Statistical Toolbox for RCRA
CVI Decisions

Lead in Slides
Introduction: Chlorinated VOCs in Indoor Air

• Challenging to assess at ‘low’ levels
• Difficult to predict
• Concentrations result from *complex* interaction of many variables
• Data-rich residential studies show significant variability:
  – Spatial (x, y, z) – across neighborhood and within building scales
  – Temporal (t) – diurnal, seasonal and climatic scales

Graphic adapted from: http://www.nature.com/ncomms/2014/140708/ncomms5344/images/ncomms5344-f2.jpg
Why Do Vapor Intrusion Plots Have Scatter? Many Variables Involved – Radon Experience

“This paper identified about thirteen factors that can affect radon: ...soil moisture content, soil permeability, wind, temperature, barometric pressure, rainfall, frozen ground, snow cover, earth tides, atmospheric tides, occupancy factors, season and time of day.

..... Four factors that influence radon concentrations indoors are properties of the building material and ground; building construction; meteorological conditions; and occupant activities.”

Lewis & Houle, A Living Radon Reference Manual (2009)

For mechanistic reasons it is likely that VOC VI is more variable and complex then radon VI.
Current Practice

• Heavy reliance on extractive samples for laboratory analysis
  – Costly (>\$350 per sample) & disruptive to measure
  – Only provide single ‘Points of Evidence’ (at a specific location & time period) within spatial and temporal distributions

• The accuracy of inferences/extrapolations between & beyond the ‘points of evidence’ (samples) have rarely been tested (but ‘data-rich’ studies informative)

• Statistics is the scientific tool to provide defensible inferences from the sample to the population. But statistical methods are rarely applied to VI even though the variability in VI is more than for groundwater

• Analysis of performance of typical sampling strategies suggests safety factor of at least 3X may be needed (Holton, 2013; Weinberg, 2014)
Why Study Statistics?

If we:
• don’t have guidance on when to sample;
• don’t have the basis for an assumption about the distribution,
• don’t want to use an additional safety factor and
• do want to see a single example of the RME

We will be sampling a long time!
Occupational Methods for Estimating Exposure

- Identify similar exposure groups (SEGs)
  - Based on similarity/frequency of tasks and types of materials/processes

- Number of samples needed for baseline assessment
  - Based on statistical estimates/methods and SEG profile
  - General AIHA recommendation: 6 – 10 samples where variability is expected to be low to moderate
  - Fewer than 6 samples can be used with caution; 3 is generally a minimum

<table>
<thead>
<tr>
<th>Ratio True 95th/OEL</th>
<th>Low Variability (GSD=1.5)</th>
<th>GSD = 2</th>
<th>Moderate Variability (GSD=2.5)</th>
<th>GSD = 3</th>
<th>High Variability (GSD=3.5)</th>
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</table>

GSDs at Industrial Buildings Shown/Expected

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Occupational Approach to Exposure Assessment: Exceedance Fraction

• The exceedance fraction (f) is the probability that a concentration in a distribution is higher than the screening level (AIHA, 2015).

• One property of a log-normal distribution is that the exceedance fraction can be related to the mean, and more specifically the ratio of the screening level (SL) to the mean,

\[ \frac{SL}{\bar{x}} = \exp\left(0.5 Z_{(1-f)}^2\right) \]

where Z is the value from a normal distribution table corresponding to the desired exceedance fraction (Rappaport, 1991). For planning purposes, Z is used in lieu of the standard deviation which generally is not known prior to sampling.

• This can provide a risk manager an indication of how far below a SL the mean concentration needs to be to keep exposures below the desired exceedance fraction. For example if the exceedance fraction is 5% (0.05), the mean should be maintained ~4-fold below the screening level.

• How much sampling is needed to evaluate this situation with confidence? That will depend on the variability of the distribution of concentrations in air in addition to the ratio of the screening level to the mean concentration.

Jeff Kurtz notes that this material is his personal opinion from experience at CDOT, Redfield and other sites

Next Slide from Paul Johnson 2013

• For full presentation see: https://iavi.rti.org/attachments/WorkshopsAndConferences/05_Johnson_03-19-13.pdf
Daily Average Concentration Data Set*

- Spring
- Summer
- Fall
- Winter
- Spring
- Summer
- Fall
- Winter
- Spring
- Summer

- **Daily Average Concentrations**
- **Average (0.078 ppbv)**
- **Median (<0.01 ppbv)**
- **50% of Exposure (25 days >0.6 ppbv)**

25 of 723 days (3.5%) contribute 50% of total exposure over this time frame.
Statistical Toolbox Outline – Basic Questions

• Is VI pathway complete & significant at a site (that has GW conc. >levels of concern & undergoing GW remediation)?

• Given that GW remediation can extend for decades, how can we ensure, with a known degree of confidence, that VI exposures are under control during the cleanup period?

Objectives

• Provide sound statistical methodologies to determine appropriate frequencies & approaches for verifying protection from CVI over long-term periods (with a known degree of confidence)

• primary applicability is to RCRA VI decisions, but could be useful for other types of VI sites
Organization and Scope

- Follows 2009 RCRA Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities (Unified Guidance) and supporting ITRC document, but applies applicable methods to VI, structured by same or similar study questions.

- Also draws on other technical resources when Unified Guidance does not address an important topic. Include the NIOSH Occupational Exposure Sampling Strategy Manual, AIHA “A Strategy for Assessing and Monitoring Occupational Exposures”, and ITRC’s “Groundwater Statistics and Monitoring Compliance: Statistical Tools for the Project Life Cycle”. The web link to some very useful and relevant Superfund Groundwater guidance for groundwater statistics and their Excel-based groundwater statistics tool is:

- Limits and Applicability: Not comprehensive, but does focus on many decisions/questions a RCRA practitioner is likely to encounter during an extended groundwater cleanup period at typical CVI sites.
<table>
<thead>
<tr>
<th>Considerations</th>
<th>Groundwater Statistical Tools</th>
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<td>Trends</td>
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<td>Closure</td>
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ARE THE INDOOR AIR CONCENTRATIONS ABOVE BACKGROUND?

• Start with lit values (mean or %); but background indoor air is highly variable

• Are there indoor VOC sources? If so, can they be removed?

• Are indoor air concentrations above outdoor air concentrations?

• Are indoor air concentrations above background? - Probably a “bright line” test against the selected background value.

• NAVFAC User’s Guide UG2-2091-ENV “Interim Final: Guidance for Environmental Background Analysis; Volume IV: Vapor Intrusion Pathway” has useful material on lines of evidence evaluation and statistical tests for this purpose.
ARE INDOOR AIR CONCENTRATIONS ABOVE OR BELOW A CRITERION?

• What is the criterion, ACUTE OR CHRONIC exposure?

• Specify certainty: e.g., max, 95th percentile, or 95% UCL of mean? Selected certainty dependent on number of samples. Maximum or 95th percentile typically used for small number of samples.

• When will criteria be met? (base on rate of change over time)

• AIHA exposure assessment strategy, similar exposure group concept & exceedance fraction concept from Rappaport provide useful tools.

• Controls & engineering modeling can constrain variability of indoor air due to VI.
IS THERE SEASONALITY?

• Most VI is seasonal, but not all; need to account for when it is.

• Seasonality cannot be captured by the simple concept of “winter worst”. Evidence suggests that “getting colder” can be more important than being cold, in some cases. Evidence shows that, even within one city, buildings have very different seasonal patterns from each other. Evidence also shows that southern climates are likely different than northern US climates.

• Extreme values can’t be removed if using max or 95th percentile
IS THERE A TREND? WHAT IS DIRECTION AND RATE OF CHANGE OVER TIME?

• Trends can be used to predict future exposure, remediation success, etc.
• Must account for seasonality, which can invalidate a trend test
• Start with scatter plot, linear regression
• Steady increase = increasing VI
• Confidence bands usually increase over (future) time unless GW is being remediated & source term is decreasing, which is likely to be common for RCRA sites under MNA
• Once trend is detected, rate of change over time can be determined
• Trends & rates can be determined at the VOC source, indoor air, or in between (subslab)
IS THE SAMPLING FREQUENCY APPROPRIATE (TEMPORAL OPTIMIZATION)?

• Optimization and design of the monitoring program must assure sample independence while covering site sufficiently & collecting adequate data over an appropriate time period for proposed statistical evaluations.

• In early stages, statistical design options should be considered such that adequate number of samples are collected.

• For sites with existing long term monitoring data, sampling frequency can often be reduced while still providing adequate data.

• Required sampling frequency can be evaluated with statistical methods that assess redundancy of sample results.

• How often do I need to sample to capture a trend?

• Cost effective sampling (CES) - rate of change (linear regression) vs Trend (Mann-Kendal)
IS THE SPATIAL COVERAGE APPROPRIATE (SPATIAL OPTIMIZATION)?

- Optimization and design of monitoring program must assure sample independence while providing adequate spatial coverage of site. Optimization can lead to decreasing or increasing number of sampling points. Expected to result in decrease in locations over time with MNA.

- Are sample locations redundant or should new locations be added?

- Geostatistics, other spatial statistical methods applicable. – unlikely to be applicable to indoor air, but might apply to GW, external soil gas, and subslab soil gas.