AIHA VIDEO SERIES:
MAKING ACCURATE EXPOSURE RISK DECISIONS

**Video 1A**
Exposure Variability and the Importance of Using Statistics to Improve Judgements

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AGENDA

• Why Important?
• Decision Statistic
• AIHA Categories
• Exposure Judgment Accuracy
• Exposure Variability
• Inferential IH Statistics
• Data Interpretation Using IHSTAT®
• Examples
• Review: Data Interpretation
• Key Resources
WHY IMPORTANT?
Effective and Efficient Exposure Risk Management

**Effective:**
Ensure that no worker has unacceptable exposures

**Efficient:**
Do it for minimum cost
What if our exposure assessment is wrong?

If we underestimate the exposure?
• Increased risk to employees

If we overestimate the exposure?
• Unnecessary expenditures for controls
• Unnecessary constraints for employees and production

<table>
<thead>
<tr>
<th>Well-Designed Exposure Risk Management Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>We Want:</strong></td>
</tr>
<tr>
<td>Good Data</td>
</tr>
<tr>
<td>To Be Effective</td>
</tr>
<tr>
<td>To Be Efficient</td>
</tr>
<tr>
<td>No Biases</td>
</tr>
<tr>
<td>Low Uncertainty</td>
</tr>
<tr>
<td><strong>Correct Decisions</strong></td>
</tr>
</tbody>
</table>
AIHA Exposure Risk Management Process

**Comprehensive Exposure Assessment and Management**
- Goal is to understand and manage all exposures
- Document both qualitative and quantitative exposure assessments
- Document low exposures
- Emphasize Accurate and Efficient Exposure Decisions
- Drive Effective and Efficient Exposure Risk Management
- Devise OELs when needed
- Continuous Prioritization
- Continuous Improvement
- Identify the critical SEGs
- Anticipate and manage change
Decision Statistic:

**Defines Objective for Acceptable Exposure**
(i.e. No Further Intervention Needed)

- Relative to Appropriate OEL
- Defined BEFORE conducting exposure risk assessment
Decision Statistic:
1st Framing Question

An employee performs a job 100 days per year. If you collected personal samples on the employee all 100 days, how many days is it acceptable for exposures to exceed the Occupational Exposure Limit (OEL) without a respirator?

1) 0 days?
2) 1 days?
3) 5 days?
4) 10 days?
5) 25 days?
6) 50 days?

We are going to have fun for a few minutes. Have everyone vote. Occupational Exposure Limit Count the votes and write them on the board!
Decision Statistic:
1st Framing Question

An employee performs a job 100 days per year. If you collected personal samples on the employee all 100 days, how many days is it acceptable for exposures to exceed the Occupational Exposure Limit (OEL) without a respirator?

1) 0 days?
2) 1 days?
3) 5 days?
4) 10 days?
5) 25 days?
6) 50 days?

- Answers emphasize the desire for very few days above the OEL
- Professional consensus developing around targeting for no more than 5 days out of 100 above the OEL (i.e. 95th Percentile)

We are going to have fun for a few minutes. Have everyone vote. Occupational Exposure Limit Count the votes and write them on the board!
Chart of the 100 Air Samples: Lognormally Distributed Data

Concentration (ppm)

Concentration Range Frequency
175 150 125 100 75 50 25 0

95%ile

Chart illustrating the distribution of air samples with concentration frequency on the y-axis and concentration (ppm) on the x-axis.
Chart of the 100 Air Samples: Lognormally Distributed Data
Usual Number of Samples << 100
Decision Statistic:  
2nd Framing Question

How sure do you want to be in your judgment?

1) 100% Sure?
2) 99%?
3) 95%?
4) 90%?
5) 70%?
6) 50%?

We are going to have fun for a few minutes. Have everyone vote. Occupational Exposure Limit Count the votes and write them on the board!
Decision Statistic:  
2nd Framing Question

How sure do you want to be in your judgment?

1) 100% Sure?  
2) 99%?  
3) 95%?  
4) 90%?  
5) 70%?  
6) 50%?

• Answers express the desire for high confidence that employees are protected.

• Implementing the AIHA Strategy with its emphasis on driving follow-up actions and continuous improvement enables a program to strive for high confidence.

• Common to strive for 95% confidence.

We are going to have fun for a few minutes. Have everyone vote. Occupational Exposure Limit Count the votes and write them on the board!
Pulling Together 1st and 2nd Framing Questions:

Decision Statistic:
“Strive for at least 95% confidence that the true 95th percentile is less than the OEL”
## AIHA Exposure Rating and Control Categories

<table>
<thead>
<tr>
<th>Exposure Rating Category**</th>
<th>Recommended Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>0</strong> (&lt;1% of OEL)</td>
<td>No action</td>
</tr>
<tr>
<td><strong>1</strong> (&lt;10% of OEL)</td>
<td>Procedures and Training; General Hazard Communication</td>
</tr>
<tr>
<td><strong>2</strong> (10-50% of OEL)</td>
<td>+ Chemical Specific Hazard Communication; Periodic Exposure Monitoring,</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3</strong> (50-100% of OEL)</td>
<td>+ Required Exposure Monitoring, Workplace Inspections to Verify Work Practice Controls; Medical Surveillance, Biological Monitoring</td>
</tr>
<tr>
<td><strong>4</strong> (&gt;100% of OEL)</td>
<td>+ Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection.</td>
</tr>
<tr>
<td>Multiples of OEL (&gt;500% of OEL or others based on respirator APF)</td>
<td>+Immediate Engineering Controls or Process Shut Down, Validate Acceptable Respirators</td>
</tr>
</tbody>
</table>

** Decision statistic = 95\textsuperscript{th} percentile**
AIHA Exposure Rating and Control Categories
Increase Effectiveness and Efficiency

• Avoid diminishing returns from “over-refining” exposure estimates
• Streamline Documentation
• Facilitate Qualitative Exposure Judgements
• Drive consistent follow-up management and control activities which lead to consistent risk management.
EXPOSURE JUDGMENT ACCURACY
**Exposure Risk Decisions: How Accurate Are We?**

**When We Have Monitoring Data . . .**

<table>
<thead>
<tr>
<th>Sample Results (ppm)</th>
<th>18</th>
<th>15</th>
<th>5</th>
<th>8</th>
<th>12</th>
<th>?</th>
<th>?</th>
<th>?</th>
<th>?</th>
</tr>
</thead>
</table>

**Exposure Rating Category**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(&lt;1% of OEL) No action</td>
</tr>
<tr>
<td>1</td>
<td>(&lt;10% of OEL) Procedures and Training; General Hazard Communication</td>
</tr>
<tr>
<td>2</td>
<td>(10-50% of OEL) + Chemical Specific Hazard Communication; Periodic Exposure Monitoring</td>
</tr>
<tr>
<td>3</td>
<td>(50-100% of OEL) + Required Exposure Monitoring; Workplace Inspections to Verify Work Practice Controls; Medical Surveillance, Biological Monitoring</td>
</tr>
<tr>
<td>4</td>
<td>(&gt;100% of OEL) + Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection; Immediate Engineering Controls or Process Shut Down, Validate Acceptable Respirators</td>
</tr>
</tbody>
</table>

**Decision statistic = 95th percentile**
Video Tasks: Quantitative Judgment Accuracy
Pre- and Post- Statistical Training

What About Real Life? . . .
Monitoring-Based Exposure Judgments

• Bad News
  • Often incorrect

• Good News
  • Simple statistical training improves judgments

• GREAT NEWS!!!
  • Using statistical tools when we make monitoring-based exposure judgments will greatly improve accuracy
Use Statistical Tools!!

Traditional Statistics

Bayesian Statistics

Expostats
EXPOSURE VARIABILITY
Our Fundamental Issue:

Exposure Variability
+
Very Low Numbers of Samples
Trying to understand this . . . .

Annual population of exposures for one worker: 250 Worker-days per Year

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>0.5</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>150</td>
<td>1.5</td>
</tr>
<tr>
<td>200</td>
<td>2</td>
</tr>
<tr>
<td>250</td>
<td>2.5</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>250</td>
<td>6.5</td>
</tr>
</tbody>
</table>

The chart shows the distribution of measurements and their corresponding concentrations.
Based on this (n=5 samples) . . . .

“See” Only 2% of Exposures

Annual population of exposures for one worker: 250 Worker-days per Year
10 Worker SEG: 2500 Worker-days per year

“See” Only 0.2% of Exposures
INFERENTIAL IH STATISTICS
Solution: Inferential Statistics . . .

Estimate From What We Looked At (Our Five Samples) . . .

Using Knowledge of Underlying Shape (Lognormal Distribution) . . .

The Actual Population Exposure Profile (SEG of 10 Workers)
Things can go wrong at several stages when extrapolating sample data to make inferences about the underlying population.

**Data (measurements)** → **Sample (Actual exposure levels during measurements)** → **Distribution of which the sample is representative** → **Target population (exposure distribution)**

- **Confidence intervals**
- **Inductive Inference**

- **Data (measurements)**:
  - Instrument quality
  - Interferences
  - Exposure periods missed

- **Sample (Actual exposure levels during measurements)**:
  - Sample size

- **Distribution of which the sample is representative**:
  - Worst case
  - Night shift
  - Summer/winter
  - Process changes
  - Selection of workers
Things can go wrong at several stages when extrapolating sample data to make inferences about the underlying population.

Data (measurements)

Target population (exposure distribution)

**Critical Data Quality Considerations**

- Defined decision statistic
- Well defined SEG
- Appropriate OEL
- Well described exposure question
- Appropriate sampling strategy
- Valid and appropriate monitoring method
- Validated analytical method

- Worst case
- Night shift
- Summer/winter
- Process changes
- Selection of workers

- Acute
- Chronic
- Diurnal
- Urbane
- Exposed
- Unexposed

- Further information gathering

- Pre-assessment
Lognormal Model Most Appropriate?

- Many papers dating back to the 60s, in Europe and the US, have shown the lognormal distribution to fit occupational exposure data reasonably well.
- Noise exposure data also follow a lognormal distribution when expressed as dose.
- Formal statistical tests exist but they have low power for small sample sizes, and reject lognormality very (too) quickly for large sample sizes.
Lognormal Model Most Appropriate?

- Many papers dating back to the 60s, in Europe and the US, have shown the lognormal distribution to fit occupational exposure data reasonably well.
- Noise exposure data also follow a lognormal distribution when expressed as dose.
- Formal statistical tests exist but they have low power for small sample sizes, and reject lognormality very (too) quickly for large sample sizes.

**A Pragmatic Approach:**

- Assume lognormality based on historical weight of evidence
- Make a graphical check (Quantile - Quantile or log – probit plot) to detect obvious departures from the model

“All models are wrong, some are useful”

- George E. P. Box
Always Check the Lognormal Assumption

- Check your monitoring data for lognormal distribution fit before detailed analysis.
- If data is not lognormal go back and verify SEG is constructed well.
  - Are jobs/tasks truly similar?
  - Does the data have errors?
  - Should SEG be broken down to smaller levels?
  - Challenge your SEG assumptions.
  - Many other factors . . .
Lognormal Distribution: A model for exposure variability

- Simple scatterplot
- Histogram
- Probability density curve
Interpreting a probability density curve is just like interpreting a histogram . . .
95\text{th}ile

\[ 95\text{th}ile = GM \cdot GSD^{1.645} \]
Lognormal Distribution Defined by GM and GSD

**Geometric mean (GM)**
Measure location. Central parameter. Cuts the distribution into 2 equal parts (median).

**Geometric standard deviation (GSD)**
Measure variability (~ distance between the lowest and highest values)
Calculate GM and GSD

<table>
<thead>
<tr>
<th>Samples</th>
<th>$x_i$ (mg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>1.16</td>
</tr>
<tr>
<td></td>
<td>1.36</td>
</tr>
<tr>
<td></td>
<td>2.66</td>
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</tbody>
</table>
Calculate GM and GSD

1. Log-Transform Data: e.g. $y_i = \ln(x_i)$

<table>
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<tr>
<th>Samples $x_i$ (mg/m$^3$)</th>
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<tr>
<td>0.84</td>
<td>-0.1744</td>
</tr>
<tr>
<td>0.98</td>
<td>-0.0202</td>
</tr>
<tr>
<td>0.42</td>
<td>-0.8675</td>
</tr>
<tr>
<td>1.16</td>
<td>0.1484</td>
</tr>
<tr>
<td>1.36</td>
<td>0.3075</td>
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<tr>
<td>2.66</td>
<td>0.9783</td>
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Calculate GM and GSD

1. Log-Transform Data:
   \( y_i = \ln(x_i) \)

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<th>( y_i = \ln(x_i) )</th>
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<tr>
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<td>0.3075</td>
</tr>
<tr>
<td>2.66</td>
<td>0.9783</td>
</tr>
</tbody>
</table>

2. Calculate Parameter of Interest:
   e.g. mean (\( \bar{y} \)) and standard deviation (\( s_y \))

\( \bar{y} = 0.062 \)

\( s_y = 0.606 \)
Calculate GM and GSD

1. Log-Transform Data: e.g. \( y_i = \ln(x_i) \)

<table>
<thead>
<tr>
<th>Samples ( x_i ) (mg/m(^3))</th>
<th>( y_i = \ln(x_i) )</th>
</tr>
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<tbody>
<tr>
<td>0.84</td>
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<td>0.3075</td>
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<tr>
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<td>0.9783</td>
</tr>
</tbody>
</table>

2. Calculate Parameter of Interest: e.g. mean (\( \bar{y} \)) and standard deviation (\( s_y \))

3. Calculate Anti-Log of the Parameter of Interest: e.g. GM=\( \exp(\bar{y}) \) and GSD=\( \exp(s_y) \)

- \( \bar{y} = 0.062 \)
- \( s_y = 0.606 \)
- GM = 1.06
- GSD = 1.83
Calculate GM and GSD
Worked Example for Reference
Welding Fume Sample Data

<table>
<thead>
<tr>
<th>Case</th>
<th>Samples x_i (mg/m^3)</th>
<th>y_i=ln(x_i)</th>
<th>(y_i-y)^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.84</td>
<td>-0.1744</td>
<td>0.055877</td>
</tr>
<tr>
<td>2</td>
<td>0.98</td>
<td>-0.0202</td>
<td>0.006762</td>
</tr>
<tr>
<td>3</td>
<td>0.42</td>
<td>-0.8675</td>
<td>0.864025</td>
</tr>
<tr>
<td>4</td>
<td>1.16</td>
<td>0.1484</td>
<td>0.007463</td>
</tr>
<tr>
<td>5</td>
<td>1.36</td>
<td>0.3075</td>
<td>0.060248</td>
</tr>
<tr>
<td>6</td>
<td>2.66</td>
<td>0.9783</td>
<td>0.839600</td>
</tr>
<tr>
<td>Sum =</td>
<td></td>
<td>0.3722</td>
<td>1.833976</td>
</tr>
<tr>
<td>\bar{y}=</td>
<td></td>
<td>0.0620</td>
<td></td>
</tr>
<tr>
<td>GM =</td>
<td></td>
<td>1.06</td>
<td></td>
</tr>
<tr>
<td>GSD =</td>
<td></td>
<td>1.83</td>
<td></td>
</tr>
</tbody>
</table>

\[ y_i = \ln(x_i) \]

\[ GM = \exp\left( \frac{\sum y_i}{n} \right) \]

\[ GM = \exp\left( \frac{0.3722}{6} \right) \]

\[ GM = 1.06 \]

\[ GSD = \exp\left( \sqrt{\frac{\sum (y_i - \bar{y})^2}{n-1}} \right) \]

\[ GSD = \exp\left( \sqrt{\frac{1.833976}{6-1}} \right) \]

\[ GSD = 1.83 \]
Calculate 95th percentile
Worked Example for Reference
Welding Fume Sample Data

- Six full-shift TWA welding fume measurements resulted in the following statistics:
  GM = 1.06 mg/m³
  GSD = 1.83
- What is the point estimate (i.e., best estimate) of the true 95th percentile?

\[
\hat{X}_{p\%ile} = GM \cdot GSD^{Z_p}
\]

95\%ile = \(1.06 \cdot 1.83^{1.645}\)

95\%ile = 2.86 mg/m³
Upper Tolerance Limit (UTL) for the 95\textsuperscript{th} Percentile [Same as 95\%ile Upper Confidence Limit (UCL)]

- **Concept**
  - Calculate the 95\% upper tolerance limit (same as upper confidence limit) for the 95\textsuperscript{th} percentile statistic to characterize uncertainty in the point estimate

- **Interpretation**
  - If the UTL\textsubscript{95\%,95\%} is less than the OEL, then we can say that we are at least 95\% confident that the true 95\textsuperscript{th} percentile is less than the OEL
Upper Tolerance Limit (UTL) for the 95th Percentile [Same as 95%ile Upper Confidence Limit (UCL)]

- Concept
  - Calculate the 95% upper tolerance limit (same as upper confidence limit) for the 95th percentile statistic to characterize uncertainty in the point estimate.

- Interpretation
  - If the UTL_{95,95} is less than the OEL, then we can say that we are at least 95% confident that the true 95th percentile is less than the OEL.

![Diagram of distribution of SEG exposures (exposure profile)](image-url)
Upper Tolerance Limit (UTL) for the 95th Percentile
[Same as 95%ile Upper Confidence Limit (UCL)]

• Concept
  • Calculate the 95% upper tolerance limit (same as upper confidence limit) for the 95th percentile statistic to characterize uncertainty in the point estimate

• Interpretation
  • If the UTL_{95,95} is less than the OEL, then we can say that we are at least 95% confident that the true 95th percentile is less than the OEL
Upper Tolerance Limit (UTL) for the 95th Percentile [Same as 95%ile Upper Confidence Limit (UCL)]

• Concept
  • Calculate the 95% upper tolerance limit (same as upper confidence limit) for the 95th percentile statistic to characterize uncertainty in the point estimate

• Interpretation
  • If the $\text{UTL}_{95\%, 95\%}$ is less than the OEL, then we can say that we are at least 95% confident that the true 95th percentile is less than the OEL

\[ \text{UTL}_{95\%, 95\%} = \text{UCL}_{95, 95} \]
Upper Tolerance Limit (UTL) for the 95th Percentile
[Same as 95%ile Upper Confidence Limit (UCL)]

• Concept
  • Calculate the 95% upper tolerance limit (same as upper confidence limit) for the 95th percentile statistic to characterize uncertainty in the point estimate

• Interpretation
  • If the UTL_{95%,95%} is less than the OEL, then we can say that we are at least 95% confident that the true 95th percentile is less than the OEL

Distribution of SEG Exposures (Exposure Profile)

\[ \text{UTL}_{95\%,95\%} = \text{UCL}_{95\%,95\%} \]
Calculate UTL_{95\%,95\%} for the 95^{th} Percentile
(UTL_{95\%,95\%} = UCL_{95\%,95\%})

**Procedure:**

1. Calculate the GM and GSD
2. Using n, read the UTL K-value from the appropriate table
   \( \gamma = \text{confidence level}, \) e.g., 0.95
   \( p = \text{proportion}, \) e.g., 0.95
   \( n = \text{sample size} \)
3. Using GM, GSD, and K, calculate the UTL_{95\%,95\%}:
   \[
   UTL_{95\%,95\%} = \exp(\bar{y} + K \cdot s_y)
   \]
   \( \bar{y} = \ln(GM) \)
   \( s_y = \ln(GSD) \)

---

**Factors for one-sided tolerance limits for normal distributions**

<table>
<thead>
<tr>
<th>( n )</th>
<th>( \gamma = 0.95 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3.904 3.055 2.726 2.446 2.221</td>
</tr>
<tr>
<td>4</td>
<td>2.619 2.413 2.245 2.114 2.003</td>
</tr>
<tr>
<td>5</td>
<td>2.149 1.974 1.830 1.712 1.618</td>
</tr>
<tr>
<td>6</td>
<td>1.895 1.773 1.658 1.556 1.471</td>
</tr>
<tr>
<td>7</td>
<td>1.732 1.620 1.524 1.435 1.358</td>
</tr>
<tr>
<td>8</td>
<td>1.617 1.516 1.427 1.347 1.275</td>
</tr>
<tr>
<td>9</td>
<td>1.532 1.441 1.358 1.283 1.214</td>
</tr>
<tr>
<td>10</td>
<td>1.465 1.381 1.304 1.234 1.169</td>
</tr>
</tbody>
</table>

Worked Example for Reference:
Calculate 95%ile UTL95,95%
Welding Fume Sample Data

- Six full-shift TWA welding fume measurements:
  \( GM = 1.06 \text{ mg/m}^3 \)
  \( GSD = 1.83 \)
- What is the 95th percentile UTL95,95%?

\[
\begin{align*}
\bar{y} &= \ln(GM) = \ln(1.06) = 0.058 \\
\sigma_y &= \ln(GSD) = \ln(1.83) = 0.604 \\
UTL_{95\%,95\%} &= \exp(\bar{y} + K \cdot \sigma_y) \\
UTL_{95\%,95\%} &= \exp(0.058 + 3.707 \cdot 0.604) \\
UTL_{95\%,95\%} &= 10 \text{ mg/m}^3
\end{align*}
\]

Factors for one-sided tolerance limits for normal distributions

<table>
<thead>
<tr>
<th>N</th>
<th>0.75</th>
<th>0.90</th>
<th>0.95</th>
<th>0.99</th>
<th>0.999</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>2.619</td>
<td>4.163</td>
<td>5.45</td>
<td>7.042</td>
<td>9.516</td>
</tr>
<tr>
<td>5</td>
<td>2.149</td>
<td>3.467</td>
<td>4.622</td>
<td>5.741</td>
<td>7.501</td>
</tr>
<tr>
<td>6</td>
<td>2.059</td>
<td>3.306</td>
<td>3.853</td>
<td>5.062</td>
<td>6.612</td>
</tr>
<tr>
<td>7</td>
<td>1.792</td>
<td>2.755</td>
<td>3.359</td>
<td>4.041</td>
<td>6.061</td>
</tr>
</tbody>
</table>
DATA INTERPRETATION USING IHSTAT ©
Use Statistical Tools!!

**Traditional Statistics**

- 95%ile = 1.2 mg/m³

**Bayesian Statistics**

- Identified that the data falls into indicated Exposure Rating Category

**Exostats**

- Initial Qualitative Assessment or Validated Model

Focus on Traditional IH Statistics
FREE Traditional Statistical Tools

• IHSTAT© (macro-free version)
  https://www.aiha.org/public-resources/consumer-resources/topics-of-interest/ih-apps-tools
• IHSTAT © (multi-language version)
  https://www.aiha.org/public-resources/consumer-resources/topics-of-interest/ih-apps-tools
• HYGINIST  http://www.tsac.nl/hyginist.html
Enter OEL

GM and GSD

Enter Sample Data
95%ile and UTL_{95,95} (UCL_{95,95})
Plot to check for sample data lognormality
Plot of “Best Guess” SEG exposure profile
Into which AIHA Exposure Category will the 95\textsuperscript{th} percentile MOST LIKELY fall?

**OEL = 100 ppm**

<table>
<thead>
<tr>
<th>Sample Results (ppm)</th>
<th>Exposure Rating Category**</th>
<th>Recommended Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>0 (&lt;1% of OEL)</td>
<td>No action</td>
</tr>
<tr>
<td>15</td>
<td>1 (&lt;10% of OEL)</td>
<td>Procedures and Training; General Hazard Communication</td>
</tr>
<tr>
<td>5</td>
<td>2 (10-50% of OEL)</td>
<td>+ Chemical Specific Hazard Communication; Periodic Exposure Monitoring.</td>
</tr>
<tr>
<td>8</td>
<td>3 (50-100% of OEL)</td>
<td>+ Required Exposure Monitoring, Workplace: Inspections to Verify Work Practice Controls; Medical Surveillance, Biological Monitoring</td>
</tr>
<tr>
<td>12</td>
<td>4 (&gt;100% of OEL)</td>
<td>+ Implement Hierarchy of Controls, Monitoring to Validate Respirator Protection Factor Selection.</td>
</tr>
<tr>
<td></td>
<td>Multiples of OEL (&gt;500% of OEL or others based on respirator APR)</td>
<td>+ Immediate Engineering Controls or Process Shut Down, Validate Acceptable Respirators</td>
</tr>
</tbody>
</table>

* Decision statistic = 95\textsuperscript{th} percentile
Into which AIHA Exposure Category will the 95th percentile MOST LIKELY fall?

OEL = 100 ppm

Sample Results (ppm)

| 18 | 15 | 5 | 8 | 12 |

Inferential Statistics

GM = 10.5 ppm  
GSD = 1.67  
95%ile = 24.5 ppm  
95%ile UCL_{95,95} (ULT) = 91.6 ppm

“Best Guess” Population (SEG) Exposure Profile

Exposure Category

Follow-Up Actions

<table>
<thead>
<tr>
<th>OEL Category</th>
<th>Recommended Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 15% of OEL</td>
<td>No action</td>
</tr>
<tr>
<td>15% to 39% of OEL</td>
<td>Hazard Communication</td>
</tr>
<tr>
<td>40% to 69% of OEL</td>
<td>Partial Permit Required</td>
</tr>
<tr>
<td>70% to 89% of OEL</td>
<td>Permit Required</td>
</tr>
<tr>
<td>&gt; 90% of OEL</td>
<td>Immediate Hazard Mitigation</td>
</tr>
</tbody>
</table>

5th percentile

95th percentile

66
Steps in Data Analysis and Interpretation*

1. **Enter Data Into Appropriate Statistical Tool**
2. **Evaluate the Goodness-of-fit**
3. **Review Descriptive and Inferential Statistics**
   - Compare...
     - the “decision statistic” (e.g., sample 95th percentile) to the OEL.
     - the 95%UCL to the OEL.
4. **Assign a Final Rating and Certainty Level**
   - **Final Rating**: Compare the sample 95th percentile to the Exposure Control Categories (ECCs) and select a category.
   - **Certainty Level**: Compare the 95%UCL to the ECCs:
     - Low certainty if ≥ 2 categories above the chosen ECC
     - Medium certainty if only 1 category above
     - High certainty if within chosen category
5. **Document the Analysis and Recommendations**
   - Recommend controls and/or PPE; work practice evaluation; additional sampling; surveillance sampling, etc.

---

*After Executing a Carefully Defined Monitoring Plan:*
- Defined decision statistic
- Well defined SEG
- Appropriate OEL
- Well described exposure question
- Appropriate sampling strategy
- Valid and appropriate monitoring method
- Validated analytical method
EXAMPLES
Example 1

Into which AIHA Exposure Category will the 95th percentile MOST LIKELY fall?

OEL = 100 ppm

<table>
<thead>
<tr>
<th>Sample Results (ppm)</th>
<th>18</th>
<th>15</th>
<th>5</th>
<th>8</th>
<th>12</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Exposure Rating Category**</th>
<th>Recommended Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (&lt;1% of OEL)</td>
<td>No action</td>
</tr>
<tr>
<td>1 (&lt;10% of OEL)</td>
<td>Procedures and Training; General Hazard Communication</td>
</tr>
<tr>
<td>2 (10-50% of OEL)</td>
<td>+ Chemical Specific Hazard Communication; Periodic Exposure Monitoring,</td>
</tr>
<tr>
<td>3 (50-100% of OEL)</td>
<td>+ Required Exposure Monitoring, Workplace Inspections to Verify Work Practice Controls; Medical Surveillance, Biological Monitoring</td>
</tr>
<tr>
<td>4 (&gt;100% of OEL)</td>
<td>+ Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection,</td>
</tr>
<tr>
<td></td>
<td>+ Immediate Engineering Controls or Process Shut Down, Validate Acceptable Respirators</td>
</tr>
</tbody>
</table>

* Decision statistic = 95th percentile
<table>
<thead>
<tr>
<th>Sample Results (ppm)</th>
<th>OEL = 100 ppm</th>
<th>GM = 10.5 ppm</th>
<th>GSD = 1.67</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

95th percentile: 24.5 ppm
95th percentile UCL$_{95}$ = 91.6 ppm
**Exposure Rating Category***

<table>
<thead>
<tr>
<th>Exposure Rating Category*</th>
<th>0 (&lt;1% of OEL)</th>
<th>1 (&lt;10% of OEL)</th>
<th>2 (10-50% of OEL)</th>
<th>3 (50-100% of OEL)</th>
<th>4 (&gt;100% of OEL)</th>
<th>Multiples of OEL (&gt;500% of OEL or others based on respirator APF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended Control</td>
<td>No action</td>
<td>Procedures and Training; General Hazard Communication</td>
<td>+ Chemical Specific Hazard Communication; Periodic Exposure Monitoring,</td>
<td>+ Required Exposure Monitoring, Workplace Inspections to Verify Work Practice Controls; Medical Surveillance, Biological Monitoring</td>
<td>+ Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection.</td>
<td>+ Immediate Engineering Controls or Process Shut Down, Validate Acceptable Respirators</td>
</tr>
</tbody>
</table>

---

**Sample Results (ppm)**

| ppm | 18 | 15 | 5 | 8 | 12 |

---

**OEL = 100 ppm**

**GM = 10.5 ppm**

**GSD = 1.67**

95%ile = 24.5 ppm

95%ile UCL_{95,95} = 91.6 ppm

---

**95%ile**

**95%ile UCL**

---

**OEL**

---

**95%ile UCL_{95,95} = 91.6 ppm**

---

**Immediate Engineering Controls or Process Shut Down, Validate Acceptable Respirators**
Exposure Rating Category*  | 0 (<1% of OEL) | 1 (<10% of OEL) | 2 (10-50% of OEL) | 3 (50-100% of OEL) | 4 (>100% of OEL) | Multiples of OEL (>500% of OEL or others based on respirator APF)

Recommended Control       | No action     | Procedures and Training; General Hazard Communication | + Chemical Specific Hazard Communication; Periodic Exposure Monitoring, Required Exposure Monitoring, Workplace Inspections to Verify Work Practice Controls; Medical Surveillance, Biological Monitoring | + Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection | + Immediate Engineering Controls or Process Shut Down, Validate Acceptable Respirators

Sample Results (ppm)  
- 18
- 15
- 5
- 8
- 12

OEL = 100 ppm  
GM = 10.5 ppm  
GSD = 1.67

95%ile = 24.5 ppm  
95%ile UCL95,95 = 91.6 ppm

95%ile Most Likely in Category 2 (Medium Certainty)
Exposure Rating Category*  | 0 (<1% of OEL)  | 1 (<10% of OEL)  | 2 (10-50% of OEL)  | 3 (50-100% of OEL)  | 4 (>100% of OEL)  | Multiples of OEL (>500% of OEL or others based on respirator APF)

Recommended Control  | No action  | Procedures and Training; General Hazard Communication  | + Chemical Specific Hazard Communication; Periodic Exposure Monitoring  | Required Exposure Monitoring, Workplace Inspections to Verify Work Practice Controls; Medical Surveillance; Biological Monitoring  | + Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection  | + Immediate Engineering Controls or Process Shut Down, Validate Acceptable Respirators

OEL = 100 ppm
GM = 10.5 ppm
GSD = 1.67
95%ile = 24.5 ppm
95%ile UCL 95,95 = 91.6 ppm

95%ile Most Likely in Category 2 (Medium Certainty)
More Than 95% Confident That True 95%ile Exposure < OEL
### Exposure Rating and Category

<table>
<thead>
<tr>
<th>Exposure Rating</th>
<th>Category*</th>
<th>Recommended Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(&lt;1% of OEL)</td>
<td>No action</td>
</tr>
<tr>
<td>1</td>
<td>(&lt;10% of OEL)</td>
<td>Procedures and Training; General Hazard Communication</td>
</tr>
<tr>
<td>2</td>
<td>(10-50% of OEL)</td>
<td>+ Chemical Specific Hazard Communication; Periodic Exposure Monitoring</td>
</tr>
<tr>
<td>3</td>
<td>(50-100% of OEL)</td>
<td>+ Required exposure monitoring, Workplace Inspections to Verify Work Practice Controls; Medical Surveillance, Biological Monitoring</td>
</tr>
<tr>
<td>4</td>
<td>(&gt;100% of OEL)</td>
<td>+ Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection</td>
</tr>
</tbody>
</table>

### Sample Results (ppm)
- 18
- 15
- 5
- 8
- 12

### OEL and Calculations
- OEL = 100 ppm
- GM = 10.5 ppm
- GSD = 1.67
- 95%ile = 24.5 ppm
- 95%ile UCL95,95 = 91.6 ppm

### Follow-Up Actions:
- Procedures and Training; General Haz. Com.
  - + Chemical Specific Haz. Com.; Periodic Exposure Monitoring.
Example 2

Into which AIHA Exposure Category will the 95\textsuperscript{th} percentile MOST LIKELY fall?

OEL = 100 ppm

<table>
<thead>
<tr>
<th>Sample Results (ppm)</th>
<th>Exposure Rating Category**</th>
<th>Recommended Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ((&lt;1%) of OEL)</td>
<td>0 ((&lt;1%) of OEL)</td>
<td>No action</td>
</tr>
<tr>
<td>1 (&lt;10% of OEL)</td>
<td>1 (&lt;10% of OEL)</td>
<td>Procedures and Training; General Hazard Communication</td>
</tr>
<tr>
<td>2 (10-50% of OEL)</td>
<td>2 (10-50% of OEL)</td>
<td>+ Chemical Specific Hazard Communication; Periodic Exposure Monitoring,</td>
</tr>
<tr>
<td>3 (50-100% of OEL)</td>
<td>3 (50-100% of OEL)</td>
<td>+ Required Exposure Monitoring, Workplace Inspections to Verify Work Practice Controls, Medical Surveillance, Biological Monitoring</td>
</tr>
<tr>
<td>4 (&gt;100% of OEL)</td>
<td>4 (&gt;100% of OEL)</td>
<td>+ Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection.</td>
</tr>
<tr>
<td>Multiples of OEL (&gt;50% of OEL or others based on respirator API)</td>
<td>Multiples of OEL (&gt;50% of OEL or others based on respirator API)</td>
<td>+ Immediate Engineering Controls or Process Shut Down, Validate Acceptable Respirators</td>
</tr>
</tbody>
</table>

* Decision statistic = 95\textsuperscript{th} percentile
Exposure Rating Category*  
0  (<1% of OEL)  
1  (<10% of OEL)  
2  (10-50% of OEL)  
3  (50-100% of OEL)  
4  (>100% of OEL)  

Recommended Control  
No action  
Procedures and Training; General Hazard Communication  
+ Chemical Specific Hazard Communication; Periodic Exposure Monitoring,  
+ Required Exposure Monitoring, Workplace Inspections to Verify Work Practice Controls; Medical Surveillance; Biological Monitoring  
+ Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection.

Follow-Up Actions:
+ Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection.

Sample Results (ppm)  
8  
75  
5  
37  
12

OEL = 100 ppm
GM = 16.8 ppm
GSD = 3.06
95%ile = 105 ppm
95%ile UCL_{95,95} = 1836 ppm

95%ile Most Likely in Category 4 (High Certainty)
Far Less Than 95% Confident That True 95%ile Exposure <OEL as 95%ile Point Estimate >OEL
**Example 3**

Into which AIHA Exposure Category will the 95\(^{th}\) percentile MOST LIKELY fall?

\[ \text{OEL} = 100 \text{ ppm} \]

<table>
<thead>
<tr>
<th>Sample Results (ppm)</th>
<th>0.75</th>
<th>5</th>
<th>2</th>
<th>1</th>
<th>3</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Exposure Rating Category**</th>
<th>Recommended Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (&lt;1% of OEL)</td>
<td>No action</td>
</tr>
<tr>
<td>1 (&lt;10% of OEL)</td>
<td>Procedures and Training; General Hazard Communication</td>
</tr>
<tr>
<td>2 (10-50% of OEL)</td>
<td>+ Chemical Specific Hazard Communication; Periodic Exposure Monitoring,</td>
</tr>
<tr>
<td>3 (50-100% of OEL)</td>
<td>+ Required Exposure Monitoring, Workplace Inspections to Verify Work Practice Controls, Medical Surveillance, Biological Monitoring</td>
</tr>
<tr>
<td>4 (&gt;100% of OEL)</td>
<td>+ Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection;</td>
</tr>
<tr>
<td>Multiples of OEL (&gt;50%)</td>
<td>+ Immediate Engineering Controls or Process Shut Down, Validate Acceptable Respirators</td>
</tr>
</tbody>
</table>

* Decision statistic = 95\(^{th}\) percentile
### Sample Results

<table>
<thead>
<tr>
<th>Sample Results (ppm)</th>
<th>OEL (100 ppm)</th>
<th>GM = 1.9 ppm</th>
<th>GSD = 2.18</th>
<th>95%ile = 6.7 ppm</th>
<th>95%ile UCL_{95,95} = 49 ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Follow-Up Actions:

**95%ile Most Likely in Category 1 (Medium Certainty)**

More Than 95% Confident That True 95%ile Exposure < OEL

- **Recommended Control**: No action
- **Exposure Rating Category**: 0 (<1% of OEL), 1 (<10% of OEL), 2 (10-50% of OEL), 3 (50-100% of OEL), 4 (>100% of OEL)
- **OEL**: Follow-Up Actions:
  - Procedures and Training; General Hazard Communication
  - Consider Periodic Monitoring
  - Implement hierarchy of controls; monitoring to validate respirator protection fac selection.
Example 4

Into which AIHA Exposure Category will the 95th percentile MOST LIKELY fall?

**OEL = 100 ppm**

| Sample Results (ppm) | 8 | 25 | 5 |

<table>
<thead>
<tr>
<th>Exposure Rating Category**</th>
<th>Recommended Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>0 (&lt;1% of OEL)</strong></td>
<td>No action</td>
</tr>
<tr>
<td><strong>1 (&lt;10% of OEL)</strong></td>
<td>Procedures and Training; General Hazard Communication</td>
</tr>
<tr>
<td><strong>2 (10-50% of OEL)</strong></td>
<td>+ Chemical Specific Hazard Communication; Periodic Exposure Monitoring</td>
</tr>
<tr>
<td><strong>3 (50-100% of OEL)</strong></td>
<td>+ Required Exposure Monitoring, Workplace Inspections to Verify Work Practice Controls, Medical Surveillance, Biological Monitoring</td>
</tr>
<tr>
<td><strong>4 (&gt;100% of OEL)</strong></td>
<td>+ Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection</td>
</tr>
</tbody>
</table>

* Decision statistic = 95th percentile
Exposure Rating Category

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
<th>Recommended Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(&lt;1% of OEL)</td>
<td>No action</td>
</tr>
<tr>
<td>1</td>
<td>(&lt;10% of OEL)</td>
<td>Procedures and Training; General Hazard Communication</td>
</tr>
<tr>
<td>2</td>
<td>(10-50% of OEL)</td>
<td>+ Chemical Specific Hazard Communication; Periodic Exposure Monitoring</td>
</tr>
<tr>
<td>3</td>
<td>(50-100% of OEL)</td>
<td>+ Required Exposure Monitoring, Workplace Inspections to Verify Work Practice Controls; Medical Surveillance, Biological Monitoring</td>
</tr>
<tr>
<td>4</td>
<td>(&gt;100% of OEL)</td>
<td>+ Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection</td>
</tr>
</tbody>
</table>

Sample Results (ppm)

- GM = 10.0 ppm
- GSD = 2.3
- 95%ile = 39.0 ppm
- 95%ile UCL < 5641.1 ppm

OEL = 100 ppm

95%ile Likely in Category 2 ??? (Low Certainty)

Less Than 95% Confident That True 95%ile Exposure < OEL

Follow-Up Actions:
- Procedures and Training; General Haz. Com.
- + Chemical Specific Haz. Com.; Required Exposure Monitoring.
Sample Results (ppm)

8 25 5

OEL = 100 ppm
GM = 10.0 ppm
GSD = 2.3
95%ile = 39.0 ppm
95%ile UCL_{95.95} = 5641.1 ppm

Sample Results (ppm)

8 25 5 10 3

OEL = 100 ppm
GM = 7.9 ppm
GSD = 2.2
95%ile = 29.1 ppm
95%ile UCL_{95.95} = 222.1 ppm

Sample Results (ppm)

8 25 5 10 7 11

OEL = 100 ppm
GM = 8.1 ppm
GSD = 1.9
95%ile = 24.2 ppm
95%ile UCL_{95.95} = 77.6 ppm
Change in UCL$_{95\%,95\%}$ and LCL$_{95\%,95\%}$

With Increasing Number of Samples

**Idealized**
GSD = 2

**Simulated**
Random measurements generated from a distribution where the true GSD=3.0 and the true 95\%ile=1.
Example 5
Into which AIHA Exposure Category will the 95\textsuperscript{th} percentile MOST LIKELY fall?

\textbf{OEL = 100 ppm}

<table>
<thead>
<tr>
<th>Sample Results (ppm)</th>
<th>8</th>
<th>55</th>
<th>5</th>
<th>37</th>
<th>12</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Exposure Rating Category\textsuperscript{**}</th>
<th>0 (&lt;1% of OEL)</th>
<th>1 (&lt;10% of OEL)</th>
<th>2 (10-50% of OEL)</th>
<th>3 (50-100% of OEL)</th>
<th>4 (&gt;100% of OEL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended Control</td>
<td>No action</td>
<td>Procedures and Training; General Hazard Communication</td>
<td>+ Chemical Specific Hazard Communication; Periodic Exposure Monitoring.</td>
<td>+ Required Exposure Monitoring, Workplace Inspections to Verify Work Practice Controls; Medical Surveillance, Biological Monitoring</td>
<td>+ Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection.</td>
</tr>
<tr>
<td>* Decision statistic = 95\textsuperscript{th} percentile</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Exposure Rating Category*

<table>
<thead>
<tr>
<th>Category*</th>
<th>Sample Results (ppm)</th>
<th>Exposure Rating</th>
<th>Recommended Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (≤1% of OEL)</td>
<td>8 55 5 37 12</td>
<td>No action</td>
<td>Procedures and Training; General Hazard Communication</td>
</tr>
<tr>
<td>1 (&gt;10% of OEL)</td>
<td></td>
<td>+ Chemical Specific Hazard Communication; Periodic Exposure Monitoring,</td>
<td>+ Required Exposure Monitoring, Workplace Inspections to Verify Work Practice Controls; Medical Surveillance, Biological Monitoring</td>
</tr>
<tr>
<td>2 (10-50% of OEL)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 (50-100% of OEL)</td>
<td></td>
<td></td>
<td>+ Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection.</td>
</tr>
<tr>
<td>4 (&gt;100% of OEL)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

OEL = 100 ppm  
GM = 15.8 ppm  
95%ile = 84.1 ppm  
95%ile UCL95,95 = 1135.3 ppm

95%ile Likely in Category 3? ??? (Low Certainty)

Less Than 95% Confident That True 95%ile Exposure < OEL

Follow-Up Actions: 
+ Required Exposure Monitoring, Workplace Inspections to Verify Work Practice Controls; Medical Surveillance, Biological Monitoring  
+ Consider Implementing Hierarchy of Controls;
A Few Words About Handling Censored Data . . .

<table>
<thead>
<tr>
<th>Sample Results (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td>&lt;5</td>
</tr>
<tr>
<td>10</td>
</tr>
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A Few Words About Handling Censored Data . . .

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Don’t:

• Remove the non-detects from the statistical analysis.
• Perform data analysis with the detection limit substituted for the less-than values.
Parametric Censored Data Analysis Methods
(Assumes Lognormal Distribution)

- Simple Substitution - DL/2 or DL/sqrt(2)
  - Very easy to implement
  - Reasonable performance [particularly DL/sqrt(2) for 95%ile estimation] for low n (<20) and low (<25%) to moderate (25-50%) censoring.

- Maximum Likelihood Estimates (MLE)
  - Complex calculations
  - Closest to best universal method

- Beta Substitution
  - Straight forward to program in a spreadsheet
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  - BDA uses same equations as MLE
  - Superior performance for characterizing parameter uncertainty
  - Can readily analyze censored data, including fully censored datasets

### Sample Results (ppm)

<table>
<thead>
<tr>
<th>Value</th>
<th>Confidence Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>90%</td>
</tr>
<tr>
<td>25</td>
<td>95%</td>
</tr>
<tr>
<td>&lt;5</td>
<td>95%</td>
</tr>
<tr>
<td>10</td>
<td>99%</td>
</tr>
<tr>
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<td>99%</td>
</tr>
<tr>
<td>7</td>
<td>99%</td>
</tr>
<tr>
<td>11</td>
<td>99%</td>
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Simple Option for IHSTAT
## Parametric Censored Data Analysis Methods ( Assumes Lognormal Distribution )

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Example:
IHSTAT Analysis of Censored Data Using Simple Substitution:
Detection Limit Divided by Square Root of Two [DL / sqrt(2)]

OEL = 100 ppm

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29% censored
Example:
IHSTAT Analysis of Censored Data Using Simple Substitution: Detection Limit Divided by Square Root of Two [DL / sqrt(2)]

OEL = 100 ppm

<table>
<thead>
<tr>
<th>Sample Results (ppm)</th>
<th>Substitute DL = DL / sqrt(2) = 1.4142</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>&lt;5</td>
<td>3.54</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>&lt;3</td>
<td>2.12</td>
</tr>
<tr>
<td>7</td>
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<td>11</td>
</tr>
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29% censored
Example:
IHSTAT Analysis of Censored Data Using Simple Substitution: Detection Limit Divided by Square Root of Two [DL / sqrt(2)]

OEL = 100 ppm

<table>
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<tr>
<th>Sample Results (ppm)</th>
<th>Sample Results With Substitutions for Non-Detects (ppm)</th>
</tr>
</thead>
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<tr>
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Substitute \( DL / \sqrt{2} = 1.4142 \)

29% censored
**Exposure Rating Category**

<table>
<thead>
<tr>
<th>Exposure Rating</th>
<th>Category*</th>
<th>Recommended Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (0)</td>
<td>(&lt;1% of OEL)</td>
<td>No action</td>
</tr>
<tr>
<td>1 (1)</td>
<td>(&lt;10% of OEL)</td>
<td>Procedures and Training; General Hazard Communication</td>
</tr>
<tr>
<td>2 (2)</td>
<td>(10-50% of OEL)</td>
<td>+ Chemical Specific Hazard Communication; Periodic Exposure Monitoring</td>
</tr>
<tr>
<td>3 (3)</td>
<td>(50-100% of OEL)</td>
<td>+ Required Exposure Monitoring, Workplace Inspections to Verify Work Practice Controls; Medical Surveillance, Biological Monitoring</td>
</tr>
<tr>
<td>4 (4)</td>
<td>(&gt;100% of OEL)</td>
<td>+ Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection</td>
</tr>
</tbody>
</table>

**Sample Results**

- **GM** = 7.35 ppm
- **GSD** = 2.3
- **95%ile** = 27.4 ppm
- **UTL95%95%** = 112 ppm

**OEL** = 100 ppm

**95%ile Most Likely in Category 2 (Low Certainty)**

Less Than 95% Confident That True 95%ile Exposure < OEL

29% censored
Example:
BDA Analysis of Censored Data

OEL = 100 ppm

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29% censored
Example:
BDA Analysis of Censored Data

OEL = 100 ppm

Sample
Results
(ppm)

8
25
<5
10
<3
7
11

29% censored

Enter Directly Into Bayesian
Statistical Analysis Tool
(IHDA or Expostats)

No Substitution
Needed

Expostats
Learn More: Censored Data References

• IHDA Help File
REVIEW: DATA INTERPRETATION
REVIEW: Steps in Data Analysis and Interpretation*

Preparation: Collect High Quality Data

*After Executing a Carefully Defined Monitoring Plan:
- Defined decision statistic
- Well defined SEG
- Appropriate OEL
- Well described exposure question
- Appropriate sampling strategy
- Valid and appropriate monitoring method
- Validated analytical method
**REVIEW:** Steps in Data Analysis and Interpretation*

1. Enter Data Into Appropriate Statistical Tool
2. Evaluate the Goodness-of-fit

---

**Evaluate Lognormal Assumption**

<table>
<thead>
<tr>
<th>Percentage</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration</td>
<td>0.1</td>
<td>1</td>
<td>10</td>
<td>100</td>
<td>100</td>
<td>100</td>
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1. Enter Data Into Appropriate Statistical Tool
2. Evaluate the Goodness-of-fit
3. Review Descriptive and Inferential Statistics
   Compare...
   • the “decision statistic” (e.g., sample 95th percentile) to the OEL.
   • the 95%UCL to the OEL.

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4. Assign a Final Rating and Certainty Level
   - **Final Rating:** Compare the sample 95th percentile to the Exposure Control Categories (ECCs) and select a category.
   - **Certainty Level:** Compare the 95%UCL to the ECCs:
     - Low certainty if ≥ 2 categories above the chosen ECC
     - Medium certainty if only 1 category above
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**Assign Exposure Rating and Certainty**

*Hewett’s ROT*
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5. **Document the Analysis and Recommendations**
   - Recommend controls and/or PPE; work practice evaluation; additional sampling; surveillance sampling, etc.

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Document Results and Implement Follow-Up Actions
KEY RESOURCES
Key References

• Papers:
Key References - Continued

- **Papers:**

- **Books:**
Key Resources

- **IH Stats and Other Exposure Assessment Tools:**
  AIHA Exposure Assessment Strategies Committee Website “Tools and Links for Exposure Assessment Strategies“:
  [https://www.aiha.org/public-resources/consumer-resources/topics-of-interest/ih-apps-tools](https://www.aiha.org/public-resources/consumer-resources/topics-of-interest/ih-apps-tools)

- **BDA Computer Tool:**
  Paul Hewett’s Website - Exposure Assessment Solutions:
  [http://www.EASInc.co](http://www.EASInc.co)

- **ExpoStats Bayesian IH Data Analysis Tools**

- **Competency Demonstration:**
  AIHA Exposure Decision Analysis Registry
Exposure Decision Analysis: Competency Assessment

Exposure Decision Criteria
• Allowable Exceedance
• Needed Confidence
• Use of Exposure Categories

Traditional Industrial Hygiene Stats
• Properties of a lognormal distribution
• Upper percentile estimate calculation & interpretation
• Tolerance Limit calculation & interpretation

Bayesian Decision Analysis (BDA)
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• Tolerance Limit calculation & interpretation

Data and Similar Exposure Groups (SEGs)
• Rules for combining data
• Indications that a SEG may need refining

Decision Heuristics and Human Biases
• Common sources of bias in data interpretation and exposure assessment
• How to avoid bias in data interpretation

Exposure Data Interpretation
• Most likely exposure category given data
• Meet the certainty requirement given data

Techniques for Improving Professional Judgments
• Feedback loops (quantitative judgment > monitoring > qualitative judgment)
• Group judgment sessions
• Documentation of rationale
• Break decisions into aggregate parts (Modeling)
AIHA VIDEO SERIES:
MAKING ACCURATE EXPOSURE RISK DECISIONS

Video 1A
Exposure Variability and the Importance of Using Statistics to Improve Judgements

John R. Mulhausen, PhD, CIH, CSP, FAIHA
AIHA VIDEO SERIES:
MAKING ACCURATE EXPOSURE RISK DECISIONS

Join us for the next video in the series . . .

Video 1A: Exposure Variability and the Importance of Using Statistics to Improve Judgements

Video 1B: Rules of Thumb for Interpreting Exposure Monitoring Data

Video 2: Introduction to Bayesian Statistical Approaches and Their Advantages

Video 3A: Free Bayesian Statistical Tools: IHDA Student Edition

Video 3B: Free Bayesian Statistical Tools: Expostats

Video 4: Implementing AIHA Strategy Using Statistical Tools: Examples