INDUSTRIAL HYGIENE EXPOSURE ASSESSMENTS:

WORST-CASE VERSUS RANDOM SAMPLING

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The two types of sampling strategies to consider when planning an exposure assessment study are worst-case sampling and random sampling. The broad difference is that worst-case sampling involves more subjectivity than a random sampling approach.

In worst-case sampling, we non-randomly select the worker(s) who are subjectively believed to have the highest exposure(s). If no worst-case sample exceeds the occupational exposure limit(s), we are subjectively satisfied (but not statistically confident) that the exposure profile is acceptable. For example, plant operators who have similar job duties within a production unit of a plant may be identified as a similar exposure group (SEG). For such workers, a worst-case exposure might occur on a day that their process unit generates the highest production output. Such a day would subjectively be considered the worst-case exposure period and targeted for evaluation.

A random sampling strategy requires workers within a SEG and the sample periods to be randomly selected. Decisions on the acceptability of the exposure profile can then be determined with a known level of confidence based on the central tendency and spread (or dispersion) of the sample distribution. Some random sampling applications include the following:

- Describe the 8-hour time-weighted average (TWA) concentrations over different days for a single worker or SEG.
- Describe the 15-minute TWA concentrations over one workshift for a single worker or SEG.
- Estimate the full-shift TWA concentration over one workshift based on short-term (or grab) samples for a single worker or SEG.

Table 1 provides a brief comparison of a worst-case sampling strategy versus a random sampling strategy.

> **"Worst-case sampling involves more subjectivity than a random sampling approach."**

Table 1 – Worst-Case Versus Random Sampling

Sampling Strategy	Advantages	Limitations
Worst-Case Sampling	• Fewer samples are typically collected to make a decision. • Use of statistics is not required.	• Relies on subjective judgments on "worst-case" exposure conditions. • Difficult to capture the actual "worst-case exposure period(s). • Decisions on exposure acceptability are made without a known level of confidence.
Random Sampling	• Provides a method of characterizing the exposure group with a known level of certainty. • Considered to be a more defensible strategy since the outcome is based on an objective analysis.	• More samples are required in order to profile the exposure group. • Takes more time to interpret the sampling results.

Exposure Profiling:

An 8-Step Process

Statistically speaking, there's always a chance of making the wrong decision no matter how confident we are but by quantifying our level of certainty through a random sampling strategy, we are able to maximize our chance of making the right decision. With the availability of computers and software programs available today, much of the statistical "grunt" work can be performed for us making it easier to employ a random sampling strategy. However, there are some statistical terms and considerations that should be understood, which are briefly described in the following 8-step process to exposure profiling.

1. Identify the SEG to profile. The key point in categorizing SEGs is to select the exposure group in order to minimize the amount of variation among the samples; otherwise, the resulting confidence intervals (calculated from the mean and variance) will be too wide to be useful. A SEG may be a single worker performing a single task; however, it is often impractical to perform random sampling for each and every worker. So, a more practical approach is to include multiple employees in a SEG who have similar exposures. For example, employees assigned to operate propane-powered lift trucks in a warehouse may be grouped as having similar potential exposures to carbon monoxide. If there are multiple SEGs identified (as most facilities have), a method to prioritize the data collection needs can be devised. AIHA's *A Strategy for Assessing and Managing Occupational Exposures*, provides a method for prioritizing SEGs (AIIHA, 89 – 101) for study based on the toxicity of the material, conditions of the workplace environment and their likelihood to influence exposures, and individual work practices that are likely to influence exposures.

2. Randomly select workers and time periods within the SEG selected for study. A random sample is one where each worker and time period has an equal probability of being selected for sample collection. It's important to collect the samples as randomly as possible; otherwise, the resulting statistics will be biased. A random number table and/or the random number function in a spreadsheet computer program (such as Microsoft Excel) are useful tools in the random selection process. Another consideration is, "how many samples should be collected in order for the exposure profile to be useful?" The answer depends on a number of factors, including the variability of the sample. However, AIHA generally recommends between six and 10 samples (AIHA, 106) are needed in order to perform a baseline exposure profile.

3. Measure the exposures of the randomly selected workers and the randomly selected time periods. There are three options in collecting the data – hire an industrial hygiene consultant to be on site to collect the samples, collect the samples using internal staff, and/or augment your internal staff with an industrial hygiene consultant where there are gaps in the required skills. Samples do not necessarily need to be collected by a Certified Industrial Hygienist (or a full-time industrial hygienists for that matter). However, if your internal staff lacks the skills and understanding in developing a sampling strategy and/or sampling methodologies, consider working with a consultant who can provide one-on-one training and instruction (as needed), assist with the development of the sampling strategy, and/or assist with the interpretation the sampling data.

4. Calculate the following descriptive statistics:

- **Minimum** – The minimum value in the sample set.
- **Maximum** – The maximum value in the sample set.
- **Range** – The difference between the largest and smallest values in a sample set.
- **Percent above the OEL** – The fraction of the sample set (in percent) that exceeded the occupational exposure limit.

- **Mean** – The arithmetic average of a set of data.
- **Median** – The measurement that divides a sample set into two equal parts.
- **Standard deviation** – The parameter for measuring the dispersion about the mean.
- **Geometric mean** – The median of the lognormally distributed data.
- **Geometric standard deviation** – The antilog of the standard deviation of the logtransformed data, which measures the variability for a lognormal distribution.

Descriptive statistics characterize the sample's distribution such as the central tendency (e.g., mean, median, etc.) and the spread (such as the range, standard deviation, variance, etc.).

5. **Determine if the data fits a lognormal and/or normal distribution.** Parametric statistics (such as upper and lower confidence limits and tolerance limits) are statistics that are calculated based on knowing (or assuming) a certain underlying distribution of the data set. The type of distribution (i.e., normal or lognormal) will generate different confidence intervals and tolerance limits. Most industrial hygiene sampling data tends to follow a lognormal distribution. However, if the data follows neither a lognormal nor a normal distribution, the SEG should be redefined. One way to qualitatively determine if the underlying distribution follows a lognormal and/or normal distribution is to plot the data on probability paper. A major advantage of probability plotting is the amount of information that can be displayed in a compact form but it requires subjectivity in the deciding how well the model fits the data (Waters, Selvin, and Rappaport 493). Probability paper is available for various types of sample distributions and plotting procedures are described in Technical Appendix I of the *NIOSH Occupational Exposure Sampling Strategy Manual* (Leidel, Busch, and Lynch 97 – 105). If a statistical program is available, a more quantitative approach should be used to evaluate the goodness-of-fit of the distribution. If both a lognormal and normal distribution is indicated, the parametric statistics should be calculated assuming a lognormal distribution.

6. **Calculate the following parametric statistics:**

- **Estimated arithmetic mean** – For a normal distribution, the estimated arithmetic mean is the same as the sample mean. However, for a lognormal distribution, the arithmetic is different and must be estimated.
- **$UCL_{1,95\%}$ of the arithmetic mean** – The $UCL_{1,95\%}$ is the one-side upper confidence at a 95% confidence level. If the $UCL_{1,95\%}$ is below the occupational exposure limits (OEL), we are 95% confident that the long-term average exposure is below the OEL. For evaluating toxicants that produce chronic diseases, the mean exposure should be examined (Rappaport and Selvin 378).
- **95^{th} percentile** – The value in which 95% of the population will be included. For example, the median is the 50^{th} percentile.
- **$UTL_{95\%,95\%}$** – The upper tolerance limit of the 95^{th} percentile. The $UTL_{95\%,95\%}$ is typically used to examine acute (or short-term) exposures (i.e., fast-acting contaminants).

7. **Make a decision on the acceptability of the exposure profile.** Generally, an $UCL_{1,95\%}$ that results in a value greater than the long-term OEL suggests that the exposure profile is unacceptable; whereas, an $UCL_{1,95\%}$ that results in a value below the long-term OEL suggests that the exposure profile is acceptable. For chemicals with acute (or short-term) effects, the upper tolerance limit of the 95^{th} percentile should be examined. However, calculating the $UTL_{95\%,95\%}$ with few data points tends to produce a wide tolerance

interval, which limits its usefulness. An $UTL_{95\%,95\%}$ that results in a value below the short-term exposure level and ceiling limit suggests that the exposure profile is acceptable, but large numbers of samples are needed in order to identify "acceptable" environments (Selvin et al. 89).

8. **Refine the SEG, if necessary.** The results of the exposure profile may indicate that the exposure group may need to be further refined. For example, it may appear that the sampling for certain individuals seem to result in higher exposures. To statistically test the significance of this variation, an analysis of variance (ANOVA) may be performed. An ANOVA is an inferential statistical test that compares two or more means to determine if the means are significantly different. If the means are statistically different, the SEG may need to be further refined.

Two sample applications are summarized in Figure 2. The first case study involved deriving a full-shift TWA estimate based on short-term samples. It is important to point out that this case study does not take into account day-to-day variation since the samples were collected on the same day. The second case study involves taking random samples on multiple days, which takes into account variations between the different workdays.

In summary, both worst-case sampling and random sampling strategies are useful in assessing exposures. However, it's important to understand the limitations of each and to correctly apply the chosen sampling strategy. A primary benefit of a random sampling strategy is that it allows SEGs to be profiled with a known level of certainty, which makes it a more defensible sampling strategy.

References

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> **"A random sampling strategy provides a method of characterizing the exposure group with a known level of certainty."**

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Figure 2 – Case Studies

Case Study 1 – Estimating Full-Shift Exposure Based on Short-Term Sampling Results

Sampling Strategy: The airborne exposures of two painters were evaluated during spray painting the exterior shell of an above ground storage tank. The employees worked from the same boom-supported elevated platform. Since 1,6-hexamethylene diisocyanate (HDI) was being aerosolized, the sampling was limited to approximately 15 minutes (based on limitations of the sampling method) and the sampling media was placed in a desorption solution immediately following the sample collection. Due to this limitation, the sampling strategy that was employed was to collected four random, short-term samples from the breathing zone of each painter and estimate the full-shift airborne concentration of HDI with a certain level of confidence.

Applicable OELs: OSHA's 8-hour permissible exposure limit (PEL) for HDI is 0.034 mg/m^3.

Descriptive statistics:

- Maximum: 0.0042 mg/m^3
- Minimum: <0.00037 mg/m^3
- Range: 0.00394 mg/m^3
- Mean: 0.002 mg/m^3
- Median: 0.002 mg/m^3
- Standard deviation: 0.001 mg/m^3
- Geometric mean: 0.002 mg/m^3
- Geometric standard deviation: 2.545 mg/m^3

Goodness-Of-Fit: Probability plotting and goodness-of-fit test indicated both a lognormal and normal distribution. As a result, the parametric statistics (i.e., arithmetic mean and upper confidence limit) were estimated assuming a lognormal distribution.

Lognormal Parametric Statistics:

- Estimated Arithmetic Mean: 0.002 mg/m^3
- $UCL_{1,95\%}$: 0.007 mg/m^3

Conclusion: Since the one-sided, 95% upper control limit is below the OEL for HDI, we are 95% confident that the actual airborne concentration collected in the breathing zone of spray painters during this task was below the OEL. Therefore, the estimated full-shift airborne exposure to HDI on the date of the sampling was determined to be acceptable.

Case Study 2 – Full-Shift Exposure Profile

Sampling Strategy: Random full-shift samples for formaldehyde were collected in the breathing zone of an operator forming fiberglass-matting material. The resin used to bind the fiberglass matting contained formaldehyde. A random sampling strategy was used to profile the exposure of the operator at this workstation.

Applicable OELs: OSHA's 8-hour PEL for formaldehyde is 0.75 parts per million (ppm).

Descriptive statistics:

- Maximum: 0.85 ppm
- Minimum: 0.43 ppm
- Range: 0.42 ppm
- Mean: 0.624 ppm
- Median: 0.60 ppm
- Standard deviation: 0.15 ppm
- Geometric mean: 0.610 ppm
- Geometric standard deviation: 1.274 ppm

Goodness-Of-Fit: Probability plotting and goodness-of-fit test indicated both a lognormal and normal distribution. As a result, the parametric statistics (i.e., arithmetic mean and upper confidence limit) were estimated assuming a lognormal distribution.

Lognormal Parametric Statistics:

- Estimated Arithmetic Mean: 0.624 ppm
- $UCL_{1,95\%}$: 0.823 ppm

Conclusion: Since the one-sided, 95% upper control limit is above the OSHA PEL for formaldehyde, we are not 95% confident that the long-term airborne concentrations in the breathing zones of the operators are below the OSHA PEL. Therefore, the potential exposures are unacceptable and interventions should be provided.