Current Approaches to Exposure Assessment

or

"Don't be a Dart Throwing Monkey"

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Data Interpretation Survey

- 8-Hr TWA results for 5 operations
  - All samples collected correctly (good data)
  - Xylene OEL = 100 ppm
- Rate as acceptable or unacceptable:

	Data (ppm)	Acceptable ?
1	21,68	Y / N
2	21,109, 38,41,48	Y / N
3	21,16,21,24	Y / N
4	5	Y / N
5	8,70,5,37,12	Y / N

Did We all Agree ??

- Was there variation in interpretation of results?
- What are the implications of this variation?
  - Different Decisions = Different Levels of Care
  - Different levels of exposure risk
- Why aren't we more consistent?
  - What do we mean by "acceptable"?
  - How would we know?

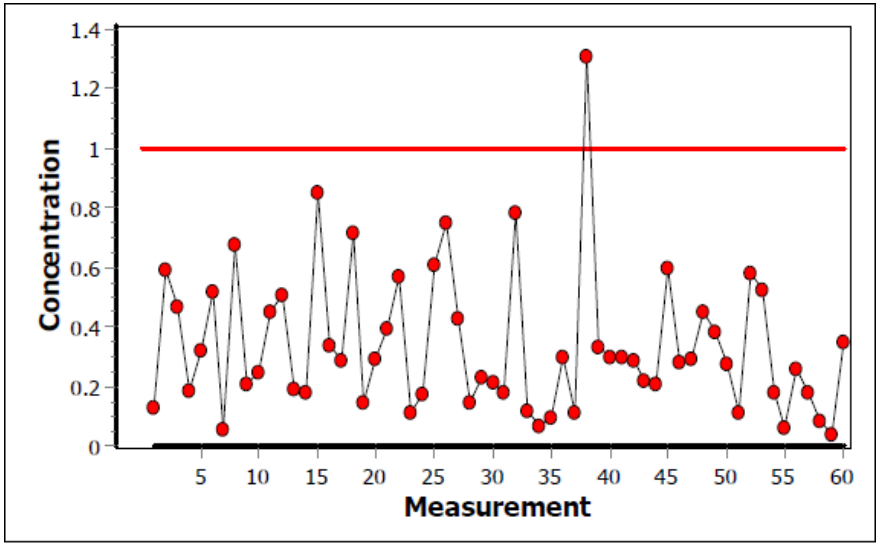
Exposure Assessment

- Worker Performs Task Daily
  - 200 working days/yr - You Sample Every Day (!)
- How many times is it acceptable for exposures to exceed OEL (w/o respirator)?
  - 0 times
  - 1 time (99.5% OK)
  - 5 time (97.5% OK)
  - 10 times (95% OK)
  - 20 times (90% OK)

How Sure Do We Want To Be:

When evaluating exposures (assuming we don't sample every exposure), how much assurance do we want that the measured exposures are below the OEL?

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



What is Acceptable?

- ALL exposures < OEL?, Nearly All?, Mostly All?
  - Average Exposure < OEL?
  - Average Exposure (plus error) < OEL?
  - Samples "looked fine"?
- What are the consequences of "Zero Exposure"
  - (How many respirators do you want to buy?)

Variation ??

What are the Consequences?

Different Decisions = Different Levels of Care

- (different levels of exposure risk)

Or

What are Industrial Hygienists Good For?

Exposure Assessment is a Key Competency !!!

Why the Inconsistencies?

- Limited Tools –
  - Data (maybe)
  - Modeling (theoretically)
  - Statistical Analysis (huh?)
  - Professional Judgment (all the time!)
- Variable definition of "acceptable" and uncertainty
  - And (sometimes)
- Over-reliance on Professional Judgment
  - But what alternatives are there?

One Alternative- Action Levels!

- No Result > 50% OEL means over-exposure unlikely
  - Efficient – few samples needed
  - Not Effective - Significant risk of "false negative"
- Other Simple strategies –
  - Generally require more data!
- What other approaches are there?

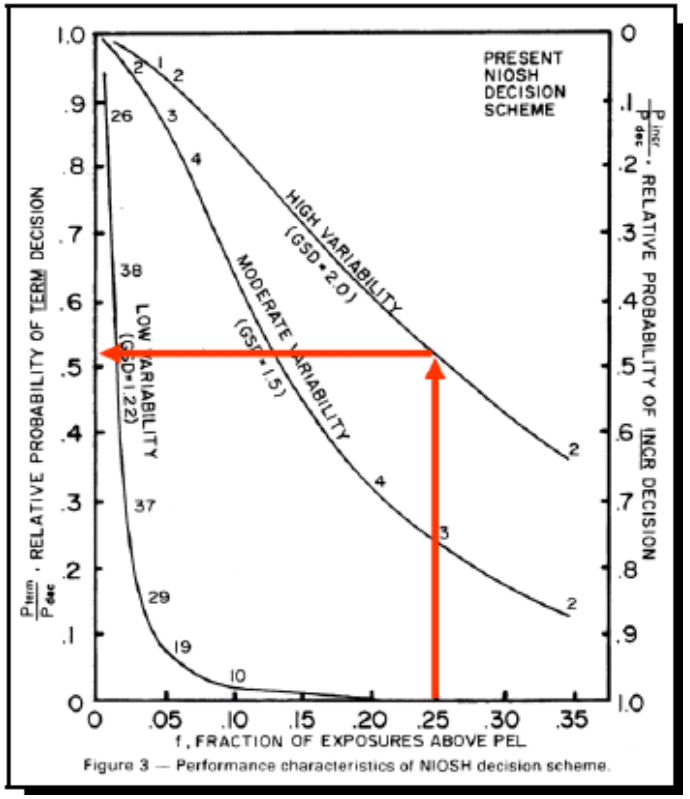


Figure 3 — Performance characteristics of NIOSH decision scheme.

So, Back to Professional Judgment

- Limited Data will always be a reality
- If we want to use judgment, Lets make sure we use it well!
  - Evaluate data using best practices
  - (maybe) incorporate some "prior" knowledge (modeling, previous exposure data)
  - Develop a "posterior" judgment regarding acceptability

2 Kinds of Professional Judgement

Good Professional Judgment

- Data-Driven
- Fact-based
- Substantiated

Bad Professional Judgement:

- "gut feeling"
- Poorly Defined"
- Unsubstantiated

USING STATISTICS

What percent of the time do you apply statistics to evaluate sampling data?

a) 100%

b) 50% to 100%

c) 25% to 50%

d) 10% to 25%

e) Never

Statistics -

We don't need no stinkin' statistics

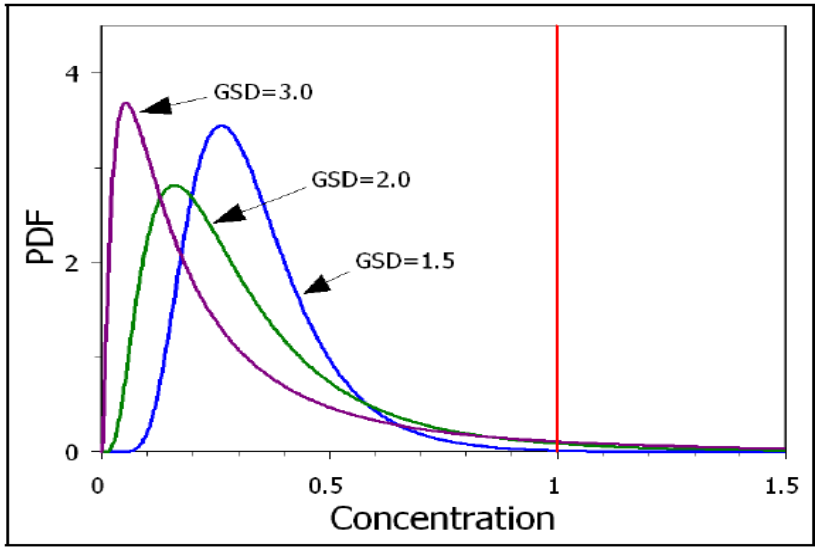
You Are Capable of More Than You Know...

– Glinda

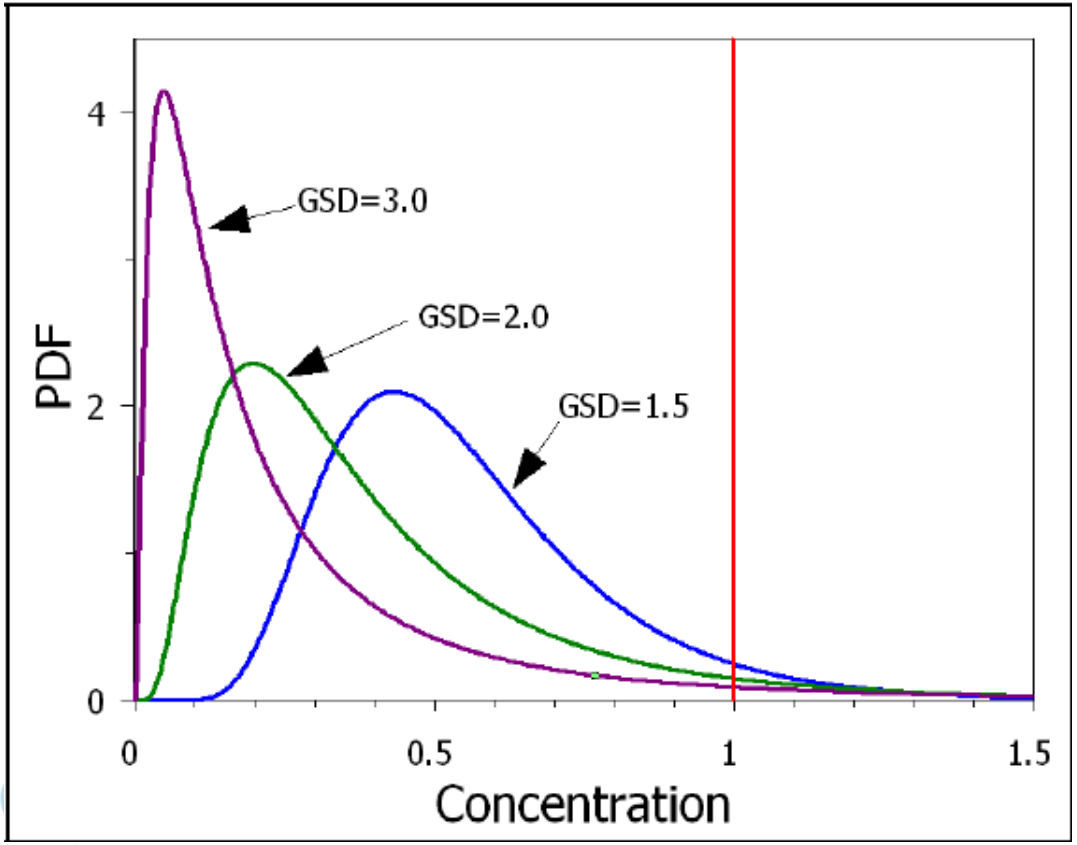
How Can We Use Statistics

- First - Decide on an applicable measurement
  - What statistics?
    - Measure of central tendency?
      - Mean (or GM)?
      - Fraction of GM?
      - What affect will distribution (and GSD) have?

or

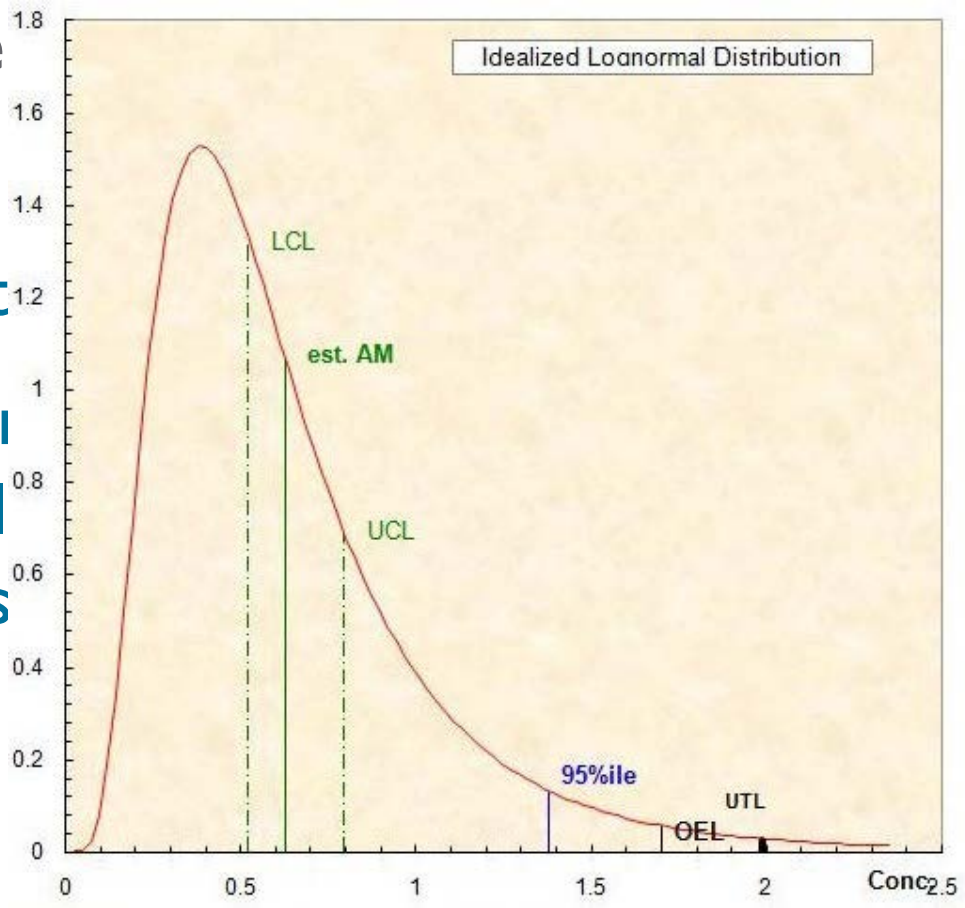


Exceedance Fraction (e.g 95th %ile value)



95th %ile

- Growing … (95% confident…
- To rate a… …G as acceptabl… …hat the 95th %ile is les…



Support/Recognition for 95%ile

- Goal of effective monitoring program is to "attain 95% confidence that no more than 5% of employee days are over the standard" – NIOSH Occupational Exposure Sampling Strategy Manual, 1977
- "Exposure profile for SEG is usually deemed acceptable if it is highly likely that only a small percentage of measurements exceed OEL" – AIHA Strategy for Assessing and Managing Occupational Exposures, 2006
- OSHA – "on only relatively rare occasions could random fluctuations results in measured TWA concentrations above the PEL" – Asbestos FR 51(119):22654
- OSHA – "…there is no requirement to control exposures so far below the PEL so as to ensure that absolutely no random exposures exceed the PEL" Benzene, FR 52(176):34460-34578, 1987
- OSHA - Unless the employer chooses to measure the exposure of each employee potentially exposed to formaldehyde, the employer shall develop a representative sampling strategy and measure sufficient exposures within each job classification for each workshift", 29 CFR 1910.1048 (d)(2)(i)
- Similar in Lead – FR 43(220):52952-53014, 1978
- Also many other organizations and authors, i.e. CEN, Hewett

How Can We Use Statistics?

- Second - Decide on a scale
  - (how to categorize or classify measurements)

Table 1. AIHA exposure category rating scheme

AIHA exposure rating	Proposed control zone description	General description	AIHA recommended statistical interpretation
1	Highly controlled	95th percentile of exposures rarely exceeds 10% of the limit.	$X_{0.95} \leq 0.10$ OEL
2	Well controlled	95th percentile of exposures rarely exceeds 50% of the limit.	0.10 OEL $< X_{0.95} \leq 0.5$ OEL
3	Controlled	95th percentile of exposures rarely exceeds the limit.	0.5 OEL $< X_{0.95} \leq$ OEL
4	Poorly controlled	95th percentile of exposures exceeds the limit.	OEL $< X_{0.95}$

An SEG is assigned an exposure rating by comparing the 95th percentile exposure ($X_{0.95}$) of the exposure distribution with the full-shift time-weighted average (TWA), OEL or short-term exposure limit to determine in which category it most likely falls (Mulhausen and Damiano, 1998; Ignacio and Bullock, 2006).

	Exposure Rating**	Recommended Follow Up / Exposure 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, work stoppage, etc.

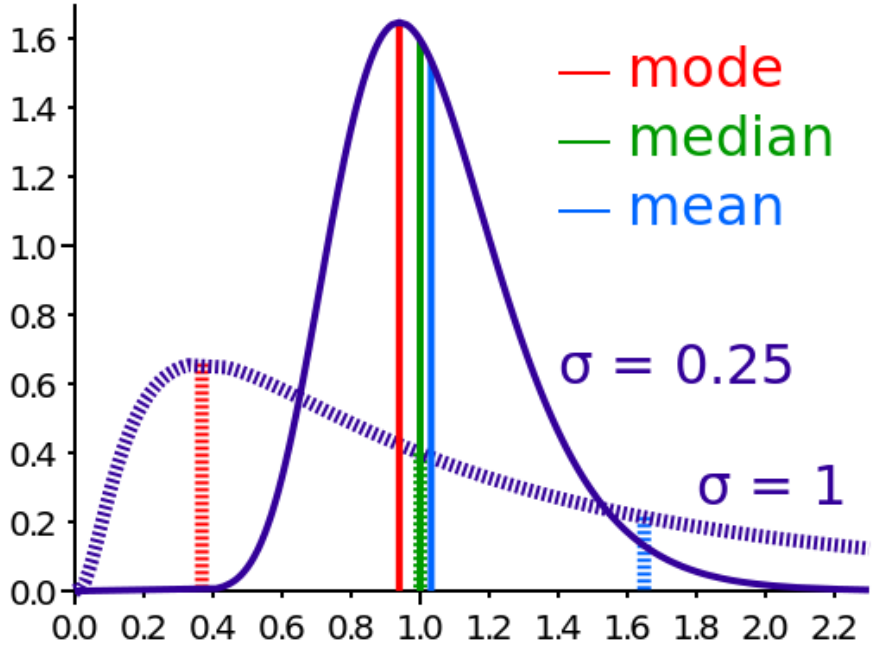
** - Decision statistic = 95th percentile

Validating Professional Judgment!

- Use the tools we have!
  - Estimate (or calculate) 95th%ile
  - Assign to exposure category
  - Take appropriate action
- But How do we do that???

First, some review:

- Occ. Exposures follow a log-normal distribution
- Characterized by GM (& GSD)
- GM equals median
- Calculated values estimate "true" values



Now, Lets Estimate the 95th%ile

- 95th%ile = GM x $GSD^{1.645}$ (based on "Z score")
  - "point estimate" of "true" value, with uncertainty
  - GSD $^{1.645}$

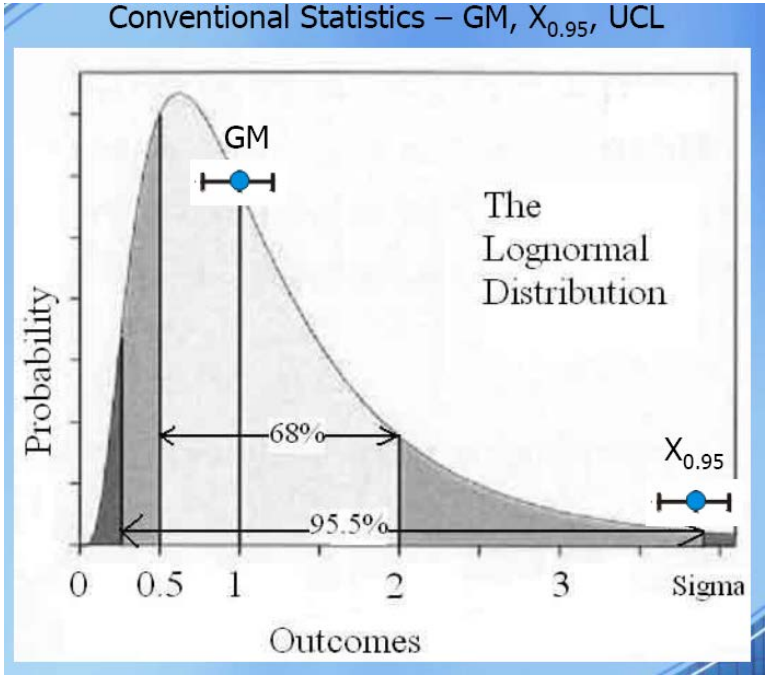
GSD	Exp	$GSD^{1.645}$	
1.5	1.645	1.95	≈2
2.0	1.645	3.13	≈4
2.5	1.645	4.5	≈4
3.0	1.645	6.09	≈6

R.O.T for Estimating 95th%ile

- For n < 6 (or so), if any measurements exceed OEL, exposure rating = Category 4.
- Otherwise estimate of 95th ile
  - sort data, find median (middle or avg. of 2 middle values
- The true GM is the median of log-normal distribution.
  - Use sample median as a surrogate estimate of the GM.
  - Multiply median by 2, 4 and 6.
  - Results are low, mid and high estimates of true 95th %ile.
- Use estimate to assign to AIHA category
  - For low GSD (e.g. 1.5), true 95th %ile is approx. 2 x GM.
  - For large GSD (e.g. 3), true 95th %ile is approx. 6 x GM
  - For mid GSDs (e.g. 2 and 2.5), the true 95th%ile is 4 x GM

Statistics Review and some "Rules of Thumb"

- **Focus on upper tail**
- **GSD typically 1 - 3**
- **GM ≈ sample median**
- **Estimate of 95th ile =**
  - median x multiplier (2,4 or 6)



Rule of Thumb Workshop

(assume OEL = 100)

X = (21, 68)

X = (21, 109, 38, 41, 48)

X = (12, 16, 21, 24)

X = (5)

X = (8, 70, 5, 37, 12)

		Med.	2x	4x	6x	Cat. 0 - 4
A	21, 68	45	90	180	270	4
B	21, 38, 41, 48, 109	41	82	162	246	4
C	12, 16, 21, 24	18.5	37	74	111	2
D	5	5	10	20	30	2
E	5, 8, 12, 37, 70	12	24	48	72	3

OK, What Else?

- How else to calculate 95th%ile (and CI)?
  - IHStat!
- Scenario C
  - Results = 12,16, 21,24
  - GM=17.6, GSD-1.36
  - 95th%ile=29.2, UCL = 85.7
  - Yeah!!
- Scenario A
  - Results = 21, 68
  - GM=37.8, GSD=2.3 (yeah!)
  - 95th%ile= 148, UCL = 1.13 x 10^{13} (Doh!)

Traditional Statistics

- Small data sets yield wide confidence intervals
- Calculations can be laborious
- Concepts can be difficult to understand
- Can be even more difficult to explain!

Bayesian to the Rescue!

- Bayesian Decision Analysis (BDA)
  - Statistical Tool
  - Useful for small n
- Can incorporate "real world" parameters, such as range of gm
  - Can also incorporate other "professional judgment"
  - Use with caution
- Many applications
  - Economics, genetics, GIS, clinical trials and many more

Foundation of BDA: Bayes' Theorem

Posterior Likelihood Prior

$$P(Pop_i|data) = \frac{P(data|Pop_i) \cdot P(Pop_i)}{\sum \left[P(data|Pop_i) \cdot P(Pop_i)\right]}$$

Correction Factor

Bayesian Benefits

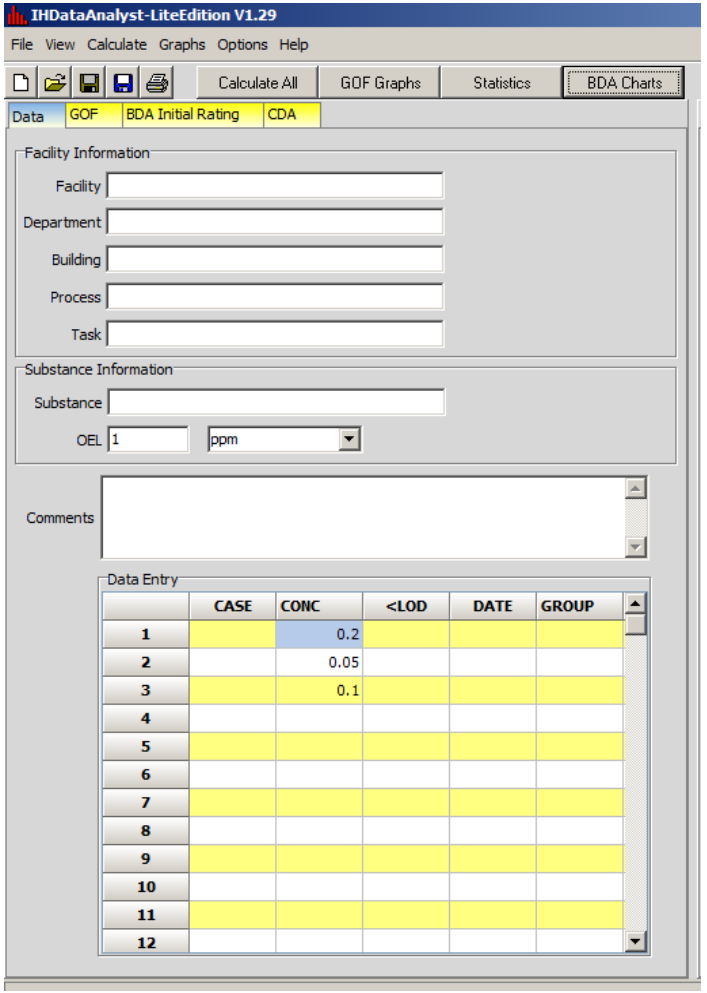
- Allows (careful) use of "prior" knowledge
  - "Correction Factor" can limit sample space to plausible (or possible) values
- Supplement limited data with "real-world assumptions
  - GSD < 4 (if not, is it SEG)
- Results are categorized – fit well with AIHA and other "banded" systems
- Helps us determine the probability that the true exposure profile falls within each group
  - Results in better protective actions

Example

- Sampling results = 0.05, 0.1, 0.2 ppm
  - OEL= 1 ppm
  - n=3, gm=0.1, gsd=2
  - 95th%ile = 0.31, UCL = 20
  - Category 2, based in 95th%ile?
  - Category 4, based on UCL?
- What Would you do?
  - Sample immediately
  - Sample later
  - Additional controls
  - No Additional controls

Bayesian Tool

- IH Data Analyst (IHDA-Lite)
  - Enter data into sheet, like spreadsheet
  - Can Save, Copy, Paste, etc.
  - Lite does not us censored data in BDA calcs
  - http://www.oesh.com/x%20Software/IHDALE.php

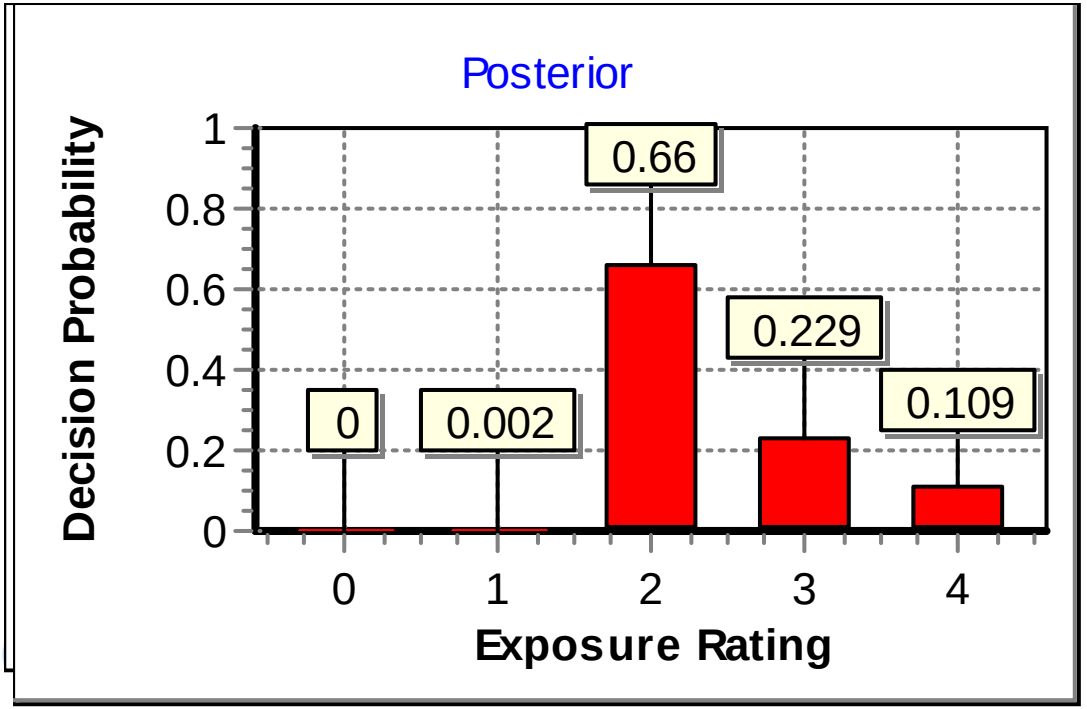


To Use:

- Configure as desired
  - GM, GSD ranges, Category Cut-offs
- Enter Data
  - Indicate <LOD values ("<" or "Y")
  - "Calculate All" and look at results
- Are data consistent with single, lognormal exposure profile?

Bayesian Analysis

- Using same data:

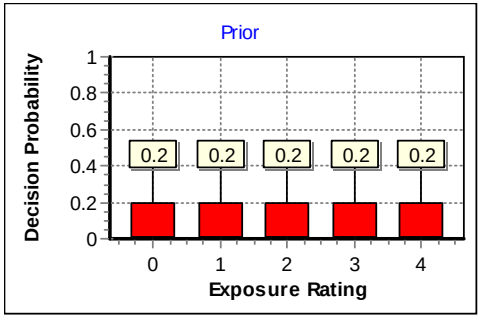


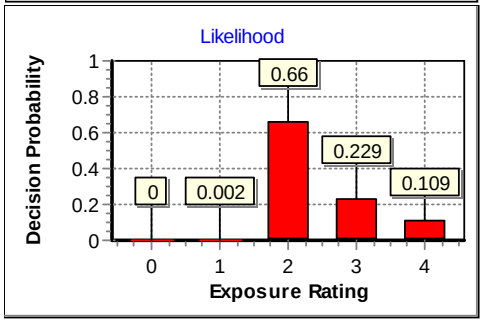
Prior
Uninformed Prior

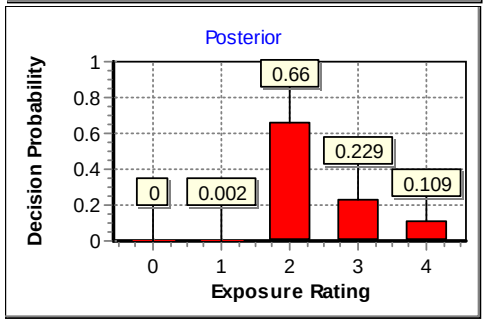
Likelihood
Monitoring Results

Posterior
Integrated Exposure Assessment

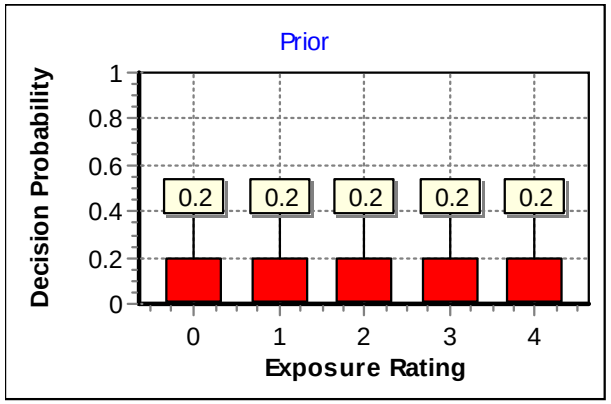
Unacceptable
>10% chance that 95th%ile is < OEL



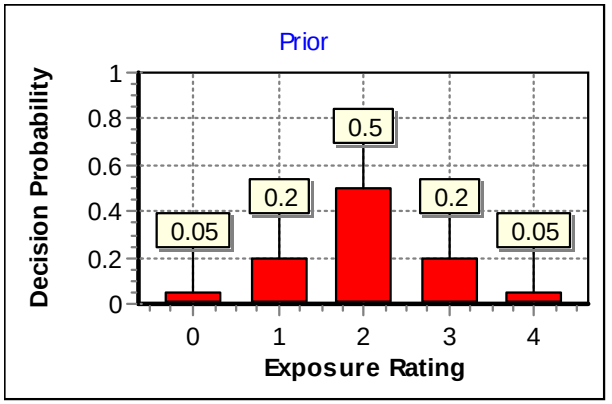




Prior Decisions



Non-Informative Prior



Informative Prior

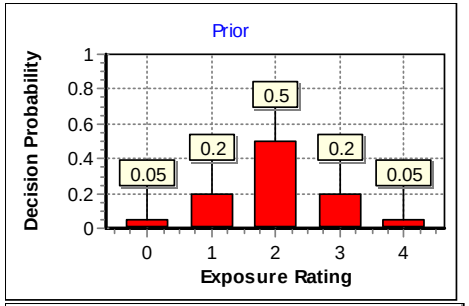
- Question – Are We Good at "priors"?
  - NY Giants were 3/1 to win Superbowl before 2013 season
  - Seahawks were 20/1

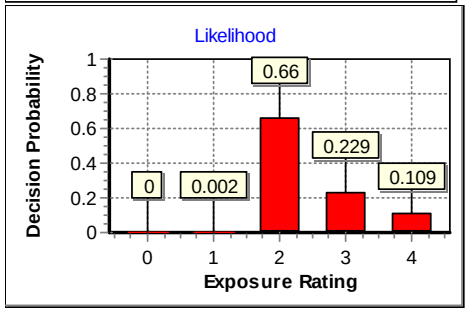
Prior
Qualitative Assessment, Validated Model, etc.

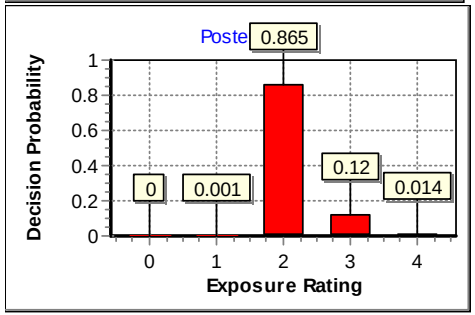
Likelihood
Monitoring Results

Posterior
Integrated Exposure Assessment

Acceptable
<10% chance that 95th%ile is < OEL



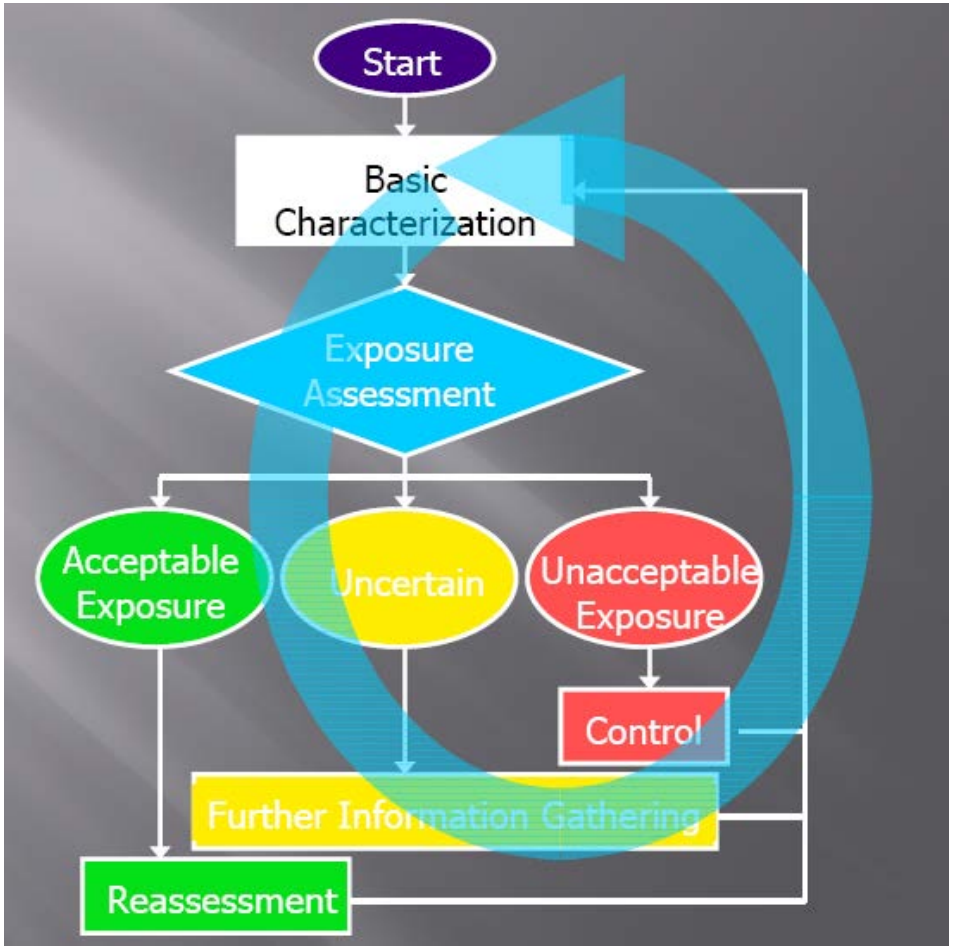




Wrapping Things Up

Why Bother?

- First -
  - Exposure Assessment is a key competency for IHs
  - We all need to be on the same page
  - BDA is an important new tool to bring rigor to our analysis of data
  - Good for small n & censored data
- Also
  - Consistent with AIHA Exposure Assessment model


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

AIHA Exposure Assessment Strategy

- Iterative **"continuous improvement cycle"**
- Includes **qualitative** (prior) and **quantitative** (posterior) information
  - The AIHA Exposure Assessment Model in inherently Bayesian
- BDA is easy to Communicate
  - "Given our data, we have a greater than 95%probability that exposures are effectively controlled
  - "… greater than 29% probability that exposures are unacceptable"

Other Issues

- Censored Data (< LOD)
- Other applications of the application
  - (e.g. respiratory protective equipment)
- Noise Results
- Want to learn more?
  - Classes are offered at all major conferences
  - Look for those offered by Mulhausen, Logan and Hewett

What Did We Learn Today?

- Variation (and the minimization thereof!)
- Importance of rigor and consistency
- An approach to validate Professional Judgment
- Tools to improve analysis and aid communication
- What Else?
- What can you do today to incorporate some or all of thee tools into your practice

IH Statistics Resources (Free!)

- IHStat Excel Spreadsheet –
  - https://www.aiha.org/get-involved/VolunteerGroups/Pages/Exposure-Assessment-Strategies-Committee.aspx
- Exposure Assessment Solution – OESH.com
  - IHDataAnalyst_LiteEdition V1.29 - http://www.oesh.com/x%20Software/Freeware.php
  - Performance-based Exposure Assessment Strategies For TWA Exposure Limits, Hewett, 2005
- "Rating Exposure Control Using BDA", Hewett, Logan, Mulhausen et al, JOEH 10/2006

ACT enviro

Questions??