# Improving Exposure Data Interpretation and Professional Judgment

**Georgia Local Section, AIHA**  
January 25, 2012  
Atlanta

## Agenda

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30 AM</td>
<td>Introduction</td>
</tr>
<tr>
<td>8:40 AM</td>
<td>Interpreting Data</td>
</tr>
<tr>
<td>9:10 AM</td>
<td>Class Exercise: Data Interpretation Test 1</td>
</tr>
<tr>
<td>9:30 AM</td>
<td>Bayesian Statistics - How Might They Help?</td>
</tr>
<tr>
<td>9:50 AM</td>
<td>AIHA Exposure Assessment Model: Inherently Bayesian</td>
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<tr>
<td>10:15 AM</td>
<td>Traditional IH Statistics</td>
</tr>
<tr>
<td>10:30 AM</td>
<td>Morning Break</td>
</tr>
<tr>
<td>10:45 AM</td>
<td>Rules of Thumb</td>
</tr>
<tr>
<td>11:15 AM</td>
<td>Class Exercise: Data Interpretation Test 2</td>
</tr>
<tr>
<td>12:00 PM</td>
<td>Lunch</td>
</tr>
<tr>
<td>12:45 PM</td>
<td>Bayesian Decision Analysis (BDA) Theory and Tool</td>
</tr>
<tr>
<td>1:45 PM</td>
<td>Scenario Examples - Decision Chart Interpretation</td>
</tr>
<tr>
<td>2:10 PM</td>
<td>GSD and Parameter Space Verification</td>
</tr>
<tr>
<td>3:00 PM</td>
<td>Afternoon Break</td>
</tr>
<tr>
<td>3:15 PM</td>
<td>BDA Potential: Integrating Professional Judgment</td>
</tr>
<tr>
<td>3:45 PM</td>
<td>Other Potential Applications for BDA</td>
</tr>
<tr>
<td>4:00 PM</td>
<td>Closing Discussion</td>
</tr>
<tr>
<td>4:30 PM</td>
<td>End Class</td>
</tr>
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</table>
### A Brief Survey

Rate Each Scenario as either Acceptable or Unacceptable

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Agent</th>
<th>TLV</th>
<th>Exposure Judgment (Choose One)</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Acceptable</th>
<th>Unacceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Xylene</td>
<td>100 ppm**</td>
<td></td>
<td>21</td>
<td>68</td>
<td>Acceptable</td>
<td>Unacceptable</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Irritation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 2</td>
<td>Xylene</td>
<td>100 ppm**</td>
<td>Exposure Judgment (Choose One)</td>
<td>21</td>
<td>59</td>
<td>38</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Irritation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 3</td>
<td>Xylene</td>
<td>100 ppm**</td>
<td>Exposure Judgment (Choose One)</td>
<td>21</td>
<td>59</td>
<td>38</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Irritation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 4</td>
<td>Xylene</td>
<td>100 ppm**</td>
<td>Exposure Judgment (Choose One)</td>
<td>12</td>
<td>16</td>
<td>21</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Irritation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 5</td>
<td>Xylene</td>
<td>50 ppm**</td>
<td>Exposure Judgment (Choose One)</td>
<td>12</td>
<td>16</td>
<td>21</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Irritation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TLV:** Threshold Limit Value

Scenario 1: Xylene exposure
- **TLV:** 100 ppm
- **Sampling:** 2 samples
- **Judgment:** Acceptable

Scenario 2: Xylene exposure
- **TLV:** 100 ppm
- **Sampling:** 4 samples
- **Judgment:** Acceptable

Scenario 3: Xylene exposure
- **TLV:** 100 ppm
- **Sampling:** 4 samples
- **Judgment:** Acceptable

Scenario 4: Xylene exposure
- **TLV:** 100 ppm
- **Sampling:** 2 samples
- **Judgment:** Acceptable

Scenario 5: Xylene exposure
- **TLV:** 50 ppm
- **Sampling:** 4 samples
- **Judgment:** Acceptable
Survey:
8-hr TWA Sample Results for five operations. Rate the exposures as acceptable or unacceptable.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Data (ppm)</th>
<th>Interpretation - Acceptable?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21, 68</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>21, 109, 38, 41, 48</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>12, 16, 21, 24</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>8, 70, 5, 37, 12</td>
<td>Yes</td>
</tr>
</tbody>
</table>

EA Symposium Survey Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Data (ppm)</th>
<th>Interpretation - Acceptable?</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>21, 68</td>
<td>17%</td>
</tr>
<tr>
<td>2</td>
<td>21, 109, 38, 41, 48</td>
<td>12%</td>
</tr>
<tr>
<td>3</td>
<td>12, 16, 21, 24</td>
<td>92%</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>49%</td>
</tr>
<tr>
<td>5</td>
<td>8, 70, 5, 37, 12</td>
<td>35%</td>
</tr>
</tbody>
</table>
Different Decisions = Different Levels of Care . . . i.e. Different Levels of Exposure Risk

Why the Inconsistencies?
Data Interpretation Example

- Employee performs a job 100 times per year
- If you collected personal samples on the employee all 100 times, how many times is it acceptable for exposures to exceed the Occupational Exposure Limit (OEL) without a respirator?
  1) 0 samples?
  2) 1 sample?
  3) 5 samples?
  4) 10 samples?
  5) 25 samples?
  6) 50 samples?

Why the Inconsistencies?

- Variable Definitions of Acceptable
How much assurance?

1) 100% Sure?
2) 99%?
3) 95%?
4) 90%?
5) 75%?
6) 50%?

Why the Inconsistencies?

- Variable Definitions of Acceptable
- Variable Definitions of Acceptable
  Uncertainty
Why the Inconsistencies?

- Variable Definitions of Acceptable
- Variable Definitions of Acceptable Uncertainty

*While not consensus, many seem to settle in on 95\%ile and would seem to desire 95\% confidence.*

*Are we getting that performance?*

---

Interpreting Data:

Data Quality Considerations

- Well defined SEG
- Appropriate OEL
- Well described exposure question
- Appropriate sampling strategy
- Valid and appropriate sampling method
- Validated analytical method
- Etc.

*For purposes of this course: Assume appropriate sampling strategy and high-quality data*
**Question:**

- Most common number of air samples used to make a judgment about exposure?
  - A. >10
  - B. 6 to 10
  - C. 3 to 5
  - D. 1 or 2
  - E. 0

**Exposure Judgments**

**Inputs**
- Basic Characterization Information
- Training
- Experience

**Outputs**
- Exposure Judgment
  - Exposure Estimate
  - Hazard Estimate
  - Uncertainty Estimate
  - Acceptability Estimate

Black Box
Improving the Black Box:

- Training
- Feedback

What if the feedback loop is faulty?
Inconsistent data interpretation

- Leads to Inconsistent Exposure Risk Decisions and Inconsistent Level of Protection
- Results in Faulty Feedback Loops for Improving Qualitative Assessments

Data Interpretation Exercise
Class Work: DIT
Exposure Rating Categories

<table>
<thead>
<tr>
<th>Exposure Rating Category</th>
<th>Cutoff (%OEL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$X_{0.95} \leq 10%$</td>
</tr>
<tr>
<td>2</td>
<td>$10% &lt; X_{0.95} \leq 50%$</td>
</tr>
<tr>
<td>3</td>
<td>$50% &lt; X_{0.95} \leq 100%$</td>
</tr>
<tr>
<td>4</td>
<td>$X_{0.95} &gt; 100%$</td>
</tr>
</tbody>
</table>

Data Interpretation Test (DIT) Rules!

- Determine the probability of the 95th Percentile being in each of the 4 categories.
- There must be only ONE highest category.
- The total probability for all 4 categories must be equal to 100%.
- There must be at least 1% in each category.
Probability Chart for 95% tile Exposure Judgements

(Example - "There is a 45% probability that the 95% tile falls between 10% & 50% of the OEL.")

Example of filling out the DIT

<table>
<thead>
<tr>
<th>Categories</th>
<th>Dataset #1 - Probability of 95th Percentile in Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10%</td>
<td>30</td>
</tr>
<tr>
<td>10-50%</td>
<td>45</td>
</tr>
<tr>
<td>50-100%</td>
<td>15</td>
</tr>
<tr>
<td>&gt;100%</td>
<td>10</td>
</tr>
</tbody>
</table>
## Data Interpretation Test (DIT) #6

**Enter Your Number**

<table>
<thead>
<tr>
<th>Sample Data Set #1</th>
<th>Sample Data Set #2</th>
<th>Sample Data Set #3</th>
<th>Sample Data Set #4</th>
<th>Sample Data Set #5</th>
<th>Sample Data Set #6</th>
<th>Sample Data Set #7</th>
<th>Sample Data Set #8</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>6</td>
<td>33</td>
<td>5</td>
<td>78</td>
<td>3</td>
<td>31</td>
<td>14</td>
</tr>
<tr>
<td>17</td>
<td>37</td>
<td>20</td>
<td>3</td>
<td>1</td>
<td>17</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>9</td>
<td>109</td>
<td>12</td>
<td>18</td>
<td>45</td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>13</td>
<td>8</td>
<td>6</td>
<td>5</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>63</td>
<td></td>
<td></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>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**OEL for all Data Sets**

- **100% OEL**
- **150% OEL**
- **200% OEL**
- **250% OEL**
- **300% OEL**

**Check**: 100? 100? 100? 100? 100? 100? 100? 100?

**Have you ever taken this statistical test before?**

- Yes
- No

**If yes, how many times & when?**

**Instructions**

- Please list any specific comments regarding this DIT.
- Make sure that each data set column adds to 100%.
Use of Statistical Tools

- For those SEG’s for which air monitoring results are available, what percent of the time do you apply statistics to aid in your exposure judgment?
  
  A. 100%
  B. 50% to 100%
  C. 25% to 50%
  D. 10% to 25%
  E. <10%

Why the Inconsistencies?

- Variable Definitions of Acceptable
- Variable Definitions of Acceptable Uncertainty
- Inconsistent use and understanding of techniques for interpreting limited data sets
  - Statistics can be difficult to interpret
  - Sampling Limited: Would like to leverage all available information
Problems with judging or estimating 95%tiles

- Limited data for many jobs or tasks
- Very large statistical confidence intervals with small data sets
- Censored Data (Below LOD)
- Log data can be difficult to judge
- Difficult to Communicate

Is the exposure represented by these samples acceptable?

Ethanol OEL = 1000 ppm

Monitoring Results:

- 215 ppm
- 52 ppm
- 395 ppm
- 700 ppm
- 75 ppm

Traditional IH Statistics

- GMD = 188
- GSD = 3

UTL_{95\%,99\%} = 18,700 ppm
Is the exposure represented by these samples acceptable?

Ethanol OEL = 1000 ppm

Monitoring Results:
- 215 ppm
- 52 ppm
- 395 ppm
- 700 ppm
- 75 ppm

Bayesian Decision Analysis (BDA)
- An adjunct or alternative to the calculation and interpretation of traditional statistics.
- The goal of BDA is to estimate the probability that the true exposure profile falls into a particular category, or Exposure Rating.
Straightforward Interpretation: Bayesian Likelihood Distribution

Much easier to communicate!
A Brief Survey

**Examples Using BDA Tool**

Rate Each Scenario as either Acceptable or Unacceptable

---

**Xylene OEL=100**

**Scenario 1**

<table>
<thead>
<tr>
<th>Agent</th>
<th>Xylene</th>
<th>TLV</th>
<th>Exposure Judgment (Choose One)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>100 ppm**</td>
<td>Sample 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>21</td>
</tr>
</tbody>
</table>

\* Irritation

X gsd: 2.295

21 95%ile: 148

68 UTL: 113,000,000,000

17% Rated as Acceptable
Xylene OEL=100
Scenario 2

<table>
<thead>
<tr>
<th></th>
<th>gsd: 1.808</th>
<th>95%ile: 117</th>
<th>UTL: 535</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>21</td>
<td>109</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>41</td>
<td>48</td>
<td></td>
</tr>
</tbody>
</table>

12% Rated as Acceptable

“Would Look More Closely at 109”

Xylene OEL=100
Scenario 3

<table>
<thead>
<tr>
<th></th>
<th>gsd: 1.36</th>
<th>95%ile: 29.2</th>
<th>UTL: 85.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>12</td>
<td>16</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

92% Rated as Acceptable
Improving Professional Judgment
John Mulhausen Ph.D., CIH, CSP
Perry Logan Ph.D., CIH

Xylene OEL=100
Scenario 4

X 5
gsd: ?
95%ile: ?
UTL: ?

49% Rated as Acceptable
“Need More Data”

Xylene OEL=100
Scenario 5

X 8 70 5 37 12
gsd: 2.99
95%ile: 100
UTL: 1645

35% Rated as Acceptable
“Maybe 2+ Exposure Groups”
AIHA Model: Inherently Bayesian

AIHA Exposure Assessment Flow Diagram
AIHA EA Strategy

Define Exposure Using All Available Information

Conditions
Qualitative Modeling EA Tools Monitoring

Exposure Profile

Exposure Profile

pdf

Concentration
Example: Exposure Rating Category Follow-up

<table>
<thead>
<tr>
<th>Exposure Control 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>general HazCom</td>
</tr>
<tr>
<td>2 (10-50% of OEL)</td>
<td>+ chemical specific HazCom</td>
</tr>
<tr>
<td>3 (50-100% of OEL)</td>
<td>+ exposure surveillance, medical surveillance, work practices</td>
</tr>
<tr>
<td>4 (&gt;100% of OEL)</td>
<td>+ respirators &amp; engineering controls, work practice controls</td>
</tr>
<tr>
<td>5 (Multiples of OEL; e.g., based on respirator APFs)</td>
<td>+ immediate engineering controls or process shutdown, validate respirator selection</td>
</tr>
</tbody>
</table>

** - Decision statistic = 95th percentile
AIHA EA Strategy

Define Exposure Using All Available Information

Conditions

Qualitative Modeling

EA Tools

Exposure Profile

Initial Assessment

Heavy Emphasis on Professional Judgment or Modeling

Conditions

Qualitative Modeling

EA Tools

Exposure Profile
Validated Assessment

Heavy Emphasis on Monitoring Data

Conditions

Qualitative Modeling

EA Tools

Monitoring

Exposure Profile

AIHA EA Strategy:

Define Exposure Using All Available Information

Conditions

Qualitative Modeling

EA Tools

Monitoring

Exposure Profile
Industrial Hygienists Are Bayesian Thinkers!
An Example Using the AIHA Model
Exposure Assessment

1. Establish Similar Exposure Groups
2. Define Exposure Profile
3. Select/Define OELs
4. Compare:
   - Exposure Profile and its Uncertainty
   - OEL and its Uncertainty

Exposure Band

1. Establish Similar Exposure Groups
2. Define Exposure Profile
3. Select/Define OELs
4. Compare:
   - Exposure Profile and its Uncertainty
   - OEL and its Uncertainty

- Acceptable
- Uncertain
- Unacceptable
**AIHA EA Strategy:**
Define Exposure Using All Available Information

**Tools for Initial Assessment**

**Qualitative Modeling**

**EA Tools**

**Exposure Profile**

---

**Example: Exposure Estimate**

**Simple Model:**

\[ C = \frac{G}{Q} \]

**Worst Case**

\[ C = \frac{65 \text{ mg/hour}}{3.6 \text{ m}^3/\text{hour}} = 18 \text{ mg/m}^3 \]

**Best Case**

\[ C = \frac{35 \text{ mg/hour}}{540 \text{ m}^3/\text{hour}} = 0.065 \text{ mg/m}^3 \]
Example: Exposure Estimate

Statistical Modeling: Monte Carlo Uncertainty Analysis

Agent “X”

- G = steady generation rate (mg/hour)
  - 35 to 65 mg/hour
- Q = steady ventilation rate (m$^3$/hour)
  - 3.6 to 540 m$^3$/hour

Forecast: Concentration

Certainty is 95.30% from 0.00 to 1.75 mg/m$^3$
Uncertainty and Acceptability

Concentration (mg/M³)

Simple Model

Monte Carlo

Monte Carlo

COSHH Essentials

Table 3: Definitions of exposure predictor bands

<table>
<thead>
<tr>
<th>Exposure predictor band</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPS1</td>
<td>Gram or kilogram</td>
</tr>
<tr>
<td>EPS2</td>
<td>Gram or kilogram</td>
</tr>
</tbody>
</table>

Table 4: The four control approaches

<table>
<thead>
<tr>
<th>Control approach type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>General ventilation</td>
</tr>
<tr>
<td>2</td>
<td>Engineering control</td>
</tr>
</tbody>
</table>

Table 5: Relating exposure predictor bands to control approach

<table>
<thead>
<tr>
<th>Predicted dust-in-air exposure ranges (mg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control approach</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
</tbody>
</table>

Table 6: Predicted vapour-in-air concentrations (ppm)

<table>
<thead>
<tr>
<th>Control approach</th>
<th>EPS1</th>
<th>EPS2</th>
<th>EPS3</th>
<th>EPS4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;5</td>
<td>5-50</td>
<td>50-500</td>
<td>&gt;500</td>
</tr>
<tr>
<td>2</td>
<td>&lt;0.5</td>
<td>0.5-5</td>
<td>5-50</td>
<td>5-500</td>
</tr>
<tr>
<td>3</td>
<td>&lt;0.05</td>
<td>0.05-0.5</td>
<td>0.5-5</td>
<td>0.5-5</td>
</tr>
</tbody>
</table>
Uncertainty and Acceptability

<table>
<thead>
<tr>
<th>Concentration (mg/M³)</th>
<th>OEL = 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Simple Model</td>
<td></td>
</tr>
<tr>
<td>10</td>
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</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Monte Carlo</td>
<td></td>
</tr>
<tr>
<td>1.75</td>
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<tr>
<td>1.0</td>
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<td>COSHH Ess.</td>
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<tr>
<td>0.065</td>
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<tr>
<td>0.22</td>
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</tr>
<tr>
<td>0.1</td>
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</tr>
<tr>
<td>OEL = 10</td>
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</tr>
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<td>Monte Carlo</td>
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<td>1.75</td>
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<td>1.0</td>
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<tr>
<td>COSHH Ess.</td>
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<td>0.065</td>
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</tr>
<tr>
<td>0.22</td>
<td></td>
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<tr>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>OEL = 1</td>
<td></td>
</tr>
</tbody>
</table>

Which To Choose? Acceptable?

Any or all of these can be used to build the Bayesian Qualitative Model

Uncertainty and Acceptability

<table>
<thead>
<tr>
<th>Concentration (mg/M³)</th>
<th>OEL = 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Simple Model</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Monte Carlo</td>
<td></td>
</tr>
<tr>
<td>1.75</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>COSHH Ess.</td>
<td></td>
</tr>
<tr>
<td>0.065</td>
<td></td>
</tr>
<tr>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>OEL = 1</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Monte Carlo</td>
<td></td>
</tr>
<tr>
<td>1.75</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>COSHH Ess.</td>
<td></td>
</tr>
<tr>
<td>0.065</td>
<td></td>
</tr>
<tr>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td></td>
</tr>
</tbody>
</table>

Which To Choose? Acceptable?
Establish Similar Exposure Groups

Define Exposure Profile

Select/Define OELs

Compare:
Exposure Profile and its Uncertainty
OEL and its Uncertainty

Acceptable
Uncertain
Unacceptable

OELs

- **Regulatory** - Set and enforced by government agencies
  - e.g. OSHA PEL, MSHA PEL

- **Authoritative** - Set and recommended by credible organizations
  - e.g. ACGIH TLV, AIHA WEEL

- **Internal** - Devised by organizations for internal use and/or recommendation
  - e.g. Company Exposure Guideline
Chemicals With OELs

OELs

- **Regulatory** - Set and enforced by government agencies
  - e.g. OSHA PEL, MSHA PEL

- **Authoritative** - Set and recommended by credible organizations
  - e.g. ACGIH TLV, AIHA WEEL

- **Internal** - Devised by organizations for internal use and/or recommendation
  - e.g. Company Exposure Guideline

- **Working** - Informal limit established in order to resolve an exposure assessment. Typically based on sparse toxicity data.
### Table 5.4

**GENERAL CONTAINMENT LEVELS USED IN ONE PHARMACEUTICAL COMPANY (ADOPTED FROM NAUMANN ET. AL.)**

<table>
<thead>
<tr>
<th>Category for Performance-Based Exposure Control Limit</th>
<th>General Corresponding Numerical “Exposure Control Limit” 8 Hour TWA</th>
<th>General Corresponding Wipe Test Criteria</th>
<th>Containment Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>In the range of 1- 5 mg/M³</td>
<td>In the range of 100 mg/100 cm³</td>
<td>Good manufacturing practices</td>
</tr>
<tr>
<td>2</td>
<td>In the range of 0.1 - 1 mg/M³</td>
<td>In the range of 1 mg/100 cm³</td>
<td>Good manufacturing practices (with more stringent controls)</td>
</tr>
<tr>
<td>3</td>
<td>In the range of 1 - 100 ug/M³</td>
<td>In the range of 100 ug/100 cm²</td>
<td>Essentially no open handling (closed systems should be used)</td>
</tr>
<tr>
<td>4</td>
<td>In the range of &lt;1 ug/M³</td>
<td>In the range of 10 ug/100 cm²</td>
<td>No open handling (closed systems must be used)</td>
</tr>
<tr>
<td>5</td>
<td>In the range of 0.1 ug/M³</td>
<td>In the range of 1 ug/100 cm²</td>
<td>No manual operations, no human intervention (robotics / remote operations encouraged)</td>
</tr>
</tbody>
</table>

---

**WOEL Example: Pharmaceutical Indust.**

**WOEL Example: COSHH Essentials**
Improving Professional Judgment

John Mulhausen Ph.D., CIH, CSP
Perry Logan Ph.D., CIH

Establish Similar Exposure Groups

Define Exposure Profile

Select/Define OELs

Risk Assessment

Compare:
Exposure Profile and its Uncertainty
OEL and its Uncertainty

Acceptable
Uncertain
Unacceptable

Uncertainty and Acceptability

Concentration (mg/M³)

18
10
0.065
1.75
0.22
1.0
0.1

Simple Model
Monte Carlo
COSHH Ess.

OEL = 10
Improving Professional Judgment
John Mulhausen Ph.D., CIH, CSP
Perry Logan Ph.D., CIH
AIHA EA Strategy: Define Exposure Using All Available Information

- Qualitative Modeling
- Monitoring
- EA Tools

Add Monitoring Data . . .

Validate Initial Judgments
Example: Exposure Estimate

Agent “X”
G = steady generation rate (mg/hour)
35 to 65 mg/hour
Q = steady ventilation rate (m³/hour)
3.6 to 540 m³/hour

Monitoring Results:

<table>
<thead>
<tr>
<th>Concentration (mg/M³)</th>
<th>95th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0.14</td>
</tr>
<tr>
<td>0.14</td>
<td>0.21</td>
</tr>
<tr>
<td>0.21</td>
<td>0.37</td>
</tr>
<tr>
<td>0.37</td>
<td>0.78</td>
</tr>
</tbody>
</table>

UTL_{95%,95%} = 16 mg/M³
Improving Professional Judgment

John Mulhausen Ph.D., CIH, CSP

Perry Logan Ph.D., CIH
Example: Exposure Estimate

<table>
<thead>
<tr>
<th>Exposure Control 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>General Haz Com</td>
</tr>
<tr>
<td>2 (10-50% of OEL)</td>
<td>+ Chemical specific Haz Com</td>
</tr>
<tr>
<td>3 (50-100% of OEL)</td>
<td>+ Medical surveillance, work practices</td>
</tr>
<tr>
<td>4 (&gt;100% of OEL)</td>
<td>+ Respirators &amp; engineering controls, work practice controls</td>
</tr>
<tr>
<td>Multiples of OEL</td>
<td>+ Immediate Engineering Controls or Process Shut Down, Validate Acceptable Respirator</td>
</tr>
</tbody>
</table>

Integrated Exposure Assessment Result Leads to Control Recommendations

Control Guidance

- ACGIH Industrial Ventilation Manual
- Company Engineering Standards
- COSHH Essentials Control Sheets
- MSDS
Review of Traditional IH Statistics

I. Lognormal distribution
II. Sample 95\textsuperscript{th} percentile
III. UCL for the sample 95\textsuperscript{th} percentile
IV. Rules-of-thumb for “Eyeballing” Exposure Data
I. Lognormal Distribution – Example
Airborne exposures to inorganic lead


Parameters vs. Statistics

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>-calculated using all elements of the population</td>
<td>-calculated from a sample of n elements randomly selected</td>
</tr>
<tr>
<td>log transform each element</td>
<td>log transform each element</td>
</tr>
<tr>
<td>Population Mean</td>
<td>Sample Mean</td>
</tr>
<tr>
<td>( \mu_y )</td>
<td>( \bar{y} )</td>
</tr>
<tr>
<td>Population Standard Deviation</td>
<td>Sample Standard Deviation</td>
</tr>
<tr>
<td>( \sigma_y )</td>
<td>( S_y )</td>
</tr>
</tbody>
</table>

The measurements are converted to natural logs: \( y = \ln(x) \)
### Parameters vs. Statistics

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>calculated using all elements of the population</td>
<td>calculated from a sample of n elements randomly selected</td>
</tr>
<tr>
<td><strong>Population</strong></td>
<td><strong>Sample</strong></td>
</tr>
<tr>
<td>Geometric Mean</td>
<td>Geometric Mean</td>
</tr>
<tr>
<td>GM</td>
<td>gm</td>
</tr>
<tr>
<td>GSD</td>
<td>gsd</td>
</tr>
</tbody>
</table>

#### Lognormal distribution PDF

- **gm**: 1.06 mg/m³
- **gsd**: 1.83

**Measures of Location**
- Mode
- Median = GM
- Mean
Lognormal

Sample geometric mean (gm) & geometric standard deviation (gsd)

\[
\text{let } y = \ln(x)
\]

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

\[
\text{gsd} = \exp \sqrt{\frac{\sum (y_i - \bar{y})^2}{n-1}}
\]
Example: Welding fume data - estimate GM and GSD

<table>
<thead>
<tr>
<th>Case</th>
<th>$x_i$ (mg/m$^3$)</th>
<th>$y_i=\ln(x_i)$</th>
<th>$(y_i-\bar{y})^2$</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>

$gm = \exp\left(\frac{0.3722}{6}\right) = 1.06$ mg/m$^3$

$gsd = \exp\sqrt{\frac{1.833976}{6-1}} = 1.83$
II. Sample 95th Percentile Exposure

- The focus is on the upper tail of the exposure profile.
- The sample 95th percentile can be considered a "decision statistic".
- The (usual) goal is to determine which category the 95th Percentile most likely falls.
- It is used to assist in reaching a decision that the exposure profile is
  - "Controlled" or "Acceptable"
  - "Unacceptable"
  - or falls in a "Control Category"

95th Percentile interpretation of TWA OELs

- ACGIH
95th Percentile interpretation of TWA OELs

- AIHA 1991 and 1998 guidance
  - Employer should maintain true group or individual upper percentile exposure < TWA OEL
  - “Similar Exposure Group” 95th percentile exposure < TWA OEL

- Ex-OSHA director:

95th Percentile interpretation of TWA OELs

- NIOSH guidance
  - Employer should 95% confident that 95% of the exposures are ≤ the TWA PEL

- OSHA
  - Measured TWA exposures should “rarely” exceed the TWA PEL (preamble to the benzene PEL, 1987)
95th Percentile interpretation of TWA OELs

- EU

Example

- A sample of six full-shift TWA welding fume measurements resulted in the following statistics:
  - (sample) geometric mean is 1.06 mg/m³
  - (sample) geometric standard deviation is 1.83

- What is the point estimate (i.e., best estimate) of the true 95th percentile?
**90\textsuperscript{th}, 95\textsuperscript{th}, and 99\textsuperscript{th} Percentiles**

Let $\bar{y} = \ln(gm)$

$s_y = \ln(gsd)$

$\hat{X}_p = \exp(\bar{y} + Z_p \cdot s_y)$

$\hat{X}_{0.90} = \exp(\bar{y} + 1.282 \cdot s_y)$

$\hat{X}_{0.95} = \exp(\bar{y} + 1.645 \cdot s_y)$

$\hat{X}_{0.99} = \exp(\bar{y} + 2.327 \cdot s_y)$

---

**95\textsuperscript{th} Percentile**

$\hat{X}_{0.95} = \exp(\bar{y} + 1.645 \cdot s_y)$

$\hat{X}_{0.95} = \exp(0.0620 + 1.645 \cdot 0.6043)$

$\hat{X}_{0.95} = 2.88 \ mg/m^3$
Alternative 95th Percentile Formula

\[ \hat{X}_{0.95} = gm \cdot gsd^{1.645} \]

\[ = 1.06 \cdot 1.83^{1.645} = 2.88 \text{ mg/m}^3 \]
III. Upper Confidence Limit (UCL) for the Sample 95\textsuperscript{th} Percentile

- Calculate confidence intervals around estimates of ...
  - upper percentile (normal & lognormal)
- Confidence intervals are used to ...
  - express uncertainty
  - test hypotheses:
    - to determine our confidence level that the SEG is in compliance with an OEL
    - to determine our confidence level that the true 95\textsuperscript{th} percentile exposure is within a specific exposure control category

For single shift, TWA exposure limits (TWA OELs) ...

- focus on the upper tail of the distribution
- e.g., 95\textsuperscript{th} percentile exposure
Upper Percentile (e.g., 95\textsuperscript{th} percentile)

- **Concept**
  - Calculate the 95\% upper confidence interval for the 95th percentile statistic (upper tolerance limit)

- **Application**
  - 95\%UCL can be used to test the following hypotheses:
    - $H_0$: 95th percentile $\geq$ OEL
    - $H_a$: 95th percentile $< OEL$

- **Interpretation**
  - If the 95\%UCL 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

95\%UCL for the 95\textsuperscript{th} Percentile

- **Procedure:**
  - Calculate the gm and gsd
  - Using $n$, read the UCL $K$-value from the appropriate table
    - $\gamma =$ confidence level, e.g., 0.95
    - $p =$ proportion, e.g., 0.95
    - $n =$ sample size
  - Using gm, gsd, and $k$, calculate the 95\%UCL
    - $\bar{y} = \ln(\ gm) \ and \ s_y = \ln(\ gsd)$
    - $95\%UCL(\hat{X}_{0.95}) = \exp(\bar{y} + K_{\gamma,p,n} \cdot s_y)$
TABLE VII.3 — Factors for One-Sided Tolerance Limits

<table>
<thead>
<tr>
<th>P</th>
<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>3</td>
<td>3</td>
<td>3.804</td>
<td>6.158</td>
<td>7.455</td>
<td>10.552</td>
<td>13.857</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>2.619</td>
<td>4.163</td>
<td>5.145</td>
<td>7.042</td>
<td>9.215</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>2.149</td>
<td>3.407</td>
<td>4.202</td>
<td>5.741</td>
<td>7.501</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>1.895</td>
<td>3.005</td>
<td>3.707</td>
<td>5.062</td>
<td>6.612</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>1.732</td>
<td>2.755</td>
<td>3.899</td>
<td>4.641</td>
<td>6.061</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>1.617</td>
<td>2.582</td>
<td>3.188</td>
<td>4.353</td>
<td>5.686</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>1.532</td>
<td>2.454</td>
<td>3.031</td>
<td>4.143</td>
<td>5.414</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>1.465</td>
<td>2.355</td>
<td>2.911</td>
<td>3.981</td>
<td>5.203</td>
</tr>
</tbody>
</table>

\[
\text{95\% } \text{UCL}(\bar{X}_{0.95}) = \exp(\bar{y} + K_{\gamma,p,n} \cdot s_y) \\
= \exp(\bar{y} + K_{0.95,0.95.6} \cdot s_y) \\
= \exp(0.0620 + 3.707 \cdot 0.6043) \\
= 10.00 \text{ mg/m}^3
\]
Rules of Thumb

$g_m = 1.06 \text{ mg/m}^3$
$g_s = 1.83$

$10.00 \text{ mg/m}^3$
$UCL_{95,95}$
IV. Rule-of-thumb for “Eyeballing” Exposure Data

- Given:
  - GM = median
  - \( X_p = GM \times GSD^{z_p} \) (e.g., \( X_{0.95} = GM \times GSD^{1.645} \))
  - ... a Rule-of-thumb, or guideline, can be devised for quickly estimating from limited data the range in which the true 95\(^{th}\) percentile might lie.

<table>
<thead>
<tr>
<th>GSD</th>
<th>Multiple of GM (median)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( X_p = 95^{th} ) percentile</td>
</tr>
<tr>
<td></td>
<td>( Z_p = 1.645 )</td>
</tr>
<tr>
<td>1.5</td>
<td>1.95</td>
</tr>
<tr>
<td>2.0</td>
<td>3.13</td>
</tr>
<tr>
<td>2.5</td>
<td>4.51</td>
</tr>
<tr>
<td>3.0</td>
<td>6.09</td>
</tr>
</tbody>
</table>
Improving Professional Judgment

John Mulhausen Ph.D., CIH, CSP
Perry Logan Ph.D., CIH

\[ X_p = GM \times GSD^{Z_p} \]

<table>
<thead>
<tr>
<th>GSD</th>
<th>Multiple of GM (median)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( X_p = 95^{\text{th}} ) percentile</td>
</tr>
<tr>
<td></td>
<td>( Z_p = 1.645 )</td>
</tr>
<tr>
<td>1.5</td>
<td>1.95</td>
</tr>
<tr>
<td>2.0</td>
<td>3.13</td>
</tr>
<tr>
<td>2.5</td>
<td>4.51</td>
</tr>
<tr>
<td>3.0</td>
<td>6.09</td>
</tr>
</tbody>
</table>

Rules of Thumb

<table>
<thead>
<tr>
<th>Variability</th>
<th>ROT Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>2</td>
</tr>
<tr>
<td>Medium</td>
<td>4</td>
</tr>
<tr>
<td>High</td>
<td>6</td>
</tr>
</tbody>
</table>
R.O.T. for Estimating the 95\textsuperscript{th} Percentile

1. If \( n \) is small (i.e., <6) and one or more measurements > OEL, then decision = Category 4 (>OEL).
2. Estimate the median and use it as a surrogate of the sample GM:
   - Sort the data
   - If \( n \) is odd the median is the middle value.
   - If \( n \) is even the median is the average of two middle values.
3. Multiply the median by 2, 4, and 6
   - The results comprise an \textit{approximate} low, middle, and high estimate of \( X_{0.95} \).
   - Emphasis on 2 x Median if data have little spread
   - Emphasis on 6 x Median if data have large spread

---

<table>
<thead>
<tr>
<th>Scenerio</th>
<th>Data (ppm)</th>
<th>Median</th>
<th>2X</th>
<th>4X</th>
<th>6X</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21, 68</td>
<td>45</td>
<td>90</td>
<td>180</td>
<td>270</td>
</tr>
<tr>
<td>2</td>
<td>21, 109, 38, 41, 48</td>
<td>41</td>
<td>82</td>
<td>164</td>
<td>246</td>
</tr>
<tr>
<td>3</td>
<td>12, 16, 21, 24</td>
<td>19</td>
<td>38</td>
<td>76</td>
<td>114</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>8, 70, 5, 37, 12</td>
<td>12</td>
<td>24</td>
<td>48</td>
<td>72</td>
</tr>
</tbody>
</table>
Rule-of-thumb Workshop (assume OEL=100)

A. \( X = \{30, 17, 7, 13, 63, 5\} \)
B. \( X = \{6\} \)
C. \( X = \{33, 37, 9, 109, 8, 5\} \)
D. \( X = \{5, 20, 3, 12\} \)
E. \( X = \{78\} \)
F. \( X = \{3, 1\} \)
G. \( X = \{31, 17, 18, 45\} \)
H. \( X = \{14, 5, 6, 12, 4, 36\} \)

For each dataset, determine the appropriate Exposure Category – 1, 2, 3, or 4 – using the above Rule-of-thumb.

Rule of Thumb Worksheet

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Data</th>
<th>Median</th>
<th>2x</th>
<th>4x</th>
<th>6x</th>
<th>Likely Category (1-4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>30, 17, 7, 13, 63, 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>33, 37, 9, 109, 8, 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>5, 20, 3, 12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>78</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>3, 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>31, 17, 18, 45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>14, 5, 6, 12, 4, 36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Rule of Thumb Worksheet

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Data</th>
<th>Median</th>
<th>2x</th>
<th>4x</th>
<th>6x</th>
<th>Likely Category (1-4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5, 7, 13, 17, 30, 63</td>
<td>15</td>
<td>30</td>
<td>60</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>6</td>
<td>6</td>
<td>12</td>
<td>24</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>5, 8, 9, 33, 37, 109</td>
<td>21</td>
<td>42</td>
<td>84</td>
<td>126</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>3, 5, 12, 20</td>
<td>8.5</td>
<td>17</td>
<td>34</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>78</td>
<td>78</td>
<td>156</td>
<td>312</td>
<td>468</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>1, 3</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>17, 18, 31, 45</td>
<td>24.5</td>
<td>49</td>
<td>98</td>
<td>147</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>4, 5, 6, 12, 14, 36</td>
<td>9</td>
<td>18</td>
<td>36</td>
<td>54</td>
<td></td>
</tr>
</tbody>
</table>

## Data Interpretation Exercise

Class Work: Post-Training DIT
## Data Interpretation Test (DIT) #5

Enter Your Number

<table>
<thead>
<tr>
<th>OEL for all Data Sets</th>
<th>Sample Data Set #1</th>
<th>Sample Data Set #2</th>
<th>Sample Data Set #3</th>
<th>Sample Data Set #4</th>
<th>Sample Data Set #5</th>
<th>Sample Data Set #6</th>
<th>Sample Data Set #7</th>
<th>Sample Data Set #8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>8</td>
<td>18</td>
<td>82</td>
<td>5</td>
<td>11</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>43</td>
<td>9</td>
<td>2</td>
<td>118</td>
<td>28</td>
<td>9</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>9</td>
<td>24</td>
<td>1</td>
<td>35</td>
<td>6</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Make your judgments on the above Statistics Test Data in the following columns

<table>
<thead>
<tr>
<th>1-10% OEL</th>
<th>Data Set #1</th>
<th>Data Set #2</th>
<th>Data Set #3</th>
<th>Data Set #4</th>
<th>Data Set #5</th>
<th>Data Set #6</th>
<th>Data Set #7</th>
<th>Data Set #8</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-50% OEL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50-100% OEL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;100% OEL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Check: 100? 100? 100? 100? 100? 100? 100? 100?

Have you ever taken this statistical test before? Yes No

If yes, how many times & when?

Instructions

Enter your name at the top

Review each data set and document the probabilities of where the 95th%tile falls

Make sure that one category has the highest percentage

Do not enter values less than 1 in any field (no zeros!)

Check to see that each Data Set Column adds to 100%

Please list any specific comments regarding this DIT

Bayesian Decision Analysis (BDA) Theory and Tool

What Do The Monitoring Data Tell Us?
Focus on Decision Making

- Regardless of the number of measurements and how we analyze the measurements, the end result is a *Decision*:
  - e.g., the Exposure Profile is a Category 0, 1, 2, 3, or 4 exposure
  - ...and that Decision leads to Actions.

The AIHA “Exposure Banding” Model

- AIHA Exposure Control Ratings for TWA OELs
  - Which exposure control band is appropriate?

<table>
<thead>
<tr>
<th>Exposure Control Ratings *</th>
<th>Cutoff (%OEL)</th>
<th>Confidence level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$X_{0.95} \leq 1%$</td>
<td>High</td>
</tr>
<tr>
<td>1</td>
<td>1% $&lt; X_{0.95} \leq 10%$</td>
<td>Medium</td>
</tr>
<tr>
<td>2</td>
<td>10% $&lt; X_{0.95} \leq 50%$</td>
<td>Medium</td>
</tr>
<tr>
<td>3</td>
<td>50% $&lt; X_{0.95} \leq 100%$</td>
<td>Low</td>
</tr>
<tr>
<td>4</td>
<td>$X_{0.95} &gt; 100%$</td>
<td></td>
</tr>
</tbody>
</table>
Example: Exposure Control Category Follow-up

<table>
<thead>
<tr>
<th>Exposure Control 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>general HazCom</td>
</tr>
<tr>
<td>2 (10-50% of OEL)</td>
<td>+ chemical specific HazCom</td>
</tr>
<tr>
<td>3 (50-100% of OEL)</td>
<td>+ exposure surveillance, medical surveillance, work practices</td>
</tr>
<tr>
<td>4 (&gt;100% of OEL)</td>
<td>+ respirators &amp; engineering controls, work practice controls</td>
</tr>
<tr>
<td>5 (Multiples of OEL; e.g., based on respirator APFs)</td>
<td>+ immediate engineering controls or process shutdown, validate respirator selection</td>
</tr>
</tbody>
</table>

** - Decision statistic = 95th percentile

- BDA helps us determine the *probability* that the true exposure profile falls within each of the five exposure categories (i.e., OEL-specific control zones)...
- ...so that an exposure control category can be selected with greater accuracy, resulting in the appropriate *actions.*
**Example Survey**

- OEL = 1 ppm
- During a baseline/initial exposure assessment, an IH collected the following full-shift measurements from an SEG:
  - 0.20, 0.05, & 0.10 ppm
  - n = 3 ; gm = 0.10 ; gsd = 2.00
- The sample 95\(^{th}\) percentile was 0.31 ppm
- but with a 95\%UCL of 20 ppm

---

**When n is small, confidence intervals are often extremely broad.**

- X = \{0.20, 0.05, 0.10 ppm\}
- n = 3

- gm = 0.1 ppm \(90\%\text{CI}( 0.03, 0.32 )\)
- gsd = 2.0 \(90\%\text{CI}( 1.5, 21 )\)

- \(\hat{X}_{0.95} = 0.31 \text{ ppm} \ 90\%\text{CI}( 0.16, 20 )\)
Example Survey (cont’d)

- The point estimate of the 95\textsuperscript{th} percentile is < 50\% of the limit.
- Exposures appear to be a Category 2 exposure.
- However, the 95\%UCL(\(X_{0.95}\)) is considerably greater than the OEL.
- What would you do?
  - Make a decision?
  - Collect more data?

Example (cont’d)

- Our IH concludes:
  - This operation is well-controlled with just the existing dilution ventilation.
  - Although the 95\%UCLs were excessive, our IH took into account his extensive past experience with this type of operation.
- His recommendations:
  - Further sampling is not necessary.
  - Routine surveillance samples should be collected using the established schedule for well-controlled operations.
- Is such a decision making process a Bayesian Decision Analysis?
Exposures appear to be a Category 2 exposure.

0.20 ppm
0.05 ppm
0.10 ppm

X0.95 = 0.31 ppm
90%CI(0.16, 20)

Our IH concludes:
This operation is well-controlled with just the existing dilution ventilation.

Key Concept – “Decision” Distributions

- **Prior** decision distribution
  - Represents our professional judgment regarding the probability of each of the Exposure Ratings.
  - Represents our professional judgment regarding the probability of each of the Exposure Ratings.

- **Likelihood** decision distribution
  - The set of probabilities of each Exposure Rating calculated using only the collected data.

- **Posterior** decision distribution
  - The set of probabilities of each Exposure Rating calculated using Bayes’ equation.
Bayesian Decision Analysis

Posterior \quad Likelihood \quad Prior

\[ P(\text{Pop}|\text{data}) = \frac{\int_{\ln G_{\text{min}} \ln D_{\text{min}}}^{\ln G_{\text{max}} \ln D_{\text{max}}} \int \left[P(\text{data}|\ln G, \ln D) \cdot P(\text{Pop})\right] d(\ln G)d(\ln D)}{\int_{\ln G_{\text{min}} \ln D_{\text{min}}}^{\ln G_{\text{max}} \ln D_{\text{max}}} \left[P(\text{data}|\ln G, \ln D) \cdot P(\text{Pop})\right] d(\ln G)d(\ln D)} \]

Correction Factor

Bayesian Statistics

- Knowledge synthesis - formalizes process of learning from data to update beliefs.
- Widespread usage: economics, genetics, spatial analysis with GIS, clinical trials, epidemiology, computer modeling, engineering, and image restoration.

![Blurred Image](Image courtesy of Massachusetts Institute of Technology)  
![Original Image](Image courtesy of Massachusetts Institute of Technology)
Books on Bayesian Statistics

- Congdon: Bayesian Statistical Modelling (2002).

Bayesian Decision Analysis

- The original Bayes’ Theorem directly applies to discrete choices.
  - e.g., Exposure Profiles A vs. B
- We are not interested in distinguishing between just two exposure profiles.
- Instead, we are interested in distinguishing between five populations of exposure profiles:
  - Exposure Zones 0, 1, 2, 3, and 4
Exposure Ratings – A “rating zone” represents a population of exposure profiles

<table>
<thead>
<tr>
<th>Exposure Rating</th>
<th>Cutoff (%OEL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$X_{0.95} \leq 1%$</td>
</tr>
<tr>
<td>1</td>
<td>$1% &lt; X_{0.95} \leq 10%$</td>
</tr>
<tr>
<td>2</td>
<td>$10% &lt; X_{0.95} \leq 50%$</td>
</tr>
<tr>
<td>3</td>
<td>$50% &lt; X_{0.95} \leq 100%$</td>
</tr>
<tr>
<td>4</td>
<td>$X_{0.95} &gt; 100%$</td>
</tr>
</tbody>
</table>

Exposure Ratings translated into parameter space for OEL=1 ppm
Prior Decision Distribution

- Categorical
  - Assign an *a priori* probability to each Exposure Rating zone

Example *Prior* Decision Distributions

- Non-informative prior
- Informative prior
Example *Likelihood* Decision Distribution for \( x = \{0.20, 0.05, 0.10\} \)

Example *Posterior* Decision Distributions

Using the non-informative prior

Using the informative prior
Decision Charts

- OEL=1 ppm
- n = 3
- x = \{0.20, 0.05, 0.10\} ppm

Here we used a uniform prior (also called Flat or Non-informative prior).

Decision Charts

- OEL=1 ppm
- n = 3
- x = \{0.20, 0.05, 0.10\} ppm

Here we used an informative prior.
Introduction to IHDA-lite

- Data is entered using a data grid similar to a spreadsheet
  - Facility Information, Substance Information, Comments, and Data
- All information is saved to an Excel compatible .xls file.
- Exposure data can be pasted from an Excel spreadsheet into the data grid.
- Sample size is limited to 50.

(Dataset24 - Welding Fumes.xls)
1. Enter the data
   1. Indicate <LOD values w/ a ‘y’ or ‘<’
   2. Press “Calculate All”
3. Review the statistics and critique the “GOF Graphs”
   1. Are the data stationary and consistent with the assumption of a single, lognormal exposure profile?
   2. Is the exposure profile likely to be within Parameter Space?
4. Review the Decision Charts

Statistics
- Order Statistics
  - N, min, max, median
- Descriptive Statistics
  - Mean, SD + CI
  - GM, GSD + CI
- Compliance Statistics (lognormal)
  - 95th percentile + CI
  - Exceedance Fraction + CI
Compliance Statistics (non-parametric)

- 95th percentile + CI
- Exceedance Fraction + CI

Note: the user can select to use the 90th, 95th, or 99th percentile.

<table>
<thead>
<tr>
<th>Statistics</th>
<th>25P</th>
<th>75P</th>
<th>ICA</th>
</tr>
</thead>
<tbody>
<tr>
<td>OEL</td>
<td>5 mg/m^3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Order Statistics:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>0.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>2.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>1.09</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Descriptive Statistics:

- Mean = 1.24
- SD = 0.76
- CV = 1.06
- UCL = 1.03

Compliance Statistics (Lognormal):

- NO.95 = 2.06
- 95%UCL = 1.81
- 95%LCL = 10.10
- ExorFrac = 0.008
- 99%LCL = <0.001
- 99%UCL = 0.149

Compliance Statistics (non-parametric):
Goodness-of-fit

- Ideally, before calculating statistics the user should evaluate the goodness-of-fit for the lognormal distribution assumption.
- GOF testing is a two step process:
  - Subjective graphical techniques
  - Objective GOF statistical test

(Dataset25 - Welding Fumes.xls)

- Subjective evaluation
  - Time series plot
    - Are the data trending upwards or downwards?
  - Log-probit plot
    - Do the data fall reasonably close to a best fit curve?
    - Are there unusual clusters or patterns in the data?
  - Histogram
    - If n is large, the histogram should look reasonably lognormal.
**Goodness-of-fit Tests:**

**Filhombens Test:**

R = 0.977

critical R = 0.009

Interpretation: the lognormal distribution hypothesis is not rejected.
Scenario Examples – Decision Chart Interpretation
Scenario #1 – Process Operator #1

- Process Operator #1 is responsible for the following tasks
  - Opening a valve that directly charges xylene into the process mixer
  - Manually charging solids into the process mixer (75 pounds once per hour)
  - Collecting multiple quality samples once each hour through manhole
  - No previous personal air samples available
- We've collected some full shift air samples for xylene, now let's do some BDA!
  - 13 ppm, 26 ppm, 18 ppm
How do we interpret this?

- The output is in probability
- “We have a ___% probability that Process Operator #1 requires additional exposure controls”

- Is that above the acceptable / unacceptable threshold?

Compare BDA vs. traditional statistics...

- “We have a ___% probability that Process Operator #1 requires additional exposure controls”

- “The population 95^{th} percentile point estimate is 32 with an upper confidence limit (95%) of 260”
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Perry Logan Ph.D., CIH

Let's collect another sample...
13 ppm, 26 ppm, 18 ppm, 12 ppm

How would you interpret this?

More examples...

"less than __% probability of..." or "greater than __% probability of..."
More Examples...

- “given our sampling data, we have a greater than 95% probability that exposures are acceptable…”
- “greater than 27% probability that exposures are unacceptable…”
- “less than 10% probability that exposures exceed our medical surveillance triggers…”
- “greater than 95% probability that exposures require immediate exposure controls…”

Rule-of-thumb Workshop (assume OEL=100)

A. $X = \{30, 17, 7, 13, 63, 5\}$
B. $X = \{6\}$
C. $X = \{33, 37, 9, 109, 8, 5\}$
D. $X = \{5, 20, 3, 12\}$
E. $X = \{78\}$
F. $X = \{3, 1\}$
G. $X = \{31, 17, 18, 45\}$
H. $X = \{14, 5, 6, 12, 4, 36\}$

For each dataset, determine the appropriate Exposure Category – 1, 2, 3, or 4 – using the above Rule-of-thumb.
Rule of Thumb (R.O.T.) v.s. BDA

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Data</th>
<th>Median</th>
<th>2x</th>
<th>4x</th>
<th>6x</th>
<th>R.O.T. Category (1-4)</th>
<th>BDA Category (1-4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5, 7, 13, 17, 30, 63</td>
<td>15</td>
<td>30</td>
<td>60</td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>6</td>
<td>6</td>
<td>12</td>
<td>24</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
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<td>42</td>
<td>84</td>
<td>126</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>3, 5, 12, 20</td>
<td>8.5</td>
<td>17</td>
<td>34</td>
<td>51</td>
<td></td>
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</tr>
<tr>
<td>F</td>
<td>1, 3</td>
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<td>147</td>
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<td>H</td>
<td>4, 5, 6, 12, 14, 36</td>
<td>9</td>
<td>18</td>
<td>36</td>
<td>54</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Workshop – Using the IHDataAnalyst-LiteEdition (IHDA-LE)

I. Limited datasets
II. Large datasets
III. Censored datasets
Limited Data (OEL = 1 ppm)

- Dataset00 - manuscript data.xls

- 0.2 ppm
- 0.05 ppm
- 0.1 ppm

Limited Data (OEL = 5 mg/M³)

- Dataset24 - Welding Fumes.xls
- Measurements collected from an SEG on a single day at a frame manufacturing facility in 1987.

- 1.63 mg/M³
- 4.28 mg/M³
- 2.04 mg/M³
- 2.32 mg/M³
- 2.02 mg/M³
- 6.04 mg/M³
Limited Data (OEL = 5 mg/M³)

- Dataset25 - Welding Fumes.xls
- Measurements collected from an SEG on a single day at frame manufacturing facility in 1987.

0.84 mg/M³
0.98 mg/M³
0.42 mg/M³
1.16 mg/M³
1.36 mg/M³
2.66 mg/M³

Simple measurement scenarios

- Let OEL = 100 ppm
- Let x = ...
  - 5 ppm
  - 50 ppm
  - 99 ppm
  - 150 ppm
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Large Datasets (OEL = 0.05 mg/M³)

- Dataset23 - CopeDataset_WorkerF_mgm3.xls
- N=15
- Inorganic lead

<table>
<thead>
<tr>
<th>Value</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.012</td>
<td>0.0081</td>
</tr>
<tr>
<td>0.0109</td>
<td>0.012</td>
</tr>
<tr>
<td>0.0086</td>
<td>0.0081</td>
</tr>
<tr>
<td>0.0382</td>
<td>0.0194</td>
</tr>
<tr>
<td>0.0073</td>
<td>0.029</td>
</tr>
<tr>
<td>0.0138</td>
<td>0.0183</td>
</tr>
<tr>
<td>0.0108</td>
<td>0.0306</td>
</tr>
<tr>
<td>0.0103</td>
<td></td>
</tr>
</tbody>
</table>

Large Datasets (OEL = 50 ug/M³)

- Dataset21 - CopeDataset_WorkerA.xls
- Inorganic lead

<table>
<thead>
<tr>
<th>Value</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.4</td>
<td></td>
</tr>
<tr>
<td>11.4</td>
<td></td>
</tr>
<tr>
<td>17.1</td>
<td></td>
</tr>
<tr>
<td>28.9</td>
<td></td>
</tr>
<tr>
<td>12.4</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>24.6</td>
<td></td>
</tr>
<tr>
<td>21.5</td>
<td></td>
</tr>
<tr>
<td>11.3</td>
<td></td>
</tr>
</tbody>
</table>

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Perry Logan Ph.D., CIH
Watch the Universe –
GSD and Parameter Space Verification

Exposure Ratings translated into
*parameter space* for OEL=1ppm
Exposure Ratings translated into *parameter space* for OEL=1 ppm
Prior decision function (i.e., prior decision distribution spread across parameter space)

Prior decision function (i.e., prior decision distribution spread across parameter space)
Likelihood function
for $x=\{0.20,0.05,0.10\}$

Posterior function (using an Informative Prior)
BDA Options: change exposure category cutoffs

<table>
<thead>
<tr>
<th>Exposure Zone Cutoffs</th>
<th>Universe Boundaries</th>
<th>Integration Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>OEL (x OEL)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 - Trihal</td>
<td>0.01</td>
<td>0.01 x OEL</td>
</tr>
<tr>
<td>1 - Highly-controlled</td>
<td>0.10</td>
<td>0.1 x OEL</td>
</tr>
<tr>
<td>2 - Well-controlled</td>
<td>0.50</td>
<td>0.5 x OEL</td>
</tr>
<tr>
<td>3 - Controlled</td>
<td>1.00</td>
<td>1.0 x OEL</td>
</tr>
<tr>
<td>4 - Poorly-controlled</td>
<td>&gt; 1.0 x OEL</td>
<td></td>
</tr>
</tbody>
</table>

Type of Decision Chart:
- 0.4 Exposure Zones
- 1.5 Exposure Zones (ALT model)
- EU Control Bands - Particulates
- EU Control Bands - Vapors

OEL Interpretation:
- 90th Percentile
- 95th Percentile
- 99th Percentile
Change dimensions of the Parameter Space:
$GM_{\text{min}}$, $GM_{\text{max}}$, $GSD_{\text{min}}$, and $GSD_{\text{max}}$

**Exposure Zone Cutoffs**

<table>
<thead>
<tr>
<th>OEL =</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>MN minimum =</td>
<td></td>
</tr>
<tr>
<td>MN maximum =</td>
<td></td>
</tr>
<tr>
<td>GSD minimum =</td>
<td></td>
</tr>
<tr>
<td>GSD maximum =</td>
<td></td>
</tr>
</tbody>
</table>

**Storage Tank**

Process Operator #1

Process Engineer

Lets focus on Process Operator #2

Process Operator #2
Scenario #2 – Process Operator #2

- Process Operator #2 is responsible for the following tasks
  - Filling products into drums 4 times per shift (a new drum local exhaust ventilation is available)
  - Manually changing filter media once per shift and periodically using xylene solution to clean filtering equipment as needed to remove plugs
  - Collecting 6 – 3 oz quality samples on each batch.

- We’ve collected some full shift air samples for xylene, now let’s do some BDA!

Enter information and sampling data & Press “Calculate All”

Let's focus on the Likelihood (ie. No prior knowledge).

Take a good look at the data!! Any comments?
How do we interpret this?

- "We have less than a __% probability that Process Operator #2 requires respiratory protection"
- Is it above the acceptable / unacceptable threshold?
- Are there any other observations? Let's take a closer look at the data...(1 ppm, 65 ppm, 0.5 ppm)

What about our sample GSD?

Let's take a journey into our universe...

What is the impact on the analysis???
What happens when our sample GSD exceeds our GSDmax parameter?

![Image of a graph showing the relationship between GSD and likelihood function.]

**Likelihood Function**

- GSD: 0.1, 1, 10, 100
- Likelihood: 0.001, 0.000, 0.000, 0.000

**Decision Probability**

- Exposure Rating: 0, 1, 2, 3, 4
- Decision Probability: 1, 0.8, 0.6, 0.4, 0.2

---

**Exposure Zone CutOffs**

- GSDmin = 0.1
- GSDmax = 10
- GSDmax = 100

---

**What happens when our sample GSD exceeds our GSDmax parameter?**

![Image of a graph showing the relationship between GSD and likelihood function.]

- GSD: 0.1, 1, 10, 100
- Likelihood: 0.001, 0.000, 0.000, 0.000

**Likelihood Function**

- GSD: 0.1, 1, 10, 100
- Likelihood: 0.001, 0.000, 0.000, 0.000
Adjust the “Universe” to account for a larger GSD...

Notice that the Max Likelihood GSD is now in parameter space!

What do we do now?

- What might be going on with Process Operator #2?
- Which tasks might be creating the issues?
- Should we institute a task-based sampling strategy? Which tasks?
Wildly disparate data result in extreme and unlikely sample GSDs, pushing the decision probabilities toward the higher Ratings.

Possible solutions:
- Separate the data and analyze separately.
- Replace low measurements with higher LODs.
- Collect more data.

Example (Dataset00.xls)

- \( x = \{0.20, 0.05, 0.10\} \)
- \( 95\text{%ile} = 0.31 \quad 90\text{%CI}(0.16, 20.2) \)
Example

- $x = \{0.20, 0.05, 0.10, 0.001, 0.005\}$
- 95%ile = 0.83   90%CI(0.13, 239)

Note: max GSD was set at 20.

Example

- Example: analyze separately
  - $x = \{0.001, 0.005\}$
  - 95%ile = 0.01   90%CI(0.004, 2E10)
What do you need to remember?

- Always check the sample GSD to make sure it does not extend beyond the Universe Parameter Space!
- Watch out for what people consider “outliers”!
- Consider task-based approaches when sample GSDs are higher than 4.

BDA Caveats

- The following assumptions apply:
  - The true exposure profile can be well described by a single lognormal distribution.
  - The true GM and GSD are in the Parameter Space.
  - Multiple measurements per worker will not unduly bias the decision.
BDA *usually* is not necessary for large datasets

- OEL = 50 µg/m³ lead
- n = 15
- $X_{0.95} = 32.6$ µg/m³
- 95%LCL($X_{0.95}$) = 24.7
- 95%UCL($X_{0.95}$) = 52.9

Dataset22 - CopeDataset_WorkerF.xls
Workshop:

- Data: 0.34 ppm, 0.09 ppm, 12 ppm, 23 ppm, 18 ppm
- OEL = 100 ppm
- GSD = _____

<table>
<thead>
<tr>
<th>Before Universe Parameter Adjustment</th>
<th>Parameter Space Upper GSD Boundary</th>
<th>Likelihood Probability of Category 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>After Universe Parameter Adjustment</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Comments and Key Learnings:

BDA Potential:
Integrating Professional Judgment

The Promise and Perils of Bayesian Priors!
Bayesian Decision Analysis (BDA)

- An adjunct or alternative to the calculation and interpretation of traditional statistics.
- The goal of BDA is to estimate the probability that the true exposure profile falls into a particular category, or Exposure Rating.
- BDA can explicitly incorporate professional judgment.

![Bayesian Decision Analysis Diagram](image_url)
The Informative Prior:
Integrating Professional Judgment
Improving Professional Judgment
John Mulhausen Ph.D., CIH, CSP
Perry Logan Ph.D., CIH

Video Tasks – Quantitative Judgments


Professional Judgment and Bayesian Statistics
NIOSH Funded U of MN Study
Actual Workplace Assessments

Quantitative judgment results for accuracy for all hygienists' pre and post training
Improving Professional Judgment

John Mulhausen Ph.D., CIH, CSP
Perry Logan Ph.D., CIH

Professional Judgment and Bayesian Statistics
NIOSH Funded U of MN Study

Actual Workplace Assessments - Preliminary Study Results

A significant improvement was noticed in judgments collected after statistical training.

Fraction of correct decisions made by each hygienist, before and after statistical training. The fraction correctness is calculated by dividing the number of correct decisions made by each hygienist to the total number of scenarios, in this case 29.

Video Tasks – Qualitative Judgments

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Perry Logan Ph.D., CIH

Professional Judgment and Bayesian Statistics
NIOSH Funded U of MN Study
Actual Workplace Assessments - Qualitative Judgment

No significant improvement noticed in judgments collected after statistical training

Agreement between hygienists

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Quantitative judgments for task 2, pre- and post-training.
Number of hygienists = 10, OEL for task 50 mg/m³

Quantitative judgments for task 10, pre- and post-training.
Number of hygienists = 3, OEL for task 0.05 mg/m³
Improving Judgments: The Use of Reasons

- Significant improvement in calibration when experts are asked to provide a list of reasons justifying their judgments, as opposed to just providing the judgment.

Improving Judgments: Disaggregation

- Decomposing a judgment into a series of smaller judgments produces better results.
- Estimate hog population of the US directly.
- Use the following model:
  - Hog population = (US Population) x (annual average bacon consumption per capita) / (average amount of bacon per hog)
- The model produced better estimates
Cognitive Psychology
Learnings for Improved Decision-Making

- Giving reasons for decision increases accuracy
- Personal discussion of results increases accuracy
- Groups do better than individuals

What elements must be included in a robust Industrial Hygiene Business Process to take advantage of this understanding?

- Break judgments down into component parts
- State problems and data in a logical order
  - Structured approach to decision making can increase accuracy
- When experts receive regular unbiased feedback they get better at making judgments
The Informative Prior: Integrating Professional Judgment

- Informative Prior Based On:
  - Customized Professional Judgment
  - AIHA Exposure & Certainty Ratings
  - Modeling
  - Past Monitoring
Improving Professional Judgment
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Perry Logan Ph.D., CIH

Informative Prior Based On Customized Professional Judgment

1) IH Estimates Exposure Rating Category

<table>
<thead>
<tr>
<th>Category</th>
<th>Exposure Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td>2</td>
<td>0.6</td>
</tr>
<tr>
<td>3</td>
<td>0.4</td>
</tr>
<tr>
<td>4</td>
<td>0.2</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

2) IH Characterizes Uncertainty
Informative Prior Based On AIHA Exposure & Certainty Ratings

- A “Professional Judgment” or “Custom Prior” Decision Chart can be used to reflect the Initial Rating and Certainty Level assigned to the SEG *before* the data were collected or from data that may be considered representative.
- When the user picks an Initial Rating and Certainty Level a recommended Prior Decision Chart is shown.
- The default category probabilities represent an example or “best guess” as to what a generic prior should look like.

<table>
<thead>
<tr>
<th>Exposure Control Ratings *</th>
<th>Cutoff (%OEL)</th>
<th>Confidence level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$X_{0.95} \leq 1%$</td>
<td>High</td>
</tr>
<tr>
<td>1</td>
<td>$1% &lt; X_{0.95} \leq 10%$</td>
<td>Medium</td>
</tr>
<tr>
<td>2</td>
<td>$10% &lt; X_{0.95} \leq 50%$</td>
<td>Low</td>
</tr>
<tr>
<td>3</td>
<td>$50% &lt; X_{0.95} \leq 100%$</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>$X_{0.95} &gt; 100%$</td>
<td></td>
</tr>
</tbody>
</table>
### Perform Qualitative Exposure Assessments

<table>
<thead>
<tr>
<th>Task Description</th>
<th>Agent</th>
<th>Duration/ Frequency</th>
<th>Initial Exposure Rating</th>
<th>Rating</th>
<th>Certainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charging 20 - 10 kg bags of TiOx into Reactor w/ local exhaust</td>
<td>Titanium Dioxide</td>
<td>90 mins / shift</td>
<td>&lt;10%OEL</td>
<td></td>
<td>1-High</td>
</tr>
<tr>
<td>Using pneumatic pump to charge 700 liters of cyclohexanone from drums into reactor</td>
<td>Cyclohexanone</td>
<td>90 mins / shift</td>
<td>10-50%OEL</td>
<td>3-Low</td>
<td>1-High</td>
</tr>
<tr>
<td>Collect a 200 ml QC samples (6) through handhole</td>
<td>Cyclohexanone</td>
<td>10 mins / shift</td>
<td>&lt;10%OEL</td>
<td>1-High</td>
<td>1-High</td>
</tr>
<tr>
<td>Charging latex super mix from storage tank (watching level through open manhole)</td>
<td>Cyclohexanone</td>
<td>120 mins / shift</td>
<td>&lt;10%OEL</td>
<td>3-Low</td>
<td>1-High</td>
</tr>
<tr>
<td>Package final product through filter system</td>
<td>Cyclohexanone</td>
<td>180 mins / shift</td>
<td>&lt;10%OEL</td>
<td>3-Low</td>
<td>1-High</td>
</tr>
<tr>
<td>Change filter media, bleed and flush pumps</td>
<td>Cyclohexanone</td>
<td>120 mins / shift</td>
<td>100-500%OEL</td>
<td>1-High</td>
<td>1-High</td>
</tr>
<tr>
<td>Monitoring process at control panel</td>
<td>Cyclohexanone</td>
<td>120 mins / shift</td>
<td>&lt;10%OEL</td>
<td>1-High</td>
<td>1-High</td>
</tr>
<tr>
<td>Calibration &amp; repair of viscosity meters</td>
<td>Cyclohexanone</td>
<td>20 mins / shift</td>
<td>&lt;10%OEL</td>
<td>2-Medium</td>
<td>1-High</td>
</tr>
<tr>
<td>Reactor equipment maintenance</td>
<td>Cyclohexanone</td>
<td>240 mins / week</td>
<td>&lt;10%OEL</td>
<td>2-Medium</td>
<td>1-High</td>
</tr>
<tr>
<td>Viscosensor rebuild welding</td>
<td>Nickel</td>
<td>120 mins / week</td>
<td>10-50%OEL</td>
<td>1-High</td>
<td>1-High</td>
</tr>
<tr>
<td>Paint area &amp; parts clean up</td>
<td>MEK</td>
<td>60 mins / week</td>
<td>10-50%OEL</td>
<td>1-High</td>
<td>1-High</td>
</tr>
</tbody>
</table>

### Informative Prior Based On AIHA Exposure & Certainty Ratings

<table>
<thead>
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<th>Cutoff (%OEL)</th>
<th>Confidence level</th>
</tr>
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<tr>
<td>1</td>
<td>$1% &lt; X_{0.95} &lt; 10%$</td>
<td>Medium</td>
</tr>
<tr>
<td>2</td>
<td>$10% \leq X_{0.95} &lt; 50%$</td>
<td>Medium</td>
</tr>
<tr>
<td>3</td>
<td>$50% \leq X_{0.95} \leq 100%$</td>
<td>Low</td>
</tr>
<tr>
<td>4</td>
<td>$X_{0.95} &gt; 100%$</td>
<td>Low</td>
</tr>
</tbody>
</table>

*Note: Exposures rated using these criteria correspond to confidence levels, but the criteria themselves are not directly comparable to actual percent exceedance levels.*
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Perry Logan Ph.D., CIH

Non-informative "decision distribution" prior

IR=Category 3
CL=low

IR=Category 3
CL=medium

IR=Category 3
CL=high

IR=Initial Rating
CL=Certainty Level

EXAMPLE ONLY

Non-informative "decision distribution" prior

IR=Category 4
CL=low

IR=Category 4
CL=medium

IR=Category 4
CL=high

IR=Initial Rating
CL=Certainty Level

EXAMPLE ONLY
Informative Prior Based On Modeling

- Disaggregation, documentation, and reason (exposure determinants)
- Many exposure models to select from - differ in their levels of sophistication.
  - Each level increases cost (information needed as inputs to the models), but yields more accurate estimates.
  - We should use the simplest model that provides the detail required for the exposure assessment scenario.
- Can be formatted to give output in exposure category likelihoods. e.g. 2-D Monte Carlo
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2-Dimensional Monte Carlo

\[ C = \frac{G}{Q} \]

Obtaining 1 distribution of C

e.g. 2-Dimensional Monte Carlo

\[ C = \frac{G}{Q} \]

Obtaining 1 distribution of C
For this distribution of the 95th percentile, different OELs lead to different decisions.

Distribution of 95th Percentile of C

Histogram of 95th Percentile in the four AIHA Exposure categories

OEL = 20 ppm

OEL = 2

OEL = 5

OEL = 15
Bayesian Decision Making

Example: Exposure Estimate

Initial Qualitative Assessment or Validated Model

Prior Exposure Rating

Decision Probability

Monitoring Results

Likelihood Exposure Rating

Decision Probability

Integrated Exposure Assessment

Bayesian Decision Making

Feedback to improve professional judgment or validate model
Informative Prior Based On Past Monitoring

- Leveraging Monitoring Data From Similar Operations

Custom Informative Priors:
Leveraging Monitoring Data From Similar Operations

- Enter sampling data from operation 1
- Press “Calculate All”
- Review the statistics and critique the “GOF Graphs”.
- Note down the probabilities in the “Likelihood” Decision Chart
- Enter above probabilities into “Custom Prior” and sampling data from operation 2
- Press “Calculate All”, review stats & GOF
- “Posterior” or Final Judgment now reflects the sampling data from both locations
Example

- Process equipment being relocated from Brazil to China. The same engineering controls are installed in the new facility in China.
- Let's utilize past sampling data from Process Operator #1 (Brazil) to construct a custom prior for our new Process Operator #1 (China).

Decision Charts

Brazil Data:
- Process Operator #1 (xylene)
- \( n = 4 \),
- OEL=100 ppm
- \( x = \{13, 26, 18, 12\} \) ppm

- Use the “Likelihood” chart as the new “Custom Prior”
Process Operator #1 (China)

- Custom Prior was constructed with data from Brazil to be leveraged for China

China Data:
- Process Operator #1 (xylene)
- \( n = 2, \)
- OEL=100 ppm
- \( x = \{26, 18\} \) ppm

Comments

- The Prior Decision Chart has a greater influence on the Posterior Decision whenever the sample size is small.
- For large sample sizes, say \( n > 10, \) the Prior has less influence on the Posterior. But for Category 4 it can still be significant!
- Consequently, the accuracy of the Initial Rating is a critical issue whenever the sample size is small.
Impact of Prior on Small & Medium* Size Datasets

Data Sets: Sampling Data = Category 2 (10-50% of OEL)

\[ X = \{12, 21\} \]

\[ X = \{12, 21, 14, 11, 18, 9, 24, 26\} \]

* - We will consider 8 data points a medium size dataset for this exercise.

Descriptive Statistics
Mean = 16.5000
SD = 6.3600
GM = 15.9000
GSD = 1.485

Compliance Statistics (lognormal)
X0.95 = 30.4000
95%LCL = 19.2000
95%UCL = 5.17E0005

Prior & Data Category Match
Prior Cat = 2
Data Cat = 2

\[ n=2 \]

\[ n=8 \]

Note Category 4

Prior

2 Samples (n=2)

8 Samples (n=8)

Likelihood
Exposure Rating
0 1 2 3 4
Decision Probability
1
0.8
0.6
0.4
0.2
0

Prior

8 Samples (n=8)

1
0.8
0.6
0.4
0.2
0

Compliance Statistics (lognormal)
X0.95 = 30.0000
95%LCL = 23.0000
95%UCL = 54.6000

250
### Impact of Prior on Small & Medium* Size Datasets

#### Data Sets:

**X = \{65, 29\}**

**X = \{65, 29, 48, 108, 42, 33, 16, 57\}**

* - We will consider 8 data points a medium size dataset for this exercise.

---

#### Descriptive Statistics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>16.5000</td>
</tr>
<tr>
<td>SD</td>
<td>6.3600</td>
</tr>
<tr>
<td>GM</td>
<td>15.9000</td>
</tr>
<tr>
<td>GSD</td>
<td>1.485</td>
</tr>
</tbody>
</table>

#### Compliance Statistics (lognormal)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>X0.95</td>
<td>30.0000</td>
</tr>
<tr>
<td>95%LCL</td>
<td>23.0000</td>
</tr>
<tr>
<td>95%UCL</td>
<td>54.6000</td>
</tr>
</tbody>
</table>

---

#### Prior & Data Category Mismatch!

**n=2**

**n=8**

---

#### Note how "n" impacts Final Decision

---

#### Sampling Data = Category 4 (>100% of OEL)
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Prior Exposure Rating
0 1 2 3 4

Decision Probability
1
0.8
0.6
0.4
0.2
0

Likelihood Exposure Rating
0 1 2 3 4

Decision Probability
1
0.8
0.6
0.4
0.2
0
0 0 0.065
0.367
0.567

Posterior Exposure Rating
0 1 2 3 4

Decision Probability
1
0.8
0.6
0.4
0.2
0
0 0
0.243
0.547
0.211

Descriptive Statistics
Mean = 47.0000
SD = 25.5000
GM = 43.4000
GSD = 1.770

Compliance Statistics (lognormal)
X0.95 = 111.0000
95%LCL = 56.9000
95%UCL = 1.4E0008

Note Very Low % in Cat 4...
THIS CREATES A BAD RESULT!!!
We get penalized for a mismatching Prior & Sampling Data

Warnings on Creating Priors to be leveraged across SEGs

- An incorrect prior can drive the wrong decision in some circumstances
  - Careful when putting a very low % in any one category of a prior
- Important to create a process for “validating” priors using sampling data from same SEG
  - Minimum # of Samples
  - Universe GSD boundaries / Max sample GSDs
  - Rules on task differences
  - Rules on engineering controls
Workshop 1 - Determine BDA Output for Following Example:

- Initial AIHA Exposure Rating = 3 (50% to 100% of OEL)
- Initial AIHA Certainty Rating = Low
- Monitoring Data (OEL = 100 ppm):
  - 23 ppm
  - 45 ppm
  - 62 ppm
  - 37 ppm

Workshop 2 - Determine BDA Output for Following Example:

- Simple Well-Mixed Room Model Output:
  - Concentration Range: 50 ppm to 430 ppm
- Monitoring Data (OEL = 1000 ppm):
  - 67 ppm
  - 48 ppm
  - 54 ppm
Workshop 3 - Determine BDA Output for Following Example:

- Monitoring Data from Similar Operation in Another Plant (OEL = 10 ppm):
  - 1.2 ppm
  - 2.3 ppm
  - 0.3 ppm
  - 2.1 ppm
  - 1.9 ppm

- Monitoring Data from Operation Being Assessed (OEL = 10 ppm):
  - 1.1 ppm
  - 0.8 ppm

Potential Applications of Bayesian Decision Analysis
Potential Applications of Bayesian Decision Analysis

- Reach a decision when $n$ is small
- Leverage professional judgment
- Provide feedback
- Assist in respirator selection
- Analyze censored datasets

Reach a decision when $n$ is small

- OEL=1 ppm
- $n = 1$
- $x = 0.05$ ppm

- BDA can be applied to sample sizes as low as $n=1$. 

![Bayesian Decision Analysis Graphs]

OEL=1 ppm
$n = 1$
$x = 0.05$ ppm

BDA can be applied to sample sizes as low as $n=1$. 
- OEL = 1 ppm
- n = 1
- x = 0.99 ppm

"Yes, the measurement is <OEL. But I strongly suspect that these exposures are not acceptable."

BDA would lead to the same conclusion.

---

Leverage professional judgment

- OEL = 1 ppm
- n = 1
- x = 0.05 ppm

Professional judgment can sharpen the decision.
Provide feedback for IH Calibration

- OEL = 1 ppm
- \( n = 3 \)
- \( x_1 = 0.25 \) ppm
- \( x_2 = 0.50 \) ppm
- \( x_3 = 1.00 \) ppm

- The Prior is inconsistent with the Likelihood.
- BDA can be used to help improve professional judgment.

Assist in respirator selection

- OEL = 1 ppm
- \( n = 3 \)
- \( x_1 = 0.99 \) ppm
- \( x_2 = 0.50 \) ppm
- \( x_3 = 2.0 \) ppm

- Decision = Category 4
- BDA can be used to guide PPE selection.
Analyze censored datasets

- OEL = 1 ppm
- n = 1
- x < LOD
- LOD = 0.05 ppm

- BDA can be applied to censored datasets, even 100% censored or with multiple LODs.

Noise Analysis

<table>
<thead>
<tr>
<th>dBA</th>
<th>80.8</th>
<th>76.5</th>
<th>82.2</th>
<th>83.9</th>
<th>78.7</th>
<th>77.3</th>
</tr>
</thead>
</table>

Acceptable Exposure?
## Noise Analysis

<table>
<thead>
<tr>
<th>dBA</th>
<th>Dose (80, 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80.8</td>
<td>55.9</td>
</tr>
<tr>
<td>76.5</td>
<td>30.8</td>
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<tr>
<td>82.2</td>
<td>67.8</td>
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<tr>
<td>83.9</td>
<td>85.9</td>
</tr>
<tr>
<td>78.7</td>
<td>41.8</td>
</tr>
<tr>
<td>77.3</td>
<td>34.4</td>
</tr>
</tbody>
</table>

![Graph showing likelihood and exposure rating](image-url)
## Noise Analysis

<table>
<thead>
<tr>
<th>dBA</th>
<th>Dose ((80, 5))</th>
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<tbody>
<tr>
<td>79.8</td>
<td>48.6</td>
</tr>
<tr>
<td>81.1</td>
<td>58.2</td>
</tr>
<tr>
<td>77.1</td>
<td>33.4</td>
</tr>
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<td>74.9</td>
<td>24.7</td>
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<td>81</td>
<td>57.4</td>
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<tr>
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</tr>
<tr>
<td>80</td>
<td>50.0</td>
</tr>
<tr>
<td>80.3</td>
<td>52.1</td>
</tr>
<tr>
<td>81.6</td>
<td>62.4</td>
</tr>
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<td>79.2</td>
<td>44.8</td>
</tr>
</tbody>
</table>

**Likelihood vs Exposure Rating**

<table>
<thead>
<tr>
<th>Exposure Rating</th>
<th>Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.009</td>
</tr>
<tr>
<td>1</td>
<td>0.616</td>
</tr>
<tr>
<td>2</td>
<td>0.375</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exposure Rating</th>
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<tbody>
<tr>
<td>0</td>
<td>0.975</td>
</tr>
<tr>
<td>1</td>
<td>0.025</td>
</tr>
</tbody>
</table>

## Closing Discussion

Running From the Dart-Throwing Monkeys: A Call to Action
Running From the Dart-Throwing Monkeys

Wall Street Journal Contest:
Dart Throwing Monkeys vs. Experts

"a blindfolded monkey throwing darts at a newspaper’s financial pages could select a portfolio that would do just as well as one carefully selected by experts."

Burton Malkiel - *A Random Walk Down Wall Street*
Exposure Judgment Accuracy Bar

Dart Throwing Monkey

Increasing Accuracy

Random Chance

Super IH

100%

Exposure Judgment Accuracy Bar

Dart Throwing Monkey

Increasing Accuracy

Random Chance

Super IH

Where do we want to be?

100%
Exposure Judgments

- THE Core Competency for the industrial hygiene profession . . .
- We must OWN the science (and art) of exposure assessment
  - Do it better than anyone else
  - Be constantly at the cutting edge of innovation and improvement
  - Discover and address issues before anyone else

Where do we want to be?
Improving Professional Judgment
John Mulhausen Ph.D., CIH, CSP
Perry Logan Ph.D., CIH

Increasing Accuracy

Random Chance

100%

Where are we today?

<table>
<thead>
<tr>
<th>Exposure Decision Category*</th>
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<tr>
<td>1  (&lt;10% of OEL)</td>
<td>General HazCom</td>
</tr>
<tr>
<td>2  (10-50% of OEL)</td>
<td>+ chemical specific HazCom</td>
</tr>
<tr>
<td>3  (50-100% of OEL)</td>
<td>+ exposure surveillance, medical surveillance, work practices</td>
</tr>
<tr>
<td>4  (&gt;100% of OEL)</td>
<td>+ respirators, engineering controls, work practice controls</td>
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Increasing Accuracy

Random Chance

100%

Where are the monkeys?
Improving Professional Judgment
John Mulhausen Ph.D., CIH, CSP
Perry Logan Ph.D., CIH

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Increasing Accuracy

25% Random Chance

Where are the monkeys?

25% 50% 75% 100%

Where are we today?
Improving Professional Judgment
John Mulhausen Ph.D., CIH, CSP
Perry Logan Ph.D., CIH

Data Interpretation Test Results
2005 EA Symposium Volunteers

---

Data Interpretation Test Results PCIH05

1%
6%
36%
49%
7%
1%
0%
0%
10%
20%
30%
40%
50%
60%
70%

Below 3
Below 2
Below 1
Correct
Above 1
Above 2
Above 3

---

Increasing Accuracy

25%  50%  75%  100%

Random Chance

Super IH

Where are we today?
Improving Professional Judgment

John Mulhausen Ph.D., CIH, CSP
Perry Logan Ph.D., CIH

Data Interpretation Test Results
2005 EA Symposium Volunteers

Pre- and Post- Statistics Training

Data Interpretation Test Results
AIHce 2007 Bayesian PDC Participants

Data Interpretation Test Results
PCIH 2006 Bayesian PDC Participants

Data Interpretation Test Results
PCIH 2006 Workshop Pre & Pos

Data Interpretation Test Results
AIHce 2006 Bayesian PDC Participants

Data Interpretation Test Results
PCIH 2006 Judgment WS Participants
Improving Professional Judgment
John Mulhausen Ph.D., CIH, CSP
Perry Logan Ph.D., CIH
Improving Professional Judgment
John Mulhausen Ph.D., CIH, CSP
Perry Logan Ph.D., CIH
What must we do to improve?

How Can We Improve Our Monitoring-Based Judgments?

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Use statistical tools!!

How Can We Improve Our Qualitative Judgments?
How Can We Improve Our Qualitative Judgments?

Learn from our colleagues in psychology . . .

- Systematic and Transparent Exposure Decision Processes
- Focused Training and Coaching
- Accurate Feedback Mechanisms
- Repeated Practice

Innovation Opportunities:
- Exposure Assessment Video Games
- Exposure Assessment Training Camps

How quickly do we want to improve?
U.S. Impact

Monitoring-Based Employee-Exposure Decisions per Year*

10%ile Estimate: 1,680,000
Median Estimate: 6,000,000
90%ile Estimate: 55,200,000

% Incorrect?
% Underestimated Risk?

*Estimated by 2009 Exposure Assessment Symposium Participants

Ethics

- Know that many current practices have high likelihood of systematic error . . .
- Know that error results in excess risk or cost . . .
- Know how to fix it . . .

Cannot continue business as usual!
Current Rate-Of-Change is Too Slow

- Low visibility -- competing priorities -- low urgency
- Available statistical tools are under-used in practice
- False sense of security with current approaches
  - Extensive reliance on professional judgment with little calibration
  - Heavy focus on sampling methods (NIOSH Validation) and analysis (AIHA Lab Accreditation) with little focus on overall strategy and final judgments.
  - Institutionalized practices that do not deliver needed performance
    - OSHA / NIOSH Action Level Decision Logic
    - OSHA SAE Approach
- Change is hard
  - You first . . .
  - Explaining the change to clients

Need to Accelerate Change

Professional Crossroads:
Status Quo
or
Focused Attention to Accelerate Improvement
We Know How to Drive Change:

The 8-Step Process of Successful Change*

Set The Stage
1. Create a Sense of Urgency.
2. Pull Together the Guiding Team.

Decide What to Do
3. Develop the Change Vision and Strategy.

Make it Happen
4. Communicate for Understanding and Buy-in.
5. Empower Others to Act.
6. Produce Short-Term Wins.

Make it Stick
8. Create a New Culture.


2015 Vision For Every Industrial Hygienist

- Use statistical tools when we make exposure judgments based on monitoring.
- Participate in at least one activity every year to improve judgment accuracy.
Mobilizing the Professionals
Mobilizing the Profession

Accelerating Change

Dart Throwing Monkey

Increasing Accuracy

Super IH

Random Chance

100%

Mobilizing the Professional

What YOU Can Do . . .

- Use statistical tools when you make a judgment using monitoring data
- Initiate qualitative judgment improvement activities
  - Incorporate rigorous and transparent feedback loops into your practice – validate your judgments
  - Find mechanisms to discuss exposure judgments with other industrial hygienists
  - Document exposure determinants and rationale for judgments
- Spread the word!
Mobilizing the Profession
What WE Can Do . . .

Spread the word!
Communication Blitz – From every organization!

Mobilizing the Profession
What WE Can Do . . .

Training and Coaching Opportunities
- Group Data Interpretation Test Exercises
- Decision Rule Calibration
- PDCs / Webmeetings
- Software Tools / Computer “Games”
- Simulation / Video Evaluations
- Exposure Modeling
- Statistical Tools
## Brainstorming just a few opportunities . . .

### AIHA
- Tools Development
- Proficiency Data Interpretation (PDI) Program . . . Like PAT program
- International Affairs – Outreach to International practitioners and organizations
- AIHA Committees: Mechanisms to improve Judgment Accuracy in various technical niches

### Local Sections
- Training Programs
- Facilitate “Decision Criteria” Discussion

### ACGIH
- Promote expectation for accurate judgments and data interpretation as part of good science when using TLVs

### AIH
- Lead role for coordinating efforts
- ABET Accreditation Requirements
- Specific ethics training
- Core Competency Rigor

---

## Brainstorming just a few opportunities . . .

### ABIH
- Ongoing judgment training requirements for CIH. . . ethics

### ORC
- Promote practices and tools- Member companies do it!
- Training and Workshops
- Research Participation

### NIOSH
- Re-write yellow book
- Research
- Tool development
- Put into practice with HHEs
- R2P → Promote Solutions
- Training - Review during ERC grant application process

### OSHA
- Generic Exposure Assessment Standard
- Incorporate into revised PEL regulation or legislation
- Discussion point when reviewing company programs
- VPP requirement

### Universities
- Incorporate into training programs - Academic SIG
Industrial Hygiene Profession
Galvanized to improve our exposure judgment accuracy . . .
and running as fast as we can from the dart-throwing monkeys!!

Random Chance  Increasing Accuracy  Super IH

100%