Improving Exposure Data Interpretation and Professional Judgment

Georgia Local Section, AIHA

January 25, 2012
Atlanta

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Agenda

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

Introduction

A Brief Survey

Rate Each Scenario as either Acceptable or Unacceptable

Survey: EA Symposium Participants

Scenario 1

Agent	Xylene					
TLV	100 ppm**				**Exposure Judgment (Choose One)**	
Sample 1	Sample 2				**Acceptable**	
21	68				**Unacceptable**	

** Irritation

Scenario 2

Agent	Xylene					
TLV	100 ppm**				**Exposure Judgment (Choose One)**	
Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	**Acceptable**	
21	109	38	41	48	**Unacceptable**	

** Irritation

Scenario 3

Agent	Xylene					
TLV	100 ppm**				**Exposure Judgment (Choose One)**	
Sample 1	Sample 2	Sample 3	Sample 4		**Acceptable**	
12	16	21	24		**Unacceptable**	

** Irritation

Scenario 4

Agent	Xylene					
TLV	100 ppm**				**Exposure Judgment (Choose One)**	
Sample 1					**Acceptable**	
5					**Unacceptable**	

** Irritation

Scenario 5

Agent	Xylene					
TLV	100 ppm**				**Exposure Judgment (Choose One)**	
Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	**Acceptable**	
8	70	5	37	12	**Unacceptable**	

** Irritation

Survey:

8-hr TWA Sample Results for five operations. Rate the exposures as acceptable or unacceptable.

Xylene: TLV = 100 ppm		Interpretation - Acceptable?	
Scenario	Data (ppm)	Yes	No
1	21, 68		
2	21, 109, 38, 41, 48		
3	12, 16, 21, 24		
4	5		
5	8, 70, 5, 37, 12		

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EA Symposium Survey Results

Xylene: TLV = 100 ppm		Interpretation - Acceptable?	
Scenario	Data (ppm)	Yes	No
1	21, 68	17%	83%
2	21, 109, 38, 41, 48	12%	88%
3	12, 16, 21, 24	92%	8%
4	5	49%	51%
5	8, 70, 5, 37, 12	35%	65%

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Different Decisions = Different Levels of Care . . . i.e. Different Levels of Exposure Risk

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Why the Inconsistencies?

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Data Interpretation Example

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

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Why the Inconsistencies?

- Variable Definitions of Acceptable

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How much assurance?

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

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Why the Inconsistencies?

- Variable Definitions of Acceptable
- Variable Definitions of Acceptable Uncertainty

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Why the Inconsistencies?

- Variable Definitions of Acceptable
- Variable Definitions of Acceptable Uncertainty

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

Are we getting that performance?

Interpreting Data: Data Quality Considerations

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

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

Question:

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

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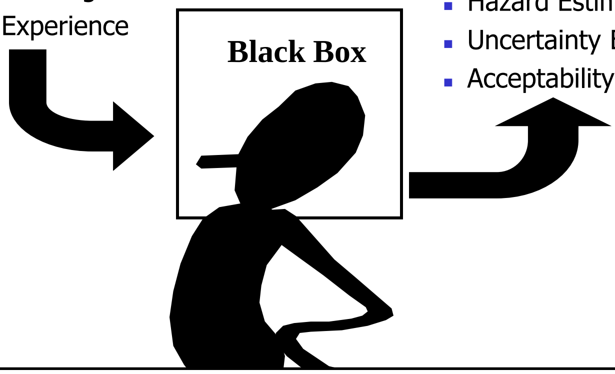
Exposure Judgments

- Inputs
  - Basic Characterization Information
  - Training
  - Experience
- Outputs
  - Exposure Judgment
    - Exposure Estimate
    - Hazard Estimate
    - Uncertainty Estimate
    - Acceptability Estimate



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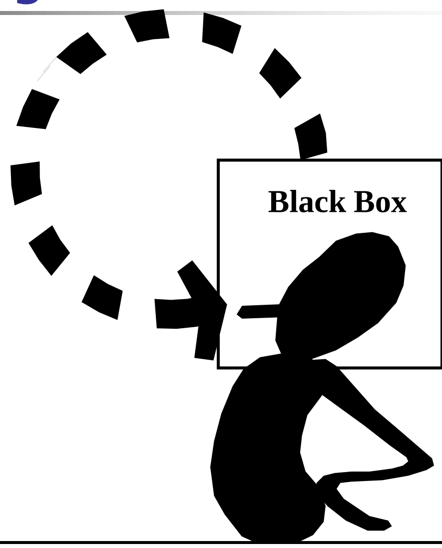
Improving the Black Box:

- Training
- Feedback



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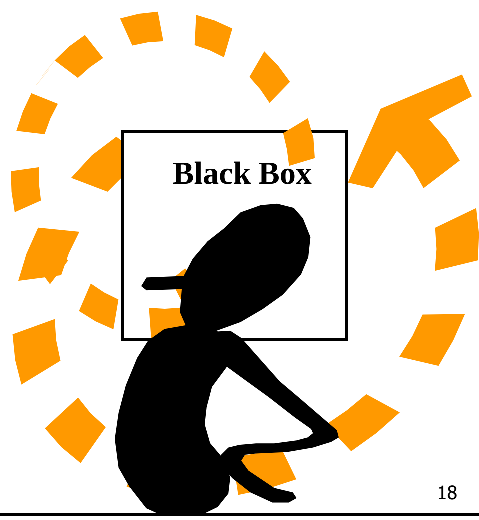
Improving the Black Box:

- Training
- Feedback

What if the feedback loop is faulty?



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Inconsistent data interpretation

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

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Data Interpretation Exercise Class Work: DIT

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Exposure Rating Categories

Exposure Rating Category		Cutoff (%OEL)
	1	$X_{0.95} \leq 10\%$
	2	$10\% < X_{0.95} \leq 50\%$
	3	$50\% < X_{0.95} \leq 100\%$
	4	$X_{0.95} > 100\%$

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Data Interpretation Test (DIT) Rules!

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

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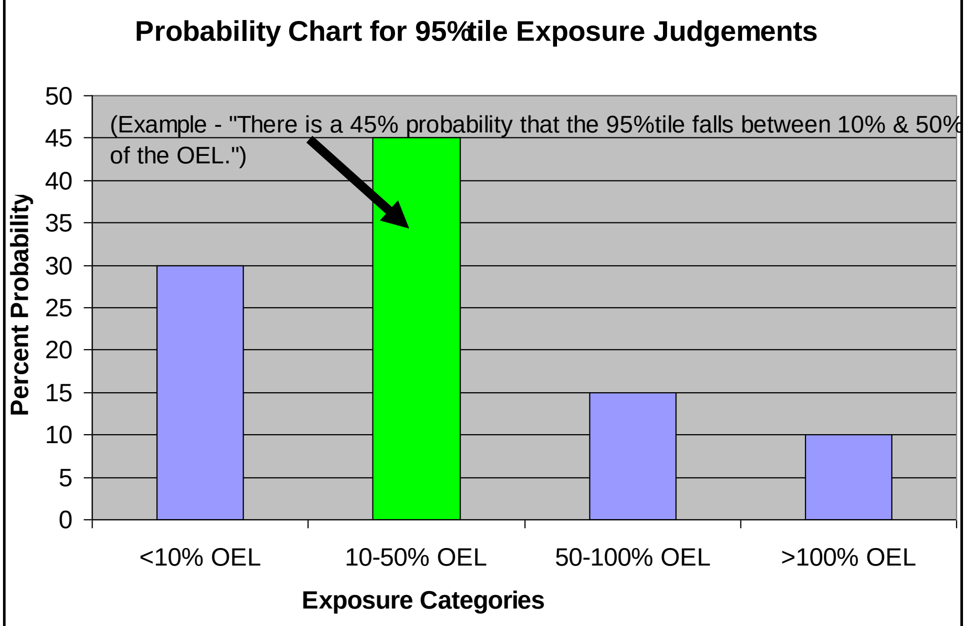

Example of filling out the DIT

Categories	Dataset #1 - Probability of 95th Percentile in Category
<10%	30
10-50%	45
50-100%	15
>100%	10

Data Interpretation Test (DIT) #6

Enter Your Number

OEL for all Data Sets
100

	Sample Data Set #1	Sample Data Set #2	Sample Data Set #3	Sample Data Set #4	Sample Data Set #5	Sample Data Set #6	Sample Data Set #7	Sample Data Set #8
	30	6	33	5	78	3	31	14
	17		37	20		1	17	5
	7		9	3			18	6
	13		109	12			45	12
	63		8					4
	5		5					36

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

	Data Set #1	Data Set #2	Data Set #3	Data Set #4	Data Set #5	Data Set #6	Data Set #7	Data Set #8
1-10% OEL								
10-50% OEL								
50-100% OEL								
>100% OEL								
Check	100?	100?	100?	100?	100?	100?	100?	100?

Have you ever taken this statistical test before? Yes No

If yes, how many times & when?

Instructions

Enter your name at the top
Review each data set and document the probabilities of where the 95th%tile falls
Make sure that one category has the highest percentage
Do not enter values less than 1 in any field (no zeros!)
Check to see that each Data Set Column adds to 100%

Please list any specific comments regarding this DIT

Bayesian Statistics –
How Might They Help?

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Use of Statistical Tools

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

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Why the Inconsistencies?

- Variable Definitions of Acceptable
- Variable Definitions of Acceptable Uncertainty
- Inconsistent use and understanding of techniques for interpreting limited data sets
  - Statistics can be difficult to interpret
  - Sampling Limited: Would like to leverage all available information

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Problems with judging or estimating 95%tiles

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

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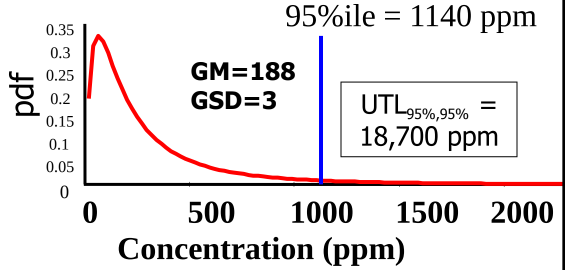
Is the exposure represented by these samples acceptable?

Ethanol OEL = 1000 ppm

Monitoring Results:

215 ppm
52 ppm
395 ppm
700 ppm
75 ppm

Traditional IH Statistics
95%ile = 1140 ppm



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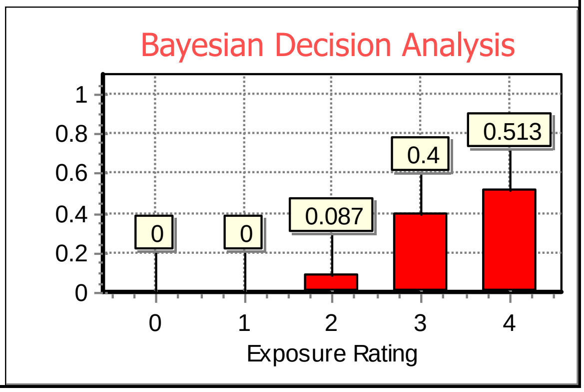

Bayesian Decision Analysis (BDA)

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

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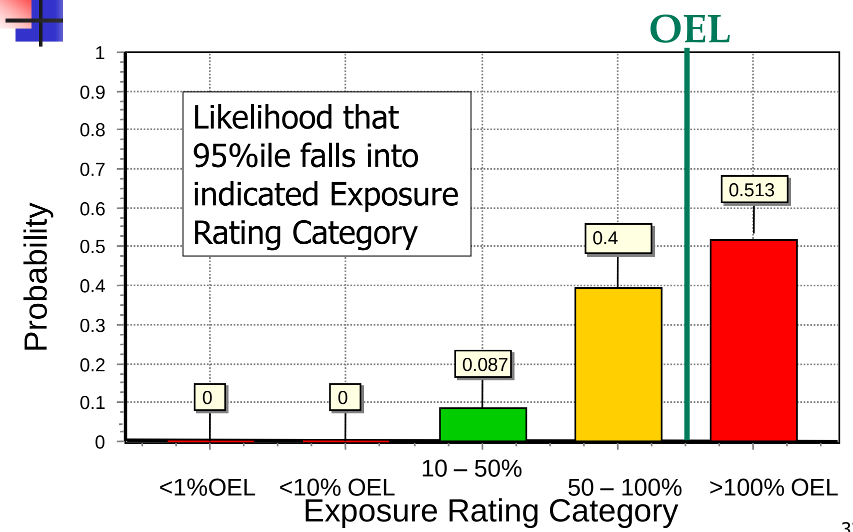
Straightforward Interpretation: Bayesian Likelihood Distribution



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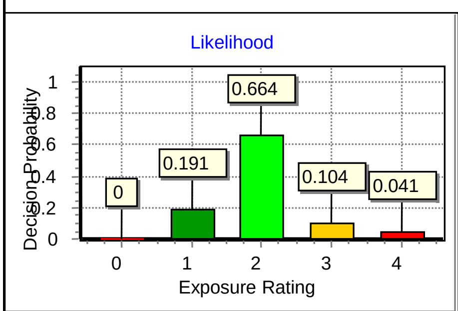

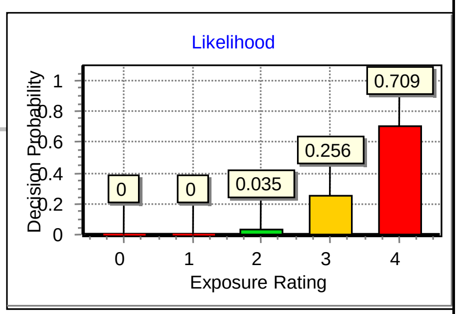

Much easier to communicate!

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A Brief Survey

Examples Using BDA Tool

Rate Each Scenario as either Acceptable or Unacceptable

Survey: EA Symposium Participants

Scenario 1

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Sample 1					**Acceptable**	
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** Irritation

Scenario 5

Agent	Xylene					
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8	70	5	37	12	**Unacceptable**	

** Irritation

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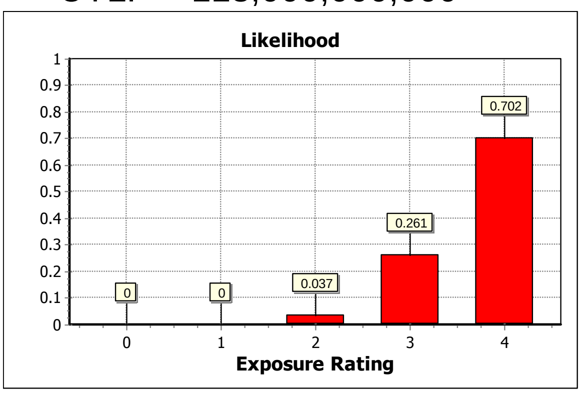
Xylene OEL=100 Scenario 1

X		
21	gsd:	2.295
68	95%ile:	148
	UTL:	113,000,000,000

17% Rated as Acceptable

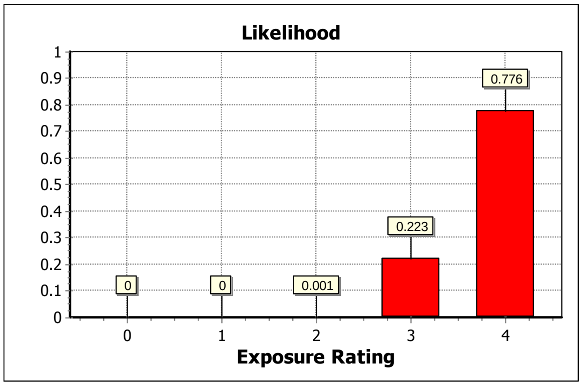


Xylene OEL=100
Scenario 2

X		
21	gsd:	1.808
109	95%ile:	117
38	UTL:	535
41		
48		

12% Rated as Acceptable

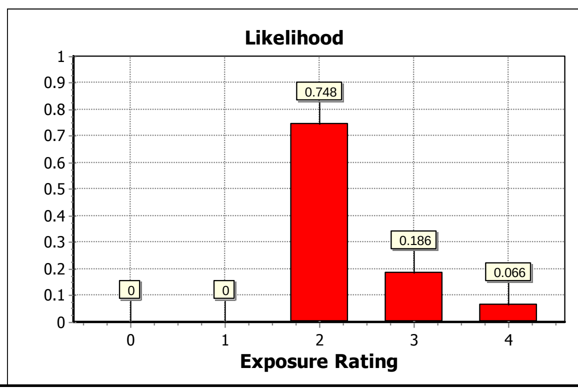
"Would Look More Closely at 109"



Xylene OEL=100
Scenario 3

X		
12	gsd:	1.36
16	95%ile:	29.2
21	UTL:	85.7
24		

92% Rated as Acceptable

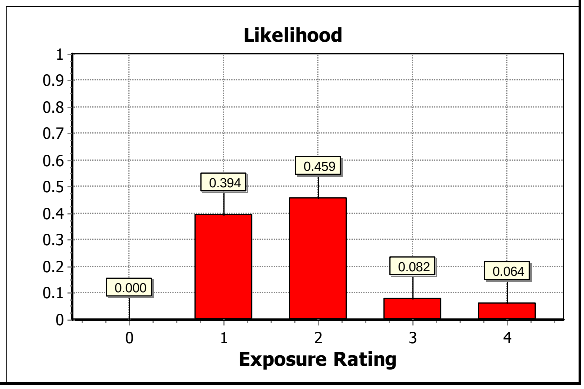


Xylene OEL=100
Scenario 4

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

49% Rated as Acceptable

"Need More Data"

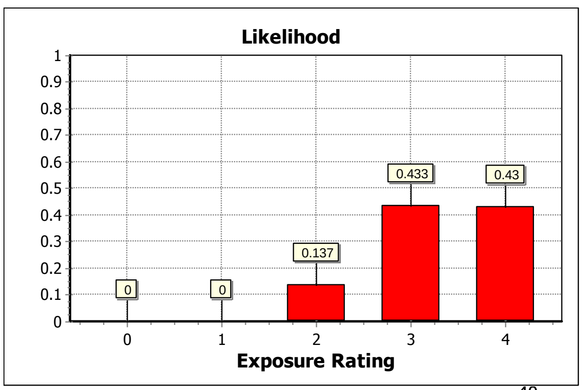


Xylene OEL=100
Scenario 5

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

35% Rated as Acceptable

"Maybe 2+ Exposure Groups"



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AIHA Model: Inherently Bayesian

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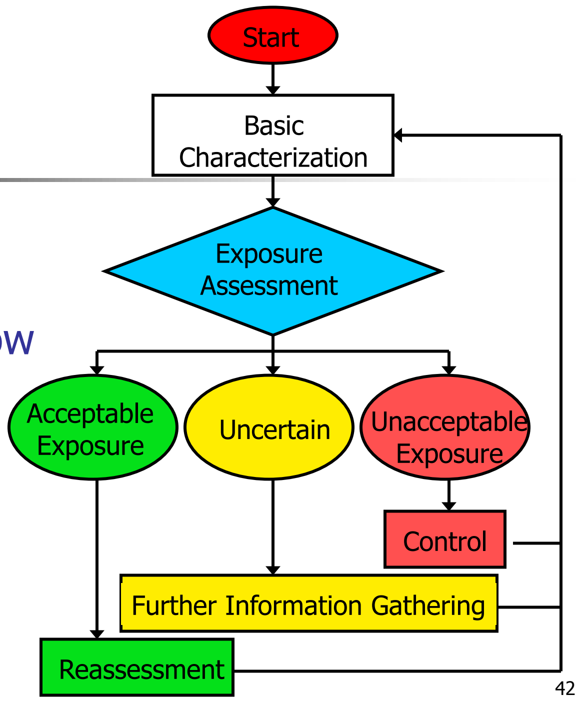
AIHA Exposure Assessment Flow Diagram



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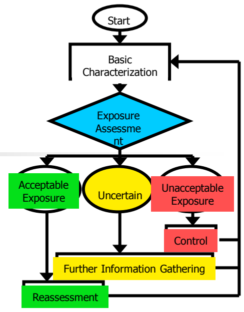
AIHA EA Strategy



Define Exposure Using All Available Information

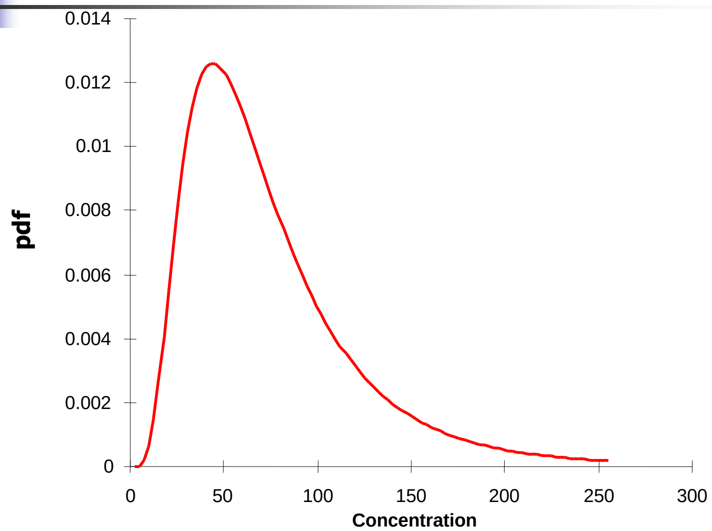
Conditions

Qualitative
Modeling
Monitoring

EA Tools

Exposure Profile

Exposure Profile



Example: Exposure Rating Category Follow-up

	Exposure Control Category**	Recommended Control
	0 (<1% of OEL)	No action
	1 (<10% of OEL)	general HazCom
	2 (10-50% of OEL)	+ chemical specific HazCom
	3 (50-100% of OEL)	+ exposure surveillance, medical surveillance, work practices
	4 (>100% of OEL)	+ respirators & engineering controls, work practice controls
	5 (Multiples of OEL; e.g., based on respirator APFs)	+ immediate engineering controls or process shutdown, validate respirator selection

** - Decision statistic = 95th percentile

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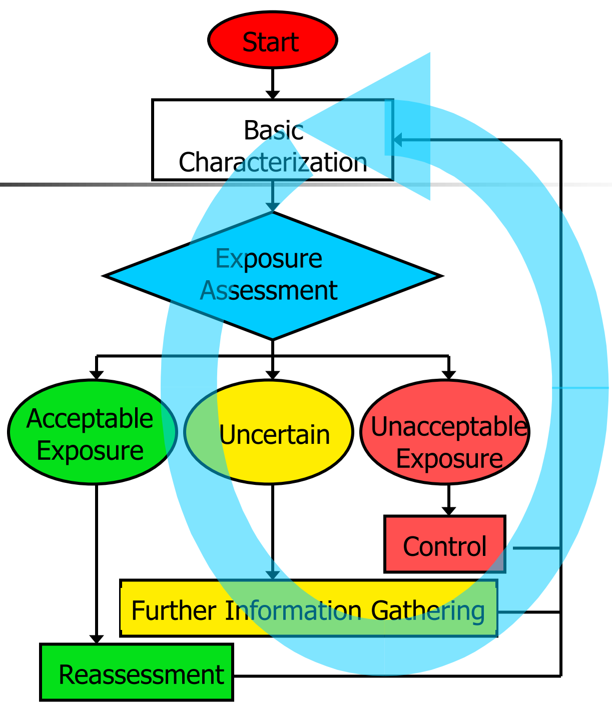

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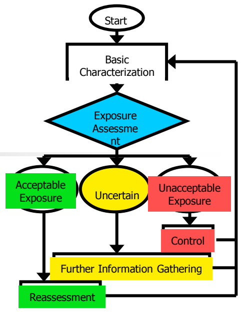
AIHA EA Strategy



Define Exposure Using All Available Information

Conditions → Qualitative / Modeling / Monitoring — EA Tools → Exposure Profile

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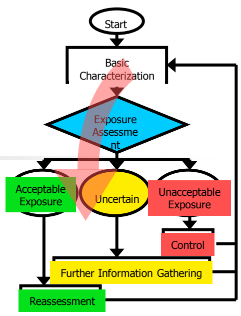
Initial Assessment



Heavy Emphasis on Professional Judgment or Modeling

Conditions → Qualitative / Modeling / Monitoring — EA Tools → Exposure Profile

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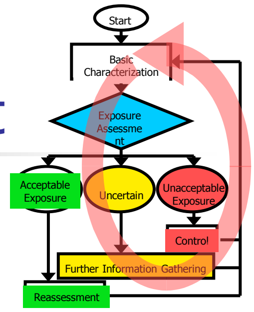
Validated Assessment



Heavy Emphasis on Monitoring Data

Conditions → Qualitative / Modeling / **Monitoring** — EA Tools → Exposure Profile

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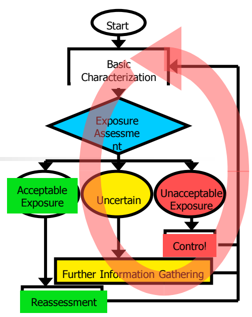
AIHA EA Strategy:



Define Exposure **Using All Available Information**

Conditions → **Qualitative** / **Modeling** / **Monitoring** — EA Tools → Exposure Profile

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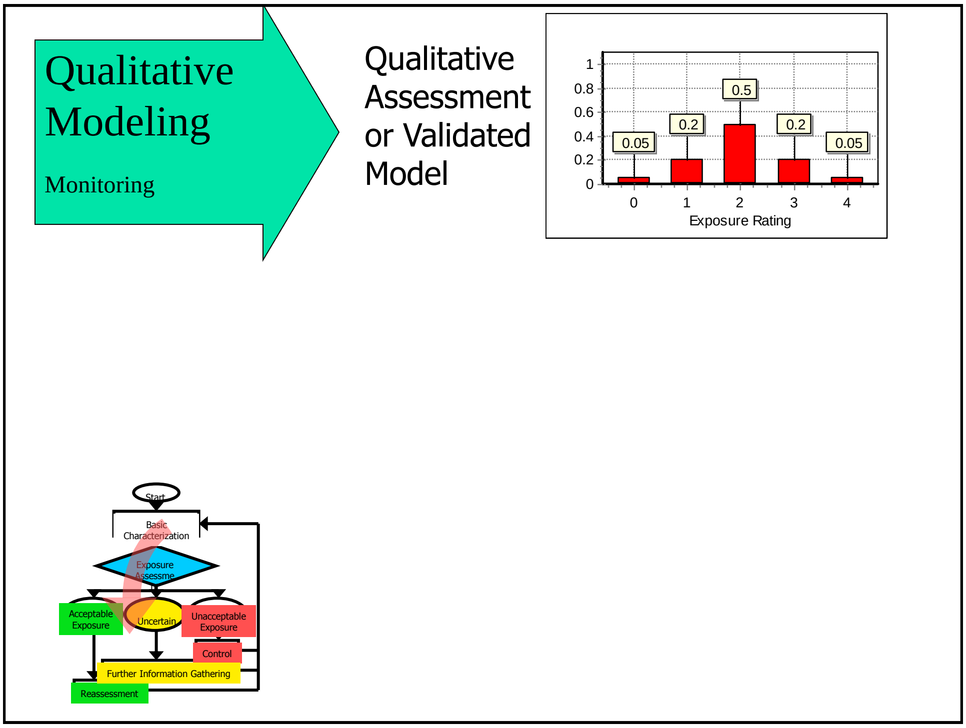
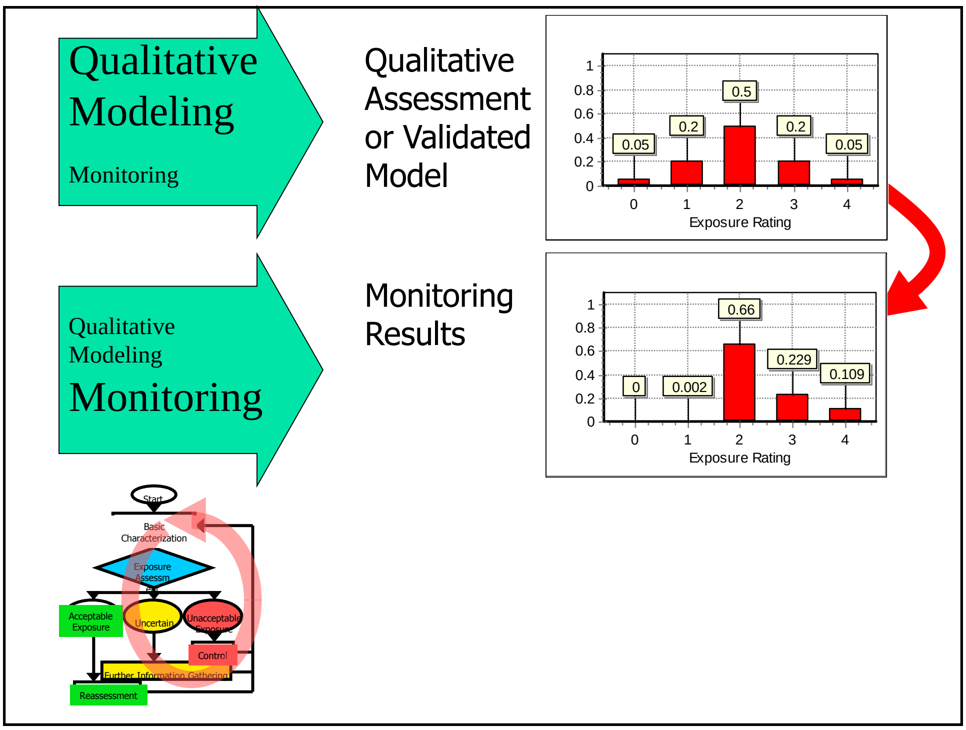
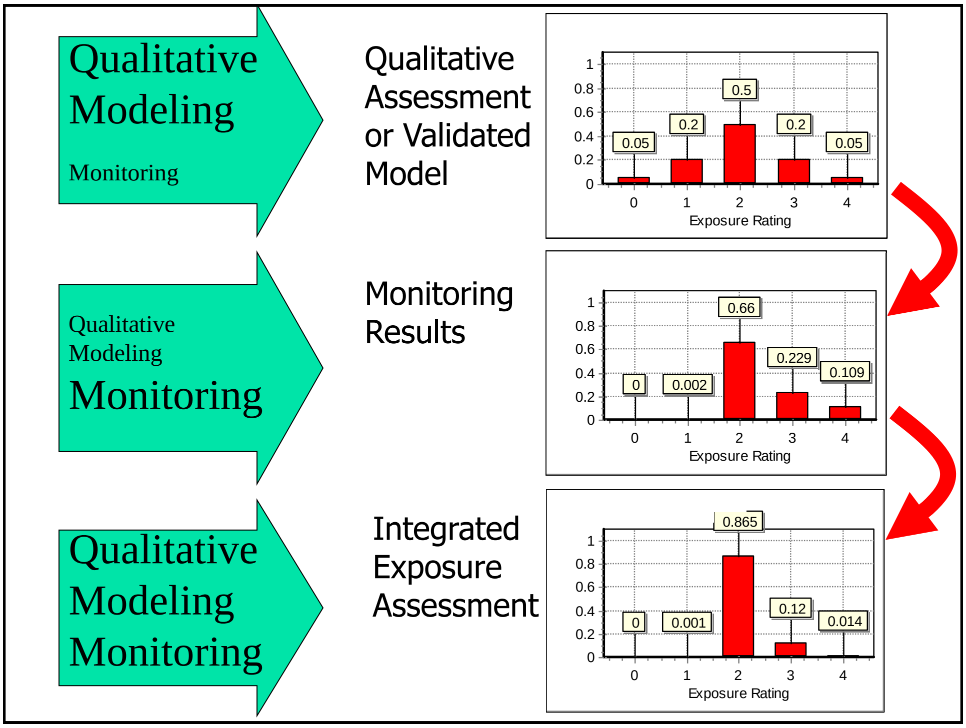

Qualitative
Modeling
Monitoring
Qualitative Assessment or Validated Model
1
0.8
0.6
0.4
0.2
0
0.05
0.2
0.5
0.2
0.05
0 1 2 3 4
Exposure Rating
Start
Basic Characterization
Acceptable Exposure
Uncertain
Unacceptable Exposure
Control
Further Information Gathering
Reassessment


Qualitative
Modeling
Monitoring
Qualitative Assessment or Validated Model
1
0.8
0.6
0.4
0.2
0
0.05
0.2
0.5
0.2
0.05
0 1 2 3 4
Exposure Rating
Qualitative
Modeling
Monitoring
Monitoring Results
1
0.8
0.6
0.4
0.2
0
0
0.002
0.66
0.229
0.109
0 1 2 3 4
Exposure Rating
Start
Basic Characterization
Acceptable Exposure
Uncertain
Control
Reassessment



Qualitative
Modeling
Monitoring
Qualitative Assessment or Validated Model
1
0.8
0.6
0.4
0.2
0
0.05
0.2
0.5
0.2
0.05
0
1
2
3
4
Exposure Rating
Qualitative
Modeling
Monitoring
Monitoring Results
0
0.002
0.66
0.229
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Qualitative
Modeling
Monitoring
Integrated Exposure Assessment
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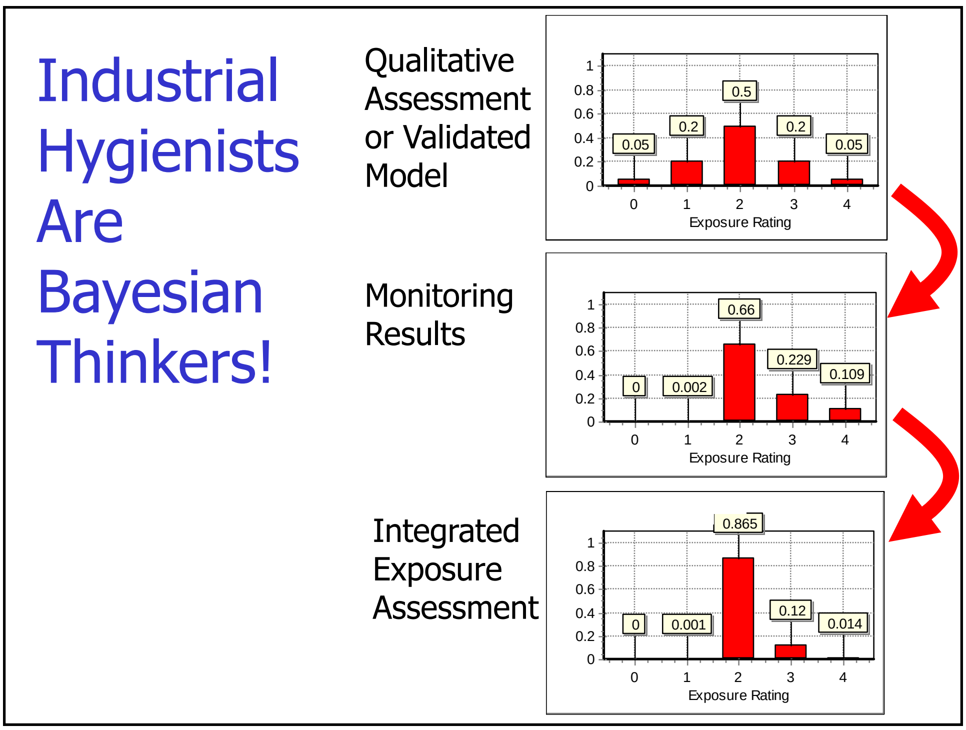
0.001
0.865
0.12
0.014
Exposure Rating



Industrial Hygienists Are Bayesian Thinkers!
Qualitative Assessment or Validated Model
0.05
0.2
0.5
0.2
0.05
Exposure Rating
Monitoring Results
0
0.002
0.66
0.229
0.109
Exposure Rating
Integrated Exposure Assessment
0
0.001
0.865
0.12
0.014
Exposure Rating

An Example Using the AIHA Model

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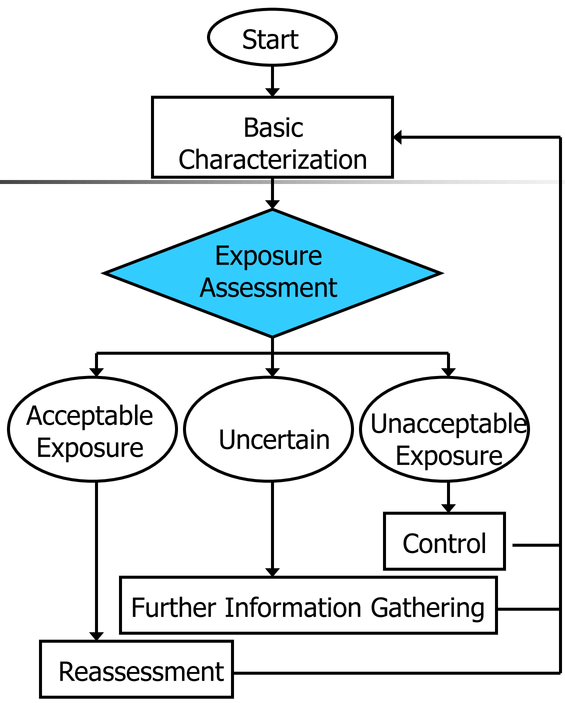

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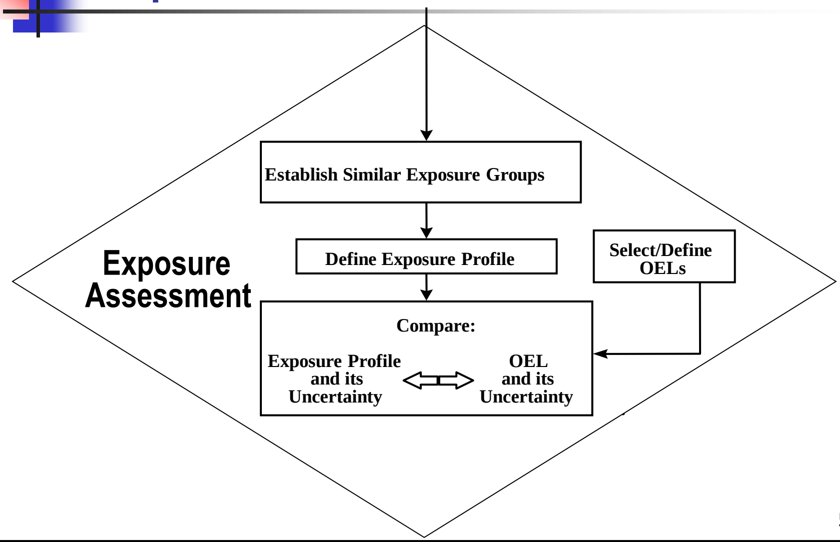
Exposure Assessment



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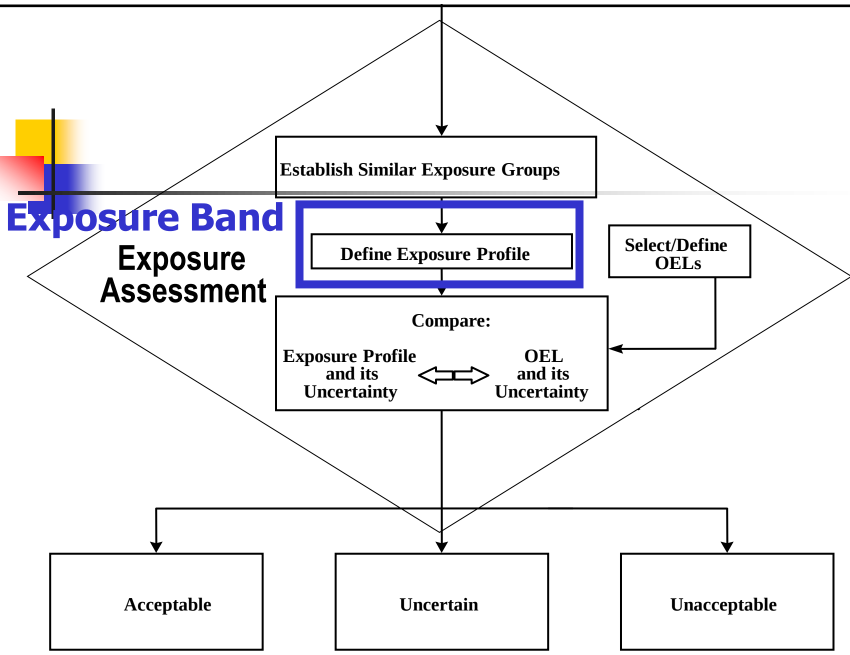

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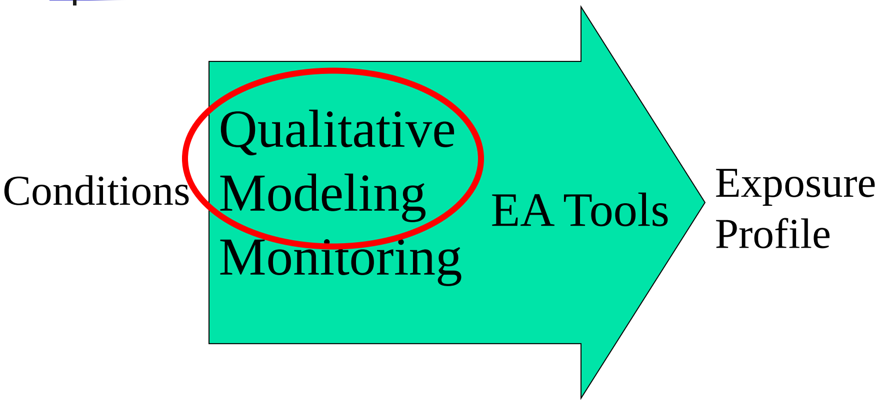
AIHA EA Strategy:
Define Exposure Using All Available Information



Tools for Initial Assessment

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Example: Exposure Estimate

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

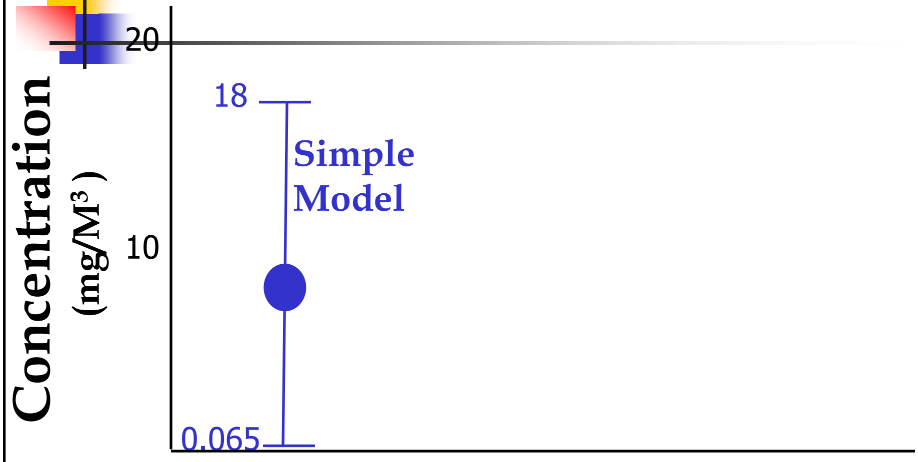
Simple Model:

$$C = \frac{G}{Q}$$

Worst Case $C = \dfrac{65 \text{ mg/hour}}{3.6 \text{ m}^3\text{/hour}} = 18 \text{ mg/m}^3$

Best Case $C = \dfrac{35 \text{ mg/hour}}{540 \text{ m}^3\text{/hour}} = 0.065 \text{ mg/m}^3$

Uncertainty and Acceptability



Example: Exposure Estimate

Statistical Modeling: Monte Carlo Uncertainty Analysis

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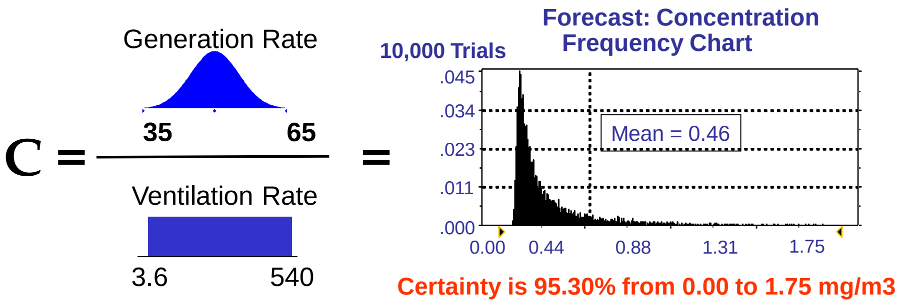
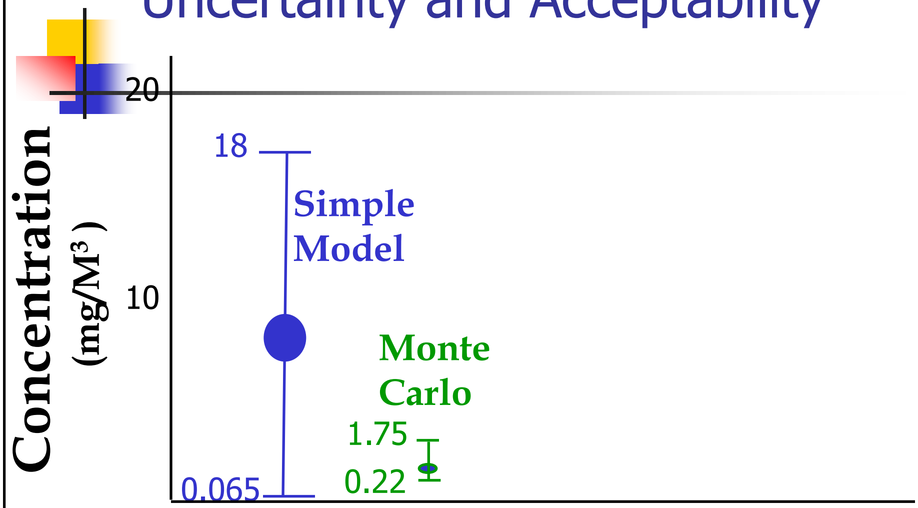
Q= steady ventilation rate (m^3/hour)
3.6 to 540 m^3/hour



Uncertainty and Acceptability



COSHH Essentials

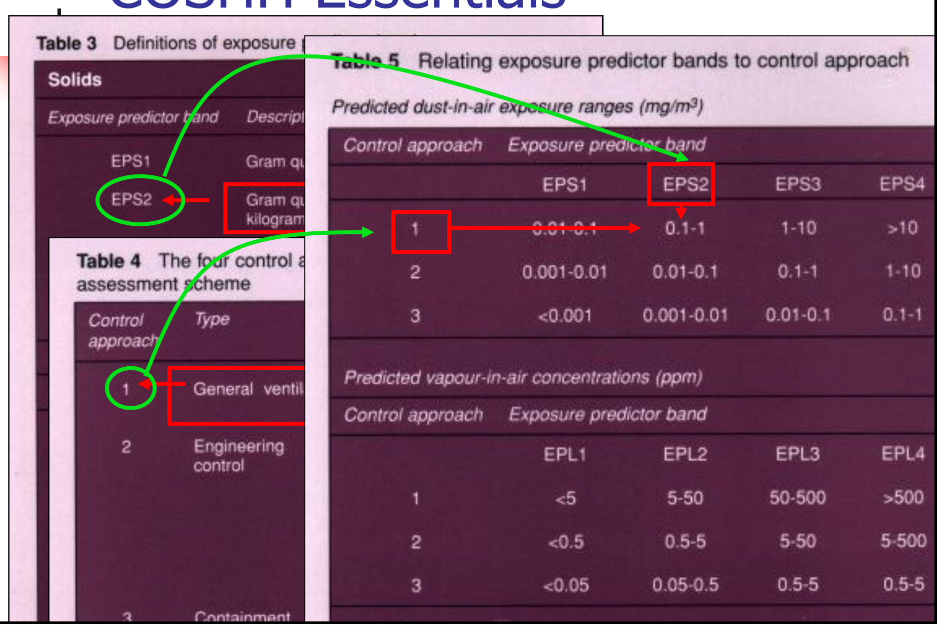


Table 3 Definitions of exposure

Solids	
Exposure predictor band	*Descript*
EPS1	Gram qu
EPS2	Gram qu kilogram

Table 4 The four control a assessment scheme

Control approach	*Type*
1	General ventil
2	Engineering control
3	Containment

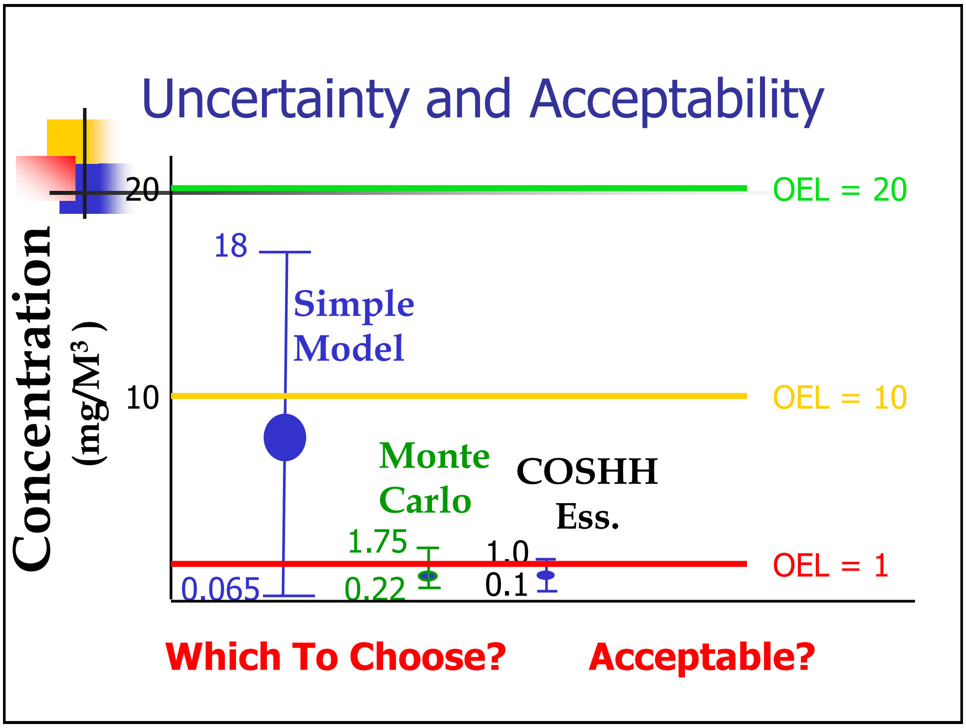
Table 5 Relating exposure predictor bands to control approach

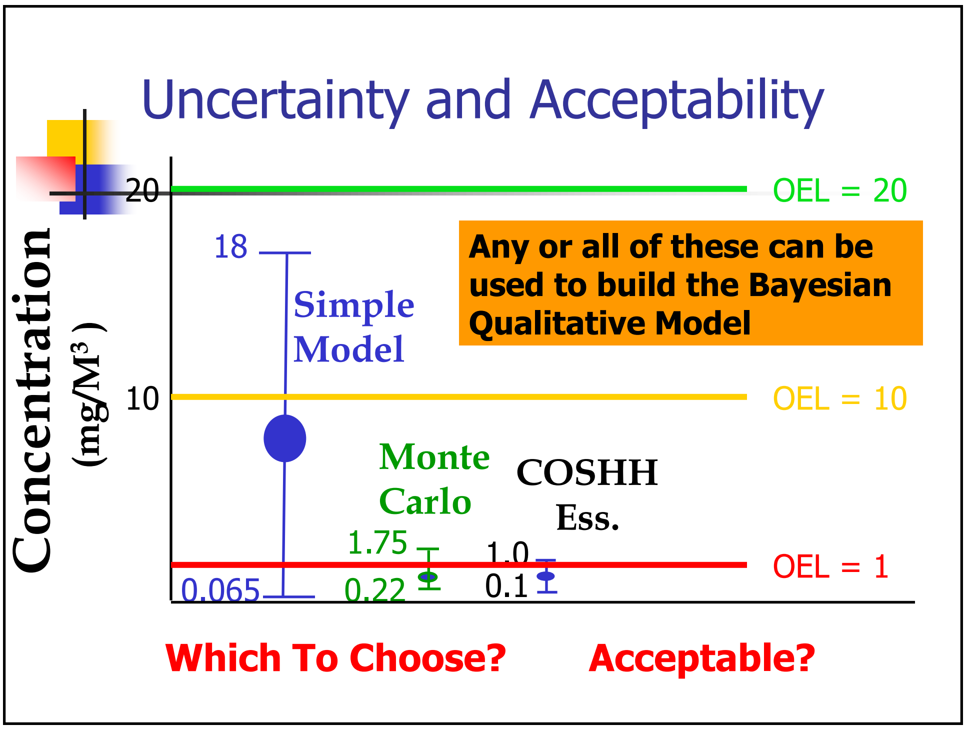
Predicted dust-in-air exposure ranges (mg/m³)

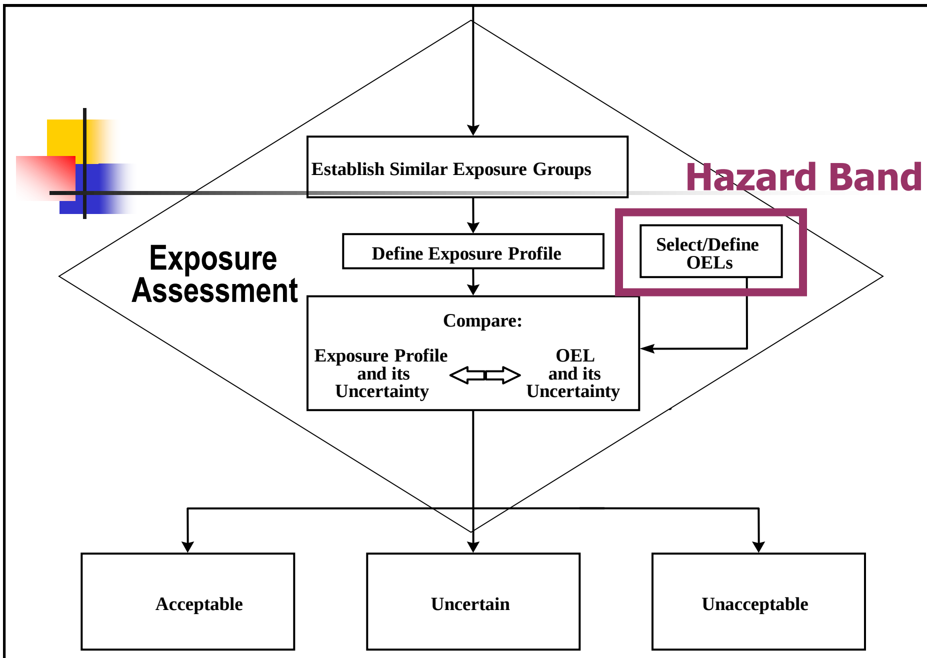
Control approach	*Exposure predictor band*			
	EPS1	EPS2	EPS3	EPS4
1	0.01-0.1	0.1-1	1-10	>10
2	0.001-0.01	0.01-0.1	0.1-1	1-10
3	<0.001	0.001-0.01	0.01-0.1	0.1-1

Predicted vapour-in-air concentrations (ppm)

Control approach	*Exposure predictor band*			
	EPL1	EPL2	EPL3	EPL4
1	<5	5-50	50-500	>500
2	<0.5	0.5-5	5-50	5-500
3	<0.05	0.05-0.5	0.5-5	0.5-5


Uncertainty and Acceptability
Concentration (mg/M³)
20
10
OEL = 20
OEL = 10
OEL = 1
18
Simple Model
0.065
Monte Carlo
1.75
0.22
COSHH Ess.
1.0
0.1
Which To Choose?
Acceptable?


Uncertainty and Acceptability
Concentration (mg/M³)
20
10
OEL = 20
OEL = 10
OEL = 1
18
Simple Model
Any or all of these can be used to build the Bayesian Qualitative Model
0.065
Monte Carlo
1.75
0.22
COSHH Ess.
1.0
0.1
Which To Choose?
Acceptable?



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OELs

- **Regulatory** - Set and enforced by government agencies
  - e.g. OSHA PEL, MSHA PEL
- **Authoritative** - Set and recommended by credible organizations
  - e.g. ACGIH TLV, AIHA WEEL
- **Internal** - Devised by organizations for internal use and/or recommendation
  - e.g. Company Exposure Guideline

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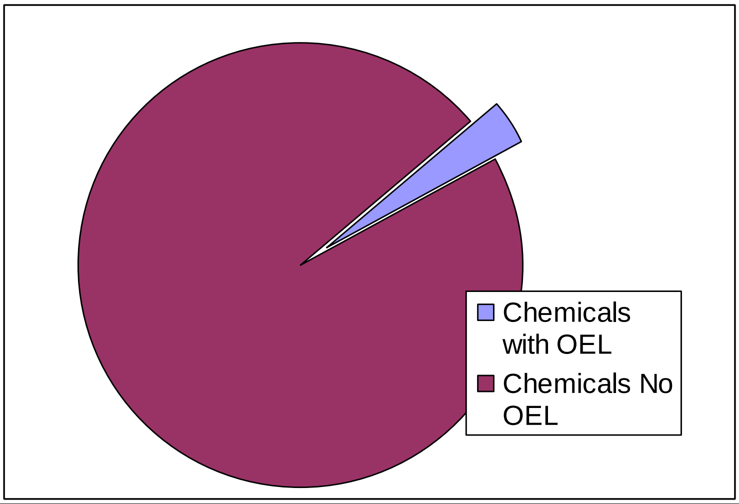
Chemicals With OELs



OELs

- **Regulatory** - Set and enforced by government agencies
  - e.g. OSHA PEL, MSHA PEL
- **Authoritative** - Set and recommended by credible organizations
  - e.g. ACGIH TLV, AIHA WEEL
- **Internal** - Devised by organizations for internal use and/or recommendation
  - e.g. Company Exposure Guideline
- **Working** - Informal limit established in order to resolve an exposure assessment. Typically based on sparse toxicity data.

WOEL Example: Pharmaceutical Indust.

Table 5.4

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

Category for Performance-Based Exposure Control Limit	General Corresponding Numerical "Exposure Control Limit" 8 Hour TWA	General Corresponding Wipe Test Criteria	Containment Level
1	In the range of 1- 5 mg/M^3	In the range of 100 mg/100 cm^2	Good manufacturing practices
2	In the range of 0.1 - 1 mg/M^3	In the range of 1 mg/100 cm^2	Good manufacturing practices (with more stringent controls)
3	In the range of 1 - 100 ug/M^3	In the range of 100 ug/100 cm^2	Essentially no open handling (closed systems should be used)
4	In the range of <1 ug/M^3	In the range of 10 ug/100 cm^2	No open handling (closed systems must be used)
5	In the range of 0.1 ug/M^3	In the range of 1 ug/100 cm^2	No manual operations, no human intervention (robotics / remote operations encouraged)

WOEL Example: COSHH Essentials

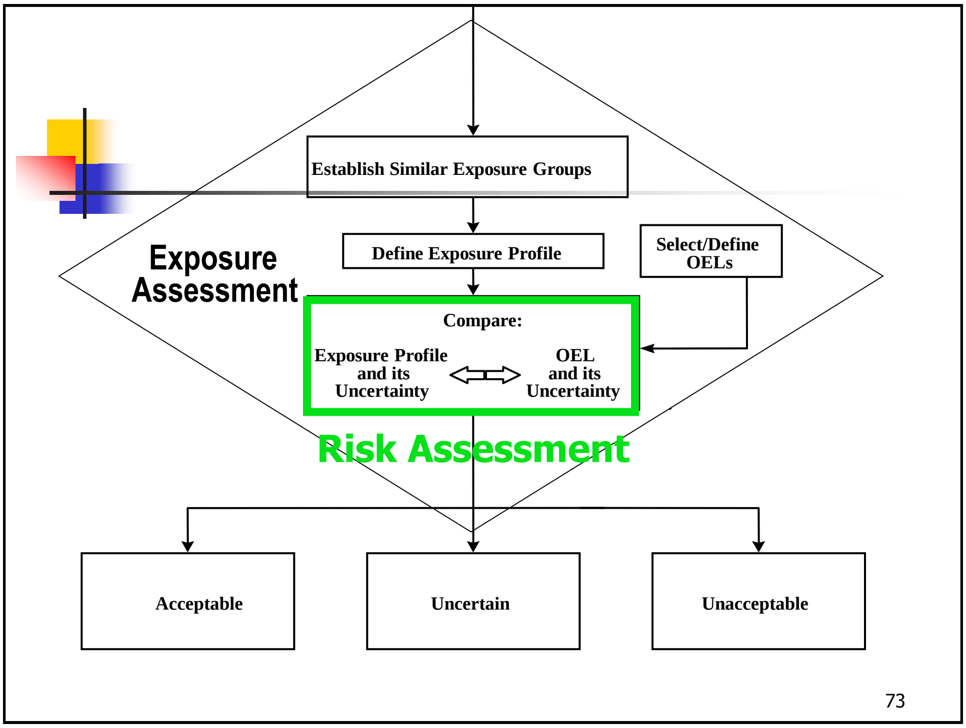
Table 1 Allocation of R phrases to hazard groups, showing airborne concentration range for each group

Hazard group	*Target airborne concentration range*	*R phrases*
A	>1-10 mg/m^3 dust >50-500 ppm vapour	R36, R38 All substances that do not have R phrases in groups B-E
B	>0.1-1 mg/m^3 dust >5-50 ppm vapour	R20/21/22*, *R40/20/21/22**
C	>0.01-0.1 mg/m^3 dust >0.5-5 ppm vapour	R48/20/21/22*, R23/24/25*, R34, R35, R36/37, R37/38, R36/37/38, R37, *R39/23/24/25**, R41, R43
D	< 0.01 mg/m^3 dust < 0.5 ppm vapour	R48/23/24/25*, R26/27/28*, *R39/26/27/28*, Carc Cat 3 R40, R60, R61, R62, R63
E	Seek specialist advice	Muta Cat 3 R40, R42, R42/43 R45, R46, R49
S: skin and eye contact	Prevention or reduction of skin and/or eye exposure	R21, R24, R27, R34, R35, R36, R38, R41, R43, R48/21, R48/24, plus R-phrase combinations containing these. Sk

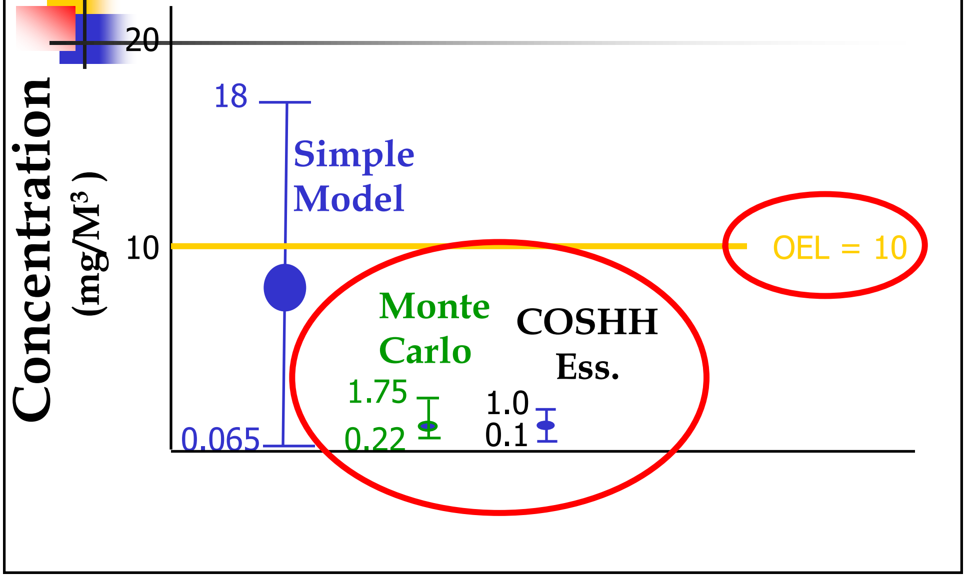
ppm = parts per million

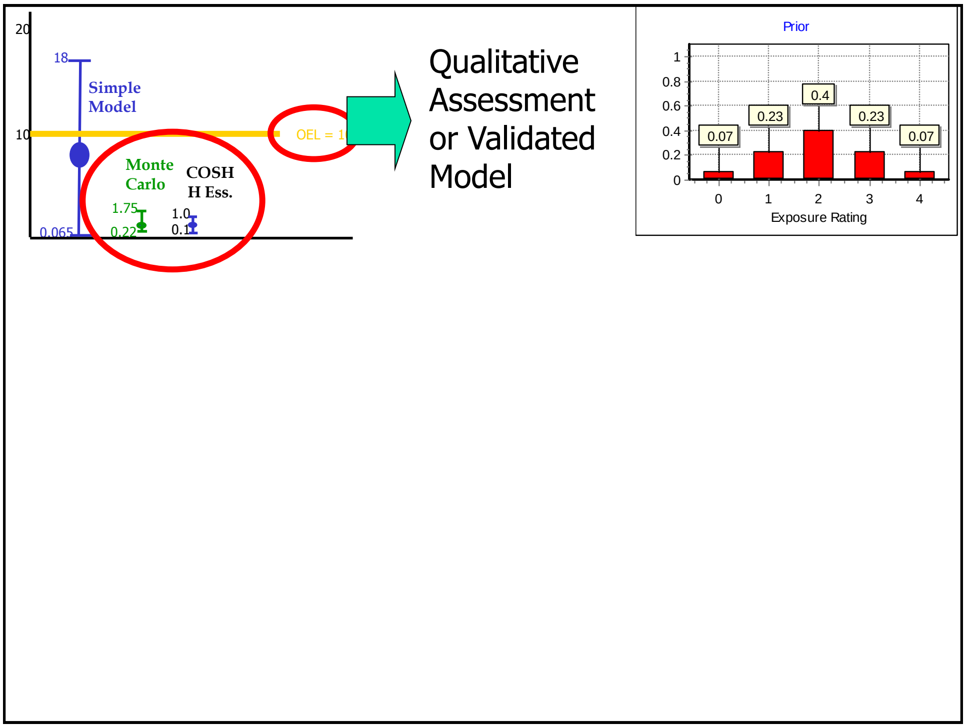
* The R-phrase combinations 20/21/22; 23/24/25 and 26/27/28 may be used alone or in pairs (eg R20/21/22 includes R20, R21, R22, R20/21, R20/22 and R21/22). The R-phrase combinations beginning R39/, R40/ and R48/ are used with one or more 'route indicator' R phrases (eg R48/20/21/22 includes R48/20, R48/21 etc).

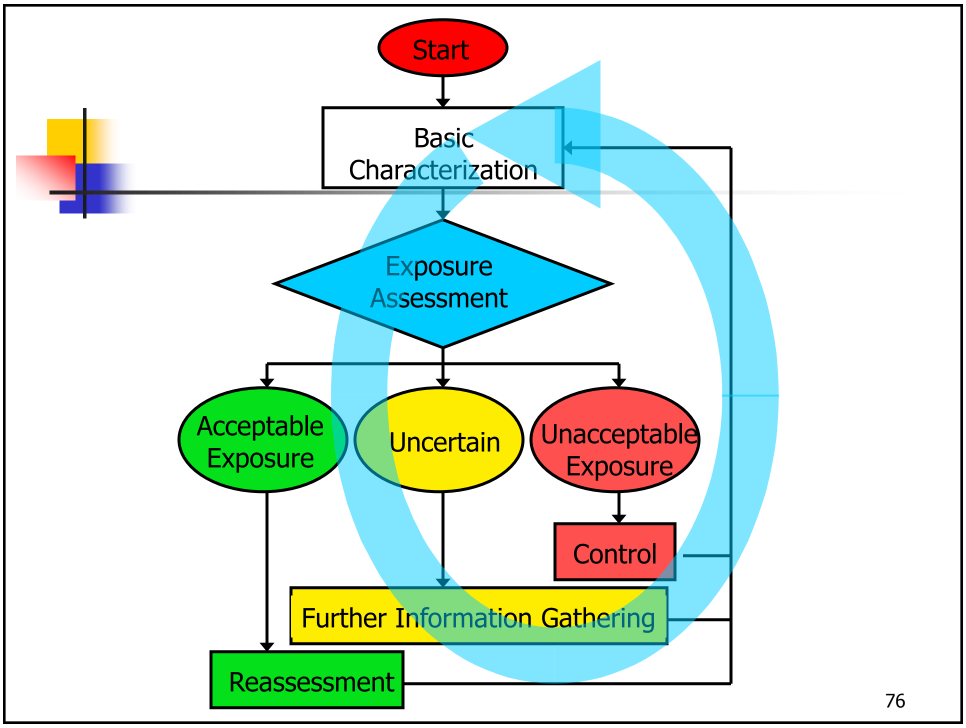
Note: R-phrase combinations given in italics are omitted from the main guidance, since these combinations are little used and would only rarely

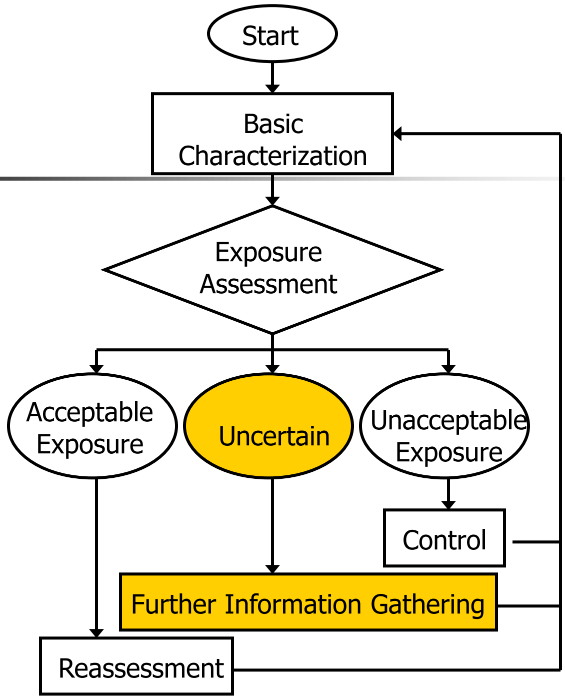


Uncertainty and Acceptability




20
18
10
Simple Model
Monte Carlo
COSH H Ess.
1.75
0.22
1.0
0.065
OEL = 1
Qualitative Assessment or Validated Model
Prior
0.07
0.23
0.4
0.23
0.07
Exposure Rating


Start
Basic Characterization
Exposure Assessment
Acceptable Exposure
Uncertain
Unacceptable Exposure
Control
Further Information Gathering
Reassessment
76



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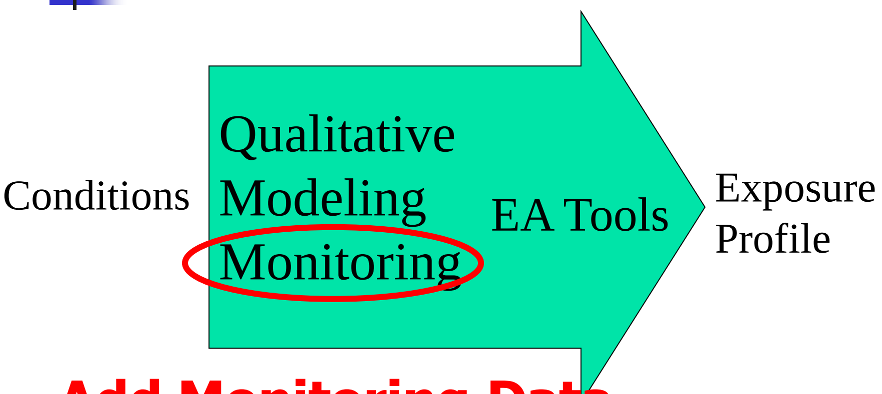
AIHA EA Strategy:
Define Exposure Using All Available Information



Add Monitoring Data . . .
Validate Initial Judgments

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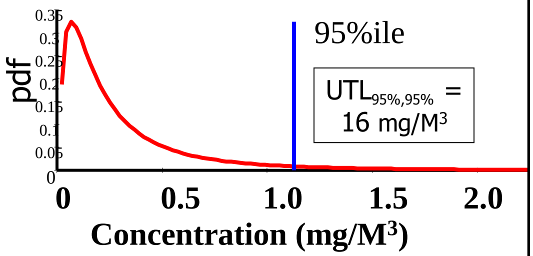
Example: Exposure Estimate

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

Monitoring Results:

0.05 mg/M^3
0.14 mg/M^3
0.21 mg/M^3
0.37 mg/M^3
0.78 mg/M^3



Example: Exposure Estimate

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G= steady generation rate (mg/hour)
35 to 65 mg/hour
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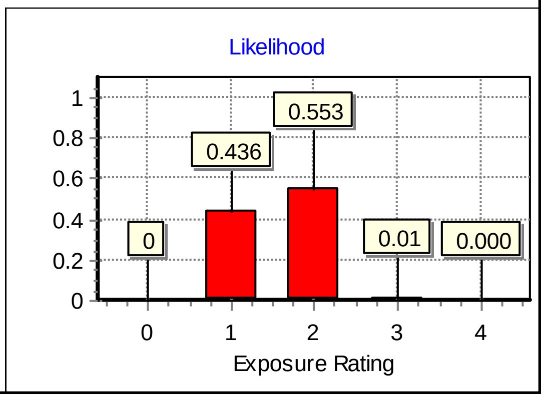
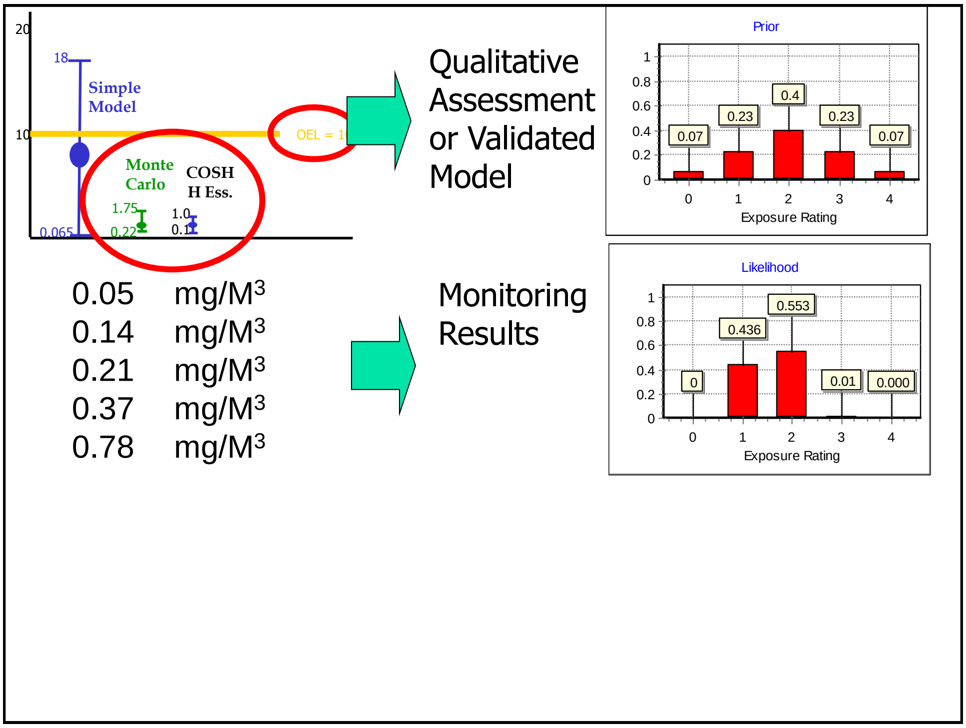
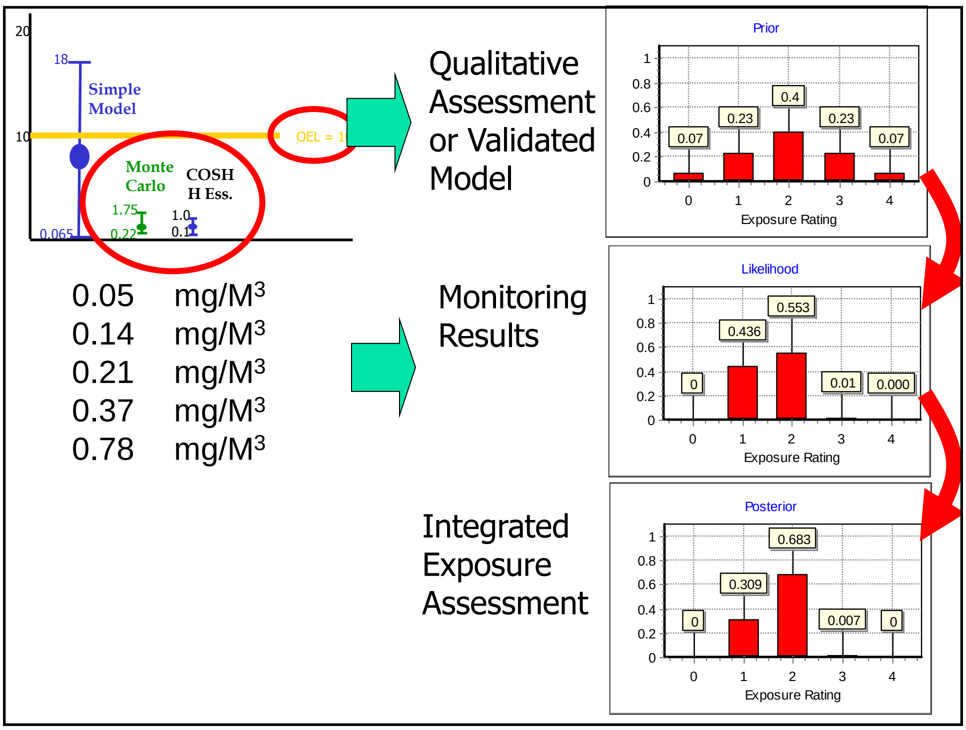
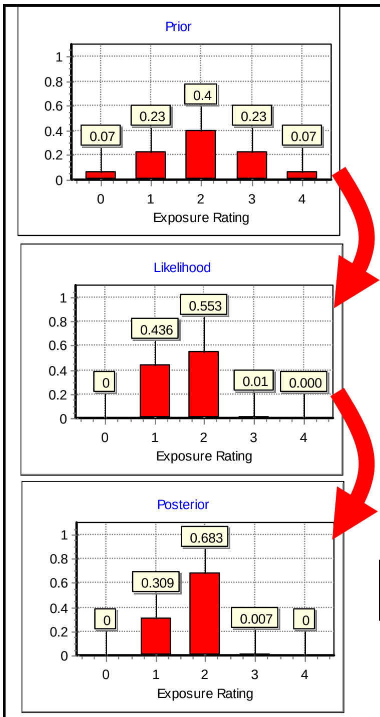
Monitoring Results:

0.05 mg/M^3
0.14 mg/M^3
0.21 mg/M^3
0.37 mg/M^3
0.78 mg/M^3




20
18
Simple Model
10
OEL = 1
Monte Carlo
COSH H Ess.
1.75
0.22
1.0
0.1
0.065
Qualitative Assessment or Validated Model
0.05 mg/M3
0.14 mg/M3
0.21 mg/M3
0.37 mg/M3
0.78 mg/M3
Monitoring Results
Prior
0.07 0.23 0.4 0.23 0.07
Exposure Rating
Likelihood
0 0.436 0.553 0.01 0.000
Exposure Rating


20
18
Simple Model
10
OEL = 1
Monte Carlo
COSH H Ess.
1.75
0.22
1.0
0.1
0.065
Qualitative Assessment or Validated Model
0.05 mg/M3
0.14 mg/M3
0.21 mg/M3
0.37 mg/M3
0.78 mg/M3
Monitoring Results
Integrated Exposure Assessment
Prior
0.07 0.23 0.4 0.23 0.07
Exposure Rating
Likelihood
0 0.436 0.553 0.01 0.000
Exposure Rating
Posterior
0 0.309 0.683 0.007 0
Exposure Rating



Integrated Exposure Assessment Result Leads to Control Recommendations

	Exposure Control Category**	Recommended Control
	0 (<1% of OEL)	No action
	1 (<10% of OEL)	General Haz Com
	2 (10-50% of OEL)	+ Chemical specific Haz Com
	3 (50-100% of OEL)	+ Medical surveillance, work practices
	4 (>100% of OEL)	+ Respirators & engineering controls, work practice controls
	Multiples of OEL (i.e., based on respirator APFs)	+ Immediate Engineering Controls or Process Shut Down, Validate Acceptable Respirator

Control Guidance

- ACGIH Industrial Ventilation Manual
- Company Engineering Standards
- COSHH Essentials Control Sheets
- MSDS

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Review of Traditional IH Statistics

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Review of IH Statistics

I. Lognormal distribution
II. Sample 95th percentile
III. UCL for the sample 95th percentile
IV. Rules-of-thumb for "Eyeballing" Exposure Data

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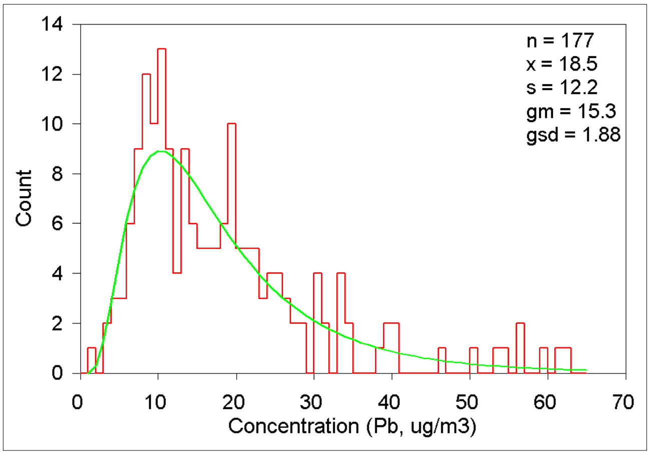
I. Lognormal Distribution – Example Airborne exposures to inorganic lead



source: Cope et al. AIHAJ 40:372-379, 1979

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Parameters vs. Statistics

Parameters		**Statistics**	
-calculated using all elements of the population -log transform each element		-calculated from a sample of n elements randomly selected -log transform each element	
Population Mean	μ_y	Sample Mean	$\bar{y}$
Population Standard Deviation	σ_y	Sample Standard Deviation	s_y

The measurements are converted to natural logs: $y = \ln(x)$

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Parameters vs. Statistics

Parameters		Statistics	
-calculated using all elements of the population		-calculated from a sample of n elements randomly selected	
Population Geometric Mean	GM	Sample Geometric Mean	gm
Population Geometric Standard Deviation	GSD	Sample Geometric Standard Deviation	gsd

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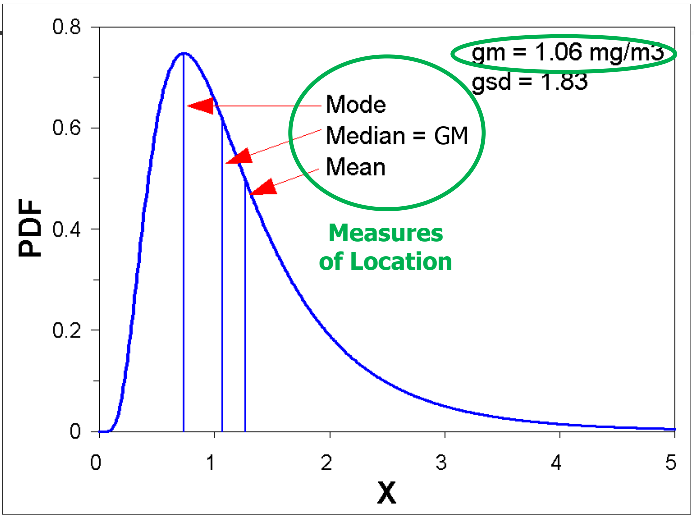
Lognormal distribution PDF



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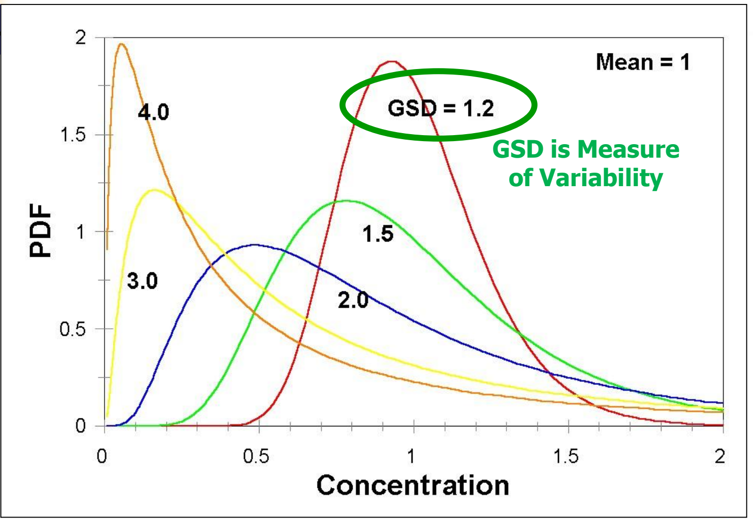
Lognormal



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

$$let\ y = \ln(x)$$

$$gm = \exp\left(\frac{\sum y_i}{n}\right)$$

$$gsd = \exp\sqrt{\frac{\sum (y_i - \bar{y})^2}{n-1}}$$

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Example: Welding fume data - estimate GM and GSD

Case	x_i (mg/m^3)	$y_i=\ln(x_i)$	$(y_i-\bar{y})^2$
1	0.84	-0.1744	0.055877
2	0.98	-0.0202	0.006762
3	0.42	-0.8675	0.864025
4	1.16	0.1484	0.007463
5	1.36	0.3075	0.060248
6	2.66	0.9783	0.839600
Sum =		0.3722	1.833976
$\bar{y}$ =		0.0620	
gm =		1.06	
gsd =			1.83

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Example: Welding fume data - estimate GM and GSD

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

$$gsd = \exp\sqrt{\frac{1.833976}{6-1}} = 1.83$$

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II. Sample 95th Percentile Exposure

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

95

95th Percentile interpretation of TWA OELs

- ACGIH
  - Roach, S.A., Baier, E.J., Ayer, H.E., and Harris, R.L.: Testing compliance with Threshold Limit Values for respirable dusts. *American Industrial Hygiene Association Journal* 28:543-553 (1967).
  - Stokinger, H.E.: Industrial air standards - theory and practice. *Journal of Occupational Medicine* 15:429-431 (1973).
  - Still, K.R. and Wells, B.: Quantitative Industrial Hygiene Programs: Workplace Monitoring. (Industrial Hygiene Program Management series, part VIII). *Applied Industrial Hygiene* 4:F14-F17 (1989).

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95^{th} Percentile interpretation of TWA OELs

- AIHA 1991 and 1998 guidance
  - Employer should maintain true group or individual upper percentile exposure < TWA OEL
  - "Similar Exposure Group" 95^{th} percentile exposure < TWA OEL
- Ex-OSHA director:
  - Corn, M. and Esmen, N.A.: Workplace exposure zones for classification of employee exposures to physical and chemical agents. *American Industrial Hygiene Association Journal* 40:47-57 (1979).

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95^{th} Percentile interpretation of TWA OELs

- NIOSH guidance
  - Employer should 95% confident that 95% of the exposures are $\leq$ the TWA PEL
  - Leidel, N.A., Busch, K.A., Lynch, J.R.: *Occupational Exposure Sampling Strategy Manual*. National Institute for Occupational Safety and Health (NIOSH) Publication No. 77-173 (available as a pdf file from NIOSH website) (1977).
- OSHA
  - Measured TWA exposures should "rarely" exceed the TWA PEL (preamble to the benzene PEL, 1987)

98

95^{th} Percentile interpretation of TWA OELs

- EU
  - CEN (Comité Européen de Normalisation): Workplace atmospheres - Guidance for the assessment of exposure by inhalation of chemical agents for comparison with limit values and measurement strategy. European Standard EN 689, effective no later than Aug 1995 (English version) (Feb 1995).

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Example

- A sample of six full-shift TWA welding fume measurements resulted in the following statistics:
  - (sample) geometric mean is 1.06 mg/m^3
  - (sample) geometric standard deviation is 1.83
- What is the point estimate (i.e., best estimate) of the true 95^{th} percentile?

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90th, 95th, and 99th Percentiles

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

$s_y = \ln(gsd)$

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

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

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

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

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95th Percentile

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

$$= \exp(0.0620 + 1.645 \cdot 0.6043)$$

$$= 2.88 \ mg/m^3$$

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Alternative 95th Percentile Formula

$$\hat{X}_{0.95} = gm \cdot gsd^{1.645}$$
$$= 1.06 \cdot 1.83^{1.645} = 2.88 \ mg/m^3$$

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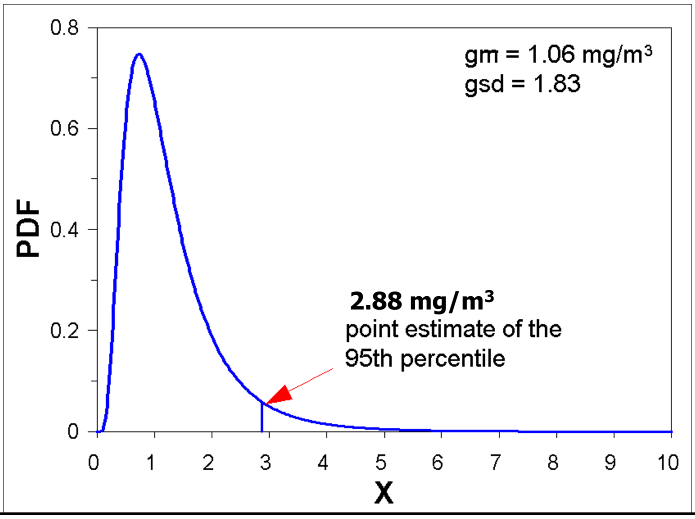
Focus on Upper Tail



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III. Upper Confidence Limit (UCL) for the Sample 95th Percentile

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

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- For single shift, TWA exposure limits (TWA OELs) …
  - focus on the upper tail of the distribution
  - e.g., 95th percentile exposure

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Upper Percentile (e.g., 95th percentile)

- Concept
  - Calculate the 95% upper confidence interval for the 95th percentile statistic (upper tolerance limit)
- Application
  - 95%UCL can be used to test the following hypotheses:
    - H_o: 95th percentile $\geq$ OEL
    - H_a: 95th percentile < OEL
- Interpretation
  - If the 95%UCL is less than the OEL, then we can say that we are at least 95% confident that the true 95th percentile is less than the OEL

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95%UCL for the 95th Percentile

- Procedure:
  - Calculate the gm and gsd
  - Using n, read the UCL K-value from the appropriate table
    - γ = confidence level, e.g., 0.95
    - p = proportion, e.g., 0.95
    - n = sample size
  - Using gm, gsd, and k, calculate the 95%UCL
    - $\overline{y}$ = ln(gm) and s_y = ln(gsd)

$$95\%UCL(\hat{X}_{0.95}) = \exp(\overline{y} + K_{\gamma,p,n} \cdot s_y)$$

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TABLE VII.3 — Factors for One-Sided Tolerance Limits

n \ P	$\gamma = 0.95$				
	0.75	0.90	0.95	0.99	0.999
3	3.804	6.158	7.655	10.552	13.857
4	2.619	4.163	5.145	7.042	9.215
5	2.149	3.407	4.202	5.741	7.501
6	1.895	3.006	3.707	5.062	6.612
7	1.732	2.755	3.399	4.641	6.061
8	1.617	2.582	3.188	4.353	5.686
9	1.532	2.454	3.031	4.143	5.414
10	1.465	2.355	2.911	3.981	5.203

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$$95\%UCL(\hat{X}_{0.95}) = \exp(\bar{y} + K_{\gamma,p,n} \cdot s_y)$$

$$= \exp(\bar{y} + K_{0.95,0.95,6} \cdot s_y)$$

$$= \exp(0.0620 + 3.707 \cdot 0.6043)$$

$$= 10.00 \; mg/m^3$$

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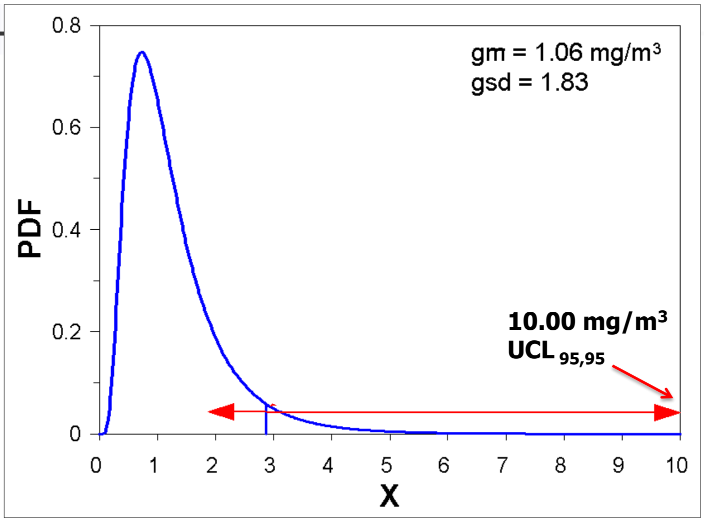

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Rules of Thumb

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IV. Rule-of-thumb for "Eyeballing" Exposure Data

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

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X_p = GM x GSD^{Zp}

GSD	Multiple of GM (median)
	X_p = 95th percentile
	Z_p = 1.645
1.5	1.95
2.0	3.13
2.5	4.51
3.0	6.09

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$$X_p = GM \times GSD^{Z_p}$$

GSD	Multiple of GM (median) X_p = 95th percentile Z_p = 1.645	
Low 1.5	1.95	2
2.0	3.13	4
2.5	4.51	
High 3.0	6.09	6

Variability

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Rules of Thumb

Variability	ROT Multiplier
Low	2
Medium	4
High	6

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R.O.T. for Estimating the 95th Percentile

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

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EA Survey

Xylene: TLV = 100 ppm		Rules of Thumb			
Scenerio	Data (ppm)	Median	2X	4X	6X
1	21, 68	45	90	180	270
2	21, 109, 38, 41, 48	41	82	164	246
3	12, 16, 21, 24	19	38	76	114
4	5	5	10	20	30
5	8, 70, 5, 37, 12	12	24	48	72

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

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

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

Rule of Thumb Worksheet

Data Set	Data	Median	2x	4x	6x	Likely Category (1-4)
A	30, 17, 7, 13 , 63, 5					
B	6					
C	33, 37, 9, 109, 8, 5					
D	5, 20, 3, 12					
E	78					
F	3, 1					
G	31, 17, 18, 45					
H	14, 5, 6, 12, 4, 36					

Rule of Thumb Worksheet

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

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Data Interpretation Exercise
Class Work: Post-Training DIT

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Data Interpretation Test (DIT) #5

Enter Your Number

OEL for all Data Sets 100	Sample Data Set #1	Sample Data Set #2	Sample Data Set #3	Sample Data Set #4	Sample Data Set #5	Sample Data Set #6	Sample Data Set #7	Sample Data Set #8
	5	8	18	82	5	11	11	15
	2		43		1	118	28	9
	11		9		2	35	6	36
	10		24		1	26		19
	34					2		23
	13					60		54

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

	Data Set #1	Data Set #2	Data Set #3	Data Set #4	Data Set #5	Data Set #6	Data Set #7	Data Set #8
1-10% OEL								
10-50% OEL								
50-100% OEL								
>100% OEL								
Check	100?	100?	100?	100?	100?	100?	100?	100?

Have you ever taken this statistical test before? Yes No

If yes, how many times & when?

Instructions

Enter your name at the top

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

Make sure that one category has the highest percentage

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

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

Please list any specific comments regarding this DIT

Bayesian Decision Analysis (BDA) Theory and Tool

What Do The Monitoring Data Tell Us?

124

Focus on Decision Making

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

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The AIHA "Exposure Banding" Model

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

Exposure Control Ratings *		Cutoff (%OEL)	Confidence level
(green)	0	$X_{0.95} \leq 1\%$	High
(light blue)	1	$1\% < X_{0.95} \leq 10\%$	
(yellow)	2	$10\% < X_{0.95} \leq 50\%$	Medium
(orange)	3	$50\% < X_{0.95} \leq 100\%$	
(red)	4	$X_{0.95} > 100\%$	Low

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Example: Exposure Control Category Follow-up

	Exposure Control Category**	Recommended Control
	0 (<1% of OEL)	No action
	1 (<10% of OEL)	general HazCom
	2 (10-50% of OEL)	+ chemical specific HazCom
	3 (50-100% of OEL)	+ exposure surveillance, medical surveillance, work practices
	4 (>100% of OEL)	+ respirators & engineering controls, work practice controls
	5 (Multiples of OEL; e.g., based on respirator APFs)	+ immediate engineering controls or process shutdown, validate respirator selection

** - Decision statistic = 95th percentile

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

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Example Survey

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

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

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

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

- $\hat{X}_{0.95}$ = 0.31 ppm 90%CI(0.16, 20)

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Example Survey (cont'd)

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

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Example (cont'd)

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

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Exposures *appear* to be a Category 2 exposure.

Prior

Qualitative Assessment or Validated Model

0.20 ppm
0.05 ppm
0.10 ppm

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

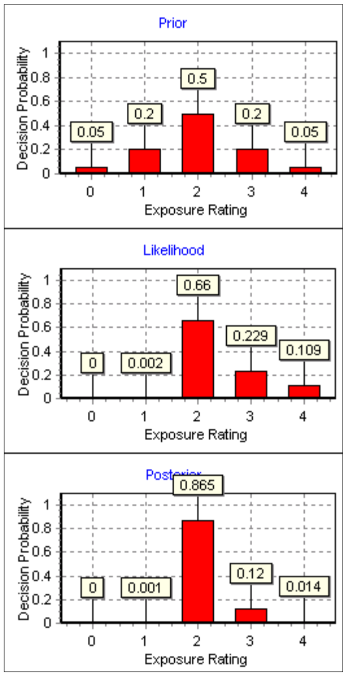
Likelihood

Monitoring Results

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

Posterior

Integrated Exposure Assessment



Key Concept – "Decision" Distributions

- **Prior** decision distribution
  - Represents our professional judgment regarding the probability of each of the Exposure Ratings.
- **Likelihood** decision distribution
  - The set of probabilities of each Exposure Rating *calculated using only the collected data.*
- **Posterior** decision distribution
  - The set of probabilities of each Exposure Rating *calculated using Bayes' equation.*

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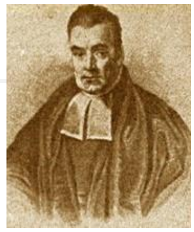
Bayesian Decision Analysis



Posterior Likelihood Prior

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

Correction Factor

135

Bayesian Statistics

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

Blurred Image

Original Image

Image courtesy of Massachusetts Institute of Technology

Books on Bayesian Statistics

- Carlin and Louis: Bayes and Empirical Bayes Methods for Data Analysis, (2000).
- Congdon: Bayesian Statistical Modelling (2002).
- Gelman, Carlin, Stern and Rubin: Bayesian Data Analysis (2003).
- Congdon: Applied Bayesian Statistical Modelling (2003).

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Bayesian Decision Analysis

- The original Bayes' Theorem directly applies to discrete choices.
  - e.g., Exposure Profiles A vs. B
- We are not interested in distinguishing between just two exposure profiles.
- Instead, we are interested in distinguishing between five *populations* of exposure profiles:
  - Exposure Zones 0, 1, 2, 3, and 4

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Exposure Ratings – A "rating zone" represents a population of exposure profiles

Exposure Rating		Cutoff (%OEL)
(green)	0	$X_{0.95} \leq 1\%$
(light blue)	1	$1\% < X_{0.95} \leq 10\%$
(yellow)	2	$10\% < X_{0.95} \leq 50\%$
(orange)	3	$50\% < X_{0.95} \leq 100\%$
(red)	4	$X_{0.95} > 100\%$

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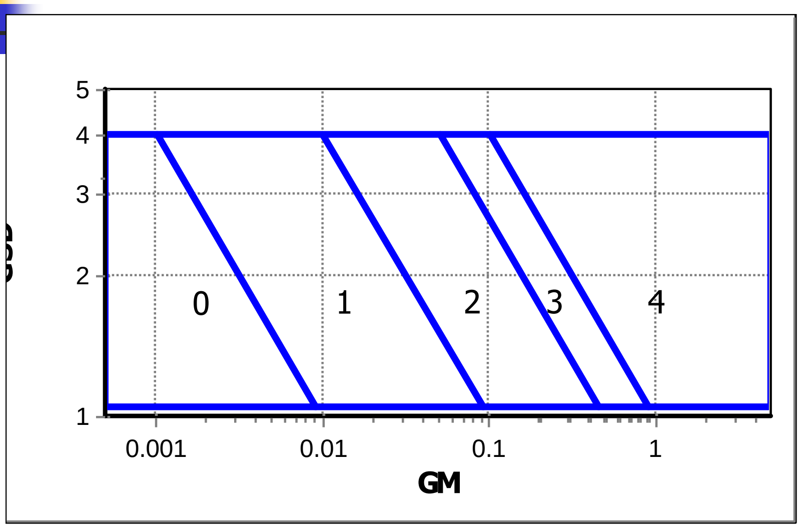
Exposure Ratings translated into *parameter space* for OEL=1ppm



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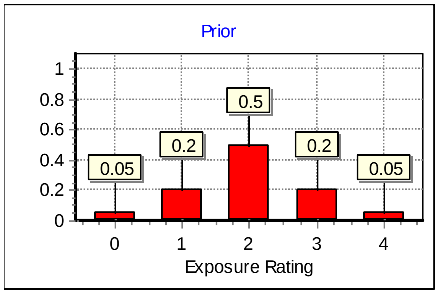
Prior Decision Distribution

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



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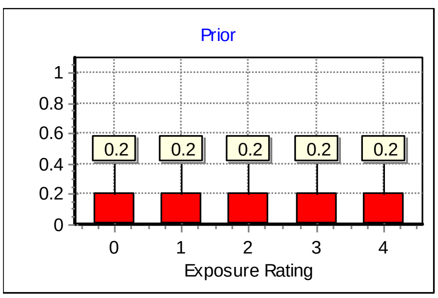
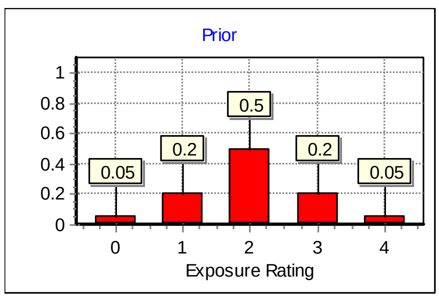
Example *Prior* Decision Distributions

Non-informative prior



Informative prior



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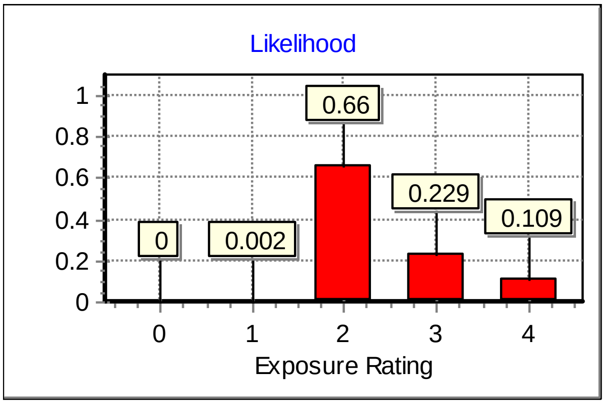
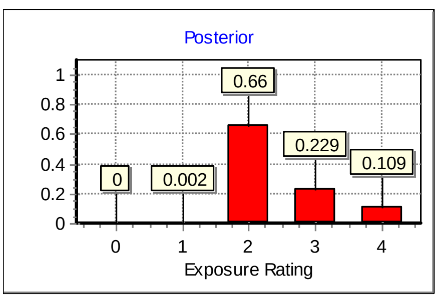
Example *Likelihood* Decision Distribution for x={ 0.20, 0.05, 0.10 }

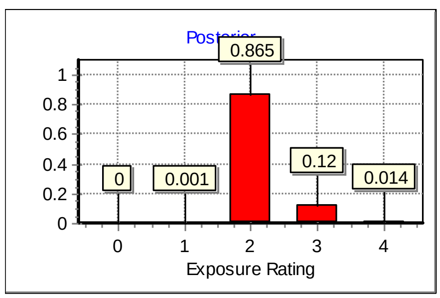


Example *Posterior* Decision Distributions

Using the non-informative prior



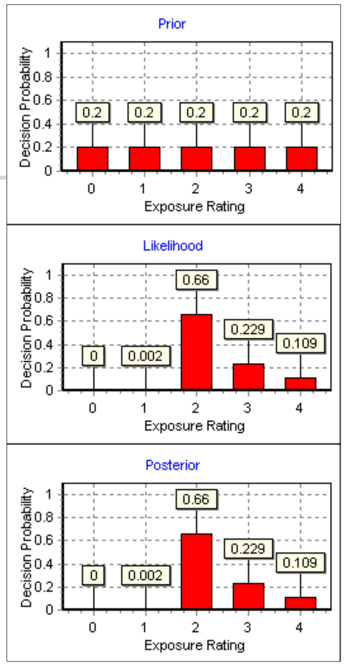
Using the informative prior



Decision Charts

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

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



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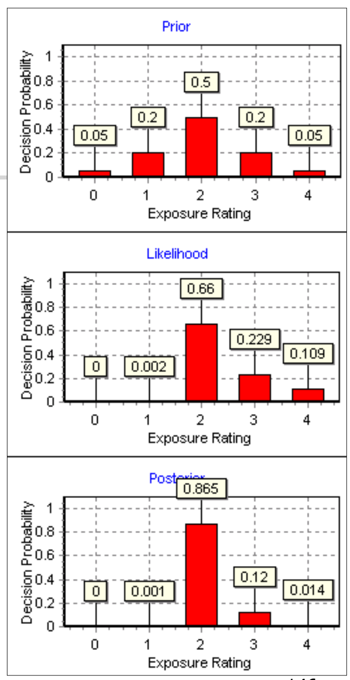
Decision Charts

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

- Here we used an informative prior.



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Introduction to IHDA-lite

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

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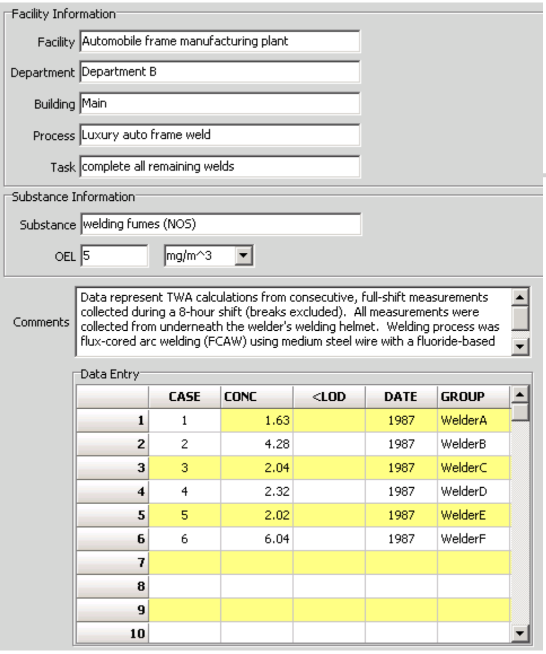

	CASE	CONC	<LOD	DATE	GROUP
1	1	1.63		1987	WelderA
2	2	4.28		1987	WelderB
3	3	2.04		1987	WelderC
4	4	2.32		1987	WelderD
5	5	2.02		1987	WelderE
6	6	6.04		1987	WelderF
7					
8					
9					
10					

(Dataset24 - Welding Fumes.xls)

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1. Enter the data
    1. indicate <LOD values w/ a 'y' or '<'
2. Press "Calculate All"
3. Review the statistics and critique the "GOF Graphs".
    1. Are the data stationary and consistent with the assumption of a single, lognormal exposure profile?
    2. Is the exposure profile likely to be within Parameter Space?
4. Review the Decision Charts

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Statistics

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

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- Compliance Statistics (non-parametric)
  - 95^{th} percentile + CI
  - Exceedance Fraction + CI

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

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Statistics | GOF | BDA | CDA

```
OEL     = 5 mg/m^3
------------------------------------------
Order Statistics:
N       = 6
Min     = 0.42
Max     = 2.66
Median  = 1.0700

------------------------------------------
Decriptive Statistics:
Mean    = 1.2400
SD      = 0.7660
GM      = 1.0600
GSD     = 1.832


------------------------------------------
Compliance Statistics (lognormal):
X0.95   = 2.8800
 95%LCL = 1.8100
 95%UCL = 10.1000
ExcFrac = 0.005
 95%LCL = <0.001
 95%UCL = 0.149

------------------------------------------
Compliance Statistics (non-parametric):
```

(Dataset25 - Welding Fumes.xls)

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Goodness-of-fit

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

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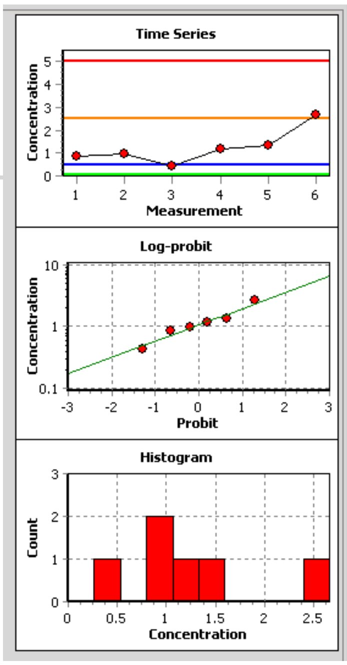
(Dataset25 - Welding Fumes.xls)



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

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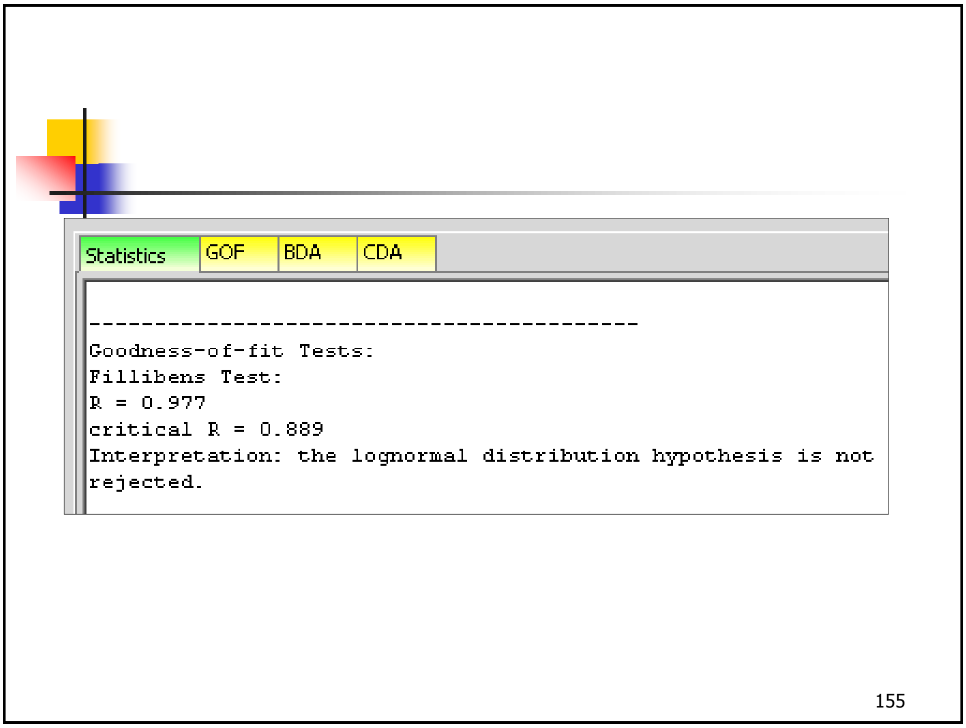
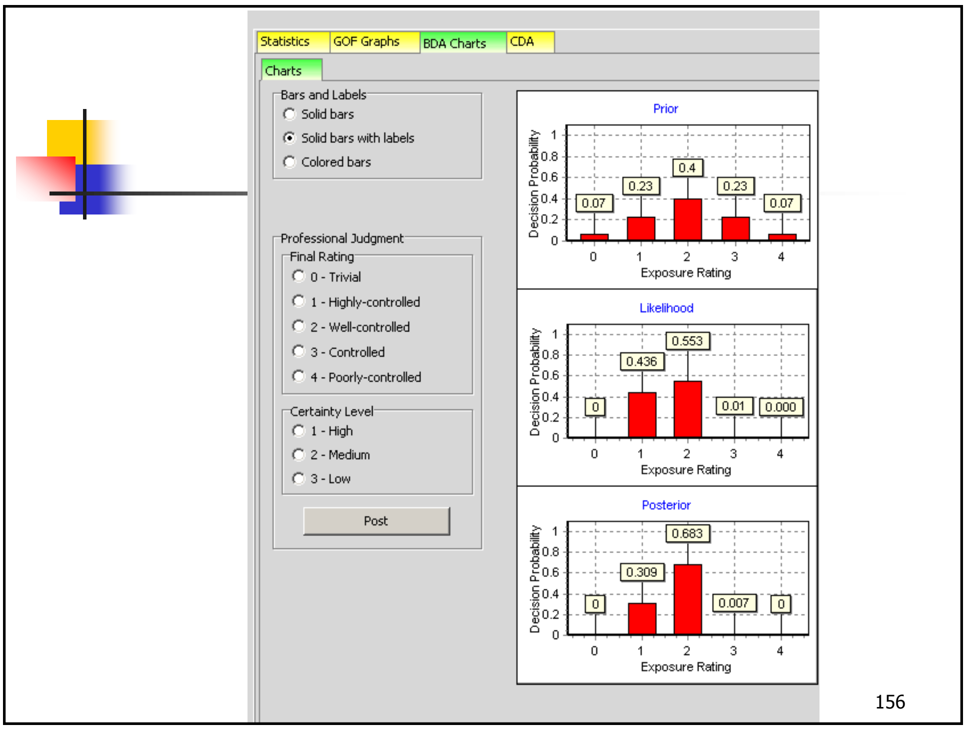

Statistics
GOF
BDA
CDA

Goodness-of-fit Tests:
Fillibens Test:
R = 0.977
critical R = 0.889
Interpretation: the lognormal distribution hypothesis is not rejected.
155


Statistics
GOF Graphs
BDA Charts
CDA
Charts
Bars and Labels
Solid bars
Solid bars with labels
Colored bars
Professional Judgment
Final Rating
0 - Trivial
1 - Highly-controlled
2 - Well-controlled
3 - Controlled
4 - Poorly-controlled
Certainty Level
1 - High
2 - Medium
3 - Low
Post
Prior
Decision Probability
Exposure Rating
0.07
0.23
0.4
0.23
0.07
Likelihood
0
0.436
0.553
0.01
0.000
Posterior
0
0.309
0.683
0.007
0
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Scenario Examples – Decision Chart Interpretation

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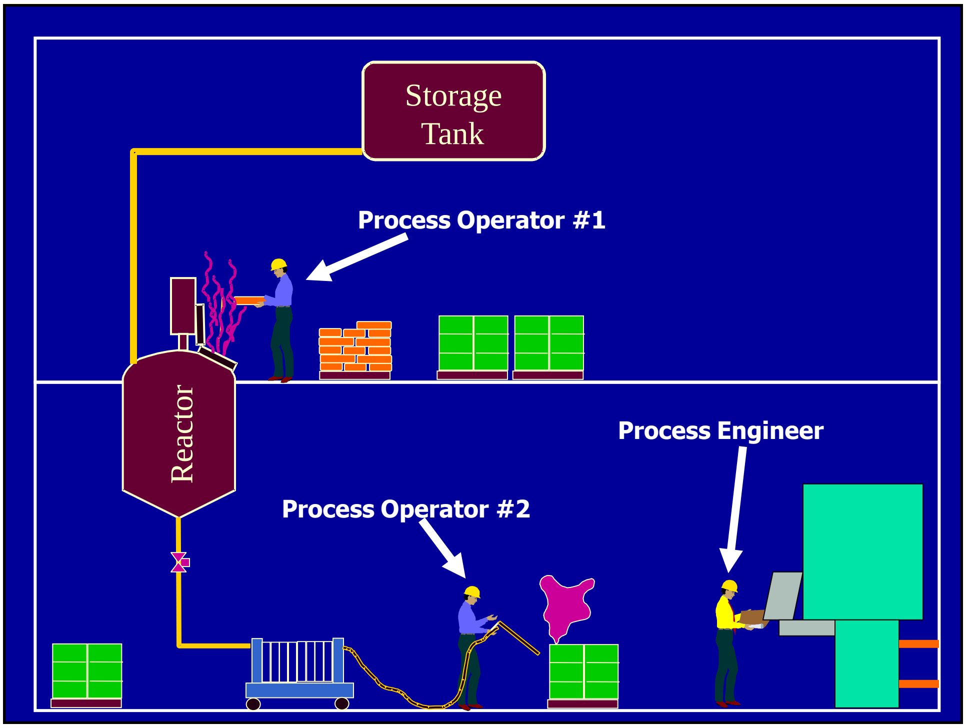

Scenario #1 – Process Operator #1

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

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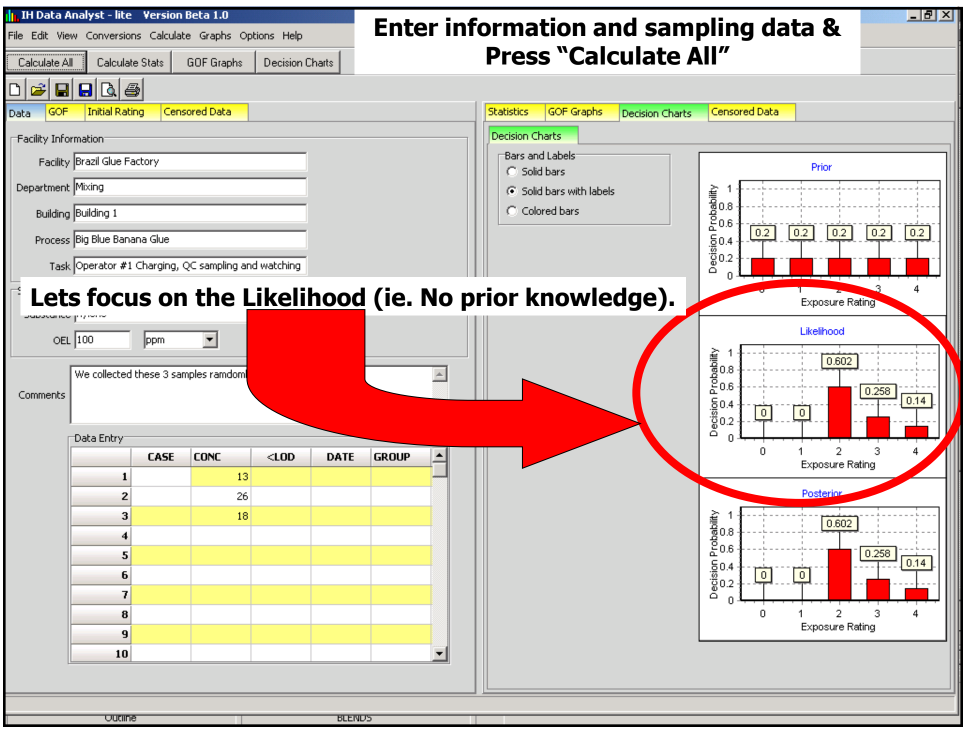
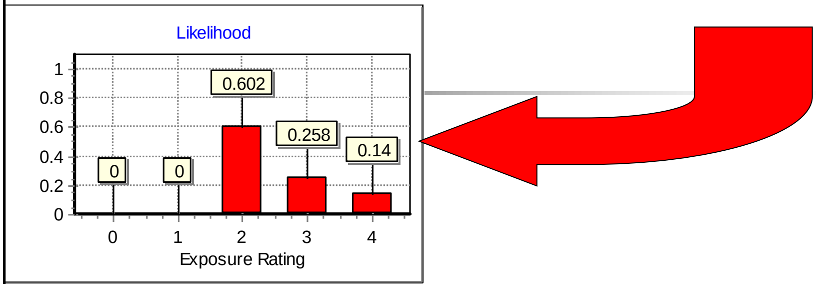


How do we interpret this?



- The output is in probability
- **"We have a __% probability that Process Operator #1 requires additional exposure controls"**
- Is that above the acceptable / unacceptable threshold?

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Compare BDA vs. traditional statistics…

- **"We have a __% probability that Process Operator #1 requires additional exposure controls"**
- "The population 95th percentile point estimate is 32 with an upper confidence limit (95%) of 260"

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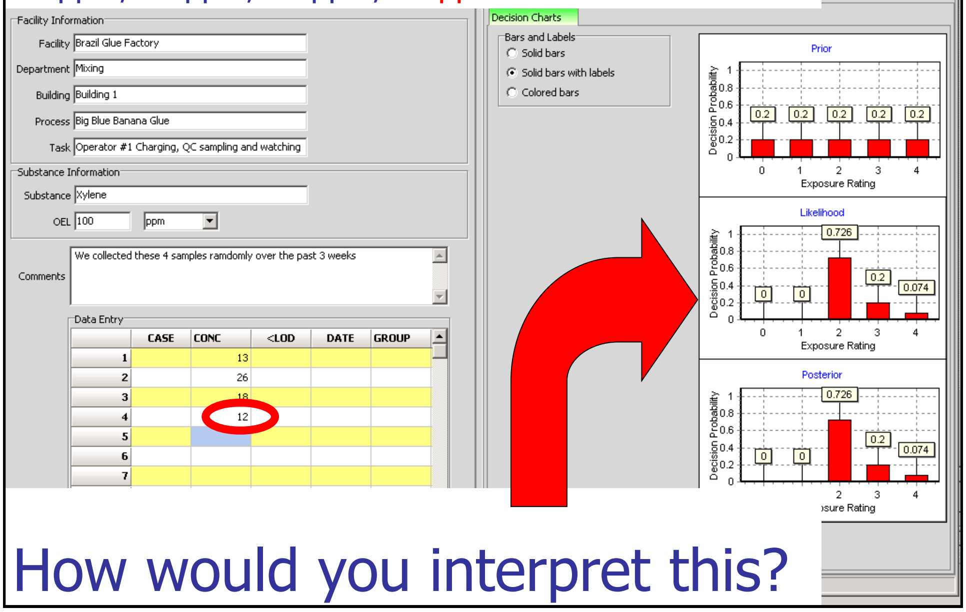
Lets collect another sample…

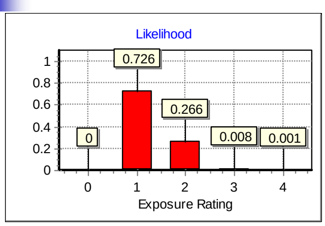
13 ppm, 26 ppm, 18 ppm, 12 ppm



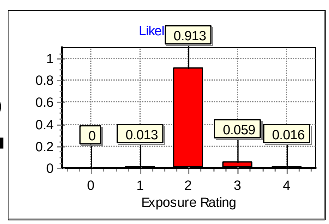
How would you interpret this?

More examples…

1

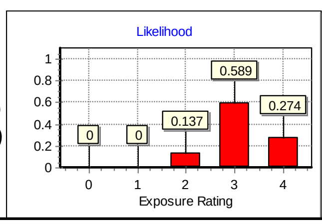


2

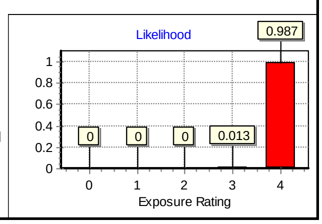


"less than __% probability of…" or "greater than __% probability of…"

3



4



More Examples…

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

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

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

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

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Rule of Thumb (R.O.T.) v.s. BDA

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

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

I. Limited datasets
II. Large datasets
III. Censored datasets

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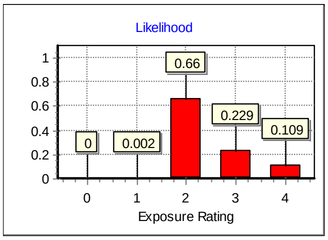
Limited Data (OEL = 1 ppm)

- Dataset00 - manuscript data.xls

0.2 ppm

0.05 ppm

0.1 ppm



169

Limited Data (OEL = 5 mg/M³)

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

1.63 mg/M³

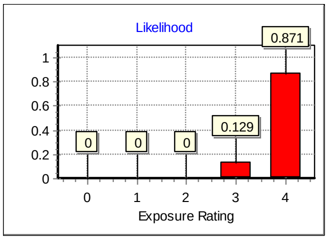
4.28 mg/M³

2.04 mg/M³

2.32 mg/M³

2.02 mg/M³

6.04 mg/M³



170

Limited Data (OEL = 5 mg/M3)

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

0.84 mg/M3

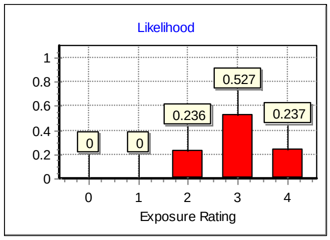
0.98 mg/M3

0.42 mg/M3

1.16 mg/M3

1.36 mg/M3

2.66 mg/M3



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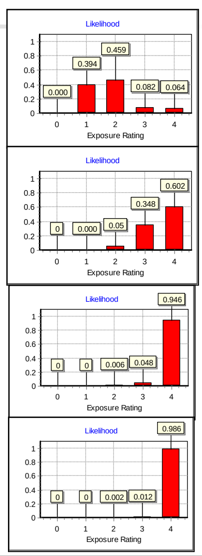
Single measurement scenarios

- Let OEL = 100 ppm
- Let x = …
  - 5 ppm
  - 50 ppm
  - 99 ppm
  - 150 ppm



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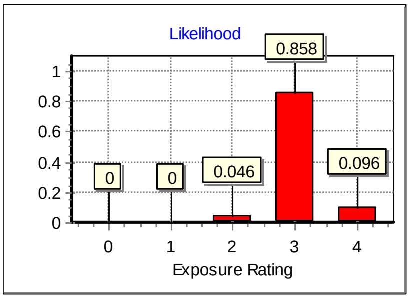
Large Datasets (OEL = 0.05 mg/M^3)

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

0.012	0.0081
0.0109	0.012
0.0086	0.0081
0.0382	0.0194
0.0073	0.029
0.0138	0.0183
0.0108	0.0306
0.0103	



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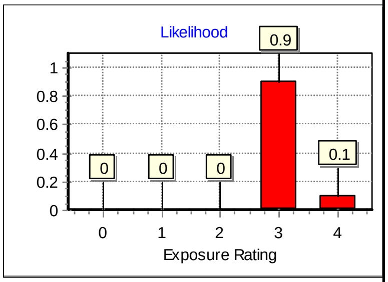
Large Datasets (OEL = 50 ug/M^3)

- Dataset21 - CopeDataset_WorkerA.xls
- Inorganic lead

10.4	**15**	**10**	**15.9**
11.4	**30.4**	**21.9**	**9**
17.1	**25.4**	**12.9**	**9.5**
28.9	**34**	**8.6**	**19.1**
12.4	**3.9**	**19.6**	**9**
10	**14.4**	**13**	**25.7**
24.6	**18.6**	**10.2**	**46.9**
21.5	**56.4**	**19.5**	**7.9**
11.3	**25.6**	**20.2**	**22.2**



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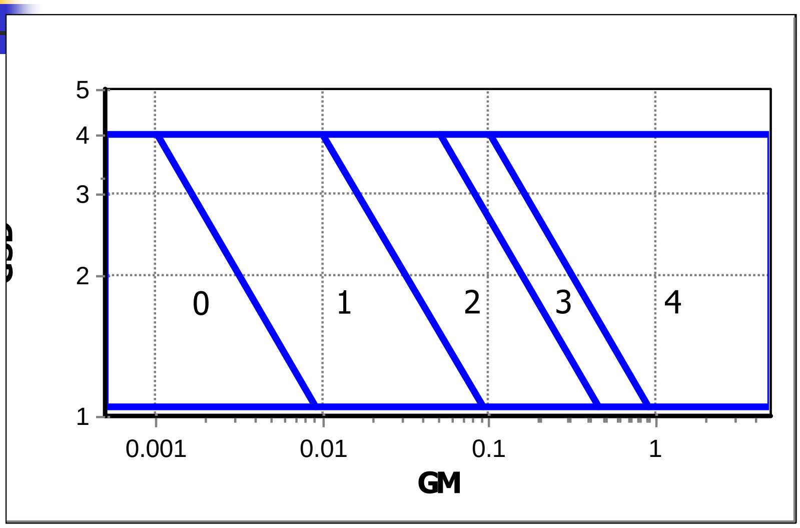
Watch the Universe – GSD and Parameter Space Verification

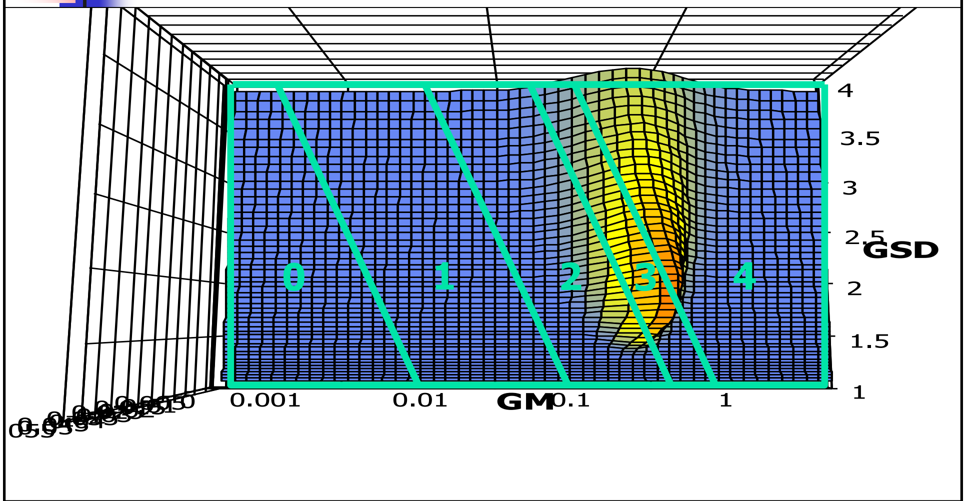
175

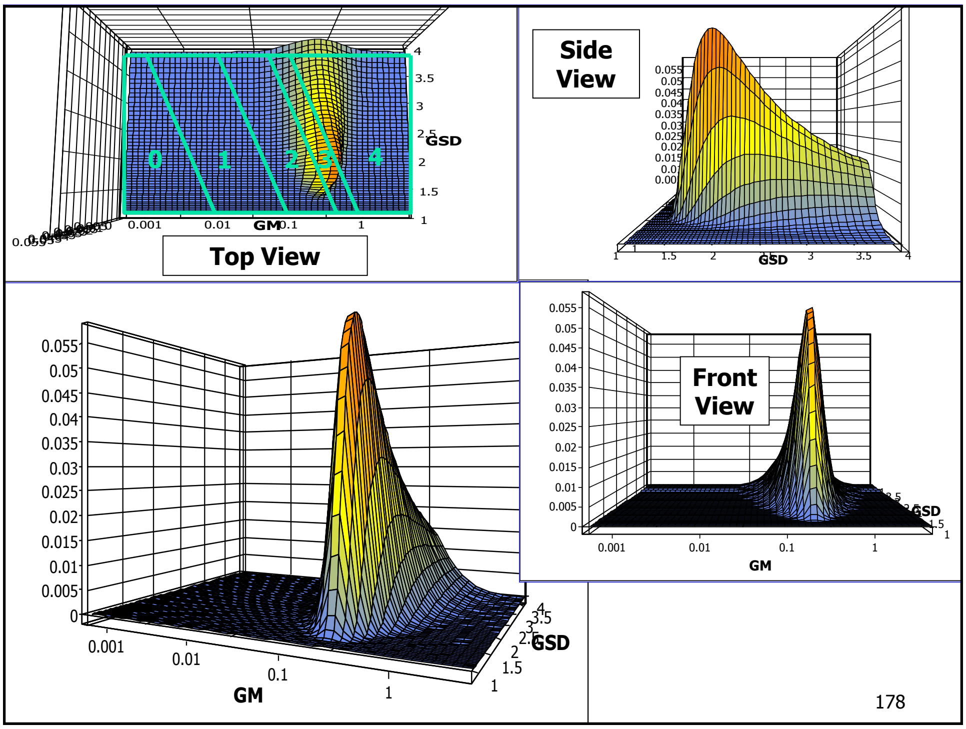
Exposure Ratings translated into *parameter space* for OEL=1ppm



176

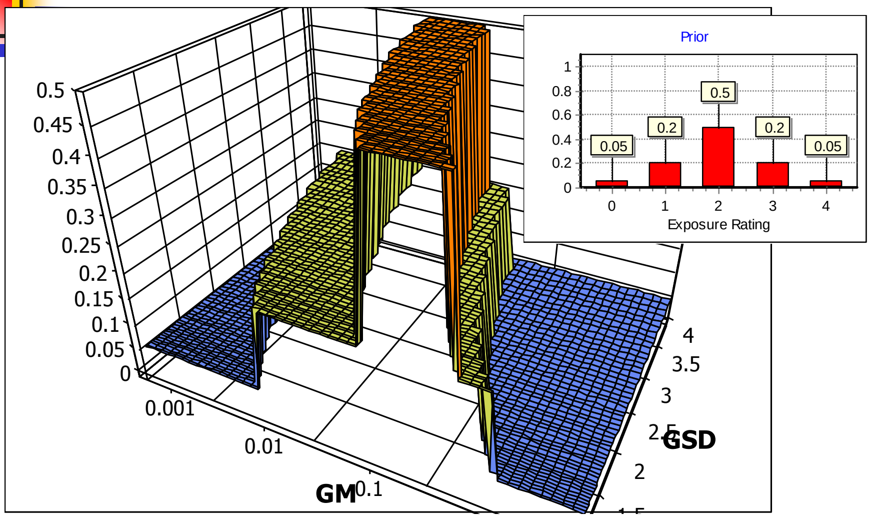
Exposure Ratings translated into *parameter space* for OEL=1ppm





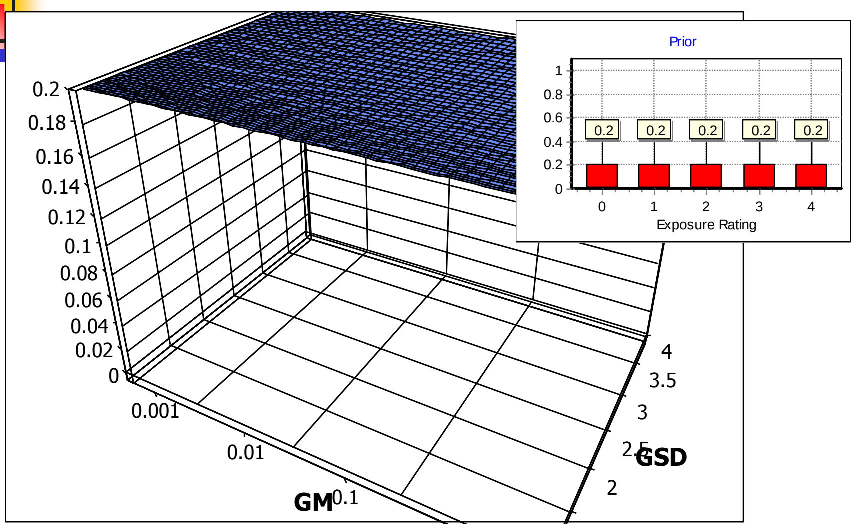
178

Prior decision function (i.e., prior decision distribution spread across parameter space)



179

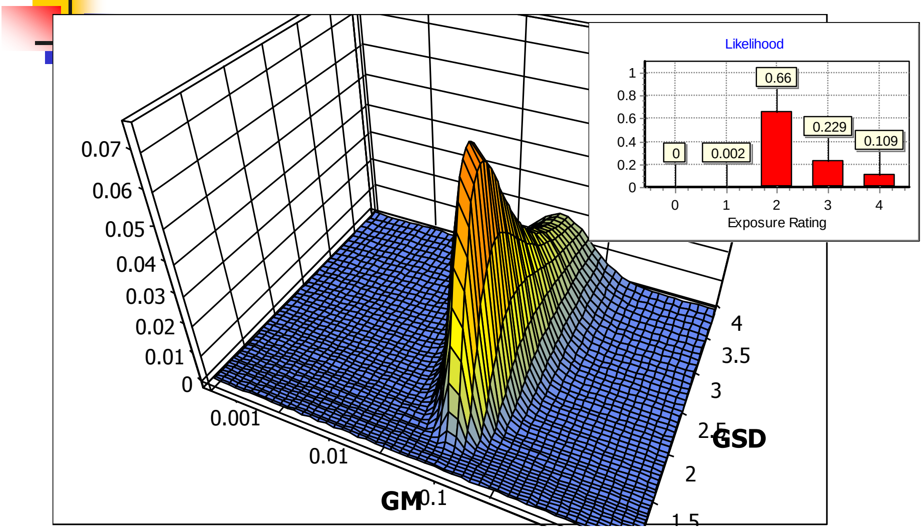
Prior decision function (i.e., prior decision distribution spread across parameter space)



180

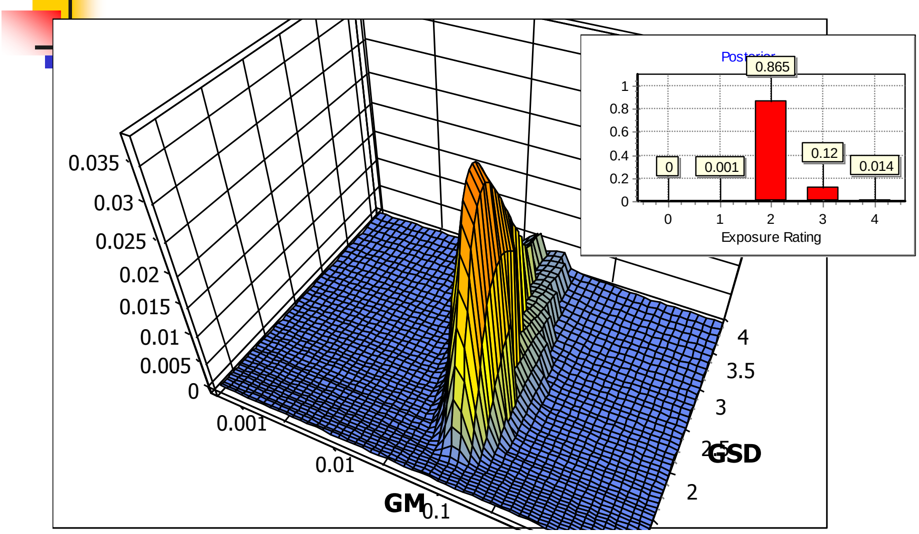
Likelihood function

for x={0.20,0.05,0.10}



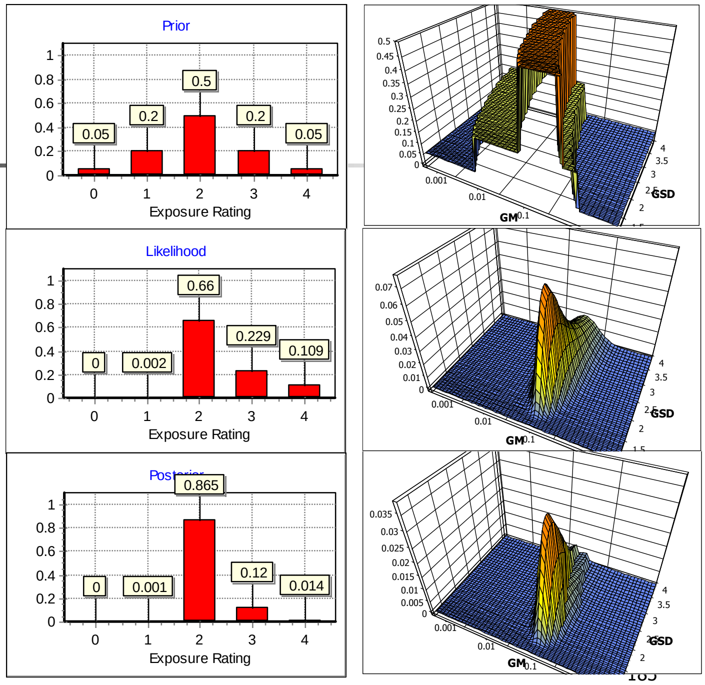
181

Posterior function (using an Informative Prior)



182

BDA



183

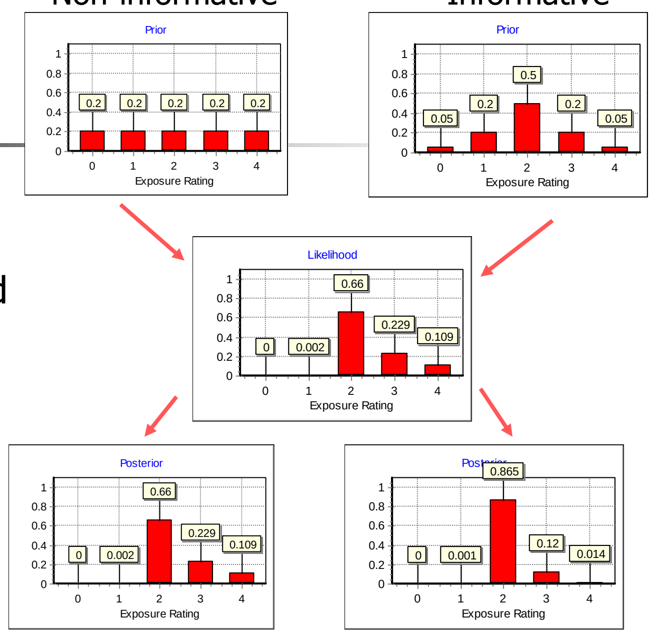
Non-informative

Informative

Prior

Likelihood

Posterior



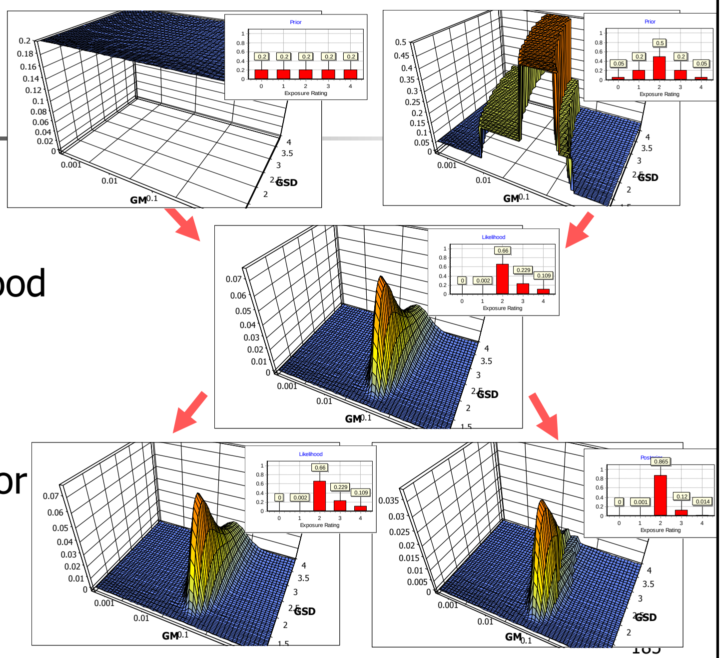
184

Non-informative Informative

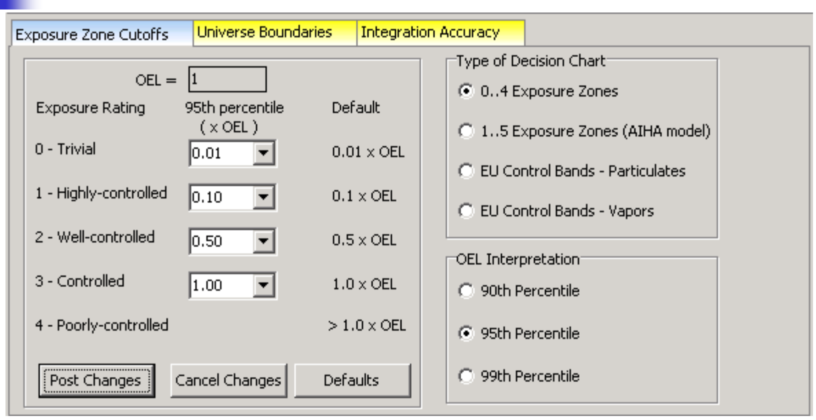
Prior

Likelihood

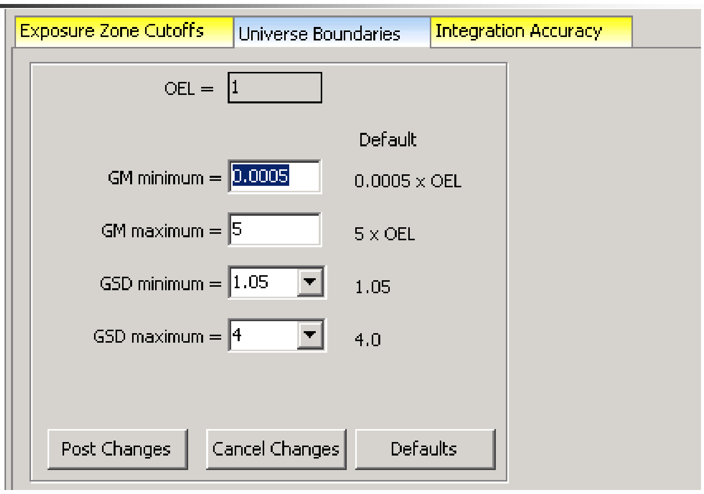
Posterior



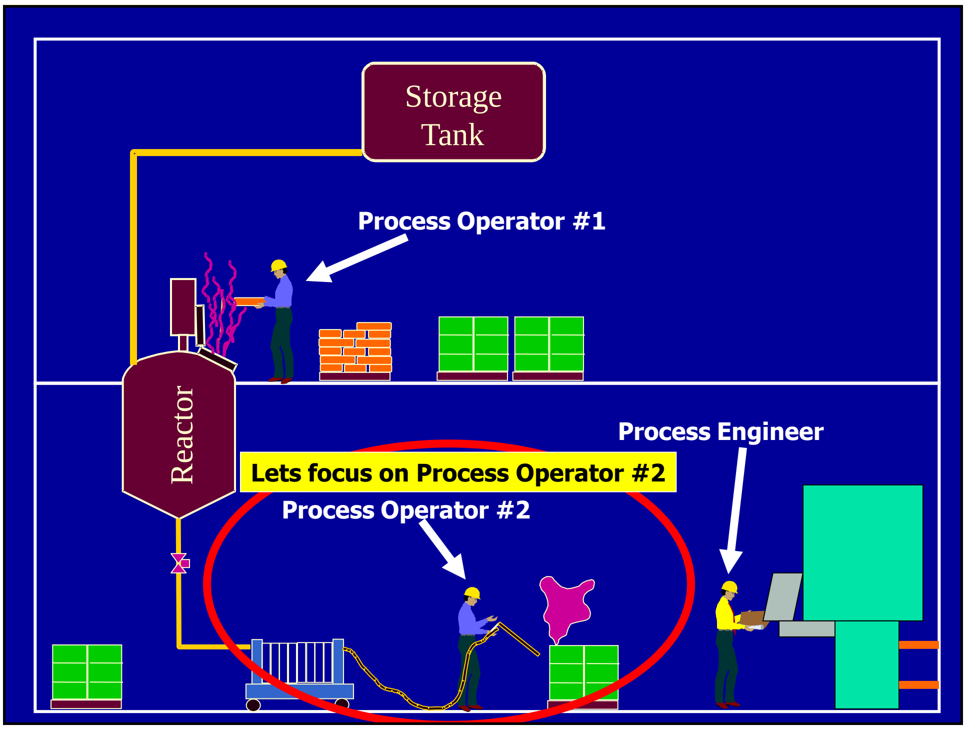
BDA Options: change exposure category cutoffs



Change dimensions of the Parameter Space: GM_{min}, GM_{max}, GSD_{min}, and GSD_{max}



187



Scenario #2 – Process Operator #2

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

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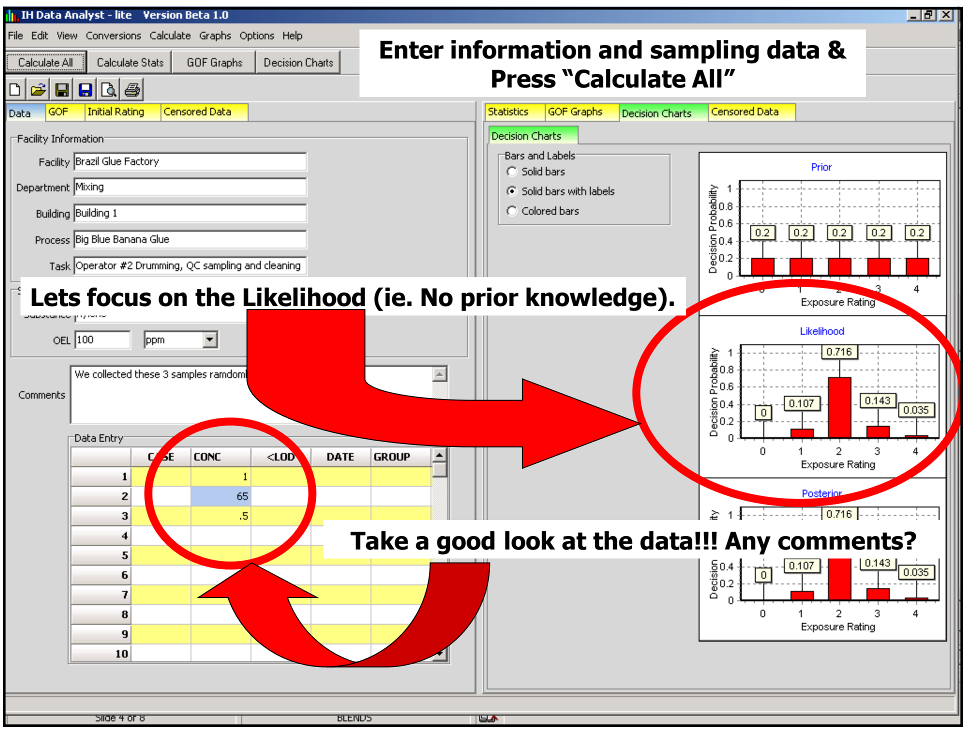
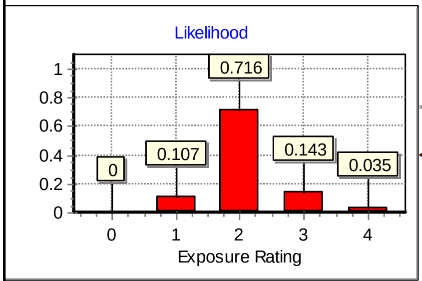


How do we interpret this?



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

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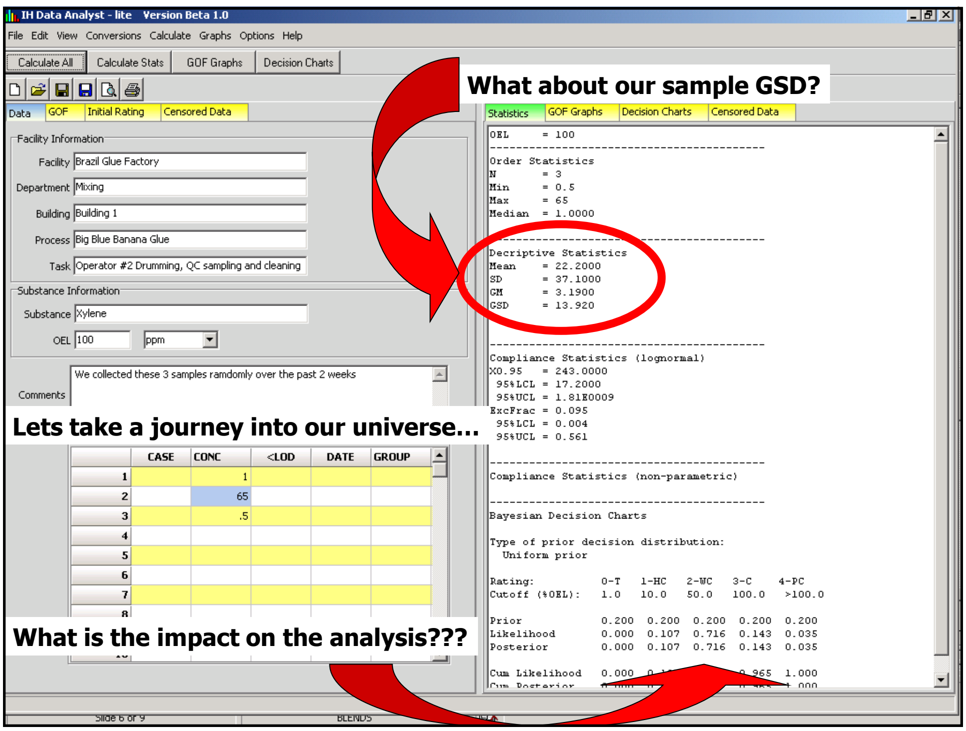
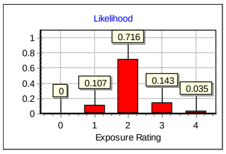
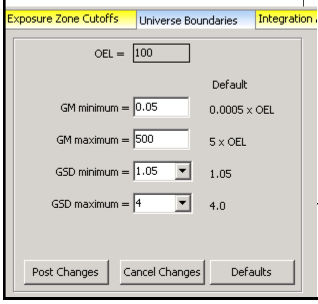
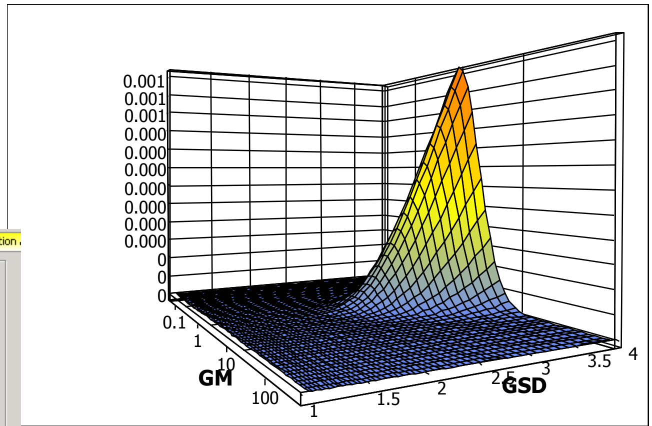


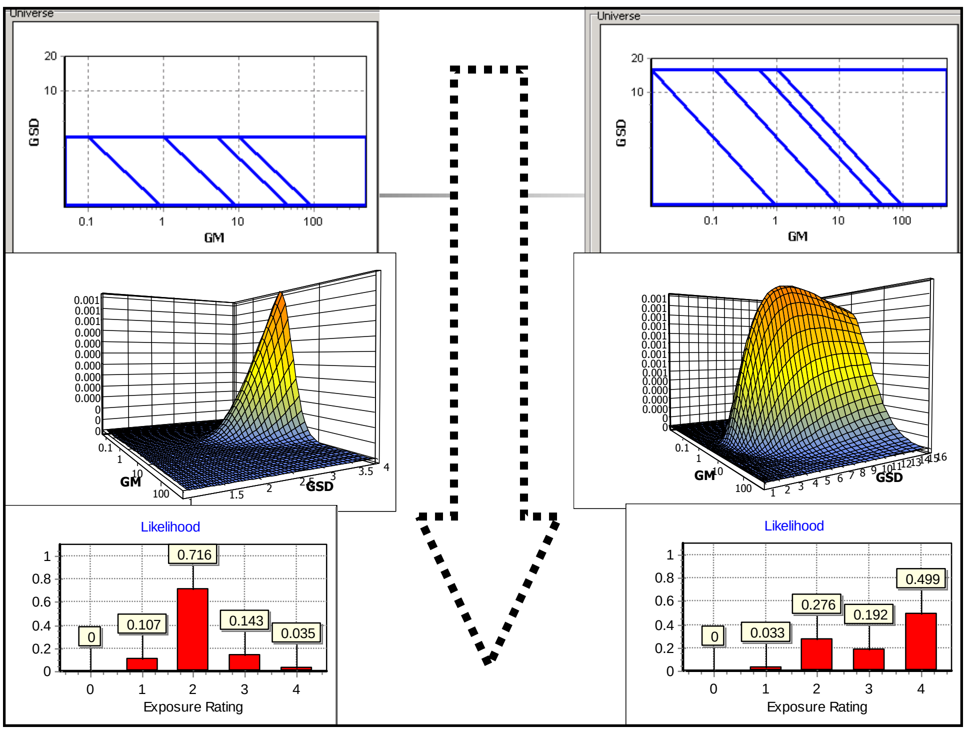
What happens when our sample GSD exceeds our GSDmax parameter?



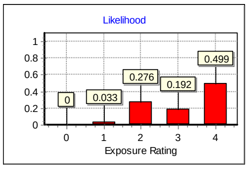


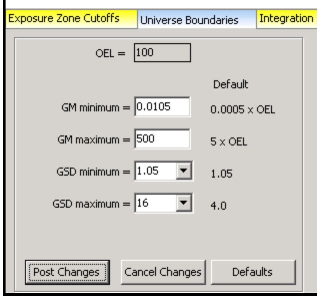


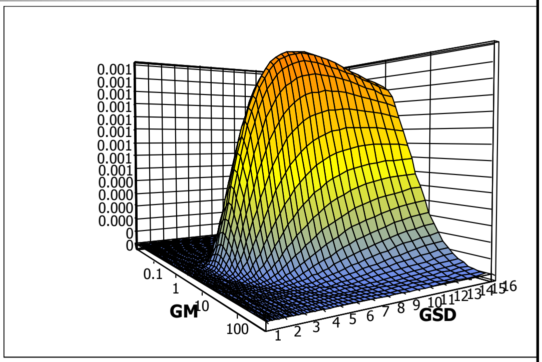
193



Adjust the "Universe" to account for a larger GSD…







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

What do we do now?

- What might be going on with Process Operator #2?
- Which tasks might be creating the issues?
- Should we institute a task-based sampling strategy? Which tasks?

- Wildly disparate data result in extreme and unlikely sample GSDs, pushing the decision probabilities toward the higher Ratings.
- Possible solutions:
  - Separate the data and analyze separately.
  - Replace low measurements with higher LODs.
  - Collect more data.

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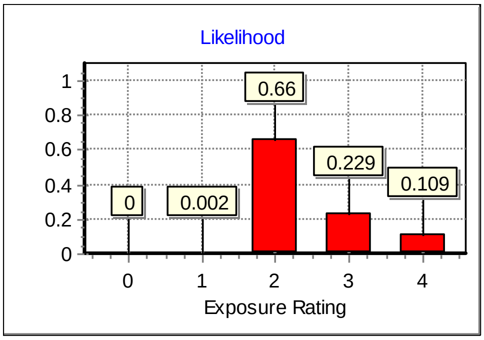
Example (Dataset00.xls)

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



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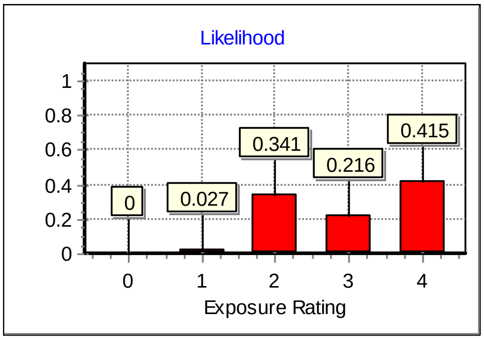
Example

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

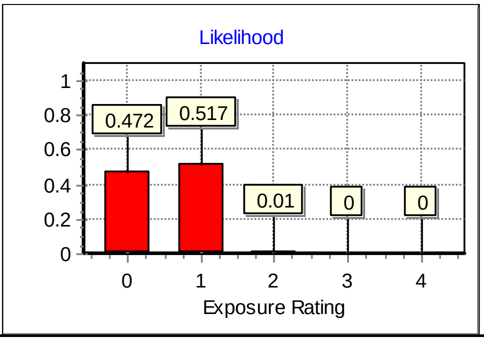


Note: max GSD was set at 20.

199

Example

- Example: analyze separately
  - x = {0.001, 0.005}
  - 95%ile = 0.01   90%CI(0.004, 2E10)



200

What do you need to remember?

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

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BDA Caveats

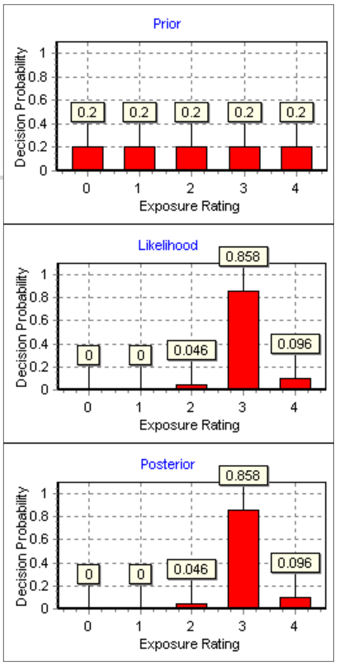
- The following assumptions apply:
  - The true exposure profile can be well described by a single lognormal distribution.
  - The true GM and GSD are in the Parameter Space.
  - Multiple measurements per worker will not unduly bias the decision.

202

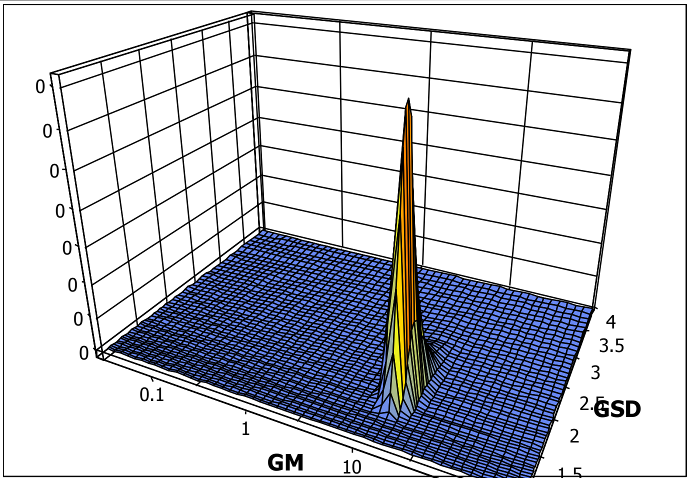
BDA *usually* is not necessary for large datasets

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

Dataset22 - CopeDataset_WorkerF.xls



203



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Workshop:

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

	Parameter Space Upper GSD Boundary	Likelihood Probability of Category 4
Before Universe Parameter Adjustment		
After Universe Parameter Adjustment		

- Comments and Key Learnings:

205

BDA Potential: Integrating Professional Judgment

The Promise and Perils of Bayesian Priors!

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Bayesian Decision Analysis (BDA)

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

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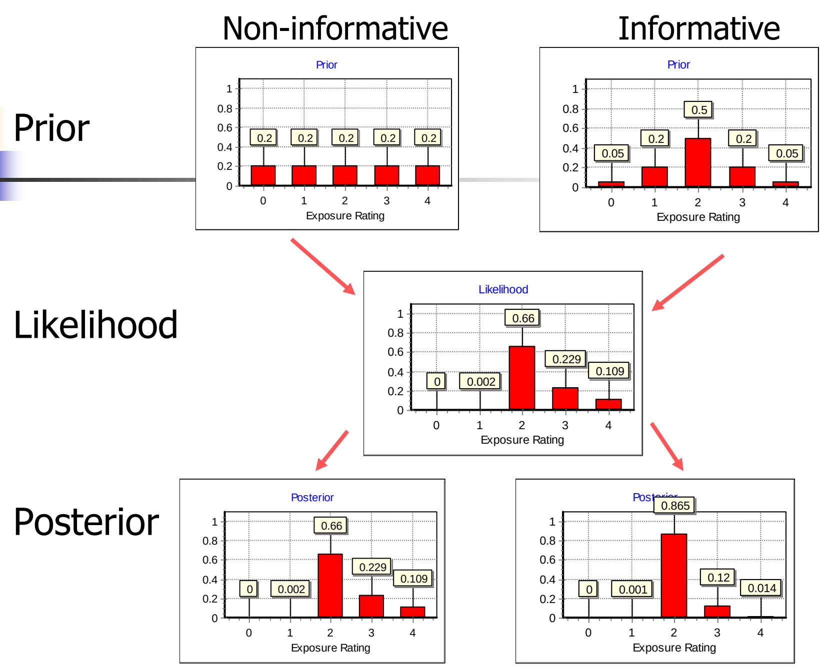

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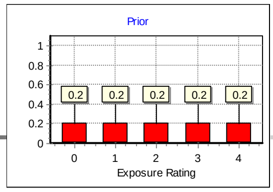
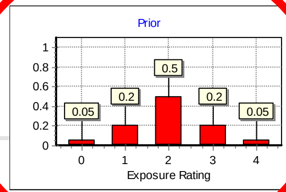
Prior

Non-informative



Informative



The Informative Prior:

Integrating Professional Judgment

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Professional Judgment Accuracy

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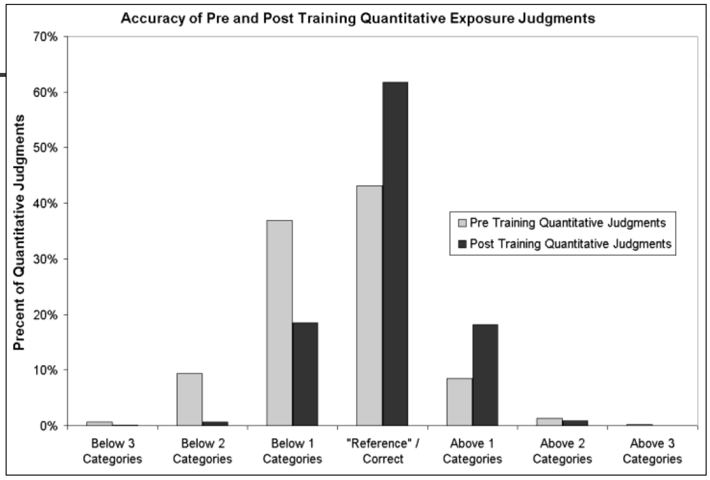
Video Tasks – Quantitative Judgments



P. Logan, G. Ramachandran, J. Mulhausen and P. Hewett "Occupational Exposure Decisions: Can Limited Data Interpretation Training Help Improve Accuracy?". Annals of Occupational Hygiene - 2009

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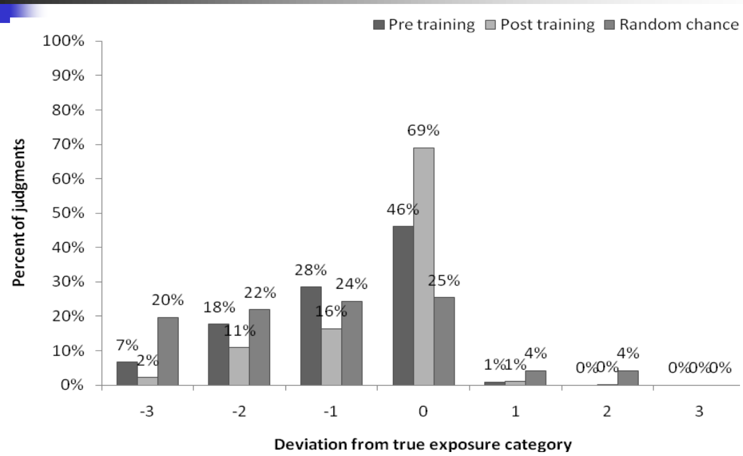
Professional Judgment and Bayesian Statistics

NIOSH Funded U of MN Study

Actual Workplace Assessments



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

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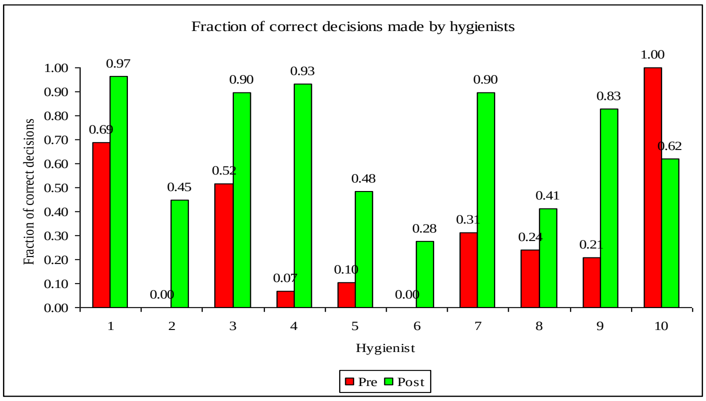
Professional Judgment and Bayesian Statistics

NIOSH Funded U of MN Study

Actual Workplace Assessments - Preliminary Study Results



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

A significant improvement was noticed in judgments collected after statistical training

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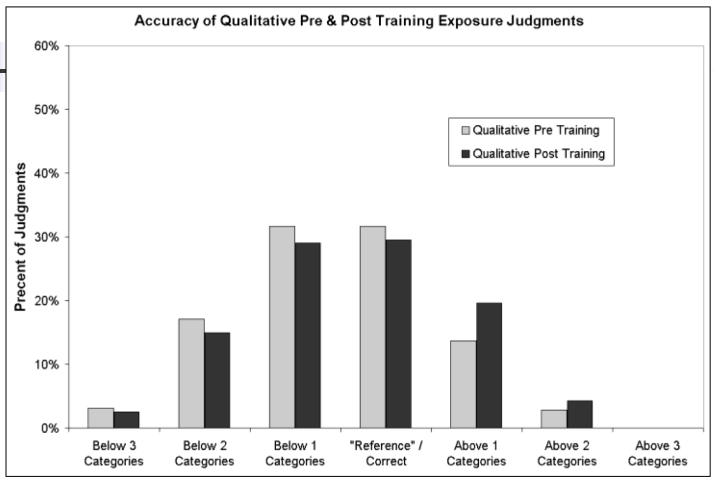
Video Tasks – Qualitative Judgments



P. Logan, G. Ramachandran, J. Mulhausen and P. Hewett "Occupational Exposure Decisions: Can Limited Data Interpretation Training Help Improve Accuracy?". Annals of Occupational Hygiene - 2009

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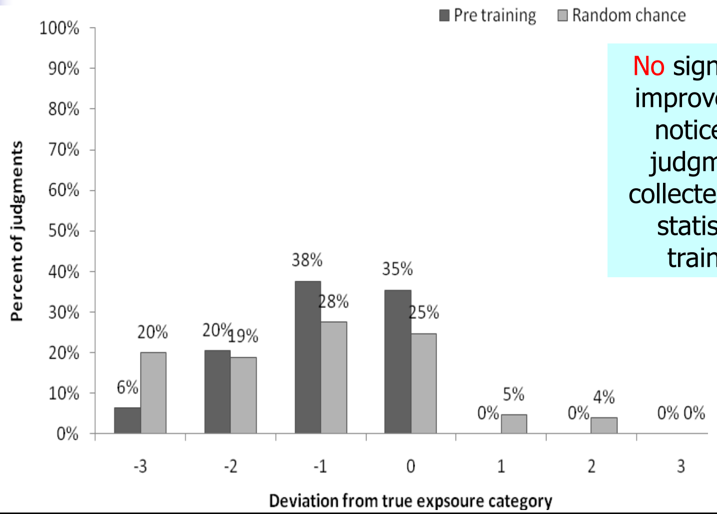
Professional Judgment and Bayesian Statistics

NIOSH Funded U of MN Study

Actual Workplace Assessments - Qualitative Judgmer



No significant improvement noticed in judgments collected after statistical training

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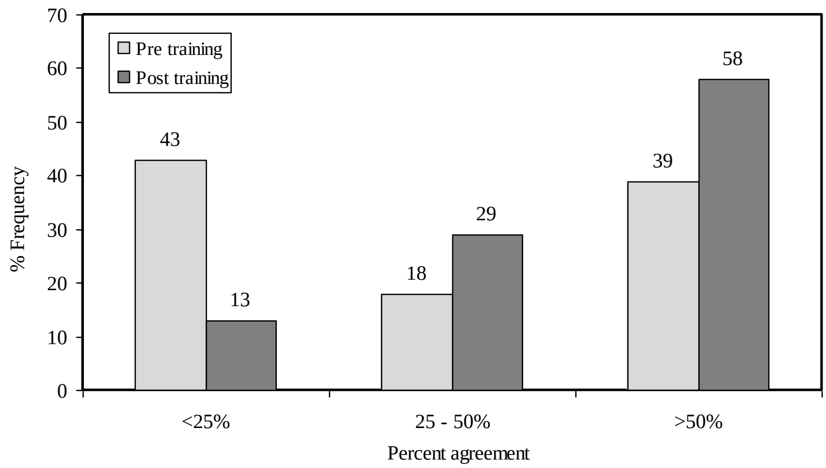
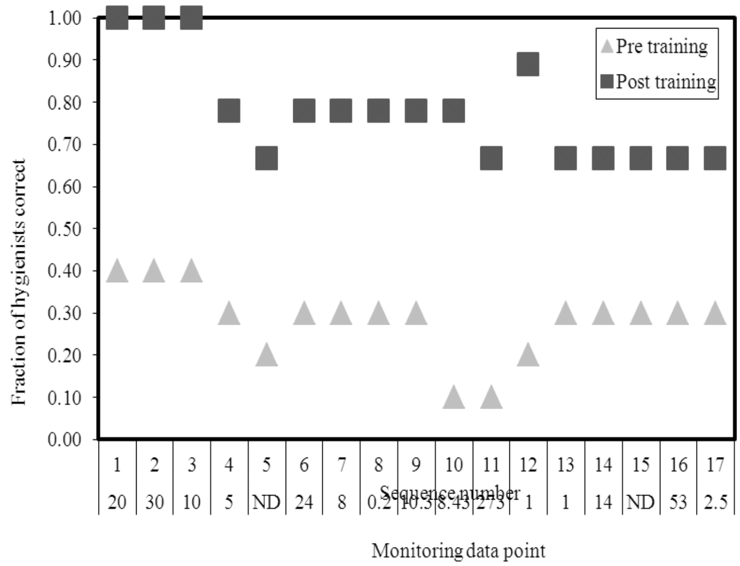
Agreement between hygienists





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

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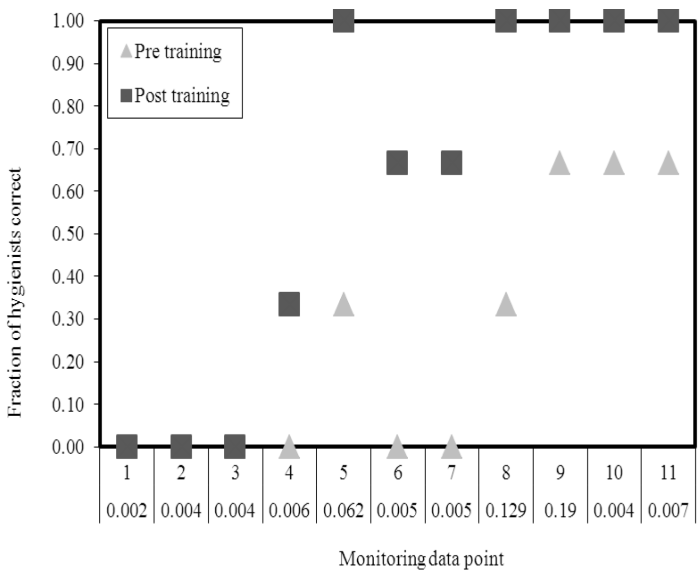
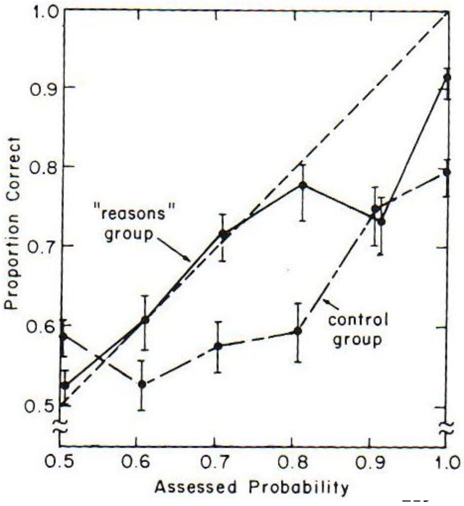


Quantitative judgments for task 10, pre- and post-training.
Number of hygienists = 3, OEL for task 0.05 mg/m3

Improving Judgments: The Use of Reasons

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



Improving Judgments: Disaggregation

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

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Cognitive Psychology
Learnings for Improved Decision-Making

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

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

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Cognitive Psychology
Learnings for Improved Decision-Making

- Giving reasons for decision increases accuracy
- Personal discussion of results increases accuracy
- Groups do better than individuals
- Break judgments down into component parts
- State problems and data in a logical order
  - Structured approach to decision making can increase accuracy
- When experts receive regular unbiased feedback they get better at making judgments

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The Informative Prior: Integrating Professional Judgment

- Informative Prior Based On:
  - Customized Professional Judgment
  - AIHA Exposure & Certainty Ratings
  - Modeling
  - Past Monitoring

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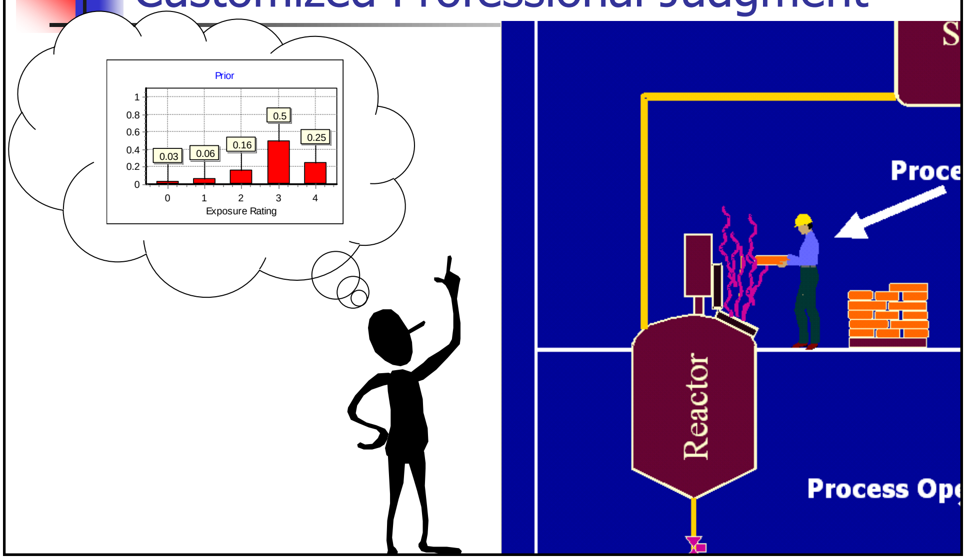
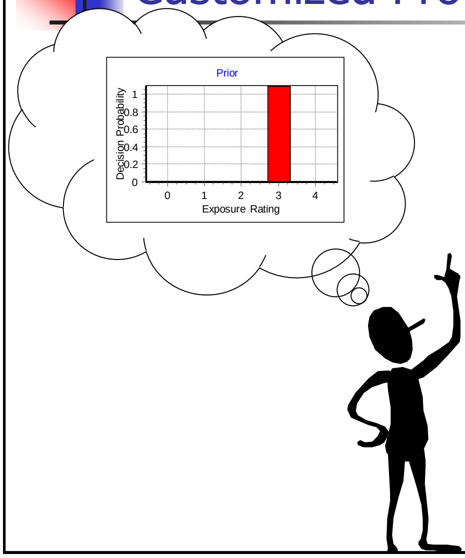
Informative Prior Based On Customized Professional Judgment



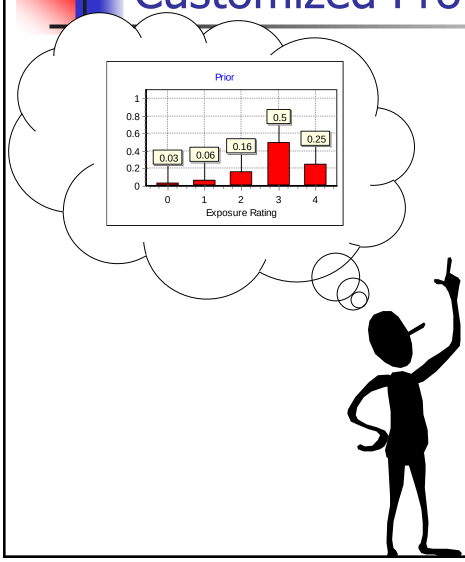
Informative Prior Based On Customized Professional Judgment



1) **IH Estimates Exposure Rating Category**

225

Informative Prior Based On Customized Professional Judgment



1) **IH Estimates Exposure Rating Category**
2) **IH Characterizes Uncertainty**

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Informative Prior Based On AIHA Exposure & Certainty Ratings

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

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AIHA Exposure Control Ratings

Exposure Control Ratings *		Cutoff (%OEL)	Confidence level
(green)	0	$X_{0.95} \leq 1\%$	High
(light blue)	1	$1\% < X_{0.95} \leq 10\%$	
(yellow)	2	$10\% < X_{0.95} \leq 50\%$	Medium
(orange)	3	$50\% < X_{0.95} \leq 100\%$	
(red)	4	$X_{0.95} > 100\%$	Low

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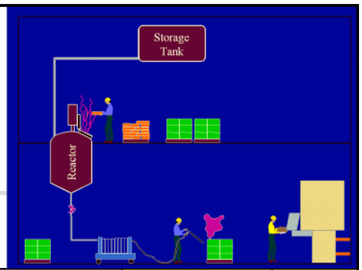
Perform Qualitative Exposure Assessments



Task Description	Agent	Duration/ Frequency	Initial Exposure Rating	Rating Certainty
Charging 20 - 10 kg bags of TiOx into Reactor w/ local exhaust	Titamium Dioxide	90 mins / shift	1 (<10%OEL)	1-High
Using pneumatic pump to charge 700 liters of cyclohexanone from drums into reactor	Cyclohexanone	90 mins / shift	2 (10-50%OEL)	3-Low
Collect a 200 ml QC samples (6) through handhole	Cyclohexanone	10 mins / shift	1 (<10%OEL)	1-High
Charging latex super mix from storage tank (watching level through open manhole)	Cyclohexanone	120 mins / shift	1 (<10%OEL)	3-Low
Package final product through filter system	Cyclohexanone	180 mins / shift	1 (<10%OEL)	3-Low
Change filter media, bleed and flush pumps	Cyclohexanone	120 mins / shift	4 (100-500%OEL)	1-High
Monitoring process at control panel	Cyclohexanone	120 mins / shift	1 (<10%OEL)	1-High
Calibration & repair of viscosity meters	Cyclohexanone	20 mins / shift	1 (<10%OEL)	2-Medium
Reactor equipment maintenance	Cyclohexanone	240 mins / week	1 (<10%OEL)	2-Medium
Viscosensor rebuild welding	Nickel	120 mins / week	2 (10-50%OEL)	1-High
Paint area & parts clean up	MEK	60 mins / week	2 (10-50%OEL)	1-High

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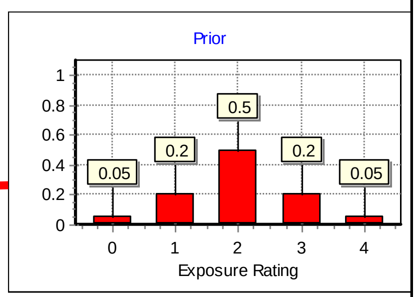
Informative Prior Based On AIHA Exposure & Certainty Ratings

Exposure Control Ratings *	Cutoff (%OEL)	Confidence level
0	$X_{0.95} \leq 1\%$	High
1	$1\% < X_{0.95} < 10\%$	
2	$10\% < X_{0.95} \leq 50\%$	Medium
3	$50\% < X_{0.95} \leq 100\%$	
4	$X_{0.95} > 100\%$	Low



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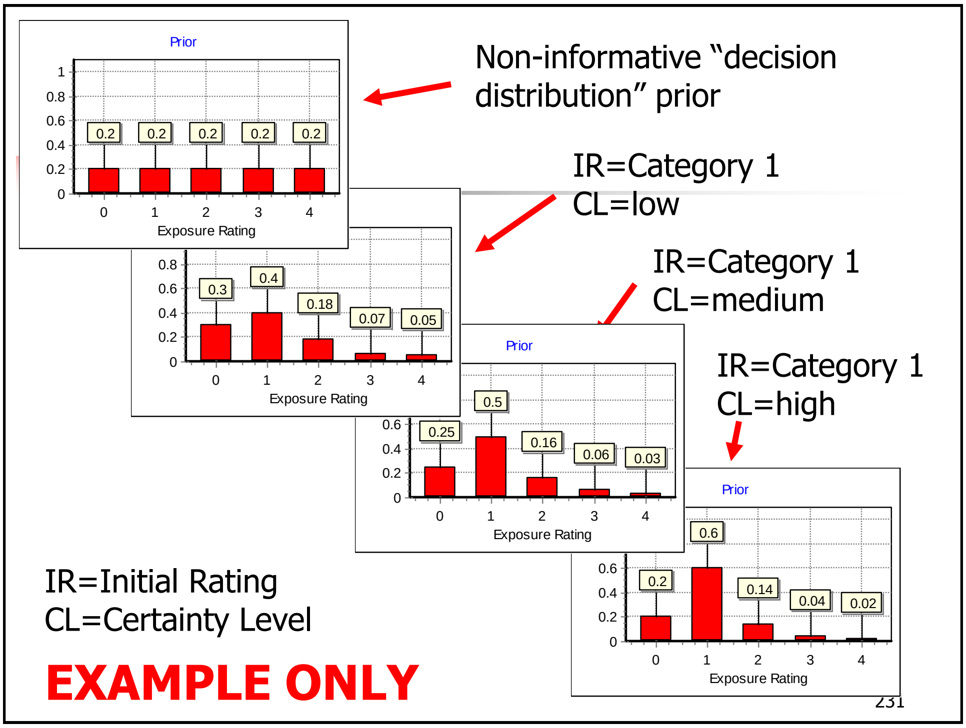
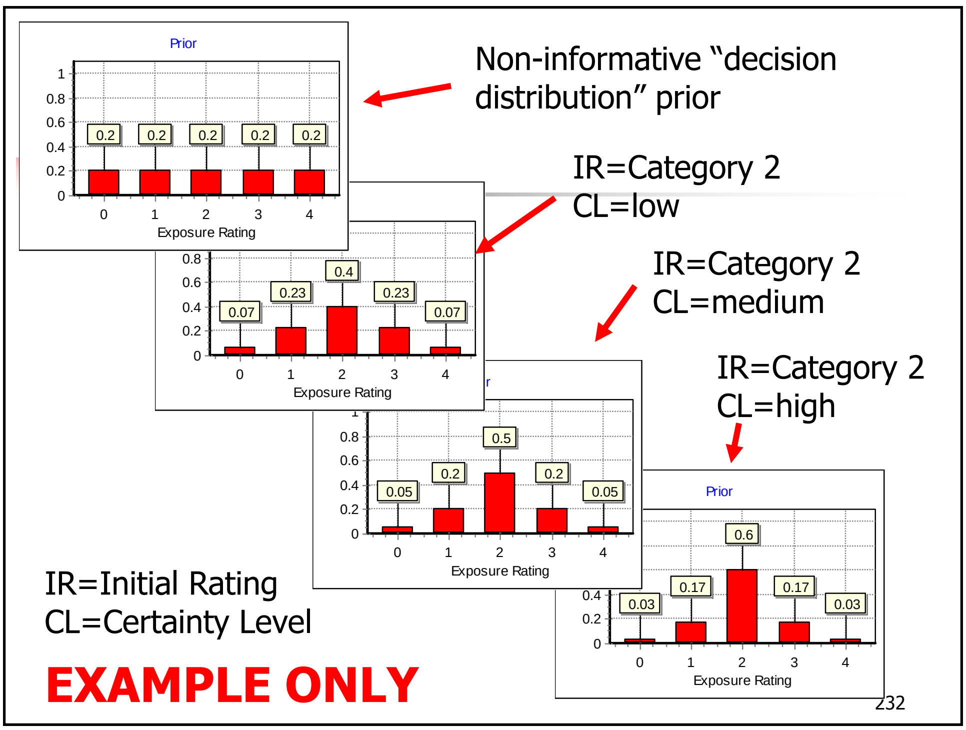
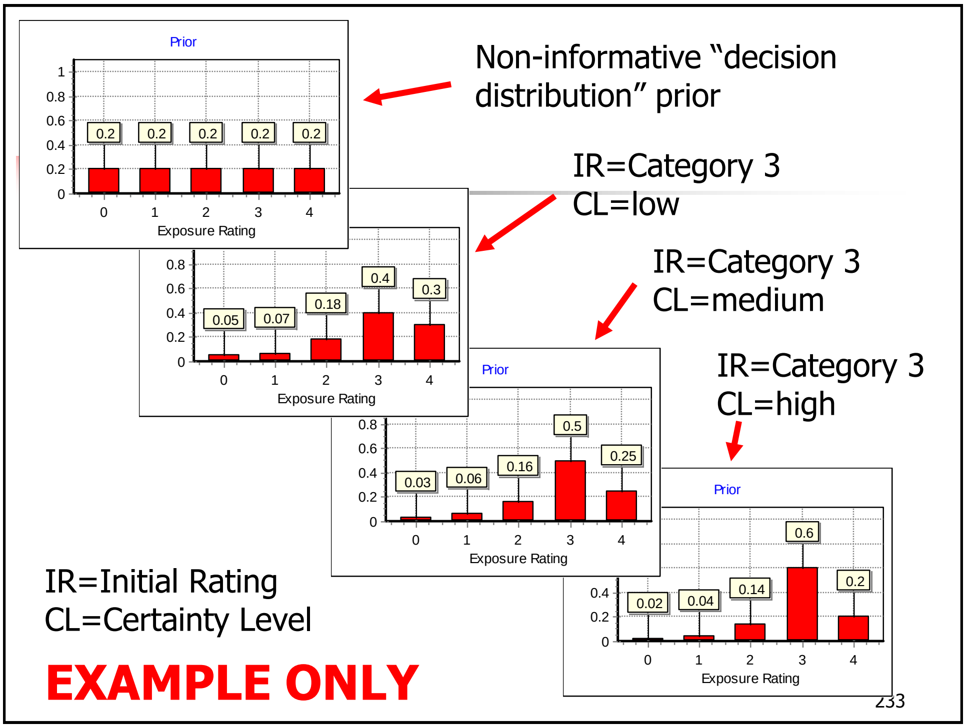
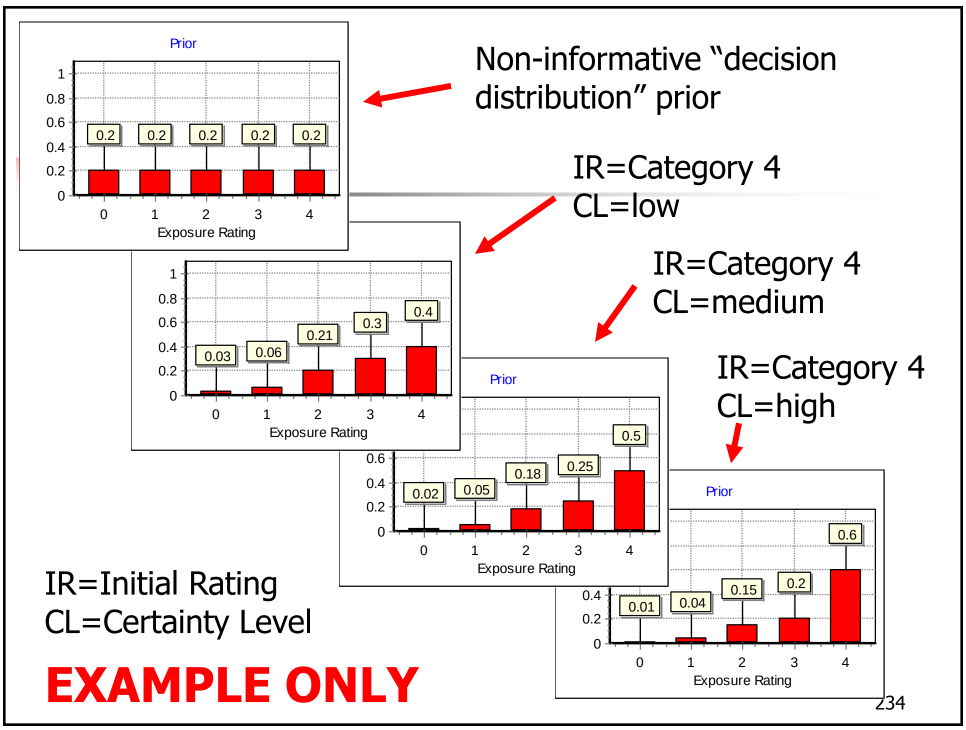
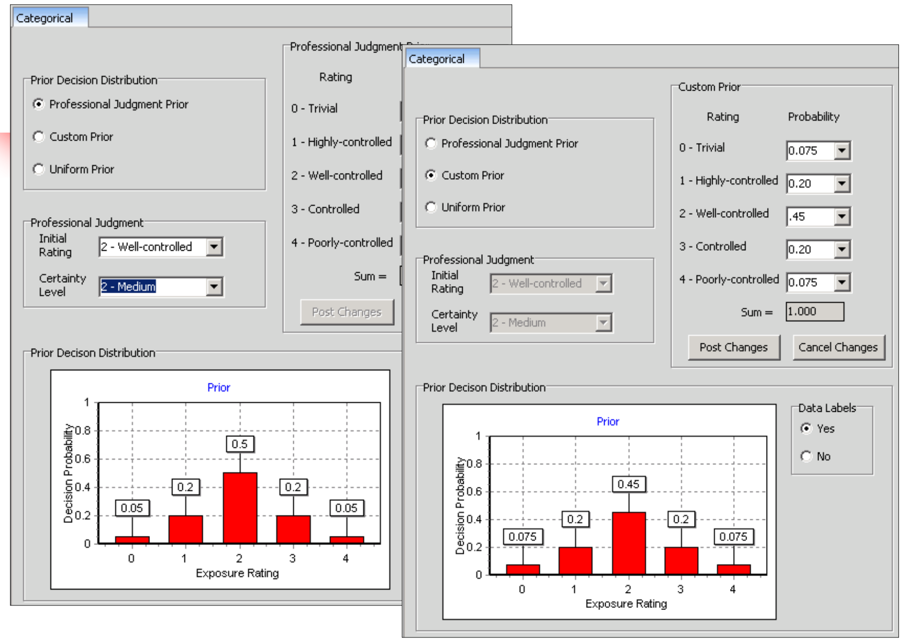

Prior
Exposure Rating
Non-informative "decision distribution" prior
IR=Category 1
CL=low
IR=Category 1
CL=medium
IR=Category 1
CL=high
IR=Initial Rating
CL=Certainty Level
EXAMPLE ONLY
231


Prior
Exposure Rating
Non-informative "decision distribution" prior
IR=Category 2
CL=low
IR=Category 2
CL=medium
IR=Category 2
CL=high
IR=Initial Rating
CL=Certainty Level
EXAMPLE ONLY
232


Non-informative "decision distribution" prior
IR=Category 3
CL=low
IR=Category 3
CL=medium
IR=Category 3
CL=high
Prior
0.2 0.2 0.2 0.2 0.2
0.05 0.07 0.18 0.4 0.3
Prior
0.03 0.06 0.16 0.5 0.25
Prior
0.02 0.04 0.14 0.6 0.2
Exposure Rating
IR=Initial Rating
CL=Certainty Level
EXAMPLE ONLY
233


Non-informative "decision distribution" prior
IR=Category 4
CL=low
IR=Category 4
CL=medium
IR=Category 4
CL=high
Prior
0.2 0.2 0.2 0.2 0.2
0.03 0.06 0.21 0.3 0.4
Prior
0.02 0.05 0.18 0.25 0.5
Prior
0.01 0.04 0.15 0.2 0.6
Exposure Rating
IR=Initial Rating
CL=Certainty Level
EXAMPLE ONLY
234



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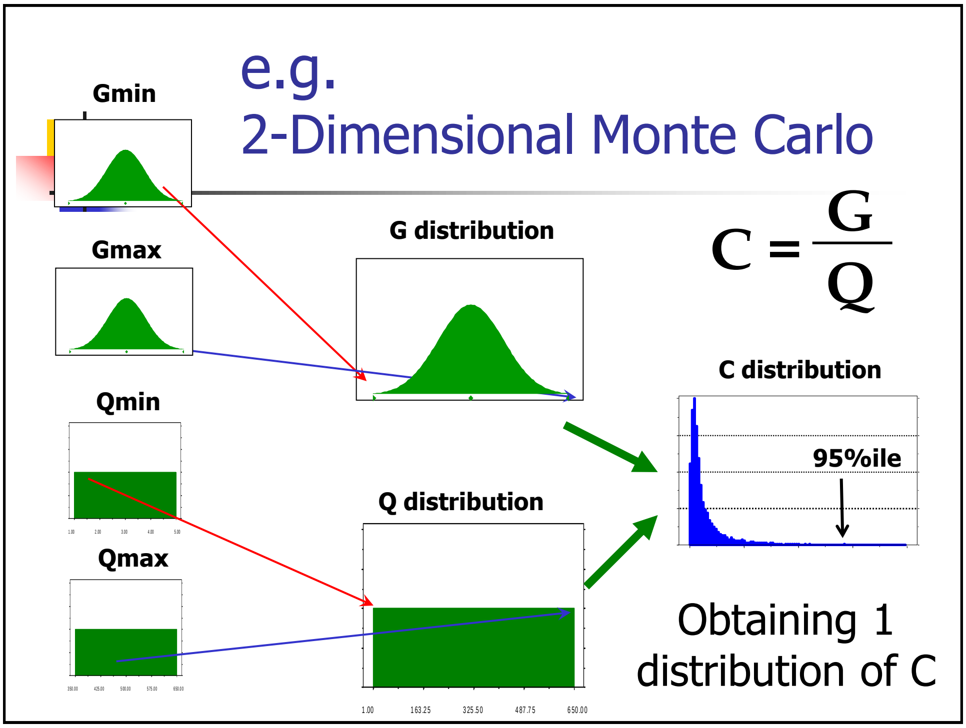
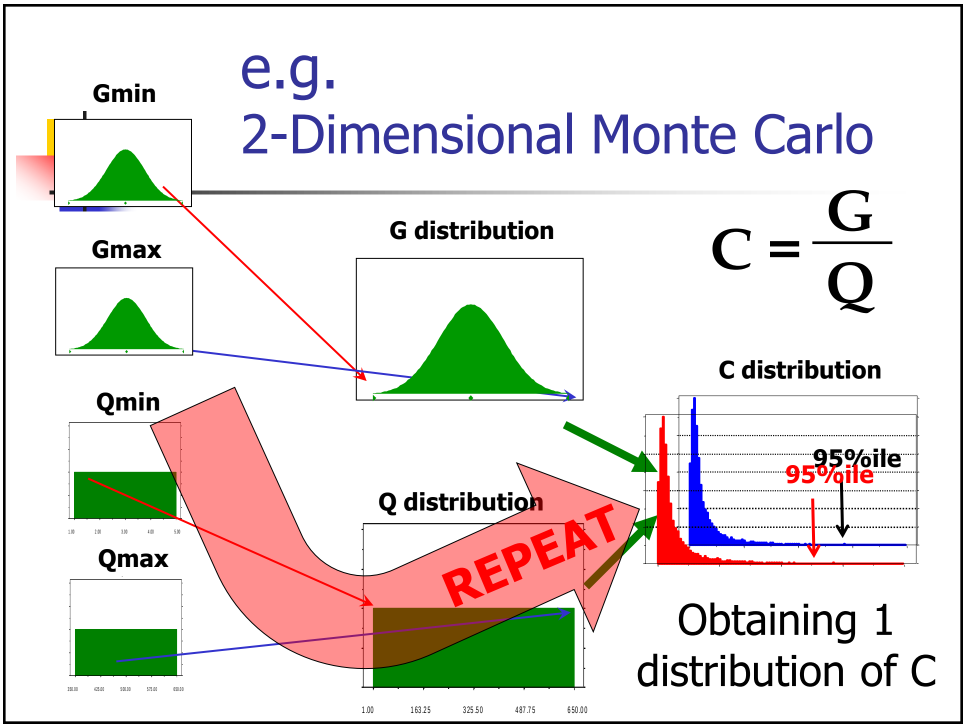
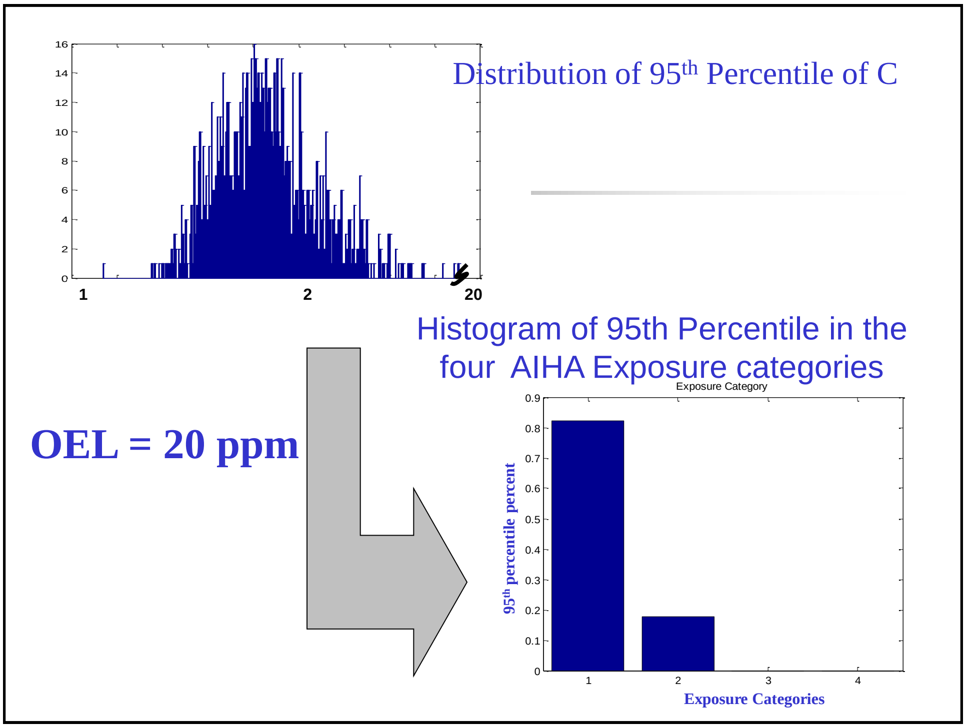
Informative Prior Based On Modeling

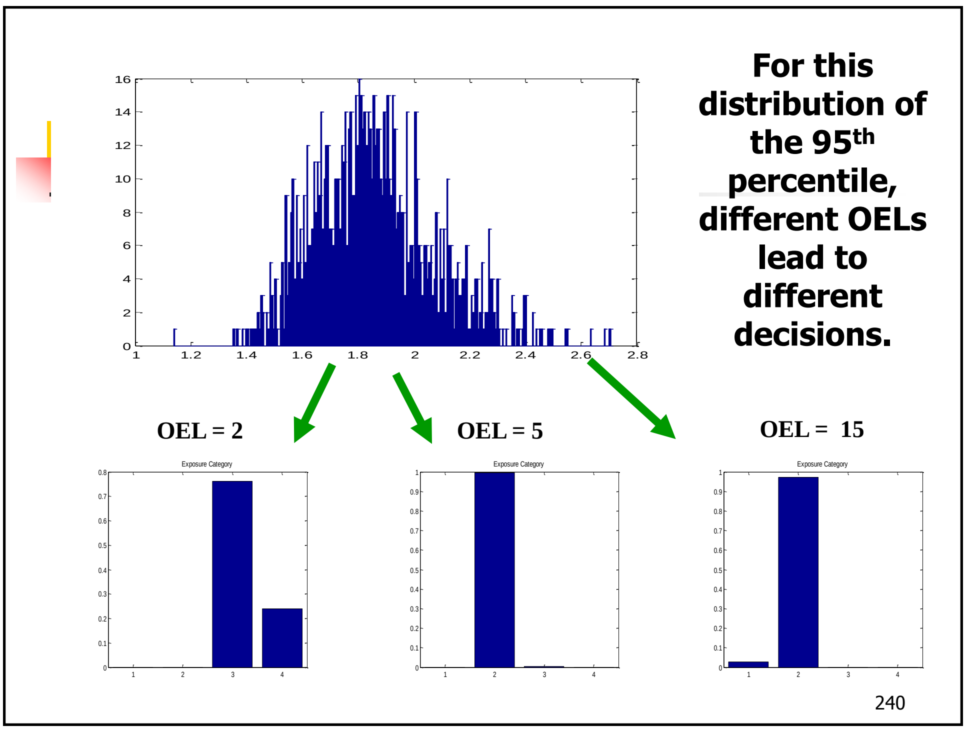
- Disaggregation, documentation, and reason (exposure determinants)
- Many exposure models to select from - differ in their levels of sophistication.
  - Each level increases cost (information needed as inputs to the models), but yields more accurate estimates.
  - We should use the simplest model that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

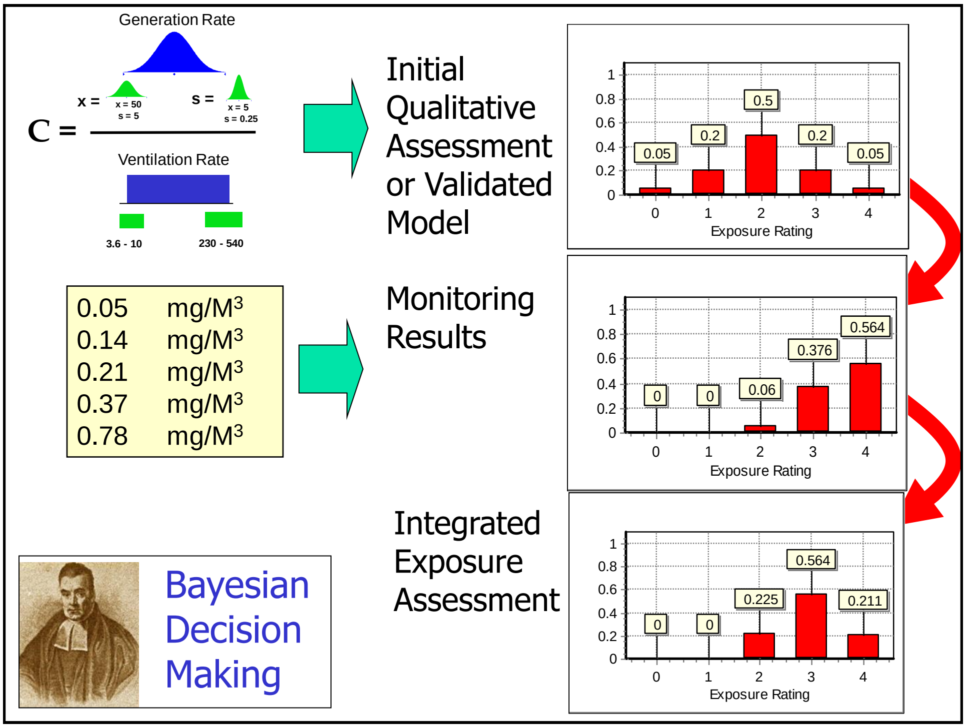
236

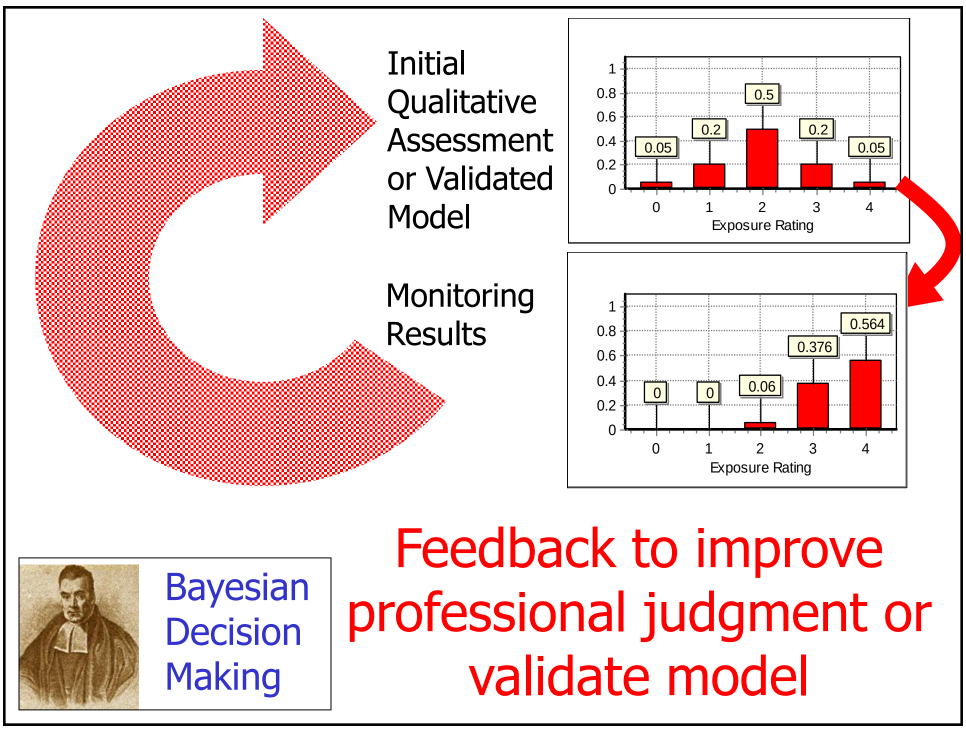

e.g.
2-Dimensional Monte Carlo
Gmin
Gmax
Qmin
Qmax
G distribution
Q distribution
C distribution
95%ile
$C = \frac{G}{Q}$
Obtaining 1 distribution of C


e.g.
2-Dimensional Monte Carlo
Gmin
Gmax
Qmin
Qmax
G distribution
Q distribution
C distribution
95%ile
95%ile
REPEAT
$C = \frac{G}{Q}$
Obtaining 1 distribution of C


Distribution of 95th Percentile of C
1
2
20
Histogram of 95th Percentile in the four AIHA Exposure categories
OEL = 20 ppm
Exposure Category
95th percentile percent
Exposure Categories


For this distribution of the 95th percentile, different OELs lead to different decisions.
OEL = 2
OEL = 5
OEL = 15
Exposure Category
240


Generation Rate
C =
x =
x = 50
s = 5
s =
x = 5
s = 0.25
Ventilation Rate
3.6 - 10
230 - 540
0.05 mg/M3
0.14 mg/M3
0.21 mg/M3
0.37 mg/M3
0.78 mg/M3
Initial Qualitative Assessment or Validated Model
Monitoring Results
Integrated Exposure Assessment
0.05
0.2
0.5
0.2
0.05
0
0
0.06
0.376
0.564
0
0
0.225
0.564
0.211
Exposure Rating
Bayesian Decision Making


Initial Qualitative Assessment or Validated Model
Monitoring Results
0.05
0.2
0.5
0.2
0.05
0
0
0.06
0.376
0.564
Exposure Rating
Bayesian Decision Making
Feedback to improve professional judgment or validate model

Informative Prior Based On Past Monitoring

- Leveraging Monitoring Data From Similar Operations

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Custom Informative Priors:
Leveraging Monitoring Data From Similar Operations

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

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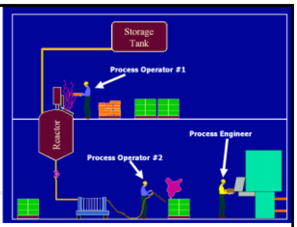
Example



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

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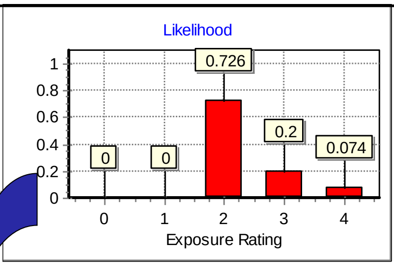
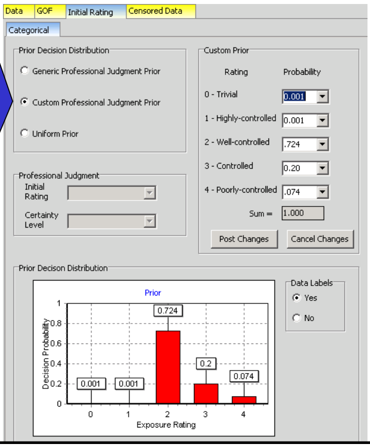
Decision Charts





Brazil Data:

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

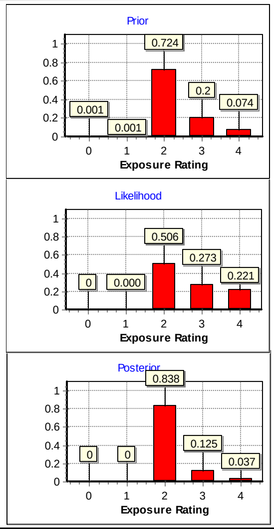
- Use the “Likelihood” chart as the new “Custom Prior”

Process Operator #1 (China)

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

China Data:

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



Comments

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

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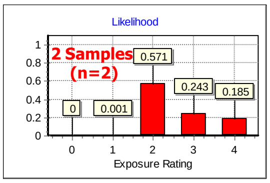
Impact of Prior on Small & Medium* Size Datasets

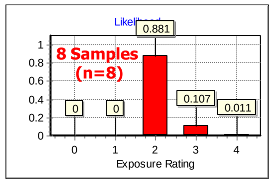
Data Sets: **Sampling Data = Category 2 (10-50% of OEL)**

X = {12, 21}

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

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





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Descriptive Statistics

Mean = 16.5000

SD = 6.3600

GM = 15.9000

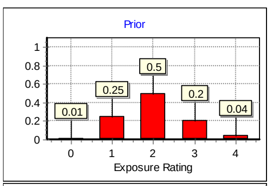
GSD = 1.485

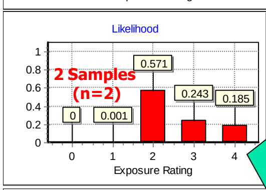
Compliance Statistics (lognormal)

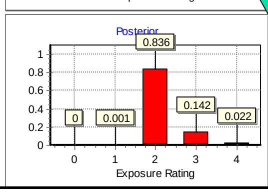
X0.95 = 30.4000

95%LCL = 19.2000

95%UCL = 5.17E0005







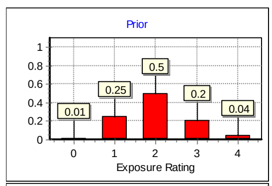
n=2

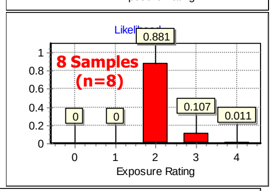
Prior & Data Category Match

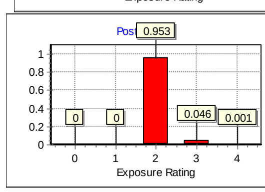
Prior Cat = 2
Data Cat = 2

Note Category 4

n=8







Descriptive Statistics

Mean = 16.9000

SD = 6.3300

GM = 15.8000

GSD = 1.475

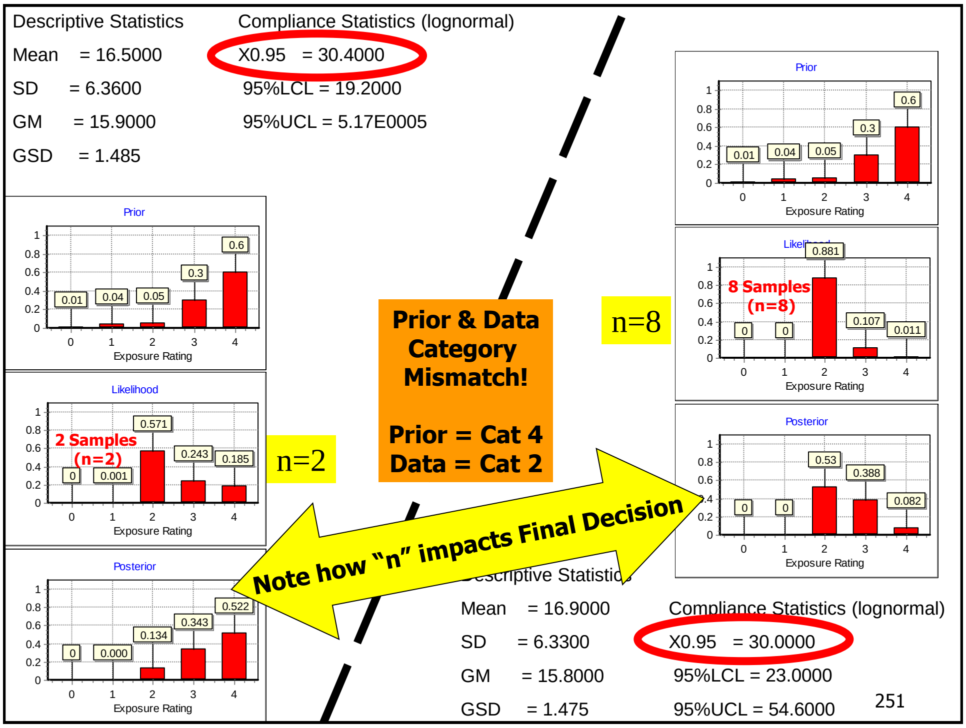
Compliance Statistics (lognormal)

X0.95 = 30.0000

95%LCL = 23.0000

95%UCL = 54.6000

250



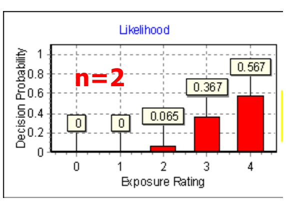
Impact of Prior on Small & Medium* Size Datasets

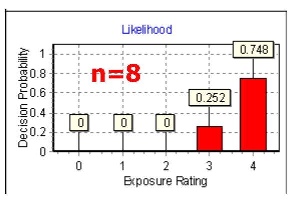
Data Sets: **Sampling Data = Category 4 (>100% of OEL)**

X = {65, 29}

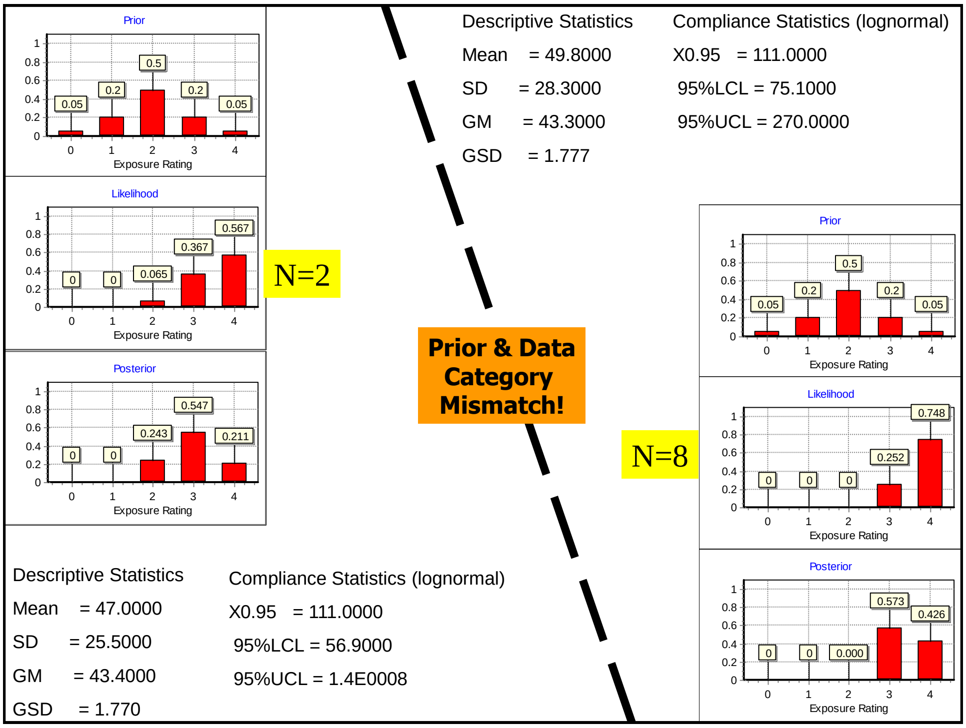
X = {65, 29, 48, 108, 42, 33, 16, 57}

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

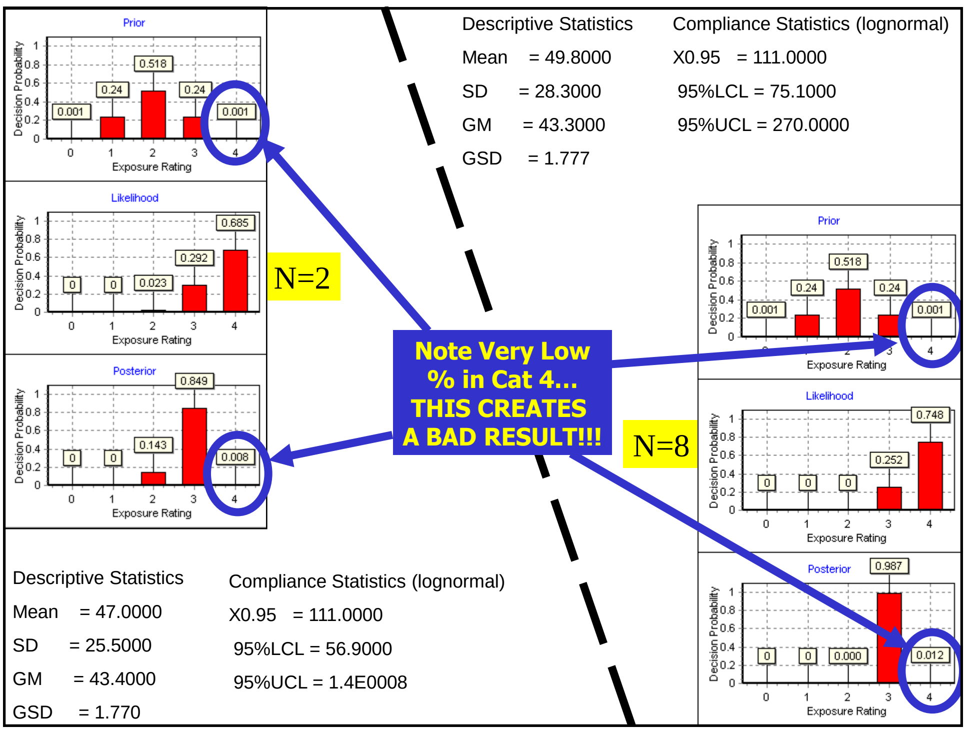




252

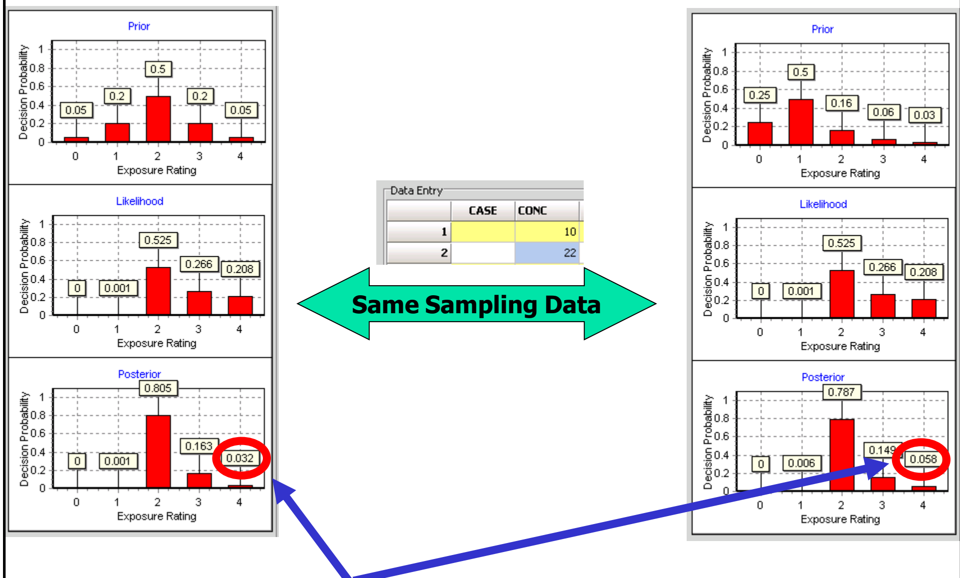


Prior
Likelihood
Posterior
Exposure Rating
N=2
N=8
Prior & Data Category Mismatch!
Descriptive Statistics
Mean = 49.8000
SD = 28.3000
GM = 43.3000
GSD = 1.777
Compliance Statistics (lognormal)
X0.95 = 111.0000
95%LCL = 75.1000
95%UCL = 270.0000
Descriptive Statistics
Mean = 47.0000
SD = 25.5000
GM = 43.4000
GSD = 1.770
Compliance Statistics (lognormal)
X0.95 = 111.0000
95%LCL = 56.9000
95%UCL = 1.4E0008



Prior
Likelihood
Posterior
Decision Probability
Exposure Rating
N=2
N=8
Note Very Low % in Cat 4… THIS CREATES A BAD RESULT!!!
Descriptive Statistics
Mean = 49.8000
SD = 28.3000
GM = 43.3000
GSD = 1.777
Compliance Statistics (lognormal)
X0.95 = 111.0000
95%LCL = 75.1000
95%UCL = 270.0000
Descriptive Statistics
Mean = 47.0000
SD = 25.5000
GM = 43.4000
GSD = 1.770
Compliance Statistics (lognormal)
X0.95 = 111.0000
95%LCL = 56.9000
95%UCL = 1.4E0008

Impact of Mismatched Prior



We get penalized for a mismatching Prior & Sampling Data

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Warnings on Creating Priors to be leveraged across SEGs

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

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Workshop 1 - Determine BDA Output for Following Example:

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

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Workshop 2 - Determine BDA Output for Following Example:

- Simple Well-Mixed Room Model Output:
  - Concentration Range: 50 ppm to 430 ppm
- Monitoring Data (OEL = 1000 ppm):
  - 67 ppm
  - 48 ppm
  - 54 ppm

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Workshop 3 - Determine BDA Output for Following Example:

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

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Potential Applications of Bayesian Decision Analysis

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Potential Applications of Bayesian Decision Analysis

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

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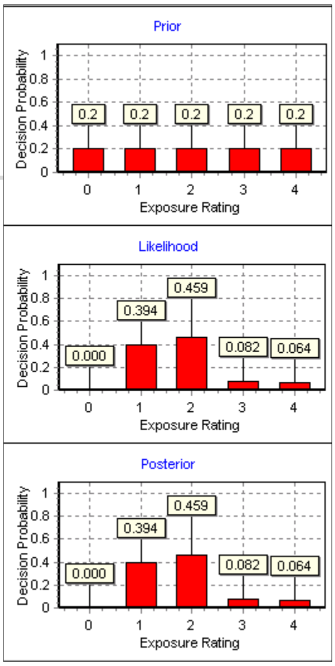
Reach a decision when n is small

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

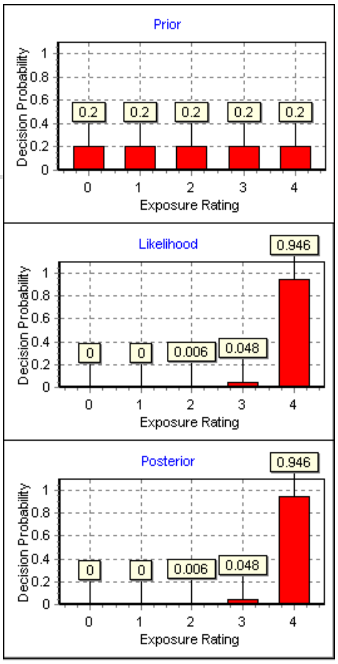
- BDA can be applied to sample sizes as low as n=1.



262

- OEL=1 ppm
- n = 1
- x = 0.99 ppm

- "Yes, the measurement is <OEL. But I strongly suspect that that exposures are not acceptable."
- BDA would lead to the same conclusion.

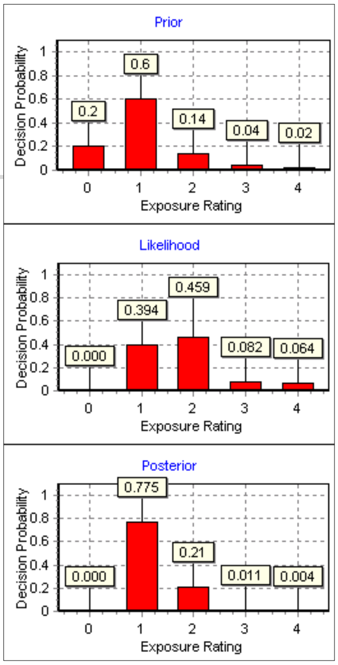


263

Leverage professional judgment

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

- Professional judgment can *sharpen* the decision.

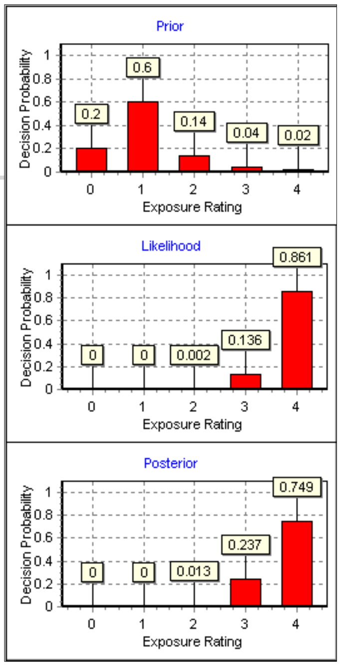


264

Provide feedback for IH Calibration

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

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

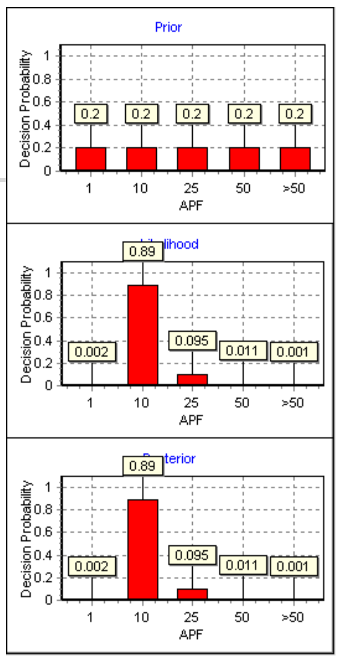


265

Assist in respirator selection

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

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

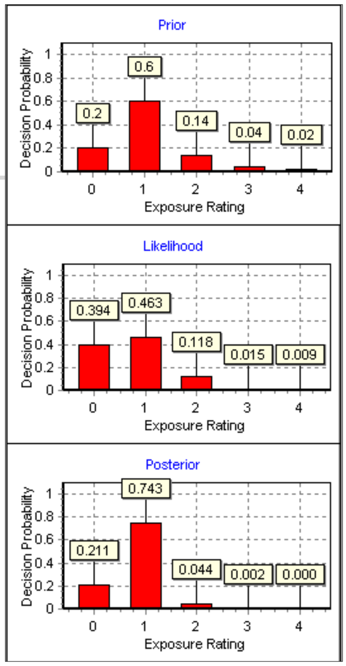


266

Analyze censored datasets

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

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



267

Noise Analysis

dBA
80.8
76.5
82.2
83.9
78.7
77.3

Acceptable Exposure?

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Noise Analysis

dBA	Dose (80, 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

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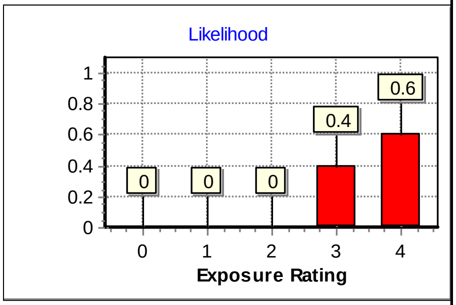
Noise Analysis

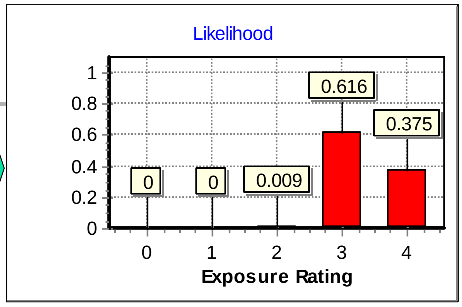
dBA	Dose (80, 5)
80.8	55.9
76.5	30.8
82.2	67.8
83.9	85.9
78.7	41.8
77.3	34.4



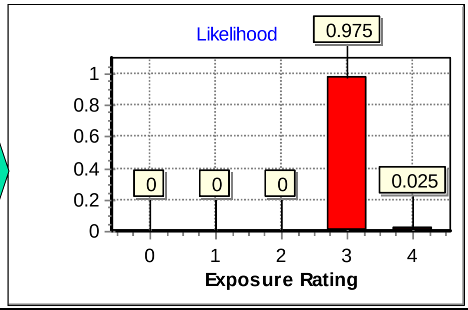
270

Noise Analysis

dBA	Dose (80, 5)
79.8	48.6
81.1	58.2
74	21.8
77.1	33.4
74.9	24.7
81	57.4



dBA	Dose (80, 5)
80.8	55.9
80	50.0
80.3	52.1
81.6	62.4
79.8	48.6
79.2	44.8



Closing Discussion

Running From the Dart-Throwing Monkeys:

A Call to Action

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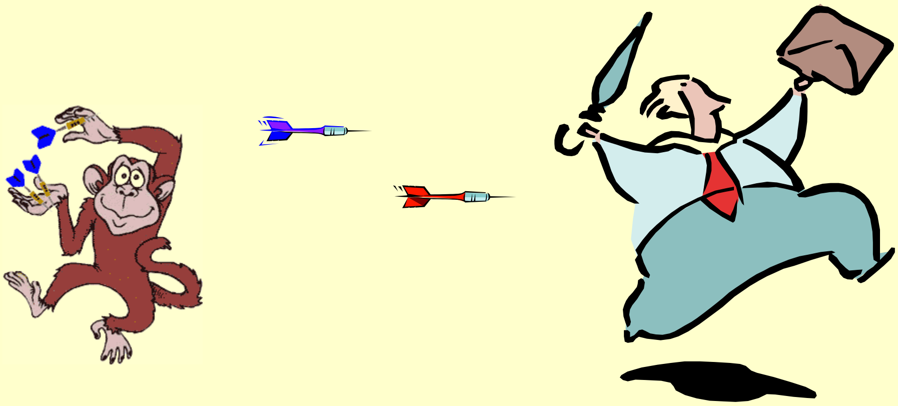
Running From the Dart-Throwing Monkeys



Dart Throwing Monkey

Wall Street Journal Contest: Dart Throwing Monkeys vs. Experts

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

Burton Malkiel - A Random Walk Down Wall Street.

Exposure Judgment Accuracy Bar

Dart Throwing Monkey

Super IH

Increasing Accuracy →

Random Chance | 100%

Exposure Judgment Accuracy Bar

Dart Throwing Monkey

Super IH

Increasing Accuracy →

Random Chance | 100%

Where do we want to be?

Exposure Judgments

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

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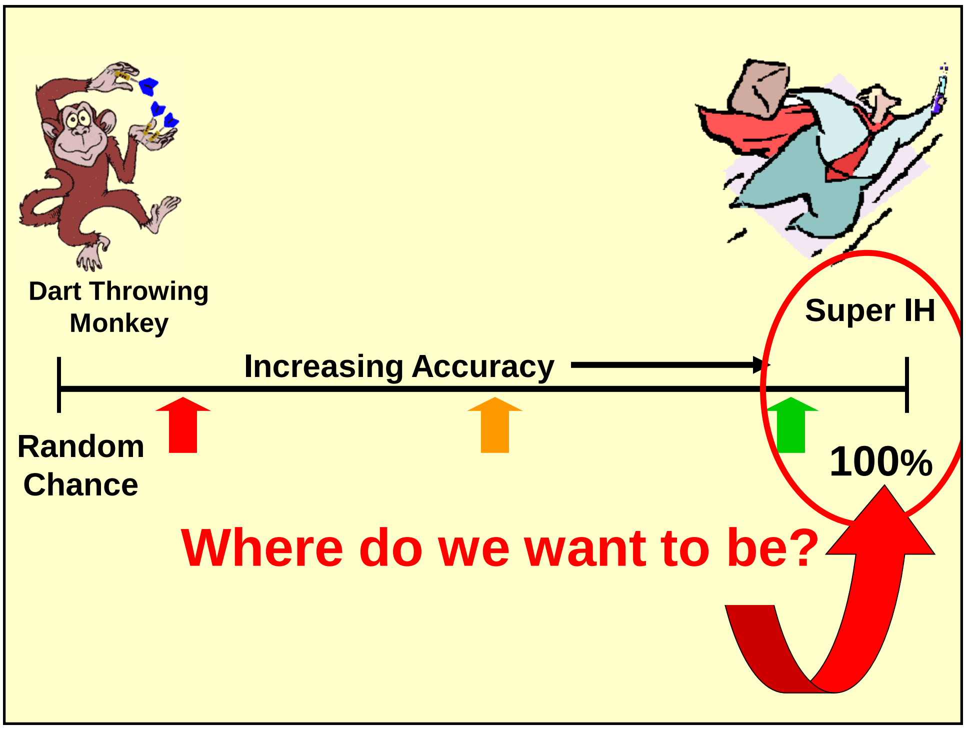
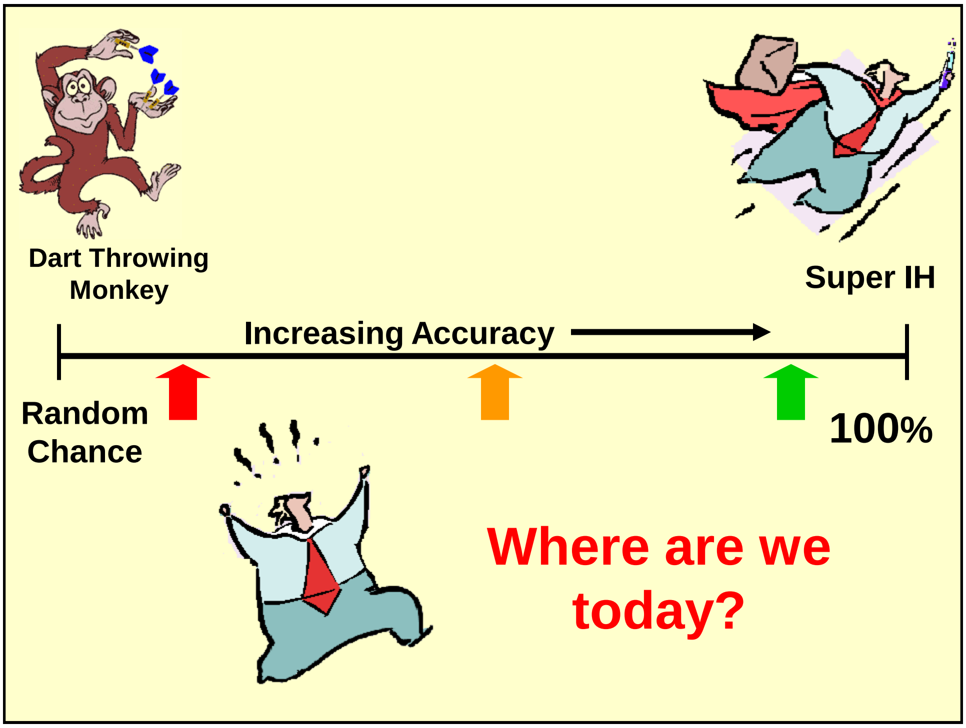
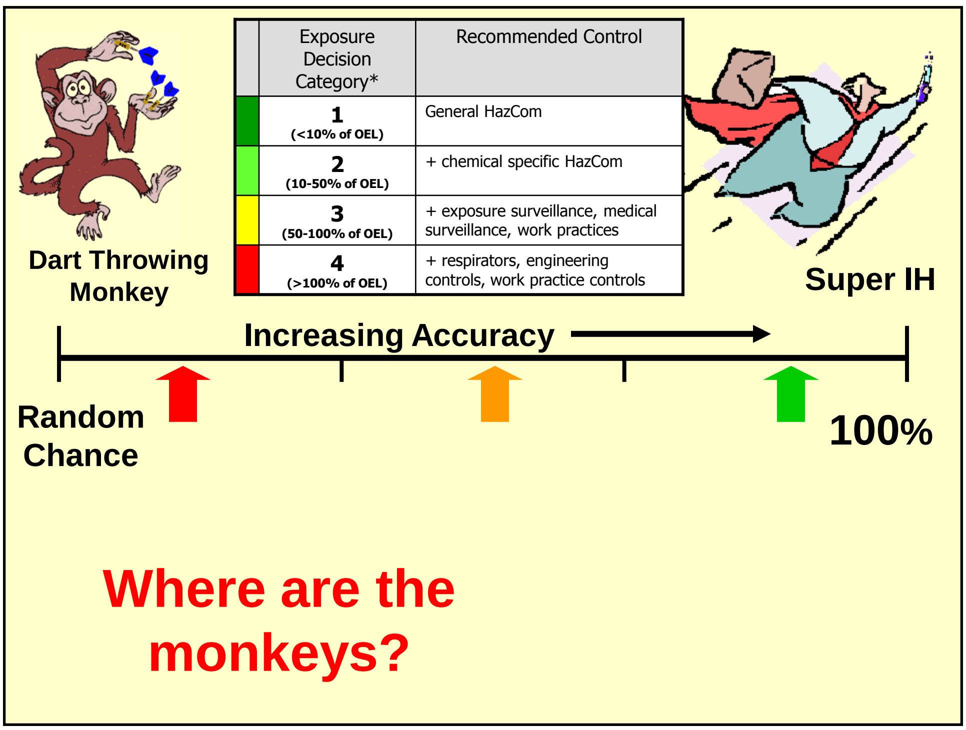
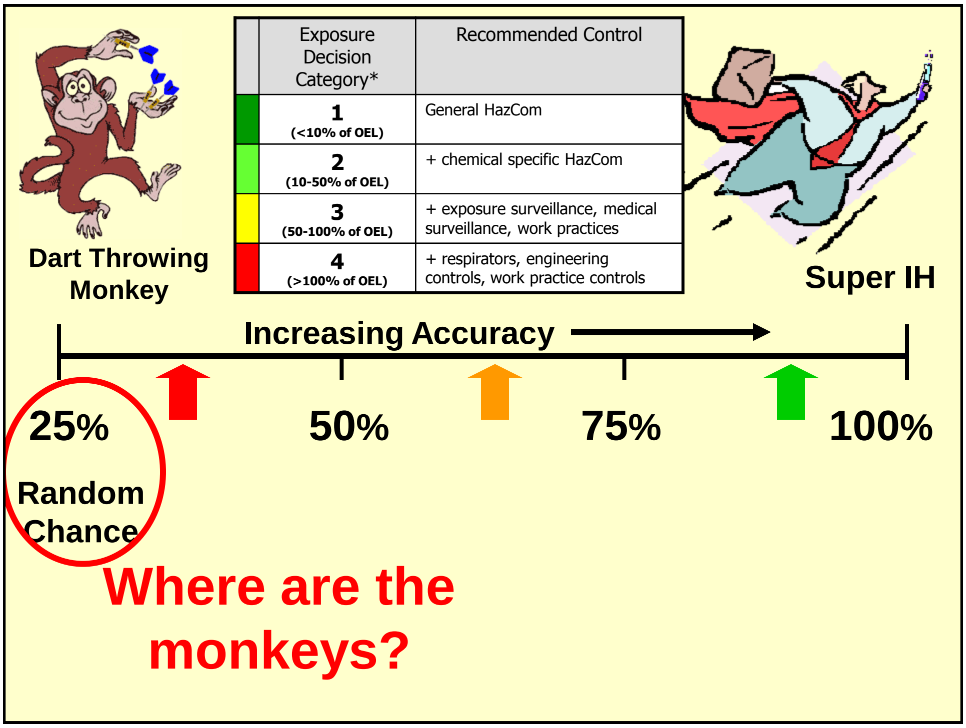
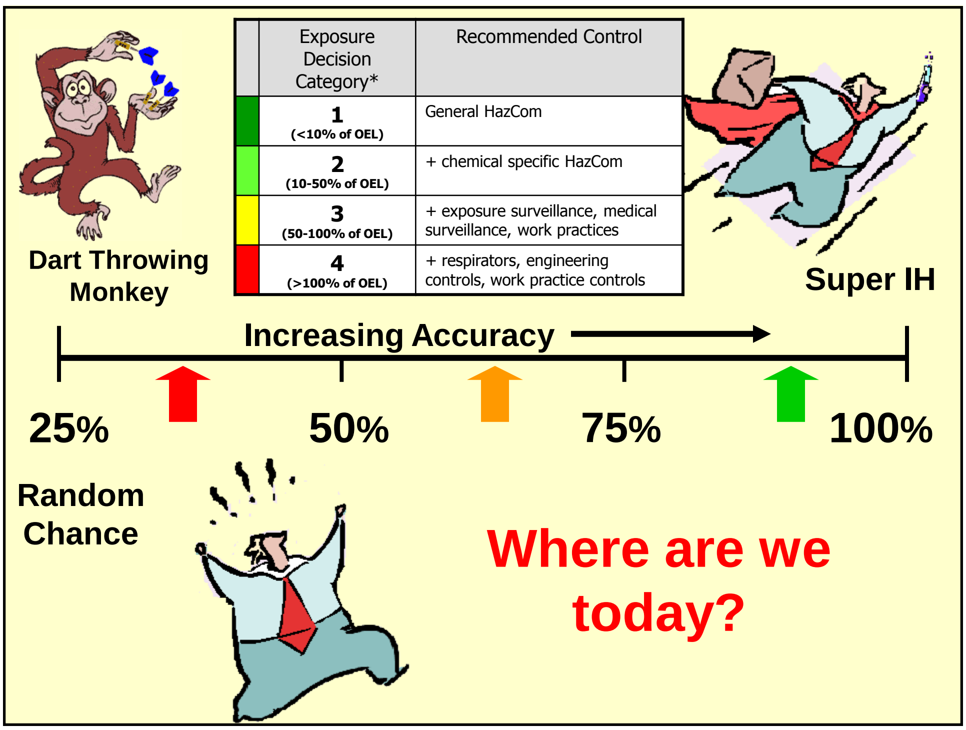


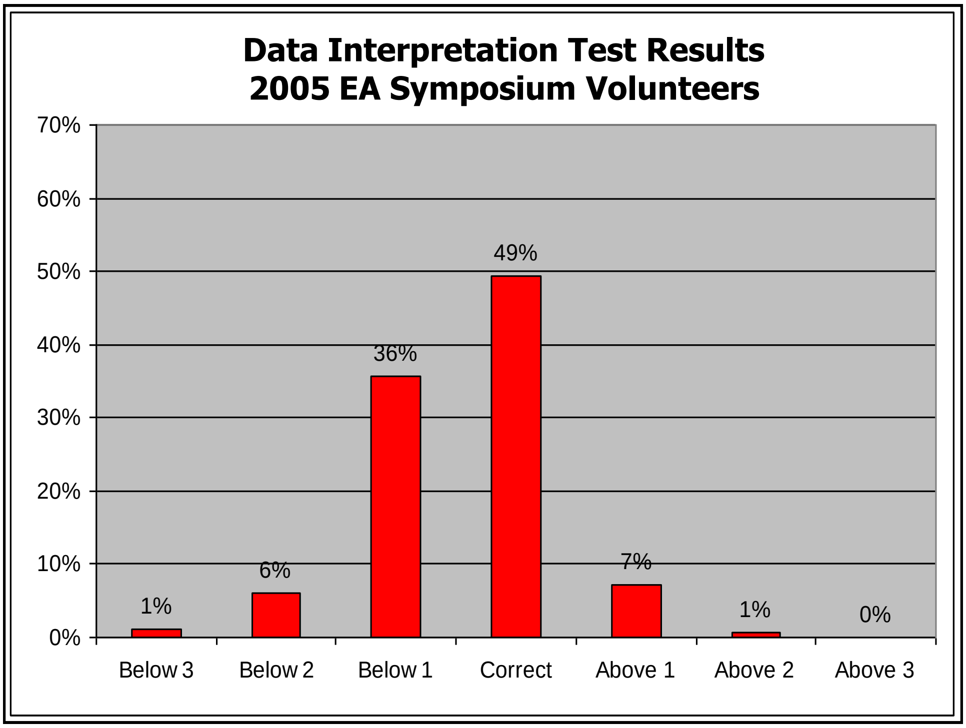


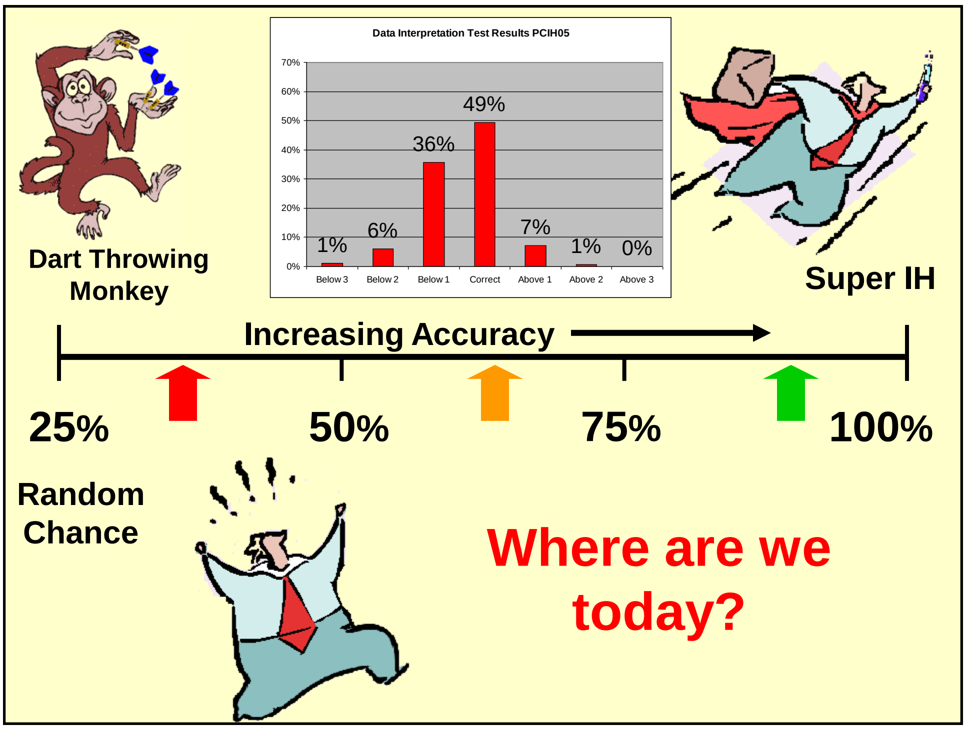


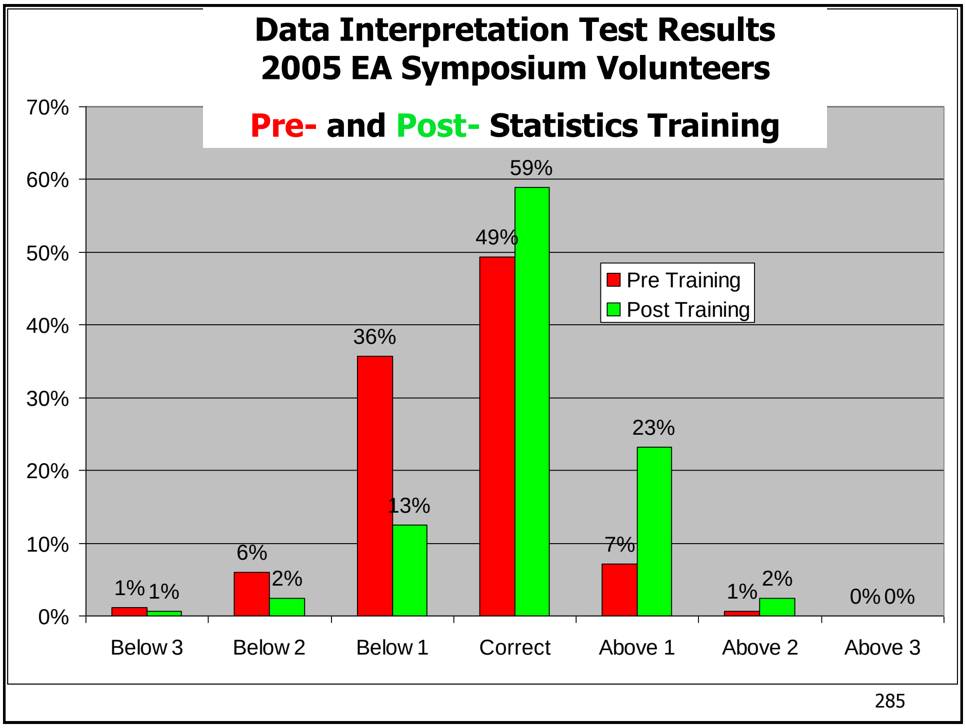
Exposure Decision Category*	Recommended Control
1 (<10% of OEL)	General HazCom
2 (10-50% of OEL)	+ chemical specific HazCom
3 (50-100% of OEL)	+ exposure surveillance, medical surveillance, work practices
4 (>100% of OEL)	+ respirators, engineering controls, work practice controls

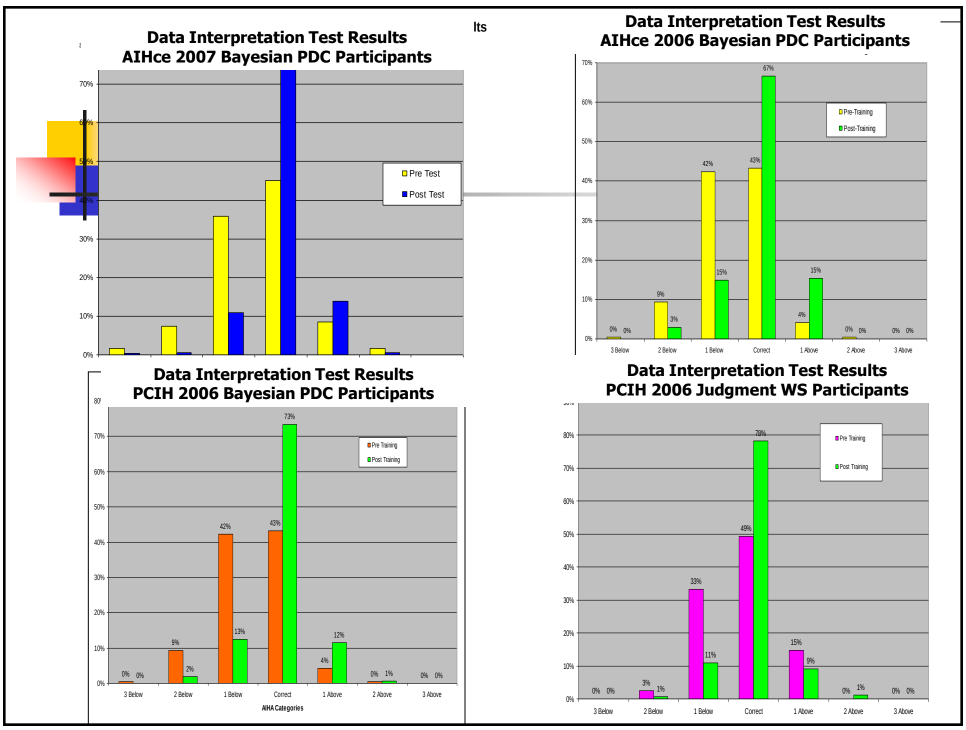

Dart Throwing Monkey
Exposure Decision Category*
Recommended Control
1 (<10% of OEL)
General HazCom
2 (10-50% of OEL)
+ chemical specific HazCom
3 (50-100% of OEL)
+ exposure surveillance, medical surveillance, work practices
4 (>100% of OEL)
+ respirators, engineering controls, work practice controls
Super IH
Increasing Accuracy
25%
50%
75%
100%
Random Chance
Where are the monkeys?

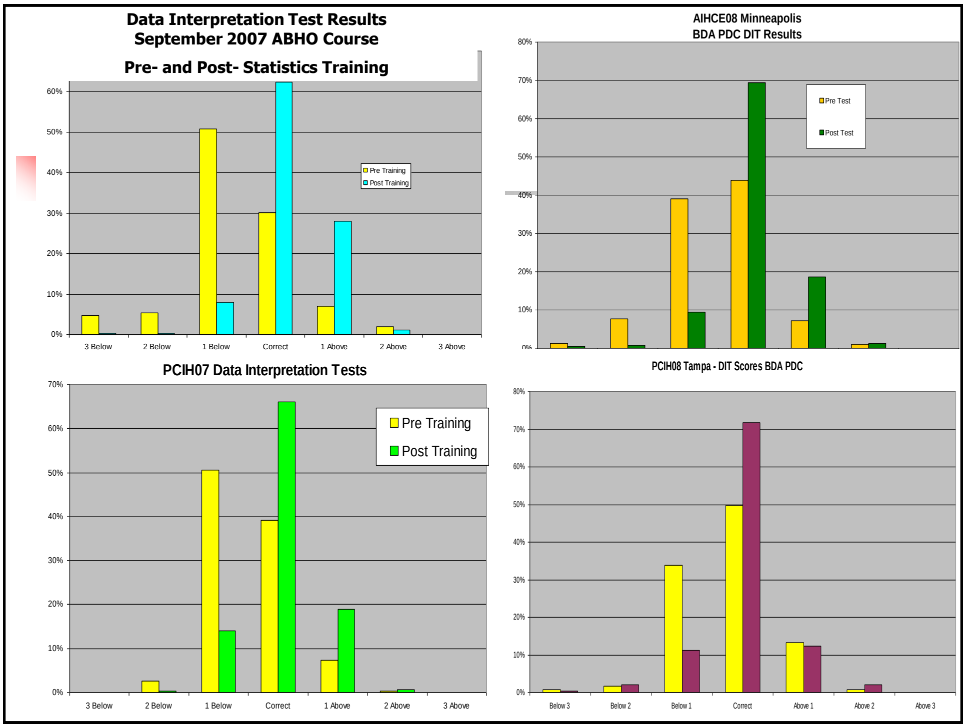

Dart Throwing Monkey
Exposure Decision Category*
Recommended Control
1 (<10% of OEL)
General HazCom
2 (10-50% of OEL)
+ chemical specific HazCom
3 (50-100% of OEL)
+ exposure surveillance, medical surveillance, work practices
4 (>100% of OEL)
+ respirators, engineering controls, work practice controls
Super IH
Increasing Accuracy
25%
50%
75%
100%
Random Chance
Where are we today?


Data Interpretation Test Results
2005 EA Symposium Volunteers
70%
60%
50%
40%
30%
20%
10%
0%
1%
6%
36%
49%
7%
1%
0%
Below 3
Below 2
Below 1
Correct
Above 1
Above 2
Above 3

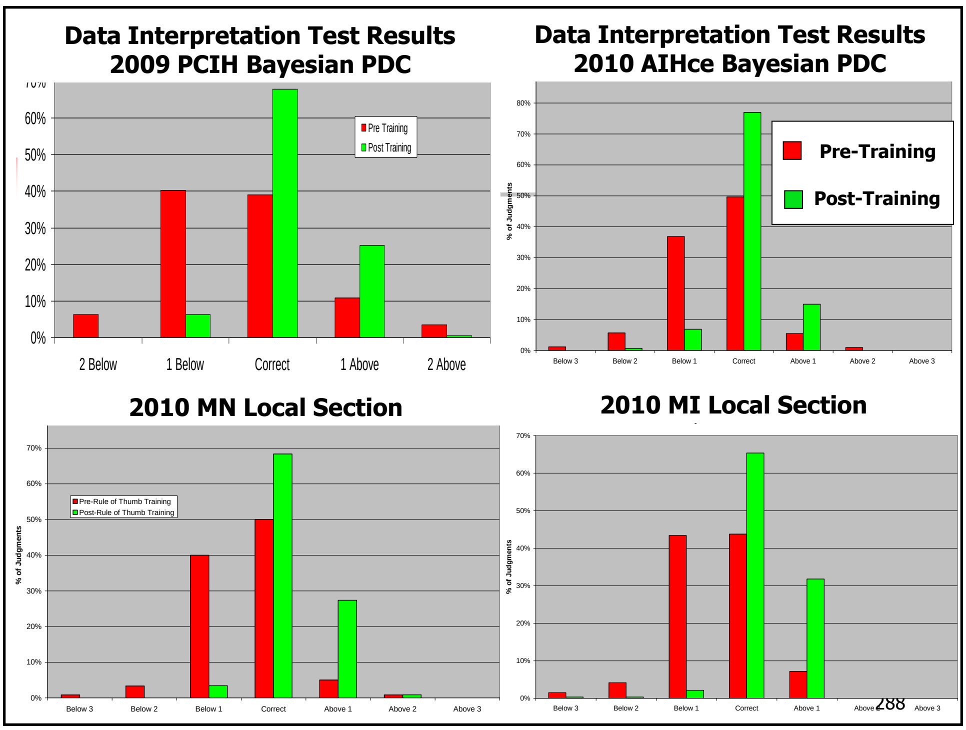

Data Interpretation Test Results PCIH05
1%
6%
36%
49%
7%
1%
0%
Below 3
Below 2
Below 1
Correct
Above 1
Above 2
Above 3
Dart Throwing Monkey
Super IH
Increasing Accuracy
25%
50%
75%
100%
Random Chance
Where are we today?


Data Interpretation Test Results
2005 EA Symposium Volunteers
Pre- and Post- Statistics Training
70%
60%
50%
40%
30%
20%
10%
0%
1%
1%
6%
2%
36%
13%
49%
59%
7%
23%
1%
2%
0%
0%
Pre Training
Post Training
Below 3
Below 2
Below 1
Correct
Above 1
Above 2
Above 3
285

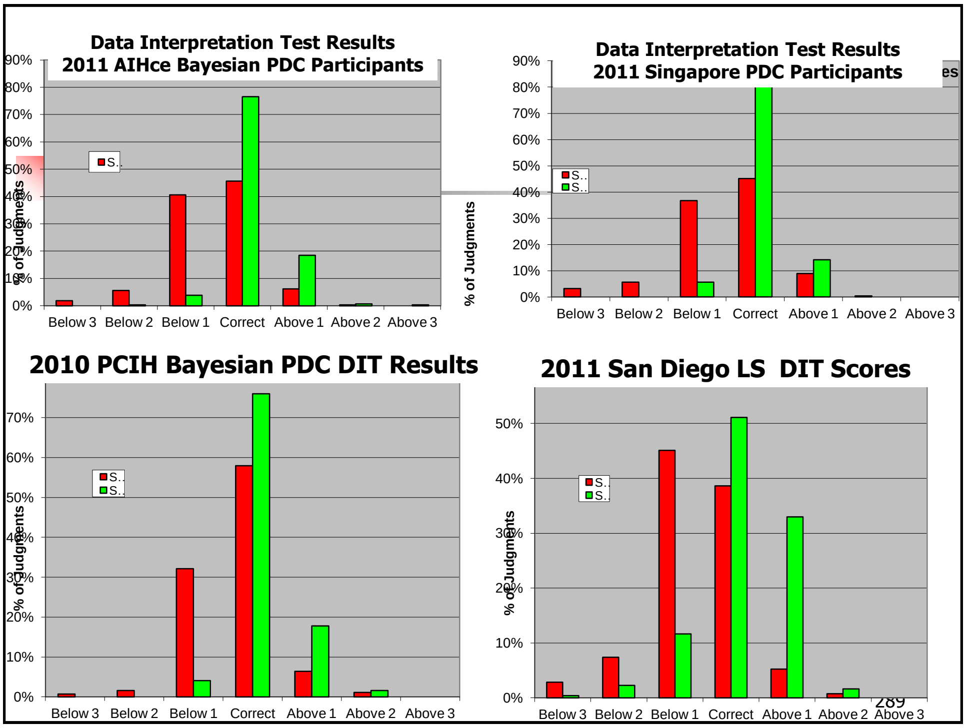

Data Interpretation Test Results
AIHce 2007 Bayesian PDC Participants
Pre Test
Post Test
Data Interpretation Test Results
AIHce 2006 Bayesian PDC Participants
Data Interpretation Test Results
PCIH 2006 Bayesian PDC Participants
Data Interpretation Test Results
PCIH 2006 Judgment WS Participants

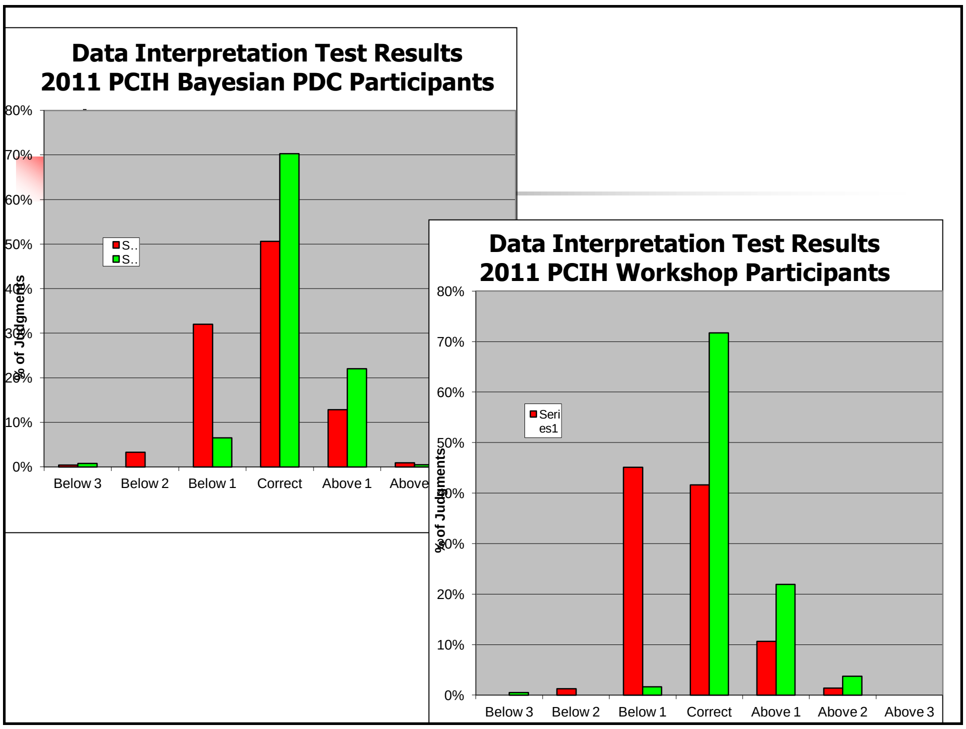


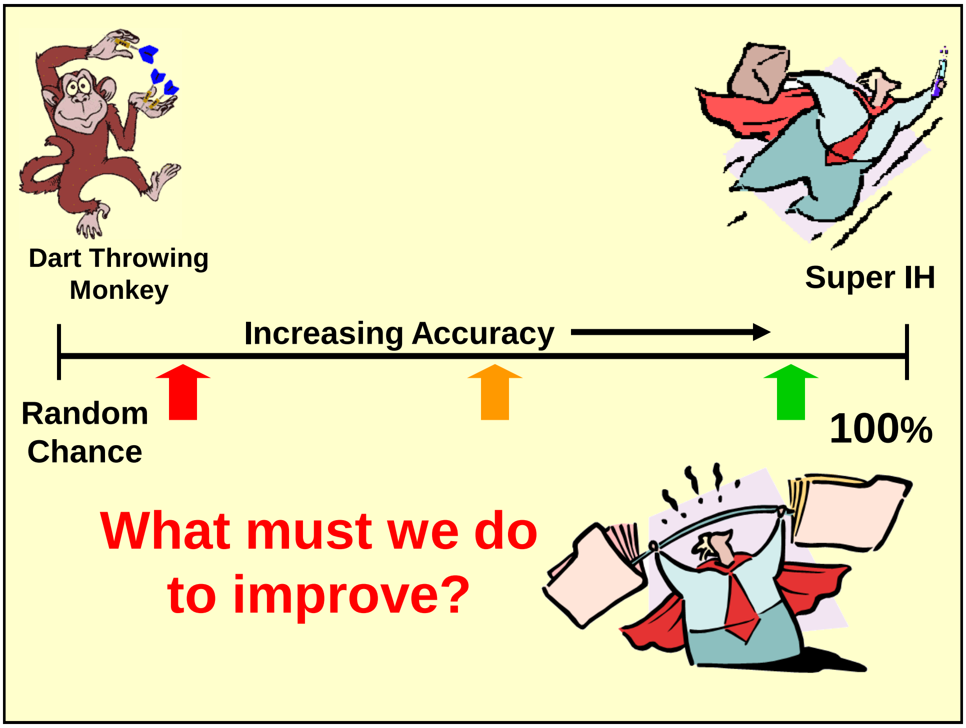
Data Interpretation Test Results
September 2007 ABHO Course
Pre- and Post- Statistics Training
Pre Training
Post Training
3 Below
2 Below
1 Below
Correct
1 Above
2 Above
3 Above
AIHCE08 Minneapolis
BDA PDC DIT Results
Pre Test
Post Test
PCIH07 Data Interpretation Tests
Pre Training
Post Training
PCIH08 Tampa - DIT Scores BDA PDC
Below 3
Below 2
Below 1
Correct
Above 1
Above 2
Above 3



Data Interpretation Test Results
2009 PCIH Bayesian PDC
Pre Training
Post Training
2 Below
1 Below
Correct
1 Above
2 Above
Data Interpretation Test Results
2010 AIHce Bayesian PDC
Pre-Training
Post-Training
% of Judgments
2010 MN Local Section
Pre-Rule of Thumb Training
Post-Rule of Thumb Training
2010 MI Local Section
Below 3
Below 2
Below 1
Correct
Above 1
Above 2
Above 3
288


Data Interpretation Test Results
2011 AIHce Bayesian PDC Participants
% of Judgments
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Below 3
Below 2
Below 1
Correct
Above 1
Above 2
Above 3
Data Interpretation Test Results
2011 Singapore PDC Participants
2010 PCIH Bayesian PDC DIT Results
2011 San Diego LS DIT Scores
289


Data Interpretation Test Results
2011 PCIH Bayesian PDC Participants
% of Judgments
80%
70%
60%
50%
40%
30%
20%
10%
0%
Below 3
Below 2
Below 1
Correct
Above 1
Above 2
Above 3
Data Interpretation Test Results
2011 PCIH Workshop Participants
Series1



How Can We Improve Our Monitoring-Based Judgments?

0.78 mg/M³
0.37 mg/M³
0.21 mg/M³
0.14 mg/M³
0.05 mg/M³

Exposure Decision Category*	Recommended Control
1 (<10% of OEL)	General HazCom
2 (10-50% of OEL)	+ chemical specific HazCom
3 (50-100% of OEL)	+ exposure surveillance, medical surveillance, work practices
4 (>100% of OEL)	+ respirators, engineering controls, work practice controls

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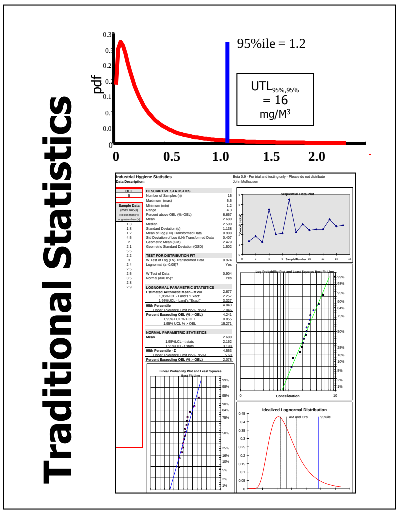
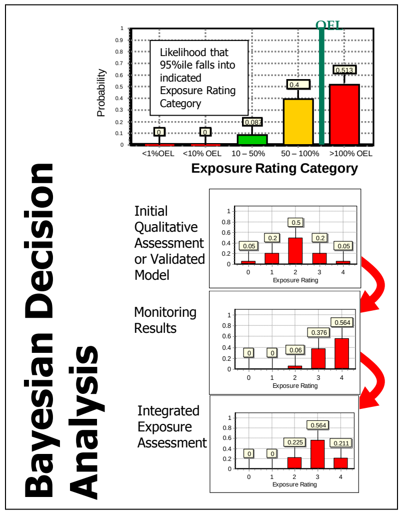
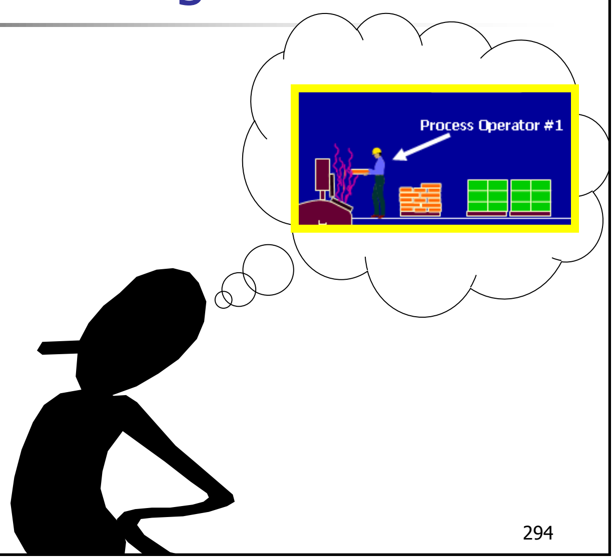
Use statistical tools!!





How Can We Improve Our Qualitative Judgments?



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How Can We Improve Our Qualitative Judgments?

Learn from our colleagues in psychology . . .

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

Innovation Opportunities:
Exposure Assessment Video Games
Exposure Assessment Training Camps

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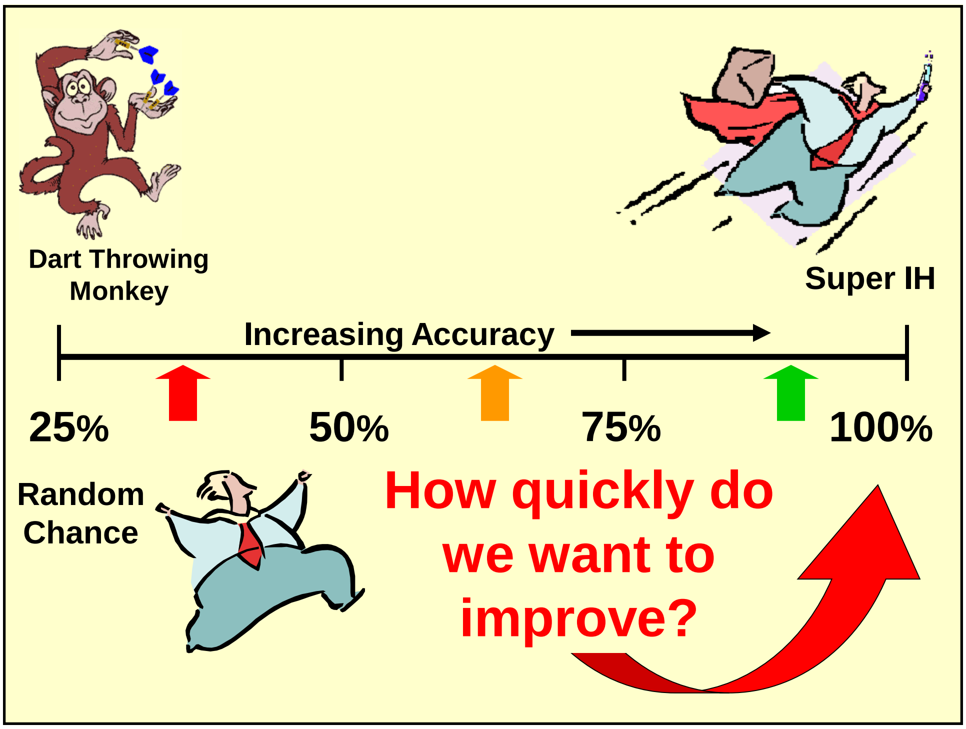
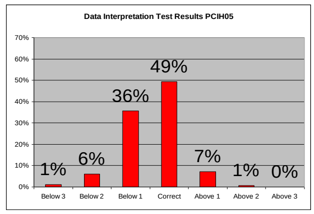


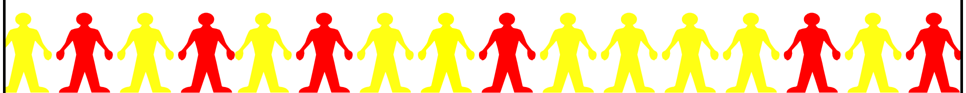
U.S. Impact

Monitoring-Based Employee-Exposure Decisions per Year*

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

% Incorrect?
% Underestimated Risk?





*Estimated by 2009 Exposure Assessment Symposium Participants

Ethics

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

Cannot continue business as usual!

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Current Rate-Of-Change is **Too Slow**

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

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Need to Accelerate Change

Professional Crossroads:

Status Quo

or

Focused Attention to
Accelerate Improvement

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We Know How to Drive Change:

The 8-Step Process of Successful Change*

Set The Stage

1. **Create a Sense of Urgency.**
2. **Pull Together the Guiding Team.**

Decide What to Do

3. **Develop the Change Vision and Strategy.**

Make it Happen

4. **Communicate for Understanding and Buy-in.**
5. **Empower Others to Act.**
6. **Produce Short-Term Wins.**
7. **Don't Let Up.**

Make it Stick

8. **Create a New Culture.**

*John Kotter - 'Leading Change' (1995) 'The Heart Of Change' (2002)

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2015 Vision For Every Industrial Hygienist

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

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Mobilizing the Professionals
Mobilizing the Profession

Dart Throwing Monkey

Accelerating Change

Super IH

Increasing Accuracy →

Random Chance — 100%

Mobilizing the Professional
What YOU Can Do . . .

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

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Mobilizing the Profession
What WE Can Do . . .

Spread the word!

Communication Blitz – From every organization!

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Mobilizing the Profession
What WE Can Do . . .

Training and Coaching Opportunities

- Group Data Interpretation Test Exercises
- Decision Rule Calibration
- PDCs / Webmeetings
- Software Tools / Computer "Games"
- Simulation / Video Evaluations
- Exposure Modeling
- Statistical Tools

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Brainstorming just a few opportunities . . .

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

Local Sections
- Training Programs
- Facilitate "Decision Criteria" Discussion

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

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

Brainstorming just a few opportunities . . .

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

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

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

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

Universities
- Incorporate into training programs - Academic SIG

Industrial Hygiene Profession

Galvanized to improve our exposure judgment accuracy . . .

and running as fast as we can from the dart-throwing monkeys!!