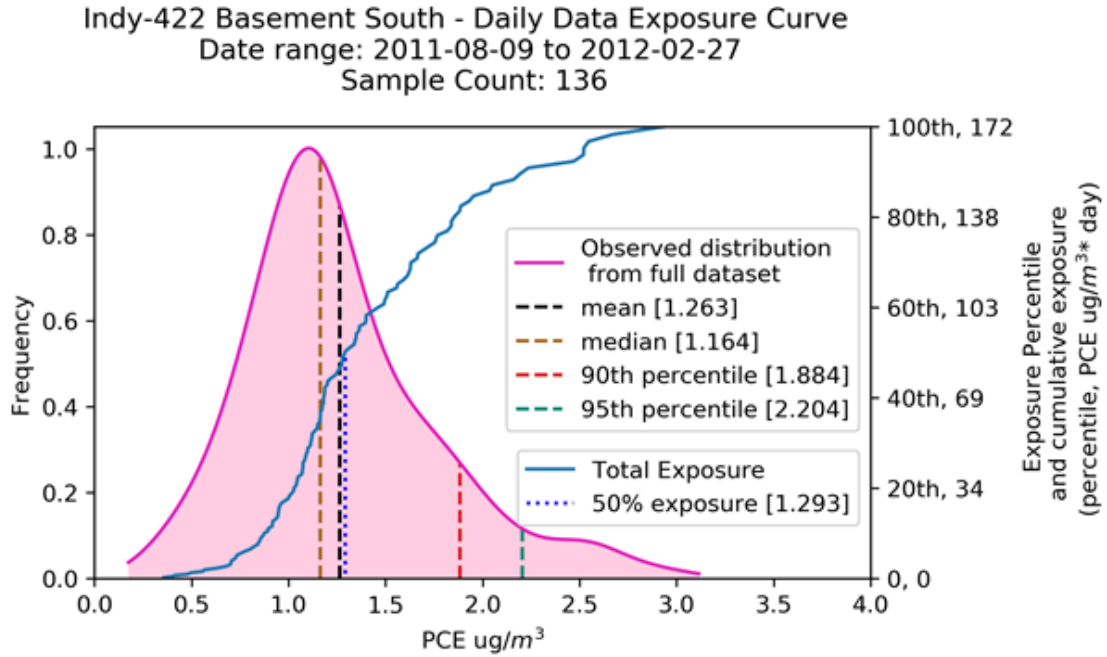
Concentrations µg/m³: *1.26* *1.34* *1.29* *1.29* *2.20*

Rule Description	At least one sample of the four samples taken ≥ the true mean	At least one of the four samples ≥ the 95% UCL of the mean	At least one of 4 samples > the 50th percentile of the cumulative exposure curve	The mean of 4 drawn samples > the 50% exposure value of the underlying distribution	At least one of the four samples> the 95th percentile of the underlying distribution
1 sample in heating season, 1 outside of heating season	68%	60%	65%	36%	10%
Random sampling	**87%**	**80%**	**84%**	**41%**	**19%**
Radon concentration greater than 2 pCi/L radon	89%	83%	86%	47%	20%
Radon greater than 90th percentile of full radon dataset	76%	64%	64%	48%	48%
Only sample in heating season	98%	97%	98%	80%	35%
Indoor outdoor differential temperature of 15F or more	99%	98%	99%	83%	39%
Differential pressure >2.49 Pa into the building	95%	95%	95%	69%	27%
Radon greater than 90th percentile of heating season radon and heating season	99%	99%	99%	93%	79%

- Note this dataset is mostly from winter and fall so random isn't truly random over the whole year.
- Heating season, radon and differential pressure I&T are all useful.

Indianapolis Basement South Daily Distribution and Mitigation Decision Making





- The constituent of concern is PCE, thus the observed concentrations only exceed the 10^{-6} risk-based screening level (and only based on CA toxicity values)
- All of the other risk-based screening levels are not shown because they are off scale.
- The true mean of 1.26 µg/m^3 is between the 10-6 and 10-5 screening levels
- The 95th percentile of 2.2 µg/m^3 is below the HQ = 0.1 value.
- Thus, the structure should not be mitigated based on the full dataset unless a cancer risk action level of 10^{-6} is chosen.
- Note that correct decision might well be different if either radon or chloroform risks were considered.

Indianapolis Basement South Daily Data Economic Analysis Results

Risk Screening Metric	Sampling Rule	Samples	Sample Co	Mitigate?	Mitigation	Total Cost
1e-4canrisk	ITS Triggered	12	$66,600	No	$0	$66,600
1e-4canrisk	Random	12	$64,800	No	$0	$64,800
1e-4canrisk	Seas					
1e-5canrisk	ITS Triggered	12	$66,600	No	$0	$66,600
1e-5canrisk	Random	12	$64,800	No	$0	$64,800
1e-5canrisk	Seas					
1e-6canrisk	ITS Triggered	2	$12,600	Yes	$11,500	$24,100
1e-6canrisk	Random	2	$10,800	Yes	$11,500	$22,300
1e-6canrisk	Seas	2	$10,800	Yes	$11,500	$22,300
HQ=0.1	ITS Triggered	58	$315,000	No	$0	$315,000
HQ=0.1	Random	58	$313,200	No	$0	$313,200
HQ=0.1	Seas	58	$313,200	No	$0	$313,200
HQ=1	ITS Triggered	58	$315,000	No	$0	$315,000
HQ=1	Random	58	$313,200	No	$0	$313,200
HQ=1	Seas	58	$313,200	No	$0	$313,200
HQ=3	ITS Triggered	58	$315,000	No	$0	$315,000
HQ=3	Random	58	$313,200	No	$0	$313,200
HQ=3	Seas	58	$313,200	No	$0	$313,200
Radon Over Ambient	Radon Over Ambient	1	$1,800	Yes	$11,500	$13,300

Seas = Seasonal

- The lowest costs are achieved when the most stringent cancer risk level is considered. This counterintuitive result occurs because a decision to undertake mitigation is made with only a small number of sample rounds and sampling costs become more important than mitigation costs with the higher risk screening levels.

- The non-cancer results for this case always default to the probability based, distribution independent, data independent default of 58 samples to decide that no mitigation is needed

- It is likely that non-cancer risks would not be the primary factor in decision making at a PCE site using CA toxicity values and thus the economics would be controlled only by the cancer risk assessment.

Indianapolis First Floor – One Daily Sample

Concentrations µg/m³: 0.61 0.65 0.66 1.08

Rule Description	one sample ≥ true mean	one sample will be ≥ 95% UCL of the mean	one sample > the 50th percentile of the cumulative exposure curve	one sample ≥ the 95th percentile of underlying distribution
Only sample outside of heating season	28%	27%	24%	0%
Random sampling	**40%**	**36%**	**35%**	**5%**
Indoor outdoor differential temperature of 15F or more	49%	42%	41%	9%
Only sample in heating season	61%	45%	45%	10%
Day over day radon concentration change of +0.5 pCi/L or more	49%	46%	46%	9%
Radon greater than 90th percentile of non-hs radon dataset AND outside heating season	78%	78%	78%	0%
Radon greater than 90th percentile of heating season radon data	75%	70%	65%	10%
Radon greater than 90th percentile of heating season radon and heating season	71%	57%	57%	29%

- Heating season and radon-based strategies perform well.
- This is the only case where radon outside of the heating season is a strong predictor.

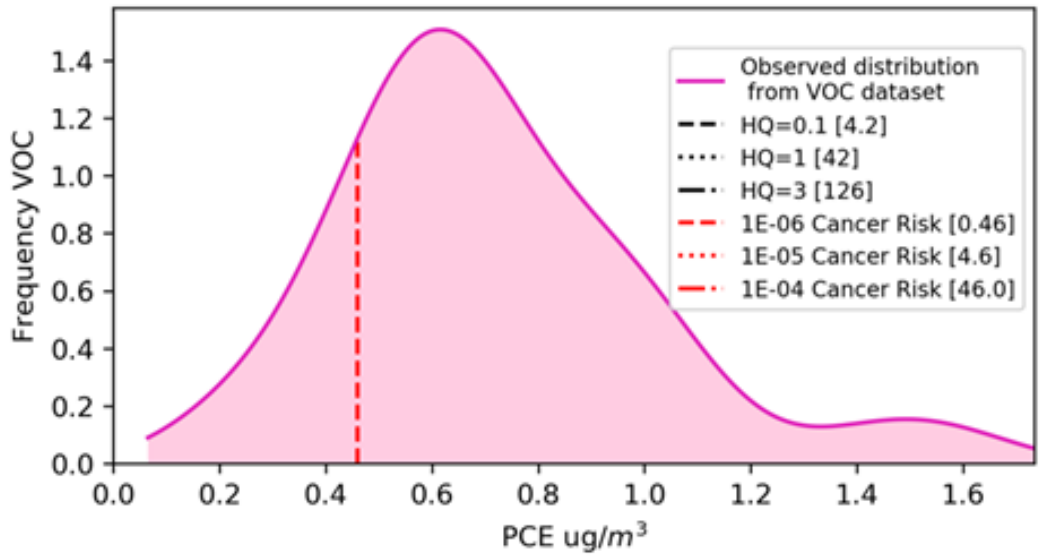
Indianapolis First Floor –Four Daily Samples

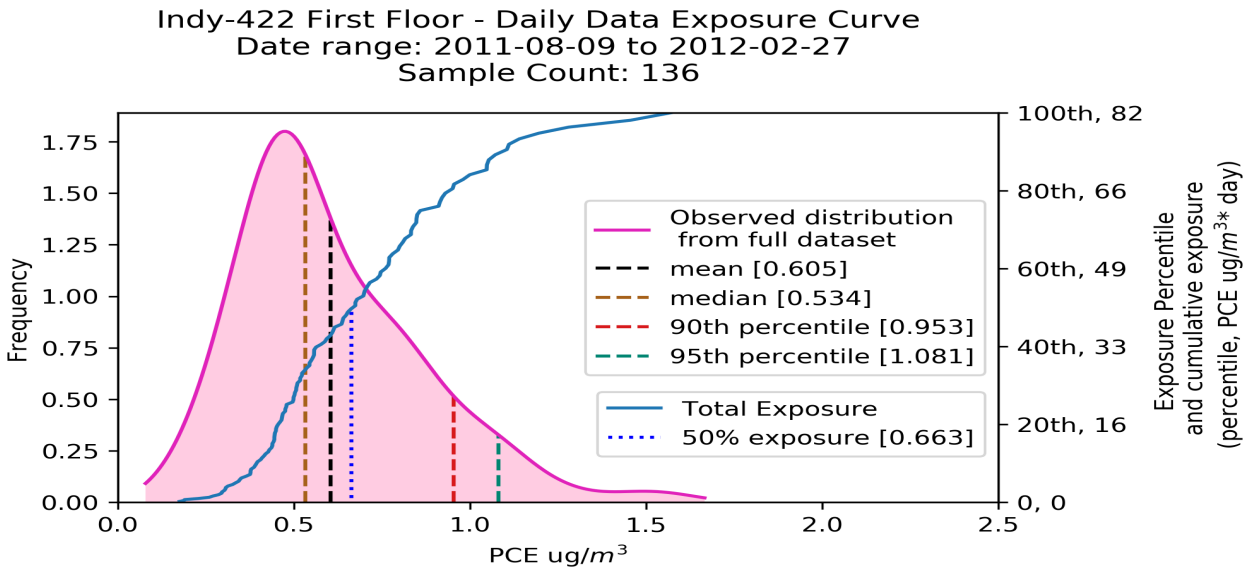
Concentrations µg/m³: *0.61* *0.65* *0.66* *0.66* *1.08*

Rule Description	At least one sample of the four samples taken ≥ the true mean	At least one of the four samples ≥ the 95% UCL of the mean	At least one of 4 samples > the 50th percentile of the cumulative exposure curve	The mean of 4 drawn samples > the 50% exposure value of the underlying distribution	At least one of the four samples > the 95th percentile
1 sample in heating season, 1 outside of heating season	66%	60%	58%	36%	10%
Random sampling	**88%**	**84%**	**82%**	**30%**	**19%**
Radon concentration greater than 2 pCi/L radon	92%	89%	87%	39%	22%
Radon greater than 90th percentile of full radon dataset	100%	100%	99%	77%	24%
Day over day radon concentration change of +0.5 pCi/L or more	94%	93%	93%	55%	31%
Only sample in heating season	95%	91%	91%	45%	35%
Indoor outdoor differential temperature of 15F or more	94%	89%	88%	42%	33%
Radon greater than 90th percentile of heating season radon and heating season	100%	100%	100%	86%	86%

- Data set predominantly winter so random odds are better then normal.
- Heating season, temperature and radon are beneficial I&T

Indianapolis First Floor Daily Distribution and Mitigation Decision Making





- Since the constituent of concern is PCE, the observed concentrations only exceed the 10^{-6} cancer risk-based screening level and only then using CA toxicity values.
- All of the other risk-based screening levels are not shown because they are off scale.
- The mean concentration is only modestly above the 10^{-6} TCR screening level and that the 95th percentile is well below the HQ=0.1 screening level.
- Thus, if the whole dataset was available, mitigation would only be implemented if decisions were being made based on the 10^{-6} TCR screening level.
- If radon or chloroform was included in the analysis the mitigation decision might differ.
- The weekly data might lead to a different decision since it was collected over a larger time period.

Indianapolis First Floor Daily Economics Results

Risk Screening Metric	Sampling Rule	Samples	Sample Cost	Mitigate?	Mitigation Cost	Total Cost
1e-4canrisk	ITS Triggered	12	$66,600	No	$0	$66,600
1e-4canrisk	Random	12	$64,800	No	$0	$64,800
1e-4canrisk	Seas			No	$0	
1e-5canrisk	ITS Triggered	12	$66,600	No	$0	$66,600
1e-5canrisk	Random	12	$64,800	No	$0	$64,800
1e-5canrisk	Seas			No	$0	
1e-6canrisk	ITS Triggered	3	$18,000	Yes	$11,500	$29,500
1e-6canrisk	Random	4	$21,600	Yes	$11,500	$33,100
1e-6canrisk	Seas	4	$21,600	Yes	$11,500	$33,100
HQ=0.1	ITS Triggered	58	$315,000	No	$0	$315,000
HQ=0.1	Random	58	$313,200	No	$0	$313,200
HQ=0.1	Seas	58	$313,200	No	$0	$313,200
HQ=1	ITS Triggered	58	$315,000	No	$0	$315,000
HQ=1	Random	58	$313,200	No	$0	$313,200
HQ=1	Seas	58	$313,200	No	$0	$313,200
HQ=3	ITS Triggered	58	$315,000	No	$0	$315,000
HQ=3	Random	58	$313,200	No	$0	$313,200
HQ=3	Seas	58	$313,200	No	$0	$313,200
Radon Over Ambien	Radon Over Amb	1	$1,800	Yes	$11,500	$13,300

Seas = Seasonal

- Since this is a PCE site primarily, the noncancer risks would probably not factor strongly in the sampling decision making.
- The most stringent cancer risk level results in lower costs because early mitigation is cheaper then 12 sample rounds.
- Radon only monitoring is the cheapest alternative even though it leads to mitigation.

Sun Devil Manor, Layton, Utah

- Two-story, split-level home on gradual slope, built in 1991
- Occupied 10-30% of time, HVAC settings for full time occupancy
- Fine sandy silt with fine sand stringers
- Depth to water 10-12 ft bgs, 10-50 µg/L TCE
- Over two years indoor air sampling, sampling at 2–4-hour intervals, converted to 24- hour data set
- Conduit VI pathway, land drain to subslab to indoor air

Sun Devil Manor – One Daily Sample

Concentrations µg/m³:	*0.48*	*0.58*	*2.67*	*1.90*
Rule Description	one sample ≥ true mean	one sample will be ≥ 95% UCL of the mean	one sample > the 50th percentile of the cumulative exposure curve	one sample ≥ the 95th percentile of underlying distribution
Only sample outside of heating season	4%	4%	0%	0%
Random sampling	**19%**	**17%**	**4%**	**5%**
Differential pressure >2.49 Pa into the building	43%	29%	0%	0%
Only sample in heating season	38%	32%	9%	11%
Day over day radon concentration change of +0.5 pCi/L or more	83%	83%	33%	33%
Radon greater than 90th percentile of heating season radon data	89%	84%	32%	42%
Radon greater than 90th percentile of heating season radon and heating season	89%	84%	32%	42%

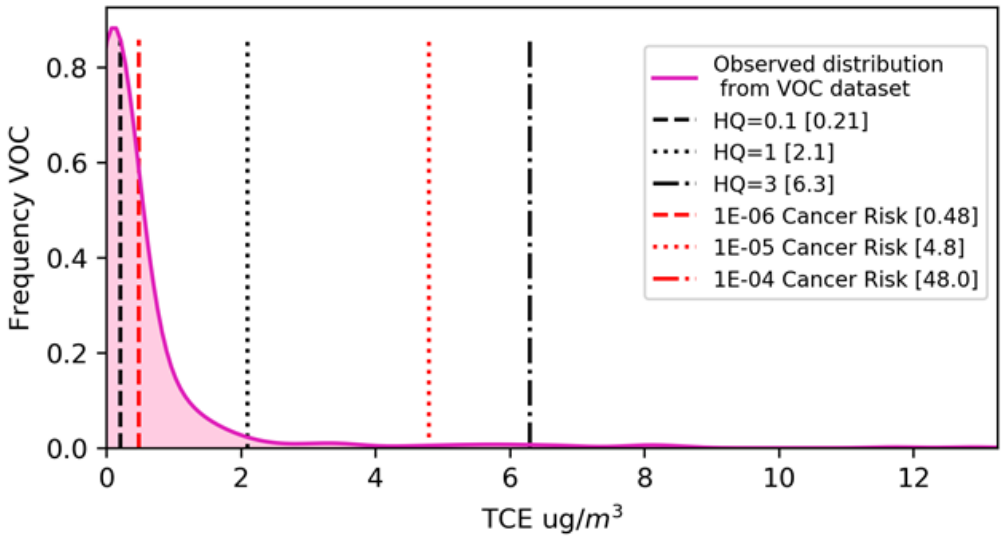
- Heating season only modestly beats random sampling
- Data set includes more heating season data than non-heating season data; this makes random sampling perform better then it ordinarily would have.
- Radon based measures are strong performers

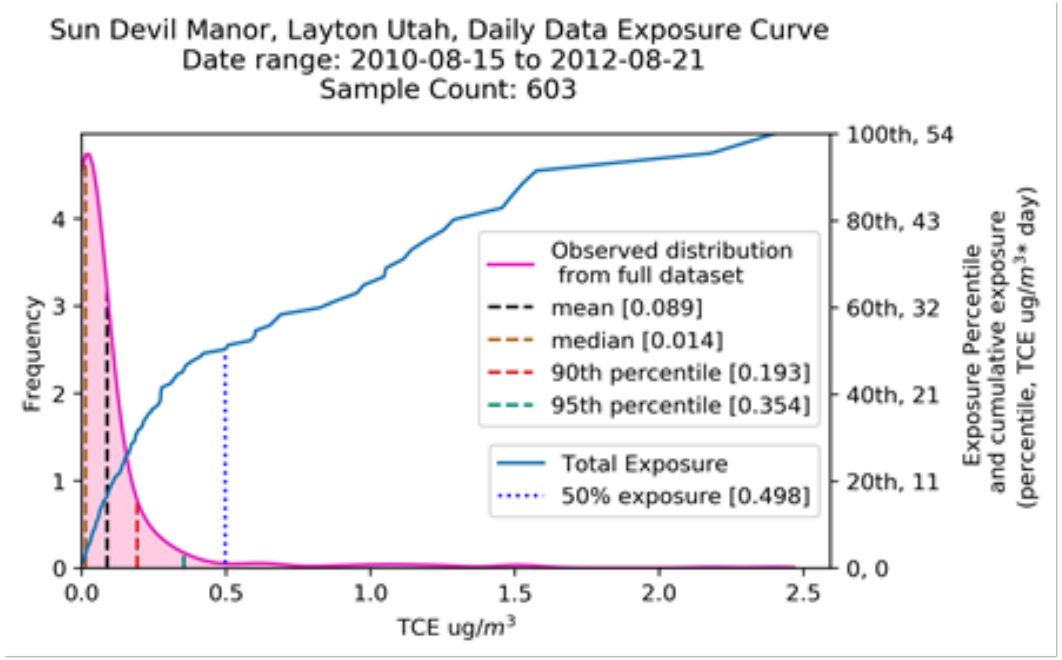
Sun Devil Manor –Four Daily Samples

Concentrations µg/m³:	*0.48*	*0.58*	*2.67*	*2.67*	*1.90*
Rule Description+N5N1C1:NC1:N21	At least one sample of the four samples taken ≥ the true mean	At least one of the four samples taken will ≥ the 95% UCL of the mean	At least one of 4 samples > the 50th percentile of the cumulative exposure curve	The mean of 4 drawn samples > the 50% exposure value of the underlying distribution	At least one of the four samples > the 95th percentile of the underlying distribution
Random sampling	**58%**	**52%**	**16%**	**2%**	**19%**
Avg temp decrease of 5F or more	57%	51%	17%	2%	20%
1 sample per season	100%	100%	2%	4%	2%
1 sample in heating season, 1 outside of heating season	45%	38%	7%	19%	7%
Only sample in heating season	85%	79%	32%	6%	38%
Radon greater than 90th percentile of full radon dataset	100%	100%	61%	13%	78%
Radon greater than 90th percentile of heating season radon and heating season	100%	100%	82%	32%	91%

- Heating season sampling and Radon (I&T) work well
- Radon combined with heating season is the best performer

SDM Daily Distributions and Mitigation Decisions





- Individual samples from the distribution are frequently near the TCR 10-6 and HQ = 0.1 lines.
- The 95th percentile of the data set is 0.35 µg/m3 just above the HQ=0.1 line but substantially below HQ = 1.
- The true mean concentration 0.089 µg/m3 is below 10-6 total cancer risk (TCR) of 0.48 µg/m3
- Thus, the correct decision if all the data from several years of monitoring was available would be “do not mitigate” if the action levels were set at 10-6 TCR and HQ=1. Mitigation would only be undertaken if HQ=0.1 was used as an action level.
- Sun Devil Manor has a broad data range, which makes decision making with a limited number of samples difficult.

SDM Daily Economics Results

Risk Screening Metric	Sampling Rule	Samples	Sample Cost	Mitigate	Mitigation Cost	Total Cost
1e-4canrisk	ITS Triggered	12	$66,600	No	$0	$66,600
1e-4canrisk	Random	12	$64,800	No	$0	$64,800
1e-4canrisk	Seas	96	$518,400	No	$0	$518,400
1e-5canrisk	ITS Triggered	12	$66,600	No	$0	$66,600
1e-5canrisk	Random	12	$64,800	No	$0	$64,800
1e-5canrisk	Seas	96	$518,400	No	$0	$518,400
1e-6canrisk	ITS Triggered	2	$12,600	Yes	$11,500	$24,100
1e-6canrisk	Random	12	$64,800	No	$0	$64,800
1e-6canrisk	Seas	9	$48,600	Yes	$11,500	$60,100
HQ=0.1	ITS Triggered	1	$7,200	Yes	$11,500	$18,700
HQ=0.1	Random	2	$10,800	Yes	$11,500	$22,300
HQ=0.1	Seas	3	$16,200	Yes	$11,500	$27,700
HQ=1	ITS Triggered	3	$18,000	Yes	$11,500	$29,500
HQ=1	Random	16	$86,400	No	$0	$86,400
HQ=1	Seas	16	$86,400	No	$0	$86,400
HQ=3	ITS Triggered	14	$77,400	No	$0	$77,400
HQ=3	Random	47	$253,800	No	$0	$253,800
HQ=3	Seas	49	$264,600	No	$0	$264,600
Radon Over Ambient	Radon Over Ambient	47	$1,800	Yes	$11,500	$13,300

Seas = Seasonal

- The lowest costs in the cancer risk evaluation are the more stringent action levels which lead to false positive mitigation decisions. ITS triggered is the lowest of those costs.
- Also, with the noncancer the lowest cost are the most stringent action levels.
- Radon only triggered preemptive mitigation is the overall lowest cost even though the mitigation is arguably not needed.

Book Store Study Site – Gaffney – AK, Commercial

- Heated connected storeroom
- Slab-on-grade foundation
- Unventilated
- Former dry-cleaning facility - occupied by a bookstore
- Slab-on-grade, hot-water baseboard radiant heating system
- Max soil concentration = 1.3 mg/kg at 1.5-3.0 m bgs
- Max GW concentration = 1.3 mg/L at 5.3 m bgs
- Higher concentrations at this site were observed in the late summer and attributed to soil temperature effects on shallow source term volatility (Barnes, 2017)

Wood stave pipe image from http://www.sewerhistory.org/photographics/pipes-wood/ Courtesy of the Idarado Mining Company, Ouray, Colorado.

Barnes, David L., and Mary F. McRae. "The predictable influence of soil temperature and barometric pressure changes on vapor intrusion." *Atmospheric Environment* 150 (2017): 15-23

Gaffney AK Soil Source Building, Four Daily Samples

Rule Description	At least one sample of the four samples taken ≥ the true mean concentration	At least one of the four samples taken will be ≥ the 95% UCL of the mean of the VOC distribution	At least one of 4 samples > the 50th percentile of the cumulative exposure curve	The mean of 4 drawn samples > the 50% cumulative exposure	At least one of the four samples > 95th percentile of the underlying distribution
Only sample in heating season	0%	0%	0%	0%	0%
1 sample in heating season, 1 outside of heating season	40%	30%	40%	11%	10%
1 sample per season	60%	43%	60%	7%	14%
Low temp decrease of 5F or more	75%	58%	75%	23%	18%
Random sampling	**78%**	**66%**	**78%**	**32%**	**28%**
Avg temp decrease of 5F or more	86%	75%	86%	41%	34%
Only sample outside of heating season	90%	79%	90%	49%	37%

- This data is from the Barnes study – no radon data available for these observations.
- Heating season performs much worse then random.
- Decreasing temperature as a signal for sampling performed well.

Sources of Uncertainty in this Effort

- The cases tested here do not represent the full diversity of US climates or building types.
- Even a continuous data set for one year is an imperfect estimate of long term exposure, because a “cold winter” and “warm winter” can be very different from each other.
- The smaller data sets (i.e. Gaffney, Moffett are incomplete samples of even the years they were taken in because not every day was sampled).
- The accuracy of concentration measurements generally decreases as concentrations approach the detection limit.

Summary Across Multiple Sites – Sampling Analysis

- Results for two sample strategies were rarely highlighted here because they were generally substantially lower then the four sample strategies.
- Sampling four times in heating season worked well at most sites, but very poorly at Gaffney (Barnes study). (Vadose zone source)
- VI sampling approaches may need to be tailored to specific climate zones and conceptual site models
- Sampling once in each of four seasons often performed poorly.
- Sampling with Radon guidance often worked well, but not all sites had radon data to test.
- Sampling approaches performed better at the sites/locations that fit the classical stack effect and winter worst theory.
- Sampling rules give better reliability in predicting the mean than predicting the upper percentiles of the distribution.
- Seeing the 95^{th} percentiles directly requires many samples even with guidance.

Summary of Economics Analysis Results

- The results of these economic analyses show that there can be dramatic differences in cost between sampling strategies employed at a particular site.
- Frequently with the assumptions used here cost advantages were provided by the radon only decision making, or the ITS guided sampling.
- Sampling costs tended to dominate over control (mitigation) costs in this analysis, and thus strategies that led to rapid decision making in favor of mitigation reduced total cost.
- Thus, counterintuitively in some cases more stringent action levels led to lower costs.
- Results are very sensitive to the action levels selected and the details of a given buildings concentration distribution. Therefore, more cases should be analyzed.

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- Previous presentation as part of this workshop, including
  - Hallberg et al., 2020, "Vapor Intrusion (VI) Indicators, Tracers, and Temporal Variability of cVOCs in Industrial Buildings, DoD Virginia Site A – Climate Zone 4," https://iavi.rti.org/assets/docs/05B_VA_site_A_Mar2020.pdf
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