INTRODUCTION TO EXPOSURE DECISION ANALYSIS STRATEGIES

CIHC 33rd ANNUAL PROFESSIONAL DEVELOPMENT SEMINAR
December 4, 2024

JOHN MULHAUSEN, PHD, FAIHA

jrmulhausen@gmail.com

Certified Industrial Hygienist

CSP

#116674

Registered Specialist
Exposure Decision Analysis

AIHA Registry Programs®

AIHA™

INTRODUCTION TO EXPOSURE DECISION ANALYSIS STRATEGIES

Agenda:

- Quick Overview: AIHA Improving OEHS Science and Practice Initiatives
- Improving Exposure Decision Accuracy
  - Why Important
  - Statistical Techniques and Tools

Q & A / Discussion Throughout

First: A Quick Poll . . .

Join at:
vevox.app

ID:
185-831-090

VEVOX Polling Software Site

POLLING QUESTION #1

Rate your response to the following statement:

“I think my exposure judgments are accurate most or all of the time.”

- ❑ Strongly agree
- ❑ Somewhat agree
- ❑ Neither agree nor disagree
- ❑ Somewhat disagree
- ❑ Strongly disagree

POLLING QUESTION #2

Below are the 8-hr TWA Sample Results for a Similar Exposure Group (SEG). Are the SEG Exposures Acceptable or Unacceptable?

OEL = 100 ppm

Sample Data (ppm) Set #1
12
37
9
105
8
33

- ❑ Acceptable
- ❑ Unacceptable

POLLING QUESTION #3

Do you currently hold the Certified Industrial Hygienist (CIH) or equivalent industrial/occupational hygiene certification?

- ❑ No, I have never held nor am I working towards the CIH or equivalent certification
- ❑ No, but I previously held the CIH or equivalent certification
- ❑ No, but I am working towards the CIH or equivalent certification
- ❑ Yes, I currently hold the CIH or equivalent certification

POLLING QUESTION #4

Below are the 8-hr TWA Sample Results for a Similar Exposure Group (SEG). Are the SEG Exposures Acceptable or Unacceptable?

OEL = 100 ppm

Sample Data (ppm) Set #2
4

- ❑ Acceptable
- ❑ Unacceptable

POLLING QUESTION #5

Which of the following best describes your use of statistics (traditional statistics or Bayesian statistics) to analyze your monitoring data?

- ❑ I rarely or never conduct statistical analysis on monitoring data (e.g., <10% of the time)
- ❑ I sometimes conduct statistical analysis on monitoring data (e.g., 10 to 50% of the time)
- ❑ I routinely conduct statistical analysis on monitoring data (e.g., More than 50% of the time)

POLLING QUESTION #6

Below are the 8-hr TWA Sample Results for a Similar Exposure Group (SEG). Are the SEG Exposures Acceptable or Unacceptable?

OEL = 100 ppm

Sample Data (ppm) Set #3
38
68
12

- ❑ Acceptable
- ❑ Unacceptable

POLLING QUESTION #7

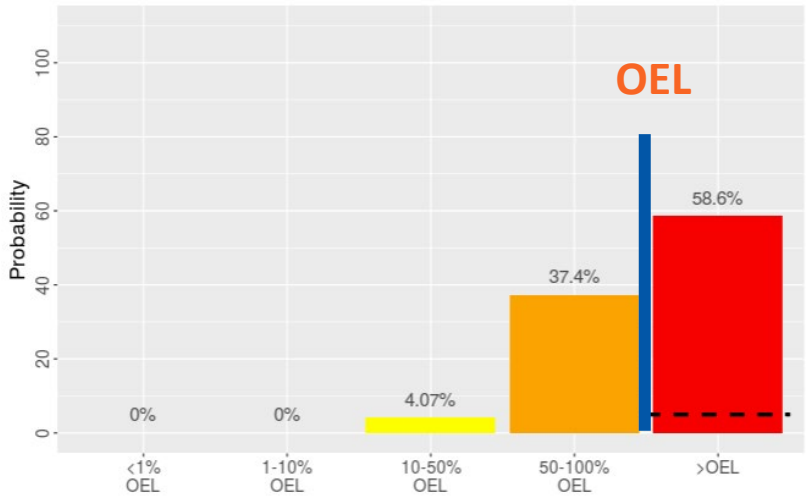
What is the most common number of air samples used to make a judgment about exposure?

- ❑ More than 10
- ❑ 6 to 10
- ❑ 3 to 5
- ❑ 1 or 2
- ❑ 0

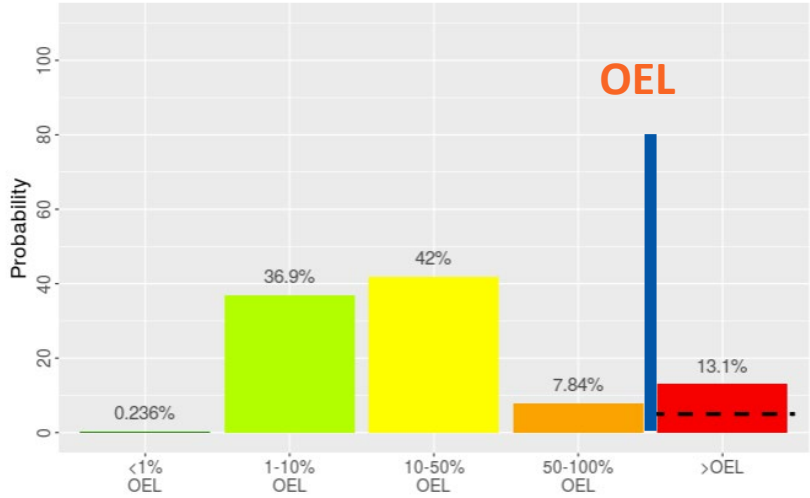
ANSWERS

(OEL = 100 ppm)

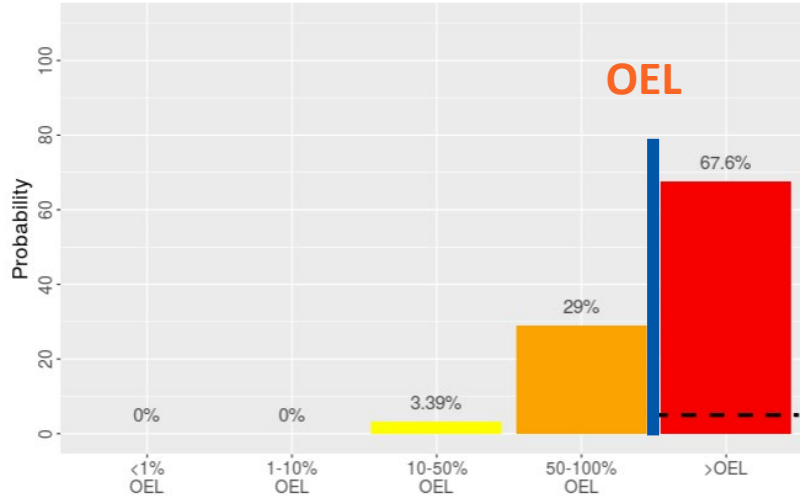
Sample Data (ppm) Set #1
12
37
9
105
8
33



Sample Data (ppm) Set #2
4



Sample Data (ppm) Set #3
38
68
12



ADVANCING OEHA SCIENCE AND PRACTICE
FOUR EXCITING INITIATIVES:

Defining the Science

Principles of Good Practice

State of the Art vs. Practice

Improving Exposure Judgment

ADVANCING OEHS SCIENCE & PRACTICE

Elevating our performance today.
Strengthening our profession for tomorrow.

AIHA's initiatives for continuous improvement.
For healthier workplaces and a healthier world.

Learn More Here

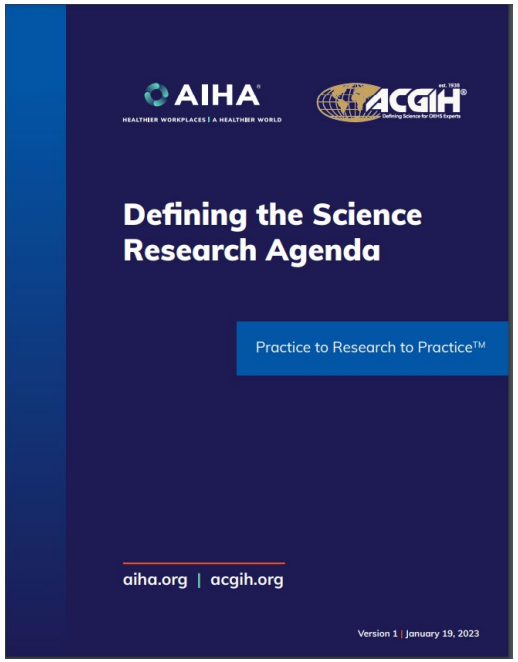
Defining the Science

AIHA - ACGIH INITIATIVE:
DEFINING THE SCIENCE

Making Research Work for Practitioners to Improve Protection for Workers and Communities

1. Identify research initiatives needed to advance the state of OEHS science to address gaps in effective and efficient practice.
2. Identify areas of practice that do not hold up to current OEHS scientific findings so that AIHA, ACGIH, and other stakeholders may improve practice through focused outreach, promotion, and training.

Learn More Here



Download Research Agenda HERE

AIHA GUIDELINE FOUNDATION:
PRINCIPLES OF GOOD PRACTICE (PGP) INITIATIVE

Principles of Good Practice

Purpose

- Document the vital OEHS professional practices that reliably and effectively protect workers and communities from unacceptable risks.
- Provide a common vision of effective risk management practices for all OEHS professionals.
- Elevate the performance of all OEHS programs by providing a set of uniform program and performance targets that can be used in continuous improvement activities.

Download the Latest PGP Version HERE

Approach

- Organized by OEHS area of practice, or domain, and include "people skills" (non-technical skills for OEHS practitioners).
- For each area of practice, the PGP AG works very closely with relevant subject matter experts from AIHA volunteer groups and other partners to document risk-critical PGP and best practices.

PGP Currently Under Development

- Exposure Assessment **COMPLETED 2022 (v2.0 in 2024)**
- Noise and Hearing Conservation **COMPLETED 2024**
- Respirator Protection Program **COMPLETED 2024**
- Thermal Stress IN PROGRESS
- Indoor Environmental Quality IH PROGRESS

PRINCIPLES OF GOOD PRACTICE (PGP) INITIATIVE

MANY REFERENCES AND GUIDANCE DOCUMENTS IN OEHS

- Which to Use?
- Key Points?
- Critical Aspects?

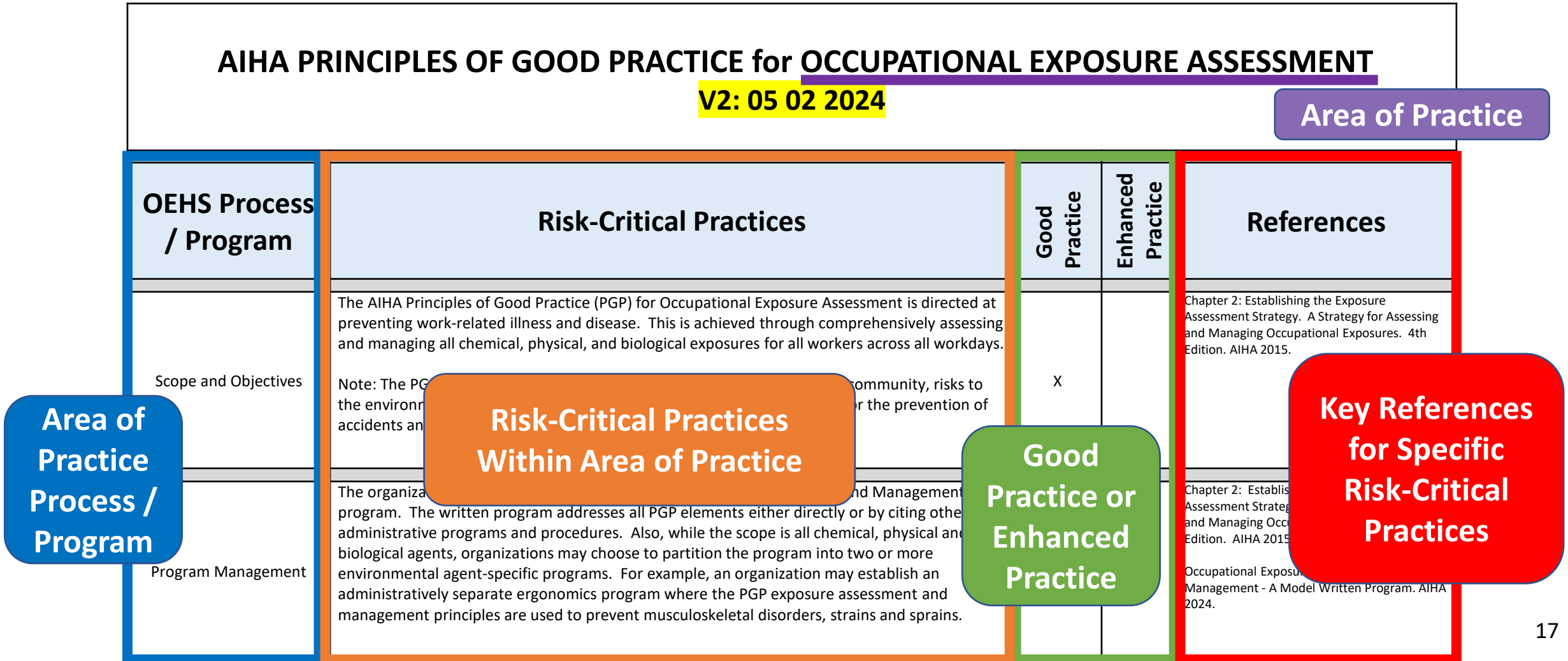
PGP: CONCISE, EASILY APPLIED SUMMARIES OF FUNDAMENTAL RECOMMENDED PROGRAM AND PERFORMANCE TARGETS

Expert Input

Principles of Good Practice

OEHS Process / Program	Risk-Critical Practices	Good Practice	Enhanced Practice	References
	The AIHA Principles of Good Practice (PGP) for Occupational Exposure Assessment is directed at preventing work-related illness and disease. This is achieved through comprehensively assessing and managing all chemical, physical, and biological exposures for all workers across all workdays.			Chapter 2: Establishing the Exposure Assessment Strategy. A Strategy for Assessing and Managing Occupational Exposures. 4th Edition. AIHA 2015.

FORMAT OF AN AREA OF PRACTICE PGP



AIHA PRINCIPLES OF GOOD PRACTICE for OCCUPATIONAL EXPOSURE ASSESSMENT

V2: 05 02 2024

Area of Practice

OEHS Process / Program	Risk-Critical Practices	Good Practice	Enhanced Practice	References
Scope and Objectives	The AIHA Principles of Good Practice (PGP) for Occupational Exposure Assessment is directed at preventing work-related illness and disease. This is achieved through comprehensively assessing and managing all chemical, physical, and biological exposures for all workers across all workdays. Note: The PG ommunity, risks to the environr r the prevention of accidents an	X		Chapter 2: Establishing the Exposure Assessment Strategy. A Strategy for Assessing and Managing Occupational Exposures. 4th Edition. AIHA 2015.
Program Management	The organiza nd Management program. The written program addresses all PGP elements either directly or by citing othe administrative programs and procedures. Also, while the scope is all chemical, physical an biological agents, organizations may choose to partition the program into two or more environmental agent-specific programs. For example, an organization may establish an administratively separate ergonomics program where the PGP exposure assessment and management principles are used to prevent musculoskeletal disorders, strains and sprains.			Chapter 2: Establis Assessment Strateg and Managing Occ Edition. AIHA 2015 Occupational Exposu Management - A Model Written Program. AIHA 2024.

Area of Practice Process / Program

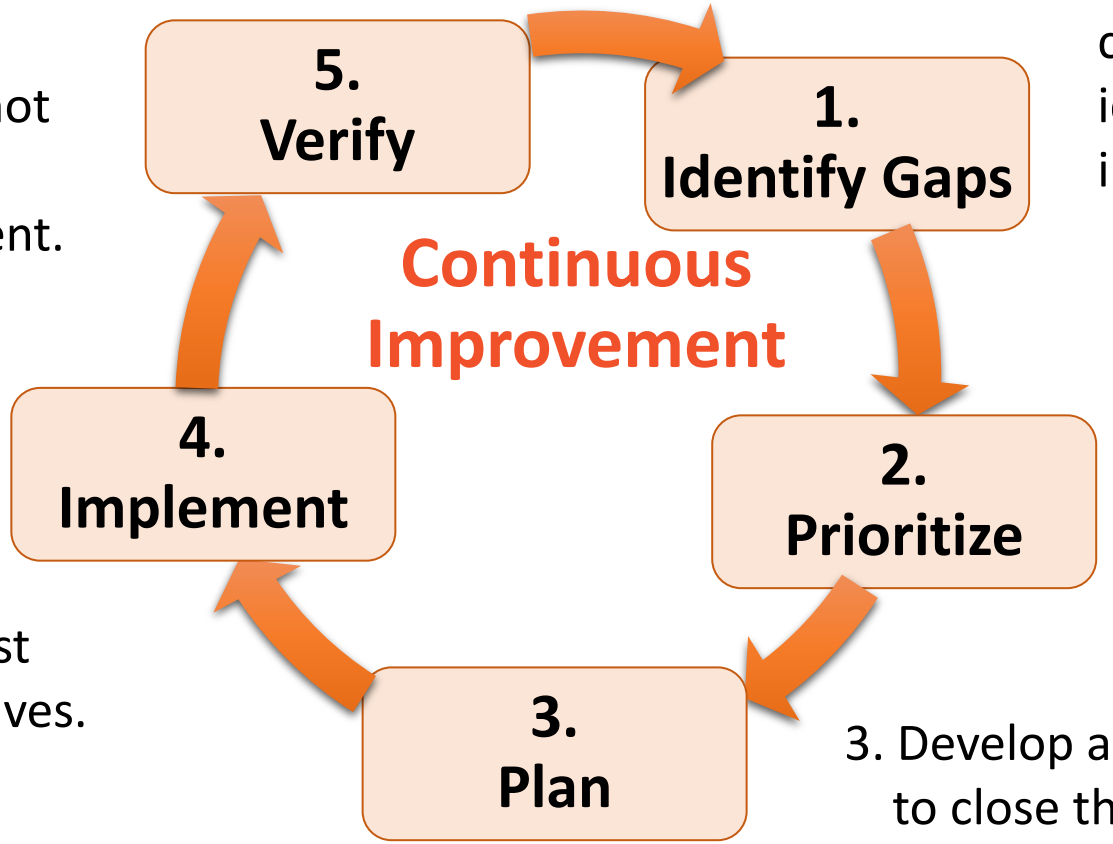
Risk-Critical Practices Within Area of Practice

Good Practice or Enhanced Practice

Key References for Specific Risk-Critical Practices

PGP SUGGESTED IMPLEMENTATION STRATEGY

5. Verify implementation progress and effectiveness. Identify where plan objectives were not fully met for consideration in the next round of improvement.



1. Compare the PGP to your current practices to identify opportunities for improvement.

2. Prioritize the opportunities for improvement.

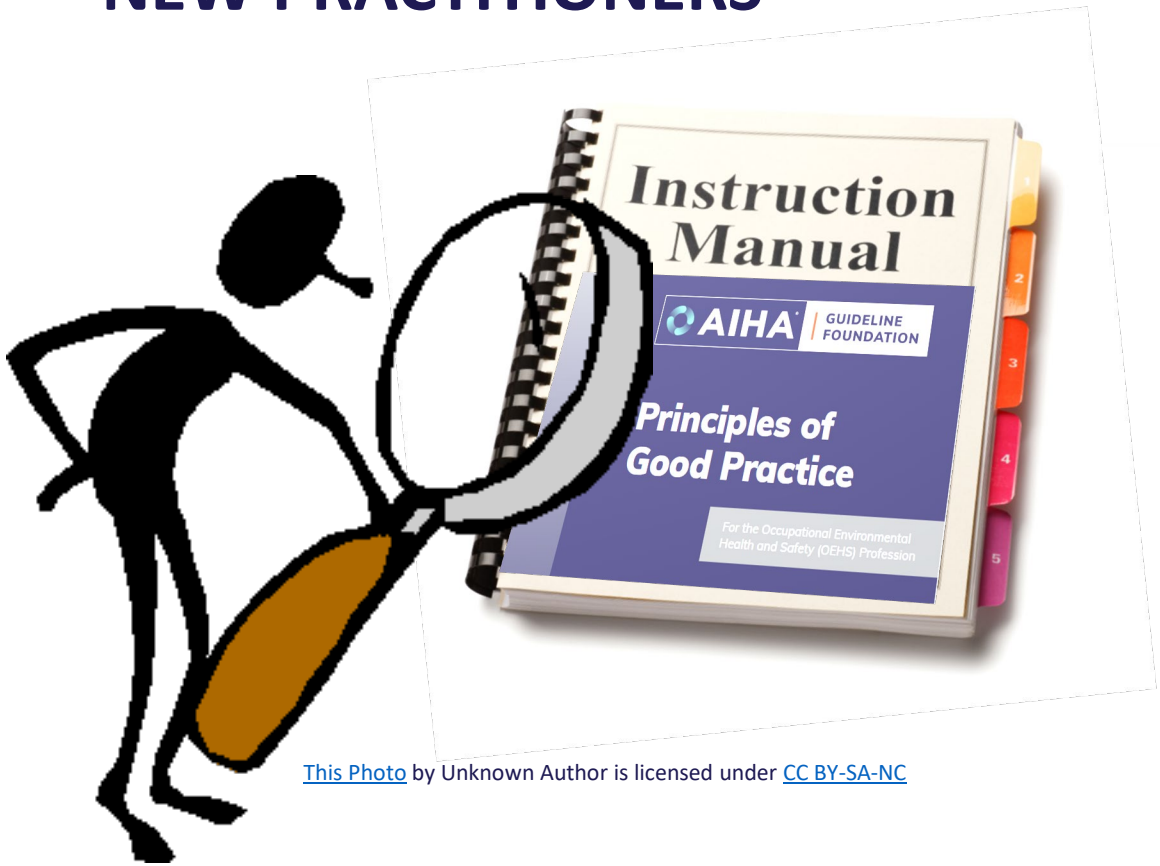
3. Develop a plan with SMART objectives to close the higher priority gaps.

4. Implement the plan and track progress against the plan's SMART objectives.

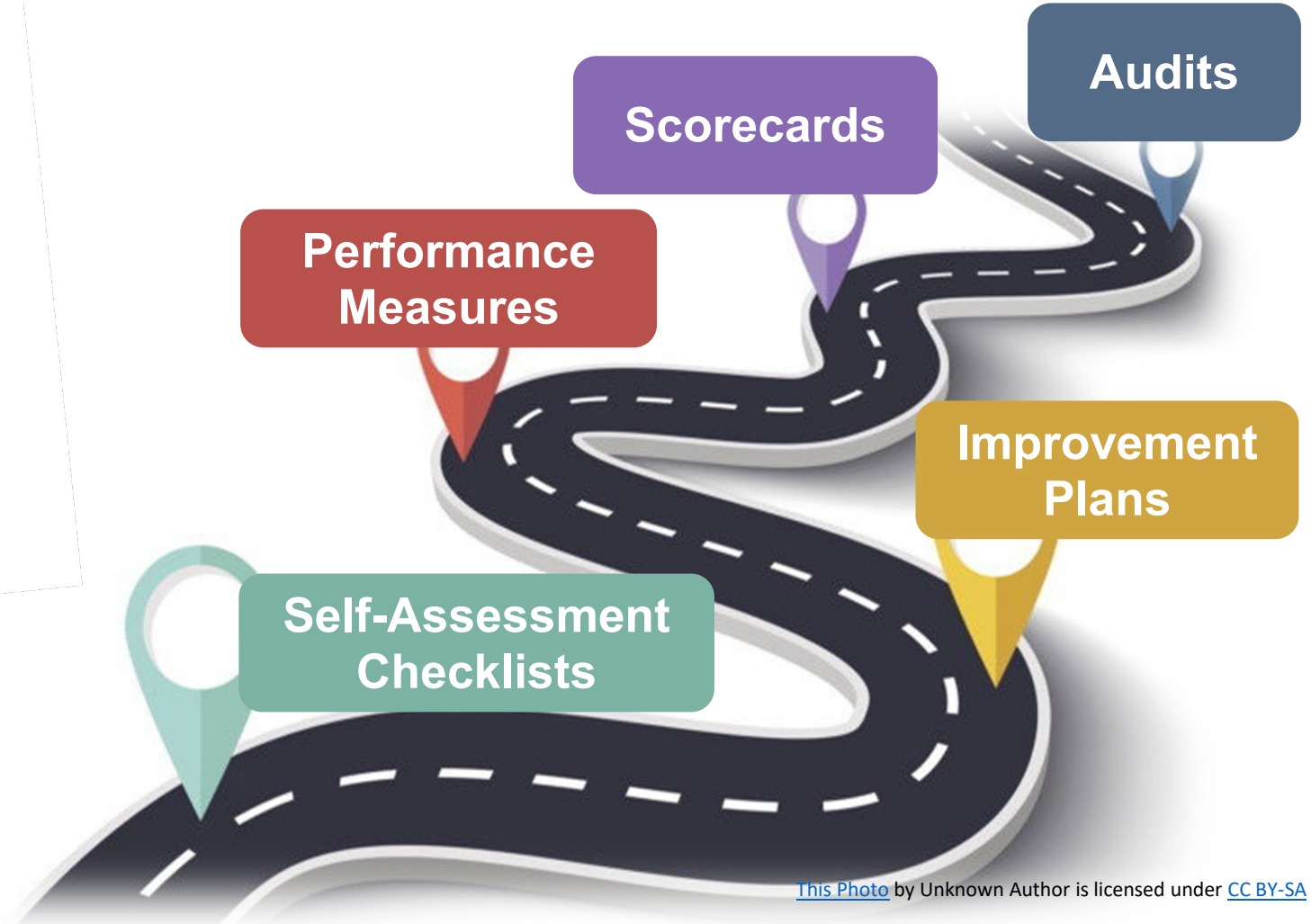
Straightforward Integration Into Existing Management Systems
(e.g. ISO 45001, ISO 14001)

PRINCIPLES OF GOOD PRACTICE

"QUICK START" GUIDE FOR NEW PRACTITIONERS



ROADMAP FOR CONTINUOUS IMPROVEMENT



State of the Art Vs. State of the Practice

STATE OF THE ART VS. PRACTICE

Continuous Improvement Process:

Address Gaps Between Current and State of the Art OEHS Practice.

First Iteration: Occupational Exposure Assessment

1. **Determine State of the Art / Best Practices.** **Using the PGPs**
2. **Survey Practitioners Regarding Their Risk-Critical Practices.**
   - Document Current Practices and How They Differ from Best Practices.
   - Identify Existing Barriers to Achieving Best Practice Performance.
3. **Define and Implement Plans to Address Barriers and Empower Practitioners to Close Practice Gaps and Achieve Best-in-Class Performance.**

SOTA v P Surveys:

2023: Occupational Exposure Assessment

2024: Noise & Hearing Conservation and Respiratory Protection Programs

Learn More Here

Improving Exposure Judgment

AIHA - ACGIH INITIATIVE:
IMPROVING EXPOSURE JUDGEMENT ACCURACY

Improve Practice to Align with Current Science

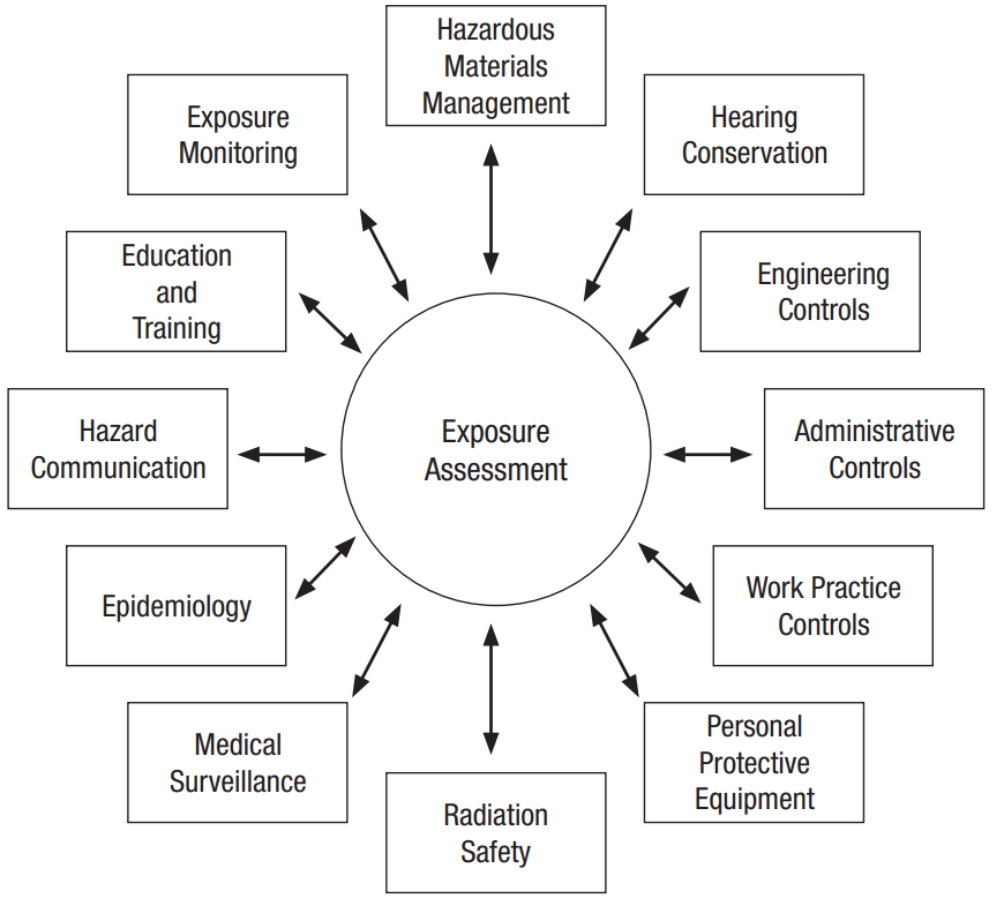
Drive a significant shift in the OEHS practice paradigm: from one where tools and activities to improve exposure judgment accuracy and interpretation are rarely or sporadically used, to one where their use is routine and expected.

Public Web Page

WHAT IF OUR EXPOSURE DECISION IS WRONG?

- **If We Underestimate the Exposure?**
  - Increased Risk to Employees
- **If We Overestimate the Exposure?**
  - Unnecessary Constraints for Employees and Production
  - Unnecessary Expenditures for Controls and Risk Management Programs

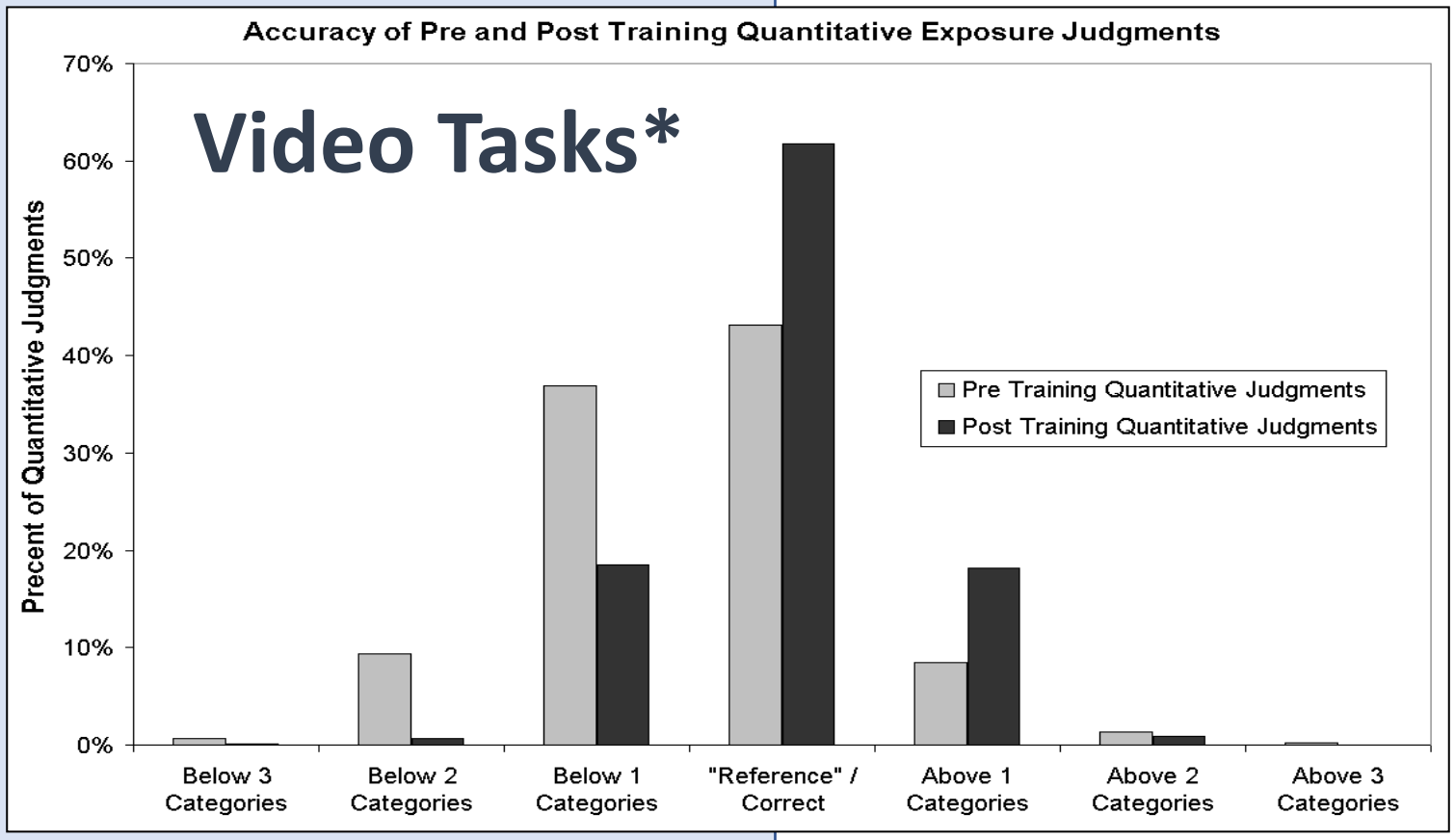
Effective and Efficient Risk Management Requires Accurate Exposure Decisions



THE SCIENCE: WE ARE OFTEN WRONG

Poor Accuracy & Underestimation Bias when we do not use tools and activities to improve exposure judgment accuracy!

With Monitoring Data



Research Studies Asked:

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

Exposure Decision Category*	
1	(<10% of OEL)
2	(10-50% of OEL)
3	(50-100% of OEL)
4	(>100% of OEL)

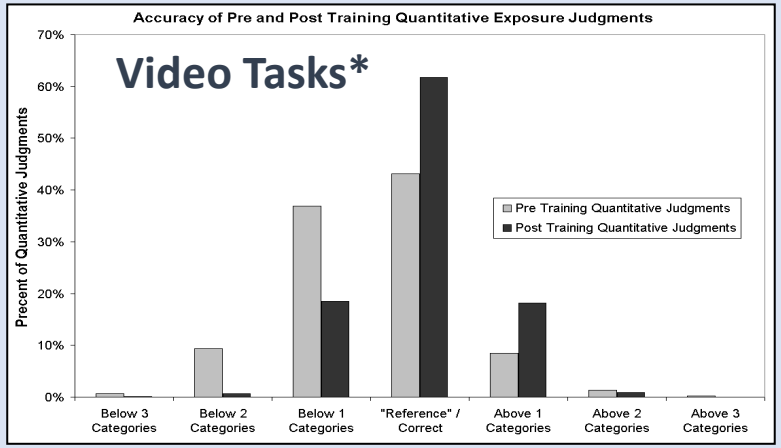
* Decision statistic = 95th percentile

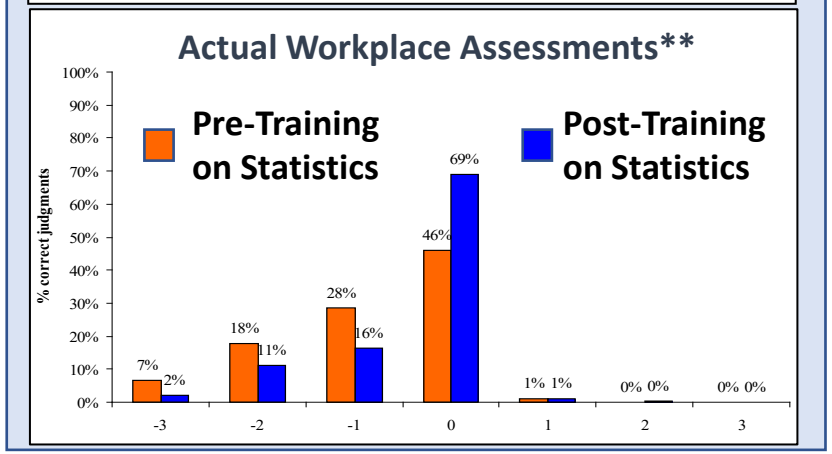
*Logan et.al. Ann of Occ Hyg, Vol. 53, No. 4, 2009

THE SCIENCE: WE ARE OFTEN WRONG

Poor Accuracy & Underestimation Bias when we do not use tools and activities to improve exposure judgment accuracy!

With Monitoring Data





Research Studies Asked:

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

Exposure Decision Category*	
1	(<10% of OEL)
2	(10-50% of OEL)
3	(50-100% of OEL)
4	(>100% of OEL)

* Decision statistic = 95th percentile

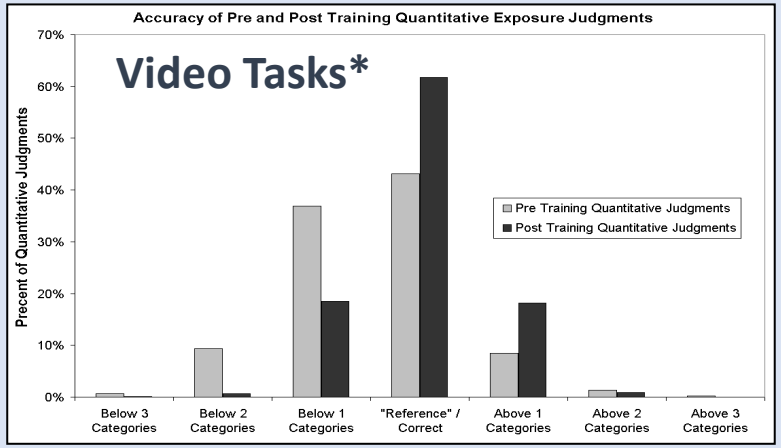
*Logan et.al. Ann of Occ Hyg, Vol. 53, No. 4, 2009

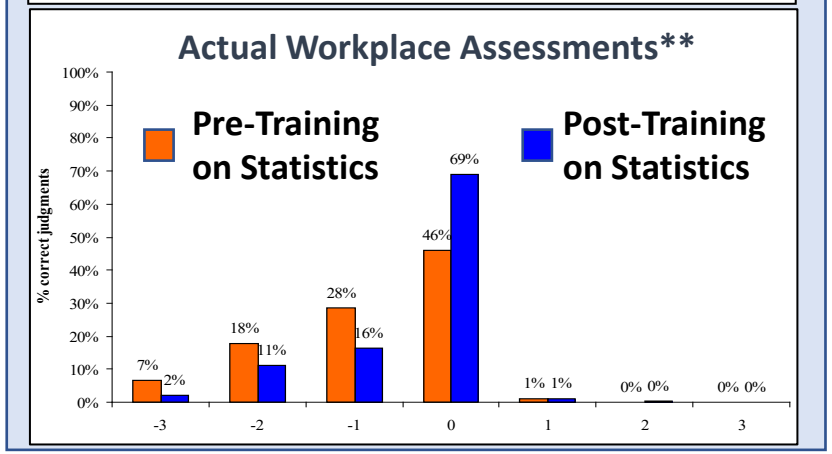
**Vadali et.al. JOEH. 9: 242–256, 2012

THE SCIENCE: WE ARE OFTEN WRONG

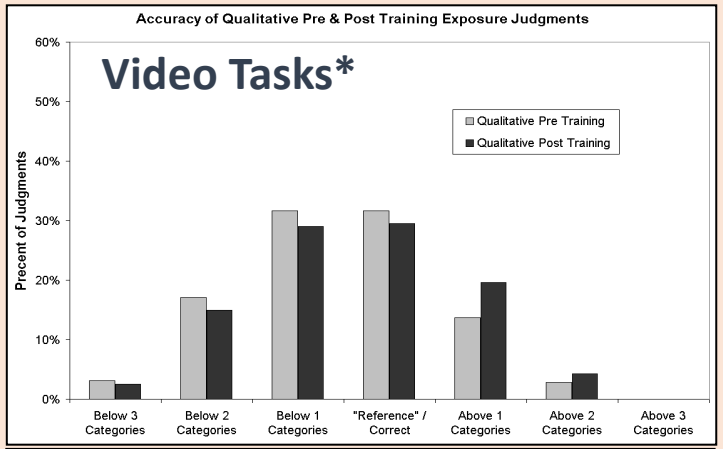
Poor Accuracy & Underestimation Bias when we do not use tools and activities to improve exposure judgment accuracy!

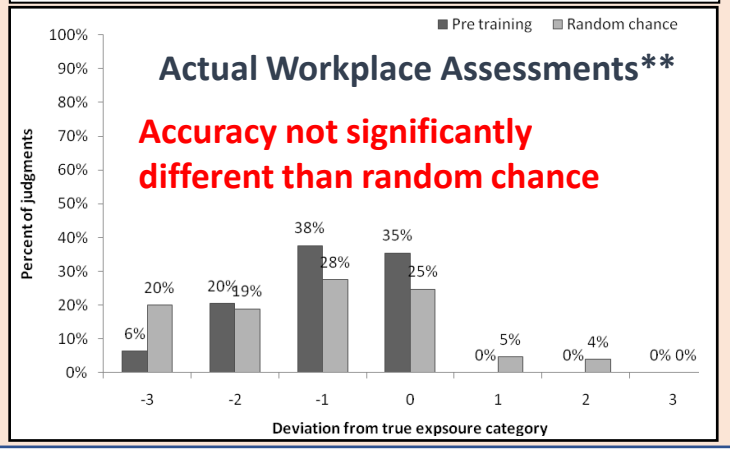
With Monitoring Data





No Monitoring Data (Qualitative Judgment)





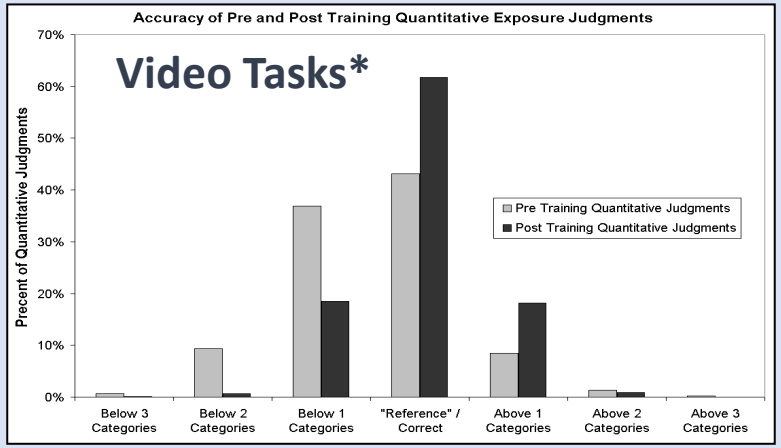
*Logan et.al. Ann of Occ Hyg, Vol. 53, No. 4, 2009

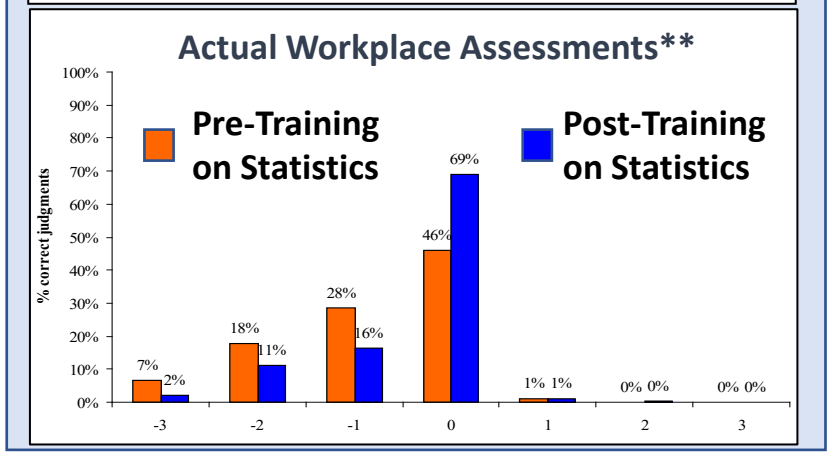
**Vadali et.al. JOEH. 9: 242–256, 2012

THE SCIENCE: WE ARE OFTEN WRONG

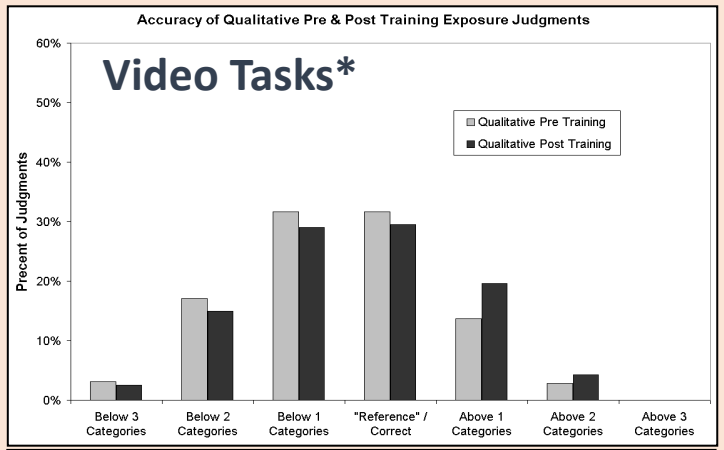
Poor Accuracy & Underestimation Bias when we do not use tools and activities to improve exposure judgment accuracy!

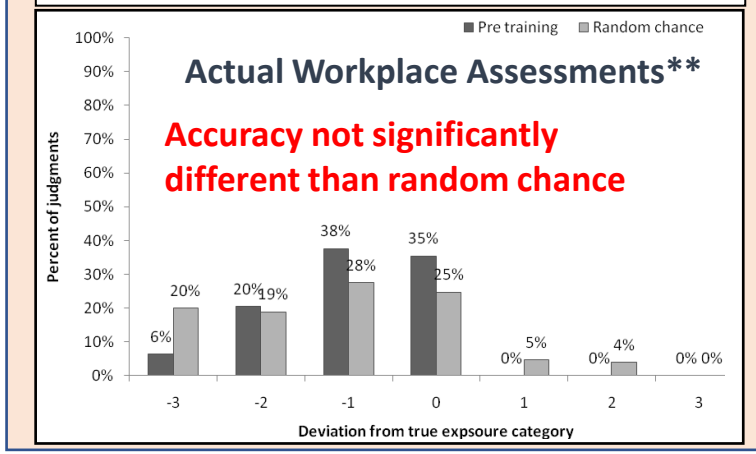
With Monitoring Data

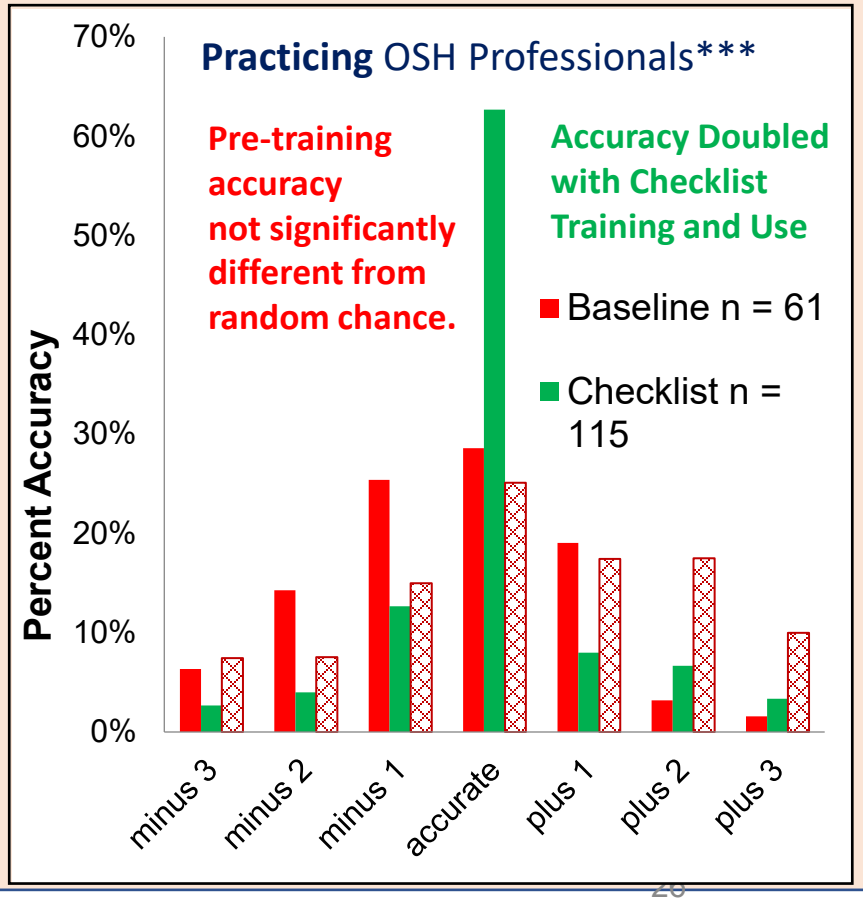




No Monitoring Data (Qualitative Judgment)



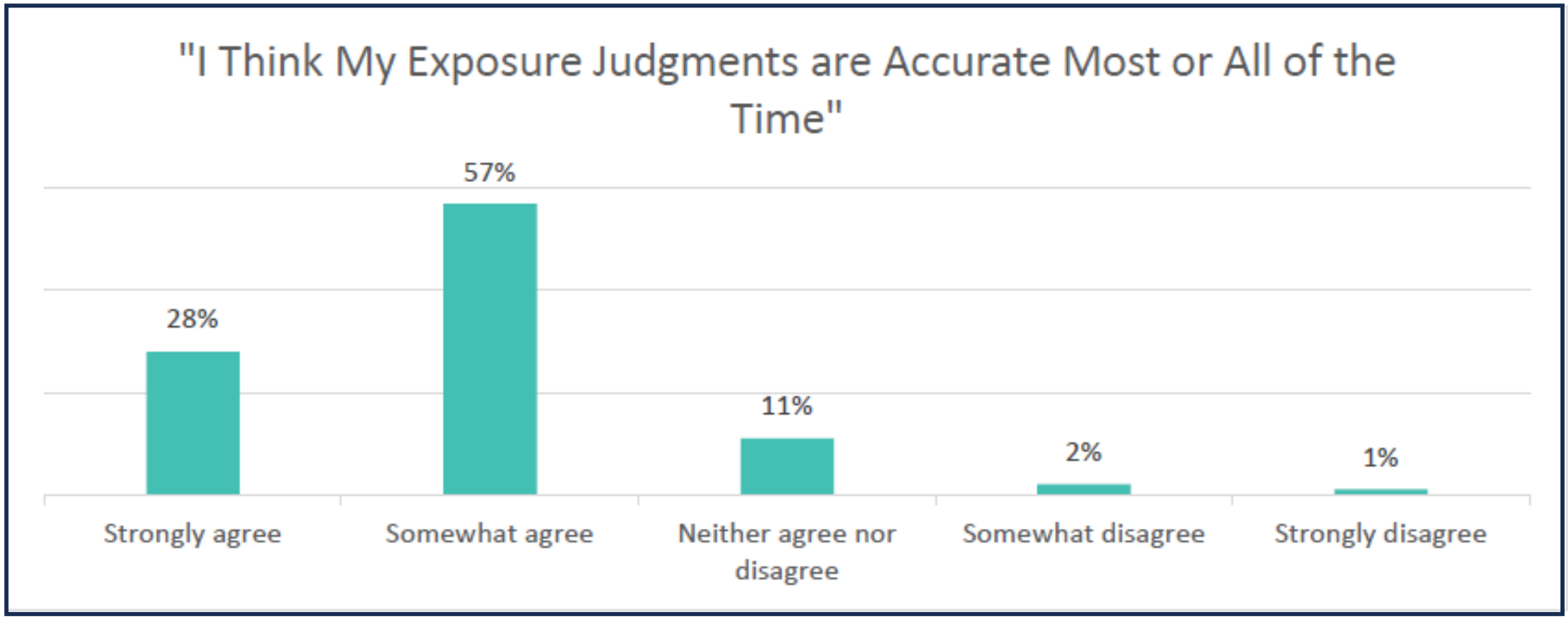




*Logan et.al. Ann of Occ Hyg, Vol. 53, No. 4, 2009

**Vadali et.al. JOEH. 9: 242–256, 2012

***Arnold et.al JOEH, 13, 159-168, 2016



QNA

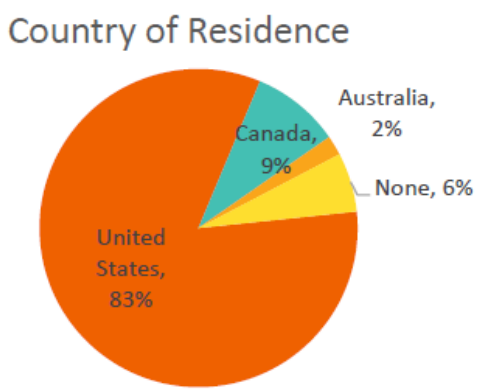
Research Report:

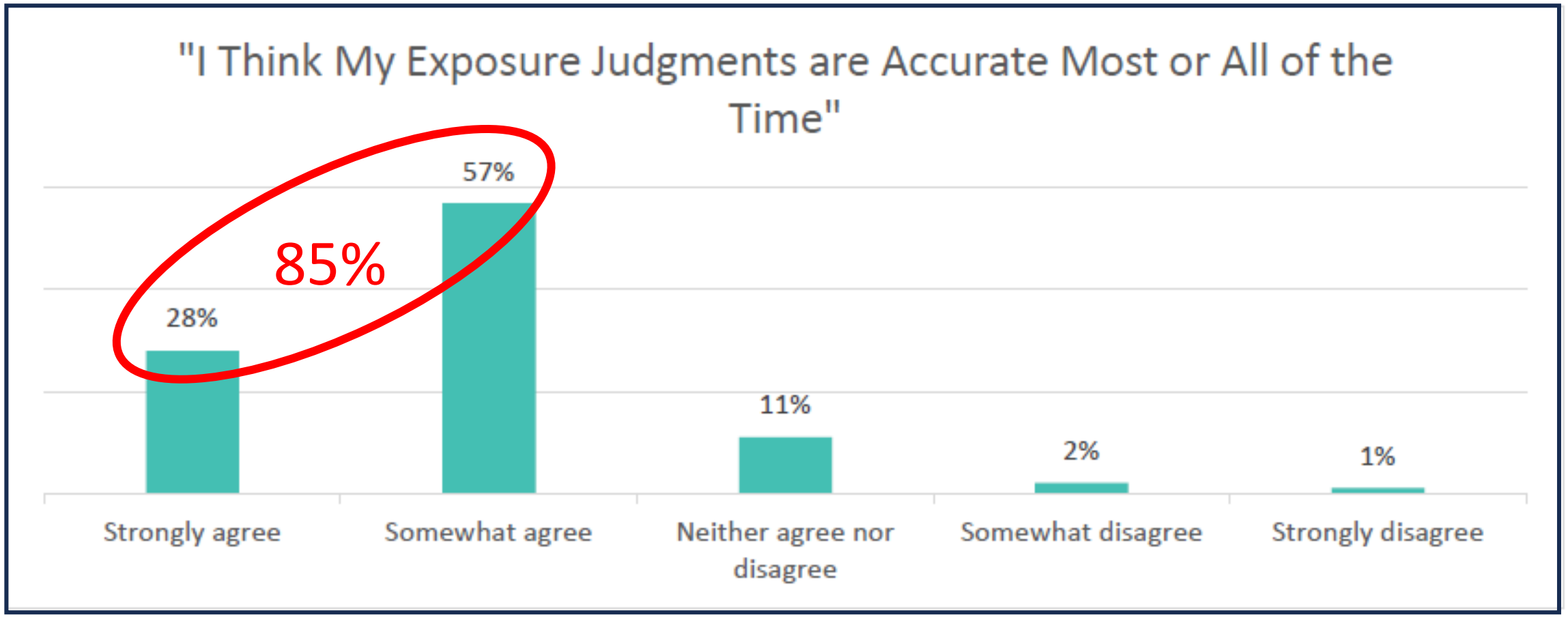
AIHA Improving Exposure Judgments Concept Evaluation

October 2023

RESPONDENT PROFILE

A total of 306 OEHS professionals completed all questions in the survey, most of whom are based in the United States (83%) or Canada (9%).

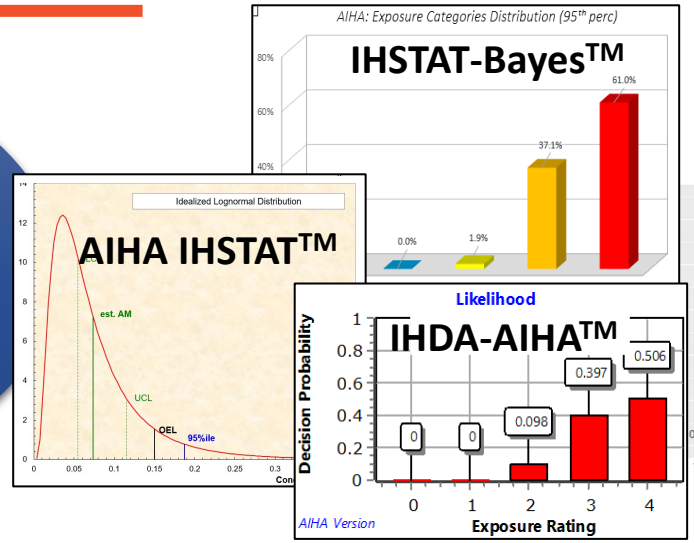


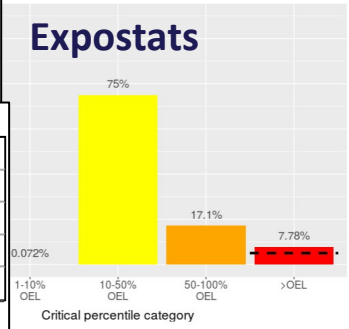


How Do We Know?
What Are Our Quality Control Processes?

IMPROVING EXPOSURE DECISION ACCURACY:
FREE COMPLETE RESOURCE PACKAGE

Tools





FREE

Assessment of Competency and Performance

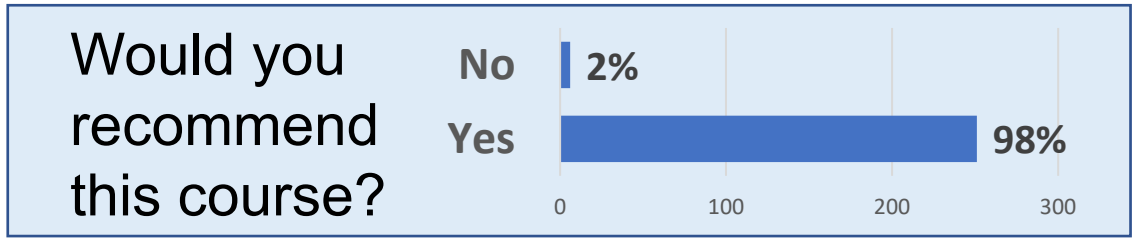
Training

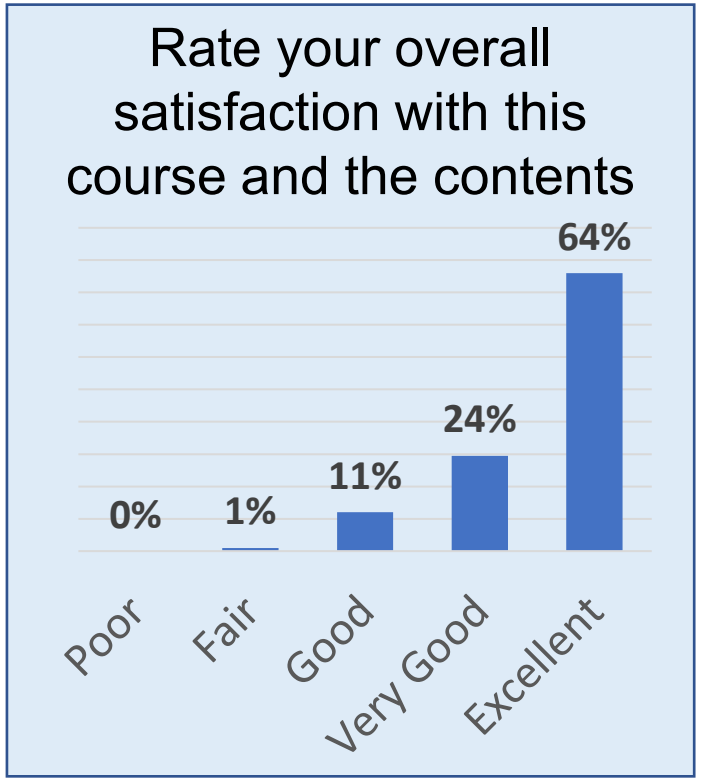
Access Resource Package HERE

FREE WEBINAR ON STATISTICAL ANALYSIS TOOLS

Participant Feedback: 49% Response Rate (537 / 1104)

"Statistics made simple – this should be a prerequisite for all industrial hygienists!"





"With this course, the light bulb went off. I have never liked/used statistics until I took this course."

"The course takes us (IHs) to the next level. It's where we should be at in our practice."

"A great overview of IH data analysis- a must for anyone charged with the interpretation of sampling results!"

"One of the easiest-to-understand offerings on this subject; ideal for individuals with little background or natural aptitude for the concepts."

"Great course. Every IH professional needs to take this course. This rubric should become part of the CIH exam."

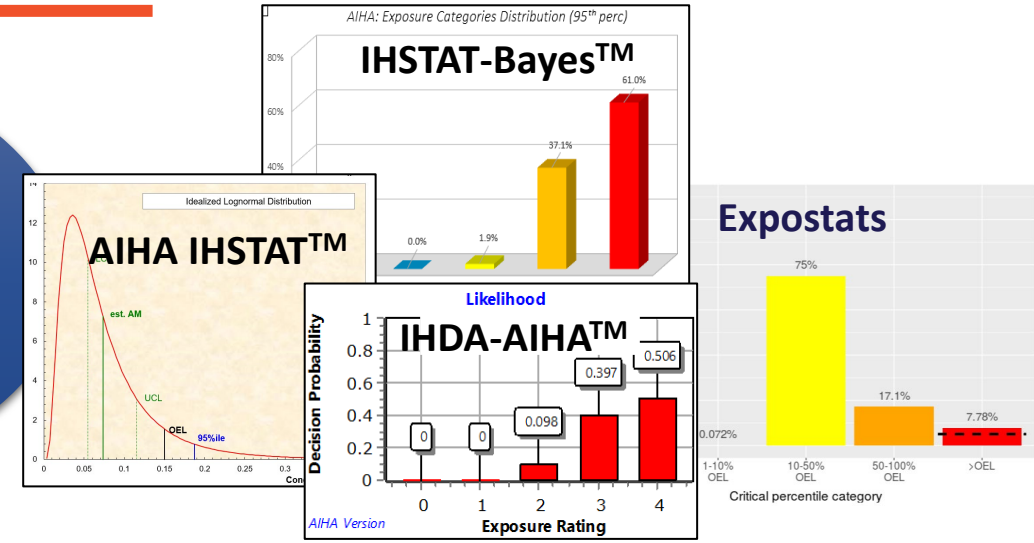
IMPROVING EXPOSURE DECISION ACCURACY:
FREE COMPLETE RESOURCE PACKAGE

Registered Specialist
Exposure Decision Analysis

#116674

AIHA Registry Programs®

Tools



FREE

Assessment of Competency and Performance

Training

Access Resource Package HERE

FREE EXPOSURE DECISION ANALYSIS (EDA) REGISTRY

Program Goal:

Improve the Accuracy and Efficiency of Exposure Assessment Decisions

Benefits Include:

- Independent validation of your knowledge, skills and performance in making accurate exposure decisions based on monitoring data.
- Recognition of your competency in rendering accurate decisions about worker exposure and exposure uncertainty.
- Improve the overall quality of your management of workplace exposures.

Requirements (No Prerequisites)

1. Score ≥70% on first exam based on the knowledge needed to accurately interpret exposure monitoring data.
2. Score ≥70% on second exam based on the correct interpretation of supplied data sets.
3. Affirm a commitment to continuous improvement.

Registration is valid for 5 years

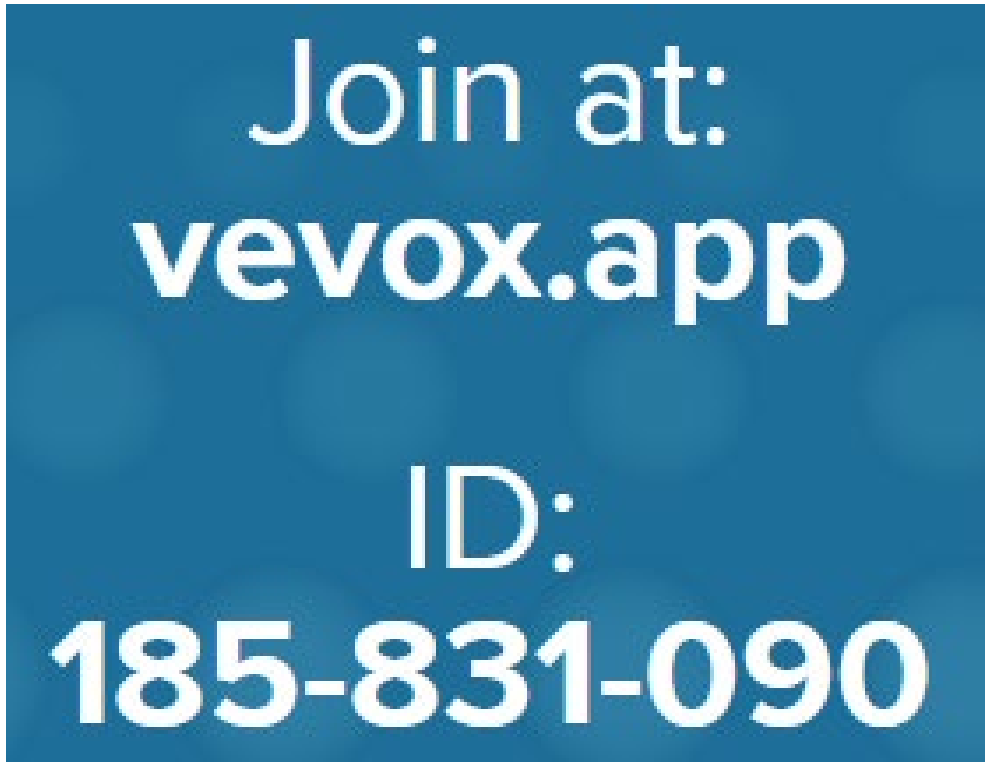
Registered Specialist
Exposure Decision Analysis

AIHA Registry Programs®

Free Assessment of the Knowledge, Skills and Performance Needed to Accurately Interpret Exposure Monitoring Data

FREE Here

A FEW MORE POLLING QUESTIONS . . .



VEVOX Polling Software Site

AIHA™

POLLING QUESTION #8

Prior to this session were you aware of the FREE EDA Registry?

- ❑ No
- ❑ Somewhat – I had a vague awareness but knew few details
- ❑ Yes – But did not realize it was free to everyone
- ❑ Yes – I was Aware of the EDA Registry and the fact that it was free to everyone

POLLING QUESTION #9
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

POLLING QUESTION #9
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)

95%ile

5/100 (5%) above

95/100 (95%) below

Chart of 100 Air Samples: Lognormally Distributed Data

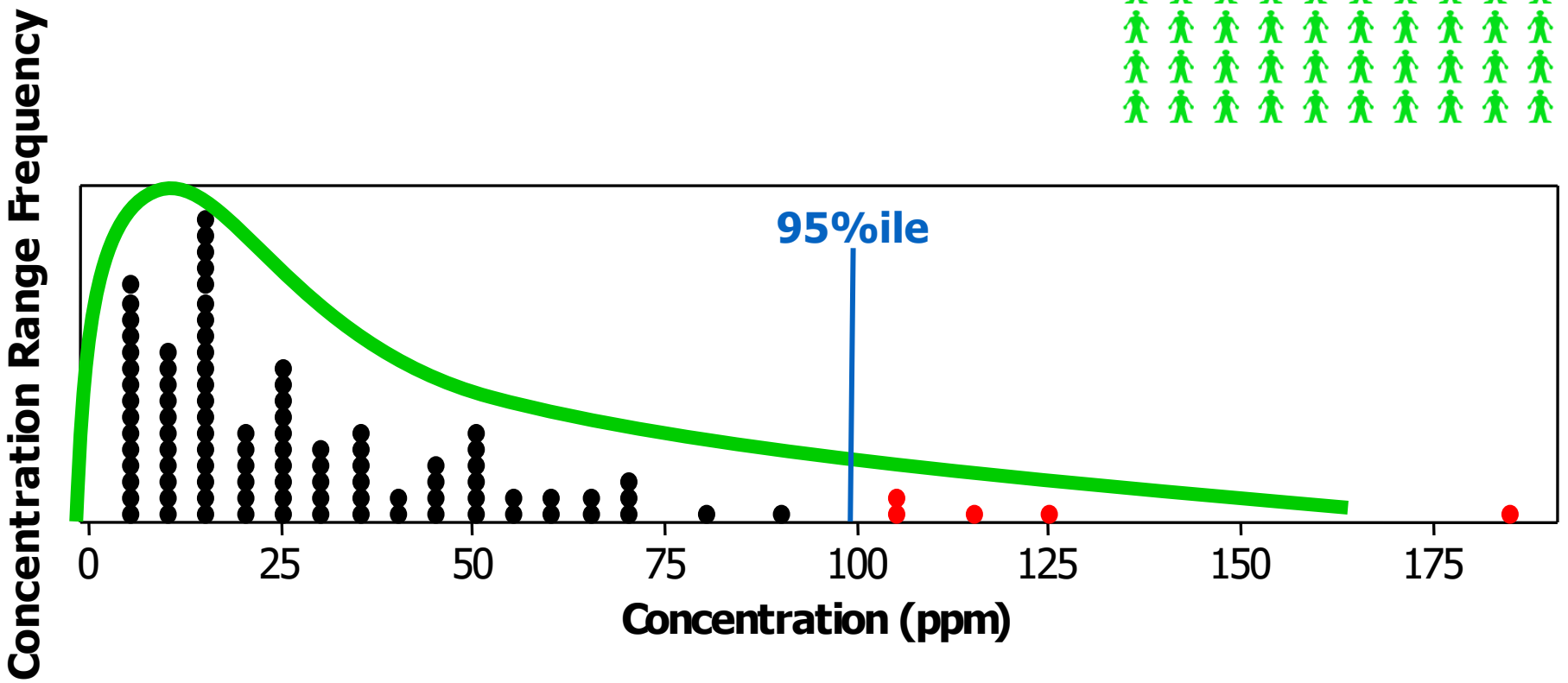
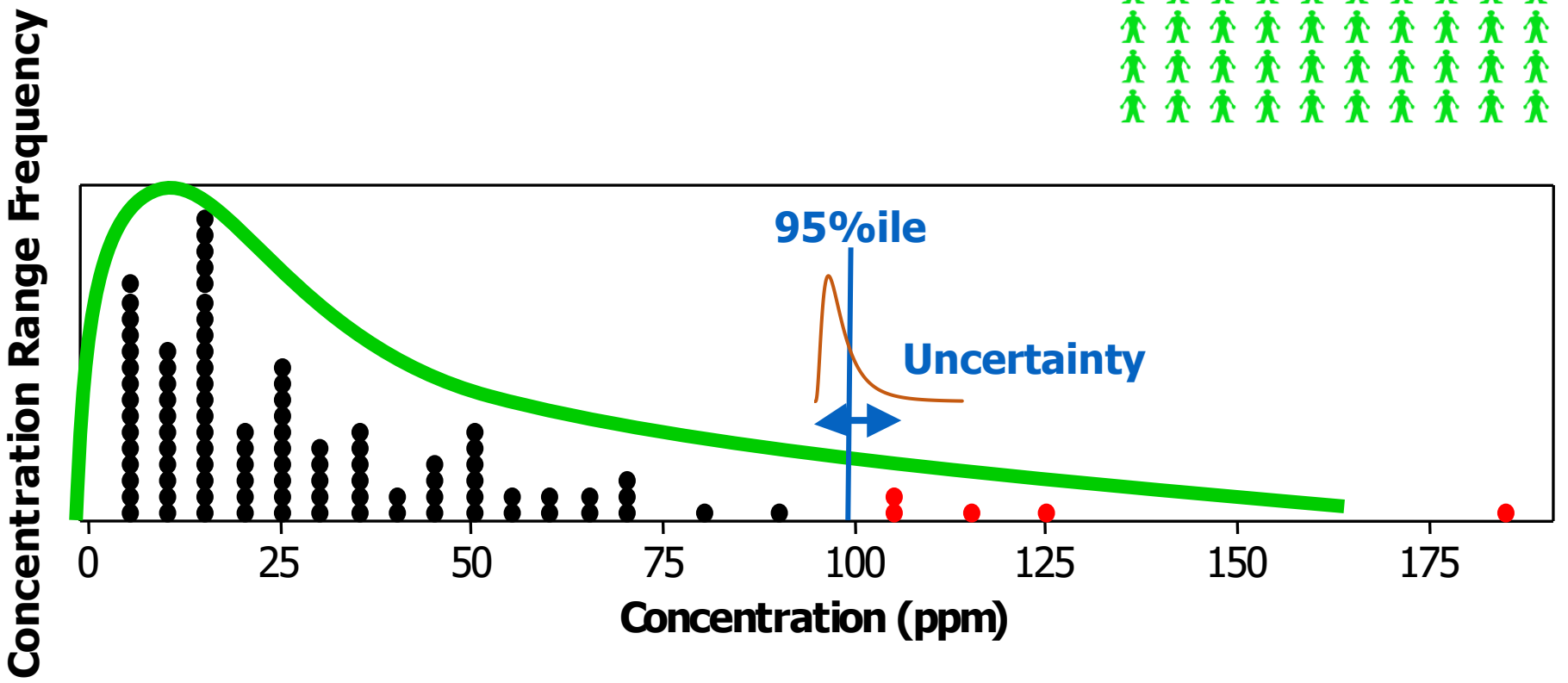
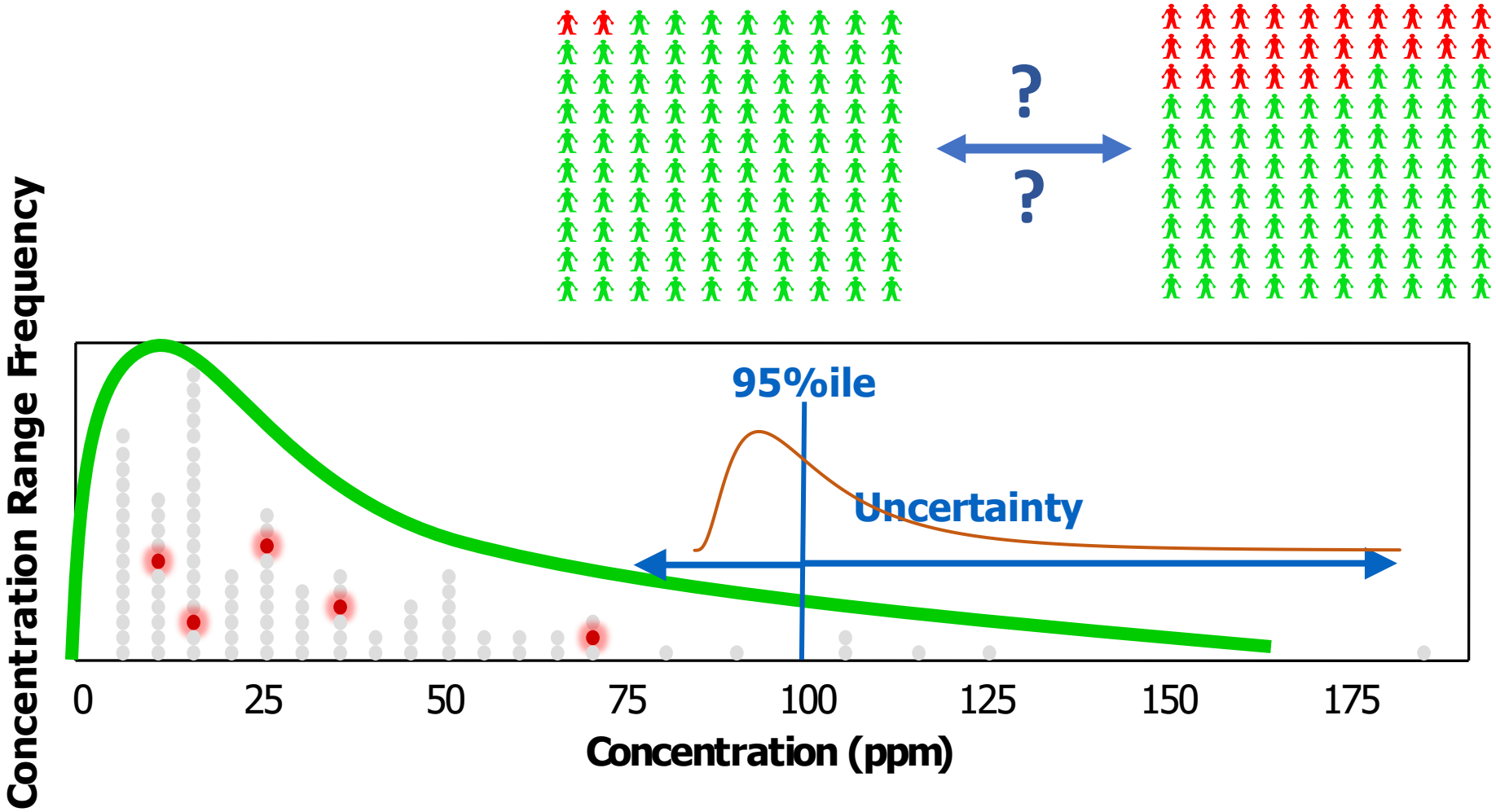


Chart of 100 Air Samples: Lognormally Distributed Data



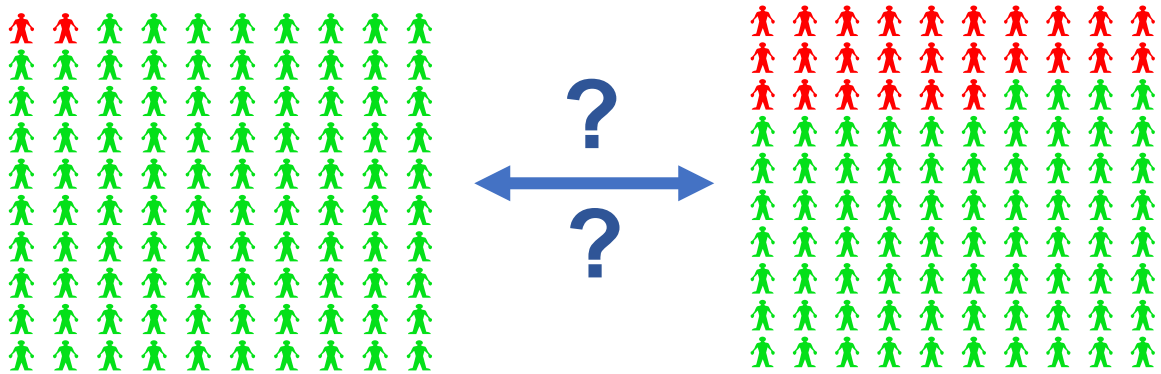
Usual Number of Samples << 100



POLLING QUESTION #10
DECISION STATISTIC: 2ND FRAMING QUESTION

How sure do you want to be in your judgment?

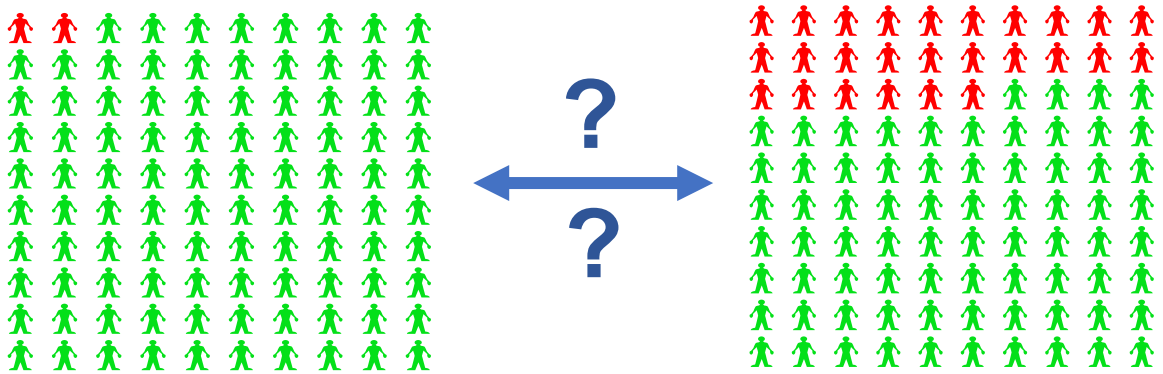
1. 100% Sure
2. 99% Sure
3. 95% Sure
4. 90 % Sure
5. 70% Sure
6. 50% Sure



POLLING QUESTION #10
DECISION STATISTIC: 2ND FRAMING QUESTION

How sure do you want to be in your judgment?

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

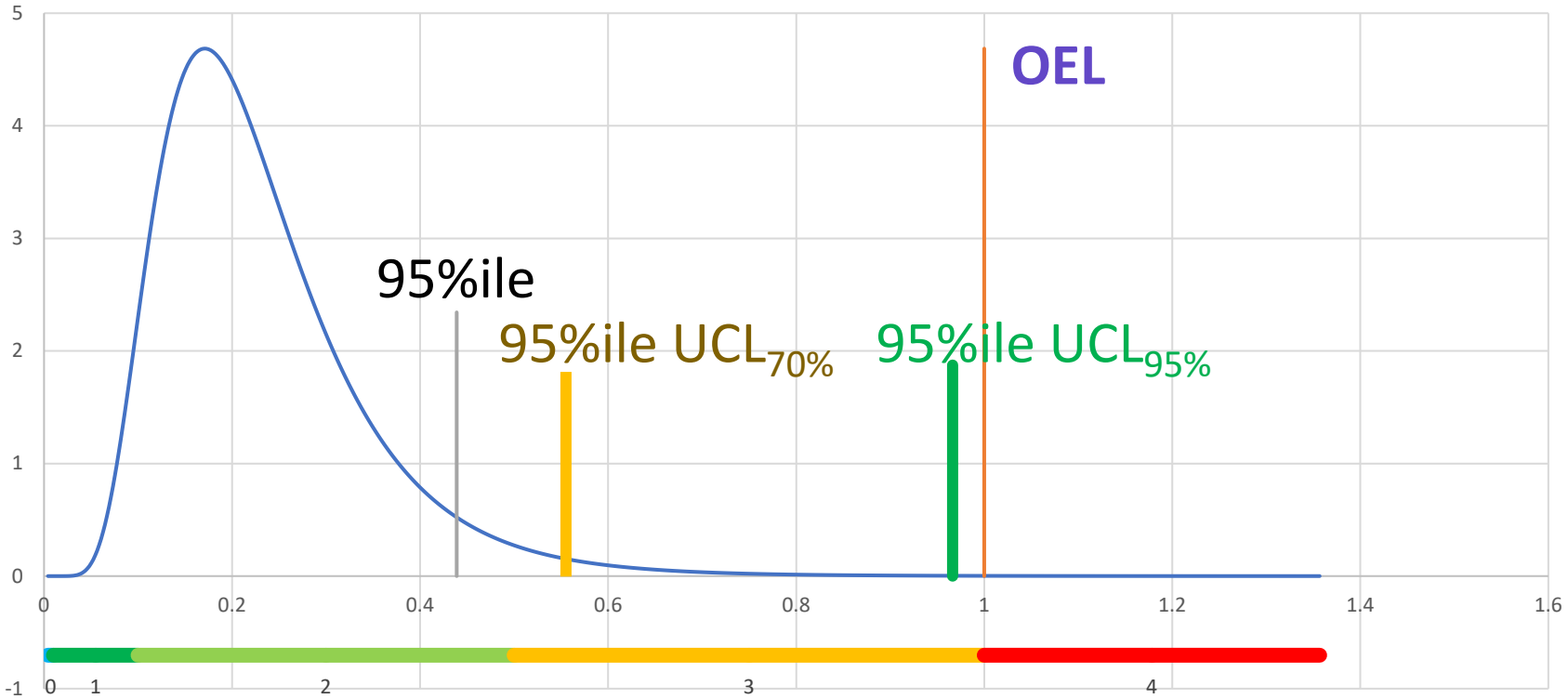


- Answers express the desire for high confidence that employees are protected.
- Implementing the AIHA Strategy with its emphasis on driving follow-up actions and continuous improvement enables a program to strive for high confidence.
- **Common to strive for 95% confidence.**

PGP DECISION STATISTIC:

Good Practice: At least 70% confident that the true 95th percentile exposure is less than the OEL

Enhanced Practice: Strive to be at least 95% confident that the true 95th percentile exposure is less than the OEL

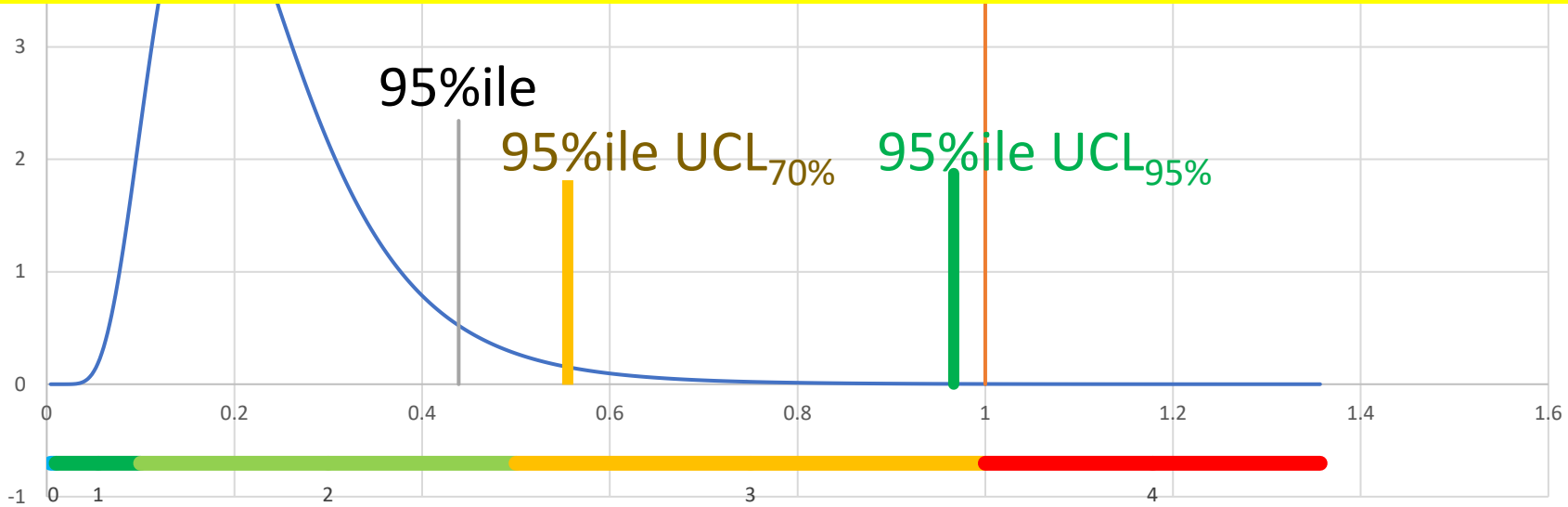


PGP DECISION STATISTIC:

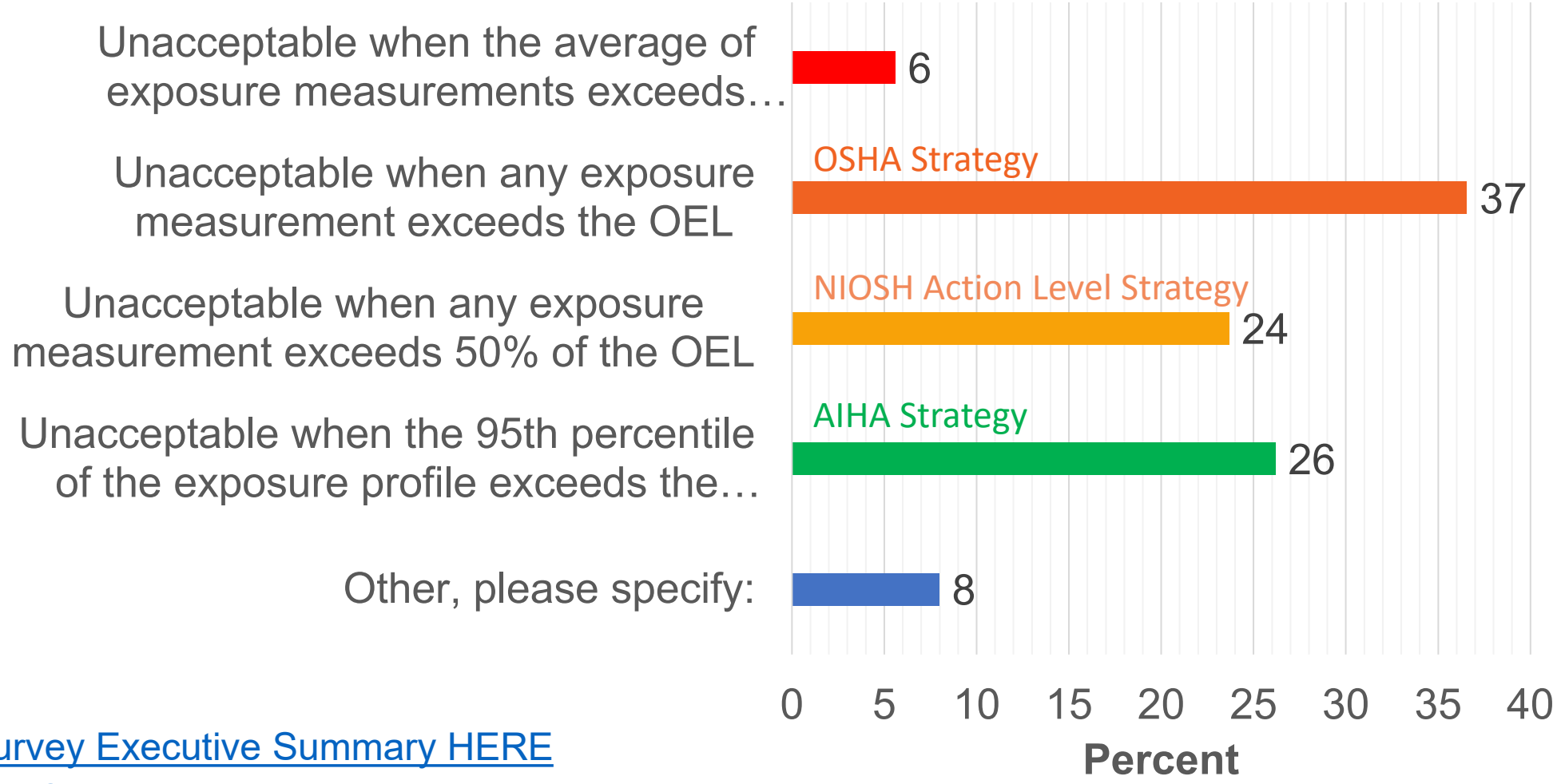
Good Practice: At least 70% confident that the true 95th percentile exposure is less than the OEL

Enhanced Practice: Strive to be at least 95% confident that the true 95th percentile exposure is less than the OEL

Are we getting this performance from current exposure assessment and management programs?



Which of the following best describes your/your team's approach to judging whether exposures are unacceptable? (Select one)



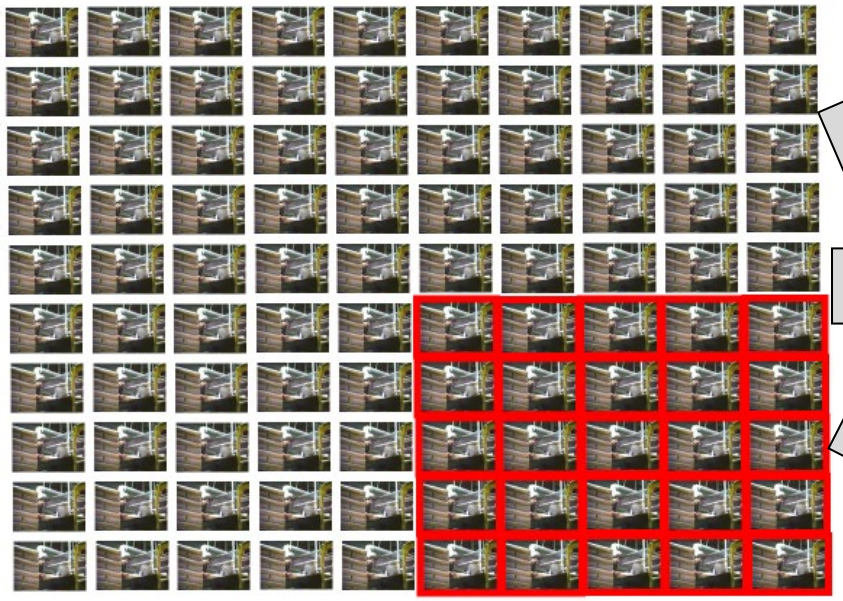
n= 714

[Access Survey Executive Summary HERE]

[Access Full Survey Results HERE]

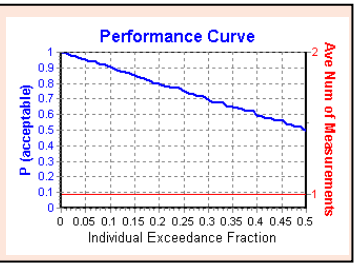
COMPARISON OF EA STRATEGY PERFORMANCE

Example Unacceptable Operation:
Exposures Exceed OEL
25% of the Time.

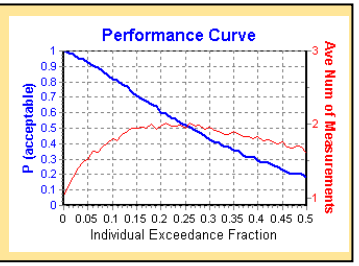


Strategy Performance

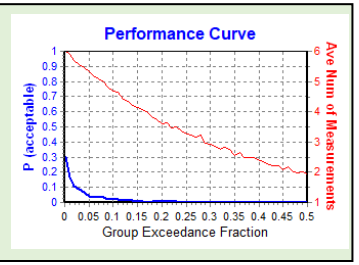
OSHA Strategy
"Acceptable" 75% of the time



NIOSH Action Level Strategy
"Acceptable" 20% to 65% of the time, depending on GSD



AIHA Strategy
95% confident that 95%ile less than OEL
"Acceptable" <1% of the time

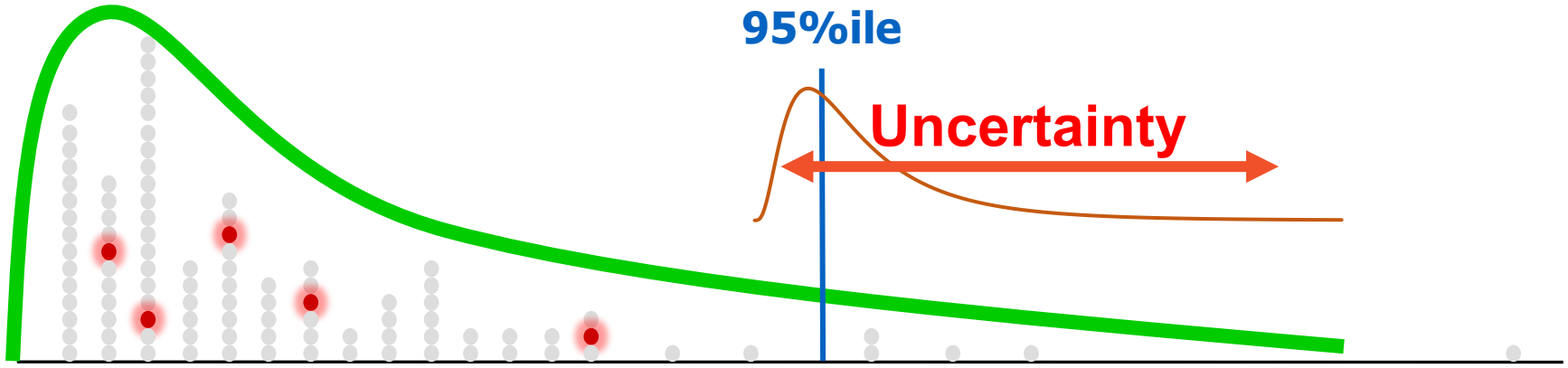


Our Fundamental Issue:

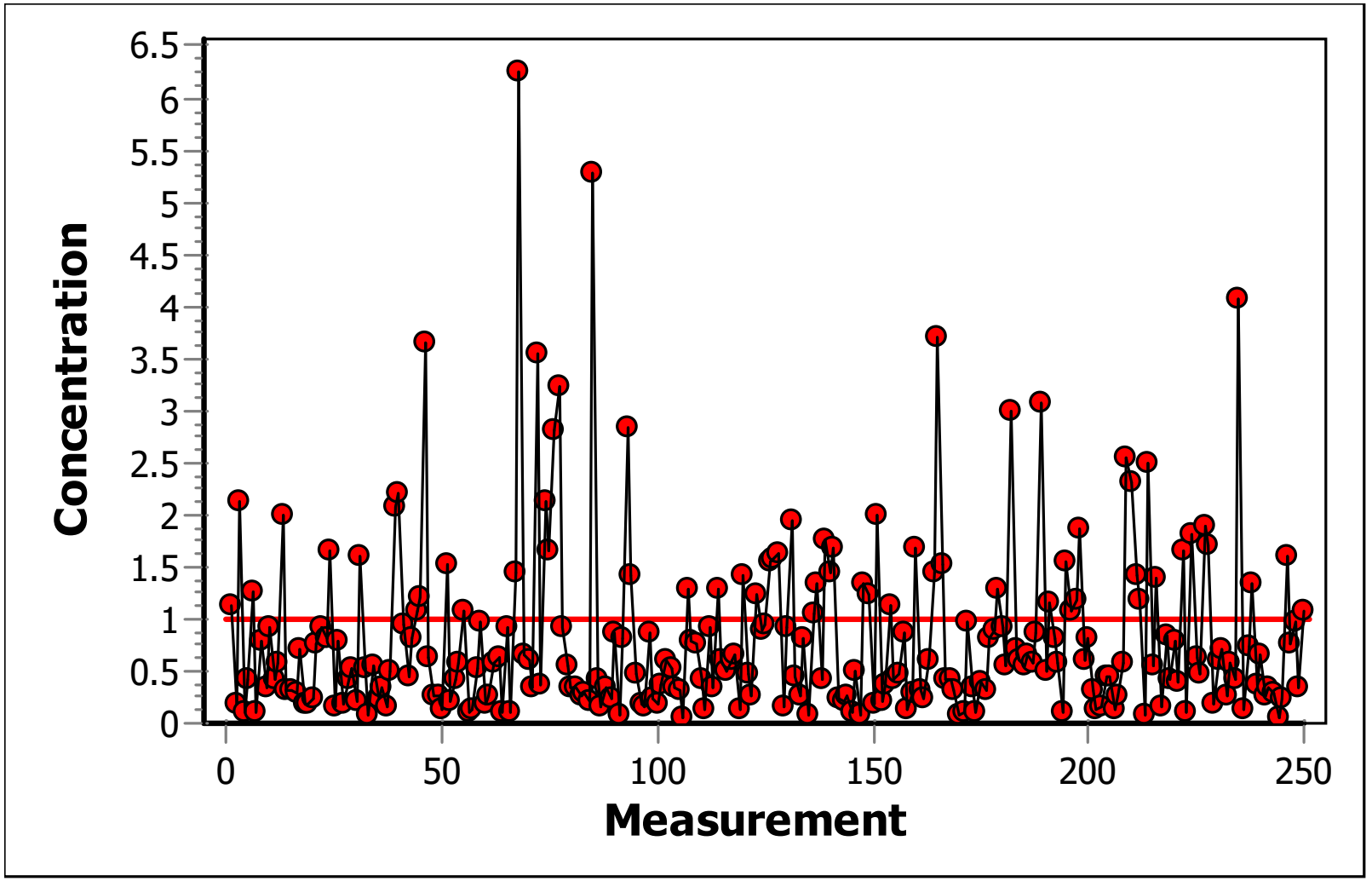
Exposure Variability

+

Very Low Numbers of Samples



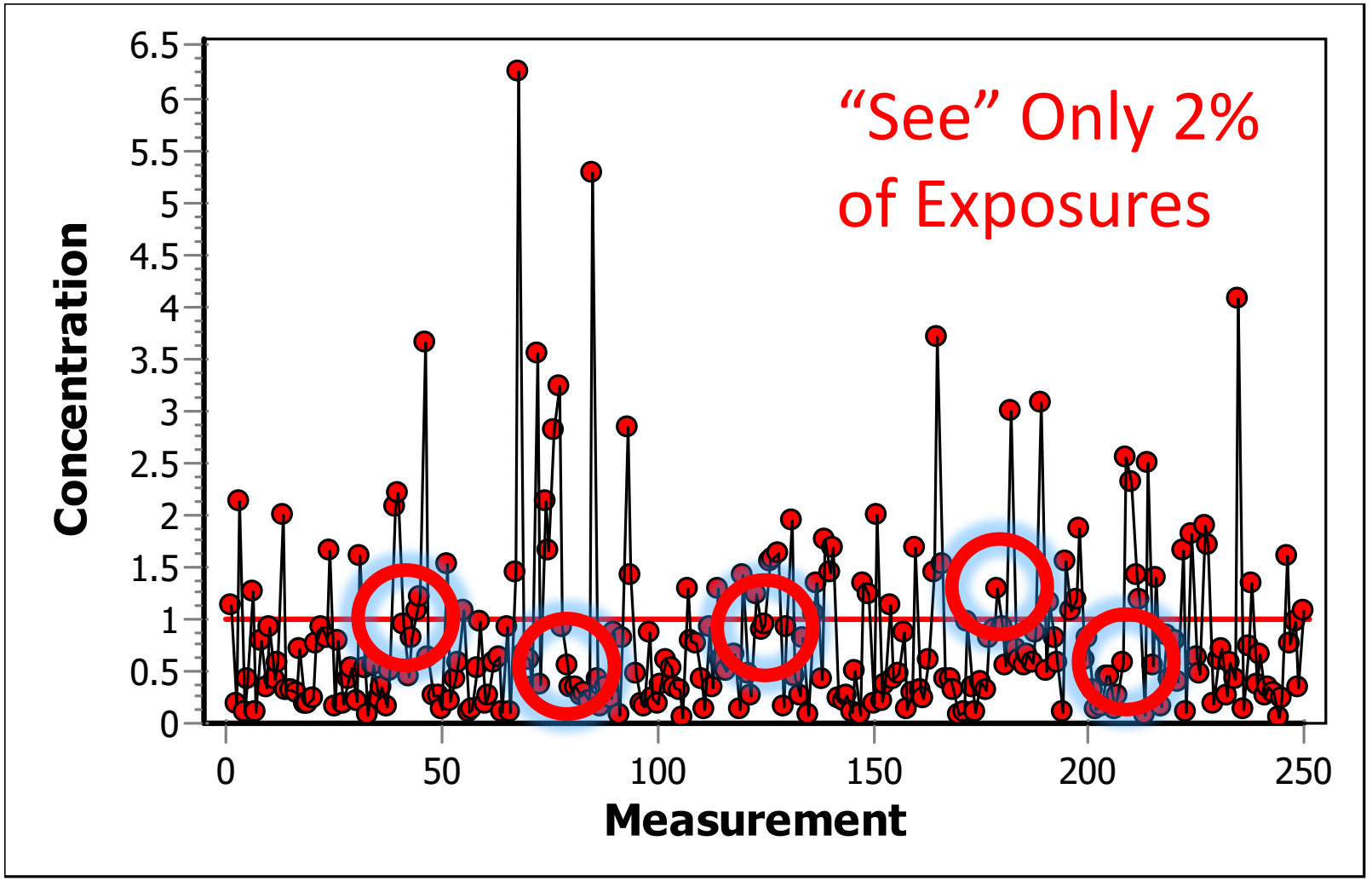
Trying to understand this . . . .



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

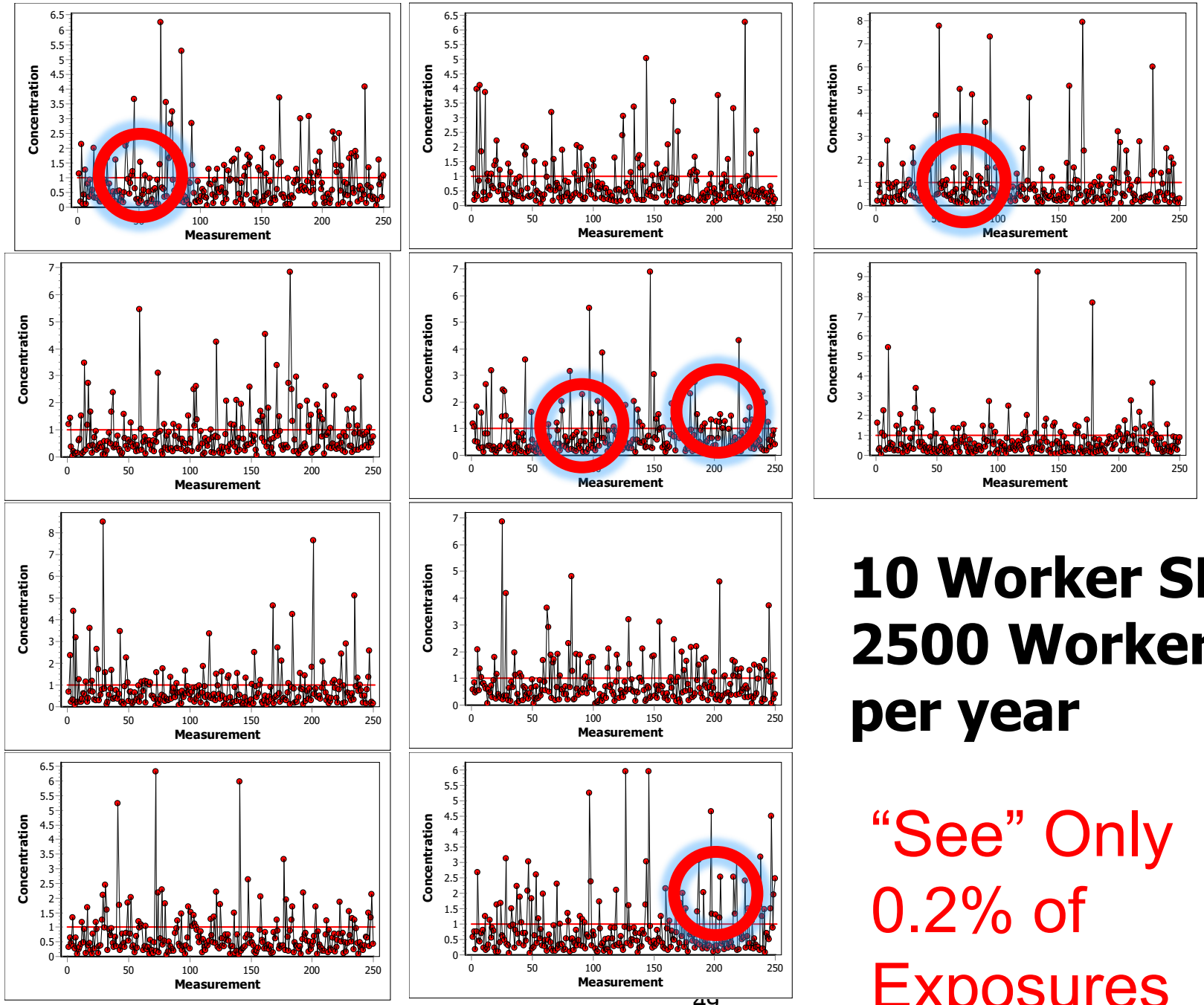
47

. . . Based on this (n=5 samples):



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

48

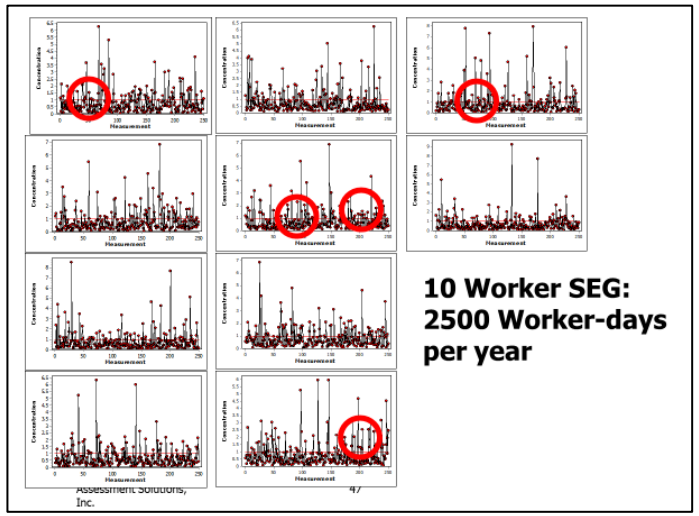


10 Worker SEG: 2500 Worker-days per year

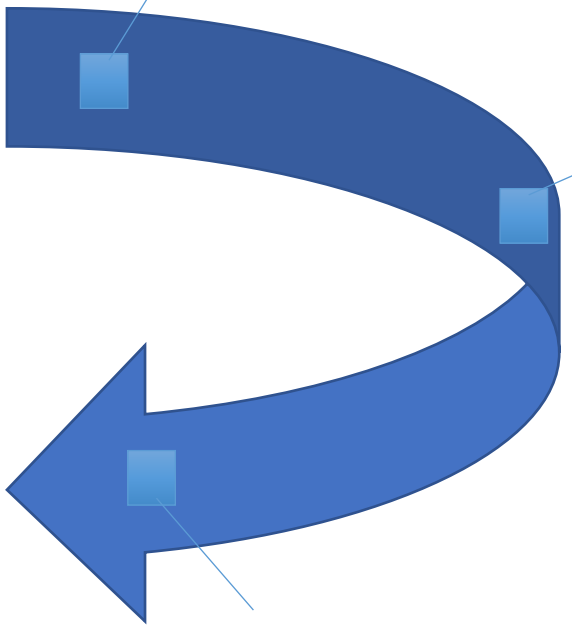
"See" Only 0.2% of Exposures

49

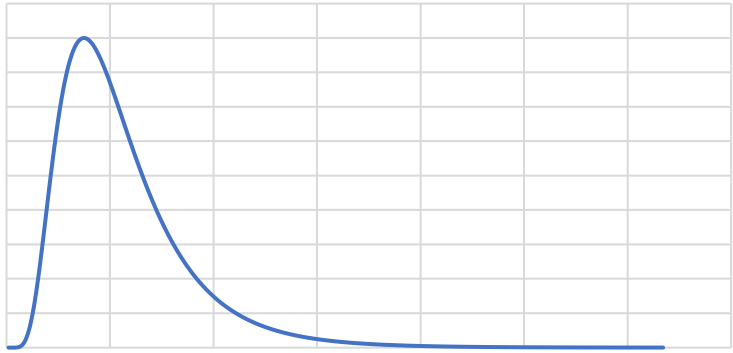
Solution: Inferential Statistics . . . .



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



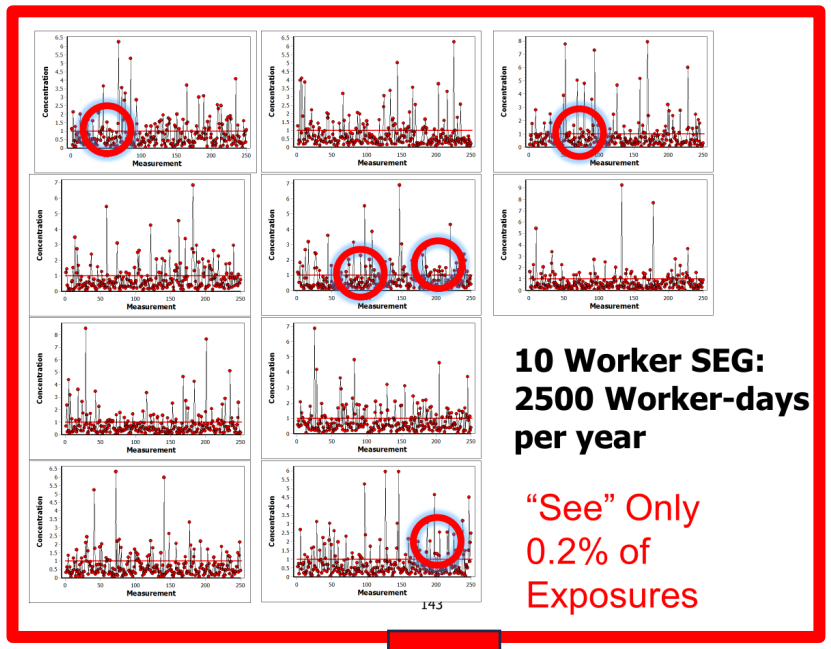
Using Knowledge of Underlying Shape (Lognormal Distribution) . . .



The Actual Population Exposure Profile (SEG of 10 Workers)

OUR CONUNDRUM: Low Sample Size

Actual Exposure Profile Being Sampled Each Time (n=5): OEL = 100, 95%ile = OEL, GSD = 3

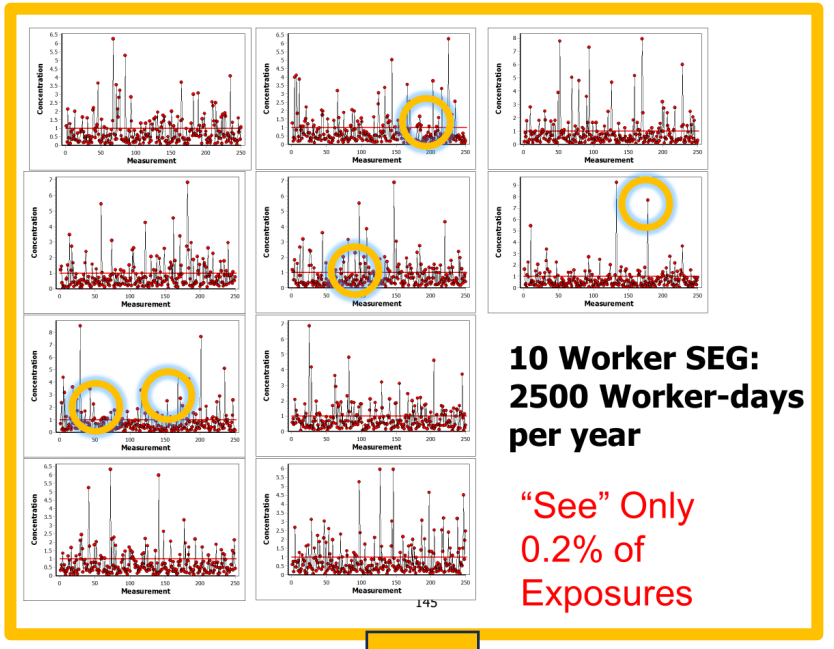


10 Worker SEG: 2500 Worker-days per year

"See" Only 0.2% of Exposures

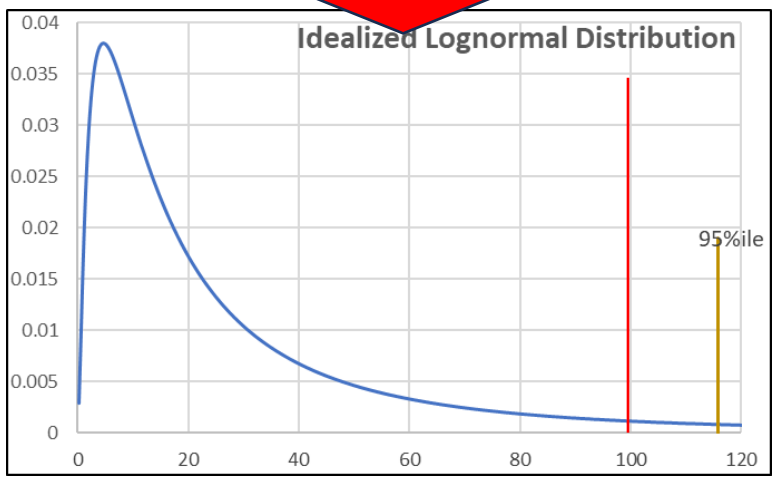
10 Worker SEG: 2500 Worker-days per year

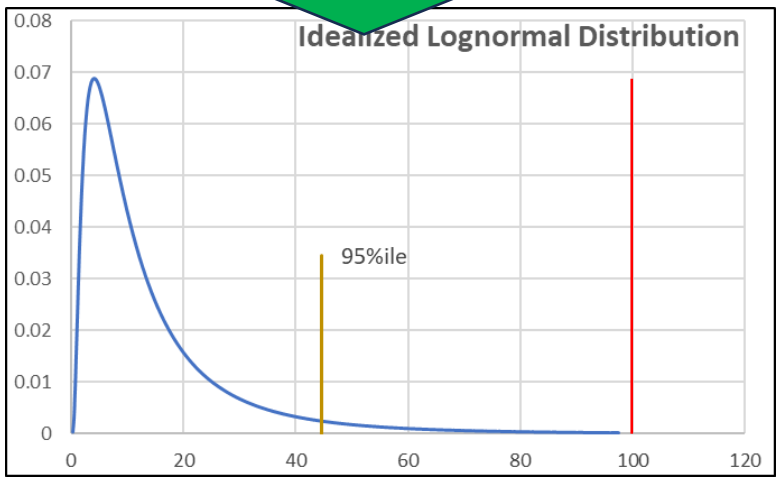
"See" Only 0.2% of Exposures

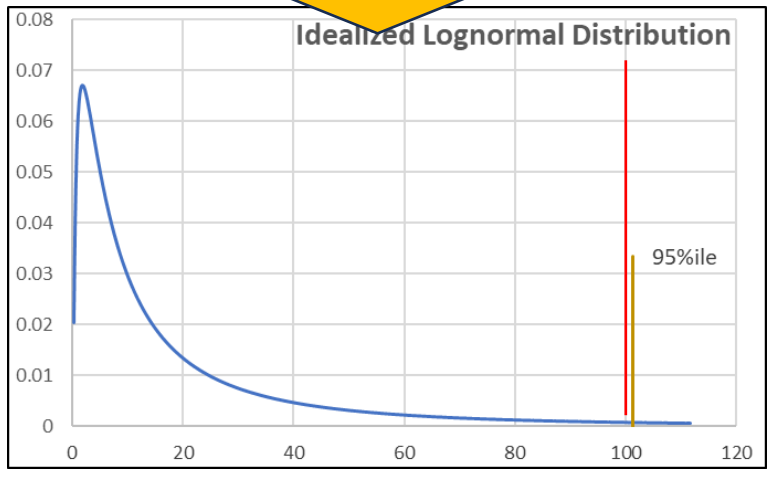


10 Worker SEG: 2500 Worker-days per year

"See" Only 0.2% of Exposures

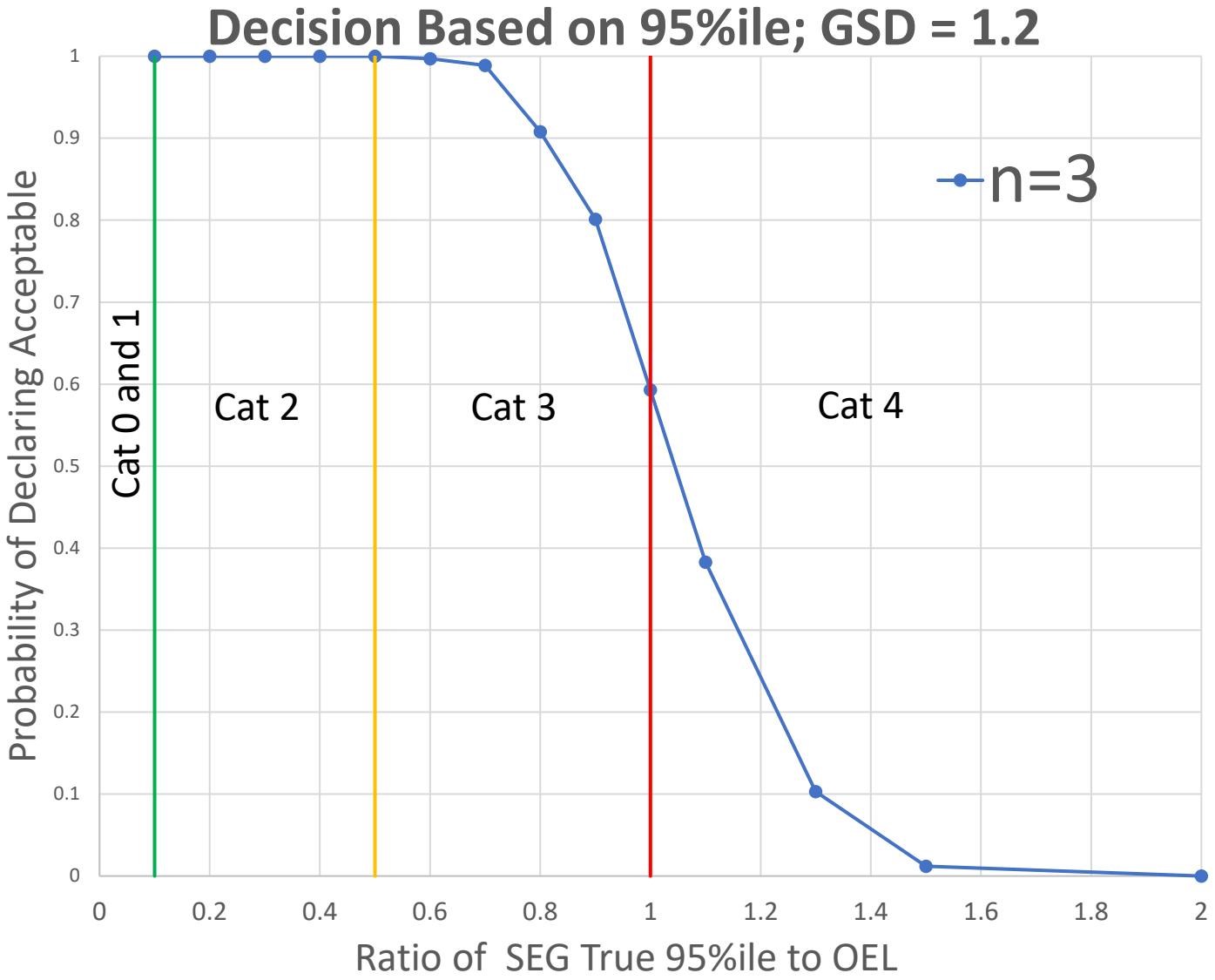






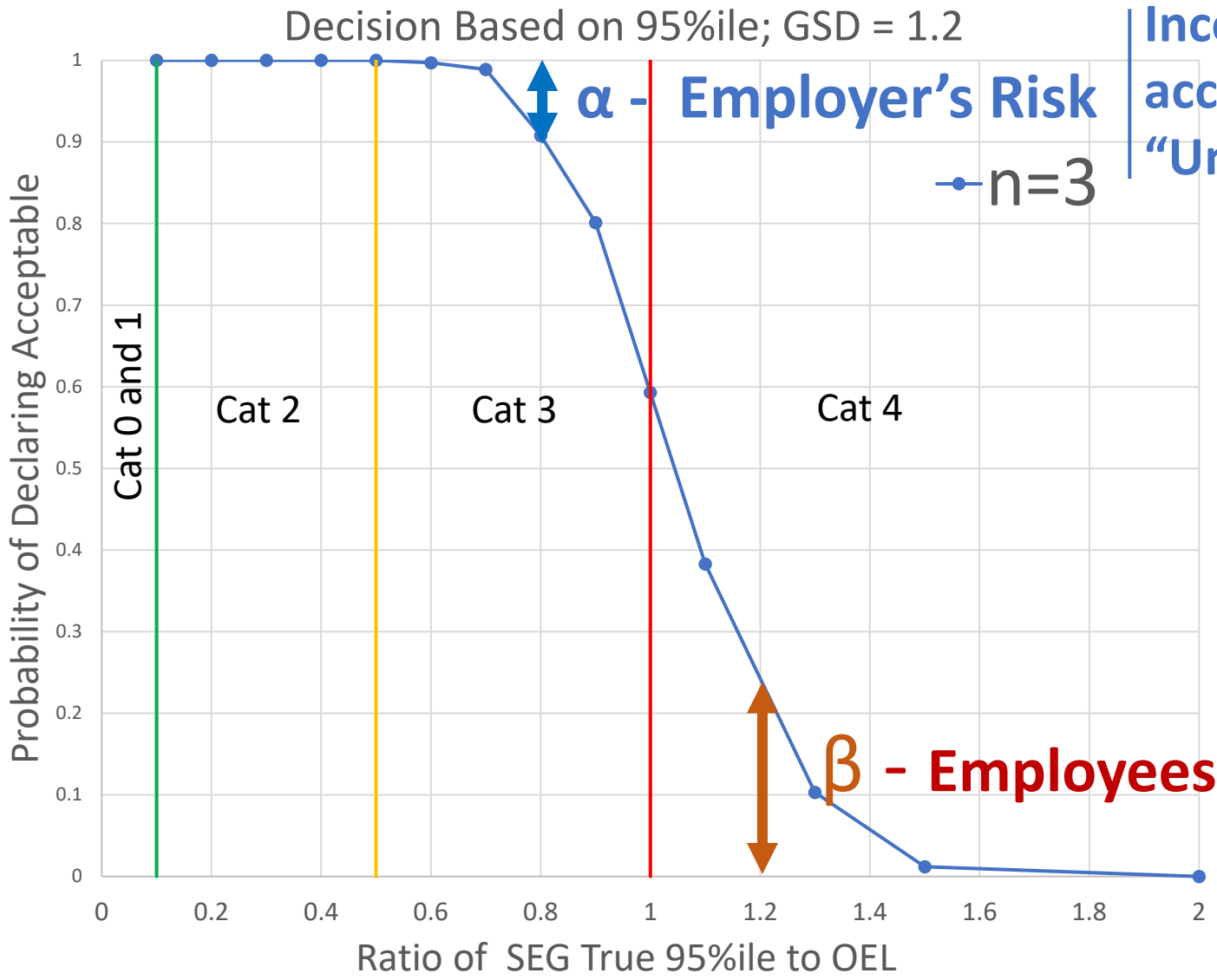
Another Way To Examine the Results:

Strategy Performance Charts



Another Way To Examine the Results:

Strategy Performance Charts

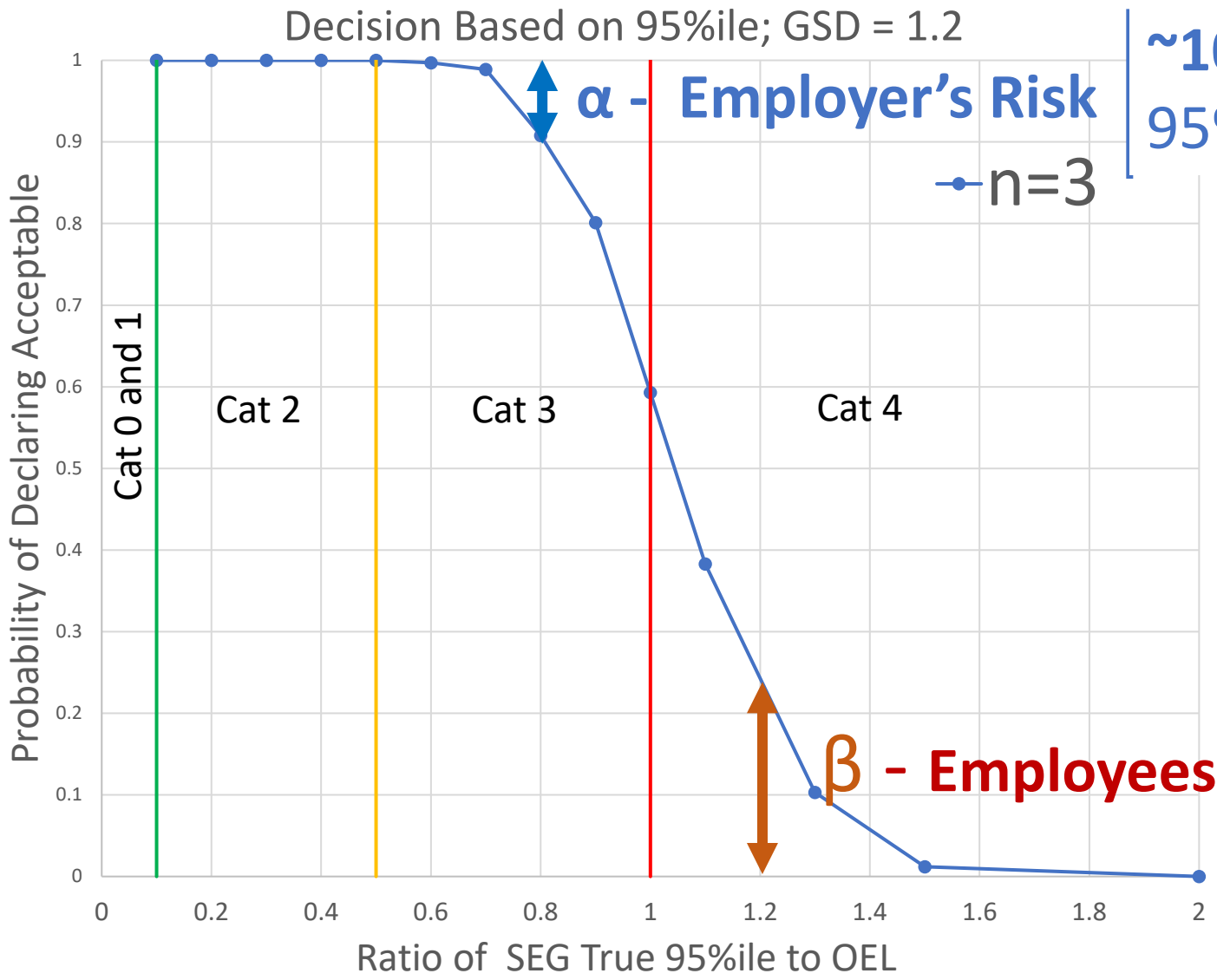


Incorrectly declaring an acceptable exposure "Unacceptable".

Incorrectly declaring an unacceptable exposure "Acceptable".

Another Way To Examine the Results:

Strategy Performance Charts

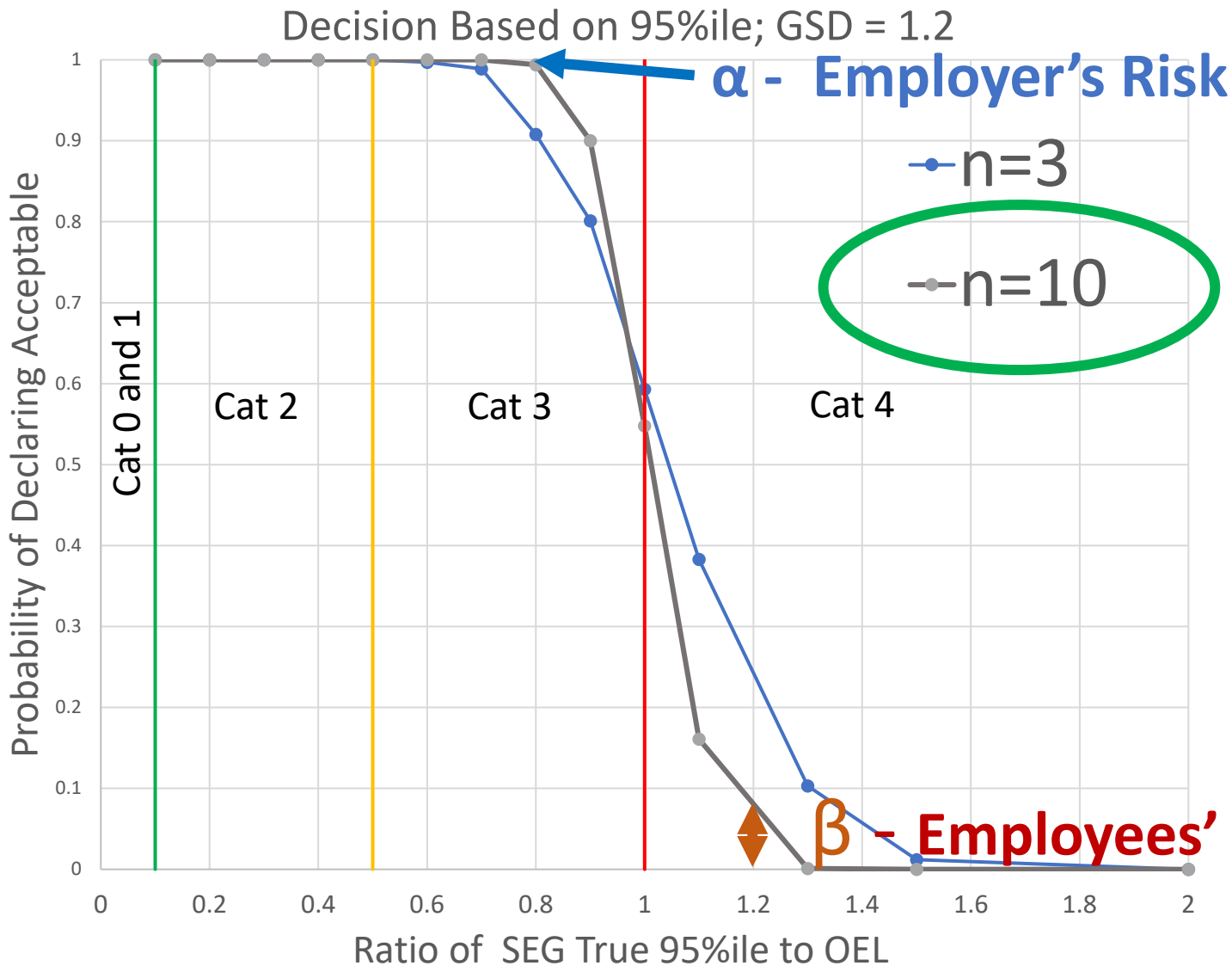


~10% When True
95%ile = 0.8 x OEL

~23% When True
95%ile = 1.2 x OEL

Another Way To Examine the Results:

Strategy Performance Charts



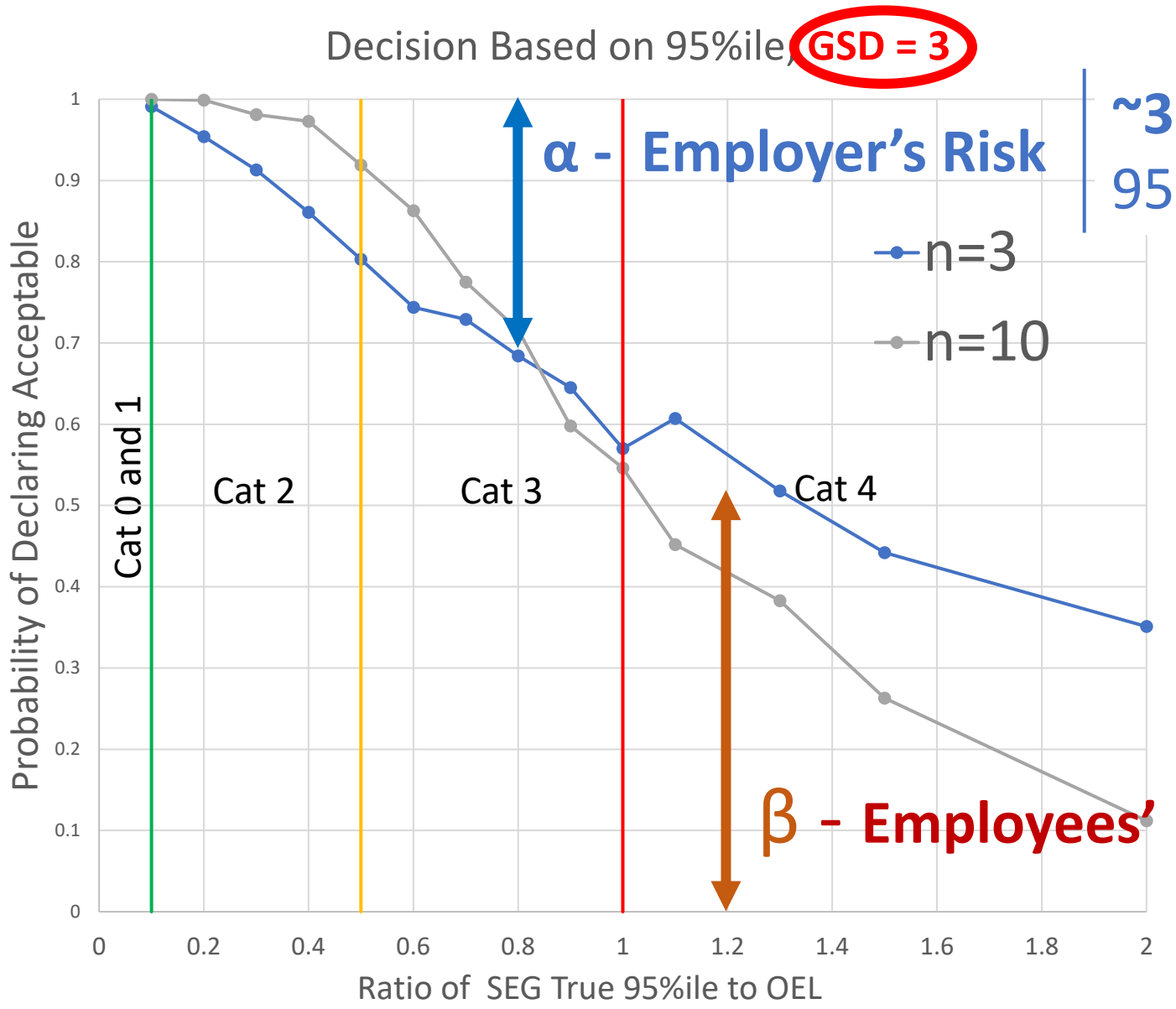
~1% When True
95%ile = 0.8 x OEL

Sampling More Often Reduces Likelihood of Incorrect Decisions

~8% When True
95%ile = 1.2 x OEL

Another Way To Examine the Results:

Strategy Performance Charts

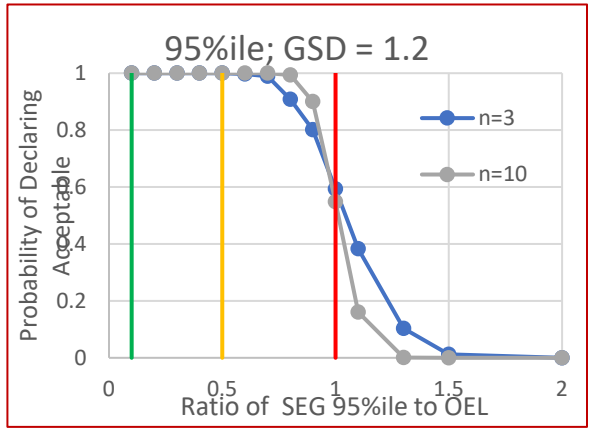
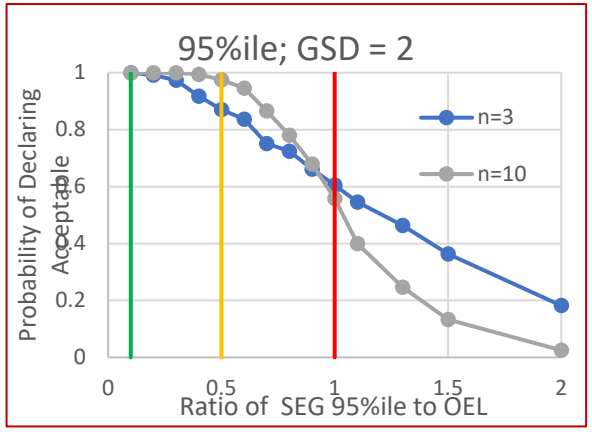
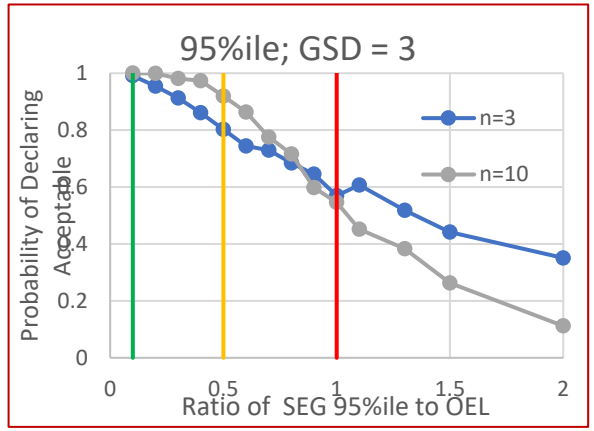
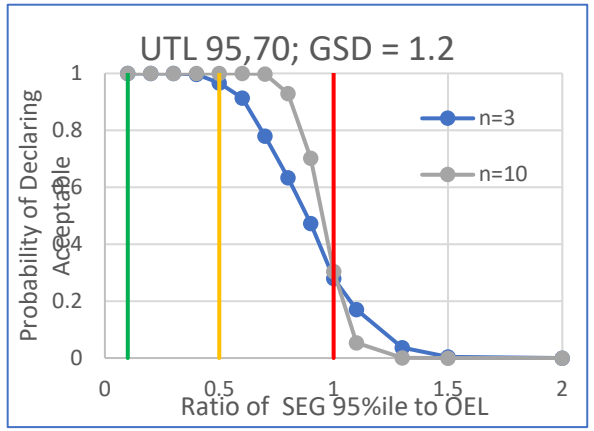
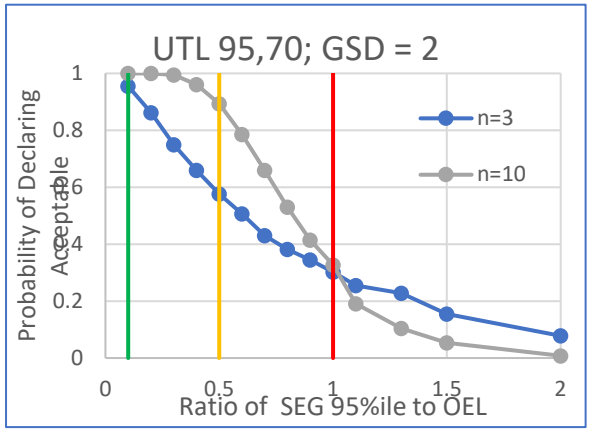
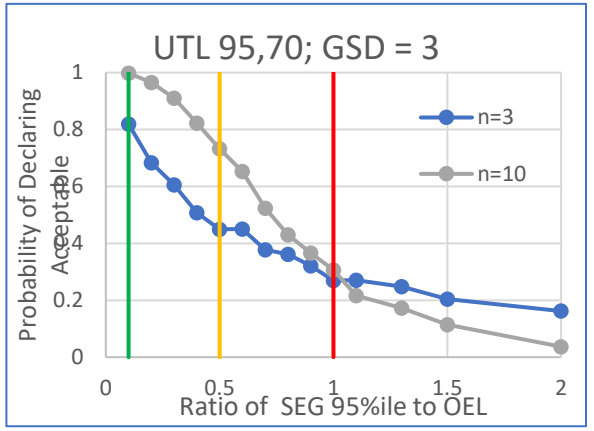
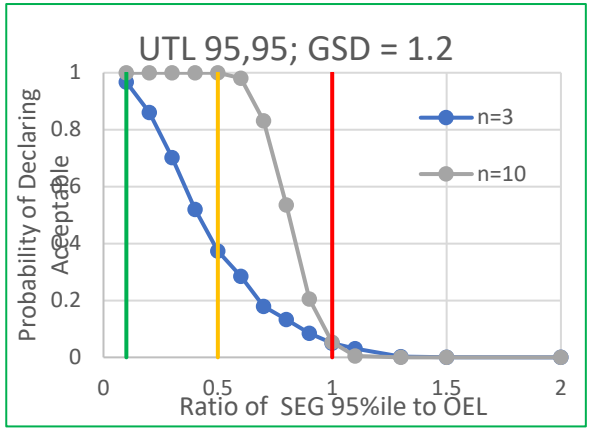
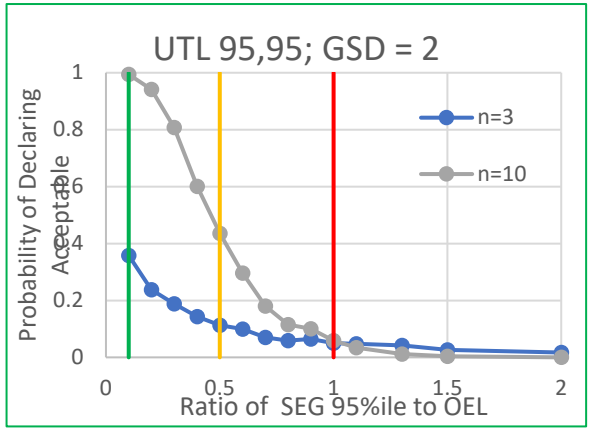
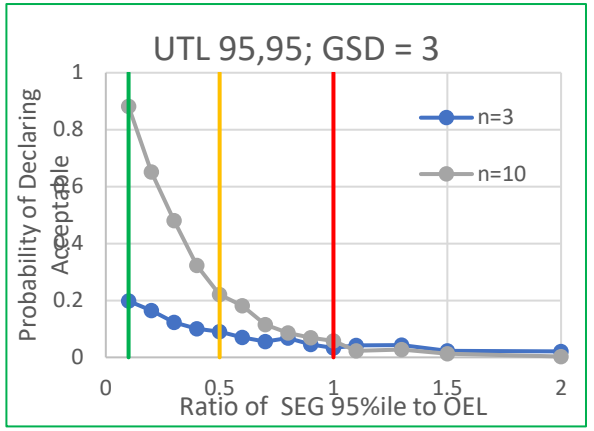


~30% When True
95%ile = 0.8 x OEL

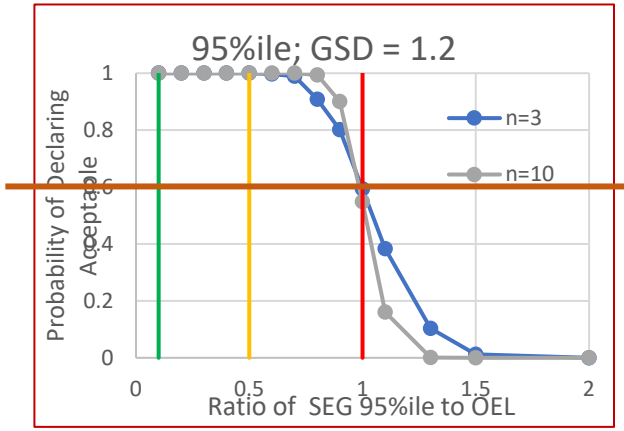
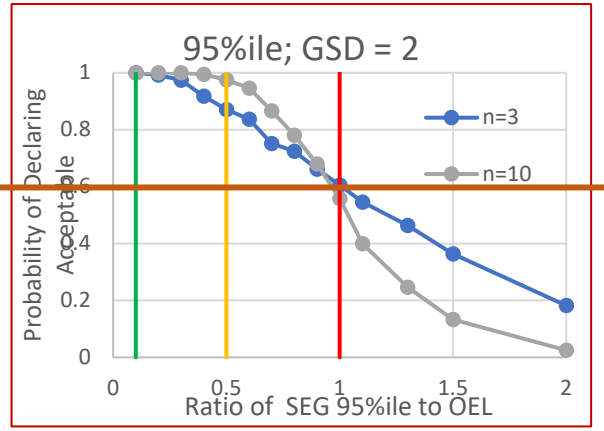
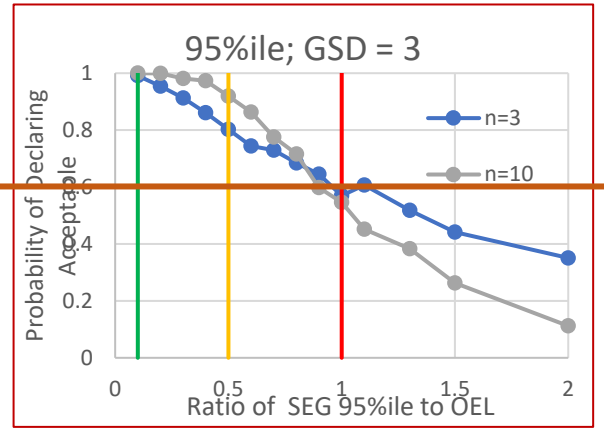
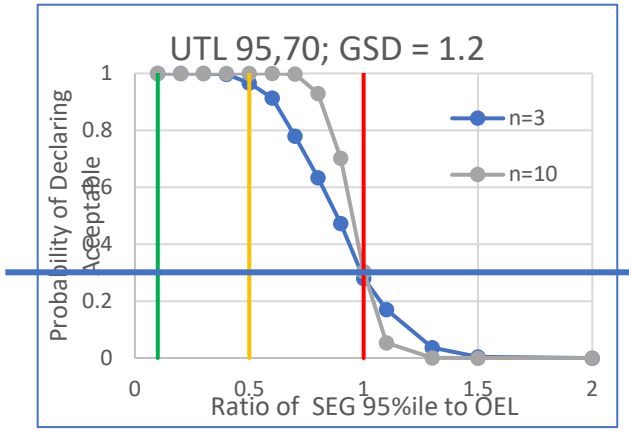
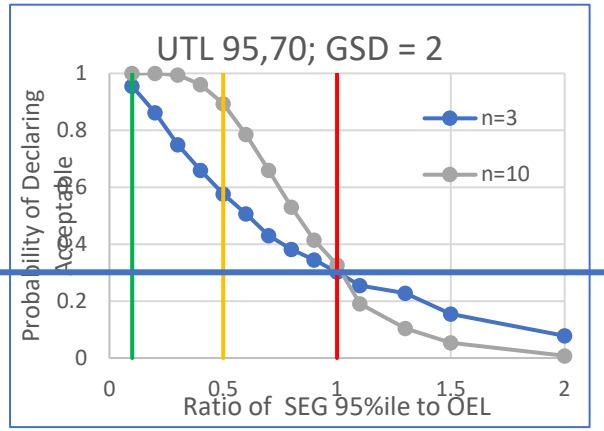
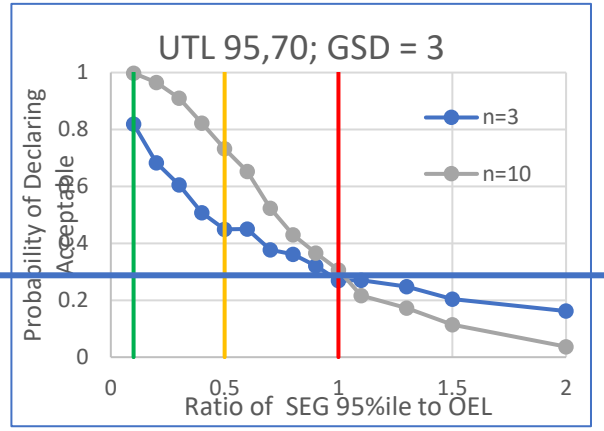
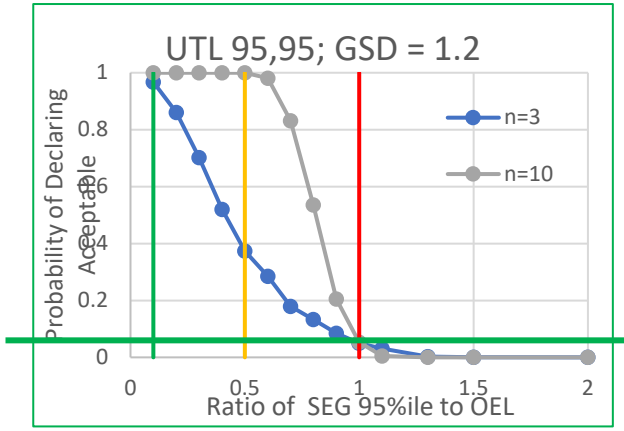
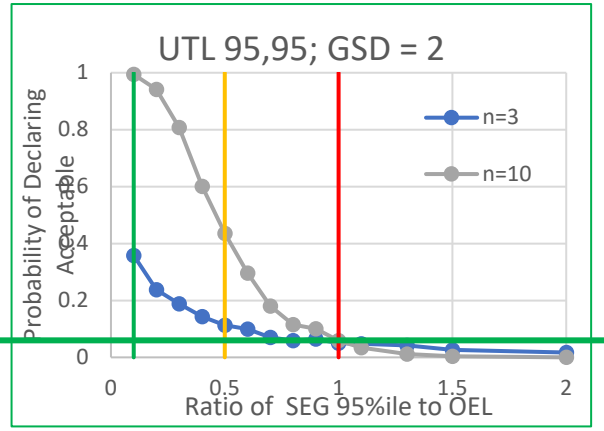
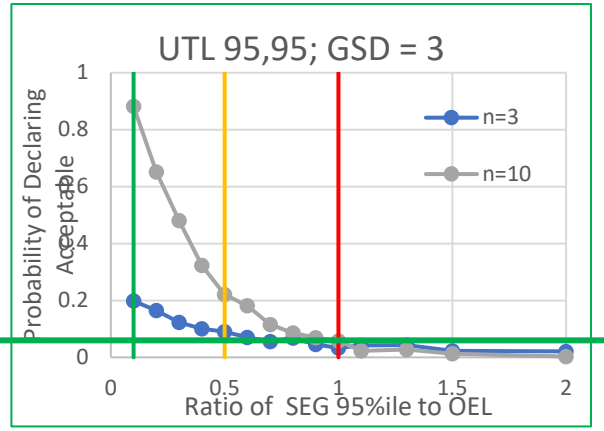
Higher Exposure Variability Increases Likelihood of Incorrect Decisions

~42% to 56% When True
95%ile = 1.2 x OEL

95%ile Upper Confidence Limits Limit Employees' Risk

	GSD = 1.2	GSD = 2	GSD = 3
95%ile Best Estimate			
$UCL_{95,70}$ 70% Confidence			
$UCL_{95,95}$ 95% Confidence			

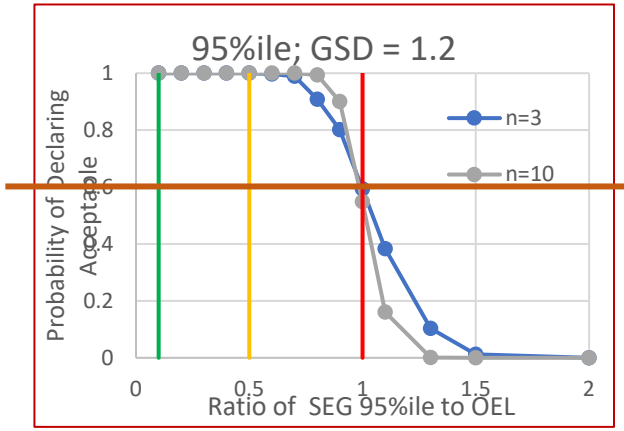
95%ile Upper Confidence Limits Limit Employees' Risk

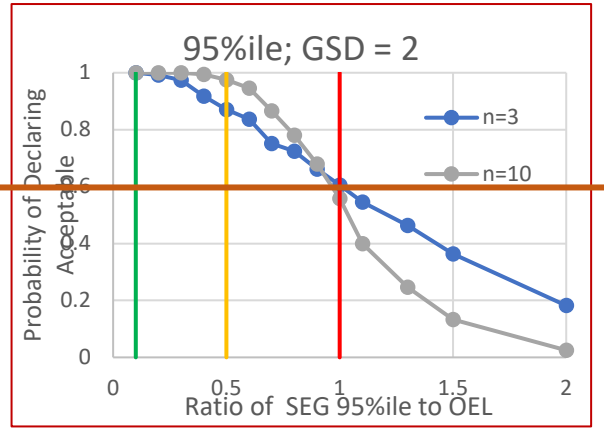
	GSD = 1.2	GSD = 2	GSD = 3
95%ile Best Estimate **Max Employees' Risk = ~60%**			
$UCL_{95,70}$ 70% Confidence **Max Employees' Risk = 30%**			
$UCL_{95,95}$ 95% Confidence **Max Employees' Risk = 5%**			

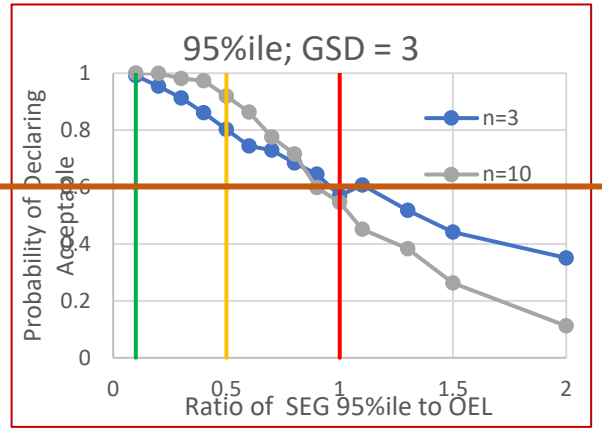
GSD = 1.2 | GSD = 2 | GSD = 3

Decreasing Employees' Risk

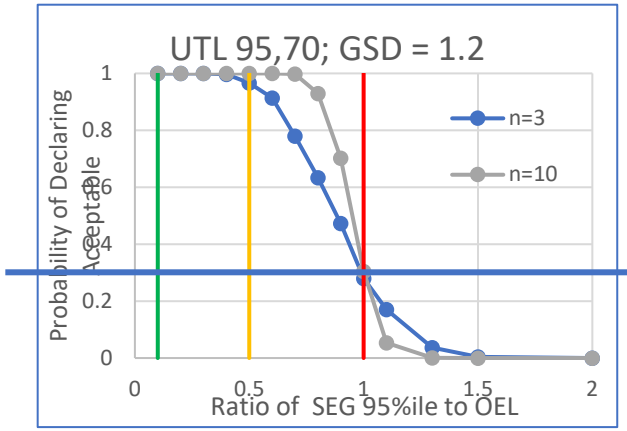
95%ile
Best Estimate
Max Employees' Risk = ~60%

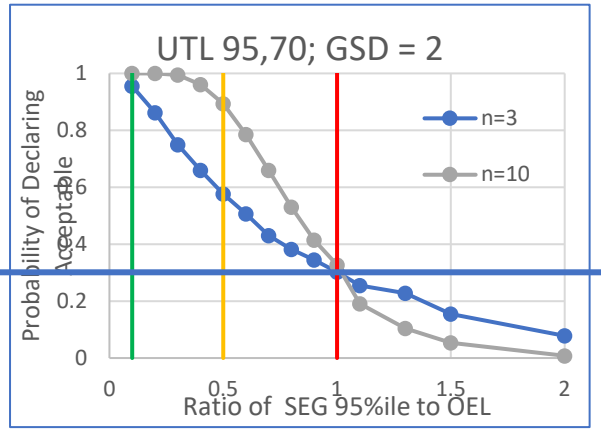


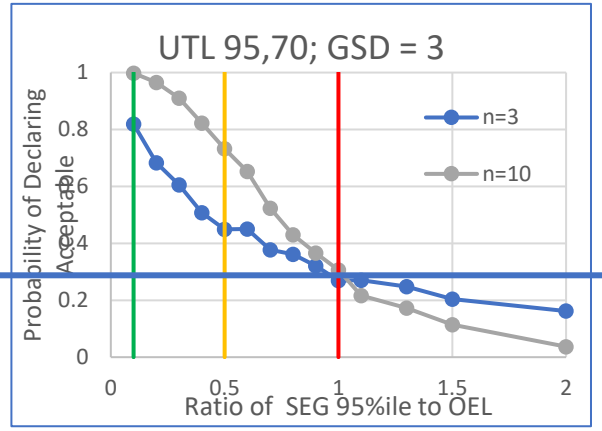




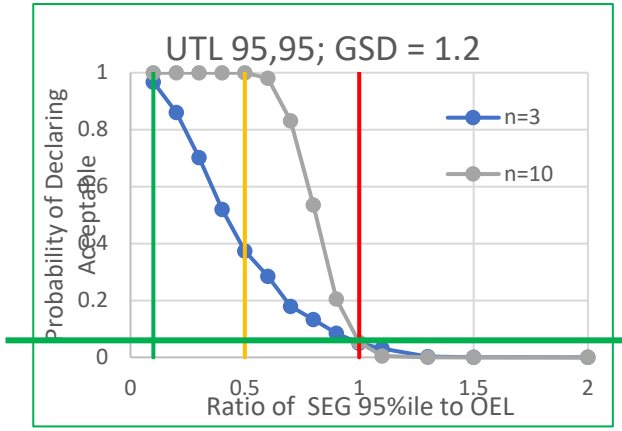
$UCL_{95,70}$
70% Confidence
Max Employees' Risk = 30%

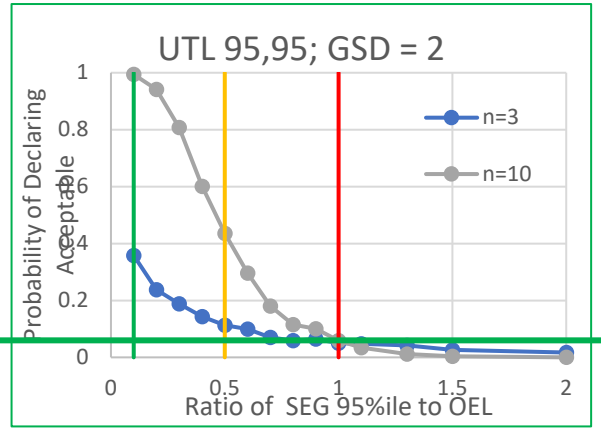


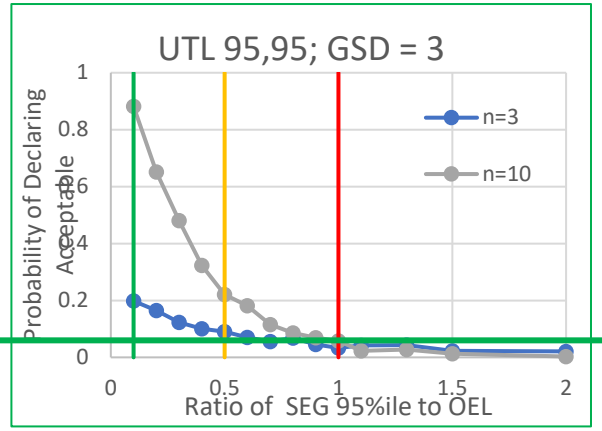


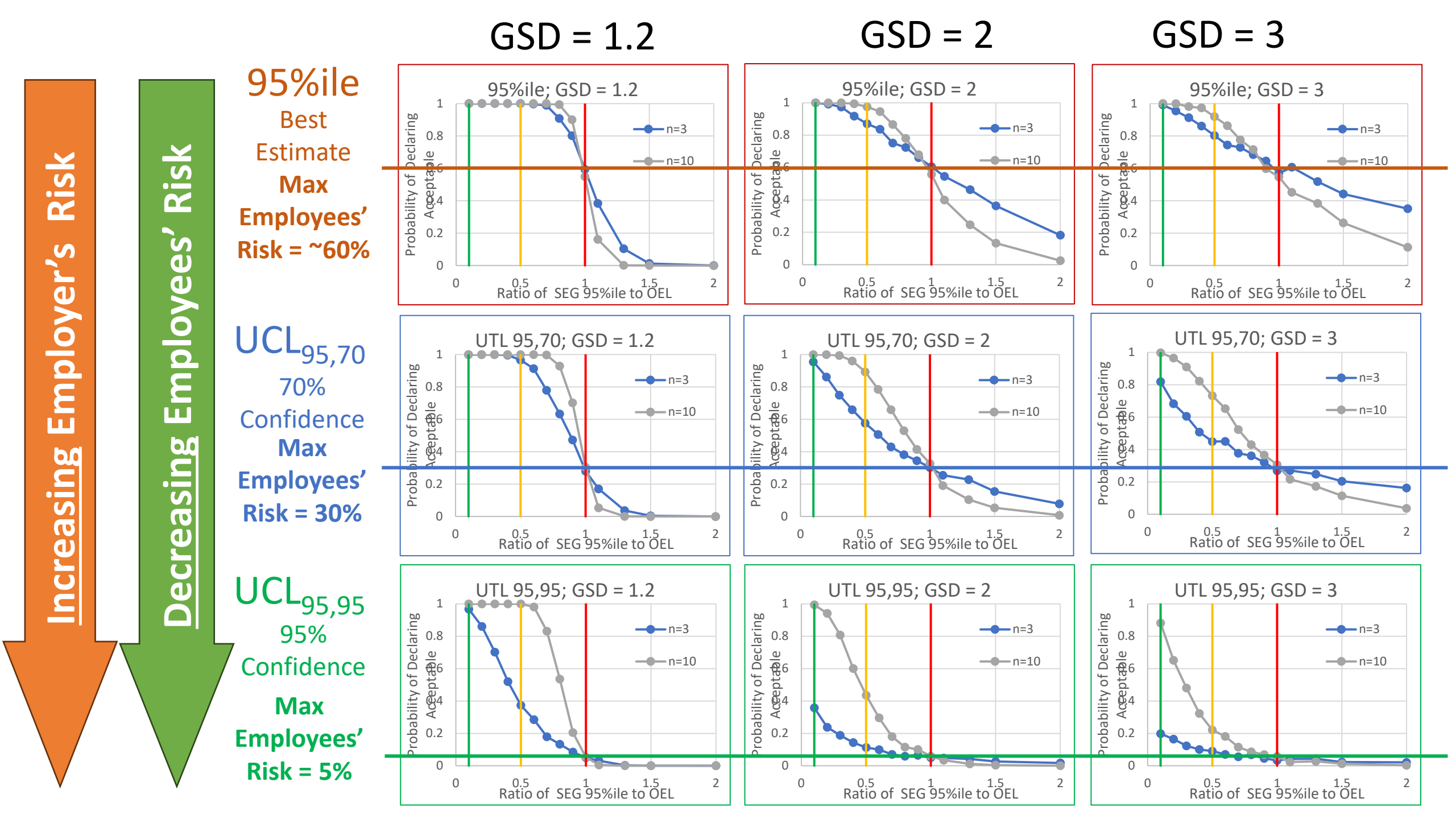


$UCL_{95,95}$
95% Confidence
Max Employees' Risk = 5%








GSD = 1.2
GSD = 2
GSD = 3
Increasing Employer's Risk
Decreasing Employees' Risk
95%ile
Best Estimate
Max Employees' Risk = ~60%
UCL95,70
70% Confidence
Max Employees' Risk = 30%
UCL95,95
95% Confidence
Max Employees' Risk = 5%
95%ile; GSD = 1.2
95%ile; GSD = 2
95%ile; GSD = 3
UTL 95,70; GSD = 1.2
UTL 95,70; GSD = 2
UTL 95,70; GSD = 3
UTL 95,95; GSD = 1.2
UTL 95,95; GSD = 2
UTL 95,95; GSD = 3
Probability of Declaring Acceptable
Ratio of SEG 95%ile to OEL
n=3
n=10

Balancing 70% Certainty and 95% Certainty Acceptability Rules of Thumb:

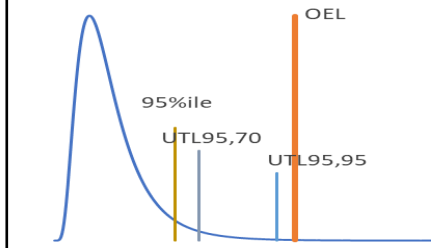
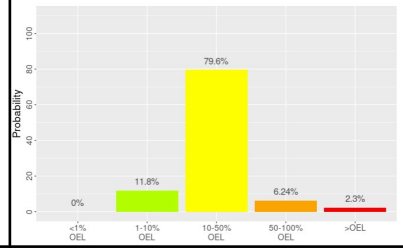
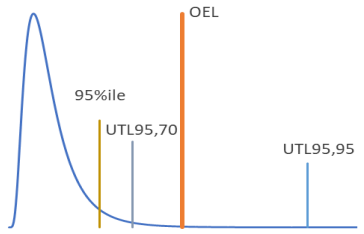
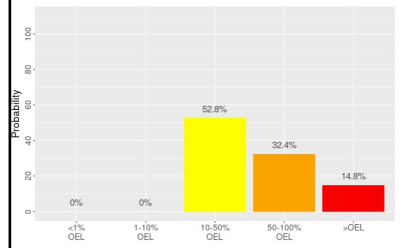
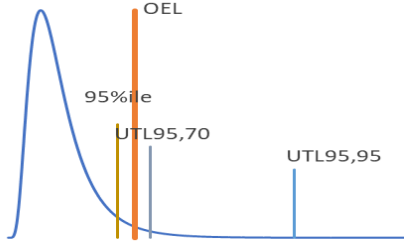
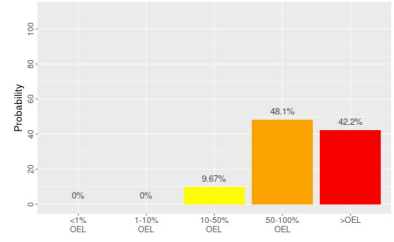
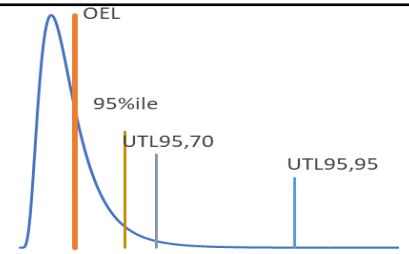
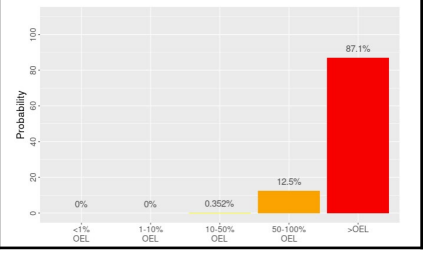
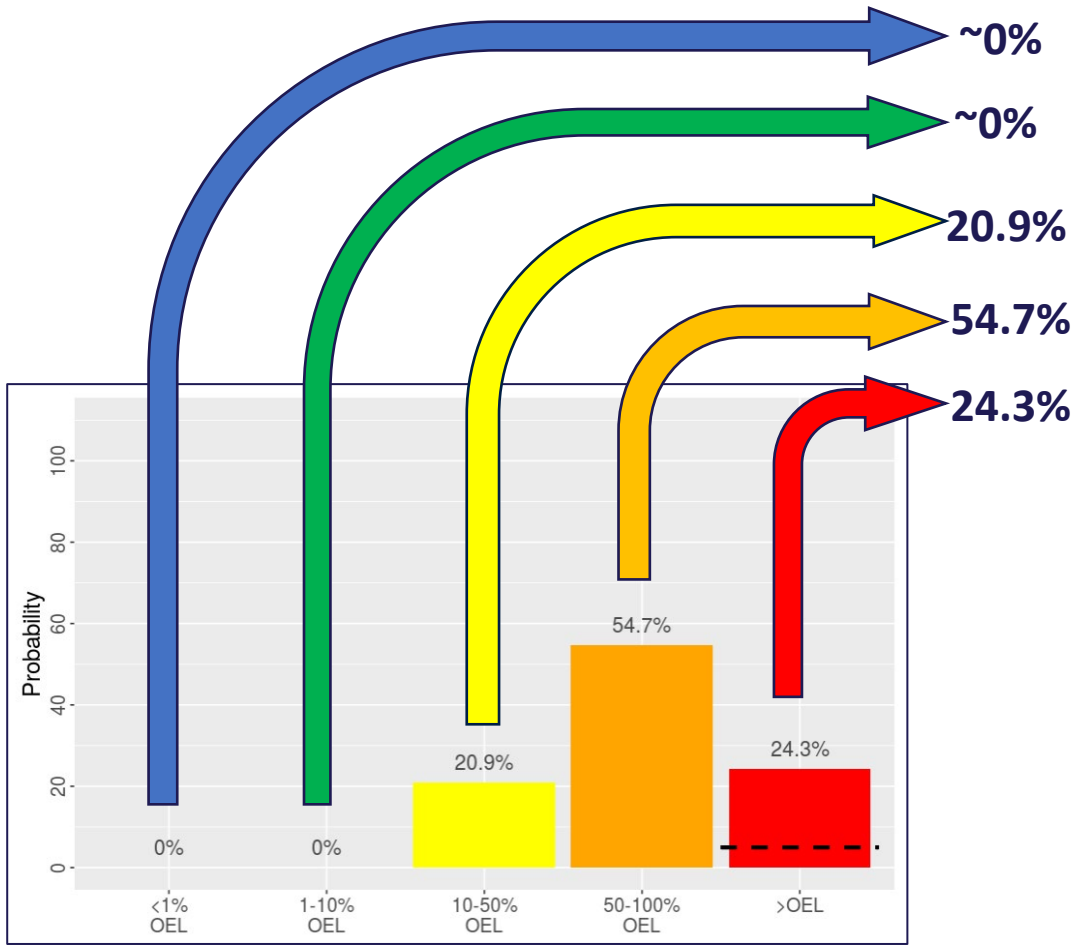
	Description	Traditional Stats Criteria	Traditional Stats Example	Bayesian Stats Criteria	Bayesian Stats Example
Acceptable	At least 95% confident that the 95%ile is less than the OEL	$UTL_{95,95}$ < OEL Note: UTL = UCL		Category 4 Likelihood < 0.05	
Tolerable* ***Assuming the SEG has a required monitoring plan**	Between 70% and 95% confident that the 95%ile is less than the OEL*	$UTL_{95,70}$ < OEL and $UTL_{95,95}$ > OEL Note: UTL = UCL		Category 4 Likelihood between 0.05 and 0.3	
Problematic	95%ile Estimate is less than the OEL but with less than 70% confidence	95%ile < OEL and $UTL_{95,70}$ > OEL Note: UTL = UCL		Category 4 is not the most likely category but its likelihood is > 0.3	
Unacceptable	95%ile Estimate is greater than the OEL	95%ile > OEL		Category 4 is the most likely category	

Table based on guidance in free [“Making Accurate Exposure Risk Decisions”] webinar.

BAYESIAN DECISION ANALYSIS (BDA):

ESTIMATES THE PROBABILITY THAT EXPOSURE PROFILE 95%ILE FALLS INTO A PARTICULAR AIHA CATEGORY



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

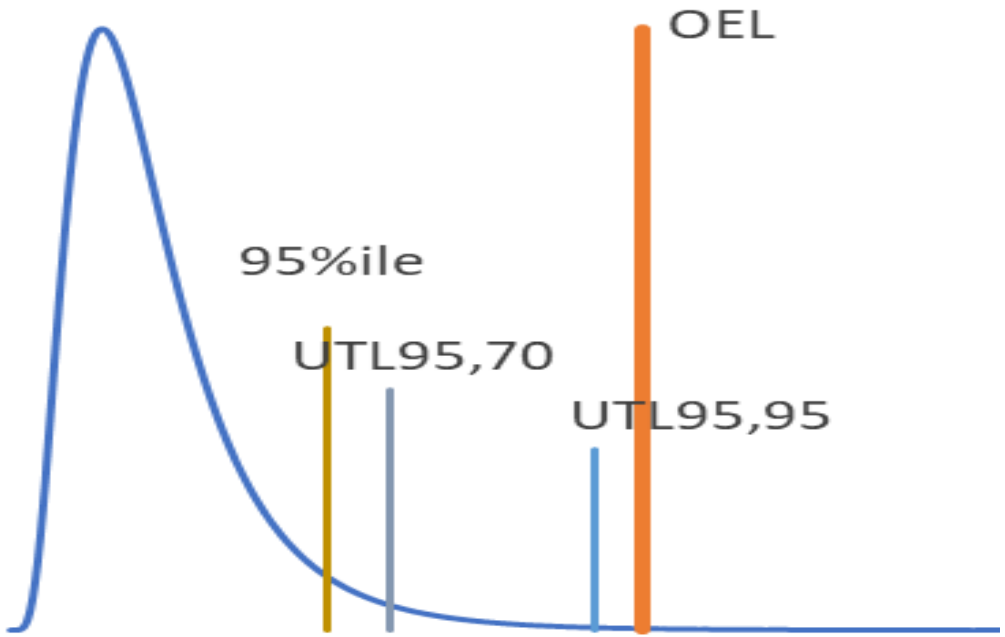
Acceptability Rules of Thumb: Likelihood of Category 4 (95%ile > OEL)

Acceptable

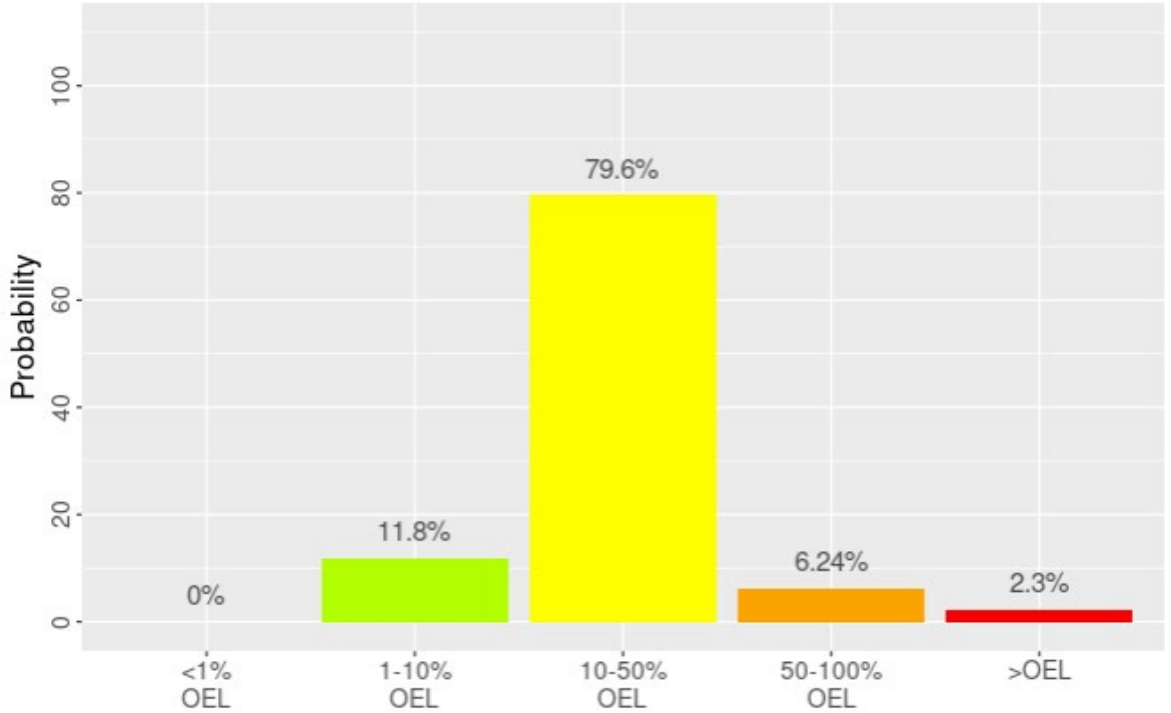
At least 95% confident that the 95%ile is less than the OEL

$UTL_{95,95}$ < OEL

Note: UTL = UCL



Category 4 (>OEL) Likelihood < 5%



Based on guidance in free "Making Accurate Exposure Risk Decisions" webinar.

Acceptability Rules of Thumb: Likelihood of Category 4 (95%ile > OEL)

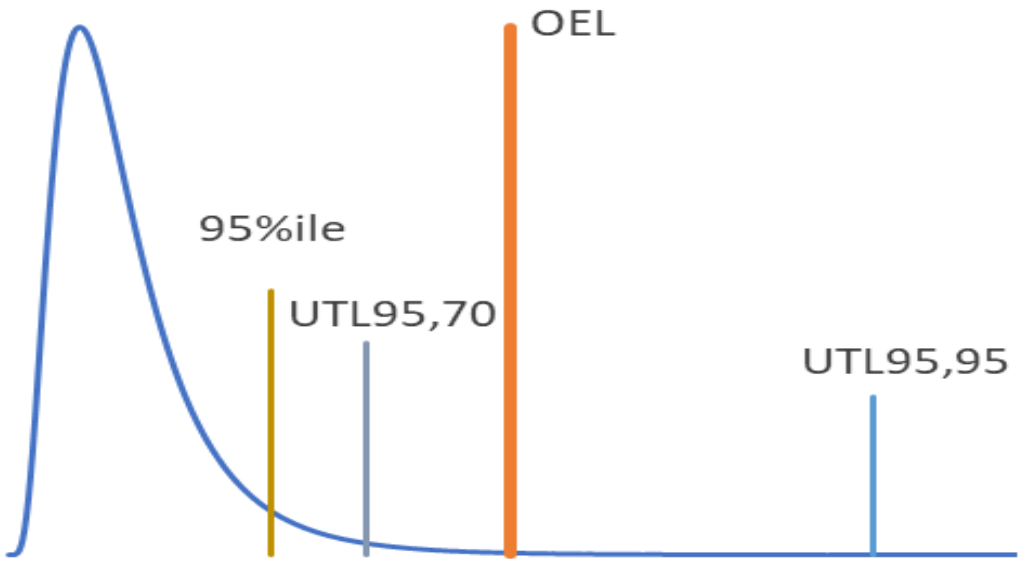
Tolerable*

***Assuming the SEG has a required monitoring plan**

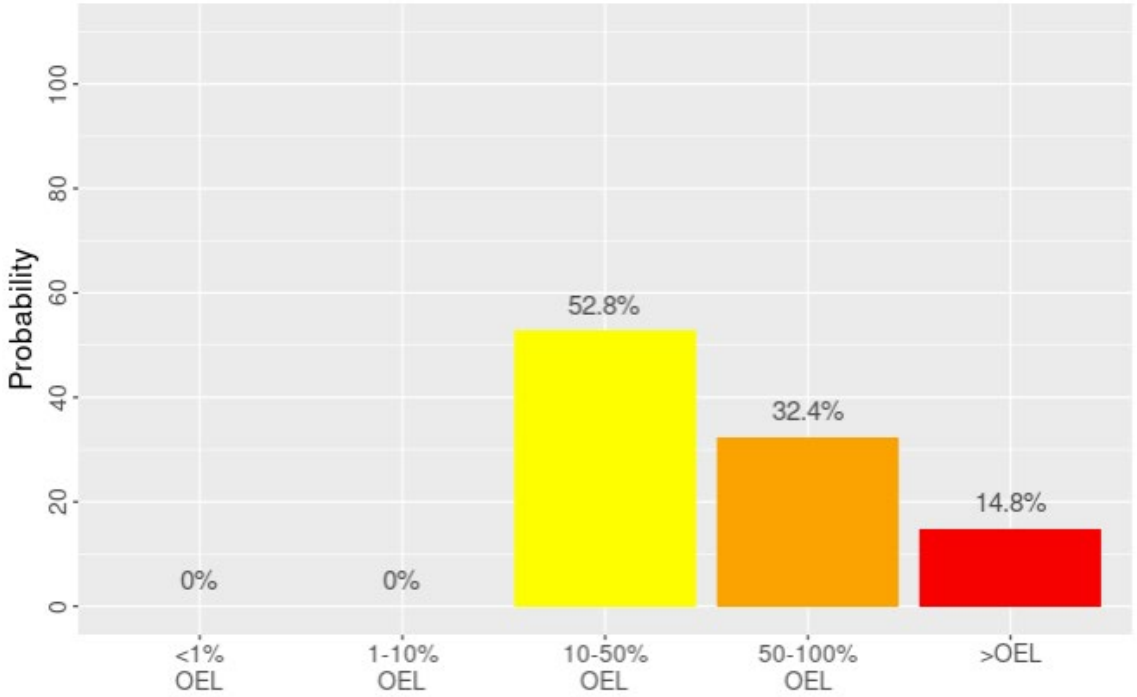
Between 70% and 95% confident that the 95%ile is less than the OEL*

$UTL_{95,70}$ < OEL and $UTL_{95,95}$ > OEL

Note: UTL = UCL



Category 4 (>OEL) Likelihood between 5% and 30%



Based on guidance in free "Making Accurate Exposure Risk Decisions" webinar.

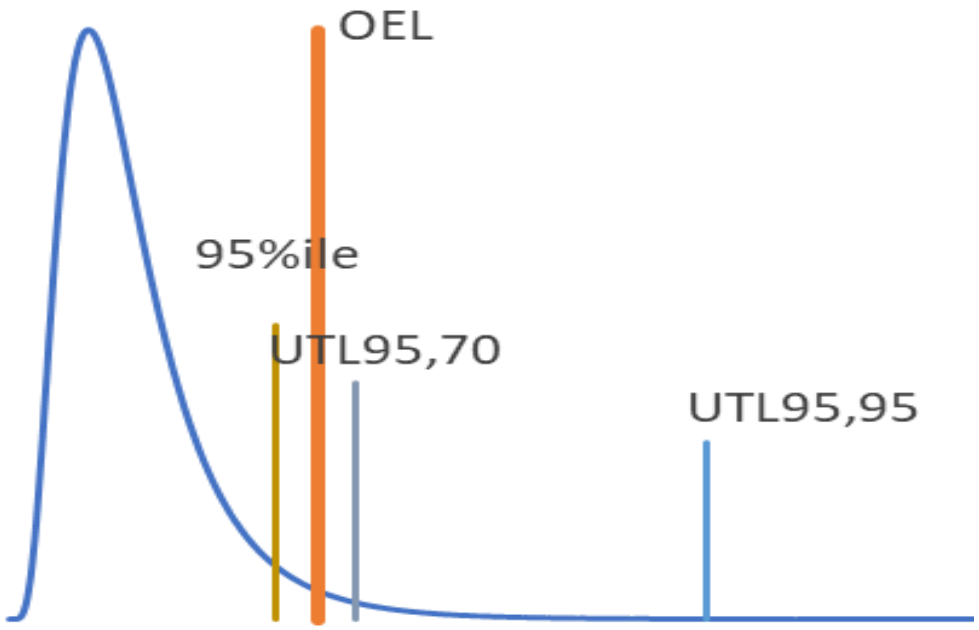
Acceptability Rules of Thumb: Likelihood of Category 4 (95%ile > OEL)

Problematic

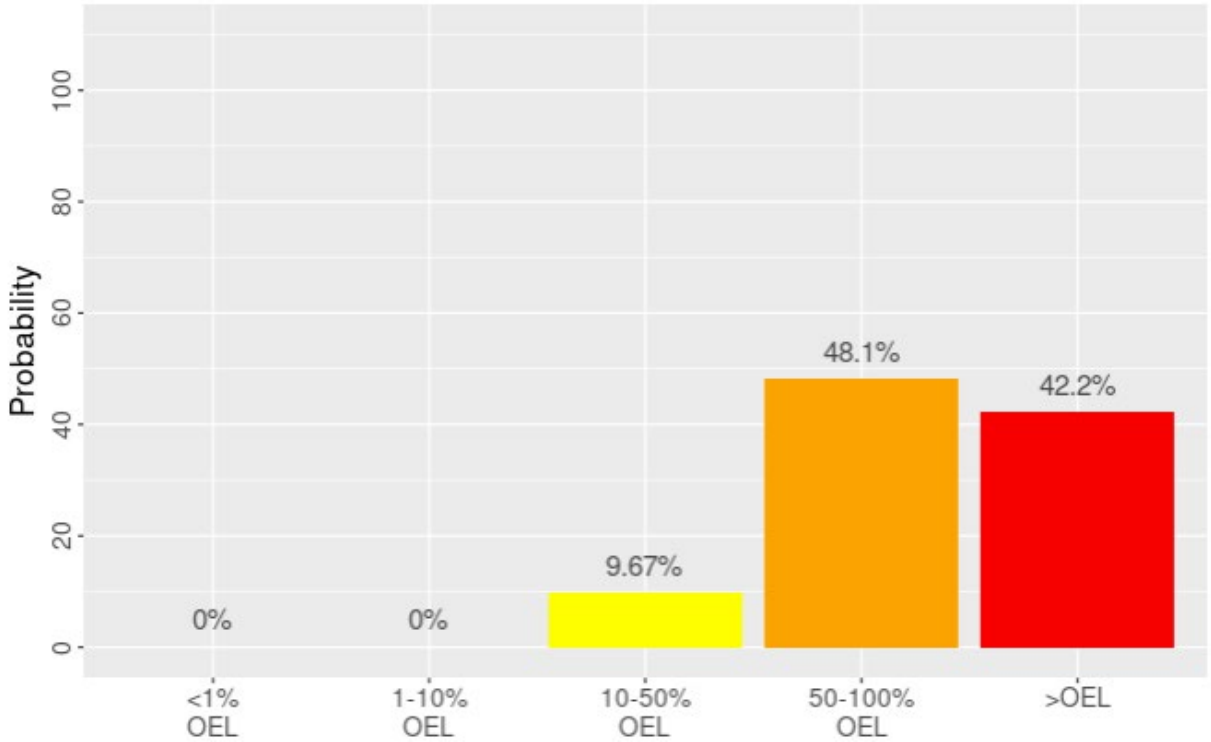
95%ile Estimate is less than the OEL but with less than 70% confidence

95%ile < OEL and $UTL_{95,70}$ > OEL

Note: UTL = UCL



Category 4 (>OEL) is not the most likely category but its likelihood is > 30%



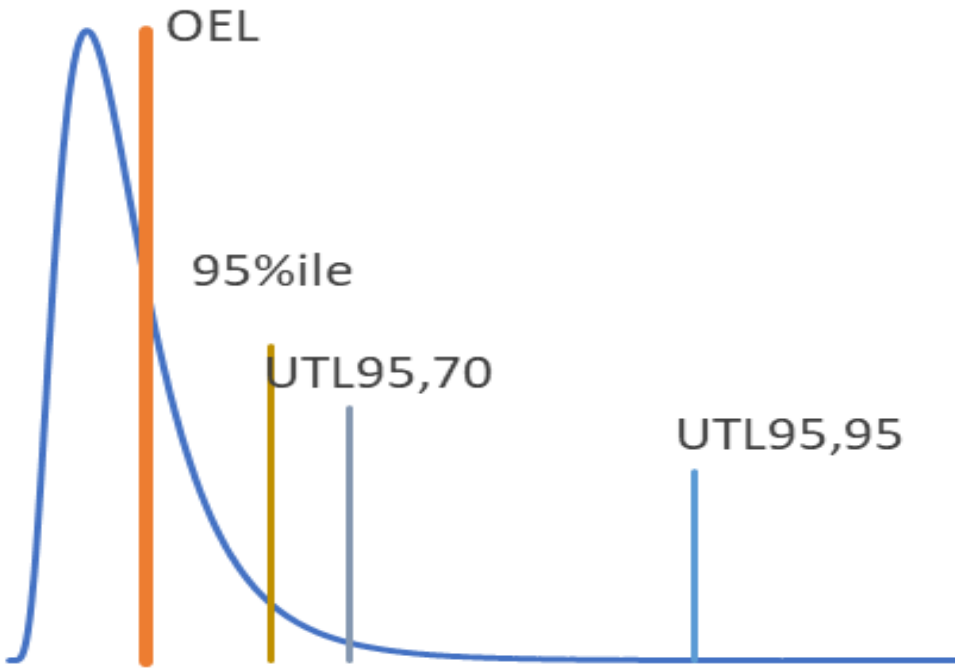
Based on guidance in free "Making Accurate Exposure Risk Decisions" webinar.

Acceptability Rules of Thumb: Likelihood of Category 4 (95%ile > OEL)

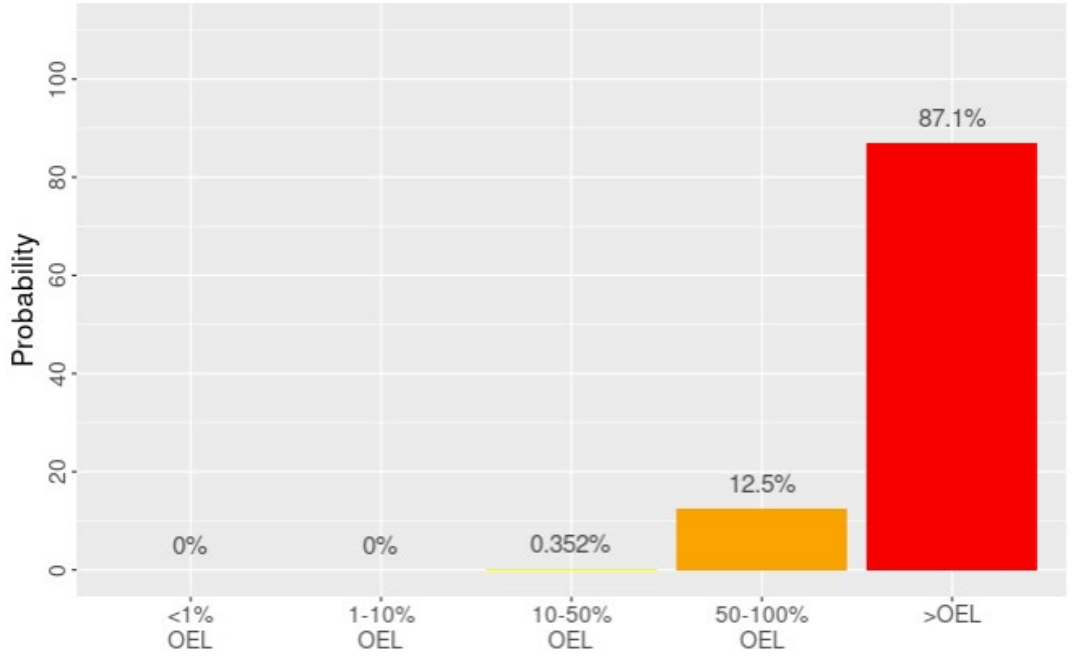
Unacceptable

95%ile Estimate is greater than the OEL

95%ile > OEL



Category 4 (>OEL) is the most likely category

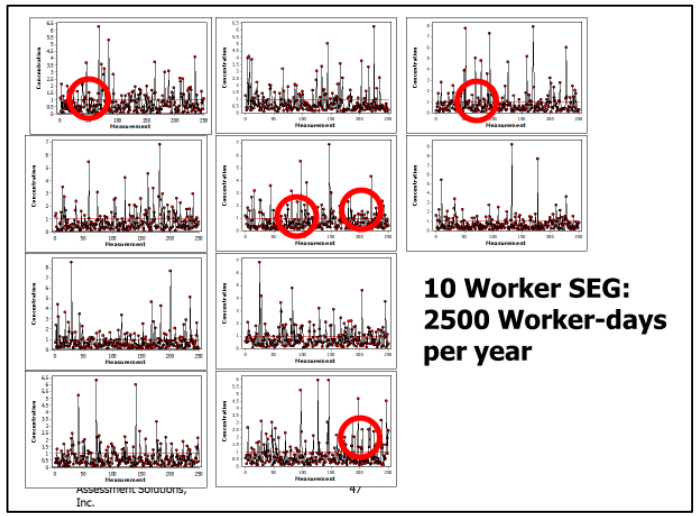


Based on guidance in free "Making Accurate Exposure Risk Decisions" webinar.

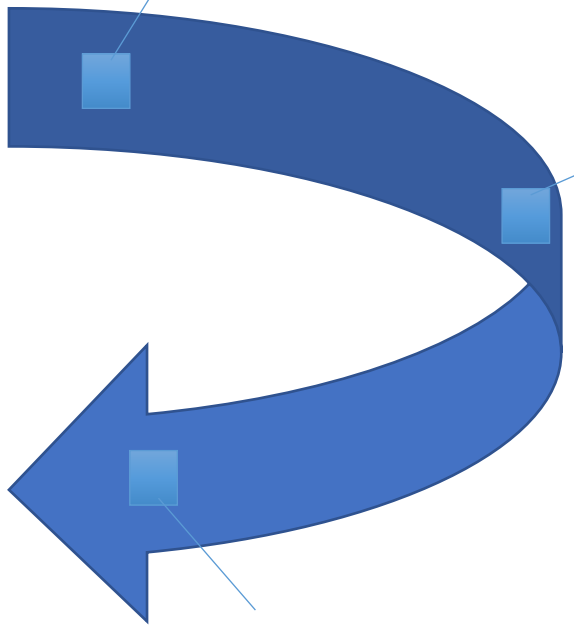
Improving Exposure Judgment

Accurate Exposure Risk Decisions: When We Have Monitoring Data

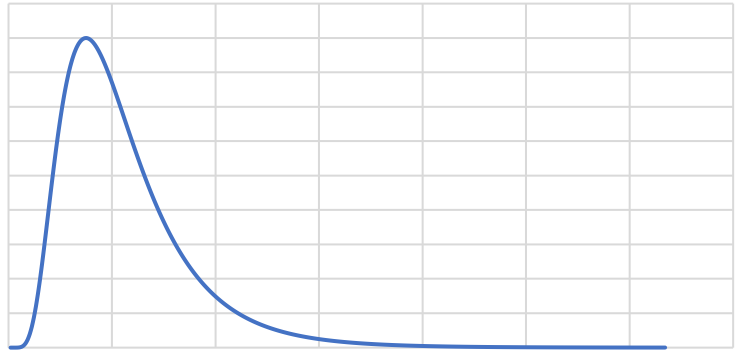
Solution: Inferential Statistics . . . .



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



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



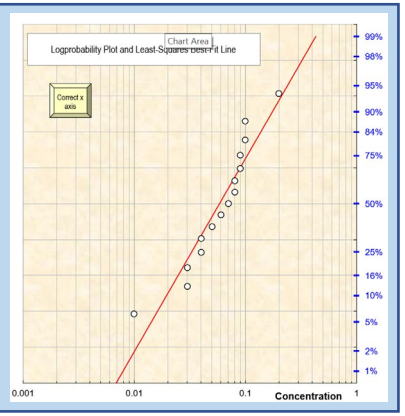
The Actual Population Exposure Profile (SEG of 10 Workers)

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

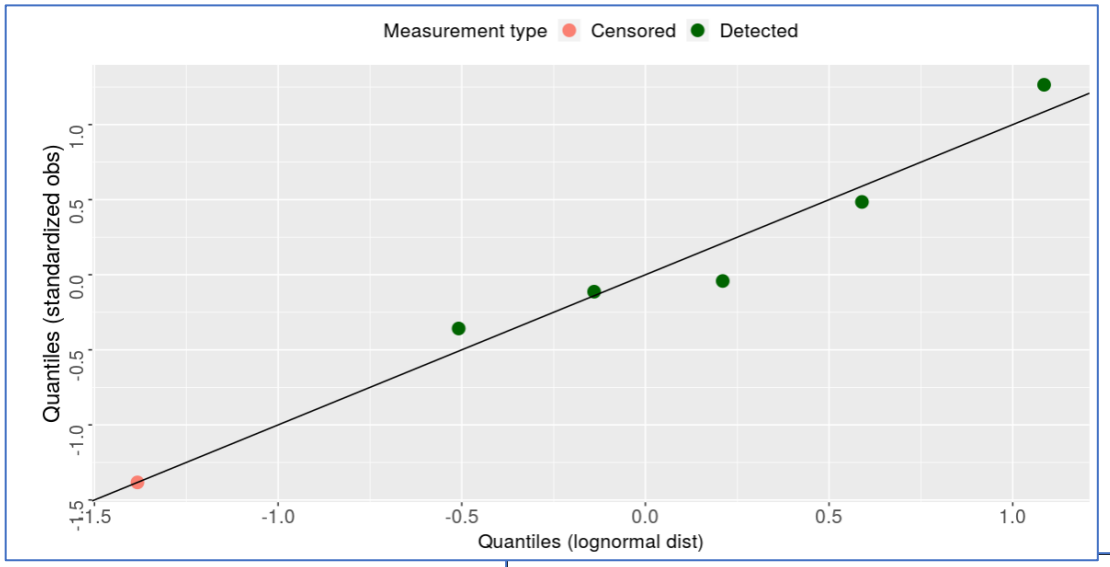


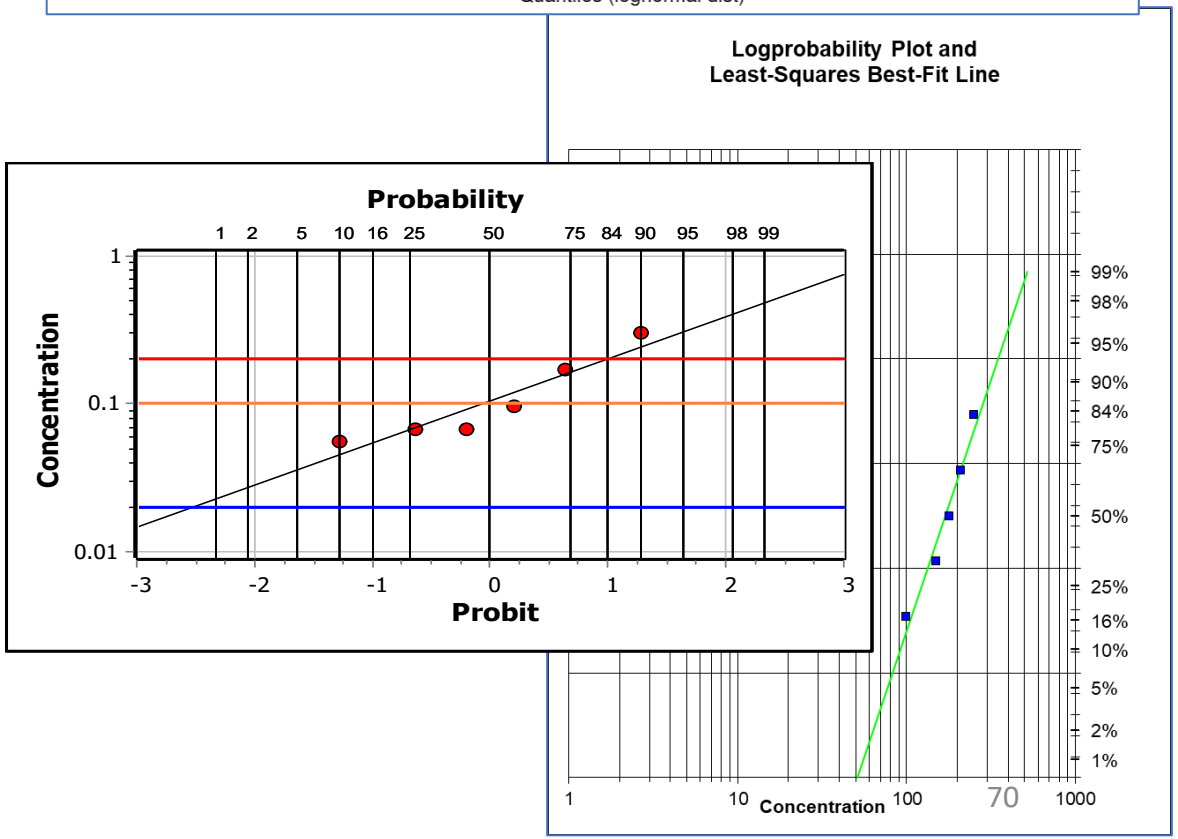
"All models are wrong, some are useful"

- George E. P. Box

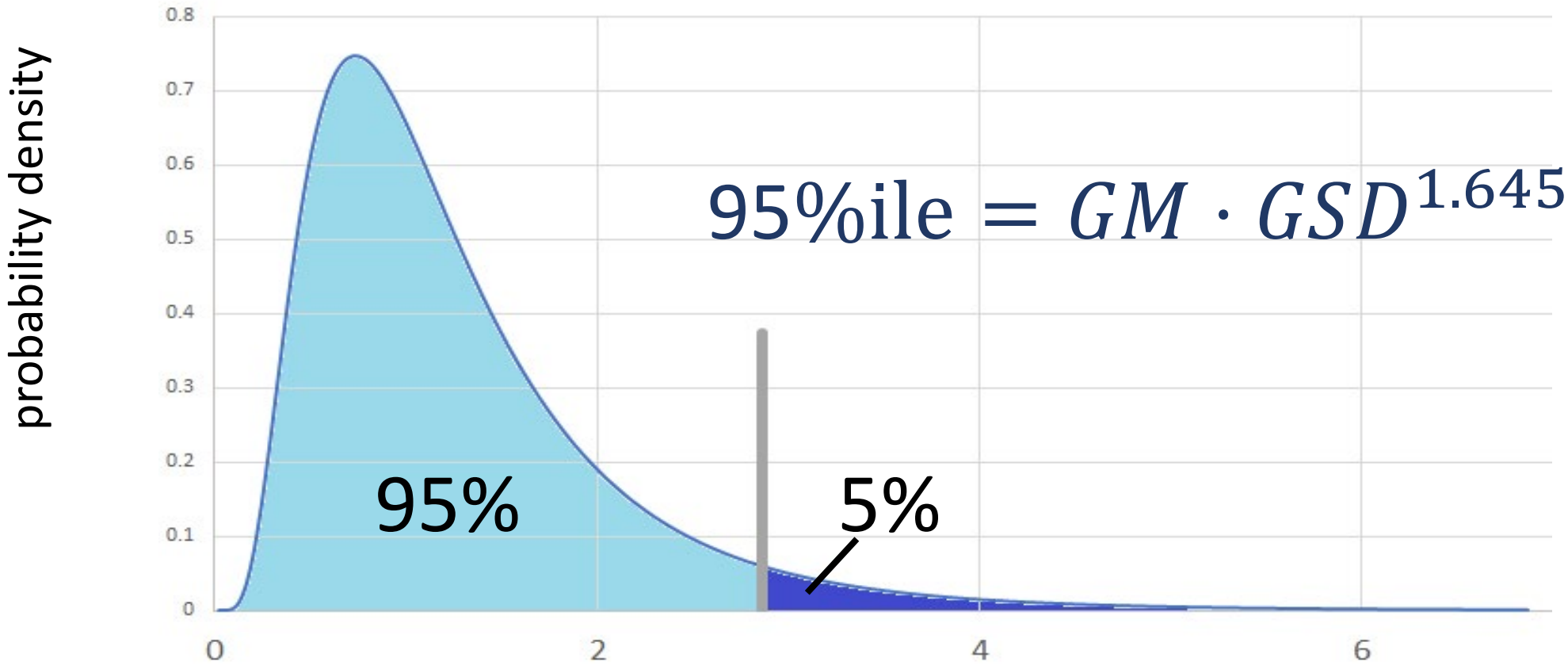
Always Check the Lognormal Assumption

- Check your monitoring data for reasonable lognormal distribution fit before detailed analysis.
- If data is not lognormal go back and verify SEG is constructed well.
  - Challenge your SEG assumptions
  - Are jobs/tasks truly similar?
  - Should SEG be broken down to smaller levels?
  - Does the data have errors?
  - Etc.





95%ile


probability density
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
95%
5%
95%ile = $GM \cdot GSD^{1.645}$

Characterizing 95%ile Uncertainty:

Upper Confidence Limit (UCL) for the 95th Percentile

[Same as 95%ile Upper Tolerance Limit (UTL)]

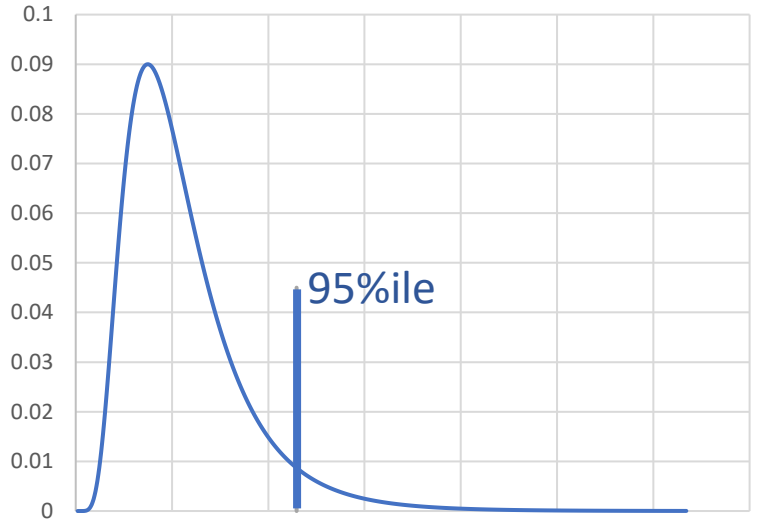
Concept

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

Interpretation

- If the $UCL_{95\%,95\%}$ 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)



Characterizing Uncertainty:

Upper Confidence Limit (UCL) for the 95th Percentile

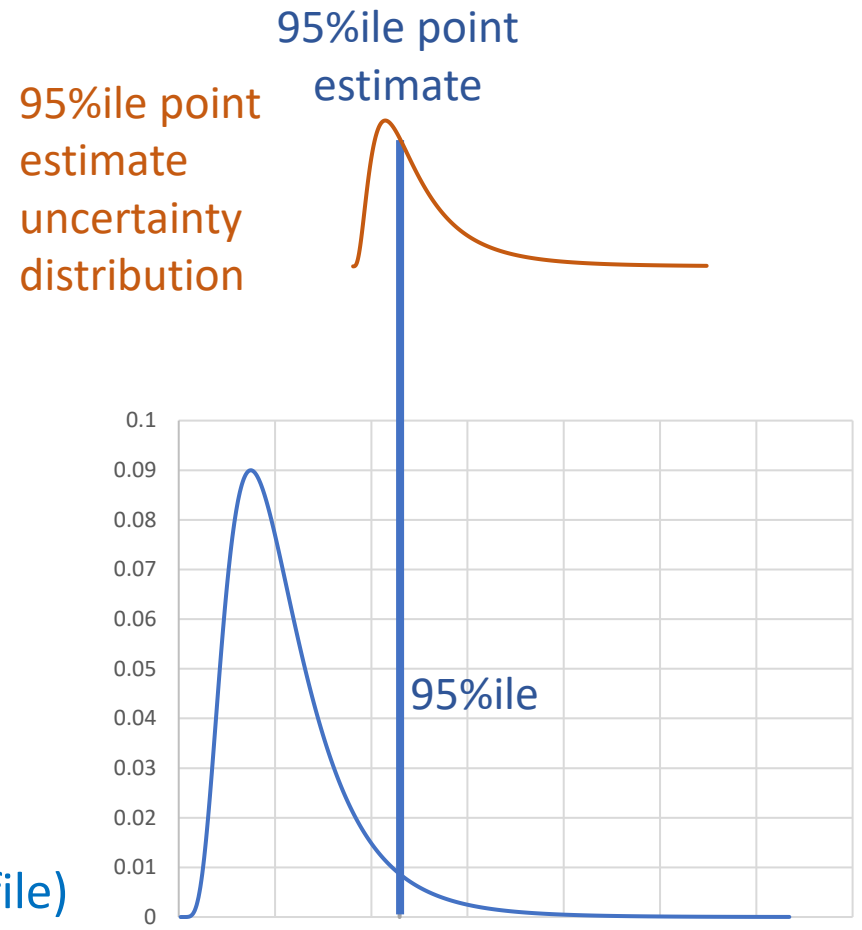
[Same as 95%ile Upper Tolerance Limit (UTL)]

Concept

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

Interpretation

- If the $UCL_{95\%,95\%}$ 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



Characterizing Uncertainty:

Upper Confidence Limit (UCL) for the 95th Percentile

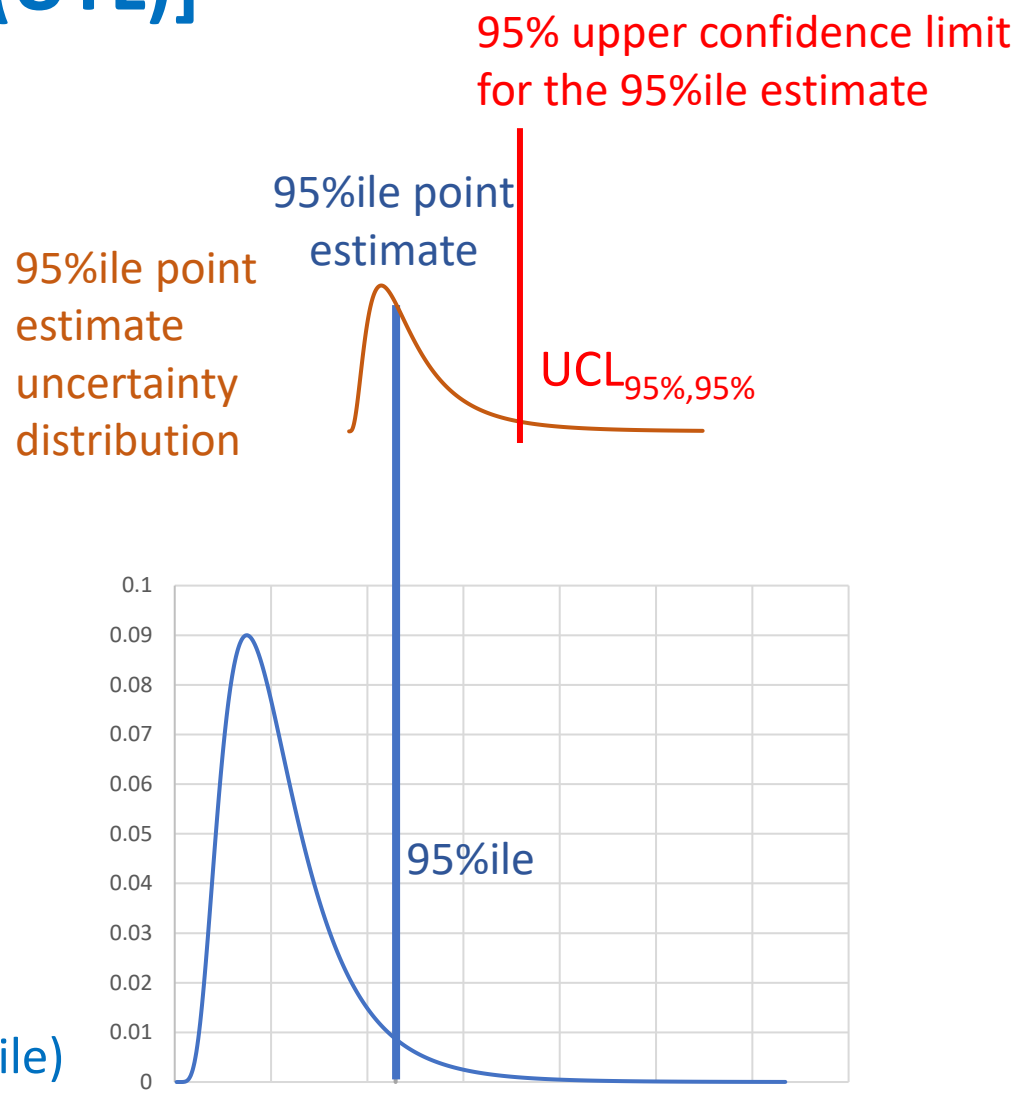
[Same as 95%ile Upper Tolerance Limit (UTL)]

Concept

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

Interpretation

- If the $UCL_{95\%,95\%}$ 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



Characterizing Uncertainty:

Upper Confidence Limit (UCL) for the 95th Percentile

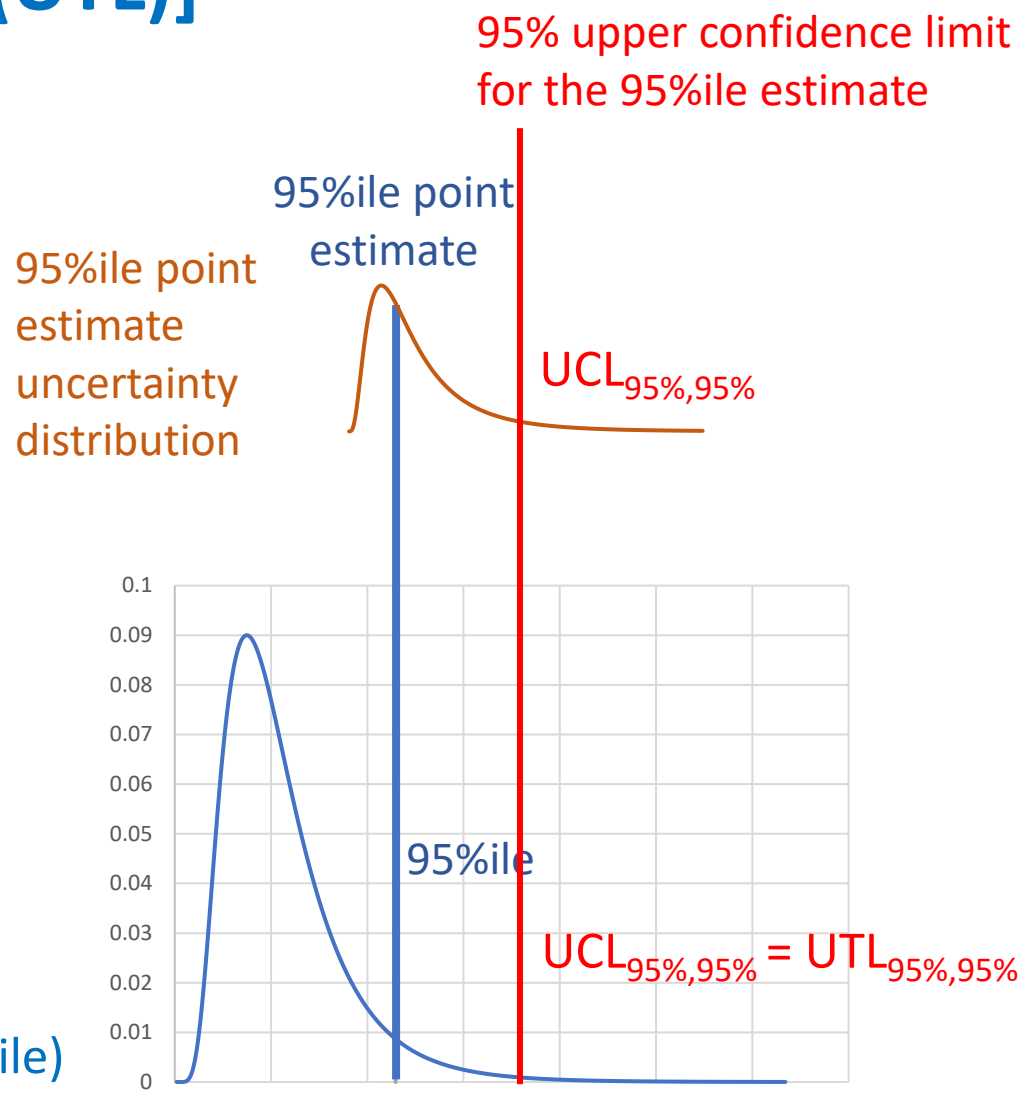
[Same as 95%ile Upper Tolerance Limit (UTL)]

Concept

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

Interpretation

- If the $UCL_{95\%,95\%}$ 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



Characterizing Uncertainty:

Upper Confidence Limit (UCL) for the 95th Percentile

[Same as 95%ile Upper Tolerance Limit (UTL)]

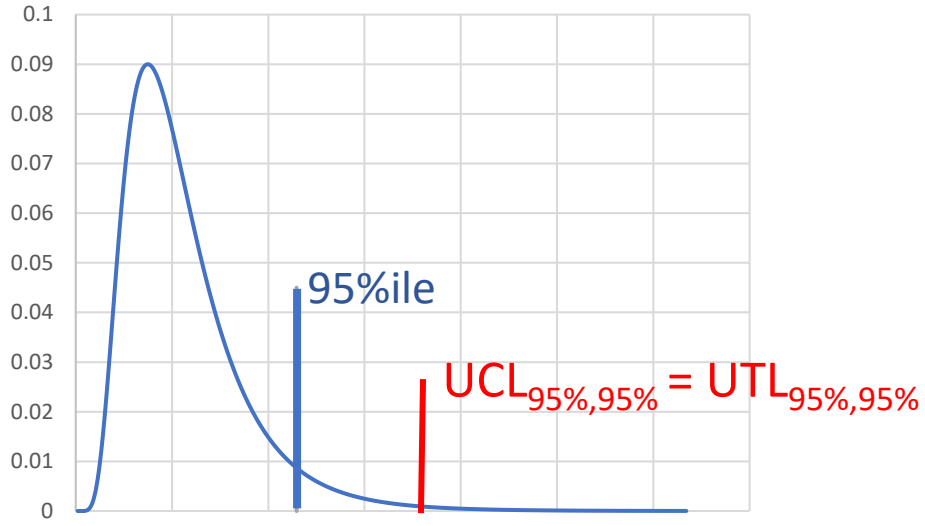
Concept

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

Interpretation

- If the $UCL_{95\%,95\%}$ 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)



Characterizing Uncertainty:

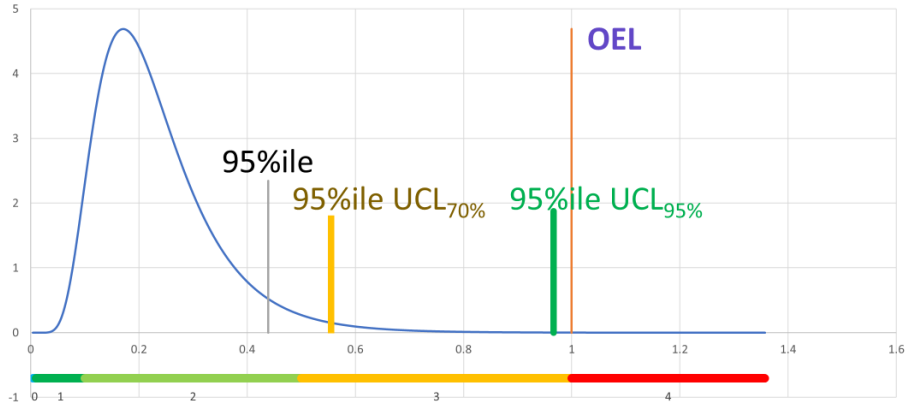
Upper Confidence Limit (UCL) for the 95th Percentile

[Same as 95%ile Upper Tolerance Limit (UTL)]

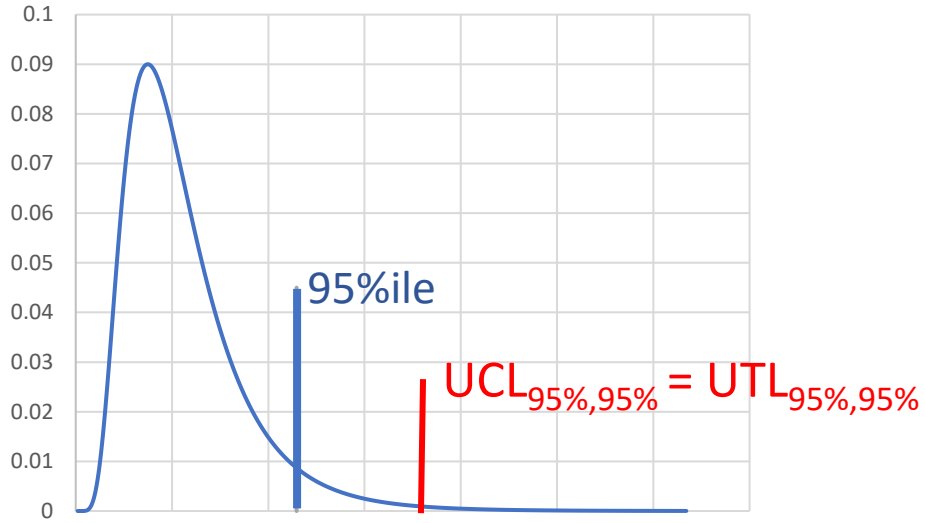
PGP DECISION STATISTIC:

Good Practice: At least 70% confident that the true 95th percentile exposure is less than the OEL

Enhanced Practice: Strive to be at least 95% confident that the true 95th percentile exposure is less than the OEL



Distribution of SEG Exposures (Exposure Profile)



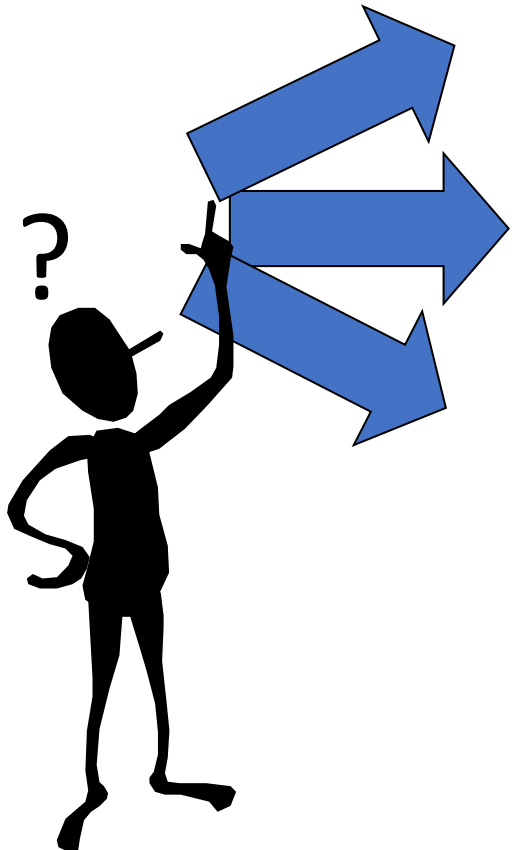
Improving Exposure Judgment

Exposure Risk Decisions: Traditional Statistics

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

OEL = 100 ppm

Sample Results (ppm)
18
15
5
8
12



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

* Decision statistic = 95th percentile

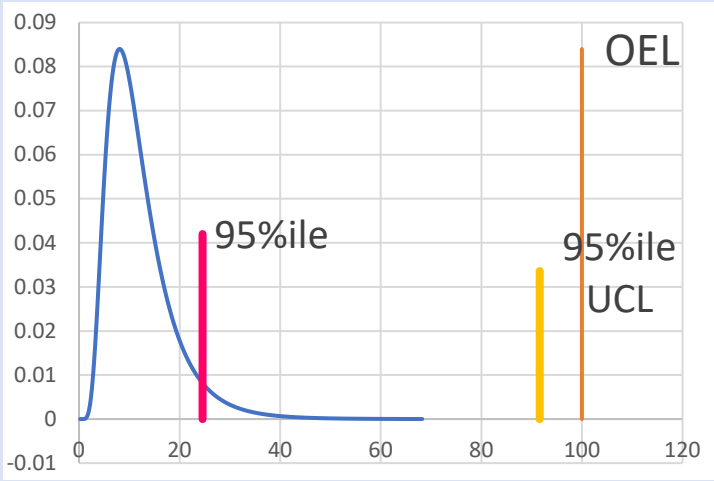
Into which AIHA Exposure Category will the 95th percentile MOST LIKELY fall?

OEL = 100 ppm

Sample Results (ppm)
18
15
5
8
12

Inferential Statistics

"Best Guess" Population (SEG) Exposure Profile



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

Exposure Category

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

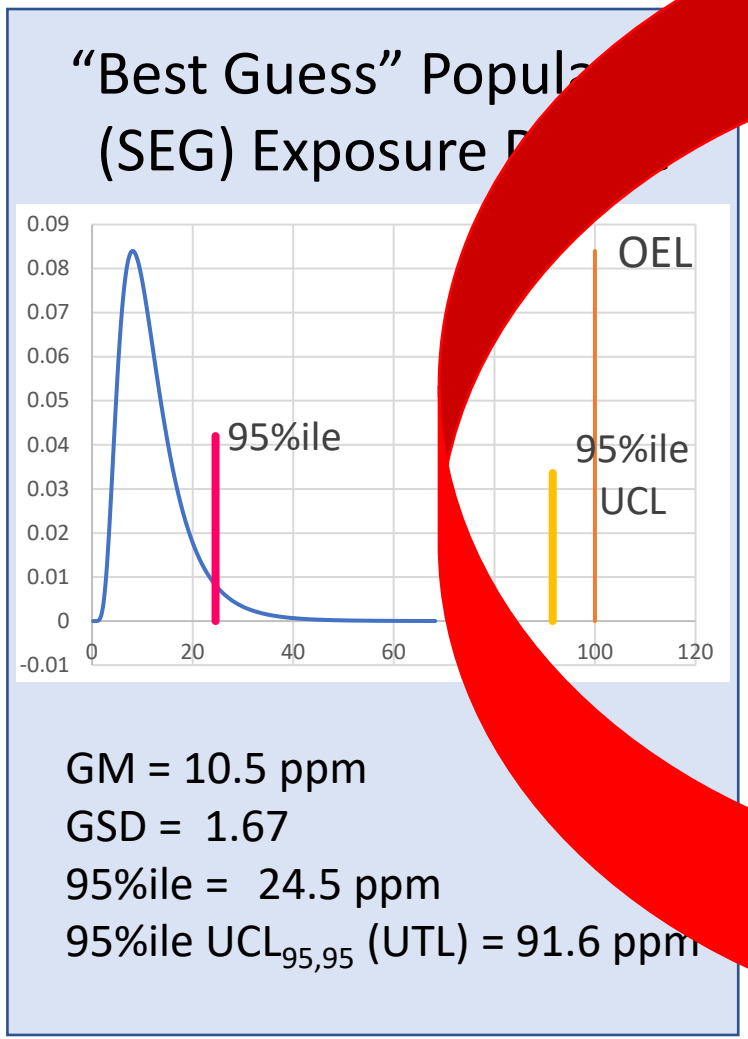
Follow-Up Actions

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



Exposure Category

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

Why we are doing this!

Follow-Up Actions

Steps in Data Analysis and Interpretation*

1. **Enter Data Into Appropriate Statistical Tool**
2. **Evaluate the Goodness-of-fit Chart**
3. **Review Descriptive and Inferential Statistics . . . Giving Special Attention to the GSD, 95%ile, UCL $_{95\%,70\%}$, and UCL$_{95\%,95\%}$**

   Compare…
   - the "decision statistic" (e.g. 95th percentile) to the OEL.
   - the UCL$_{95\%,70\%}$ and UCL$_{95\%,95\%}$ to the OEL.
4. **Assign a Final Rating and Certainty Level**
   - **Final Rating:** Compare the sample 95th percentile to the AIHA Exposure Rating Categories (ERCs) and select a category.
   - **Certainty Level:** Compare the UCL$_{95\%,95\%}$ to the ERCs:

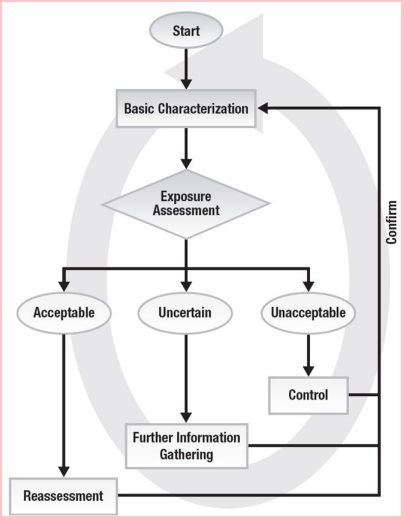
Hewett's ROT
   - Low certainty if ≥ 2 categories above the chosen ERC
   - Medium certainty if only 1 category above
   - High certainty if within chosen category

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

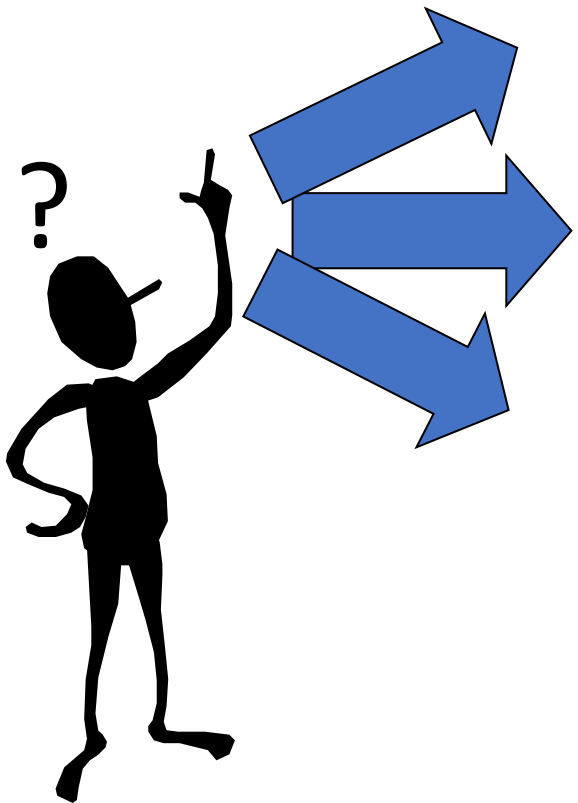


Example 1

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

OEL = 100 ppm

Sample Results (ppm)
18
15
5
8
12



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

** Decision statistic = 95th percentile

OEL = 100 ppm

Sample Results (ppm)
18
15
5
8
12

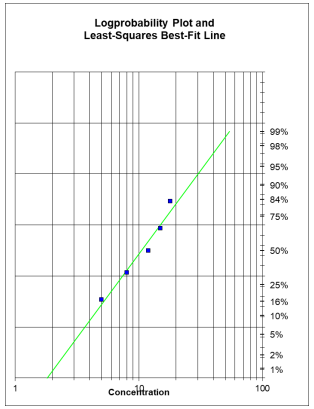
GM = 10.5 ppm

GSD = 1.67

95%ile = 24.5 ppm

$UCL_{95,70}$ = 34.2 ppm

$UCL_{95,95}$ = 91.6 ppm



OEL = 100 ppm

GM = 10.5 ppm

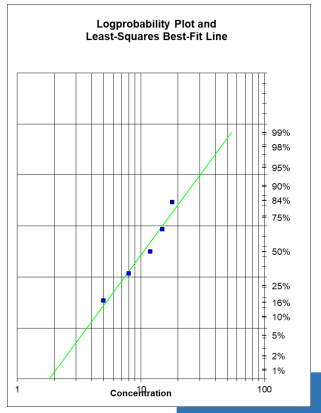
GSD = 1.67

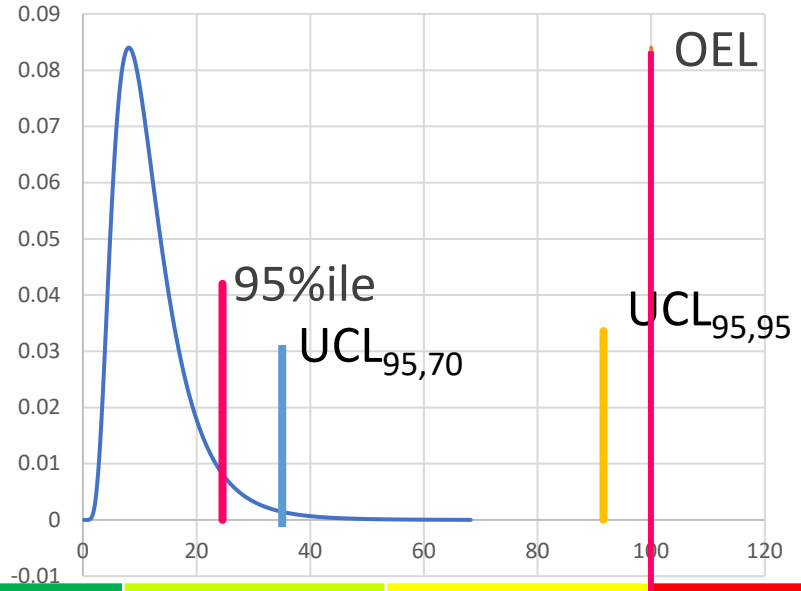
95%ile = 24.5 ppm

$UCL_{95,70}$ = 34.2 ppm

$UCL_{95,95}$ = 91.6 ppm

Sample Results (ppm)
18
15
5
8
12





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

Sample Results (ppm)
18
15
5
8
12

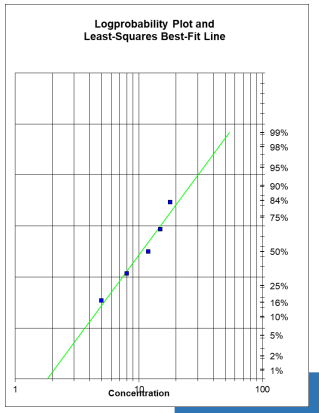
GM = 10.5 ppm

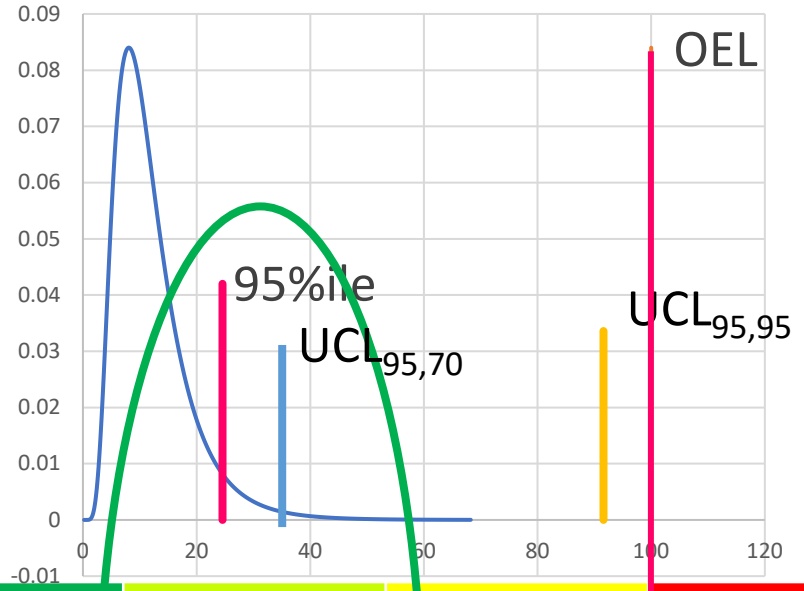
GSD = 1.67

95%ile = 24.5 ppm

$UCL_{95,70}$ = 34.2 ppm

$UCL_{95,95}$ = 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

Sample Results (ppm)
18
15
5
8
12

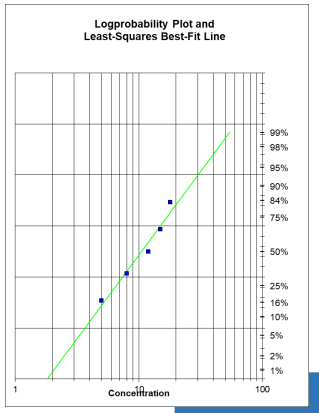
GM = 10.5 ppm

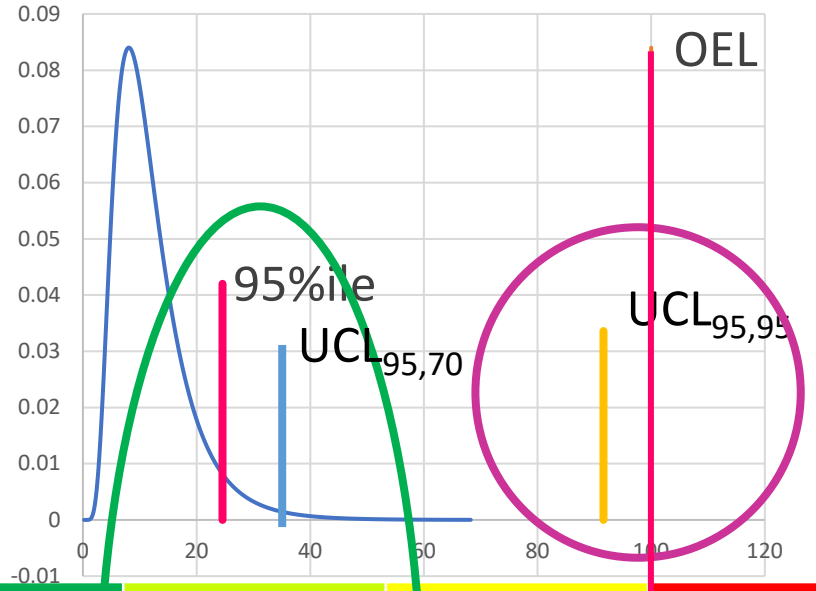
GSD = 1.67

95%ile = 24.5 ppm

$UCL_{95,70}$ = 34.2 ppm

$UCL_{95,95}$ = 91.6 ppm





95%ile Most Likely in Category 2 (Medium Certainty)

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

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

Sample Results (ppm)
18
15
5
8
12

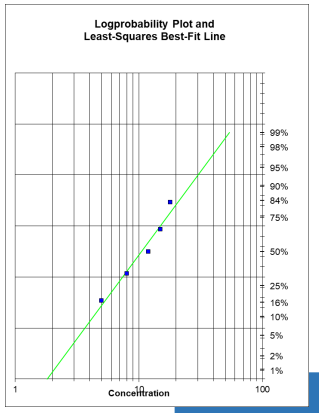
GM = 10.5 ppm

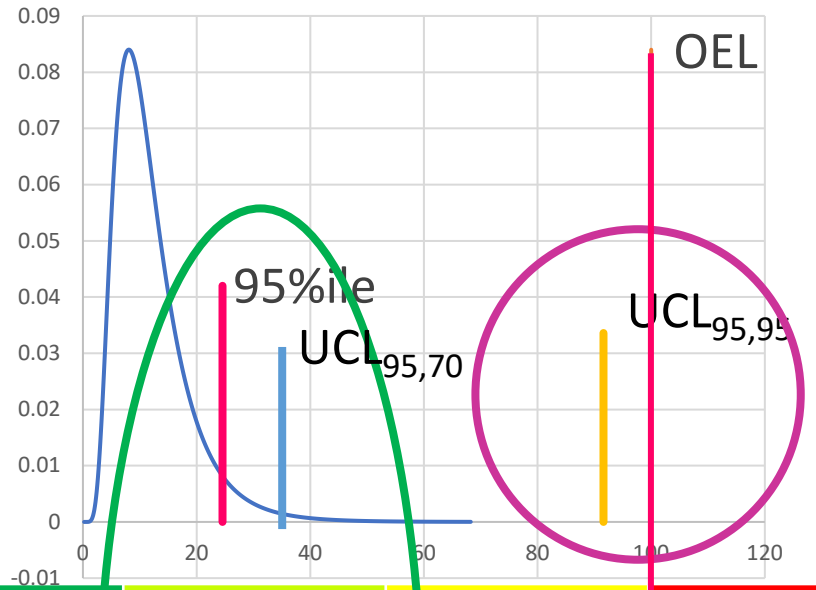
GSD = 1.67

95%ile = 24.5 ppm

$UCL_{95,70}$ = 34.2 ppm

$UCL_{95,95}$ = 91.6 ppm





95%ile Most Likely in Category 2 (Medium Certainty)

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

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
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:

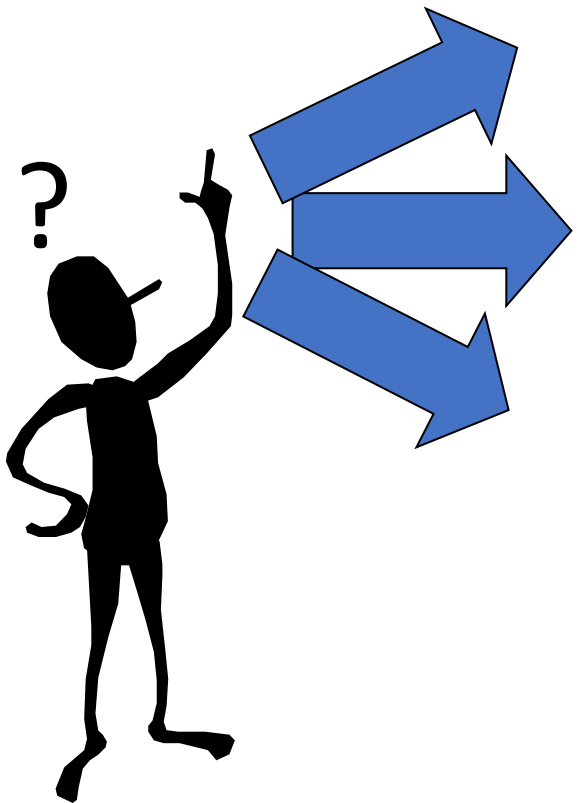
- Procedures and Training; General Haz. Com.
- + Chemical Specific Haz. Com.; Periodic Exposure Monitoring,

Example 2

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

OEL = 100 ppm

Sample Results (ppm)
8
75
5
37
12



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

* Decision statistic = 95th percentile

OEL = 100 ppm

Sample Results (ppm)
8
75
5
37
12

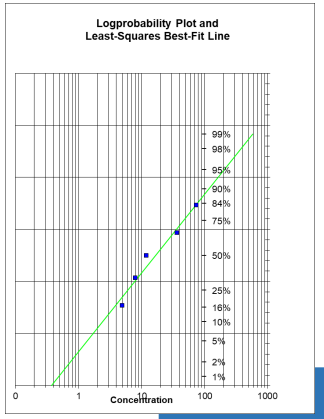
GM = 16.8 ppm

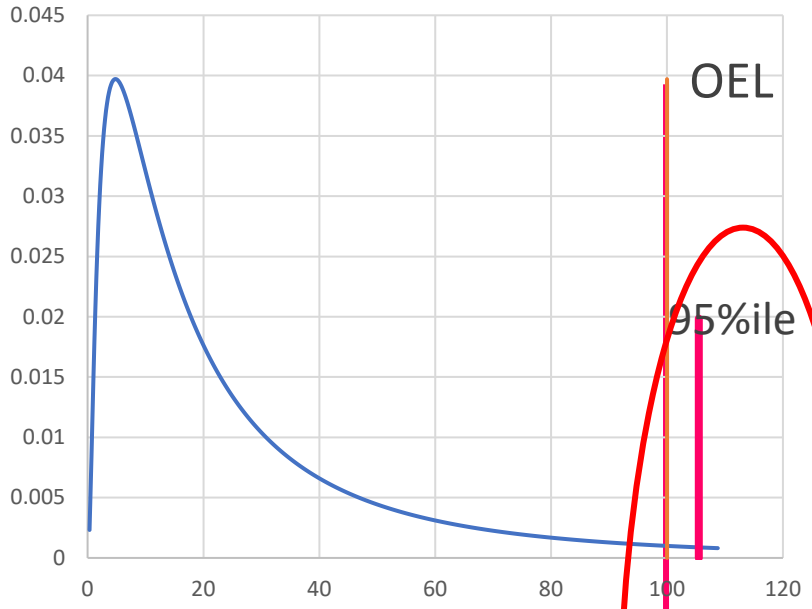
GSD = 3.06

95%ile = 105 ppm

$UCL_{95,70}$ = 216 ppm

$UCL_{95,95}$ = 1836 ppm





95%ile Most Likely in Category 4
(High Certainty)

Unacceptable:
Far Less Than 70% or 95% Confident That True 95%ile Exposure <OEL

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
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.	Respirators

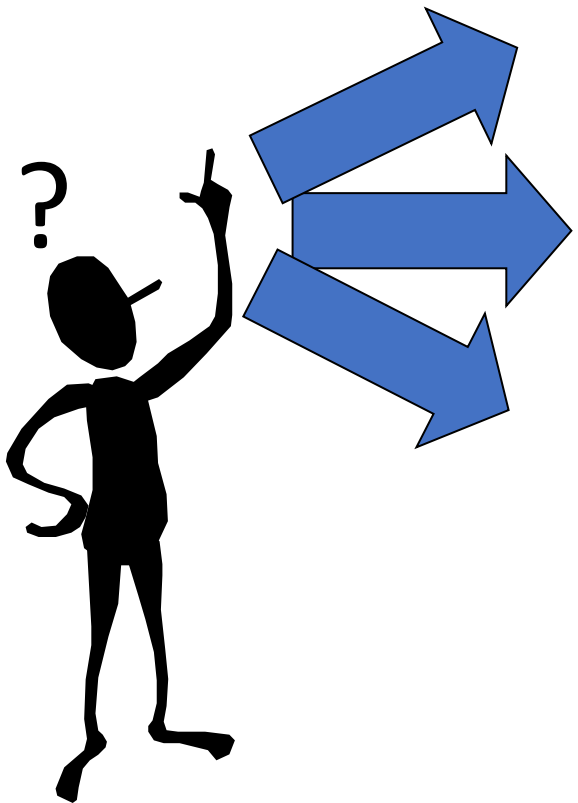
Follow-Up Actions:
+ Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection.

Example 3

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

OEL = 100 ppm

Sample Results (ppm)
8
25
7



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

* Decision statistic = 95th percentile

OEL = 100 ppm

Sample Results (ppm)
8
25
7

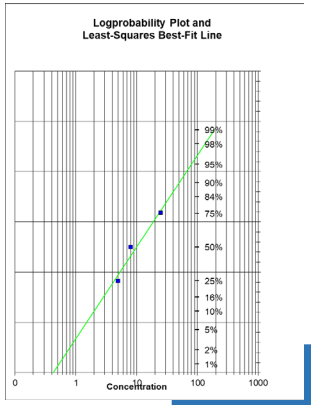
GM = 10.0 ppm

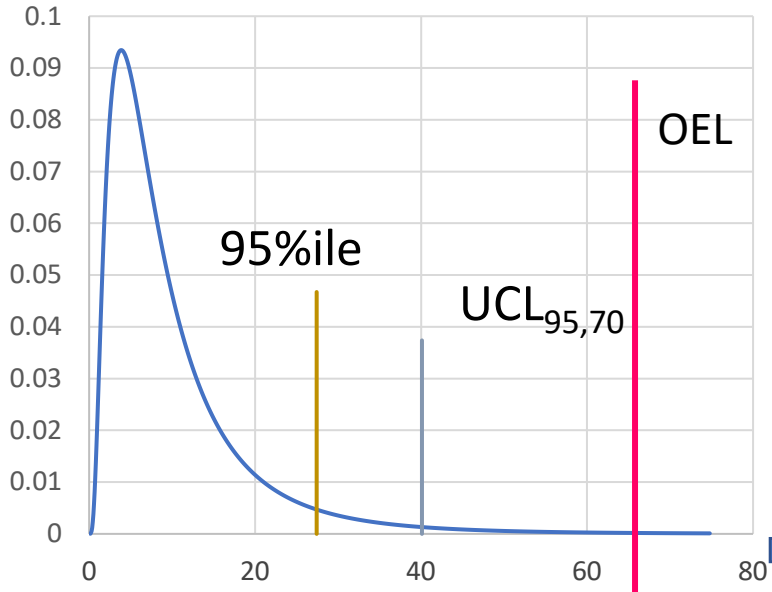
GSD = 2.01

95%ile = 35.4 ppm

$UCL_{95,70}$ = 80 ppm

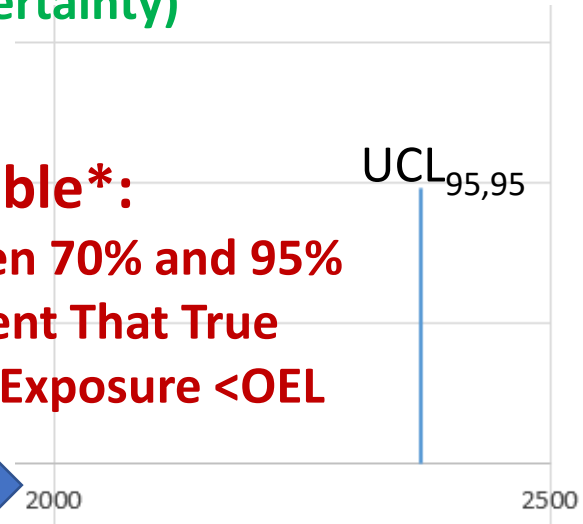
$UCL_{95,95}$ = 2370 ppm





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

Tolerable*:
Between 70% and 95% Confident That True 95%ile Exposure <OEL



Exposure Rating Category*	**0** (<1% of OEL)	**1** (<10% of OEL)	**2** (10-50% of OEL)	**3** (50-100% of OEL)	**4** (>100% o 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 Fact Selection.

Follow-Up Actions:

- Procedures and Training; General Haz. Com.
- + Chemical Specific Haz. Com.; **Required** Exposure Monitoring,

A Few Words About Handling Censored Data (Non-Detects). . .

Sample Results (ppm)
8
25
<5
10
<3
7
11

A Few Words About Handling Censored Data (Non-Detects). . .

Sample Results (ppm)
8
25
<5
10
<3
7
11

Do:

- Minimize the Likelihood and Impact of Censored Data with Good Sample Planning
  - Strive for a detection limit that is less than 10% of the OEL.
  - Ask the laboratory performing sample analysis if they would calculate results down to their limit of detection (LOD) in addition to their limit of quantification (LOQ) as the LOD is often significantly lower than the LOQ.

A Few Words About Handling Censored Data (Non-Detects). . .

Sample Results (ppm)
8
25
<5
10
<3
7
11

Do:

- Minimize the Likelihood and Impact of Censored Data with Good Sample Planning
  - Strive for a detection limit that is less than 10% of the OEL.
  - Ask the laboratory performing sample analysis if they would calculate results down to their limit of detection (LOD) in addition to their limit of quantification (LOQ) as the LOD is often significantly lower than the LOQ.

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)

Sample Results (ppm)
8
25
<5
10
<3
7
11

- 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%) censoring.
- Maximum Likelihood Estimates (MLE)
  - Complex calculations
  - Closest to best universal method
- Beta Substitution
  - Straight forward to program in a spreadsheet
  - Performance similar to MLE
- Log-Probit Regression (LPR) - also called Regression on Order Statistics (ROS)
  - Straight forward to program in a spreadsheet
  - Good choice for 25% to 50% censored data if n greater than 10 or 15.
- Bayesian Decision Analysis
  - BDA uses same equations as MLE
  - Superior performance for characterizing parameter uncertainty
  - Can readily analyze censored data, including fully censored datasets

Parametric Censored Data Analysis Methods (Assumes Lognormal Distribution)

Sample Results (ppm)
8
25
<5
10
<3
7
11

- 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%) censoring.

Simple Option for IHSTAT

- Maximum Likelihood Estimates (MLE)
  - Complex calculations
  - Closest to best universal method
- Beta Substitution
  - Straight forward to program in a spreadsheet
  - Performance similar to MLE
- Log-Probit Regression (LPR) - also called Regression on Order Statistics (ROS)
  - Straight forward to program in a spreadsheet
  - Good choice for 25% to 50% censored data if n greater than 10 or 15.
- Bayesian Decision Analysis
  - BDA uses same equations as MLE
  - Superior performance for characterizing parameter uncertainty
  - Can readily analyze censored data, including fully censored datasets

Parametric Censored Data Analysis Methods (Assumes Lognormal Distribution)

Sample Results (ppm)
8
25
<5
10
<3
7
11

- 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%) censoring.

Simple Option for IHSTAT

- Maximum Likelihood Estimates (MLE)
  - Complex calculations
  - Closest to best universal method
- Beta Substitution
  - Straight forward to program in a spreadsheet
  - Performance similar to MLE
- Log-Probit Regression (LPR) - also called Regression on Order Statistics (ROS)
  - Straight forward to program in a spreadsheet
  - Good choice for 25% to 50% censored data if n greater than 10 or 15.

- Bayesian Decision Analysis
  - BDA uses same equations as MLE
  - Superior performance for characterizing parameter uncertainty
  - Can readily analyze censored data, including fully censored datasets

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

OEL = 100 ppm

Sample Results (ppm)
8
25
<5
10
<3
7
11

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

Sample Results (ppm)
8
25
<5
10
<3
7
11

29% censored

Substitute

$$\frac{DL}{\sqrt{2}} = \frac{DL}{1.4142}$$

Sample Results With Substitutions for Non-Detects (ppm)
8
25
3.54
10
2.12
7
11

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

OEL = 100 ppm

Sample Results (ppm)
8
25
<5
10
<3
7
11

29% censored

Substitute

$$\frac{DL}{\sqrt{2}} = \frac{DL}{1.4142}$$

Sample Results With Substitutions for Non-Detects (ppm)
8
25
3.54
10
2.12
7
11

Industrial Hygiene Statistics

IHSTAT

OEL
100

Sample data
8
25
3.54
10
2.12
7
11

Descriptive statistics

Number of samples (n)	7
Maximum (max)	25
Minimum (min)	2.12
Range	22.88
Mean	9.52
Median	8
Standard deviation (s)	7.54
Geometric mean	7.35
Geometric standard deviation	2.23
Percent above OEL	0.0%

Test for distribution fit

W-test of log-transformed data	0.970
Lognormal (α = 0.05) ?	**Yes**
W-test of data	0.842
Normal (α = 0.05) ?	**Yes**

Lognormal parametric statistics

Estimated Arithmetic Mean - AM est.	9.580
LCL1,95% - Land's "Exact"	6.010
UCL1,95% - Land's "Exact"	28.300
95th Percentile	27.417
UTL95%,95%	112
Percent above OEL	0.1%
LCL1,95% %>OEL	
UCL1,95% %>OEL	5.85

OEL = 100 ppm

Sample Results DL/sqrt(2) Substitution for Non-Detects (ppm)
8
25
<5 → 3.54
10
<3 → 2.12
7
11

29% censored

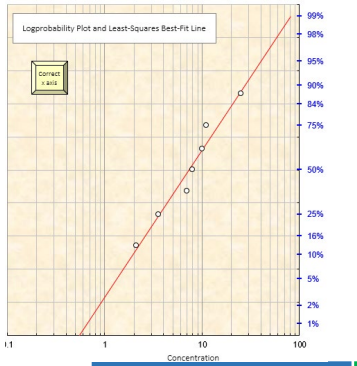
GM = 7.35 ppm

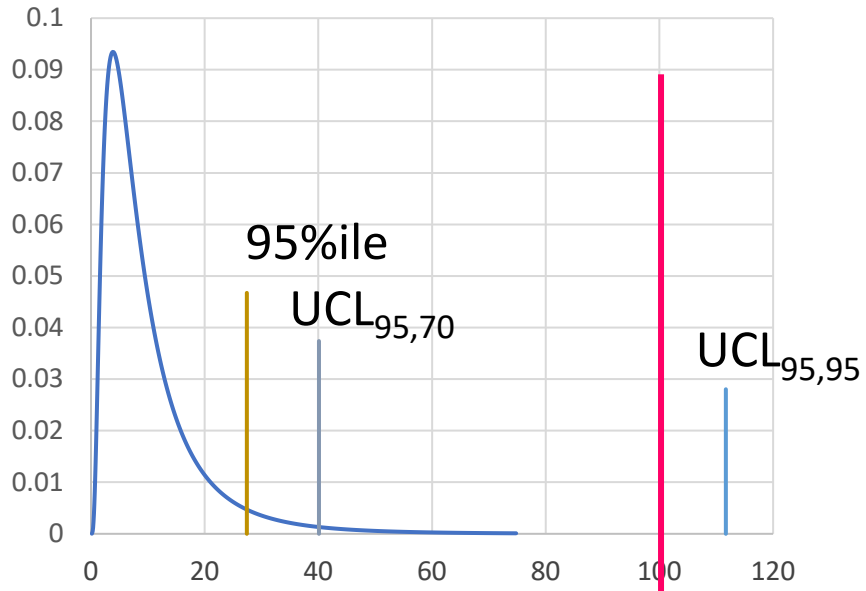
GSD = 2.23

95%ile = 27.4 ppm

$UCL_{95,70}$ = 40 ppm

$UCL_{95,95}$ = 112 ppm





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

Tolerable*:

Between 70% and 95% Confident That True 95%ile Exposure <OEL

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
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.	+ E C P D A R

Follow-Up Actions:

- Procedures and Training; General Haz. Com.
- + Chemical Specific Haz. Com.; **Required** Exposure Monitoring,

Example:
Bayesian Decision Analysis of Censored Data

OEL = 100 ppm

Sample Results (ppm)
8
25
<5
10
<3
7
11

29% censored

Example:
Bayesian Decision Analysis of Censored Data

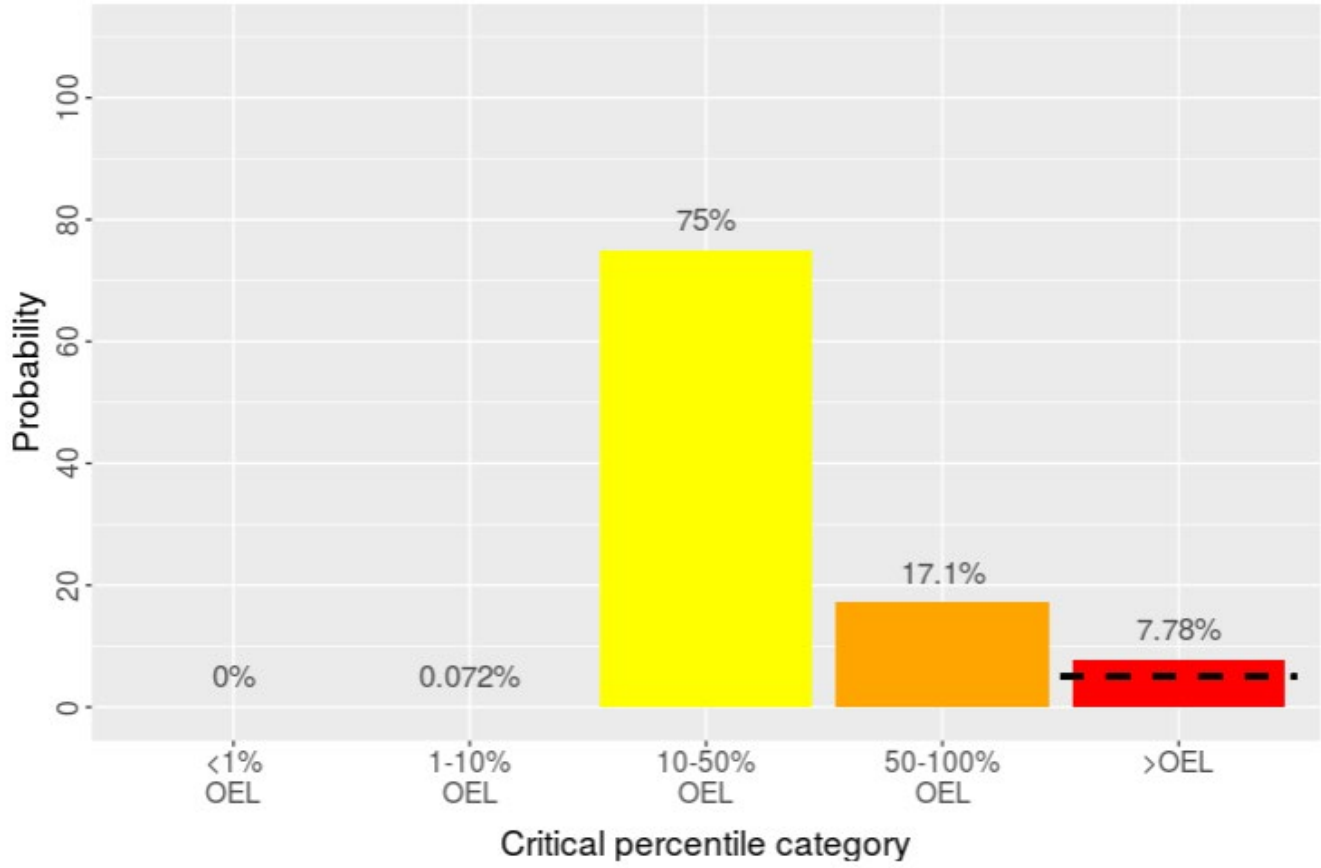
OEL = 100 ppm

Sample Results (ppm)
8
25
<5
10
<3
7
11

29% censored

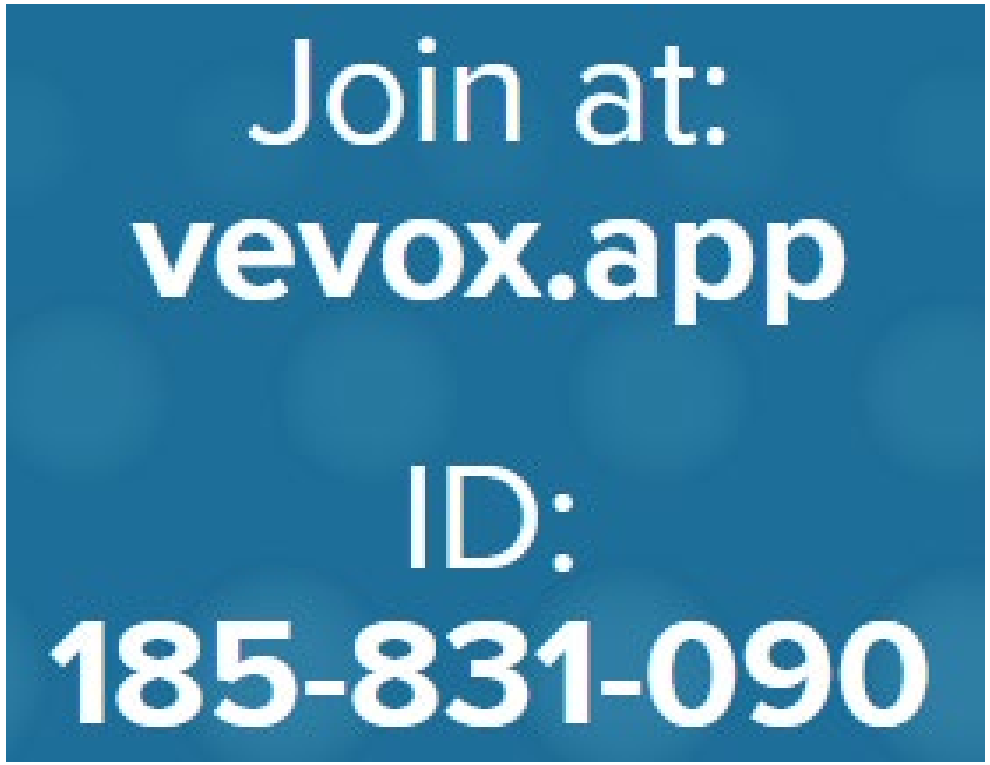
Enter Directly Into Bayesian Statistical Analysis Tool (IHDA or Expostats)

No Substitution Needed



Expostats

YET MORE POLLING QUESTIONS . . .



VEVOX Polling Software Site

AIHA™

POLLING QUESTION #11

If an organization decides that the decision statistic should allow no more than 2 samples out of 100 samples above an exposure limit, which statistical interpretation does it best represent?

- ❑ Desire 90th percentile ≤ OEL
- ❑ Desire 92nd percentile ≤ OEL
- ❑ Desire 95th percentile ≤ OEL
- ❑ Desire 98th percentile ≤ OEL
- ❑ Desire 99th percentile ≤ OEL

POLLING QUESTION #11

If an organization decides that the decision statistic should allow no more than 2 samples out of 100 samples above an exposure limit, which statistical interpretation does it best represent?

- ❑ Desire 90th percentile ≤ OEL
- ❑ Desire 92nd percentile ≤ OEL
- ❑ Desire 95th percentile ≤ OEL
- ❑ Desire 98th percentile ≤ OEL
- ❑ Desire 99th percentile ≤ OEL

98%ile

2/100 (2%) above

98/100 (98%) below

POLLING QUESTION #12

What is the best interpretation of this traditional statistics analysis of worker SEG exposure data (OEL = 10 ppm)?

95%ile = 8.3 ppm

$UTL_{95\%,70\%}$ = 11.72 ppm

- ❑ We are at least 95% certain that the worker SEG exposures exceed the OEL for 70 percent of the time.
- ❑ We are at least 70% certain that the worker SEG exposures exceed the OEL for less than 5 percent of the time.
- ❑ We are not 70% certain that the worker SEG exposures exceed the OEL for less than 5 percent of the time.
- ❑ We are at least 70% certain that the worker SEG exposures exceed the OEL for 95 percent of the time.

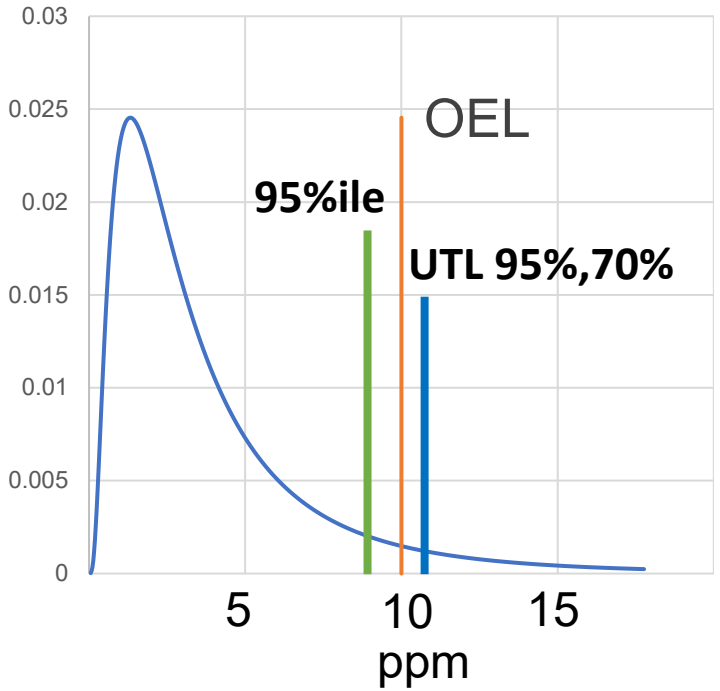
POLLING QUESTION #12

What is the best interpretation of this traditional statistics analysis of worker SEG exposure data (OEL = 10 ppm)?

95%ile = 8.3 ppm

$UTL_{95\%,70\%}$ = 11.72 ppm

- ❑ We are at least 95% certain that the worker SEG exposures exceed the OEL for 70 percent of the time.
- ❑ We are at least 70% certain that the worker SEG exposures exceed the OEL for less than 5 percent of the time.
- ❑ We are not 70% certain that the worker SEG exposures exceed the OEL for less than 5 percent of the time.
- ❑ We are at least 70% certain that the worker SEG exposures exceed the OEL for 95 percent of the time.



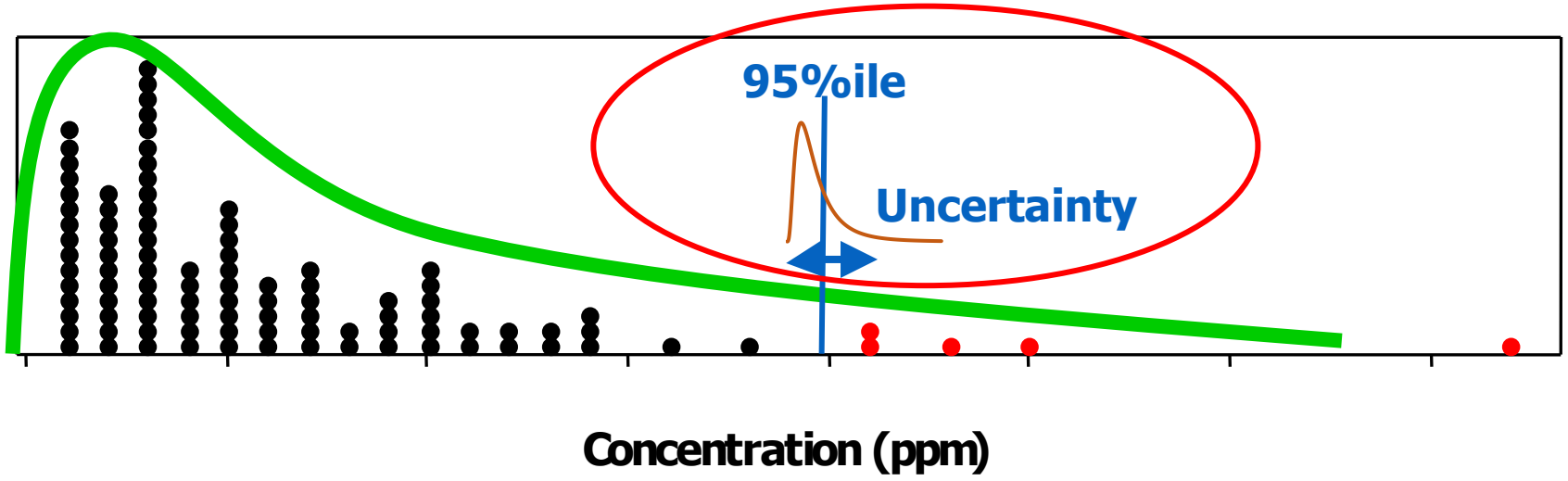
Improving Exposure Judgment

Exposure Risk Decisions:
Bayesian Decision Analysis (BDA)

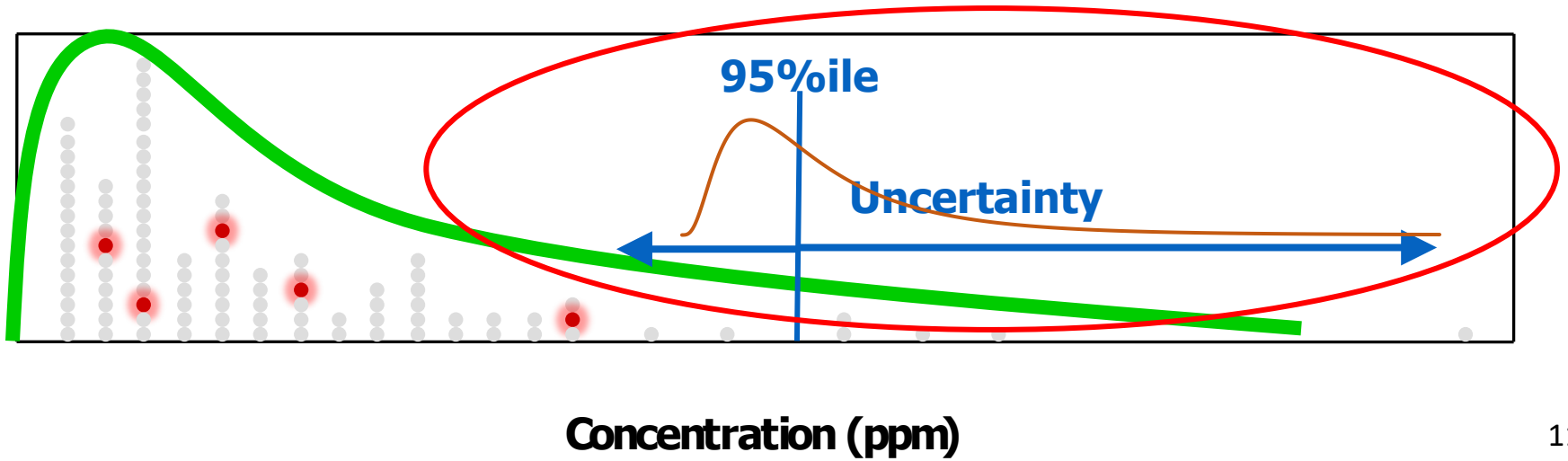
Focus is on the 95%ile's Distribution of Uncertainty

Let's focus in on the distribution of uncertainty around the 95%ile Point Estimate . . .

n=100



n=5



OEL = 100 ppm

GM = 10.5 ppm

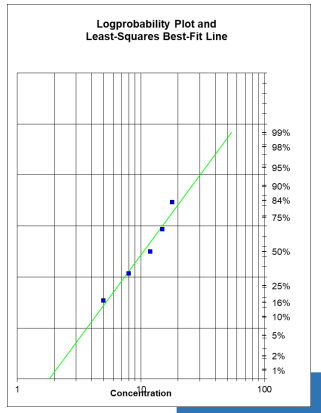
GSD = 1.67

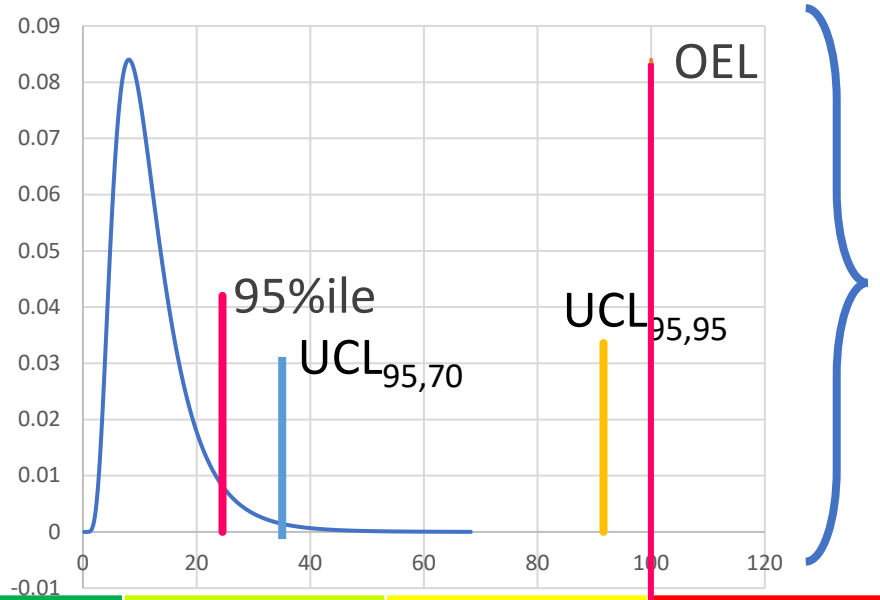
95%ile = 24.5 ppm

$UCL_{95,70}$ = 34.2 ppm

$UCL_{95,95}$ = 91.6 ppm

Sample Results (ppm)
18
15
5
8
12





Distribution of SEG Exposures (Exposure Profile)

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

Sample Results (ppm)
18
15
5
8
12

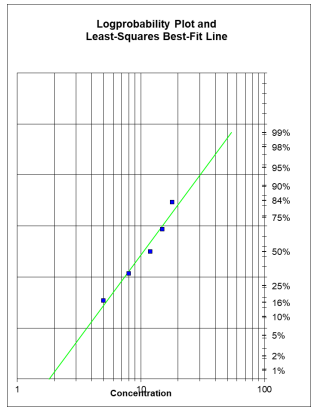
GM = 10.5 ppm

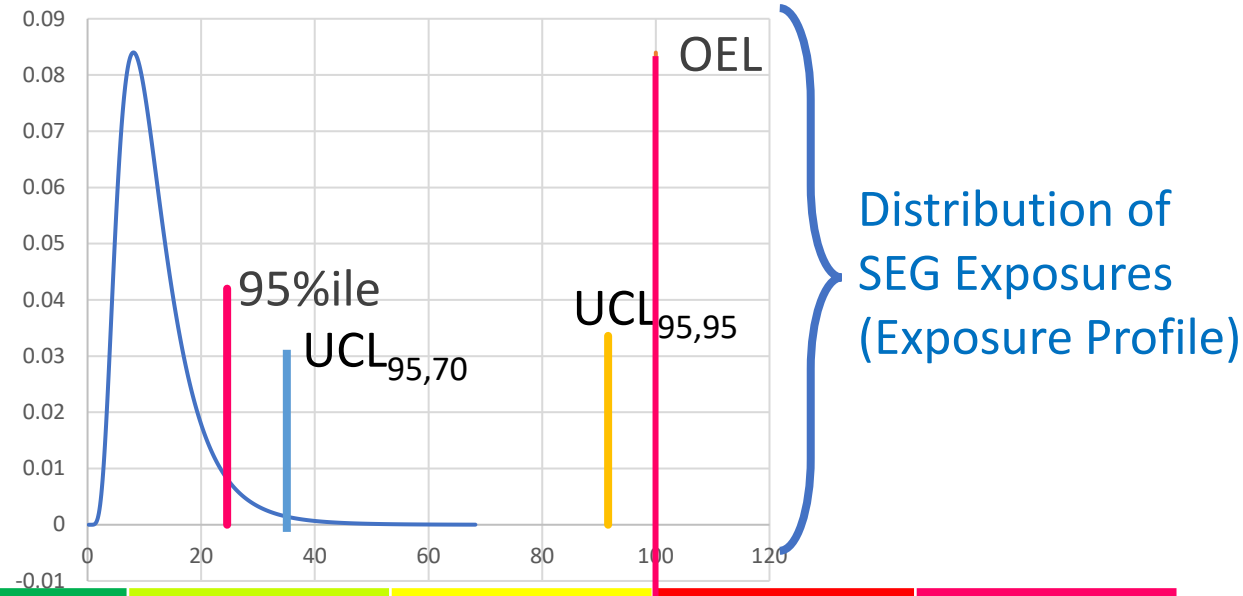
GSD = 1.67

95%ile = 24.5 ppm

$UCL_{95,70}$ = 34.2 ppm

$UCL_{95,95}$ = 91.6 ppm





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)

OEL = 100 ppm

GM = 10.5 ppm

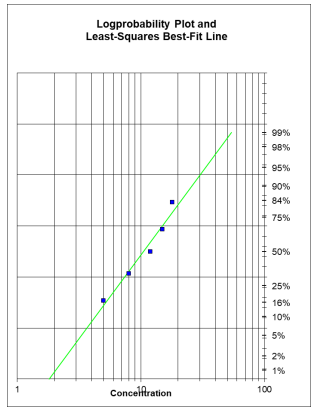
GSD = 1.67

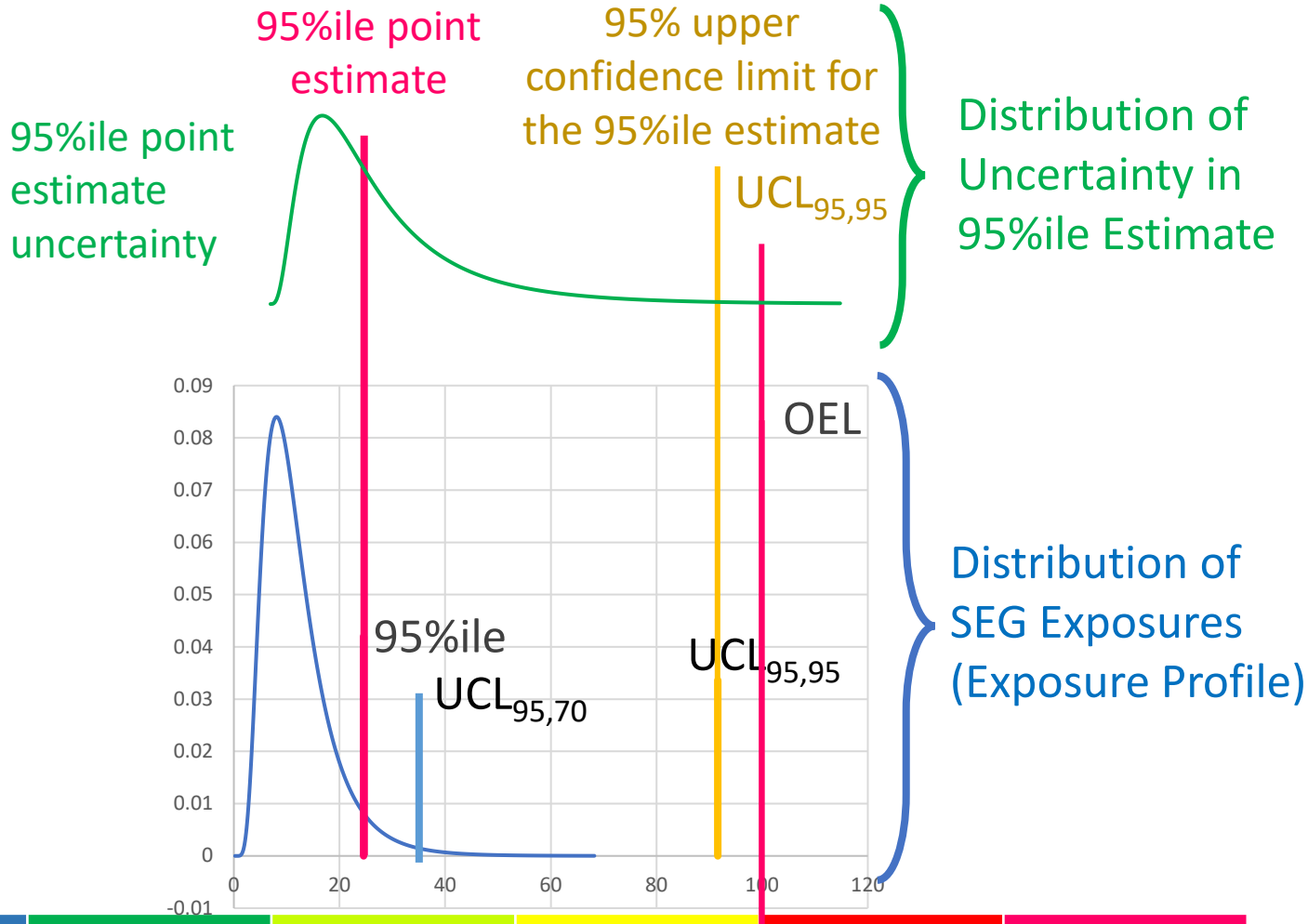
95%ile = 24.5 ppm

$UCL_{95,70}$ = 34.2 ppm

$UCL_{95,95}$ = 91.6 ppm

Sample Results (ppm)
18
15
5
8
12





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)

Focus on the 95%ile uncertainty

OEL = 100 ppm

Sample Results (ppm)
18
15
5
8
12

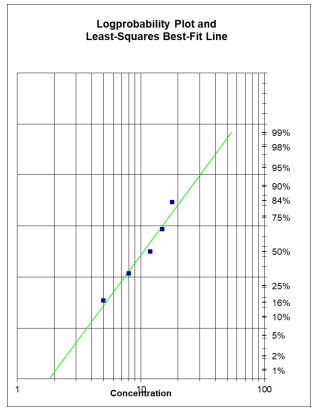
GM = 10.5 ppm

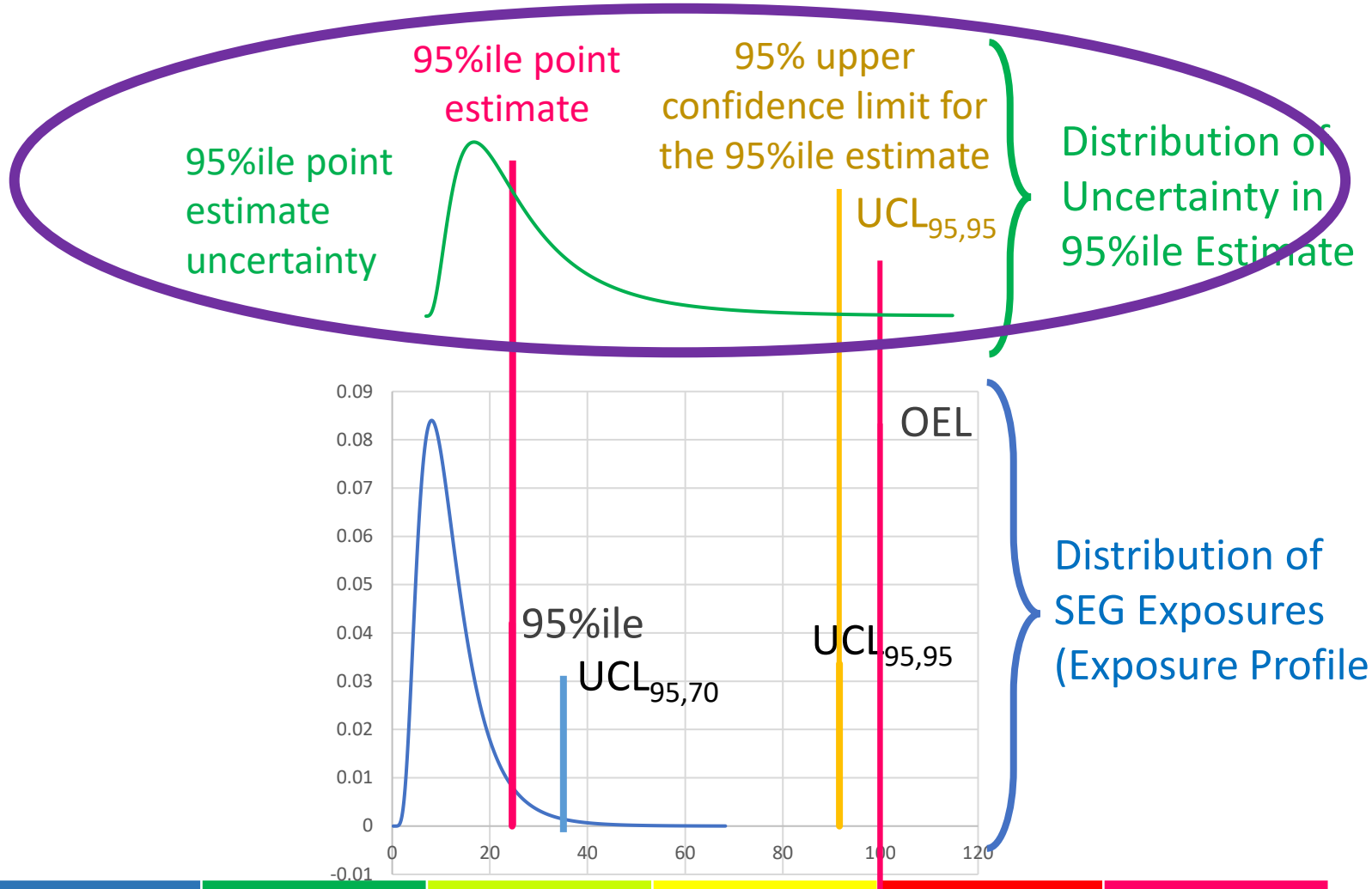
GSD = 1.67

95%ile = 24.5 ppm

$UCL_{95,70}$ = 34.2 ppm

$UCL_{95,95}$ = 91.6 ppm





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)

OEL = 100 ppm

Sample Results (ppm)
18
15
5
8
12

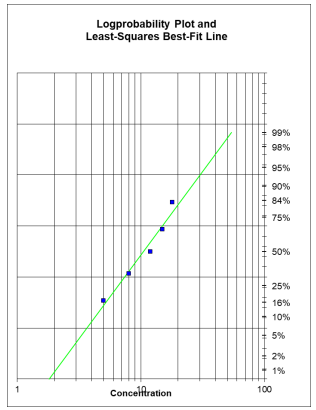
GM = 10.5 ppm

GSD = 1.67

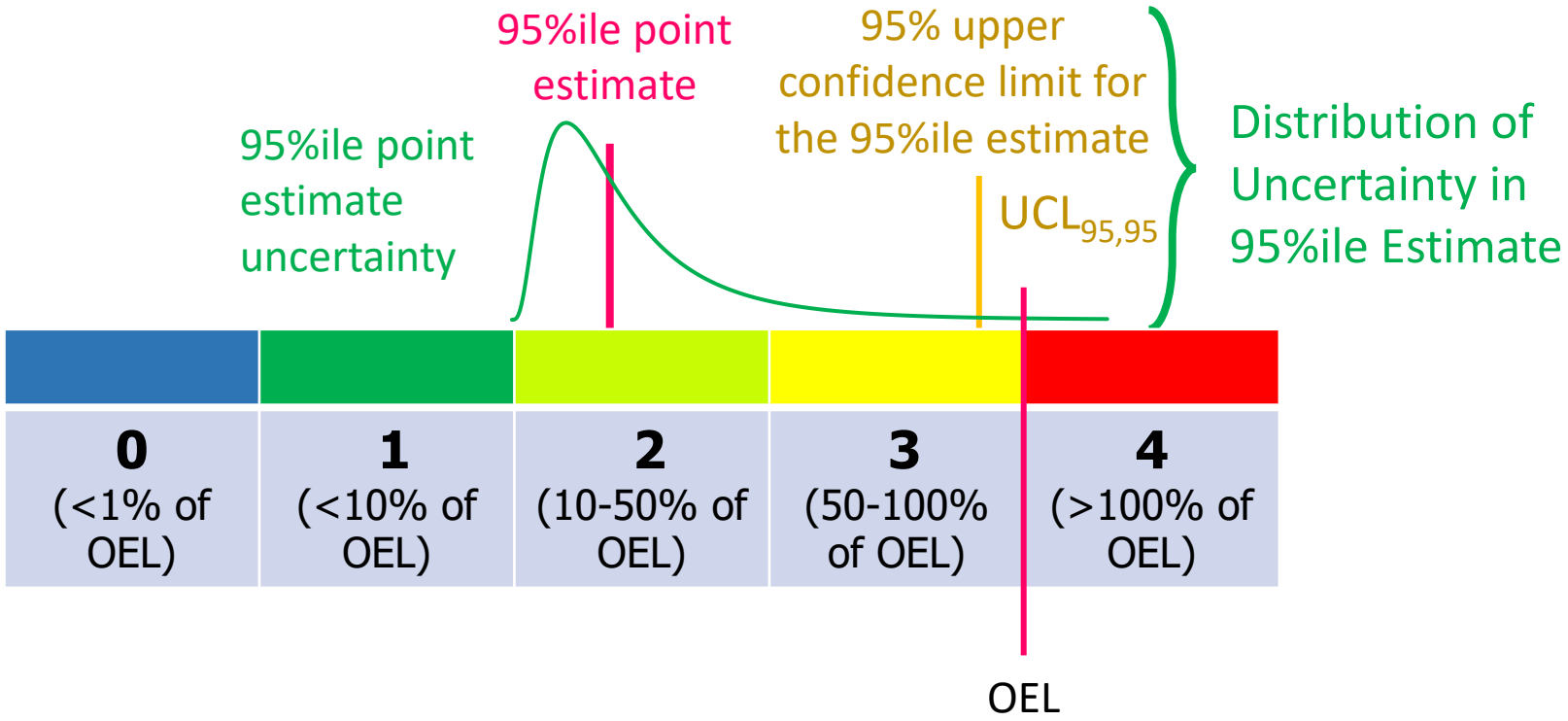
95%ile = 24.5 ppm

$UCL_{95,70}$ = 34.2 ppm

$UCL_{95,95}$ = 91.6 ppm



Focus on the 95%ile uncertainty



OEL = 100 ppm

Sample Results (ppm)
18
15
5
8
12

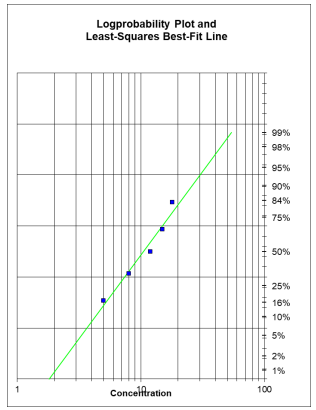
GM = 10.5 ppm

GSD = 1.67

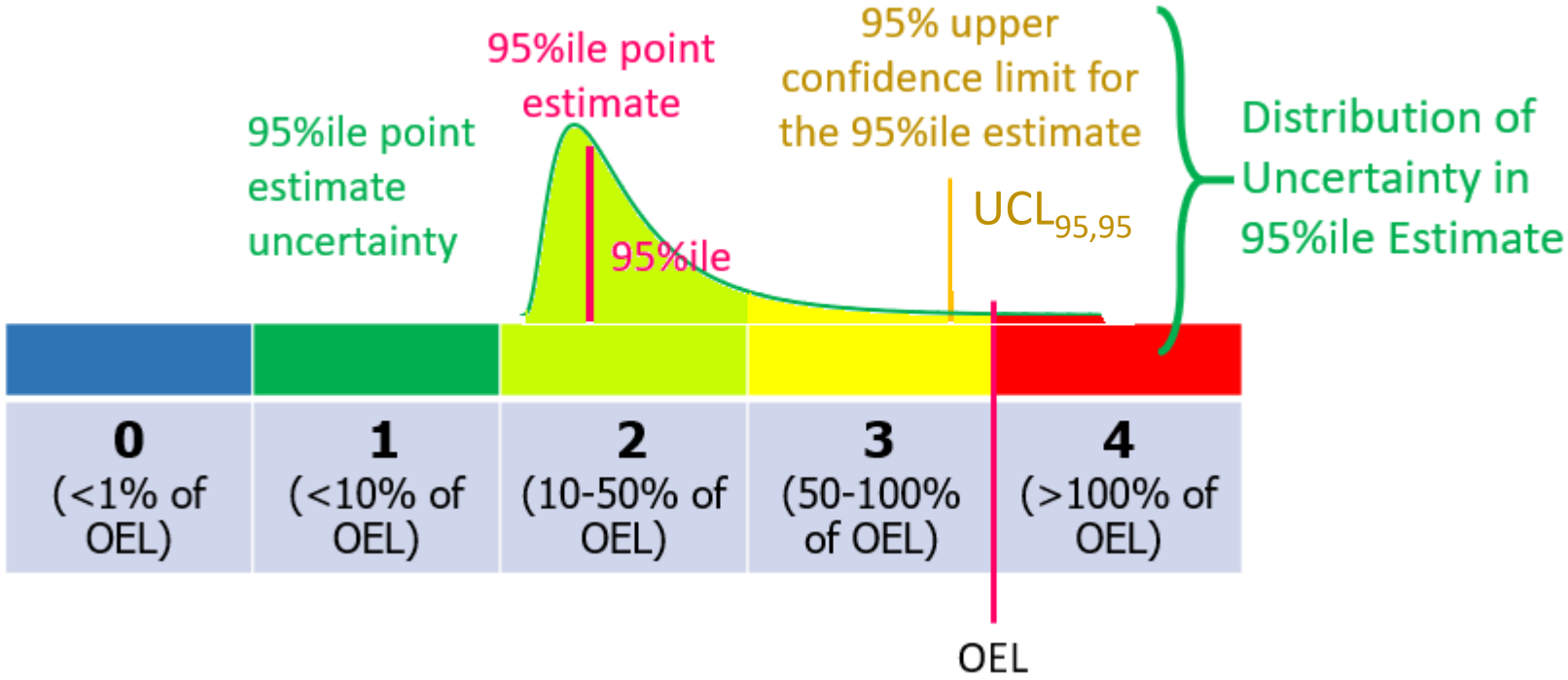
95%ile = 24.5 ppm

$UCL_{95,70}$ = 34.2 ppm

$UCL_{95,95}$ = 91.6 ppm



Focus on the 95%ile uncertainty



- Most of the 95%ile probability is in Category 2
- The next most likely is Category 3
- There is a small probability of Category 4
- There is almost no probability that the 95%ile is in Categories 0 or 1

OEL = 100 ppm

Sample Results (ppm)
18
15
5
8
12

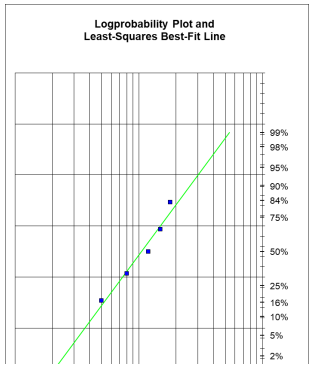
GM = 10.5 ppm

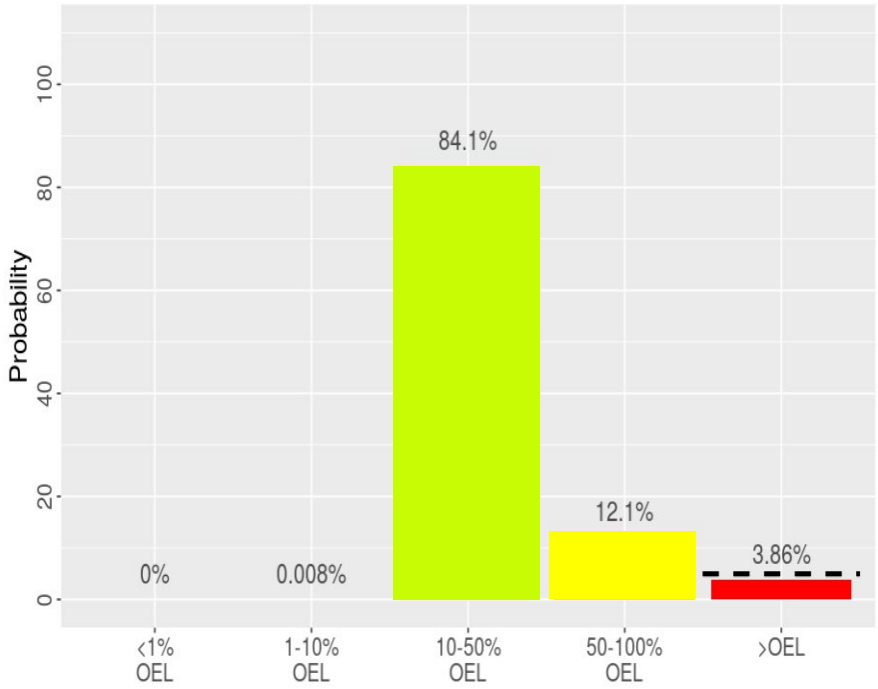
GSD = 1.67

95%ile = 24.5 ppm

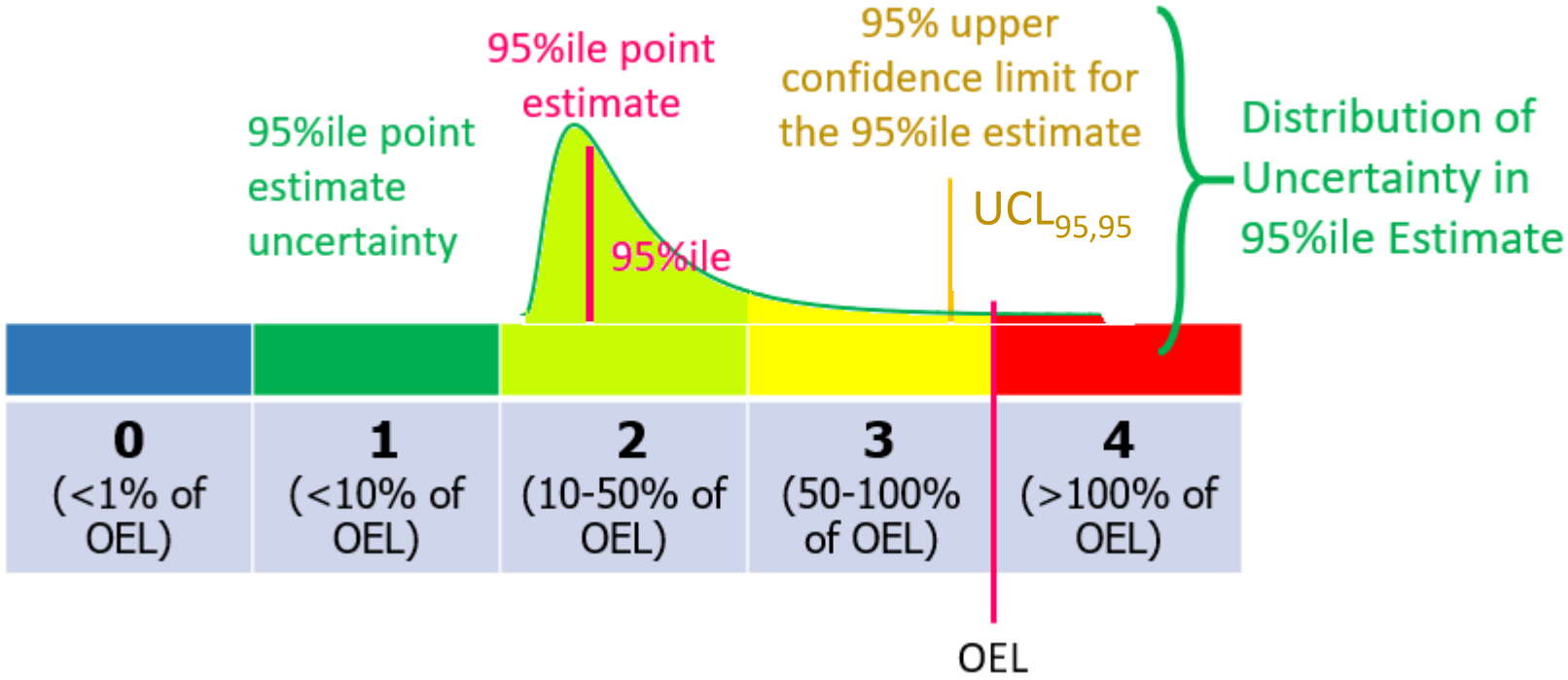
$UCL_{95,70}$ = 34.2 ppm

$UCL_{95,95}$ = 91.6 ppm





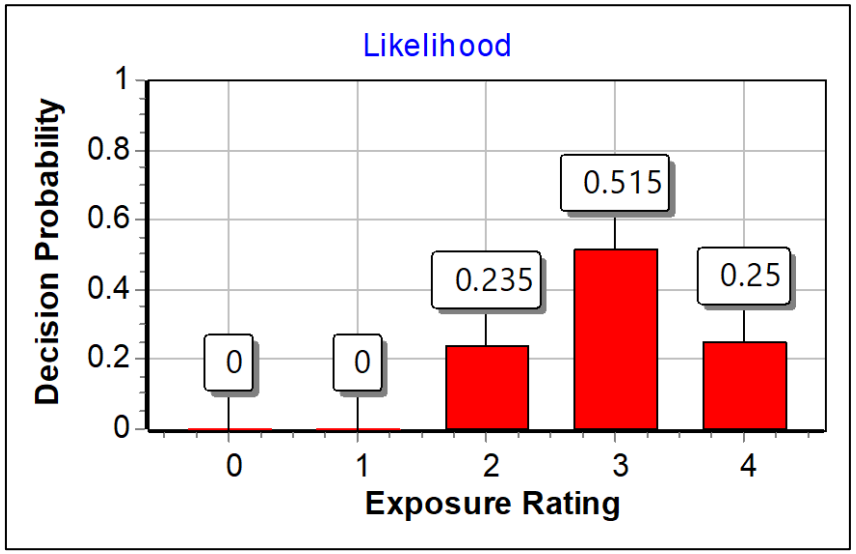
Focus on the 95%ile uncertainty



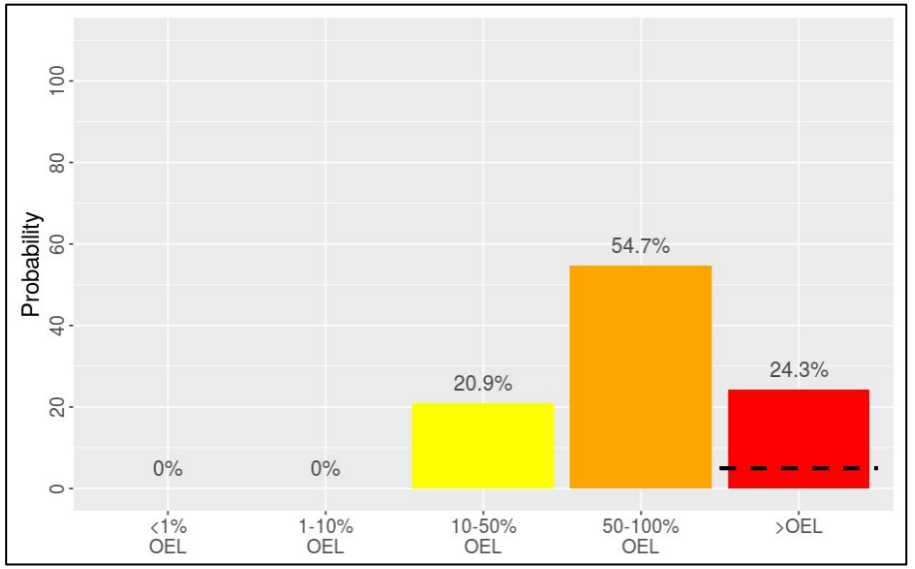
- Most of the 95%ile probability is in Category 2
- The next most likely is Category 3
- There is a small probability of Category 4
- There is almost no probability that the 95%ile is in Categories 0 or 1

Bayesian Decision Analysis (BDA)

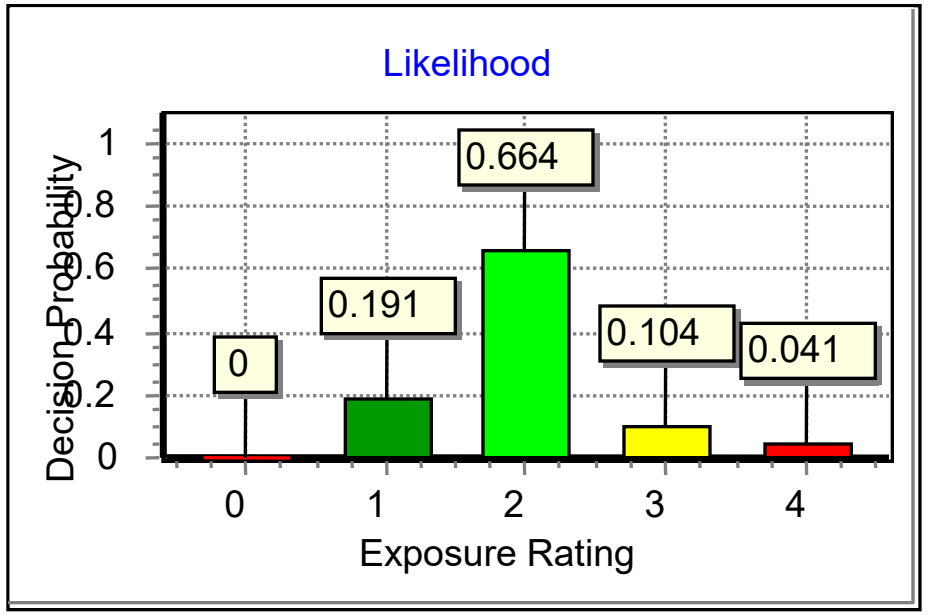
- An adjunct or alternative to the calculation and interpretation of traditional statistics.
- Characterize 95%ile and its uncertainty
- The goal of BDA is to estimate the probability that the *true* exposure profile 95%ile falls into a particular category, or *AIHA Exposure Rating.*

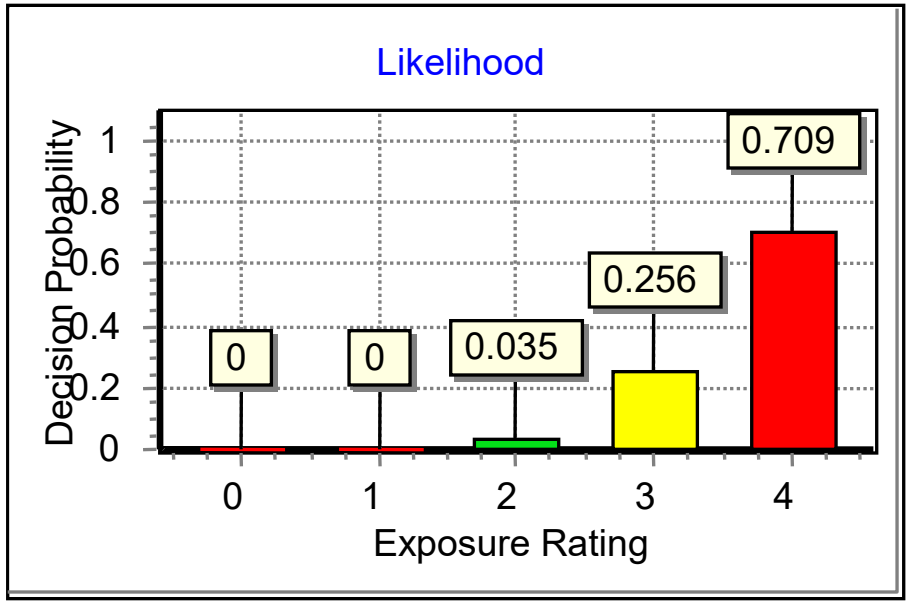


IHDA-AIHA



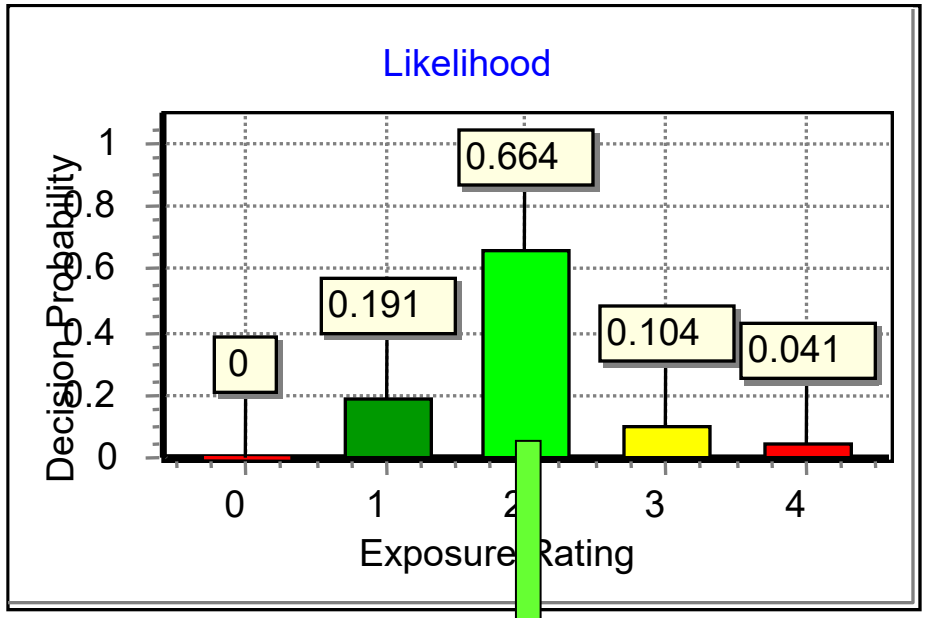
Expostats

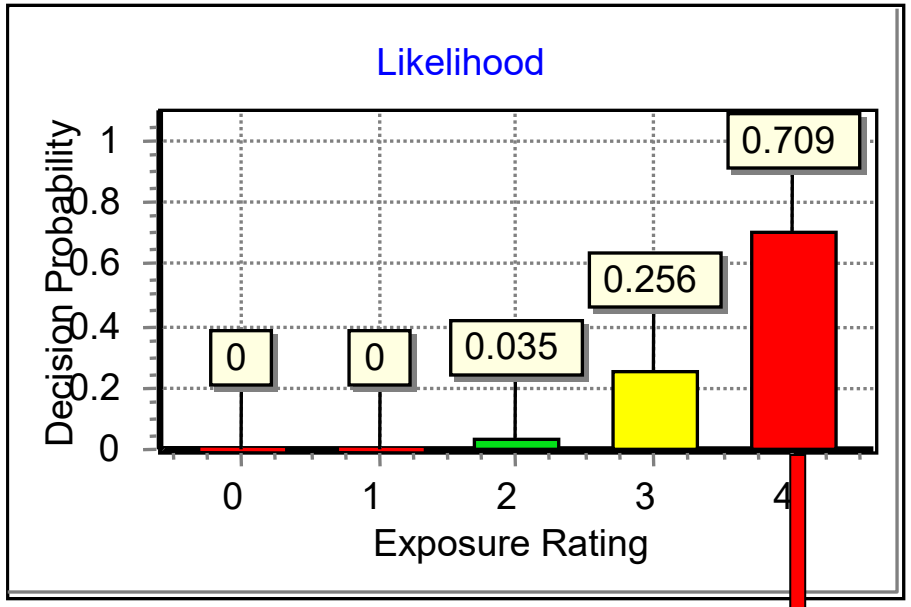




Easier to Interpret!
Easier to Communicate!

- BDA output gives probabilities - easier for people to understand than traditional confidence intervals
- The uncertainty associated with small data sets shows up clearly so risk can be better communicated

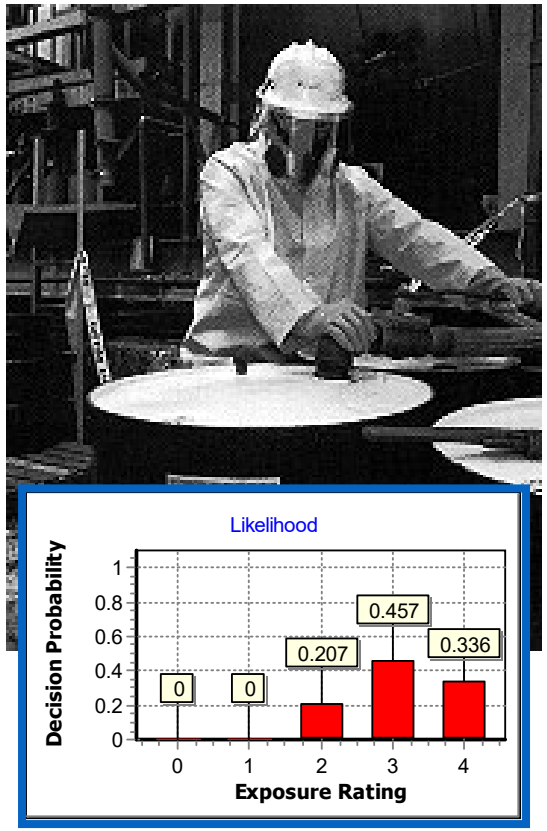


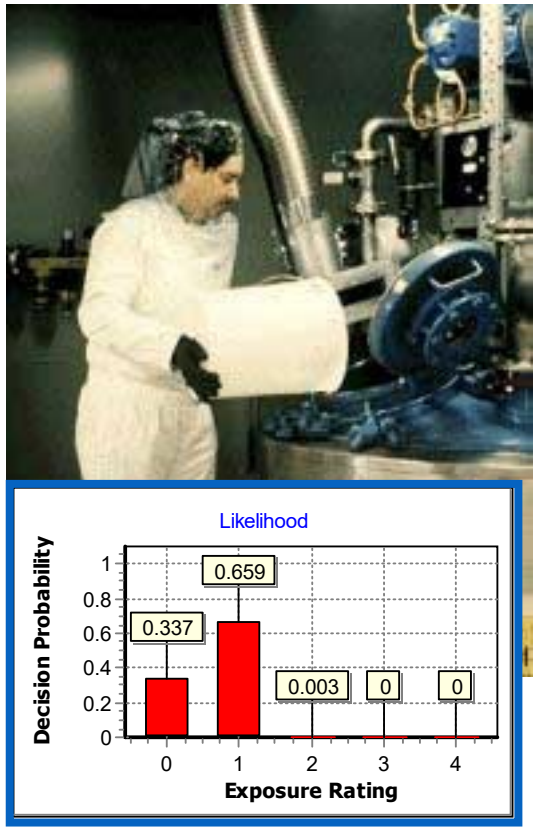


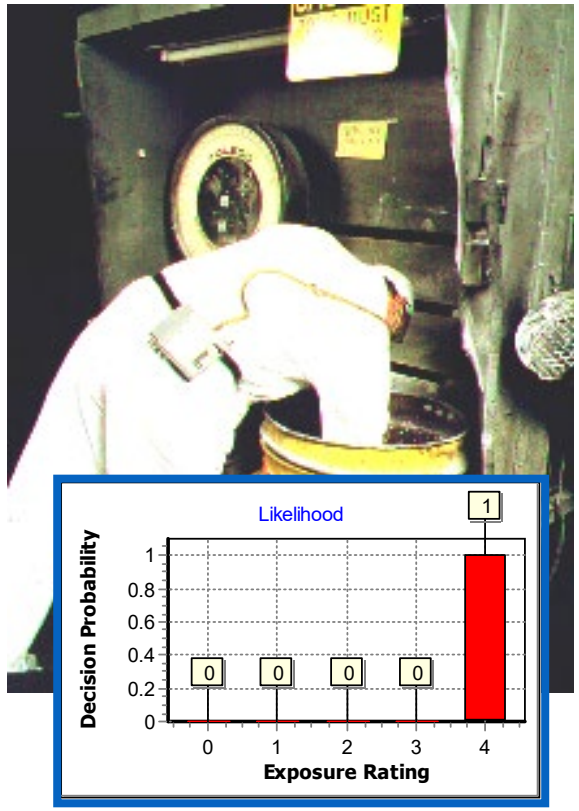
Follow-up is Straightforward

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

Quickly Summarize Exposure Scenarios

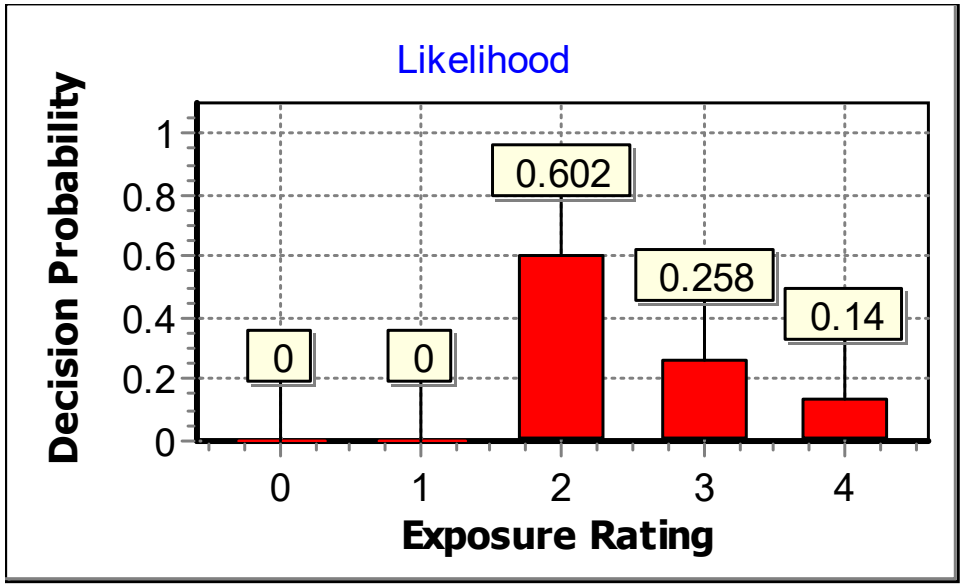






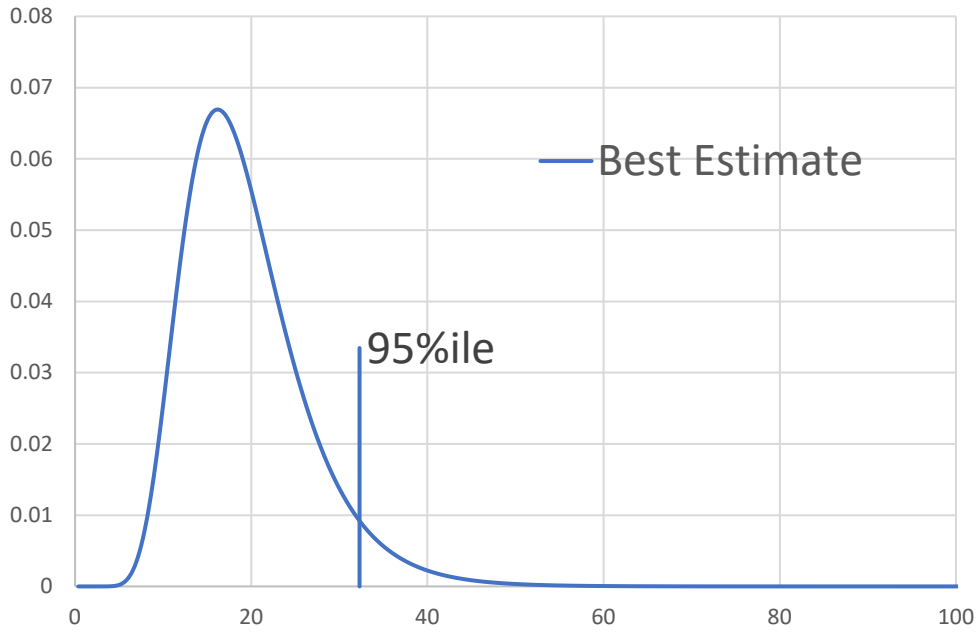
BDA Chart NOT the same as the Exposure Distribution

95%ile Uncertainty Expressed as Likelihood that the 95%ile is in an AIHA Exposure Rating and Control Category



≠

Best Guess Exposure Frequency Distribution (SEG Exposure Profile)



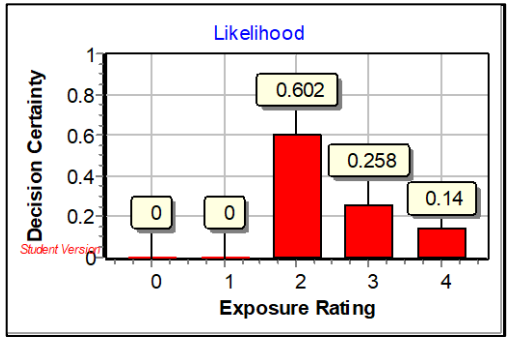
OEL = 100 ppm
x = 13 ppm, 26 ppm, 18 ppm
GM = 18.2 ppm
GSD = 1.41
95%ile = 32.3 ppm
$UCL_{95\%, 95\%}$ = 260 ppm

BDA Chart NOT the same as the Exposure Distribution

OEL = 100 ppm

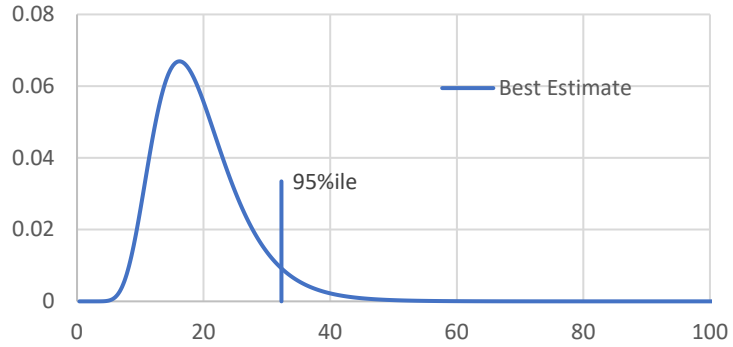
n=3, x = 13 ppm, 26 ppm, 18 ppm
GM = 18.2 ppm
GSD = 1.41
95%ile = 32.3 ppm
$UCL_{95\%, 95\%}$ = 260 ppm

Likelihood that the 95%ile is in an AIHA Exposure Rating and Control Category



≠

SEG Exposure Frequency Distribution (SEG Exposure Profile)

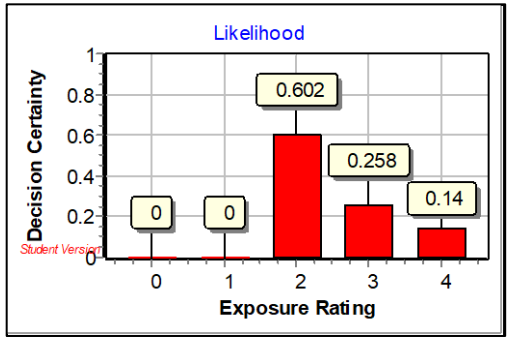


BDA Chart NOT the same as the Exposure Distribution

OEL = 100 ppm

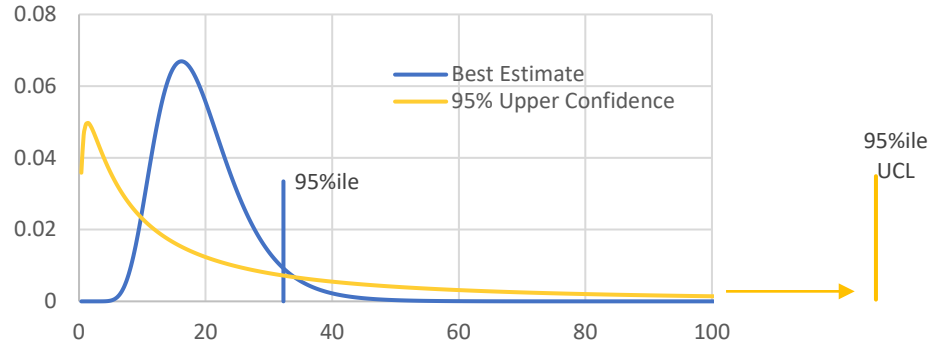
n=3, x = 13 ppm, 26 ppm, 18 ppm
GM = 18.2 ppm
GSD = 1.41
95%ile = 32.3 ppm
$UCL_{95\%, 95\%}$ = 260 ppm

Likelihood that the 95%ile is in an AIHA Exposure Rating and Control Category



≠

SEG Exposure Frequency Distribution (SEG Exposure Profile)



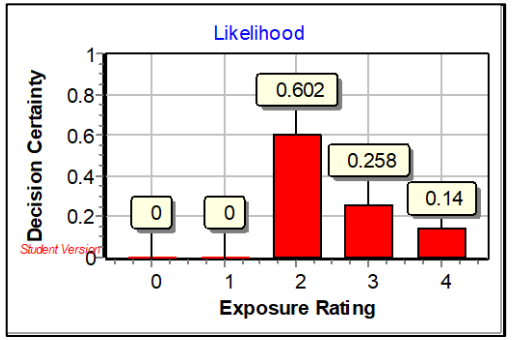
BDA Chart NOT the same as the Exposure Distribution

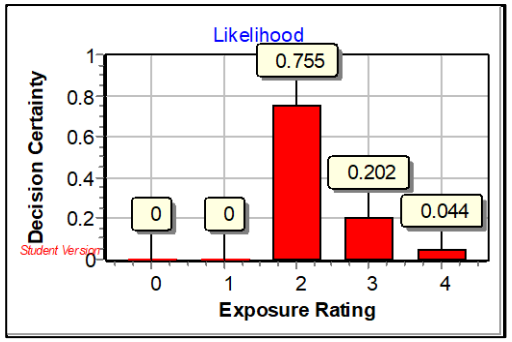
OEL = 100 ppm

n=3, x = 13 ppm, 26 ppm, 18 ppm
GM = 18.2 ppm
GSD = 1.41
95%ile = 32.3 ppm
$UCL_{95\%, 95\%}$ = 260 ppm

n=6, x = 13, 26, 18, 22, 8, 17 ppm
GM = 16.2 ppm
GSD = 1.52
95%ile = 32.3 ppm
$UCL_{95\%, 95\%}$ = 76.6 ppm

Likelihood that the 95%ile is in an AIHA Exposure Rating and Control Category

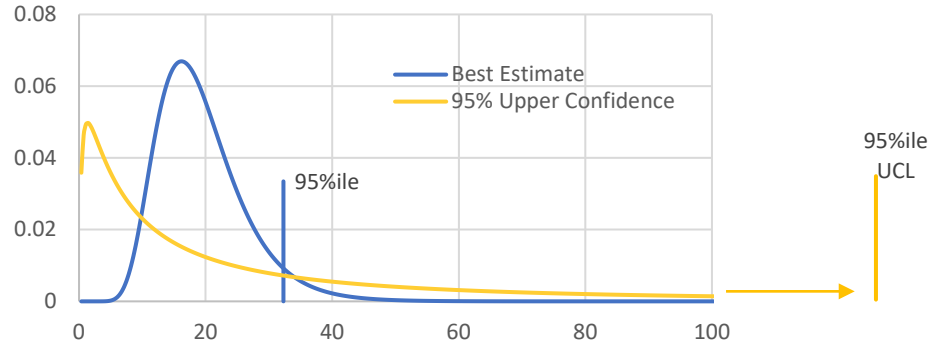


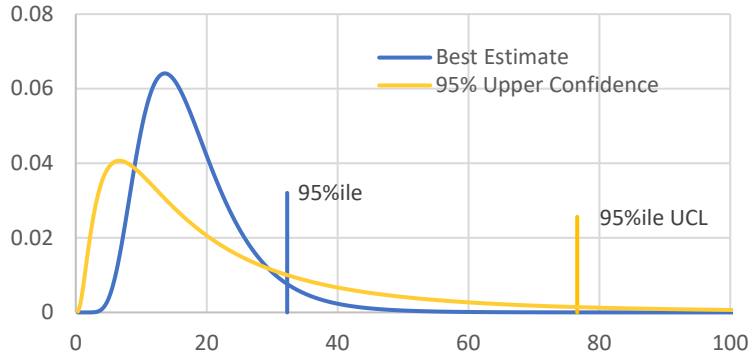


≠

≠

SEG Exposure Frequency Distribution (SEG Exposure Profile)





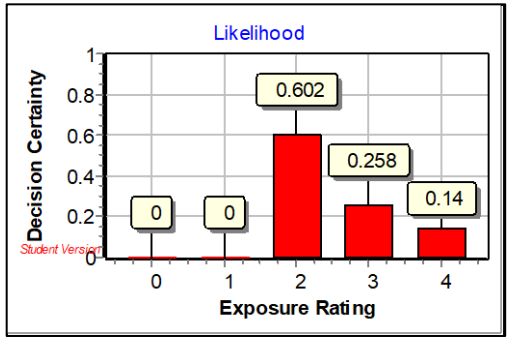
BDA Chart NOT the same as the Exposure Distribution

OEL = 100 ppm

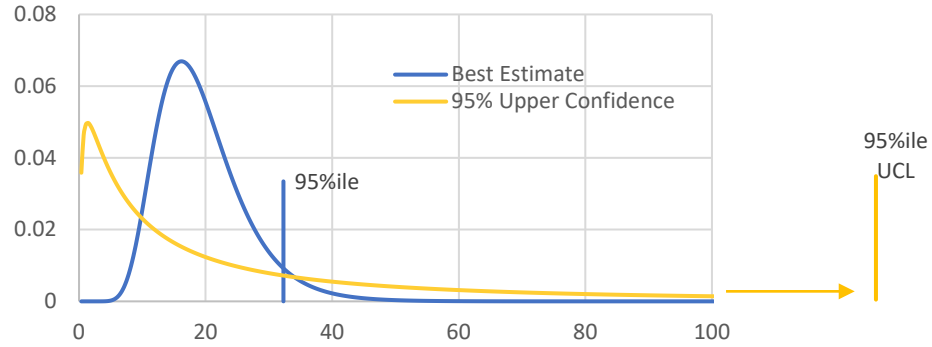
Likelihood that the 95%ile is in an AIHA Exposure Rating and Control Category

SEG Exposure Frequency Distribution (SEG Exposure Profile)

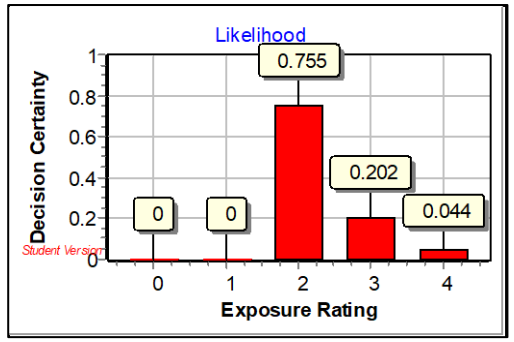
n=3, x = 13 ppm, 26 ppm, 18 ppm
GM = 18.2 ppm
GSD = 1.41
95%ile = 32.3 ppm
UCL $_{95\%, 95\%}$ = 260 ppm



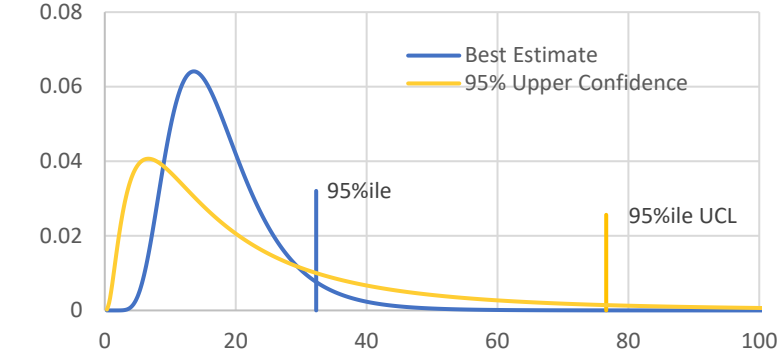
≠



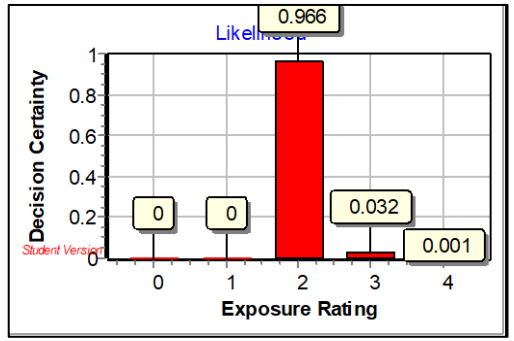
n=6, x = 13, 26, 18, 22, 8, 17 ppm
GM = 16.2
GSD = 1.52
95%ile = 32.3 ppm
UCL $_{95\%, 95\%}$ = 76.6 ppm



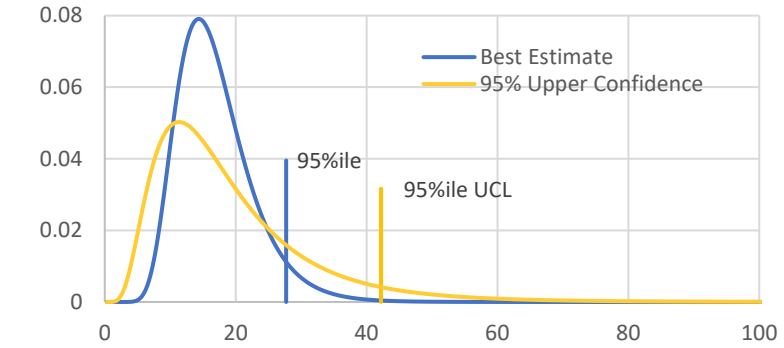
≠



n=10, x = 13, 26, 18, 22, 8, 17, 19, 12, 16, 17 ppm
GM = 16.0 ppm
GSD = 1.39
95%ile = 27.7 ppm
UCL $_{95\%, 95\%}$ = 42.2 ppm



≠

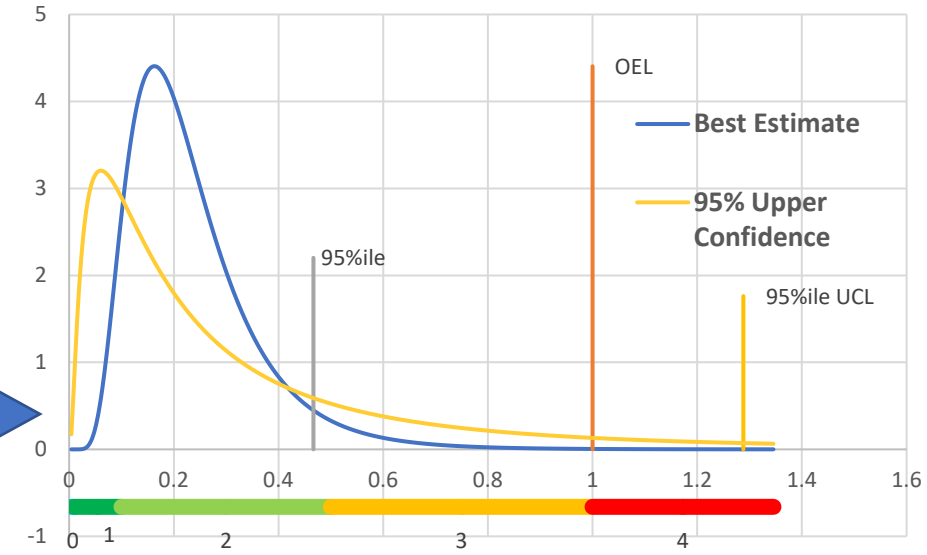


Traditional IH Statistics

OEL = 1 ppm

Sample Results (ppm)
0.18
0.25
0.1
0.36
0.33
0.15

Use sample results, along with understanding of underlying population shape (e.g. lognormal), to calculate best estimate of true population (e.g. SEG) exposure profile and its uncertainty

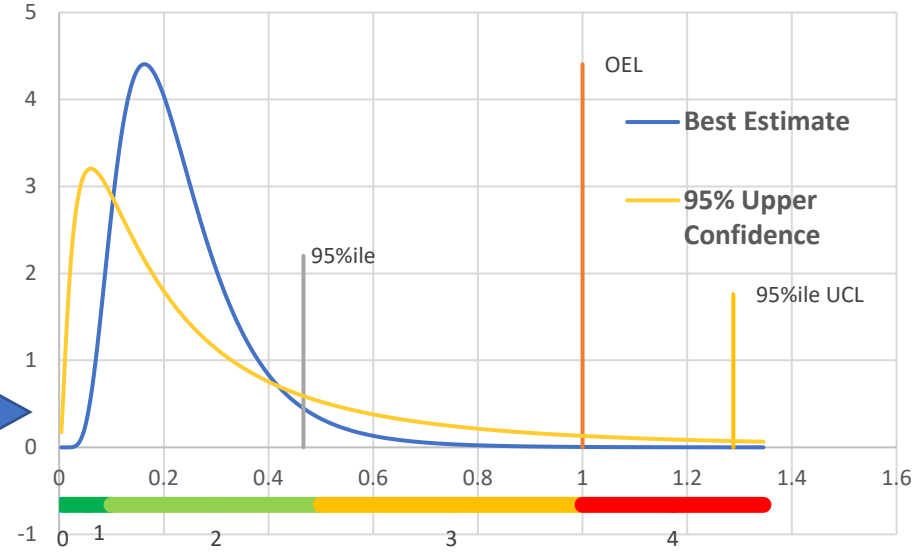


Traditional IH Statistics

OEL = 1 ppm

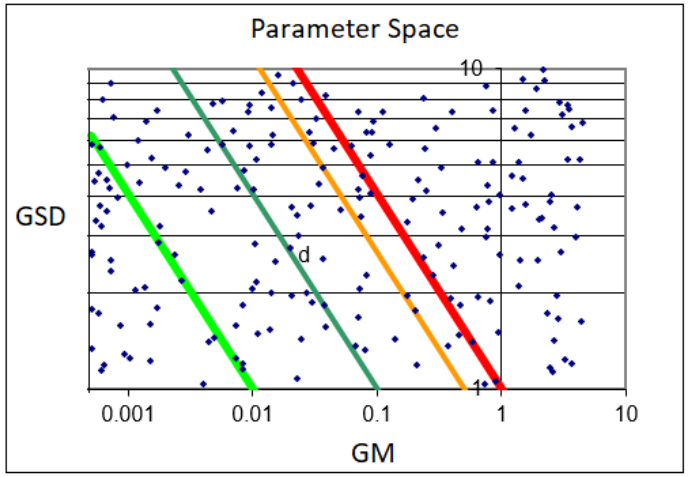
Sample Results (ppm)
0.18
0.25
0.1
0.36
0.33
0.15

Use sample results, along with understanding of underlying population shape (e.g. lognormal), to calculate best estimate of true population (e.g. SEG) exposure profile and its uncertainty



Bayesian Approach

Define “parameter space” of possible lognormal exposure profiles (each GM - GSD combination with associated 95%ile).

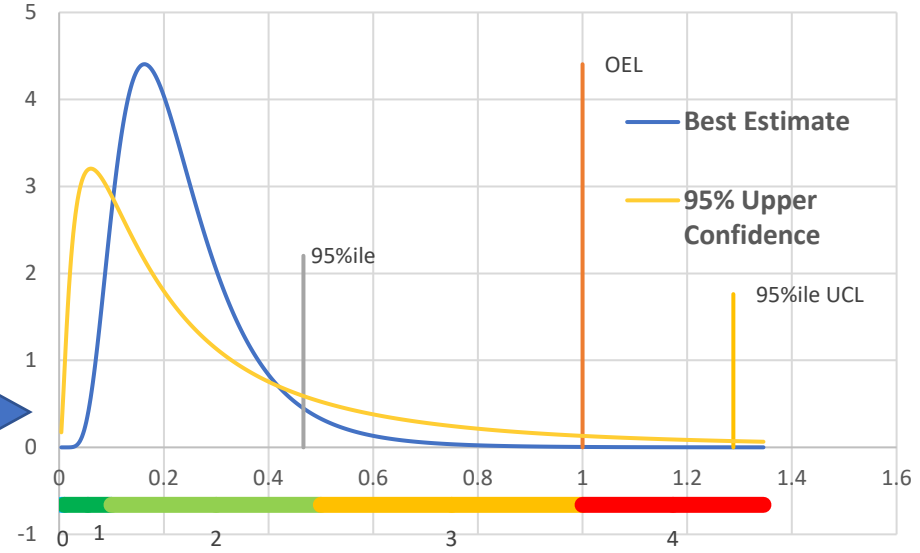


Traditional IH Statistics

OEL = 1 ppm

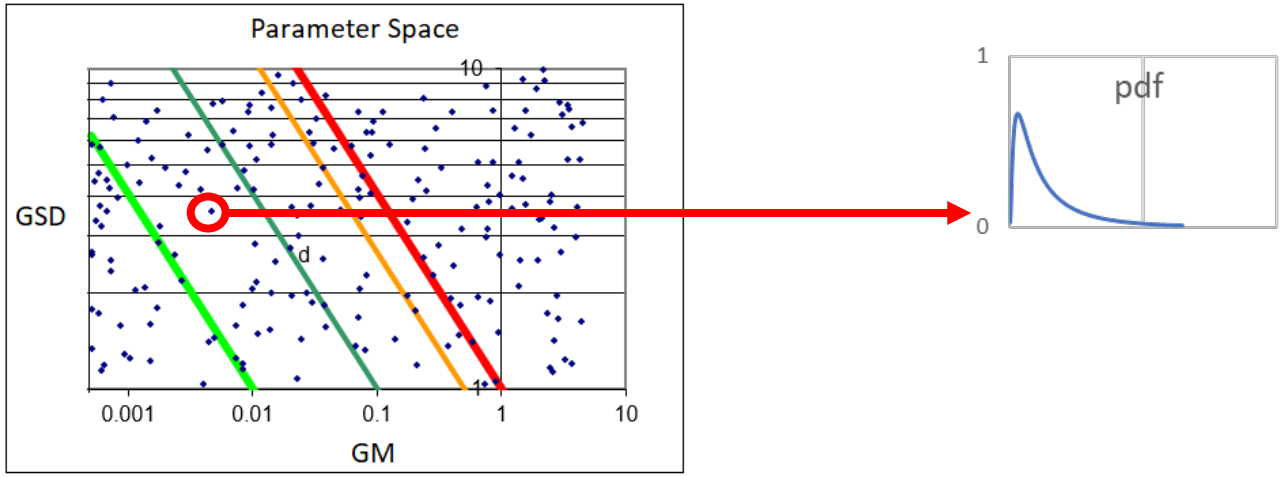
Sample Results (ppm)
0.18
0.25
0.1
0.36
0.33
0.15

Use sample results, along with understanding of underlying population shape (e.g. lognormal), to calculate best estimate of true population (e.g. SEG) exposure profile and its uncertainty



Bayesian Approach

Define “parameter space” of possible lognormal exposure profiles (each GM - GSD combination with associated 95%ile).

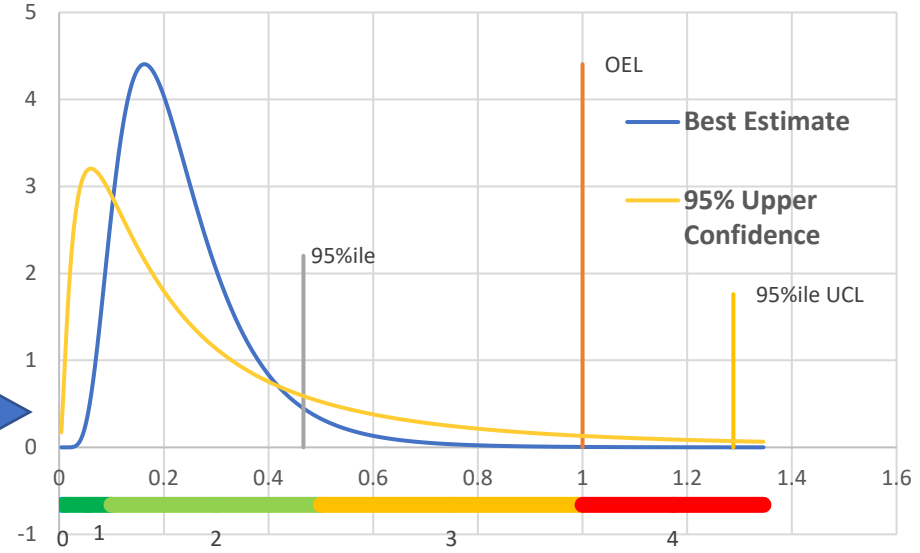


Traditional IH Statistics

OEL = 1 ppm

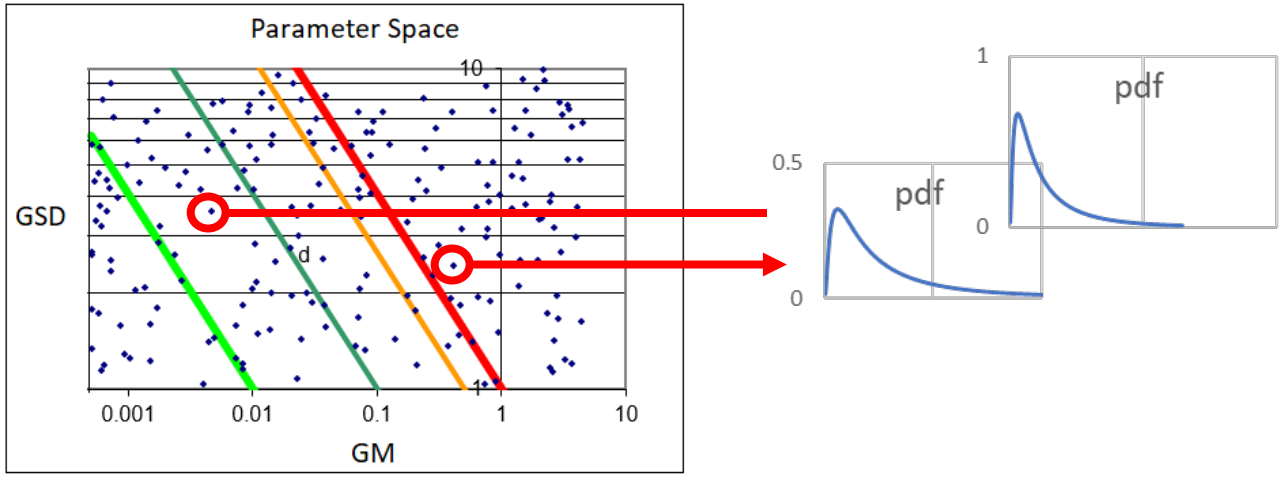
Sample Results (ppm)
0.18
0.25
0.1
0.36
0.33
0.15

Use sample results, along with understanding of underlying population shape (e.g. lognormal), to calculate best estimate of true population (e.g. SEG) exposure profile and its uncertainty



Bayesian Approach

Define “parameter space” of possible lognormal exposure profiles (each GM - GSD combination with associated 95%ile).

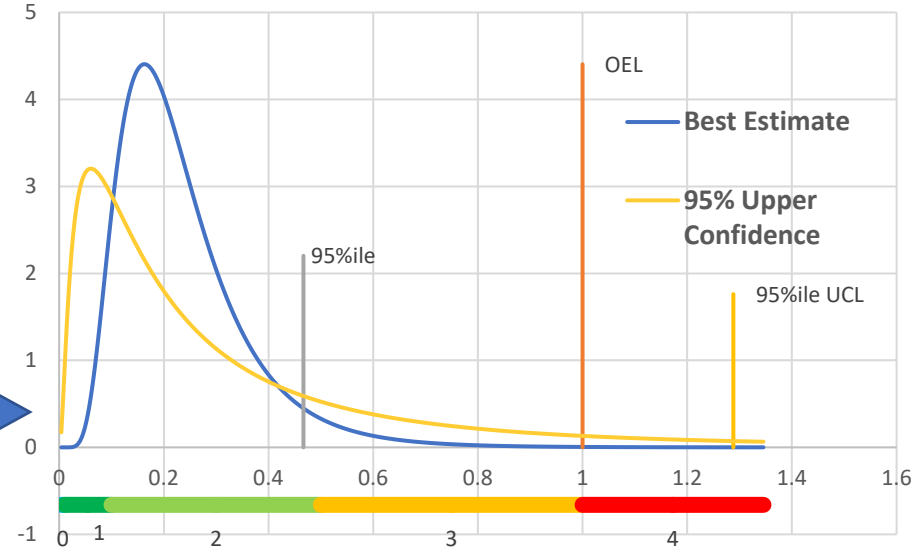


Traditional IH Statistics

OEL = 1 ppm

Sample Results (ppm)
0.18
0.25
0.1
0.36
0.33
0.15

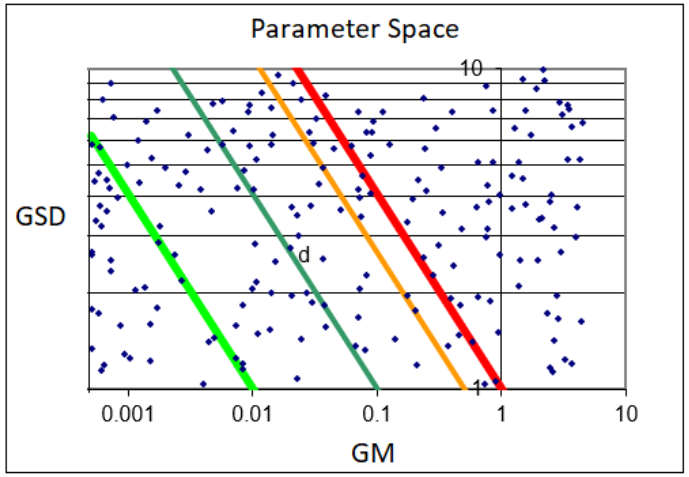
Use sample results, along with understanding of underlying population shape (e.g. lognormal), to calculate best estimate of true population (e.g. SEG) exposure profile and its uncertainty

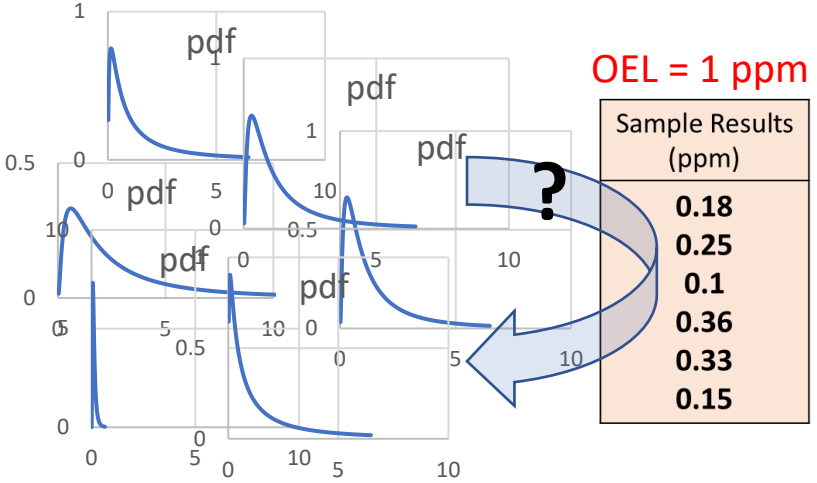


Bayesian Approach

Define "parameter space" of possible lognormal exposure profiles (each GM - GSD combination with associated 95%ile).

Calculate likelihood that sample data came from each exposure profile in parameter space.





OEL = 1 ppm

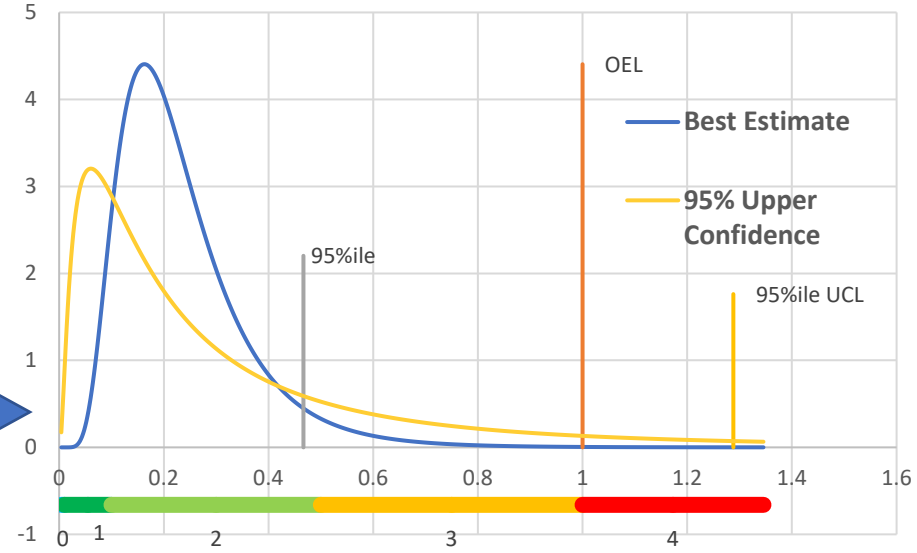
Sample Results (ppm)
0.18
0.25
0.1
0.36
0.33
0.15

Traditional IH Statistics

OEL = 1 ppm

Sample Results (ppm)
0.18
0.25
0.1
0.36
0.33
0.15

Use sample results, along with understanding of underlying population shape (e.g. lognormal), to calculate best estimate of true population (e.g. SEG) exposure profile and its uncertainty

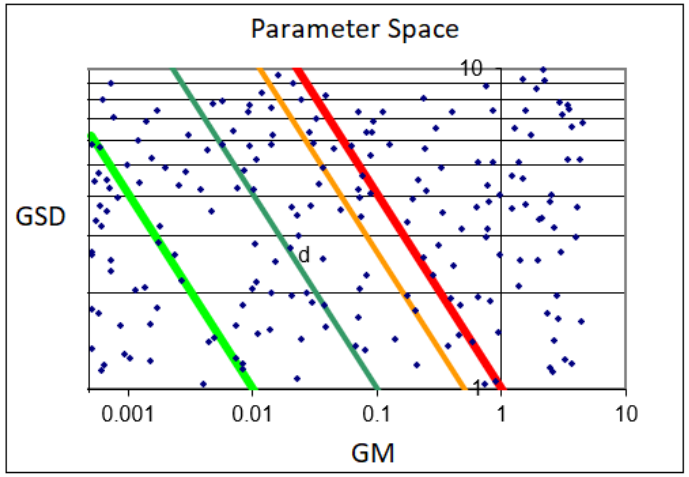


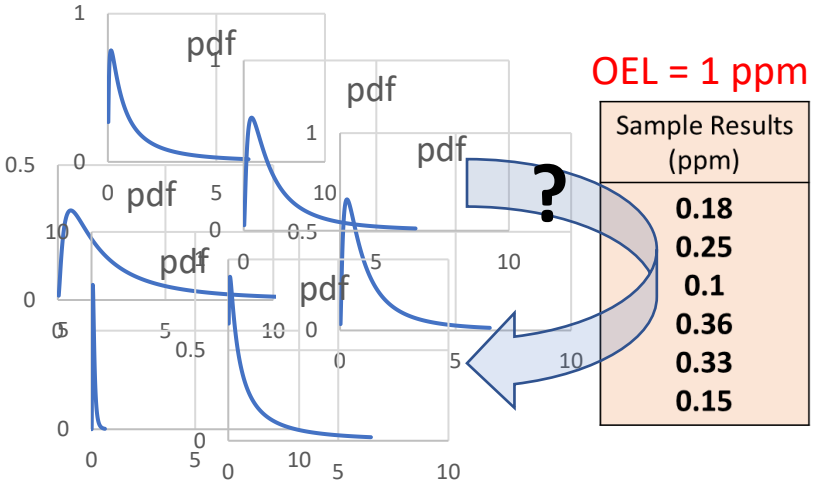
Bayesian Approach

Define "parameter space" of possible lognormal exposure profiles (each GM - GSD combination with associated 95%ile).

Calculate likelihood that sample data came from each exposure profile in parameter space.

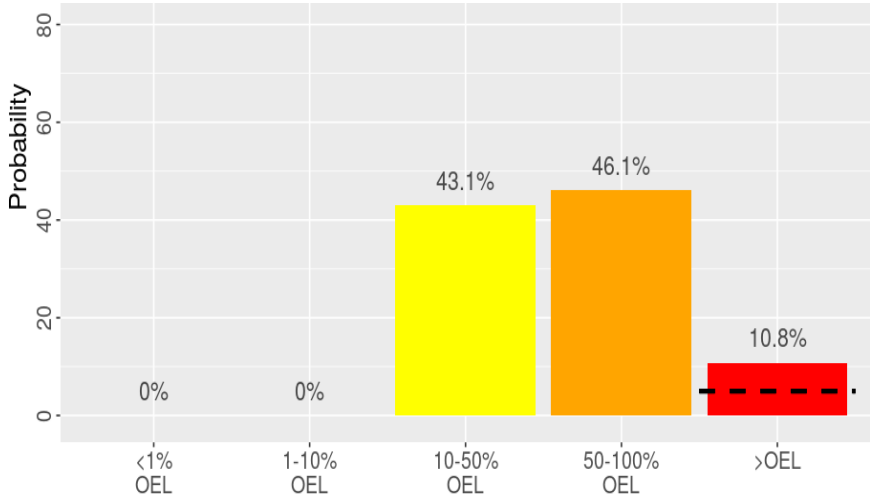
Sum and normalize likelihoods for all parameter space exposure profiles having 95%iles in each exposure category.





OEL = 1 ppm

Sample Results (ppm)
0.18
0.25
0.1
0.36
0.33
0.15



Improving Exposure Judgment

Interpreting BDA Charts

Steps in Data Analysis and Interpretation*

1. **Enter Data Into Appropriate Statistical Tool**
2. **Evaluate the Goodness-of-fit Chart**
3. **Review Descriptive and Inferential Statistics . . . Giving Special Attention to the GSD, 95%ile, UCL $_{95\%,70\%}$, and UCL$_{95\%,95\%}$**

   Compare…
   - the "decision statistic" (e.g. 95th percentile) to the OEL.
   - the UCL$_{95\%,70\%}$ and UCL$_{95\%,95\%}$ to the OEL.
4. **Assign a Final Rating and Certainty Level**
   - **Final Rating:** Compare the sample 95th percentile to the AIHA Exposure Rating Categories (ERCs) and select a category.
   - **Certainty Level:** Compare the UCL$_{95\%,95\%}$ to the ERCs:

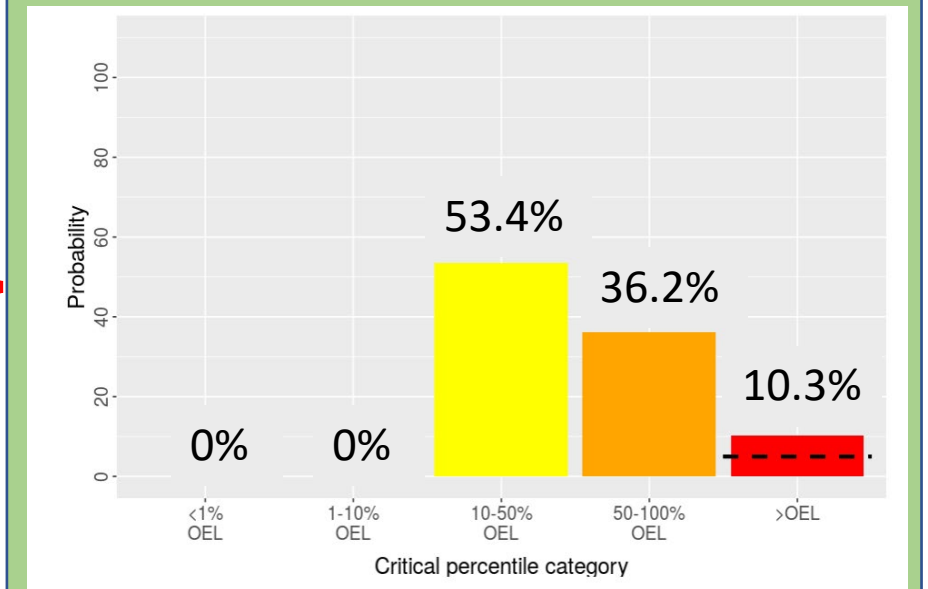
   Hewett's ROT
   - Low certainty if ≥ 2 categories above the chosen ERC
   - Medium certainty if only 1 category above
   - High certainty if within chosen category
5. **Document the Analysis and Recommendations**

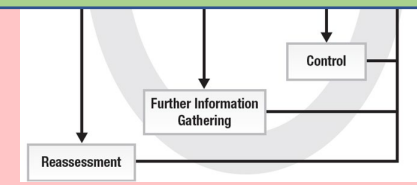
   Recommend controls and/or PPE; work practice evaluation; additional sampling; surveillance sampling, etc.

***After Executing a Carefully Defined Monitoring Plan:**

- Defined decision statistic
- Well defined SEG

Use BDA to Further Inform Final Rating and Certainty Decision

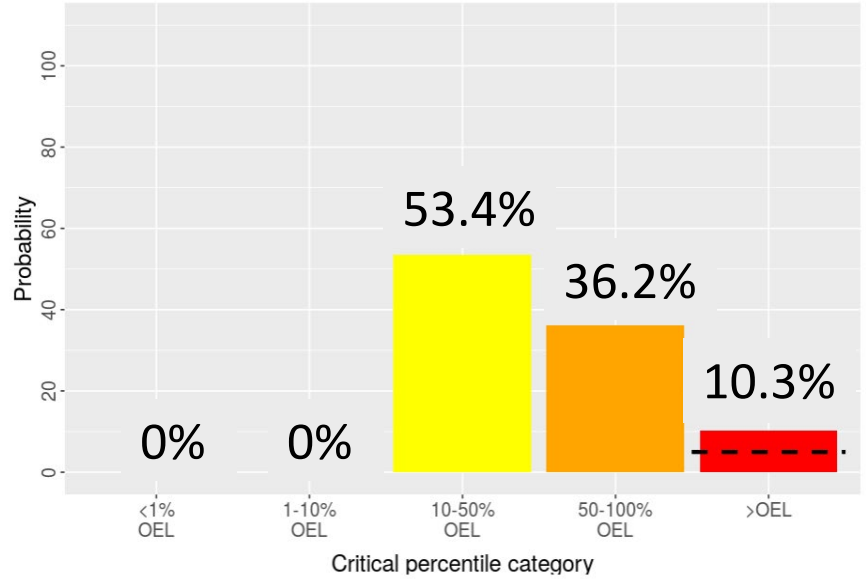




BDA Charts to Assign a Final Rating and Certainty Level

- **Final Exposure Rating**
  - Exposure Rating Category (ERCs) = category with highest bar
- **Certainty Level Rules of Thumb**
  - Low Certainty – decision probability is < 0.5
  - Medium Certainty – decision probability is between 0.5 and 0.75
  - High Certainty – decision probability is greater than 0.75.

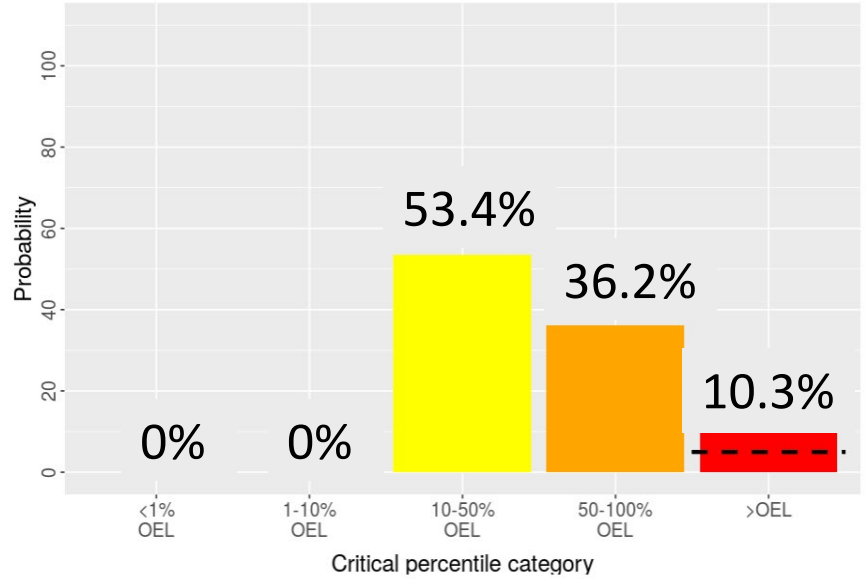
Rules of thumb are *guidelines*, not bright lines.



Category 2 (Medium Certainty)

Checking Likelihood of Category 4 (95%ile > OEL)

- **If ERC ≤ 3, check Category 4:**
  - Large Category 4 decision probabilities indicate that the true 95th percentile may exceed the OEL and therefore should be a cause for concern whenever the SEG is unlikely to be reevaluated for an extended period.
  - As a rule-of-thumb, Category 4 decision probabilities up to 0.30 are tolerable, provided the SEG is regularly checked as part of an ongoing monitoring strategy.
    - < 0.05 – **acceptable**
    - 0.05-0.3 – **tolerable**, **assuming the SEG has a required monitoring plan**
    - > 0.3 – **problematic**, particularly if the SEG has no monitoring plan.



Category 2
(Medium Certainty)

Tolerable assuming SEG has a required monitoring plan

Discussion

It is useful to think of interpreting BDA charts as a two step process:

1) What is the most likely category? (i.e. Which category has the highest likelihood bar?)

2) Is the likelihood in Category 4 less than the decision criteria for the upper percentile (e.g. is there a less-than 5% likelihood that the 95%ile is in Category 4?)

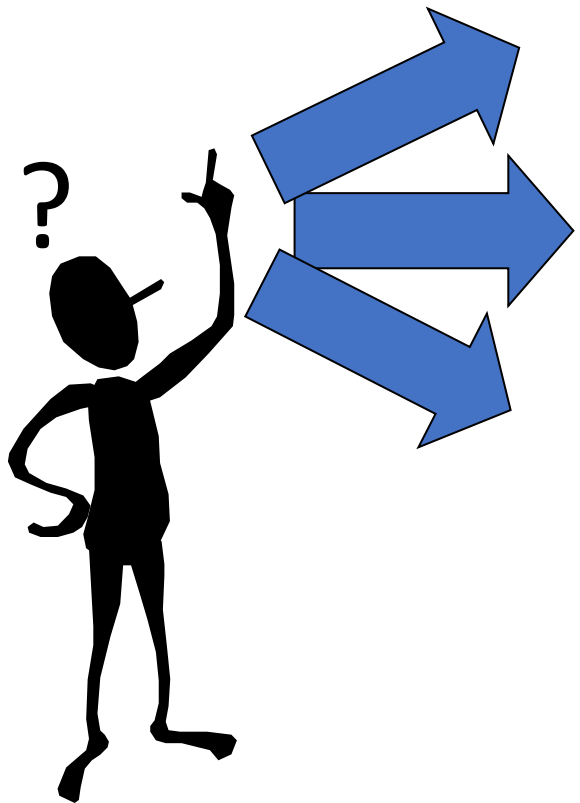
Examples

Example 1

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

OEL = 100 ppm

Sample Results (ppm)
13
26
18



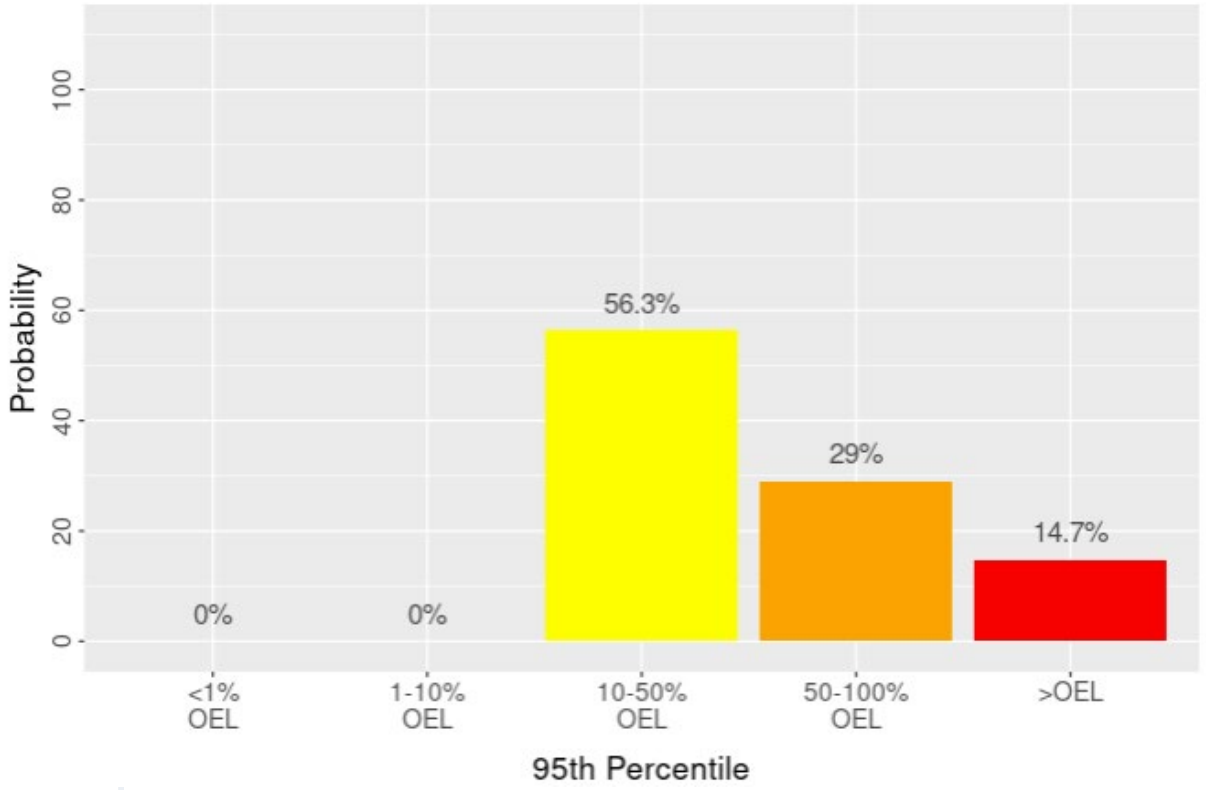
	Exposure Rating Category**	Recommended Control
	0 (<1% of OEL)	No action
	1 (<10% of OEL)	Procedures and Training; General Hazard Communication
	2 (10-50% of OEL)	+ Chemical Specific Hazard Communication; Periodic Exposure Monitoring,
	3 (50-100% of OEL)	+ Required Exposure Monitoring, Workplace Inspections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

* Decision statistic = 95th percentile

How do we interpret this?

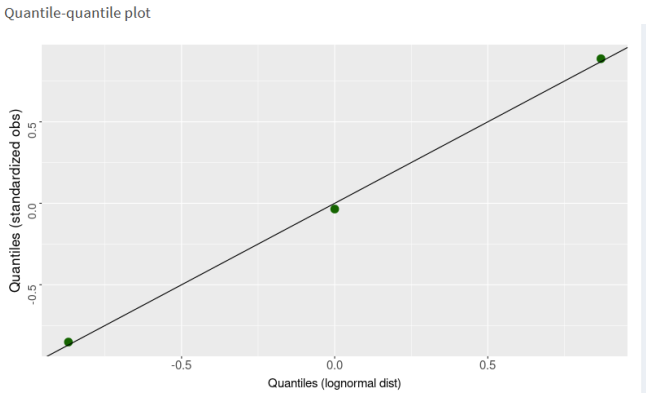
Sample Results (ppm)
13
26
18

OEL = 100 ppm
GM = 18.3 ppm
GSD = 1.41
95%ile = 32.3 ppm
$UCL_{95,95}$ = 260 ppm



Likely Category 2
(Medium Certainty)

Cat 4 = 0.1-0.3: **Tolerable**, assuming the SEG has a monitoring plan

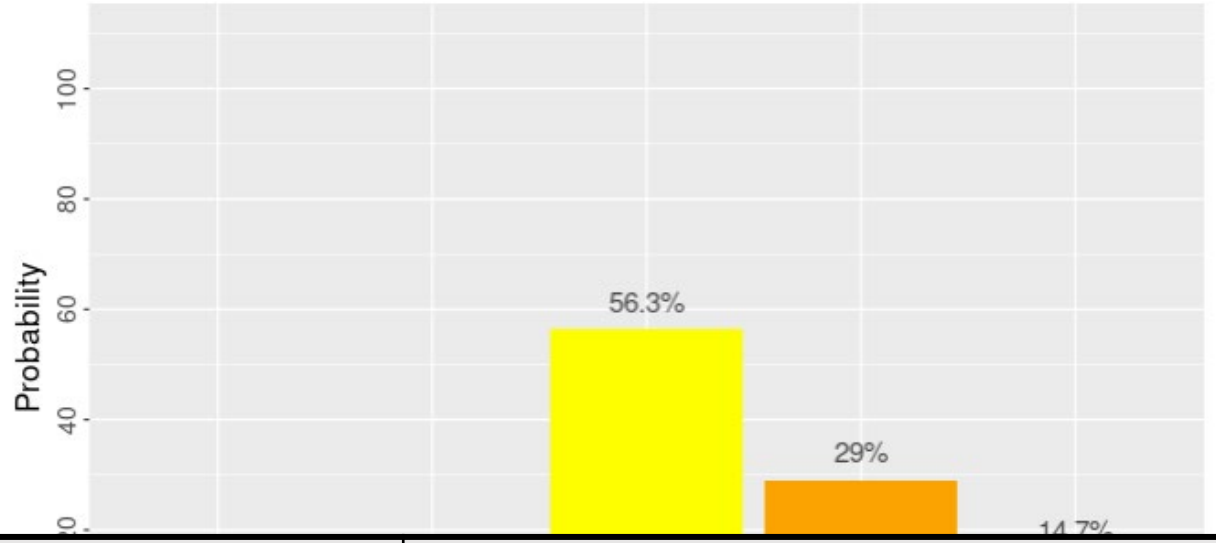


"We have a 14.7% probability that Process Operator #1 requires additional exposure controls"

How do we interpret this?

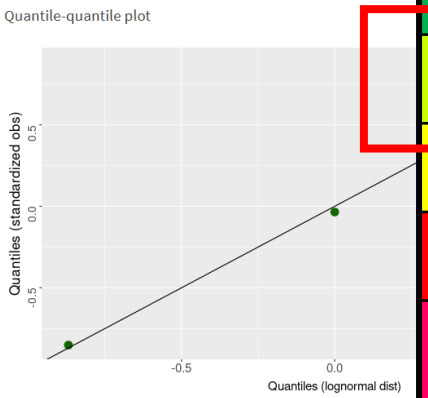
Sample Results (ppm)
13
26
18

OEL = 100 ppm
GM = 18.3 ppm
GSD = 1.41
95%ile = 32.3 ppm
$UCL_{95,95}$ = 260 ppm



Likely Category 2
(Medium Certainty)

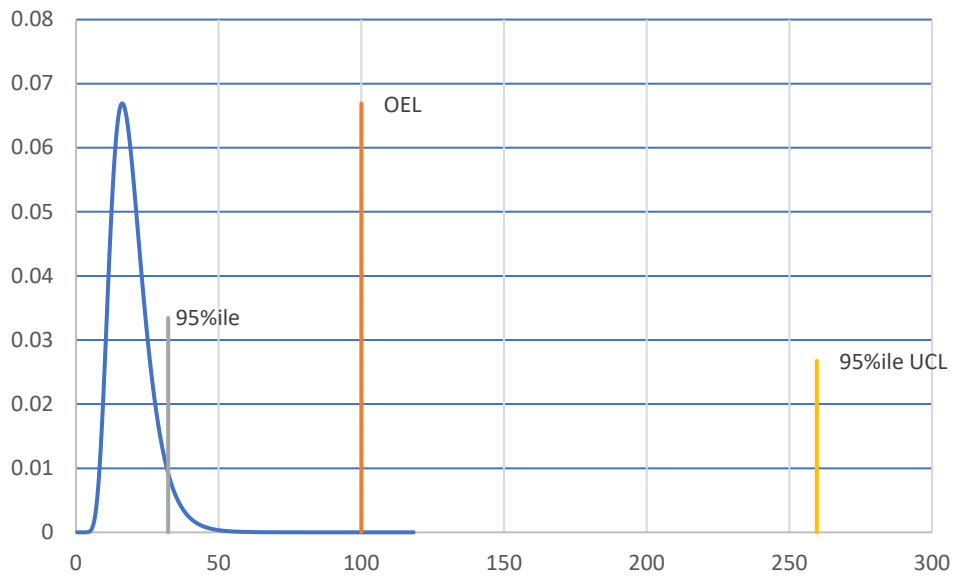
Cat 4 = 0.1-0.3: **Tolerable**, assuming the SEG has a monitoring plan



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

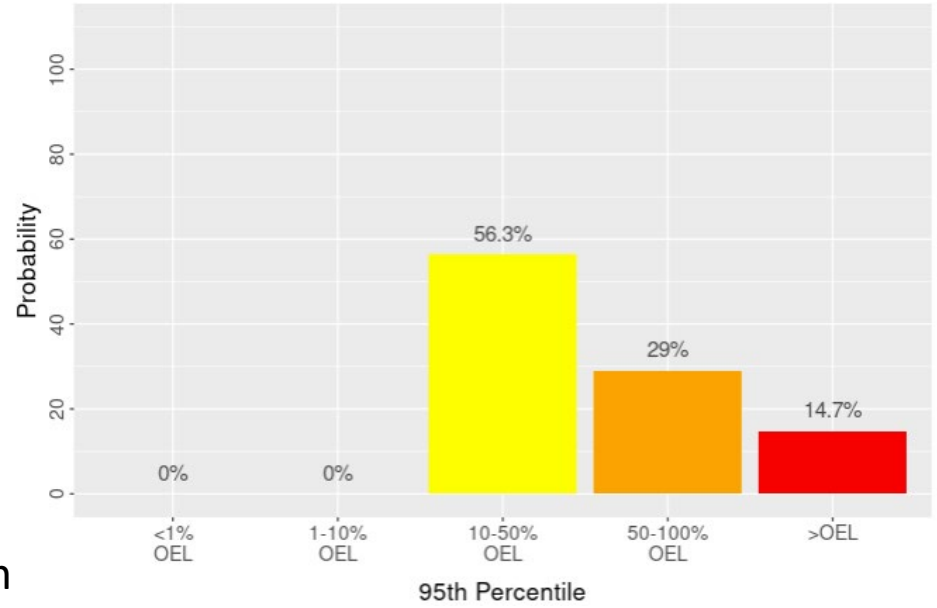
Action:
Procedures and Training; Chemical Specific Hazard Communication; Required Exposure Monitoring,

Compare traditional statistics vs. BDA …



Sample Results (ppm)
13
26
18

OEL = 100 ppm
GM = 18.3 ppm
GSD = 1.41
95%ile = 32.3 ppm
$UCL_{95,95}$ = 260 ppm



"The population 95th percentile point estimate is 32 ppm with a 95% upper confidence limit of 260 ppm"

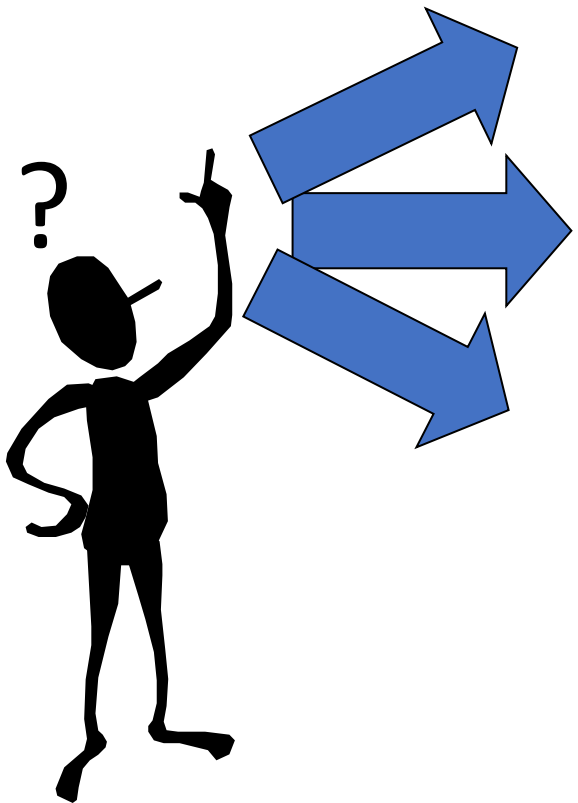
"We have a 14.7 % probability that Process Operator #1 requires additional exposure controls"

Example 2

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

OEL = 100 ppm

Sample Results (ppm)
13
26
18
32
18
13



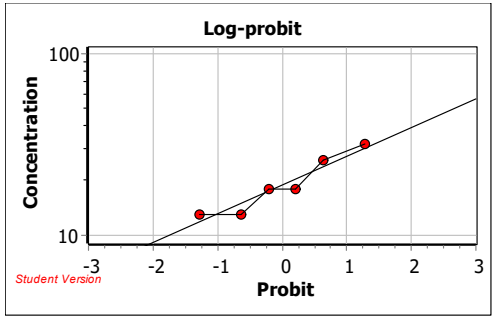
	Exposure Rating Category**	Recommended Control
	0 (<1% of OEL)	No action
	1 (<10% of OEL)	Procedures and Training; General Hazard Communication
	2 (10-50% of OEL)	+ Chemical Specific Hazard Communication; Periodic Exposure Monitoring,
	3 (50-100% of OEL)	+ Required Exposure Monitoring, Workplace Inspections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

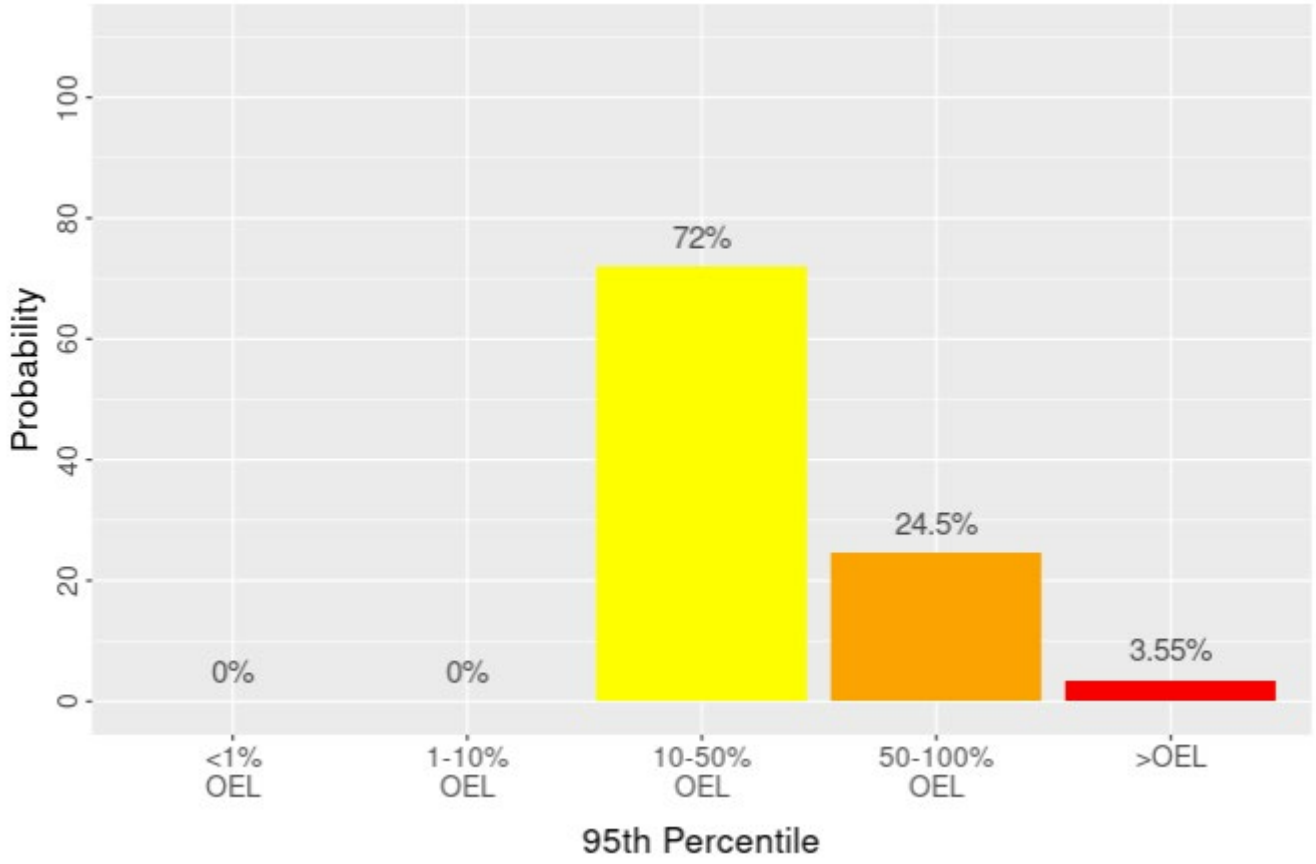
* Decision statistic = 95th percentile

Example Likelihood Decision Chart:

Sample Results (ppm)
13
26
18
32
18
13

OEL = 100 ppm
GM = 18.9 ppm
GSD = 1.44
95%ile = 34.4 ppm
$UCL_{95,95}$ = 73 ppm





"(Given the data,) I am moderately confident that the true 95th percentile falls between 10% and 50% of the OEL."

Likely Category 2
(Medium Certainty)

Cat 4 < 0.05: **Acceptable**,

Actions:

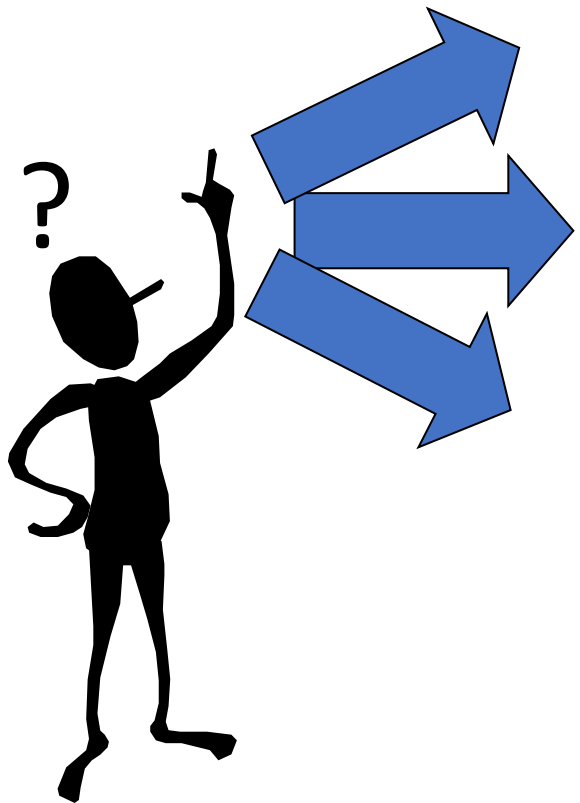
Procedures and Training; Chemical Specific Hazard Communication; Periodic Exposure Monitoring,

Example 3

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

OEL = 100 ppm

Sample Results (ppm)
75
50
42



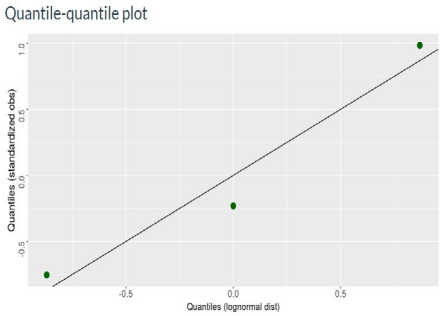
	Exposure Rating Category**	Recommended Control
	0 (<1% of OEL)	No action
	1 (<10% of OEL)	Procedures and Training; General Hazard Communication
	2 (10-50% of OEL)	+ Chemical Specific Hazard Communication; Periodic Exposure Monitoring,
	3 (50-100% of OEL)	+ Required Exposure Monitoring, Workplace Inspections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

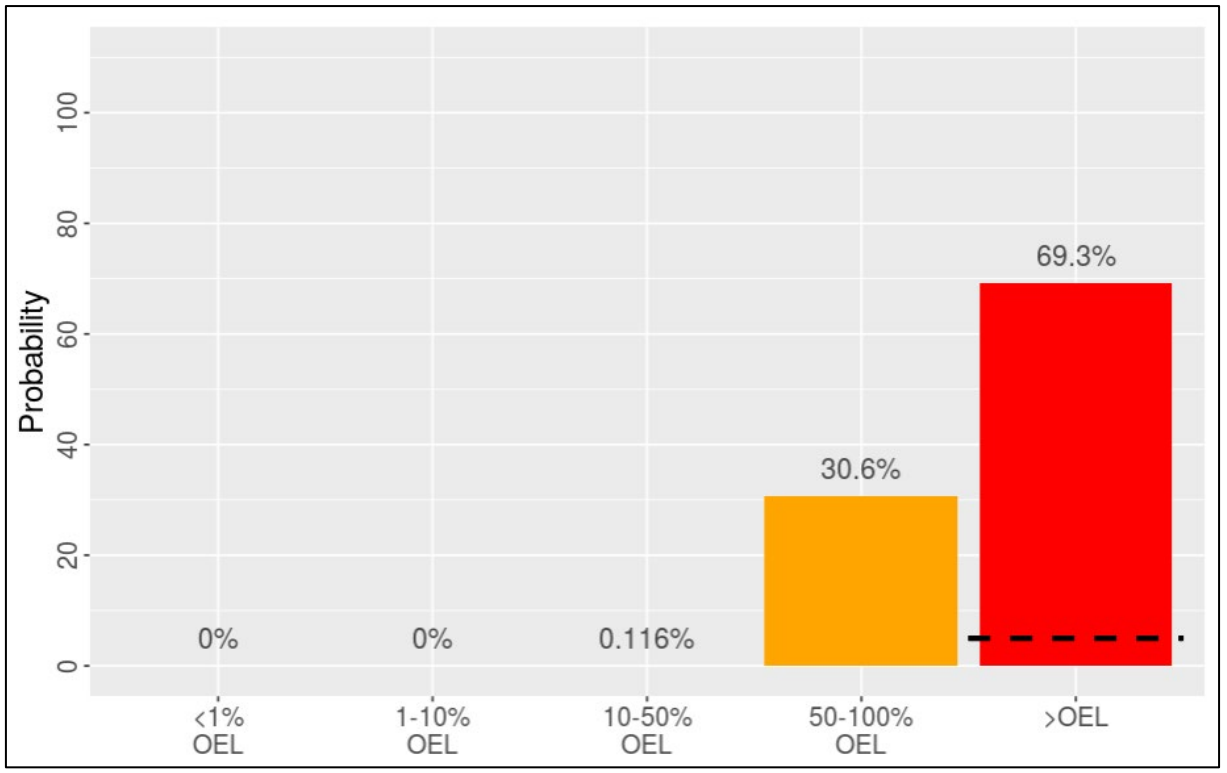
* Decision statistic = 95th percentile

Example Likelihood Decision Chart:

Sample Results (ppm)
75
50
42

OEL = 100 ppm
GM = 54 ppm
GSD = 1.35
95%ile = 126 ppm
$UCL_{95,95}$ = 549 ppm





"(Given the data,) nearly 70% chance that exposures are unacceptable"

Likely Category 4
(Medium Certainty)

Unacceptable

Actions:

Chem. Specific Haz. Com.; Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection.

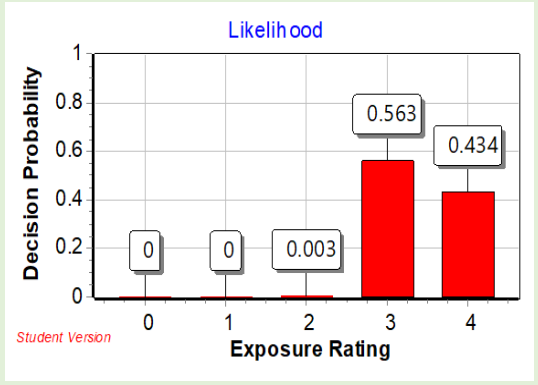
Improving Exposure Judgment

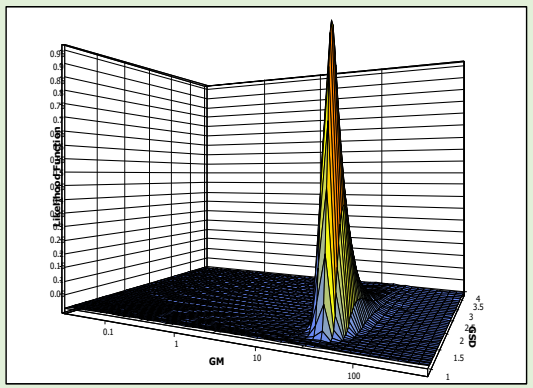
BDA and Censored Data

BDA Handles Censored Data Very Well (OEL = 100)

None Censored

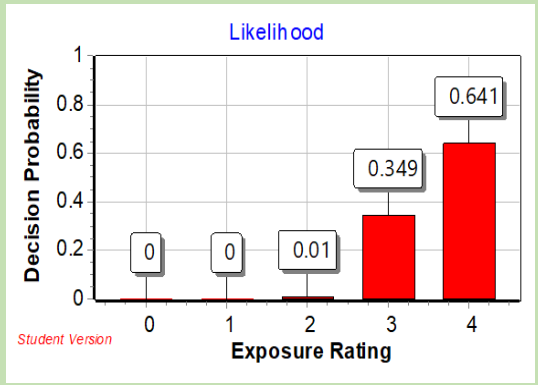
X
65
29
48
42
33
16
57

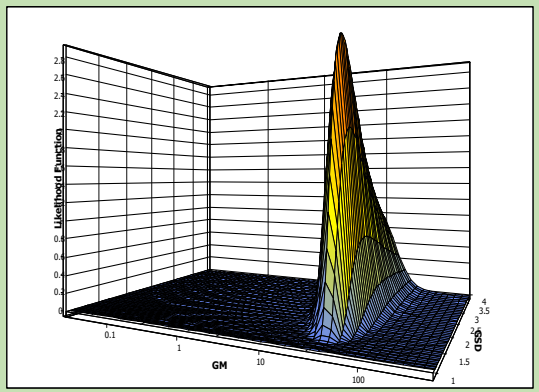




Partially Censored

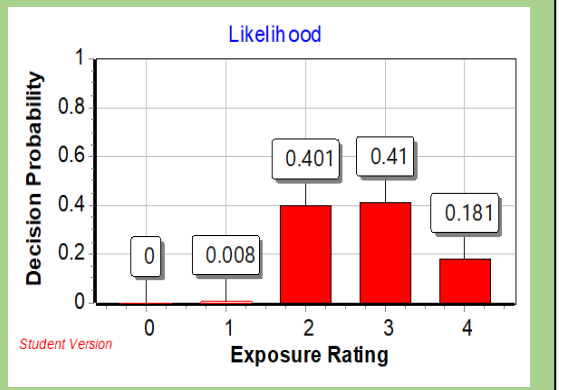
X
65
<29
48
42
<33
<16
57

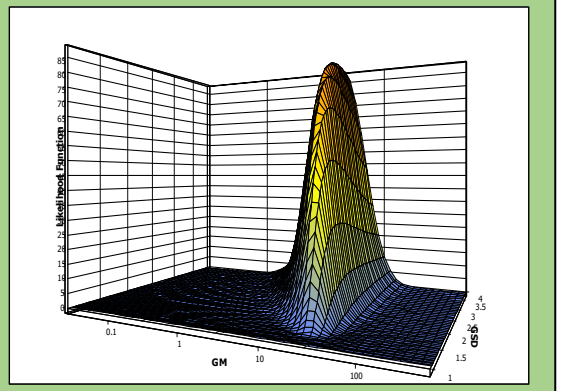




Severely Censored

X
65
<29
<48
<42
<33
<16
<57

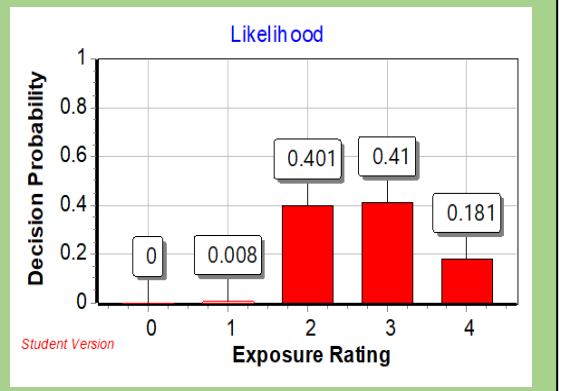


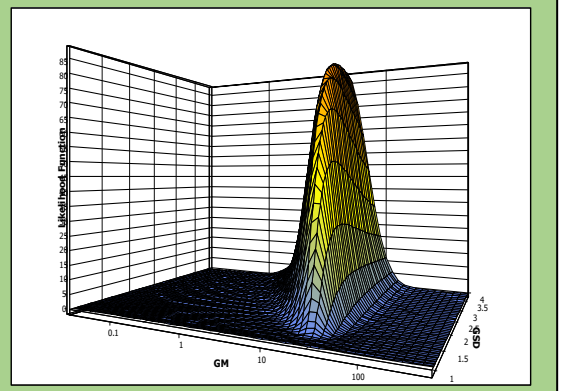


BDA Handles Censored Data Very Well (OEL = 100)

Severely Censored

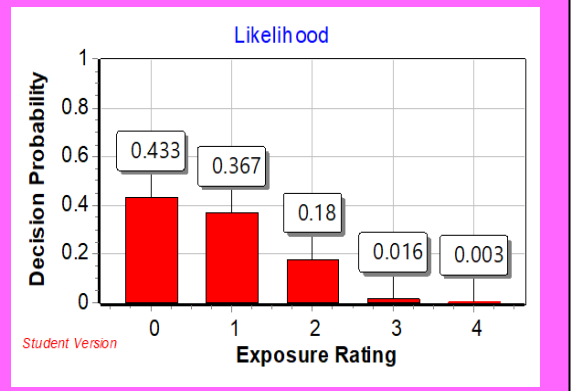
X
65
<29
<48
<42
<33
<16
<57

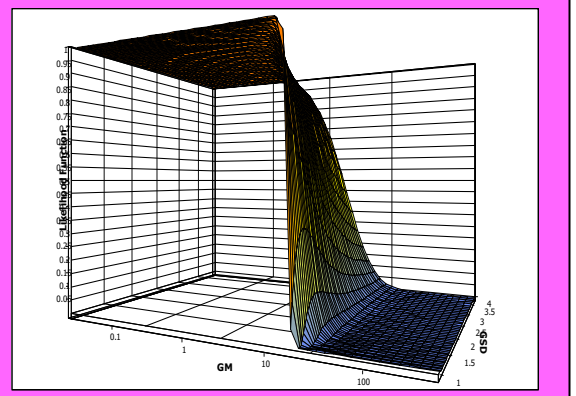




Fully Censored

X
<65
<29
<48
<42
<33
<16
<57





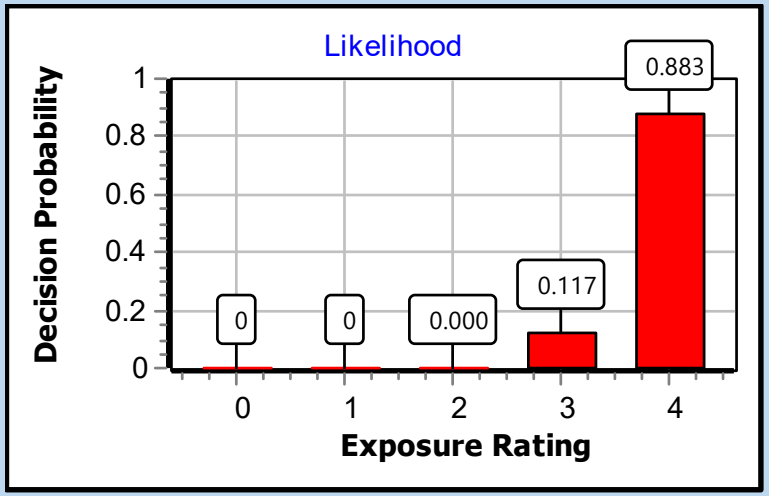
Reminder: Garbage In = Garbage Out

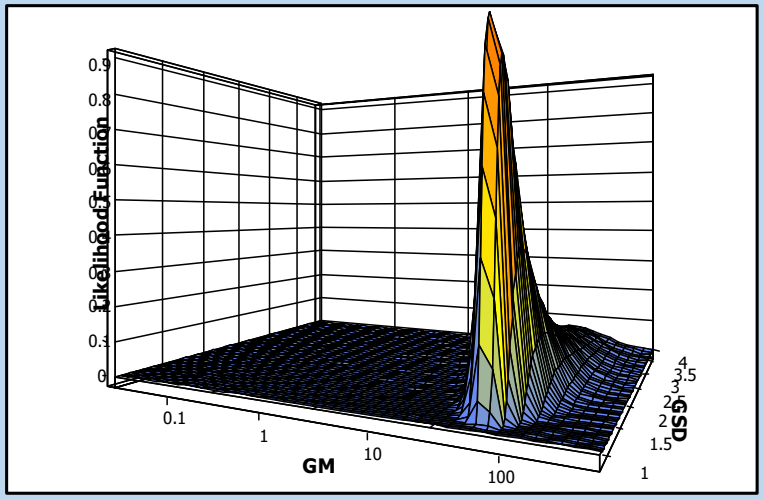
- Bayesian and traditional statistical tools assume scientifically-sound data.
- Statistical tools know nothing about flow rates, sample times, sampling / analytical detection limits or other factors that can influence the censoring of monitoring results.
- **Take the time to plan your sampling strategy to ensure a reasonably low detection limit (e.g. 10% of the OEL or lower)**

Caution About Fully Censored Data Near the OEL

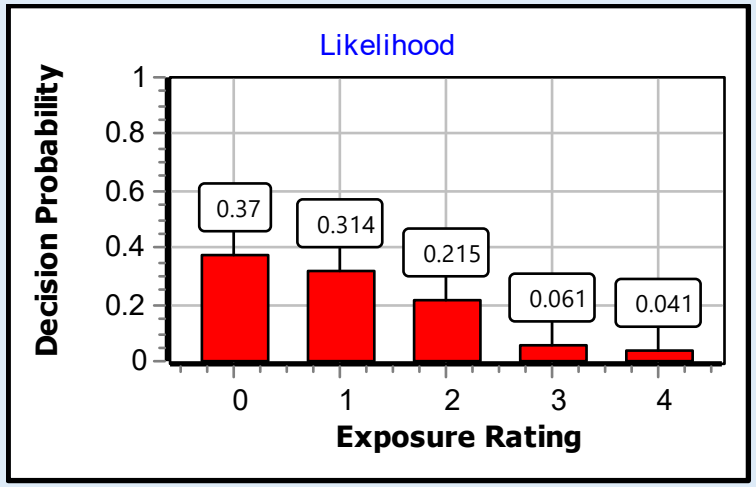
(OEL = 100 ppm)

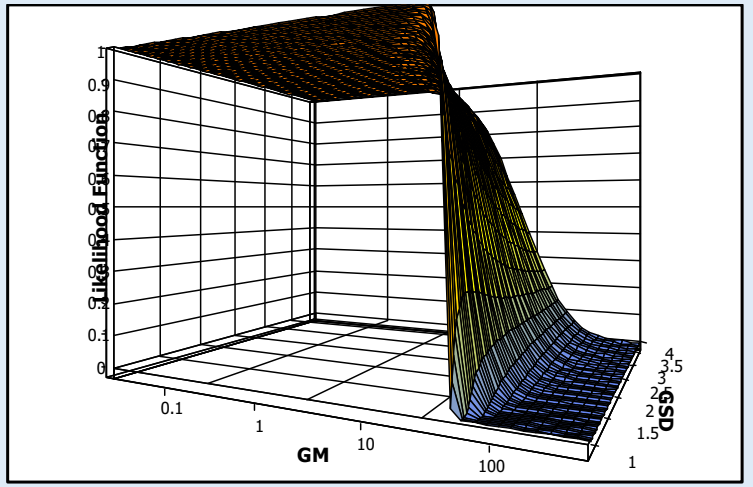
X
64
98
42





X
<65
<99
<43

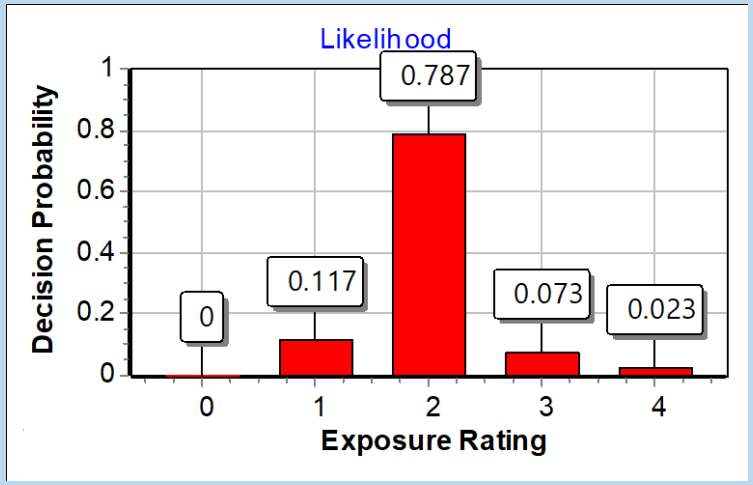


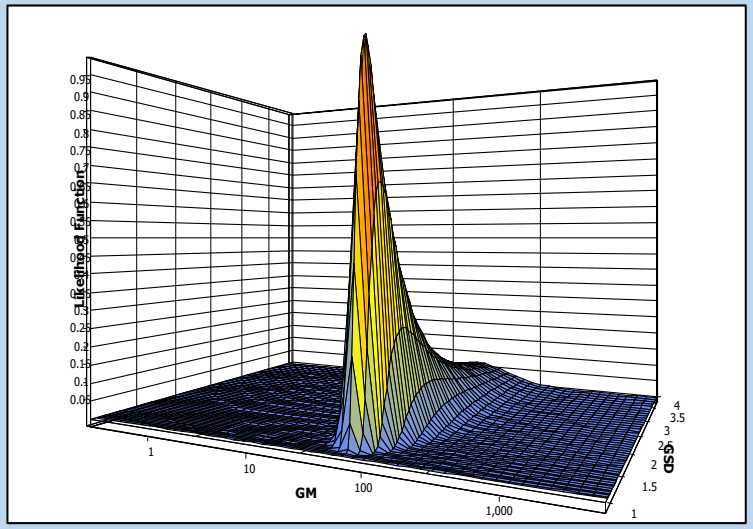


Caution About Fully Censored Data Near the OEL

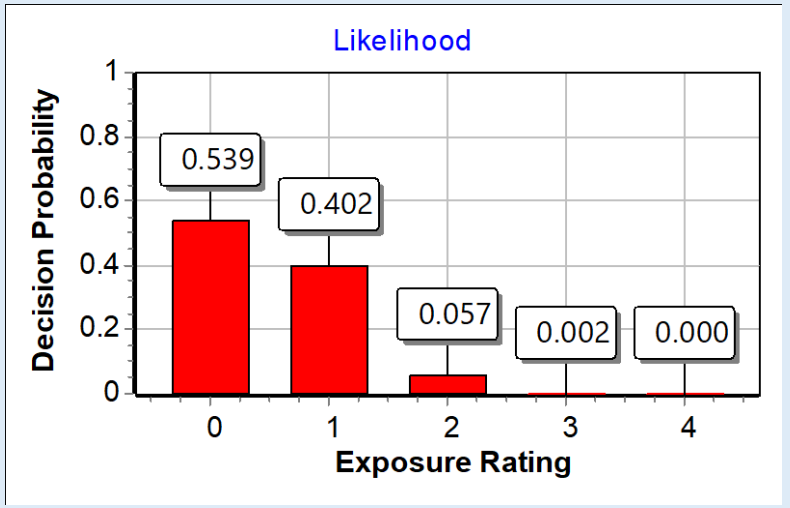
(OEL = **1000** ppm)

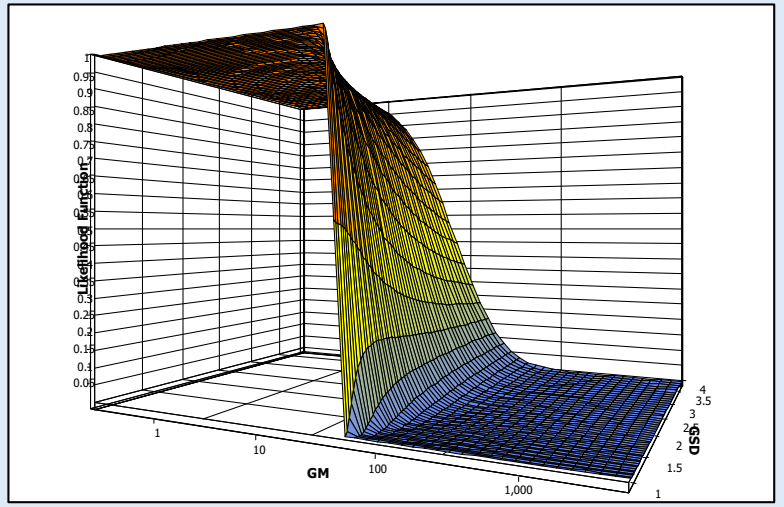
X
64
98
42





X
<65
<99
<43

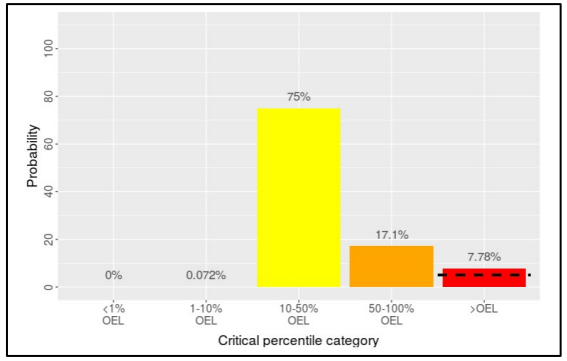




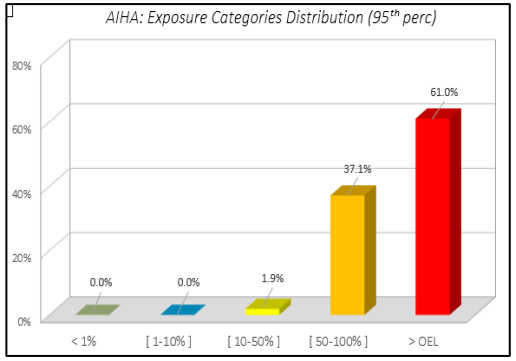
Improving Exposure Judgment

FREE Bayesian Tools . . .

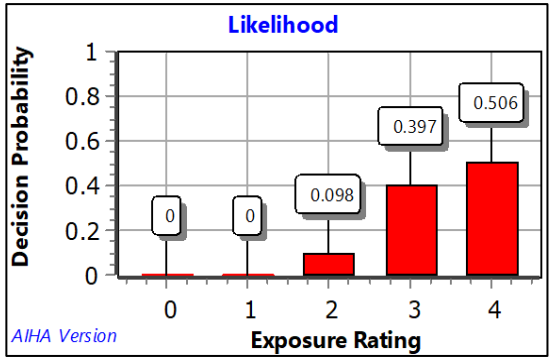
Available HERE



Expostats



IHSTAT-Bayes

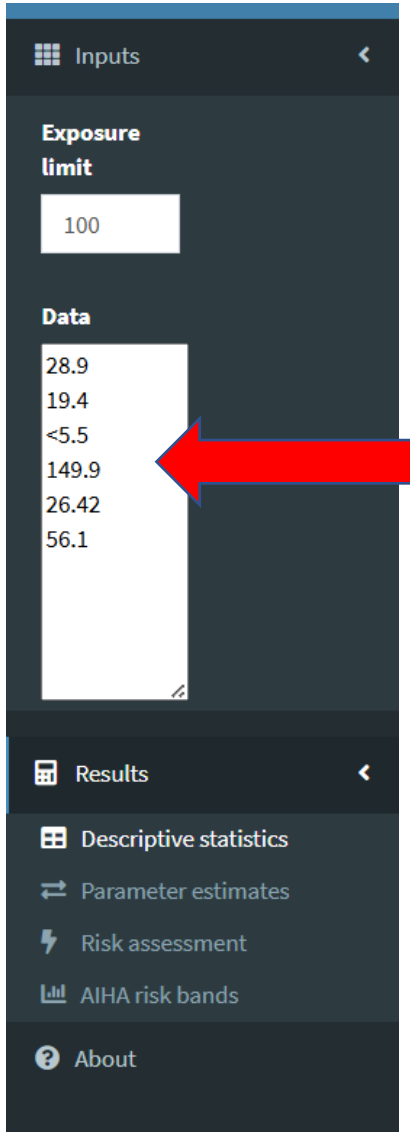


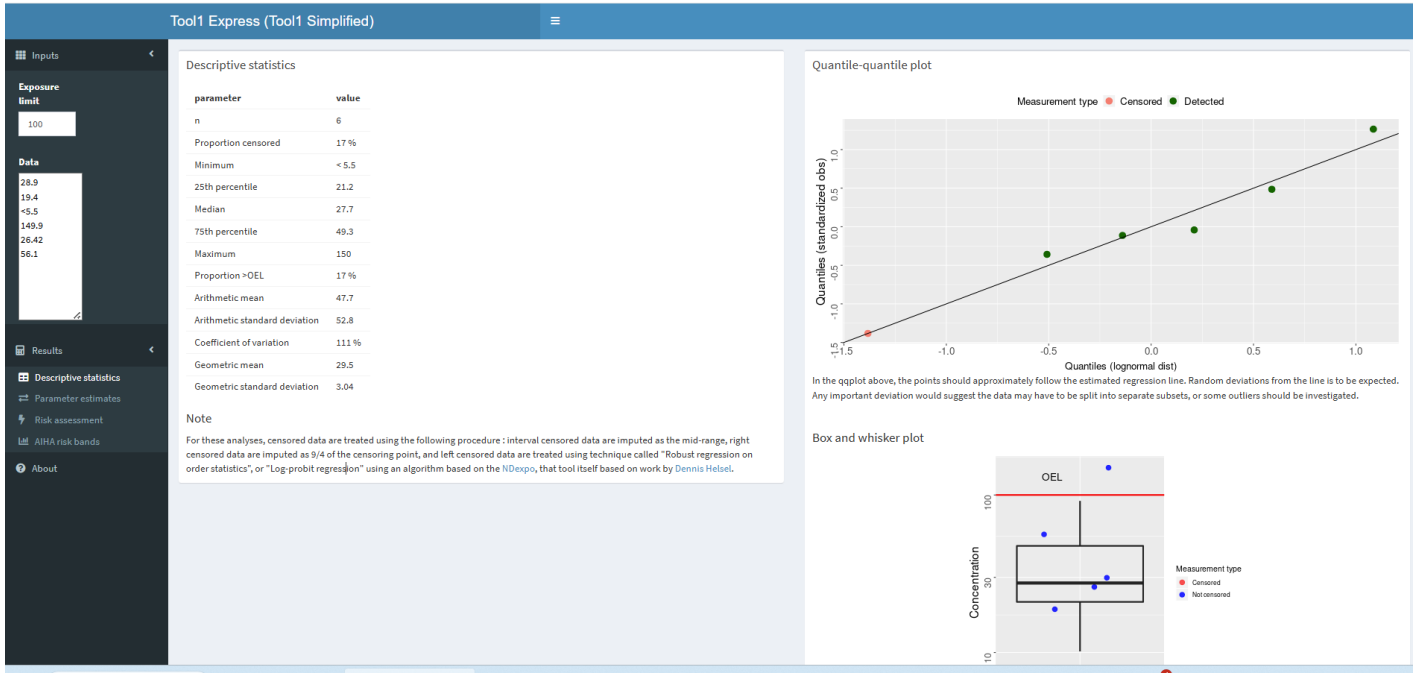
IHDA-AIHA

Expostats

Simplified Version

1. Enter OEL

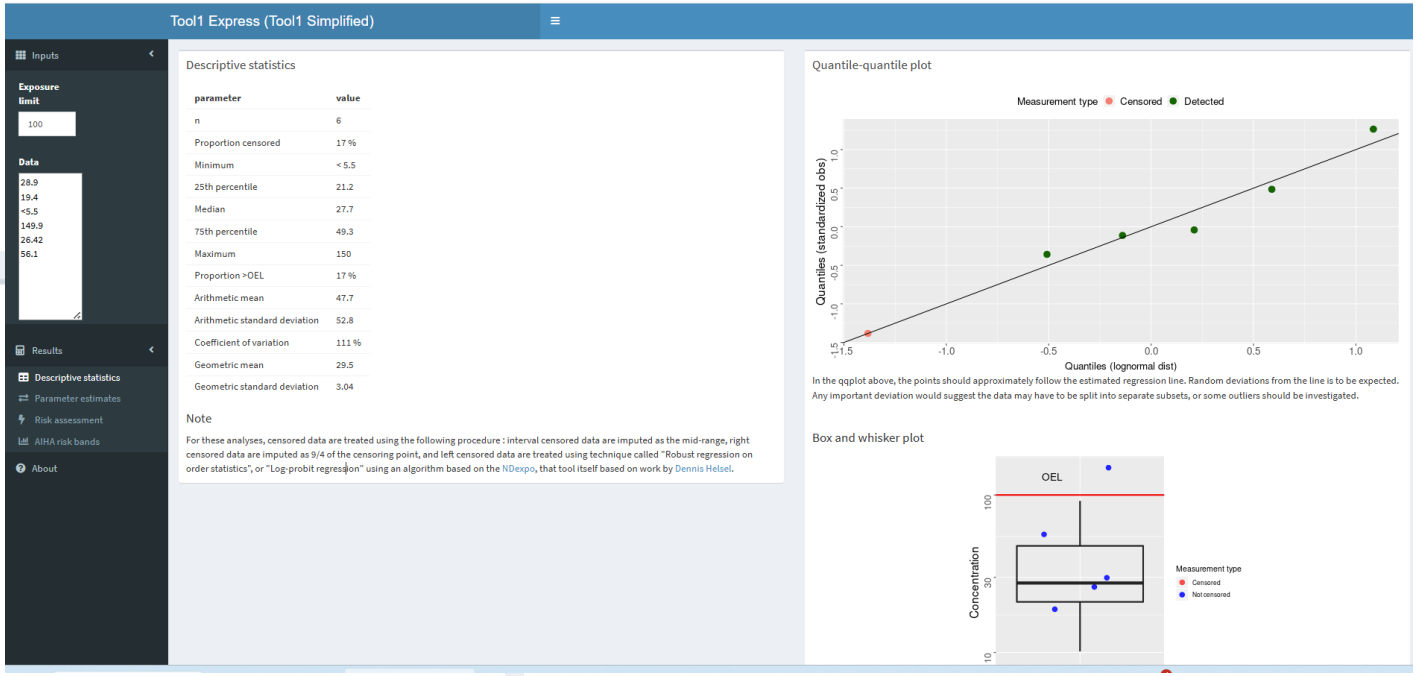




2. Enter Sample Results
(Enter leading zero if less than 1)
(Indicate <LOD values with a '<' preceding the LOD value)

Expostats

Simplified Version



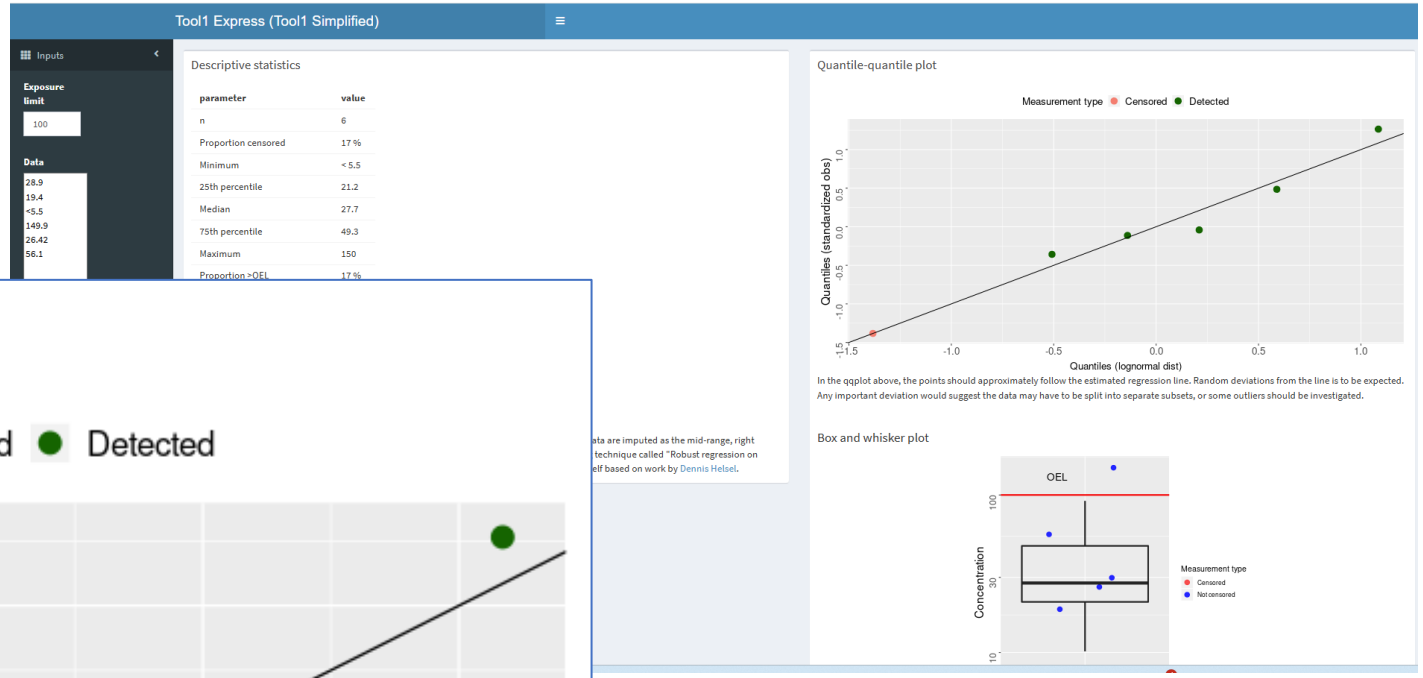
Descriptive statistics

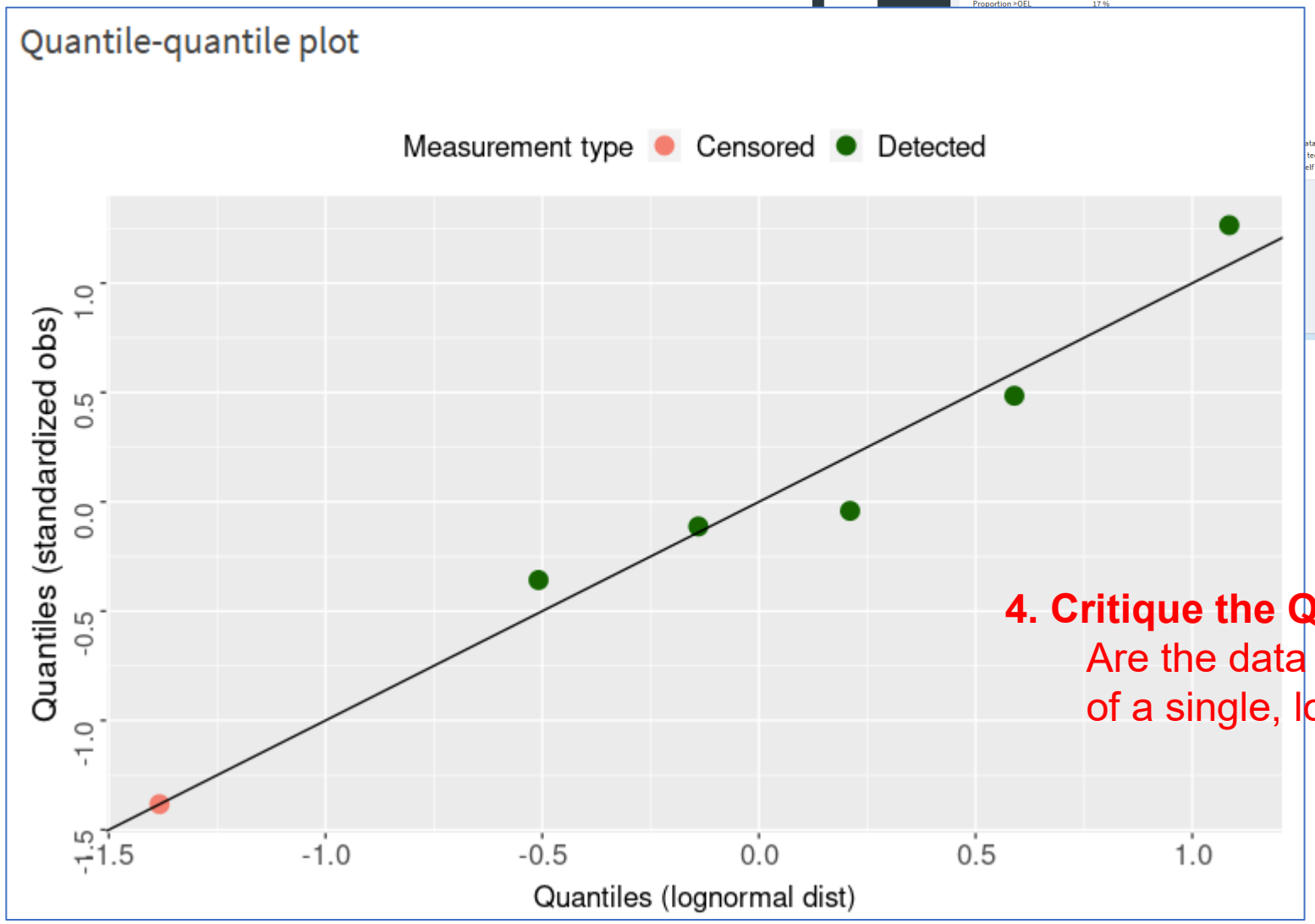
parameter	value
n	6
Proportion censored	17 %
Minimum	< 5.5
25th percentile	21.2
Median	27.7
75th percentile	49.3
Maximum	150
Proportion >OEL	17 %
Arithmetic mean	47.7
Arithmetic standard deviation	52.8
Coefficient of variation	111 %
Geometric mean	29.5
Geometric standard deviation	3.04

3. Review the GSD
(Here it is Calculated Using Traditional / Frequentist Statistics)

Expostats

Simplified Version



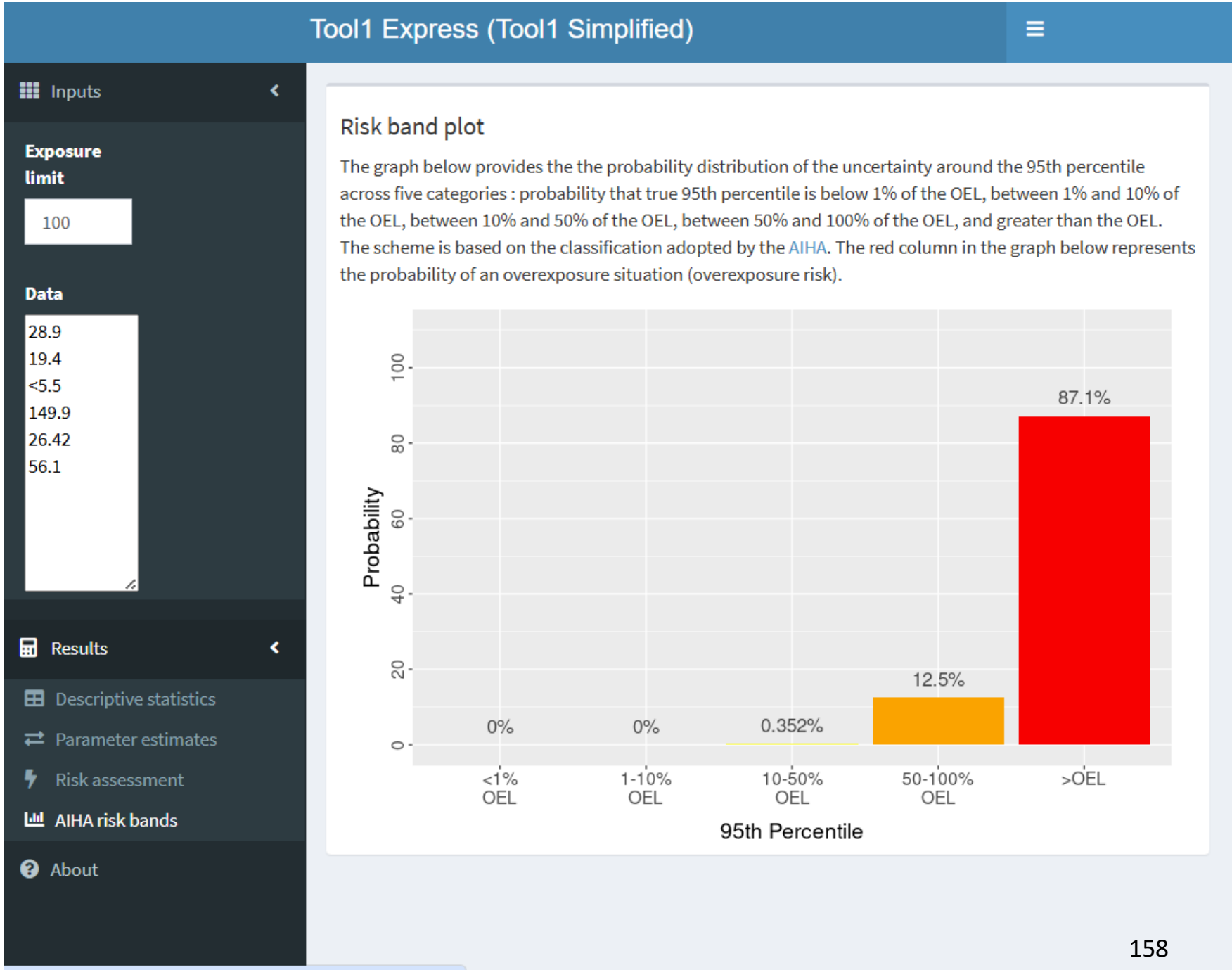


4. Critique the Quantile-Quantile Plot

Are the data consistent with the assumption of a single, lognormal exposure profile?

Expostats
Simplified Version

5. Review the "AIHA Risk Bands" (AKA BDA Chart)



A Few Notes Regarding Tool Differences:

- Expostats and IHSTAT-Bayes use the same underlying Expostats calculation engine.
- Expostats/IHSTAT-Bayes and IHDA-AIHA use different approaches in their underlying assumptions and calculations. Therefore outputs may differ slightly for the same monitoring data.
- Expostats/IHSTAT-Bayes use a fixed parameter space. IHDA-AIHA uses a parameter space that can be adjusted by the user and must be carefully considered.
- IHDA-AIHA uses traditional / frequentist statistical equations for the exposure profile parameter estimates (GM, GSD, 95%ile, etc.). Expostats /IHSTAT-Bayes use Bayesian analysis.
- Expostats has some interesting tools for risk communication beyond BDA charts.

FREE Learn More: "Making Accurate Exposure Risk Decisions" webinar.

WORKING THROUGH SOME EXAMPLES

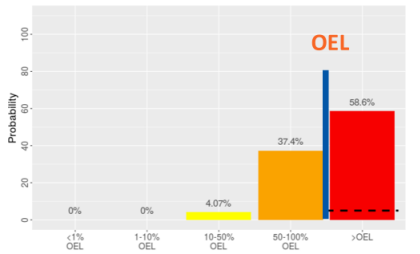
Expostats

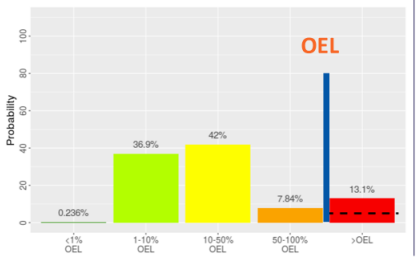
ANSWERS (OEL = 100 ppm)

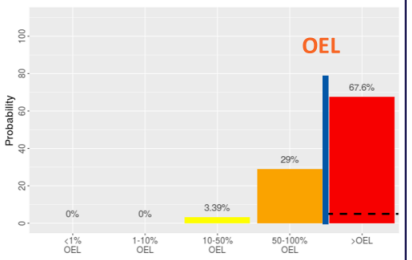
Sample Data (ppm) Set #1
12
37
9
105
8
33

Sample Data (ppm) Set #2
4

Sample Data (ppm) Set #3
38
68
12



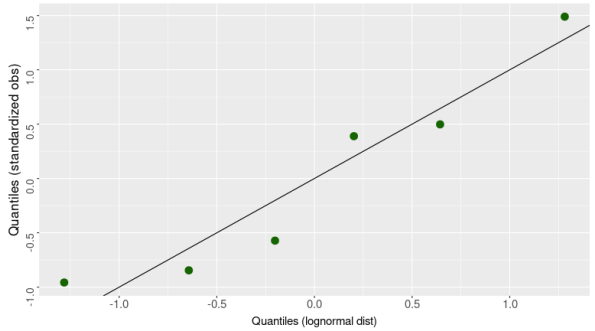


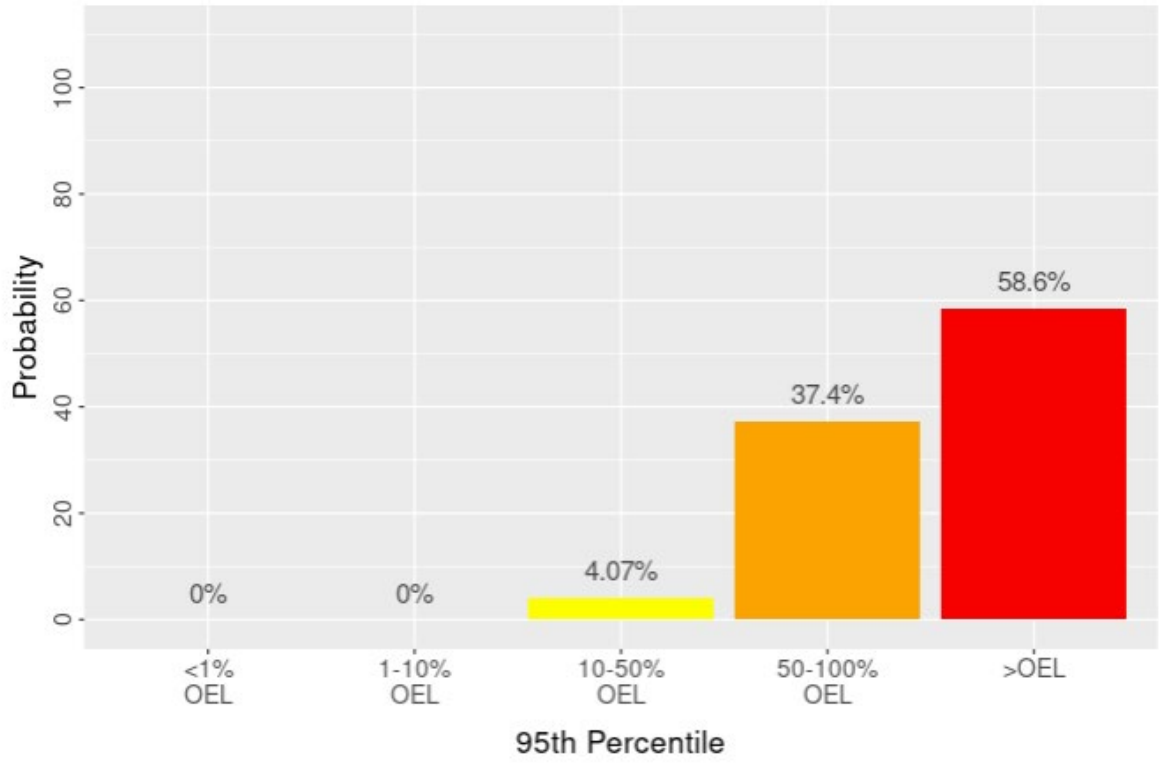


Example Likelihood Decision Chart:

Sample Data (ppm) Set #1
12
37
9
105
8
33

OEL = 100 ppm
GM = 22
GSD = 2.7 ppm
95%ile = 114 ppm
$UCL_{95,95}$ = 473 ppm





Likely Category 4
Medium Certainty
(50-75% Likelihood in Cat 4)

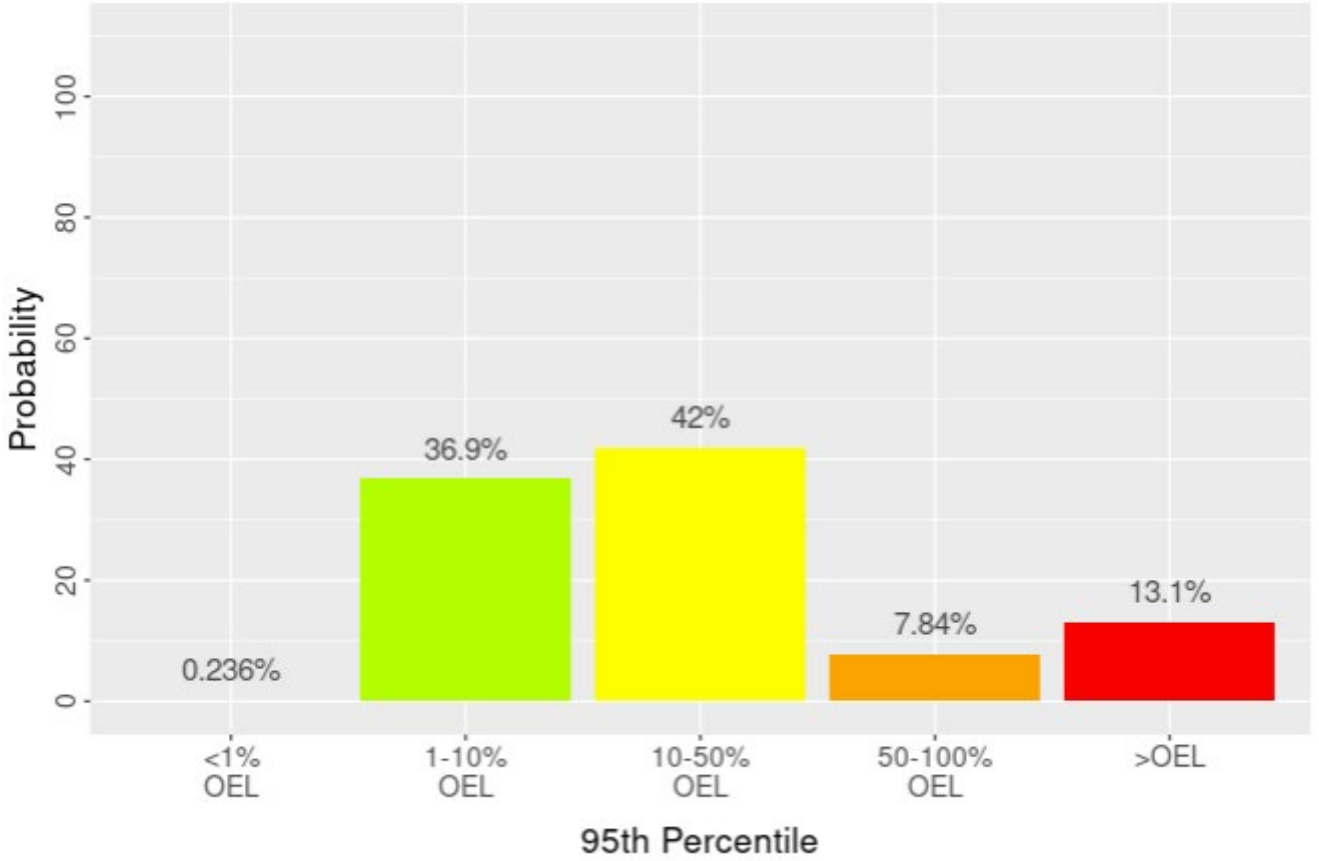
Unacceptable
(Cat 4 > 30%)

Actions:
Chem. Specific Haz. Com.; Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection.

Example Likelihood Decision Chart:

Sample Data (ppm) Set #2
4

OEL = 100 ppm
GM = 4 ppm
GSD = NA
95%ile = NA
$UCL_{95,95}$ = NA



Likely Category 2
Low Certainty
(<50% Likelihood in Cat 2)

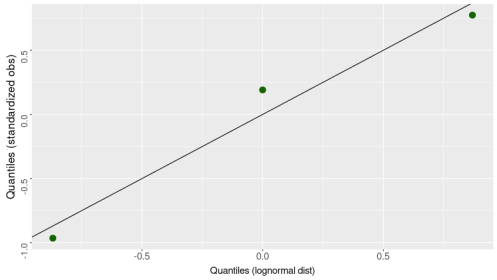
Tolerable
(Cat 4 Between 5% and 30%)

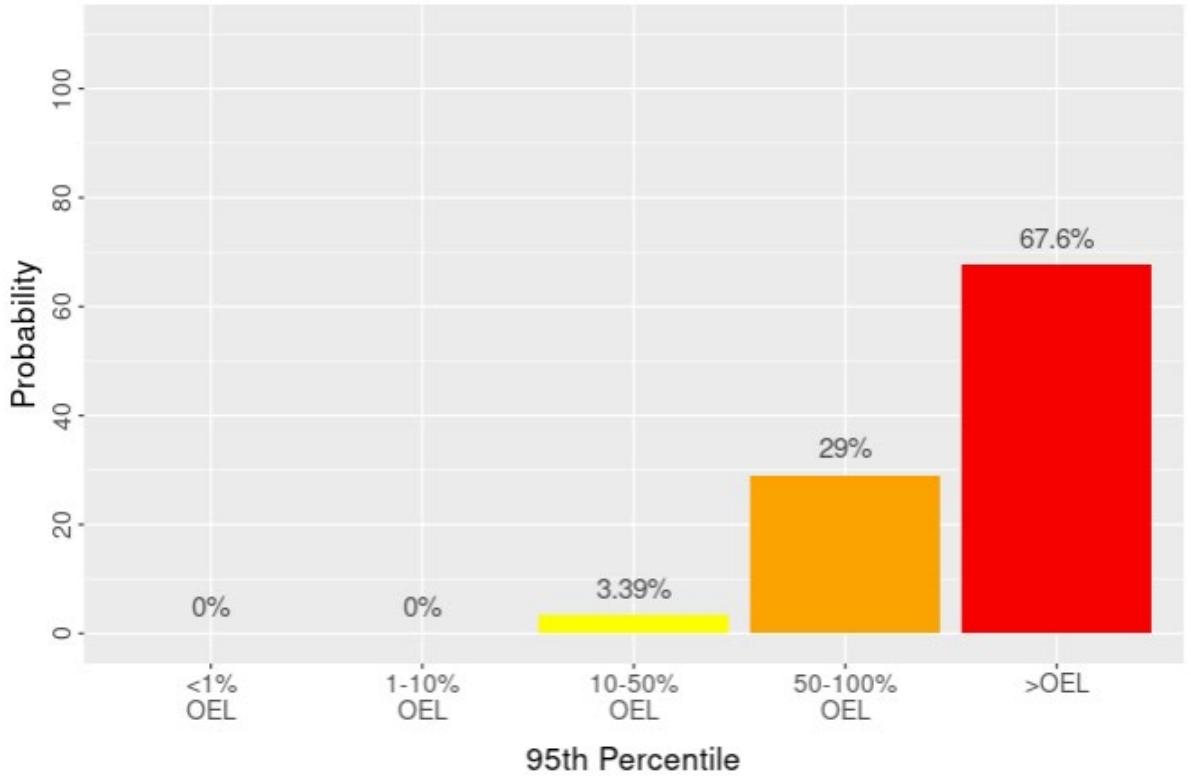
Actions:
Procedures and Training; Chemical Specific Hazard Communication; Periodic Exposure Monitoring

Example Likelihood Decision Chart:

Sample Data (ppm) Set #3
38
68
12

OEL = 100 ppm
GM = 31.4 ppm
GSD = 2.42
95%ile = 138 ppm
$UCL_{95,95}$ = 1040 ppm





Likely Category 4
Medium Certainty
(50-75% Likelihood in Cat 4)

Unacceptable
(Cat 4 > 30%)

Actions:
Chem. Specific Haz. Com.; Implement Hierarchy of Controls; Monitoring to Validate Respirator Protection Factor Selection.

Noise Exposure Risk Assessment

Acceptable Exposure?

dBA
80.8
76.5
82.2
83.9
78.7
77.3

Noise Exposure Risk Assessment

Normally Distributed

Lognormally Distributed

dBA	Dose $_{(85, 5)}$
80.8	55.9%
76.5	30.8%
82.2	67.8%
83.9	85.9%
78.7	41.8%
77.3	34.4%

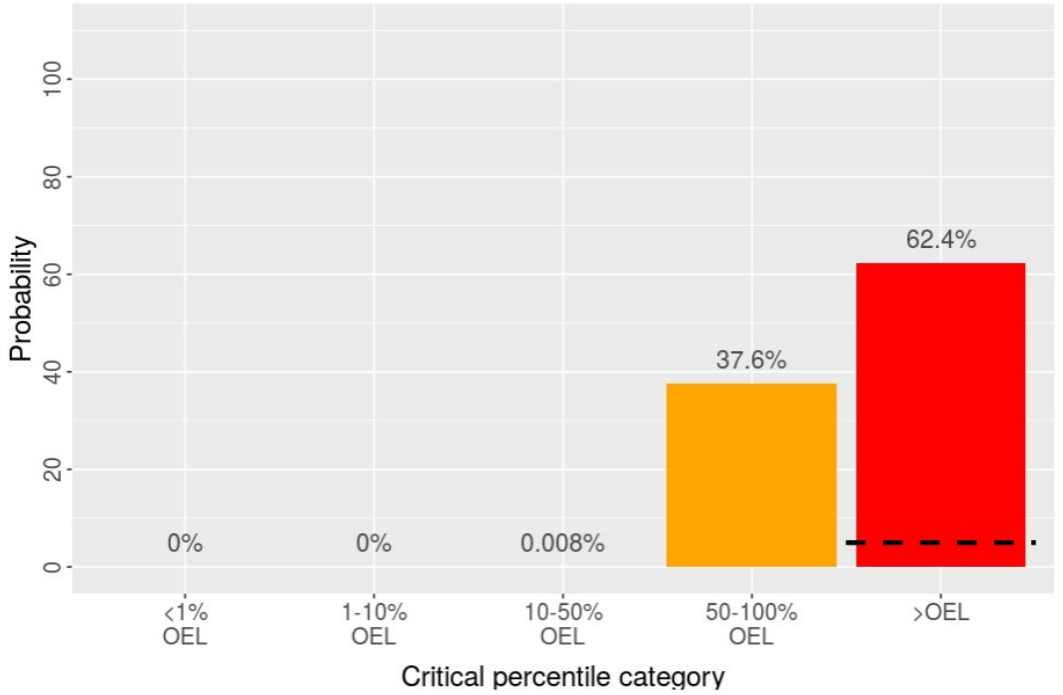
Noise Exposure Risk Assessment

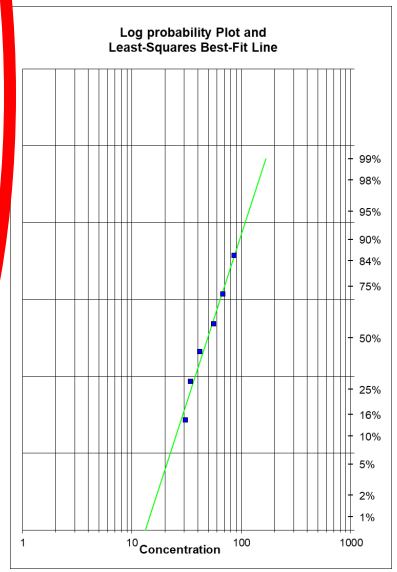
Normally Distributed

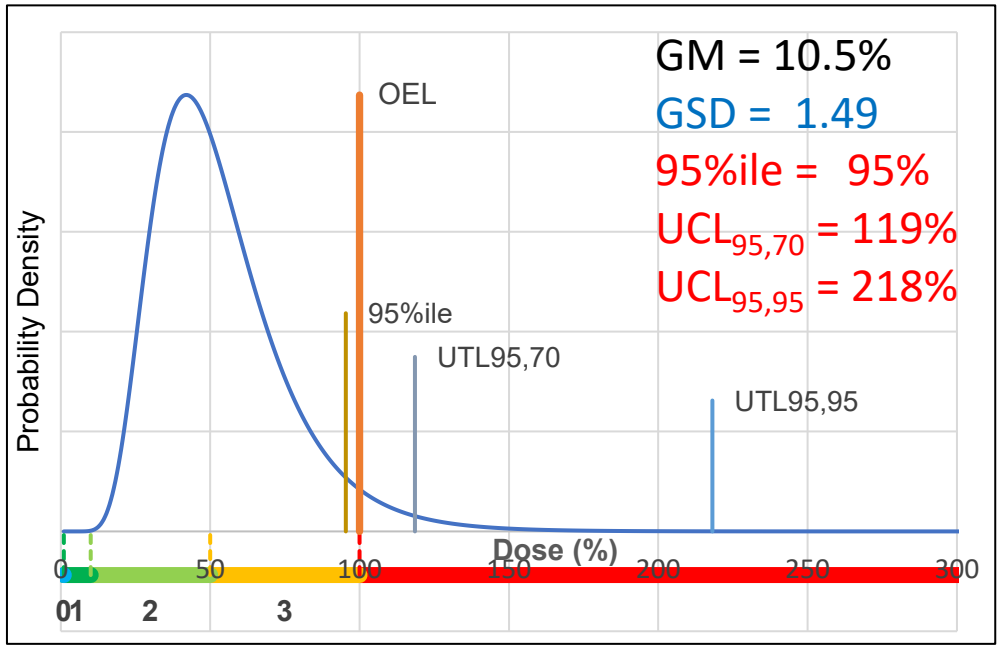
Lognormally Distributed

dBA	Dose (85, 5)
80.8	55.9%
76.5	30.8%
82.2	67.8%
83.9	85.9%
78.7	41.8%
77.3	34.4%

OEL = 100%







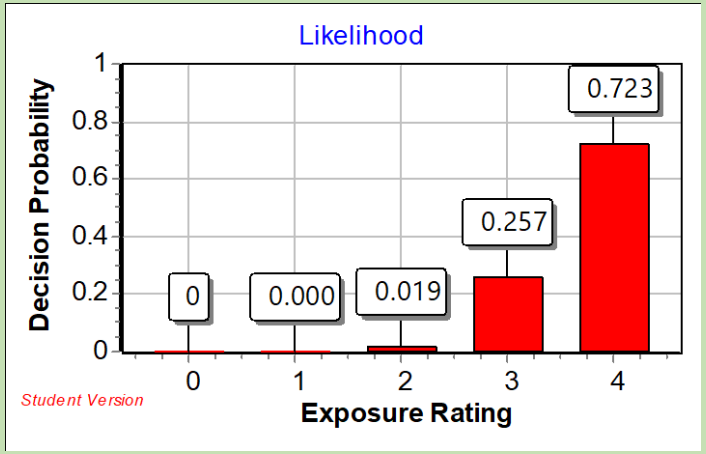
Advantages of Bayesian Statistics

- More Intuitive Depiction of Exposures and Uncertainty than Traditional Statistics
- Direct Alignment with AIHA Exposure Rating and Control Categories
- Easy to Communicate
- Great for small monitoring data sets . . . Including n=1
- Elegant Handling of Censored Data (Non-Detects) . . . Including Fully Censored Data

Sample Size n=1

OEL = 1 ppm

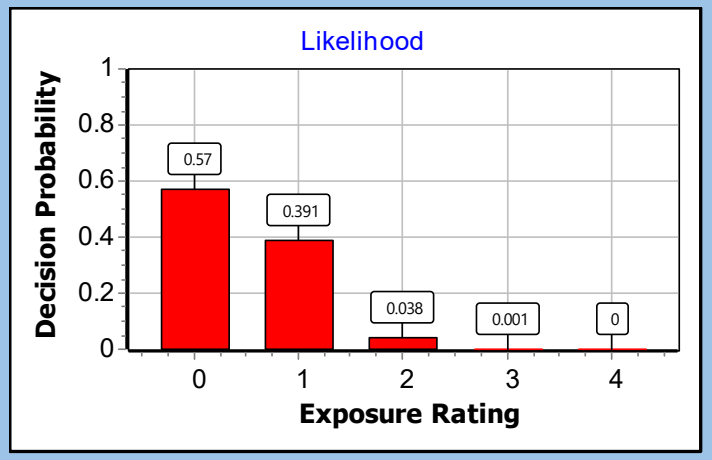
Sample Results (ppm)
0.65



Fully Censored Data

OEL = 100 ppm

Sample Results (ppm)
<5
<3.3
<12
<9



Assist in respirator selection: IHDA-AIHA or Expostats/IHSTAT-Bayes

Substitute APF x OEL for OEL in data analysis tool – Category 4 now shows the likelihood that APF x OEL will be exceeded given the data

OEL=1 ppm

n = 3

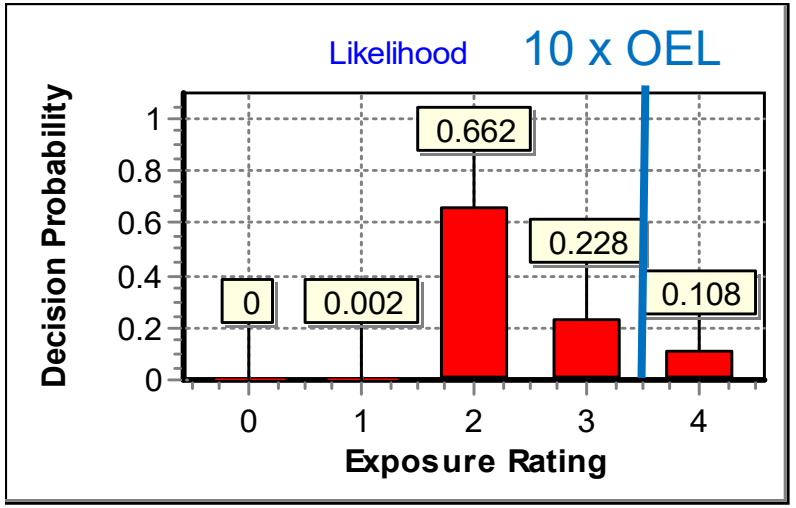
x_1 = 0.99 ppm

x_2 = 0.50 ppm

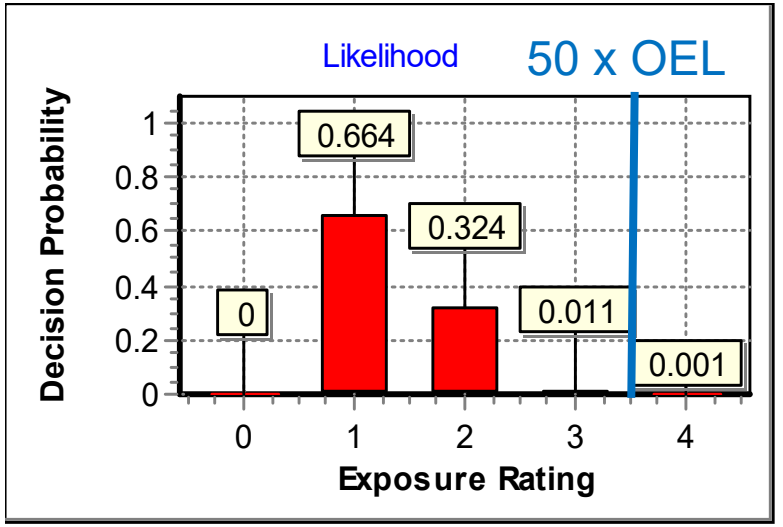
x_3 = 2.0 ppm

APF = 10
Use 10 x OEL

APF = 50
Use 50 x OEL

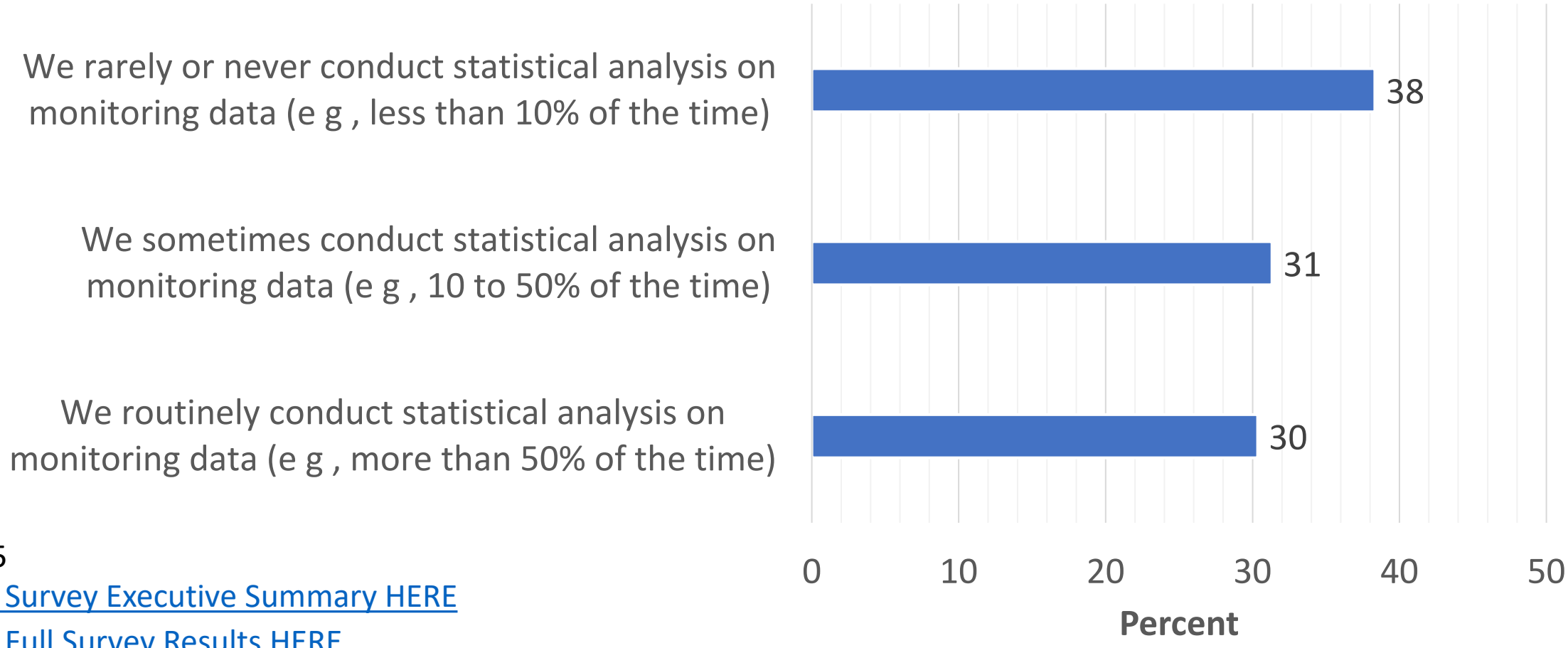


10.8% Likelihood of exceeding 10 x OEL



0.1% Likelihood of exceeding 50 x OEL

Which of the following best describes your/your team's use of statistics (traditional statistics or Bayesian statistics) to analyze your monitoring data? (Select one)



n = 715

[Access Survey Executive Summary HERE]

[Access Full Survey Results HERE]

Why don't we use statistics?

Q32: Why don't you/doesn't your team routinely conduct statistical analysis on exposure data? (Select all that apply) *[Shown to respondents who selected "We rarely or never…." Or "We sometimes…" in Q31]*	United States	International (net)	Canada	Australia	United Kingdom	NET	*n* =
We do not usually have enough monitoring data for statistical analysis	70%	70%	71%	77%	70%	70%	342
Our data are often too censored (i.e., too many results below the detection limit) for statistical analysis	30%	24%	20%	27%	30%	28%	139
Statistical analysis is not required by regulation	24% ↓	40% ↑	35%	50%	33%	28%	138
Management/decisionmakers do not provide support for conducting statistical analysis	21%	21%	18%	23%	15%	21%	102
We do not have training in conducting statistical analysis	19%	17%	18%	14%*	18%	19%	92
There is not time to conduct statistical analysis	16%	15%	20%	18%*	12%*	16%	79
The statistical analysis results are too difficult to explain to others	16%	13%	16%	14%*	9%*	15%	75
The statistical analysis results are too difficult to interpret	5%	2%*	2%*	0%*	0%*	4%	21
Other, please specify:	8% ↓	20% ↑	24% ↑	9%*	24%	11%	54
n =	359	130	49	22	33	489	

Access Survey Executive Summary HERE

Access Full Survey Results HERE

Improving Exposure Judgment

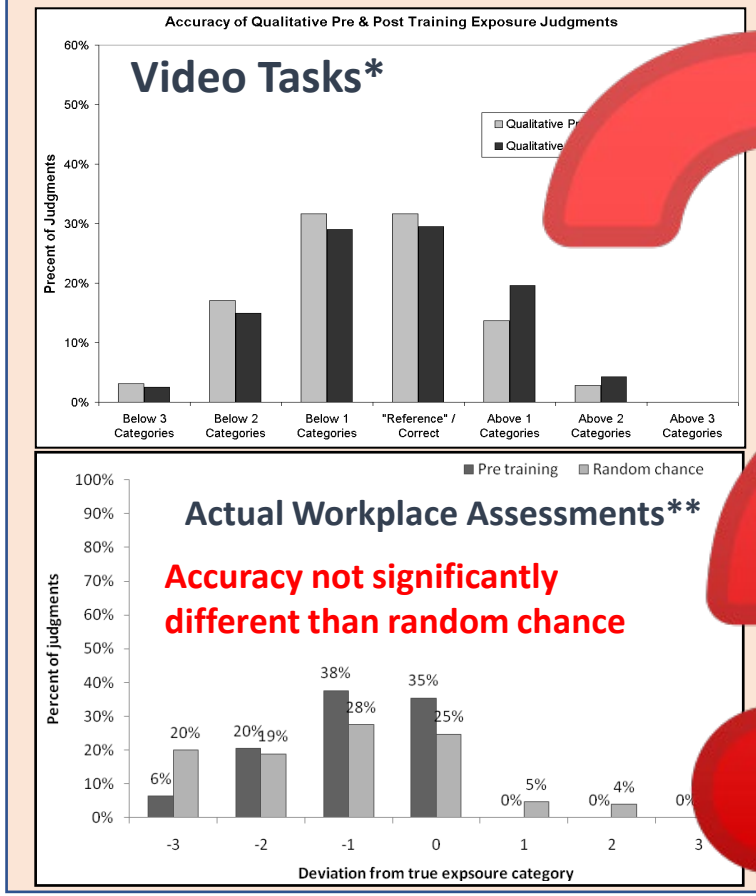
Accurate Exposure Risk Decisions:
When We Don’t Have Monitoring Data

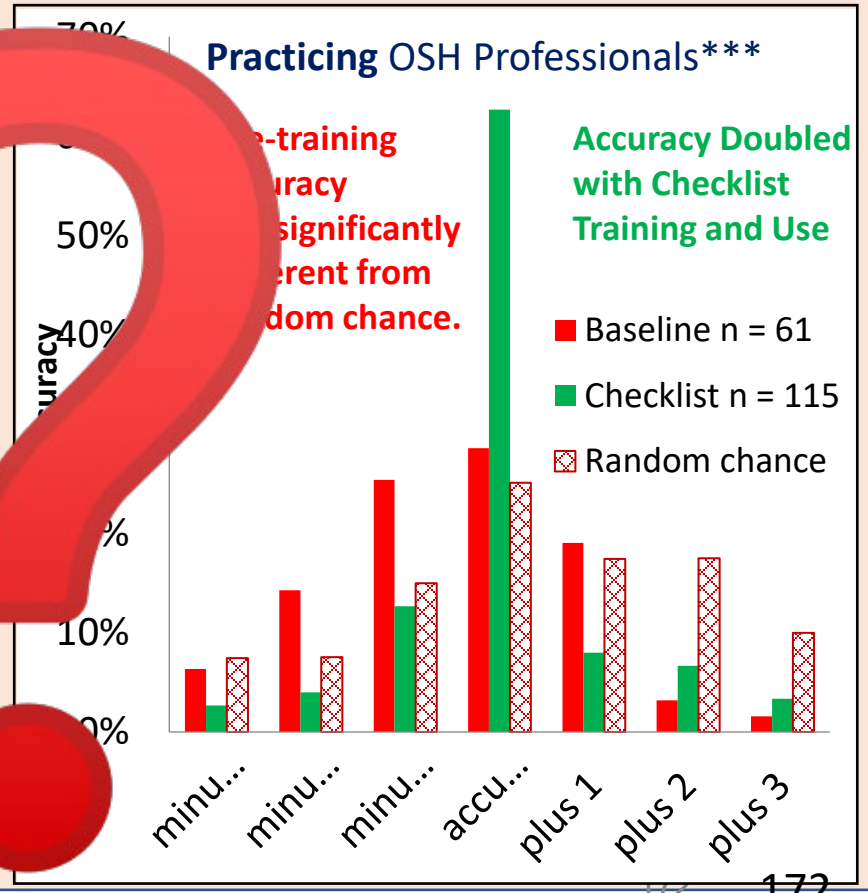
THE SCIENCE: WE ARE OFTEN WRONG

Poor Accuracy & Underestimation Bias when we do not use tools and activities to improve exposure judgment accuracy!

With Monitoring Data

No Monitoring Data (Qualitative Judgment)





*Logan et.al. Ann of Occ Hyg, Vol. 53, No. 4, 2009

**Vadali et.al. JOEH. 9: 242–256, 2012

***Arnold et.al JOEH, 13, 159-168, 2016

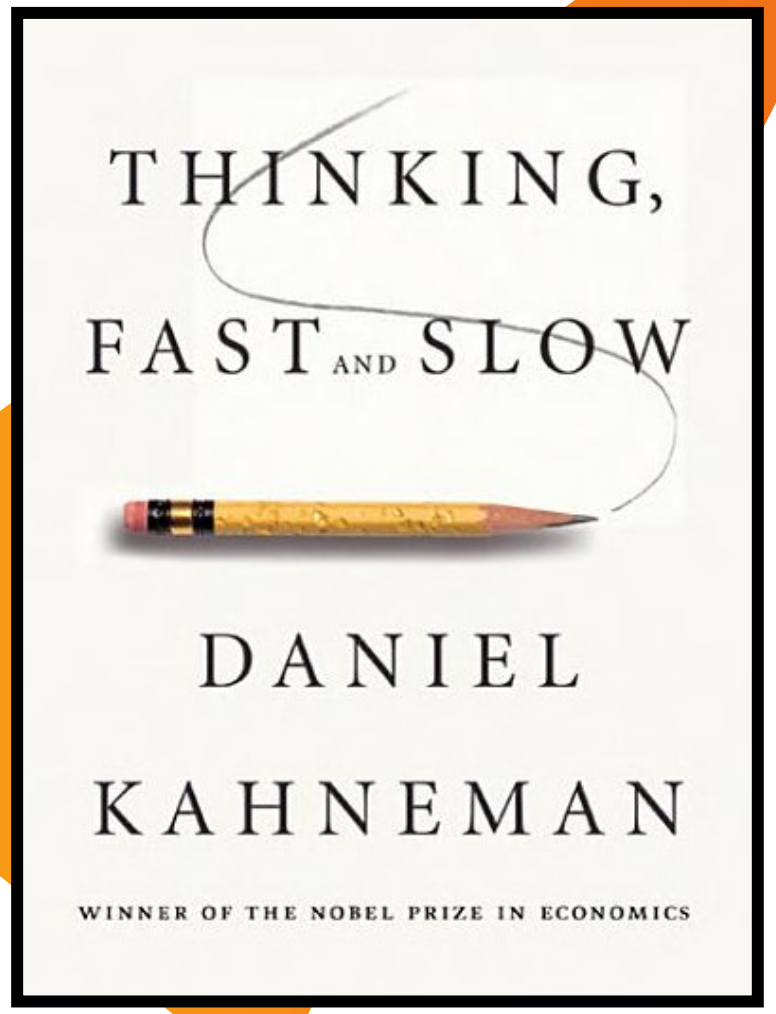
Making Decisions: Thinking Fast and Slow

Fast Thinking

- Reflexive, quick, emotion-driven and instinctive.
- Good for the many routine decisions that we make every day.
- **Reliance on emotion and individual experiences can lead to biases and faulty decision making**.

Slow Thinking

- Deliberate and logical.
- Requires energy and conscious focus.
- **Serves us well when we have important decisions to make.**



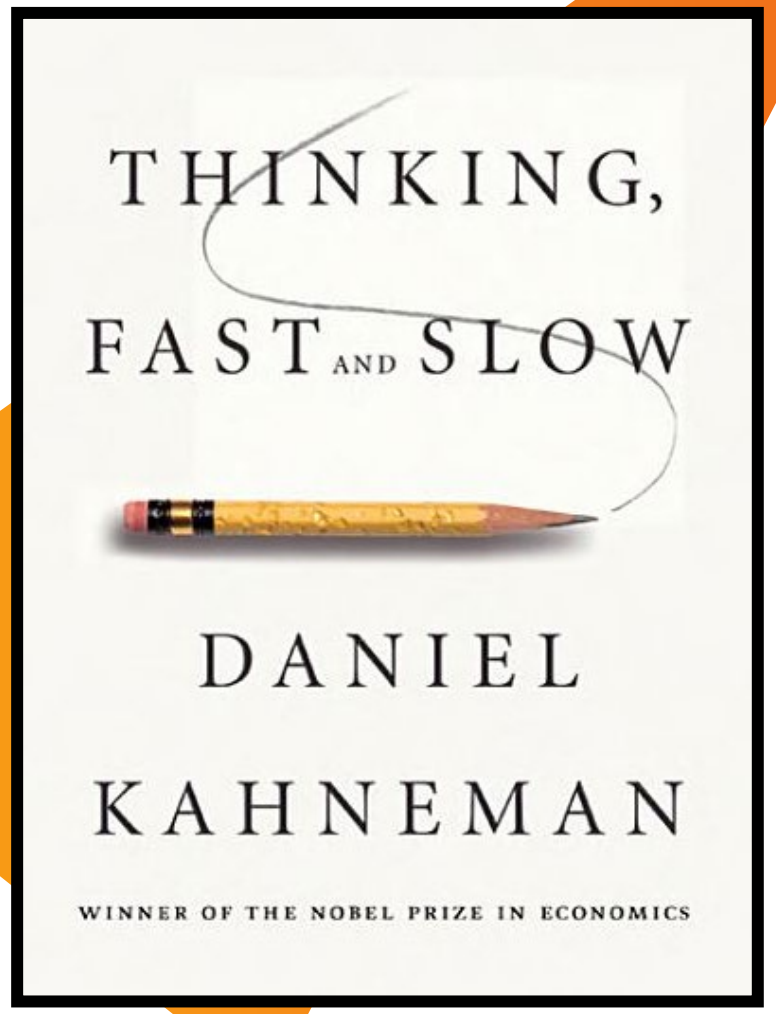
Driving Slow Thinking and Expertise:

Setting Ourselves Up to Make Accurate Exposure Risk Decisions

Learning from our friends in psychology . . .

Use a Structured Approach

- Systematic and transparent processes
- Clear decision rules
- Document facts and assumptions
- Questions and data in a logical order
- Break judgments into component parts
- Document decision
- Provide reasons for the decision
- Discuss with colleagues
- Focused training, coaching, and practice
- Accurate feedback mechanisms



Driving Slow Thinking and Expertise:

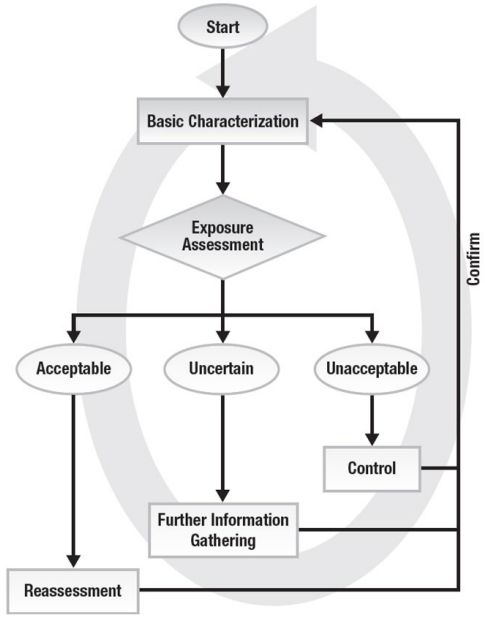
Setting Ourselves Up to Make Accurate Exposure Risk Decisions

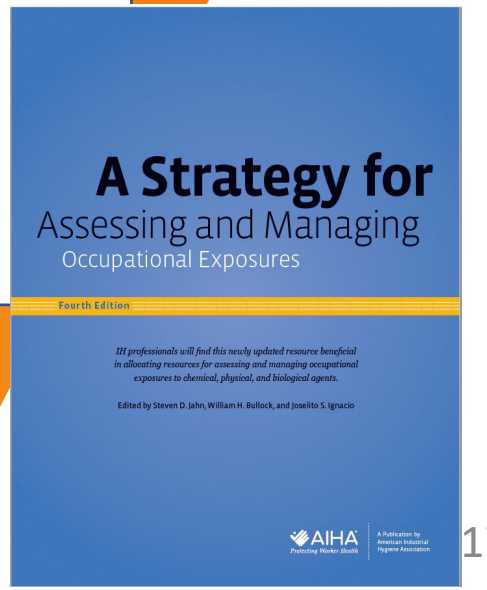
Learning from our friends in psychology . . .

Use a Structured Approach

- ✓ Systematic and transparent processes
- Clear decision rules
- Document facts and assumptions
- Questions and data in a logical order
- Break judgments into component parts
- Document decision
- Provide reasons for the decision
- Discuss with colleagues
- Focused training, coaching, and practice
- Accurate feedback mechanisms

A Strategy for Assessing and Managing Occupational Exposures 4th Edition





Driving Slow Thinking and Expertise:

Setting Ourselves Up to Make Accurate Exposure Risk Decisions

Learning from our friends in psychology . . .

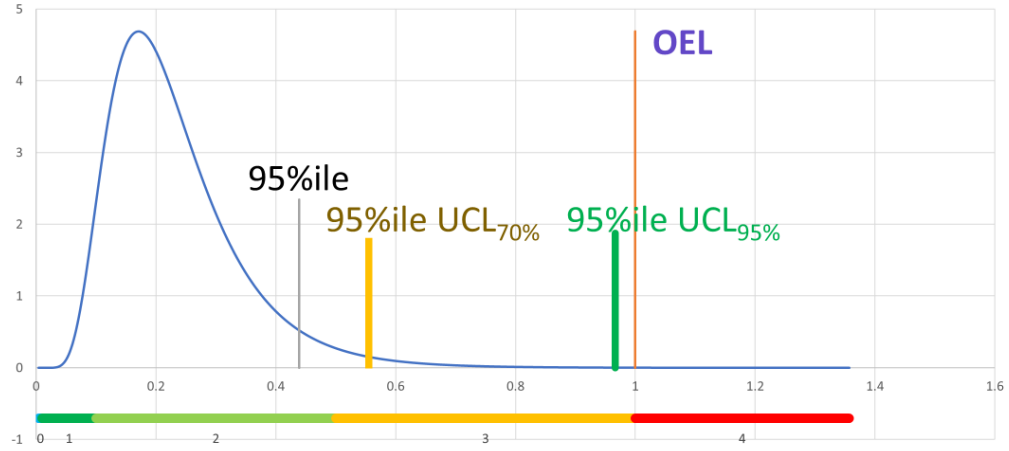
Use a Structured Approach

- ✓ Systematic and transparent processes
- ✓ Clear decision rules
- Document facts and assumptions
- Questions and data in a logical order
- Break judgments into component parts
- Document decision
- Provide reasons for the decision
- Discuss with colleagues
- Focused training, coaching, and practice
- Accurate feedback mechanisms

PGP DECISION STATISTIC:

Good Practice: At least 70% confident that the true 95th percentile exposure is less than the OEL

Enhanced Practice: Strive to be at least 95% confident that the true 95th percentile exposure is less than the OEL



Driving Slow Thinking and Expertise:

Setting Ourselves Up to Make Accurate Exposure Risk Decisions

Learning from our friends in psychology . . .

Use a Structured Approach

- ✓ Systematic and transparent processes
- ✓ Clear decision rules
- ✓ Document facts and assumptions
- ✓ Questions and data in a logical order
- ✓ Break judgments into component p
- ✓ Document decision
- ✓ Provide reasons for the decision
- Discuss with colleagues
- Focused training, coaching, and practice
- Accurate feedback mechanisms

MORE FREE TOOLS!

FREE AIHA EXPOSURE ASSESSMENT TOOLS

- **IH/OEHS Exposure Scenario Tool (IHEST)**
  Excel tool to aid Basic Characterization
- **Basic Exposure Assessment and Sampling Spreadsheet**
  Excel template for documenting EA/BC and sampling data
- **Structured Deterministic Model (SDM 2.0)**
  Excel tool for estimating exposures
- **IHMOD 2.0©**
  Excel-based mathematical modeling spreadsheet
- **Dermal Risk Assessment Model (DRAM)**
  Excel tool for evaluating dermal exposure
- **IHSkinPerm©**
  Excel tool to estimate dermal absorption.

Access Tools HERE

Driving Slow Thinking and Expertise:

Setting Ourselves Up to Make Accurate Exposure Risk Decisions

Learning from our friends in psychology . . .

Use a Structured Approach

- ✓ Systematic and transparent processes
- ✓ Clear decision rules
- ✓ Document facts and assumptions
- ✓ Questions and data in a logical order
- ✓ Break judgments into component parts
- ✓ Document decision
- ✓ Provide reasons for the decision
- ✓ Discuss with colleagues
- ✓ Focused training, coaching, and practice
- Accurate feedback mechanisms

Training and Practice

- Decision Rule Calibration
- Data Interpretation Discussions
- Case Studies
- Repeated Practice
- Video Evaluations

Driving Slow Thinking and Expertise:

Setting Ourselves Up to Make Accurate Exposure Risk Decisions

Learning from our friends in psychology . . .

Use a Structured Approach

- ✓ Systematic and transparent processes
- ✓ Clear decision rules
- ✓ Document facts and assumptions
- ✓ Questions and data in a logical order
- ✓ Break judgments into component parts
- ✓ Document decision
- ✓ Provide reasons for the decision
- ✓ Discuss with colleagues
- ✓ Focused training, coaching, and practice
- ✓ Accurate feedback mechanisms

Accurate Feedback Mechanisms

Compare initial qualitative judgment to final result from the statistical analysis of monitoring data

SEG	Agent / Chemical	OEL	Initial Exposure Rating	Initial Certainty Rating	Final Exposure Rating	Final Certainty Rating

Driving Slow Thinking and Expertise:

Setting Ourselves Up to Make Accurate Exposure Risk Decisions

Learning from our friends in psychology . . .

Use a Structured Approach

- ✓ Systematic and transparent processes
- ✓ Clear decision rules
- ✓ Document facts and assumptions
- ✓ Questions and data in a logical order
- ✓ Break judgments into component parts
- ✓ Document decision
- ✓ Provide reasons for the decision
- ✓ Discuss with colleagues
- ✓ Focused training, coaching, and practice
- ✓ Accurate feedback mechanisms

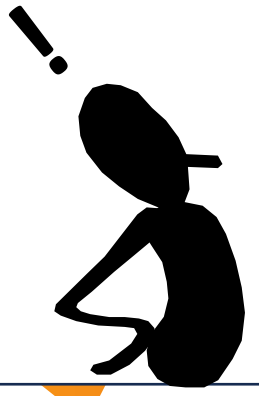
Accurate Feedback Mechanisms

Compare initial qualitative judgment to final result from the statistical analysis of monitoring data

SEG	Agent / Chemical	OEL	Initial Exposure Rating	Initial Certainty Rating	Final Exposure Rating	Final Certainty Rating
			Cat 2	Low	Cat 3	High

Before Monitoring

After Statistical Analysis of Monitoring Results



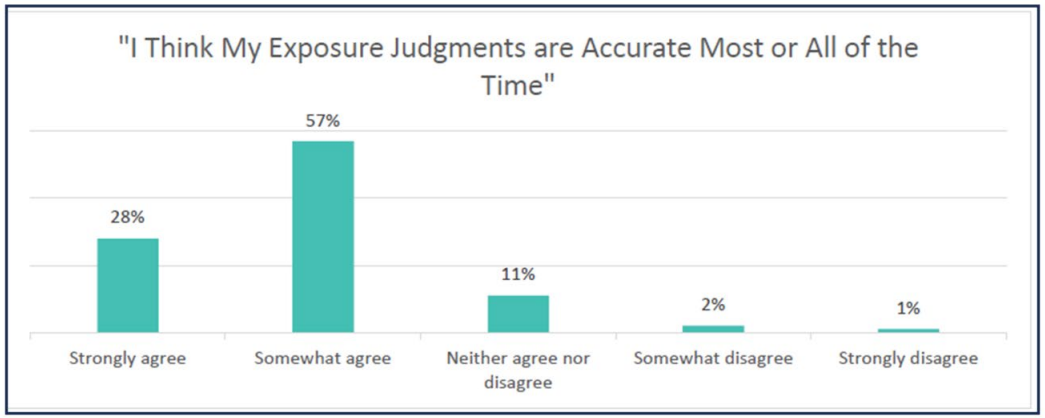
Driving Slow Thinking and Expertise:

Setting Ourselves Up to Make Accurate Exposure Risk Decisions

Learning from our friends in psychology . . .

Use a Structured Approach

- Systematic and transparent processes
- Clear decision rules
- Docum
- Questic
- Break ju
- Docum
- Provide
- Discuss
- Focuse
- Accurat



Quality Control Processes

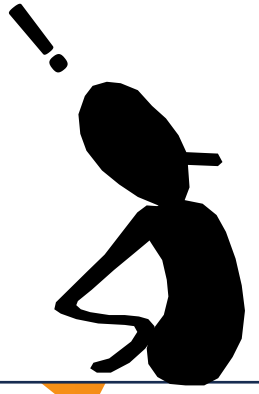
Accurate Feedback Mechanisms

Compare initial qualitative judgment to final result from the statistical analysis of monitoring data

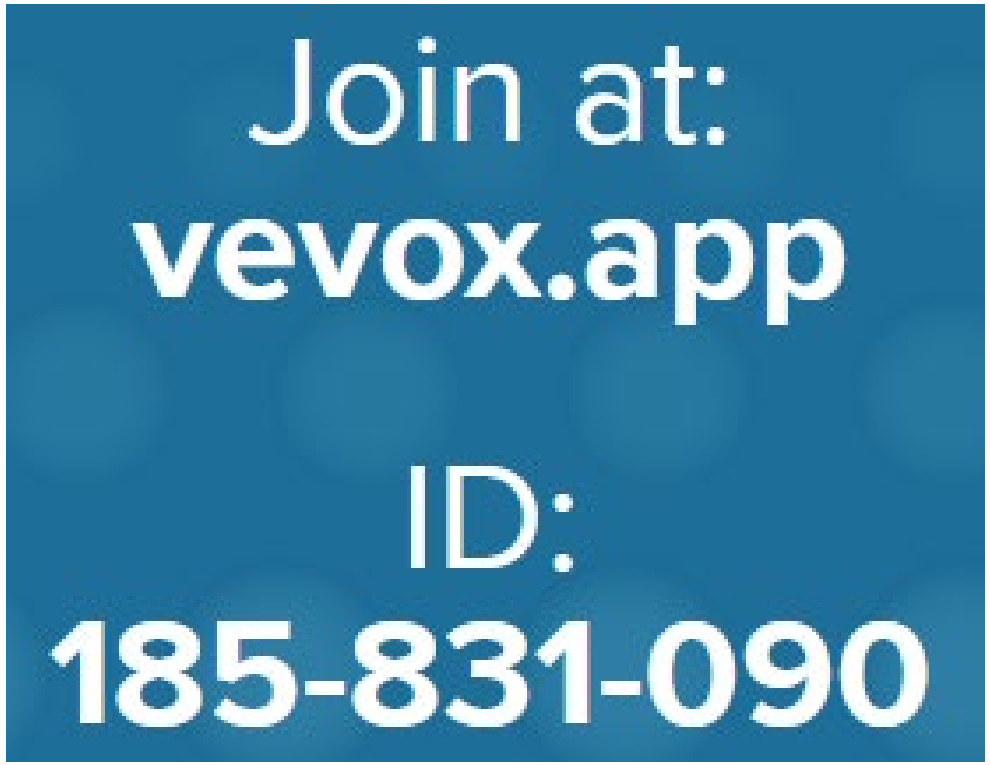
OEL	Initial Exposure Rating	Initial Certainty Rating	Final Exposure Rating	Final Certainty Rating
	Cat 2	Low	Cat 3	High

Before Monitoring

After Statistical Analysis of Monitoring Results



FINAL POLLING QUESTIONS (WHEW!). . .



VEVOX Polling Software Site

AIHA™

POLLING QUESTION #13

Which of the following is not an advantage of Bayesian Decision Analysis (BDA) over traditional statistical tools?

- ❑ Can be used when n=1
- ❑ Can be used for large data sets (n > 25)
- ❑ Output more easily communicated
- ❑ Can be used for highly-censored data

POLLING QUESTION #14

When performing statistical analysis of censored data, the best approach is to:

- ❑ Enter the censored data with the less-than values into a Bayesian statistical analysis tool along with the uncensored data
- ❑ Enter the censored values as the limit of detection into a statistical analysis tool
- ❑ Enter only the uncensored data into a statistical analysis tool
- ❑ For each censored value, divide the detection limit by the square root of two (DL / √2) and enter the result into a Bayesian statistical analysis tool along with the uncensored data.

POLLING QUESTION #15

Are you aware of any requirement for the CIH professional certification that requires demonstration of proficiency in making accurate exposure risk decisions?

- ❑ Yes
- ❑ No – but there is no reason to add that requirement
- ❑ No - but that should be a requirement

Improving Exposure Judgment

Learn More:

References to Learn More:

Papers - Bayesian Analysis :

- Hewett, P., Logan, P., Mulhausen, J., Ramachandran, G., and Banerjee, S.: “Rating Exposure Control using Bayesian Decision Analysis”, Journal of Occupational and Environmental Hygiene, 3: 568–581, 2006
- Jérôme Lavoué, Lawrence Joseph, Peter Knott, Hugh Davies, France Labrèche, Frédéric Clerc, Gautier Mater, Tracy Kirkham, “Expostats: A Bayesian Toolkit to Aid the Interpretation of Occupational Exposure Measurements”, Annals of Work Exposures and Health, Volume 63, Issue 3, April 2019, Pages 267–279

Papers – Improving Exposure Decision Accuracy

- Logan P., G. Ramachandran, J. Mulhausen, S. Banerjee, and P. Hewett “Desktop Study of Occupational Exposure Judgments: Do Education and Experience Influence Accuracy?” Journal of Occupational and Environmental Hygiene, 8:12, 746-758, 2011.
- Logan P., G. Ramachandran, J. Mulhausen, and P. Hewett:” Occupational Exposure Decisions: Can Limited Data Interpretation Training Help Improve Accuracy?” Annals of Occupational Hygiene, Vol. 53, No. 4, pp. 311–324, 2009.
- Vadali, M. G. Ramachandran, J. Mulhausen, S. Banerjee, "Effect of Training on Exposure Judgment Accuracy of Industrial Hygienists”. Journal of Occupational & Environmental Hygiene. 9: 242–256, 2012.
- Arnold S., M. Stenzel, D. Drolet, G. Ramachandran; Journal of Occupational and Environmental Hygiene, 13, 159-168, 2016

References to Learn More:

Papers – Censored Data Analysis

- Hewett, P. Appendix VIII: Analysis of Censored Data. A Strategy for Assessing and Managing Occupational Exposures. 4th Ed. AIHA Press. 2015.
- Hewett, P., and G. Ganser. "A Comparison of Several Methods for Analyzing Censored Data". Ann. Occup. Hyg., Vol. 51, No. 7, pp. 611–632, 2007
- Ganser, G. and P. Hewett. "An Accurate Substitution Method for Analyzing Censored Data". Journal of Occupational and Environmental Hygiene, 7:4, 233-244, 2010.
- Huynh, Tran, Harrison Quick, Gurumurthy Ramachandran, Sudipto Banerjee, Mark Stenzel, Dale P Sandler, Lawrence S Engel, Richard K Kwok, Aaron Blair, and Patricia A Stewart. "A Comparison of the β-Substitution Method and a Bayesian Method for Analyzing Left-Censored Data." The Annals of Occupational Hygiene 60, no. 1 (January 2016): 56–73.

Books – Censored Data Analysis

- Helsel, D. Non Detects and Data Analysis - Statistics for Censored Environmental Data. Hoboken, NJ: John Wiley & Sons, Inc., 2005.
- Helsel, Dennis R. Statistics for Censored Environmental Data Using Minitab and R (CourseSmart). Wiley, 2012.

References to Learn More:

- **Books:**
  - A Strategy for Assessing and Managing Occupational Exposures. 4th Ed. AIHA Press. 2015.
- **Opinion:**
  - Mulhausen, J. “Faulty Judgment” President’s Message. The Synergist. (November 2021). Access HERE
  - Mulhausen, J. “How to Improve Exposure Judgments” President’s Message. The Synergist. (December 2021). Access HERE
  - Mulhausen, J. “Standards of Care: Competence PLUS Performance” President’s Message. The Synergist. (January 2022). Access HERE
  - Mulhausen, J. “Acknowledging and Addressing Our Blind Spots” President’s Message. The Synergist. (March 2022). Access HERE
  - Martin, K., Murphy, M. and Taruru S. “How “Professional” Is Professional Judgment?” Viewpoint. The Synergist. (December 2022). Access HERE
- **Video Webinar:**
  - Mulhausen, J. “Top 10 Imperatives for the AIHA Exposure Risk Management Process.” Free from AIHA HERE

Improving Exposure Judgment

Next Steps . . .

MOVING FORWARD

AIHA Registry PROGRAMS™

Use The FREE Statistical Tools!!!

- Complete the FREE Training Webinar: "Making Accurate Exposure Risk Decisions"
- Demonstrate competency in tool use by passing the FREE AIHA Exposure Decision Analysis Registry exam. Learn More Here

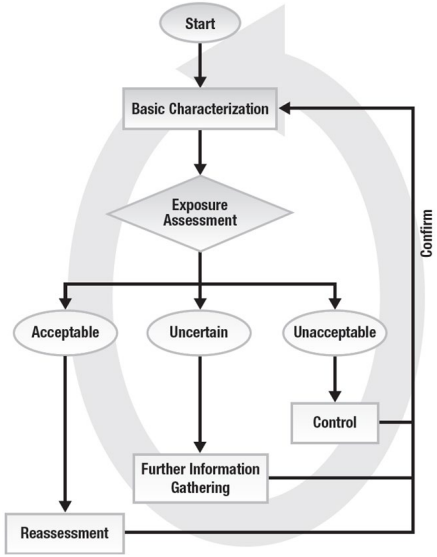
Implement Simple Qualitative Judgment Improvement Activities

- 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

Expand Your Expertise in Exposure Assessment Tools and Techniques

- Modeling and checklist tools
- Robust noise assessment techniques
- Dermal exposure assessment

Implement The AIHA Strategy!



Engage! Spread the Word!

MAKING CONNECTIONS: OUTREACH AND PARTNERSHIP

1. Share IEJ Initiative Information With Others
2. Identify Local OEHS Training Programs and Contacts
   - Local Section Members with Connections to the Training Programs/Contacts
   - Training Program Faculty Members
   - Training Program Advisory Group Members
   - Training Program Graduates
   - Student Local Section Members / Current Students
3. Reach Out and Engage!

We're in this Together - Motivated and Energized!

Improving Exposure Judgment

Free Tools and Training Materials

Improving Exposure Judgments: An Introduction to IH Statistics

Four Roadmaps on How to Use the Free Materials

Roadmap #1: Self-study using the standalone online training and assessment

LINK

Roadmap #2: Instructor assigned independent study using the standalone online training and assessment

LINK

Roadmap #3: Integration of the materials into virtual or in-person classroom lecture programs

LINK

Roadmap #4: Hybrid approach that mixes self-study with focused in-person lecture programs

LINK

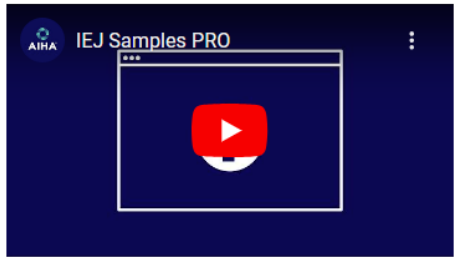
DRIVING CULTURE CHANGE . . .

IEJ MARKETING AND COMMUNICATION CAMPAIGN

Discover the Many Benefits of Improved Exposure Judgments

How Statistical Tools Can Improve Exposure Judgments

Three Ways Improved Exposure Judgments Can Save You Time



Think you need to be a stats expert to IMPROVE EXPOSURE JUDGMENTS? (Think again.)

LINK


AIHA

*1 IN A SERIES

Discover the many benefits of

IMPROVED EXPOSURE JUDGMENTS

For workers. For workplaces. For you.

When you take steps to strengthen your own exposure risk decisions—by bringing statistical tools and other approaches into your daily practice—you'll discover a wide range of benefits.

- **BETTER PROTECTION OF WORKERS AND COMMUNITIES**, through improved judgments that lead to safer workplaces.
- **INCREASED CONFIDENCE** in your own judgments, with verifiable data analysis to inform and validate your assessments.
- **STRONGER COMMUNICATION** with your colleagues and clients.
- **GREATER EFFICIENCIES** in assessing risk that require less time and money, and fewer samples than you might think.

The truth is current approaches to exposure judgments tend to underestimate the risk to workers. That is why AIHA is committed to helping you elevate your risk-assessment abilities by offering FREE access to the education, software and resources you need to improve the accuracy of your exposure judgments.

By learning about these approaches and applying them in your own work setting, you'll take important steps toward protecting workers and strengthening


AIHA

*2 IN A SERIES

Three ways

IMPROVED EXPOSURE JUDGMENTS can save you time.

We all strive to improve our performance as OEHS professionals, but who has the time?

The everyday demands of our careers make it challenging to learn new skills and put them into practice. That's why AIHA has launched a long-term initiative to help make improving exposure judgments attainable and a big time saver, too.

- **TIME SAVER #1:** You can quickly learn how to use statistical tools to improve judgments with our FREE online course, Making Accurate Exposure Risk Decisions. In just nine hours, you'll gain a basic understanding of lognormally distributed exposure profiles and the knowledge you need to put traditional and Bayesian statistical analysis tools into practice.
- **TIME SAVER #2:** You also have FREE access to the software tools you can use to characterize exposures. It takes just a few minutes to enter the data points and get the output you need to make informed risk decisions.
- **TIME SAVER #3:** Because your risk decisions

Studies show that using statistical tools to characterize exposures, rather than relying on our professional judgment alone, greatly improves the accuracy of our risk decisions. So, don't let time constraints keep you from learning about these approaches and applying them in your own work setting.

Visit the Improving Exposure Judgments Portal at AIHA.org/iej to learn about the free suite of courses and tools available to every OEHS professional.

Discover the many benefits **IMPROVED EXPOSURE JUDGMENTS** can create for workers, for workplaces, and for you.


AIHA

*3 IN A SERIES

How statistical tools can

IMPROVE EXPOSURE JUDGMENTS. (Even if you think you don't have enough samples or your results are less than the limits of detection.)

According to a recent AIHA survey*, most OEHS professionals don't think they have enough measurements above the limit of detection to use statistical tools to characterize exposure risks.

While we'd all love to be able to collect 10, 20 or even more samples for every exposure risk decision we make, we are often limited by practical or operational constraints to making decisions based on far fewer samples.

In those instances, you might be surprised to learn that:

- Statistical tools for assessing risk have the ability to **analyze data sets with sample sizes as low as ONE.**
- Modern Bayesian tools can efficiently analyze data sets **where some or even all of the values are below the limit of detection.**

How is that possible? Bayesian tools take advantage of prior knowledge regarding likely workplace exposure variability. They can expand upon the information provided by very small numbers of samples to help us make accurate exposure decisions.

So, whether you have a few samples or several, you can confidently put these tools into your everyday practice and achieve quality analysis.

AIHA is committed to helping you elevate your risk-assessment abilities by giving you FREE access to everything you need to improve your exposure judgments.

Visit the Improving Exposure Judgments Portal at AIHA.org/iej and discover the many benefits **IMPROVED EXPOSURE JUDGMENTS** can create for workers, for workplaces, and for you.

*AIHA "State of the Art Versus Practice" Survey - January 2024

Access your FREE suite of resources:
Visit our online portal at AIHA.ORG/IEJ

Video Courses you can take on your own schedule to acquire and apply new skills.

Software Tools you can download and use to accurately evaluate exposure profiles.

Real Case Examples, Exercises and More.


AIHA

*4 IN A SERIES

Think you need to be a stats expert to

IMPROVE EXPOSURE JUDGMENTS? (Think again.)

Bayesian statistical tools can improve the accuracy of our exposure risk assessments. But you may not think they're right for you. Give us a minute and we'll show you how easily they can help you.

HOW WE INTUITIVELY THINK OF RISK

When assessing exposure risk, we usually think in terms of a symmetrical bell-shaped normal distribution.

THE REALITY OF RISK

The reality is that we are less likely to think in terms of a skewed lognormal distribution, with its long tail snaking out at the high end.

As demonstrated above, the truth is we're unable to intuitively picture what's happening during periods of high exposures on the high end of a lognormal exposure profile. Statistical tools help us accurately see just how much variability could be in our dataset and how high exposures are likely to be.

That's great news for anyone striving to accurately assess risk. And here's even better news: You don't need to be an expert in statistics to use these tools successfully. AIHA gives you all the training and tools you need—for FREE.

Our nine-hour online course, Making Accurate Exposure Risk Decisions, gives you the basics of using statistical analysis in your risk assessments. You can then download and use our FREE software tools to efficiently characterize exposures in just minutes.

Visit the Improving Exposure Judgments Portal at AIHA.org/iej and discover the many benefits **IMPROVED EXPOSURE JUDGMENTS** can create for workers, for workplaces, and for you.

Access your FREE suite of resources:
Visit our online portal at AIHA.ORG/IEJ

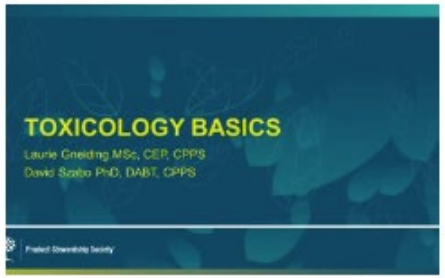
Video Courses you can take on your own schedule to acquire and apply new skills.

Software Tools you can download and use to accurately evaluate exposure profiles.

Real Case Examples, Exercises and More.

Resources for Academics

FREE for Everyone

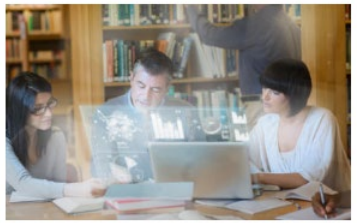


Toxicology Basics

Occupational Exposure Banding

Workshop Series: Occupational Risk Assessment

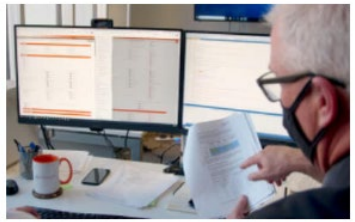
Lab Safety



Frameworks

EHS Business Case e-Tool

ABSA Biosafety, Biosecurity, and Biohazards Courses



Industrial Hygiene Hazard Identification and Exposure Risk Assessment by Market Segment

https://www.aiha.org/public-resources/aiha-academic-portal

DISCUSSION Q&A

Jumpstart Your Practice Improvement Journey:

Access the FREE Tools and Training for Improving Exposure Decisions:

- Get the Free Tools HERE
  - Take the Free Course HERE
    - Pass the Free EDA Exam HERE
      - **YOUR NAME HERE**

Registered Specialist
Exposure Decision Analysis

AIHA Registry Programs®