(Evaluation of Control Banding through) Statistical Analysis of Exposure Monitoring Data

Brent Altemose, CIH, CSP
Principal Consultant
SABRE Health & Safety
Phone: 908.500.4784
Email: baltemose@sabresafety.net

January 15, 2009

Donald Rumsfeld on probability:

As we know, there are known knowns; there are things we know we know.

We also know there are known unknowns; that is to say, we know there are some things we do not know.

But there are also unknown unknowns – the ones we don’t know we don’t know.

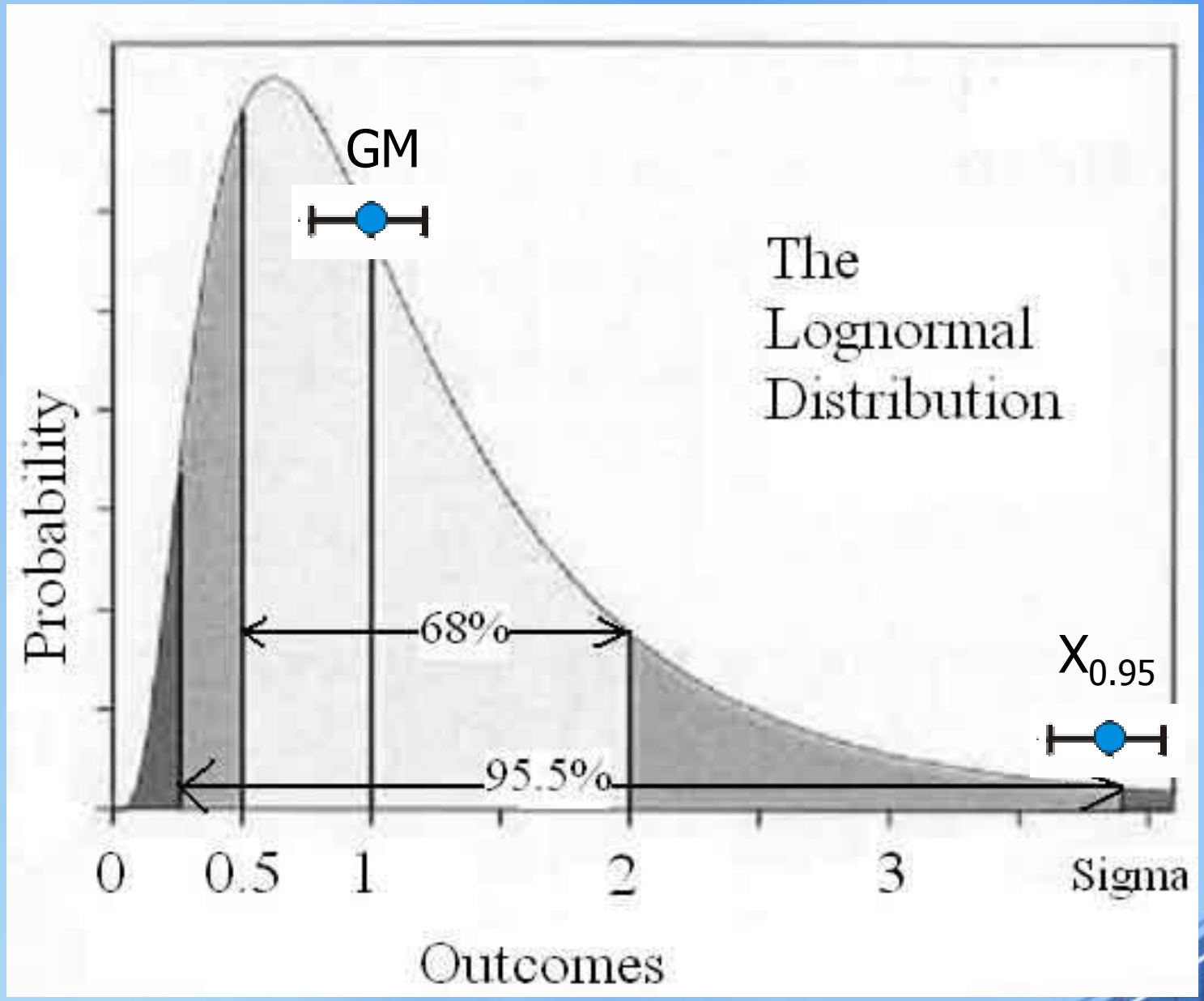
Hypotheses

- Expert judgment and therefore expert systems, such as control bands, are not good at precise estimates.
- However, they are good within an order of magnitude – and depending on the context, that is often sufficient
- Acceptance criteria also depends on context
- Bayesian statistics may be very useful in assessing control banding systems – but realistic estimates on which to base prior probabilities are critical

Statistical Terms - Review

- Arithmetic (μ or $\bar{x}$) v. Geometric Mean (GM)
- 95th Percentile ($X_{0.95}$)
- Confidence interval (CI)
  - Upper Confidence Limit (UCL)

Conventional Statistics – GM, $X_{0.95}$, UCL

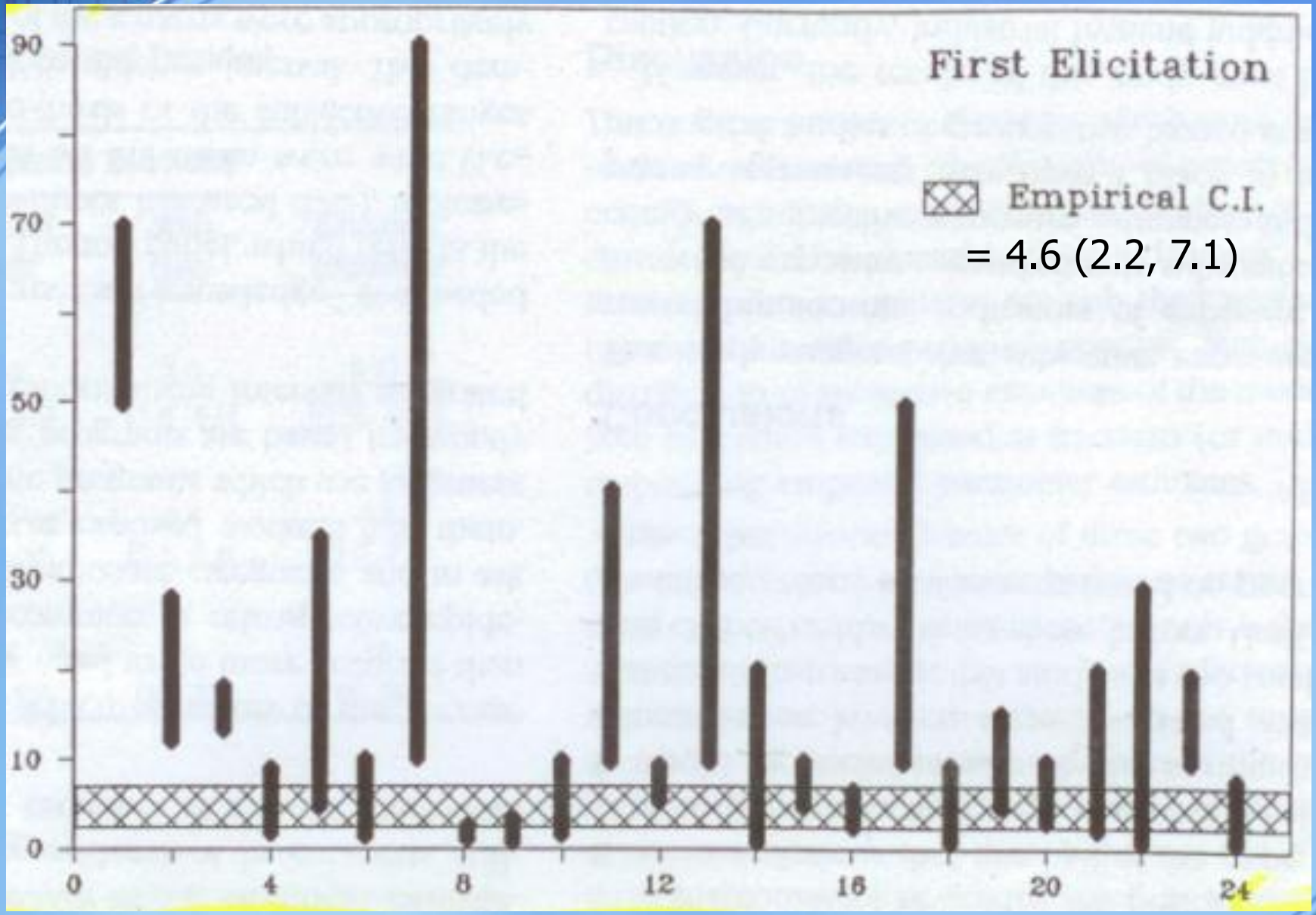


Typical Statistical Assumptions

- Homogeneous data set
- Random data
- Normal / lognormal data

Accuracy and Precision of Experts: Importance of Context

- Expert judgment and therefore expert systems, such as control bands, are not good at precise estimates.
- However, they are good within an order of magnitude – and depending on the context, that is often sufficient



Source: Hawkins and Evans, Appl. Ind. Hyg. 4: 61-68, 1989

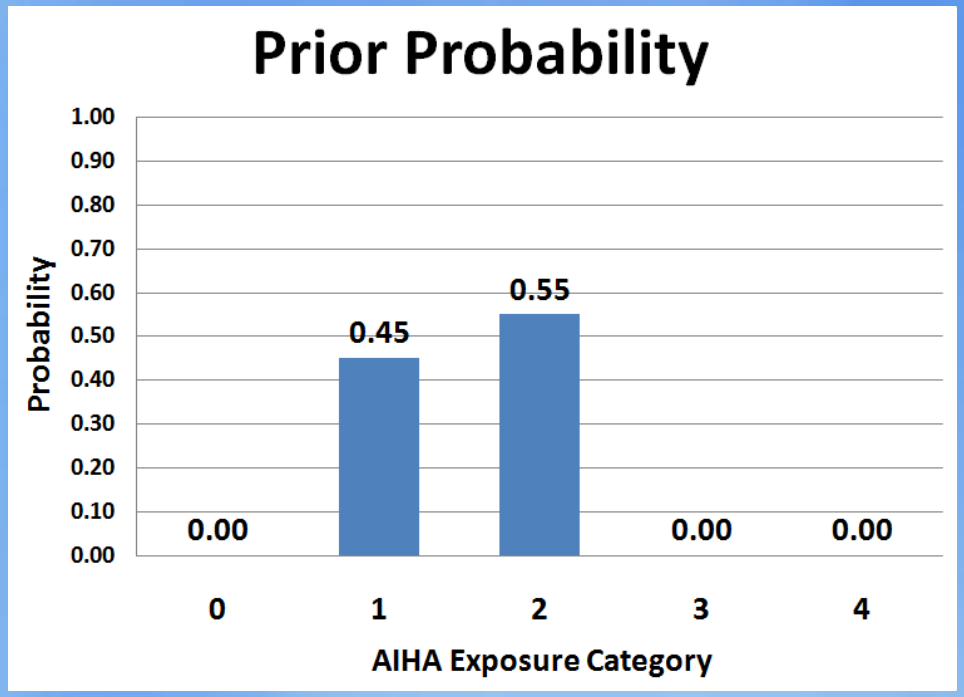
AIHA Exposure Ratings

Rating*	Description	Values
0	Trivial	< 0.01 x OEL
1	Highly controlled	0.01 to 0.1 x OEL
2	Well controlled	0.1 to 0.5 x OEL
3	Controlled	0.5 to 1 x OEL
4	Poorly controlled	>1 x OEL

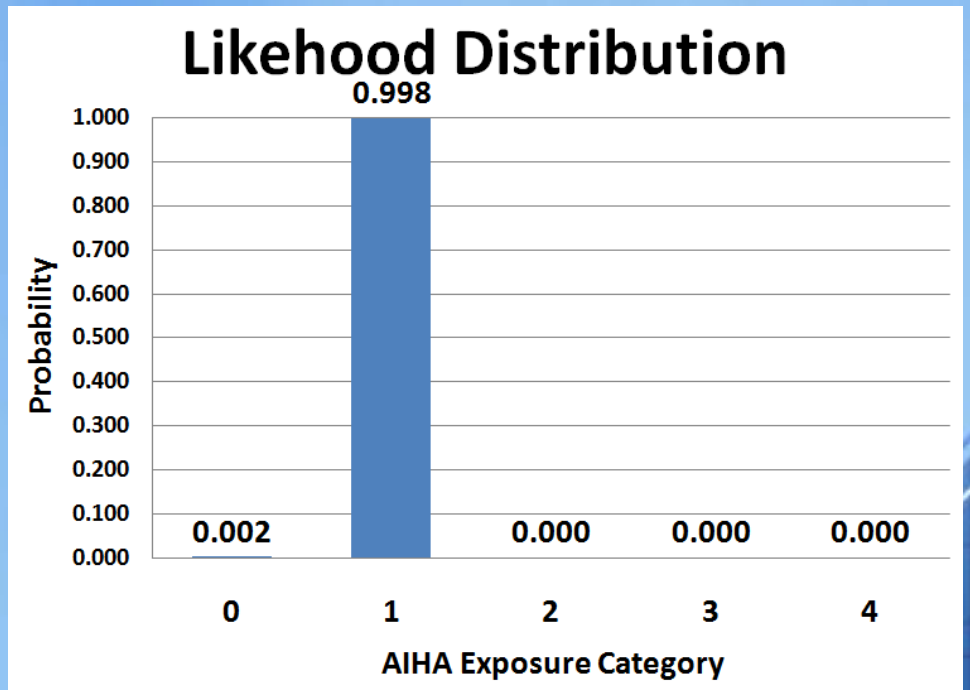
OEL = Occupational Exposure Limt

*Ratings based on "A Strategy for Assessing and Managing Occupational Exposures", 2006, 3rd edition. American Industrial Hygiene Association, Farifax, VA. (trivial category added)

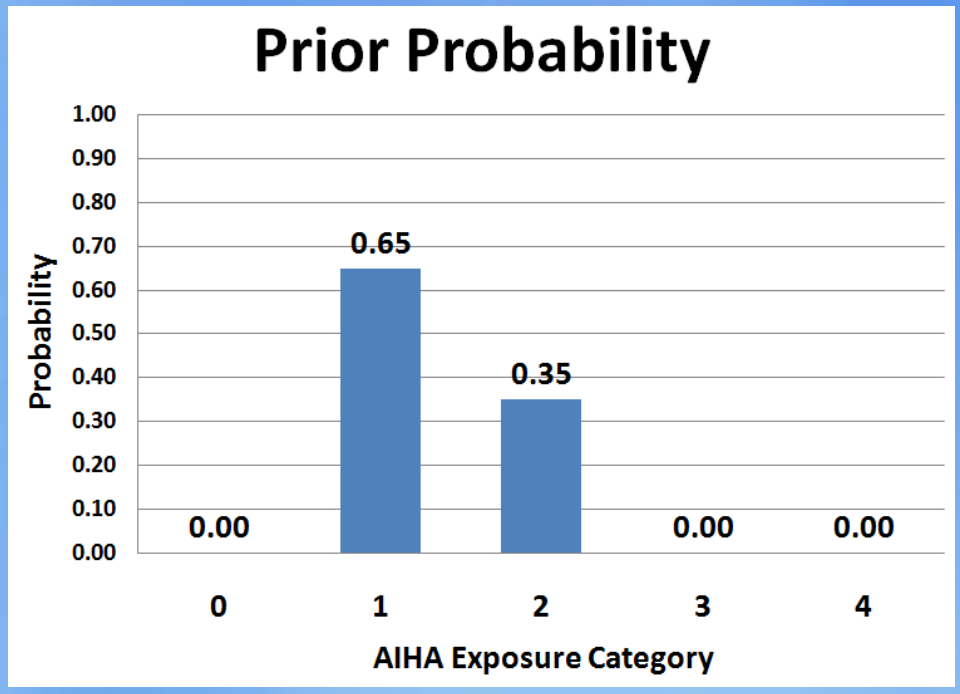
OEL = 100 ppm
(top and bottom 2 removed)

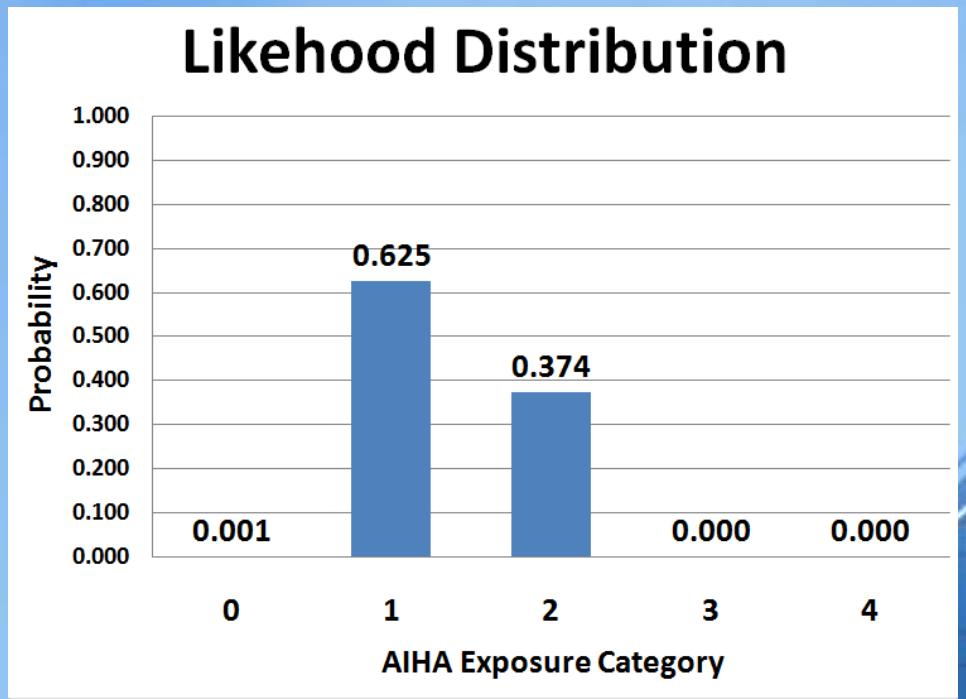


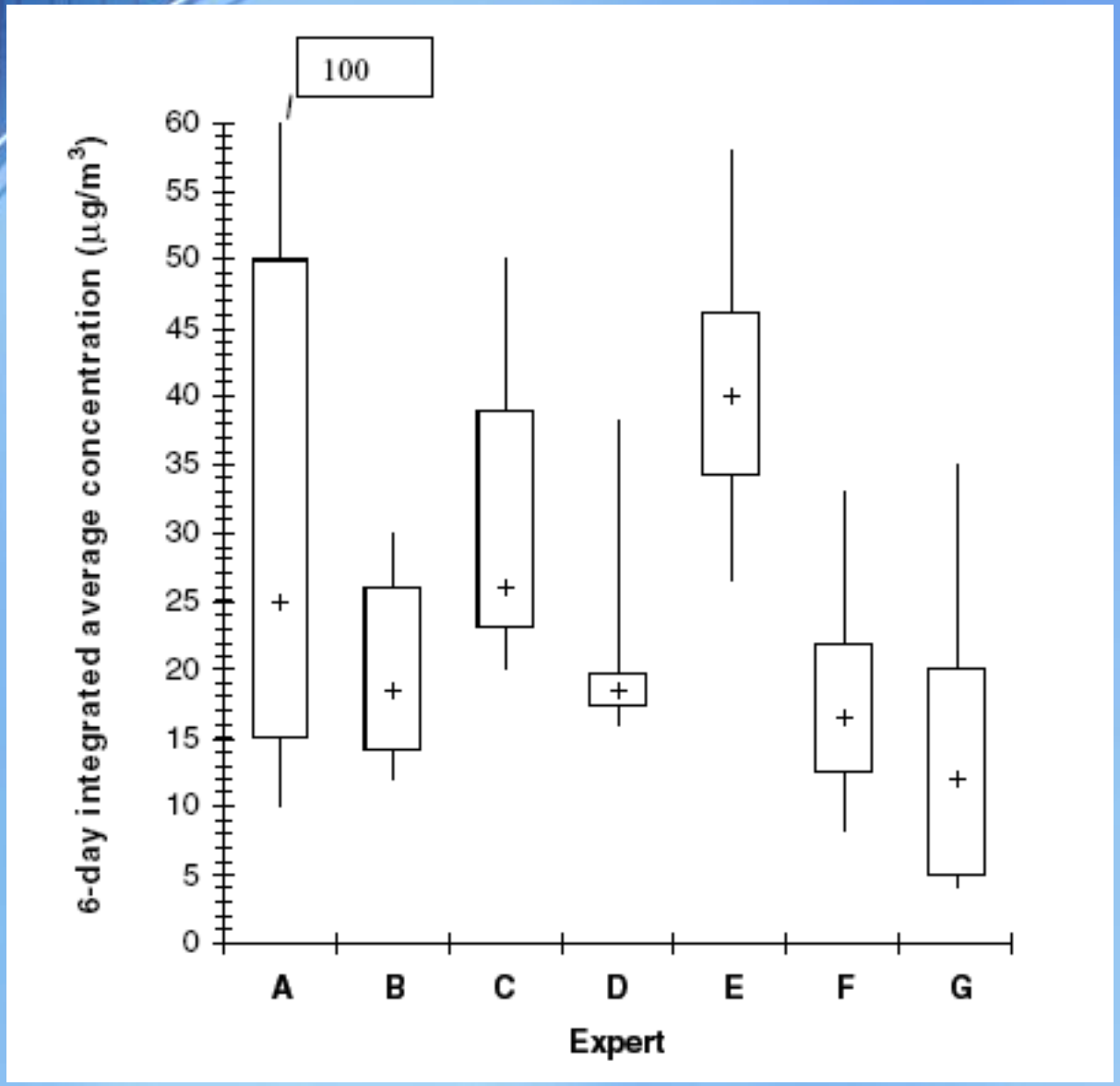
134 8-hr TWA measurements →



OEL = 50 ppm
(top and bottom 2 removed)





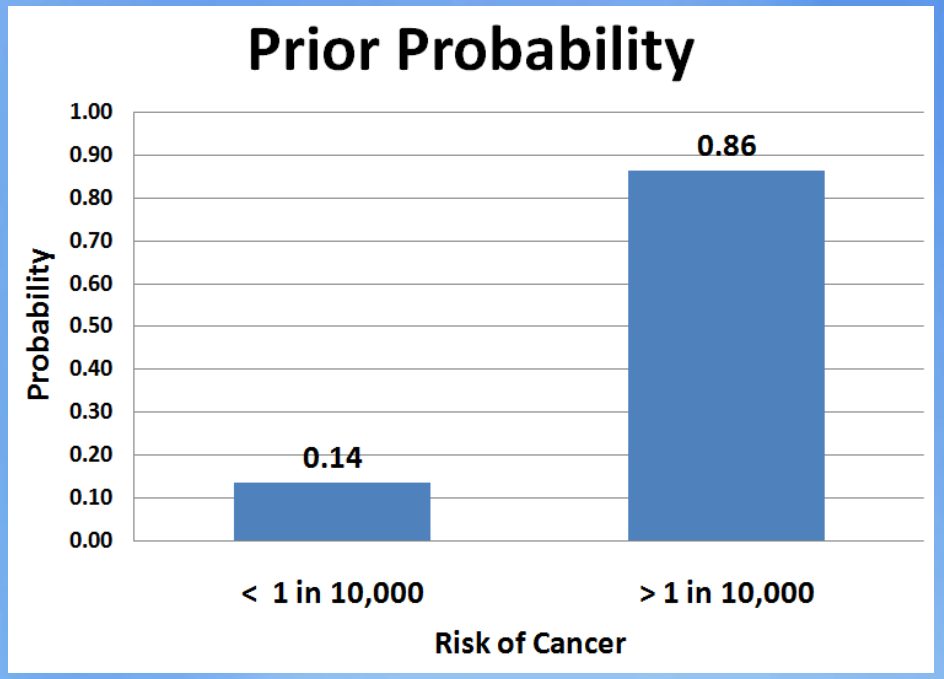


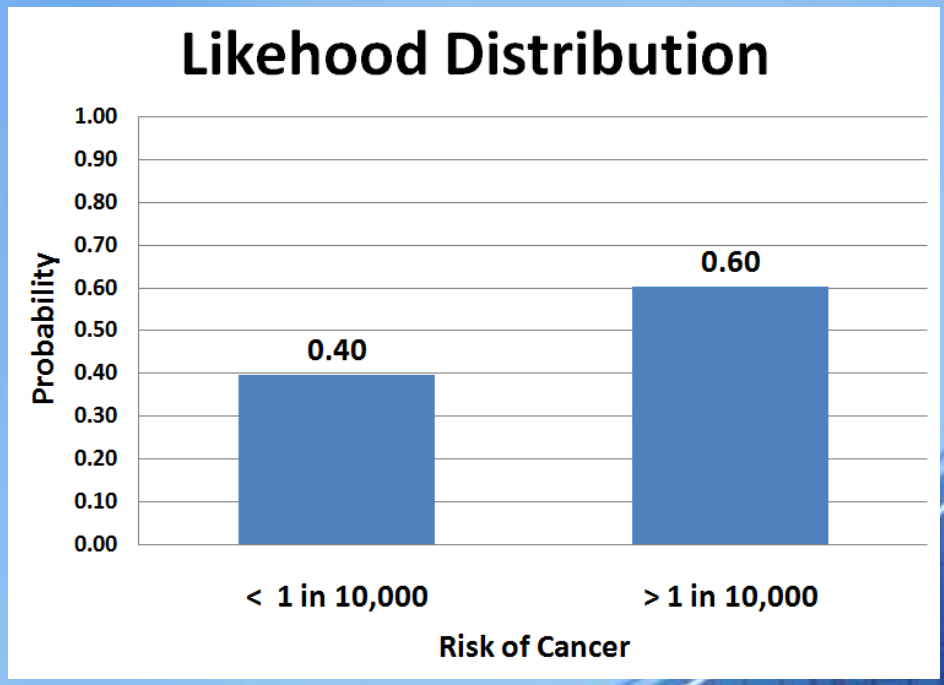
True distribution of 90th percentile = 13.7 (10.2, 17.1)

Source: Walker et al., J. of Exp. Analysis and Env. Epi., 11(4): 308-322. (2001)

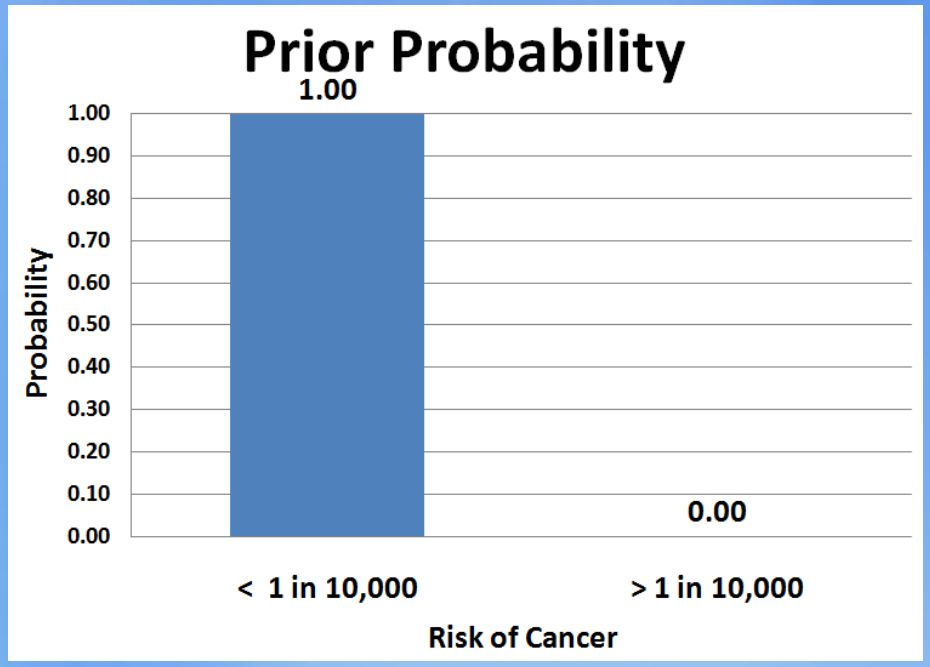
Value used for risk of 1 in 10,000 = 13 µg/m^3

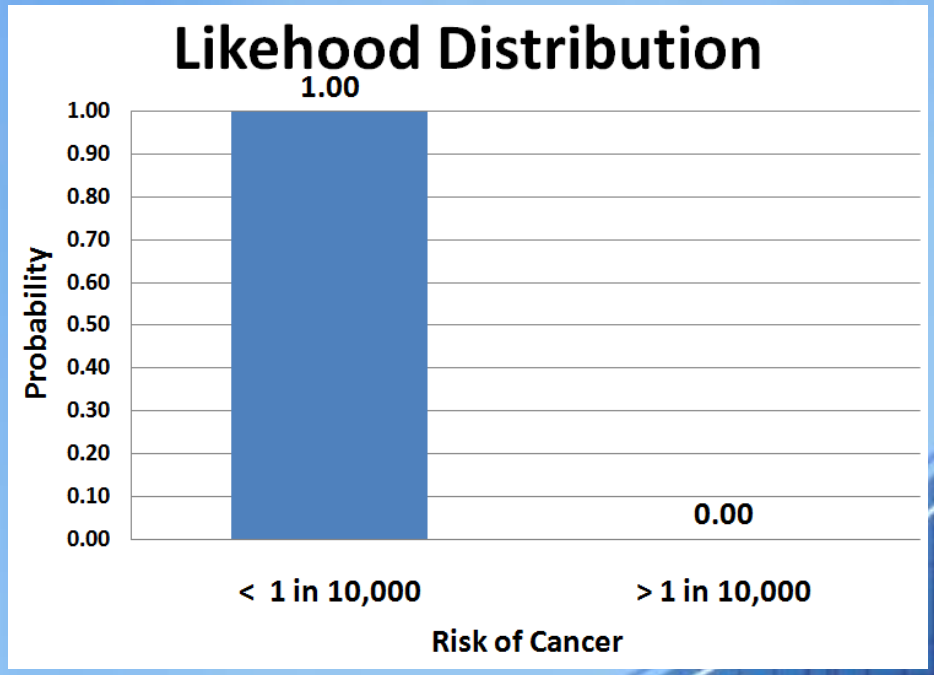
386 6-day personal exposure measurements





Value used for risk of 1 in 10,000 = 45 µg/m^3





Acceptance Criteria

If they can get you asking the wrong questions, they don't have to worry about the answers.

--Thomas Python

Acceptance Criteria

- What does an acceptable exposure distribution look like for a population?

  . . . For an individual?
- What statistical measure and/or acceptance criteria should be used?

Common acceptance criteria in industrial hygiene

- Calculated $X_{0.95}$ < OEL
- UCL of $X_{0.95}$ < OEL
- UCL of $\overline{X}$ < OEL
- Posterior Bayesian probability of exceeding OEL< 5%
- One (or more) samples looked fine

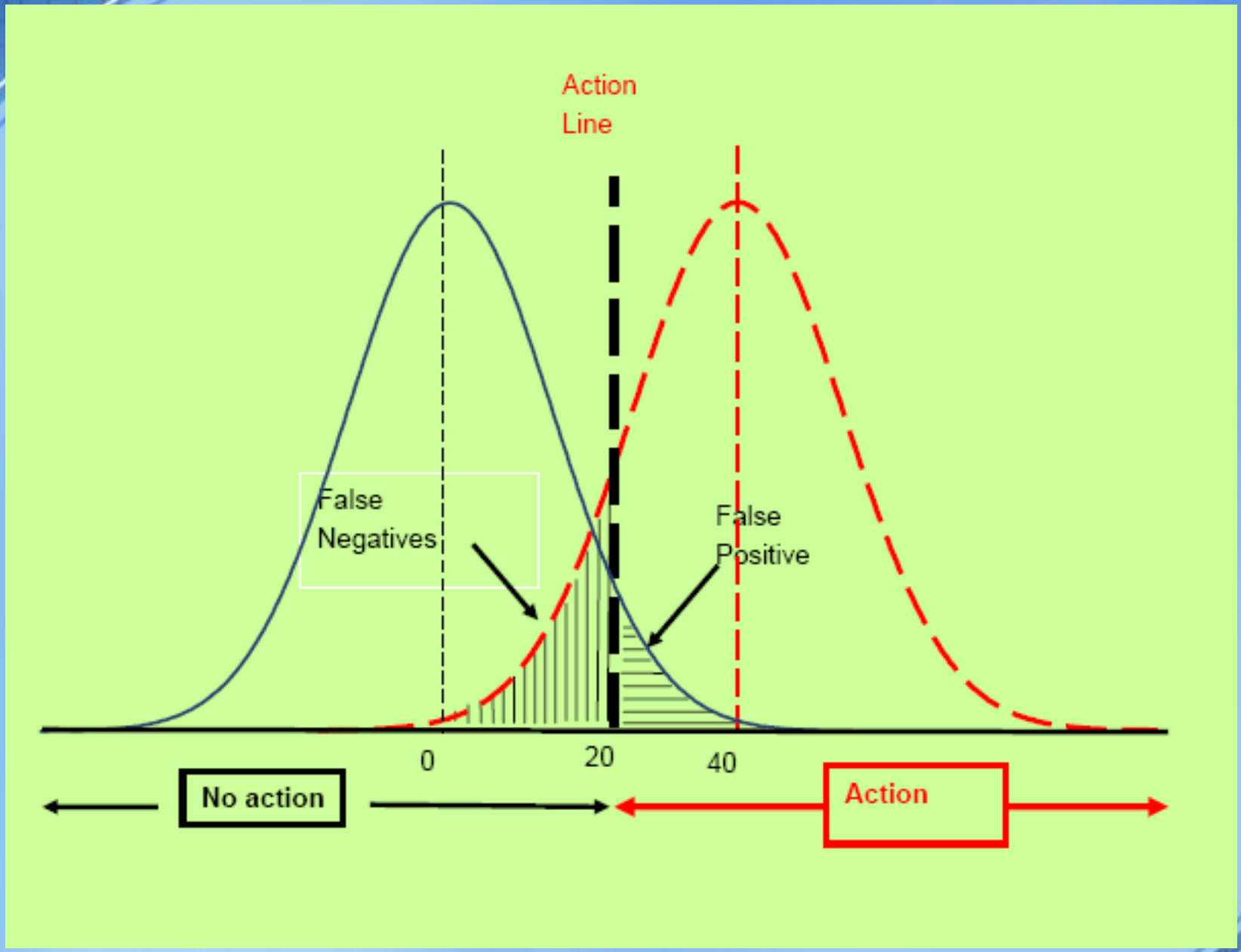
Questions we're really trying to answer

- What is the likelihood of health effects given a particular exposure profile?
- What is the likelihood that an OSHA compliance officer will find an exposure that is in violation of the PEL?
- Overexposure = any TWA measurement exceeds the TWA TLV (allowing for a margin of measurement error)?

So which to use?

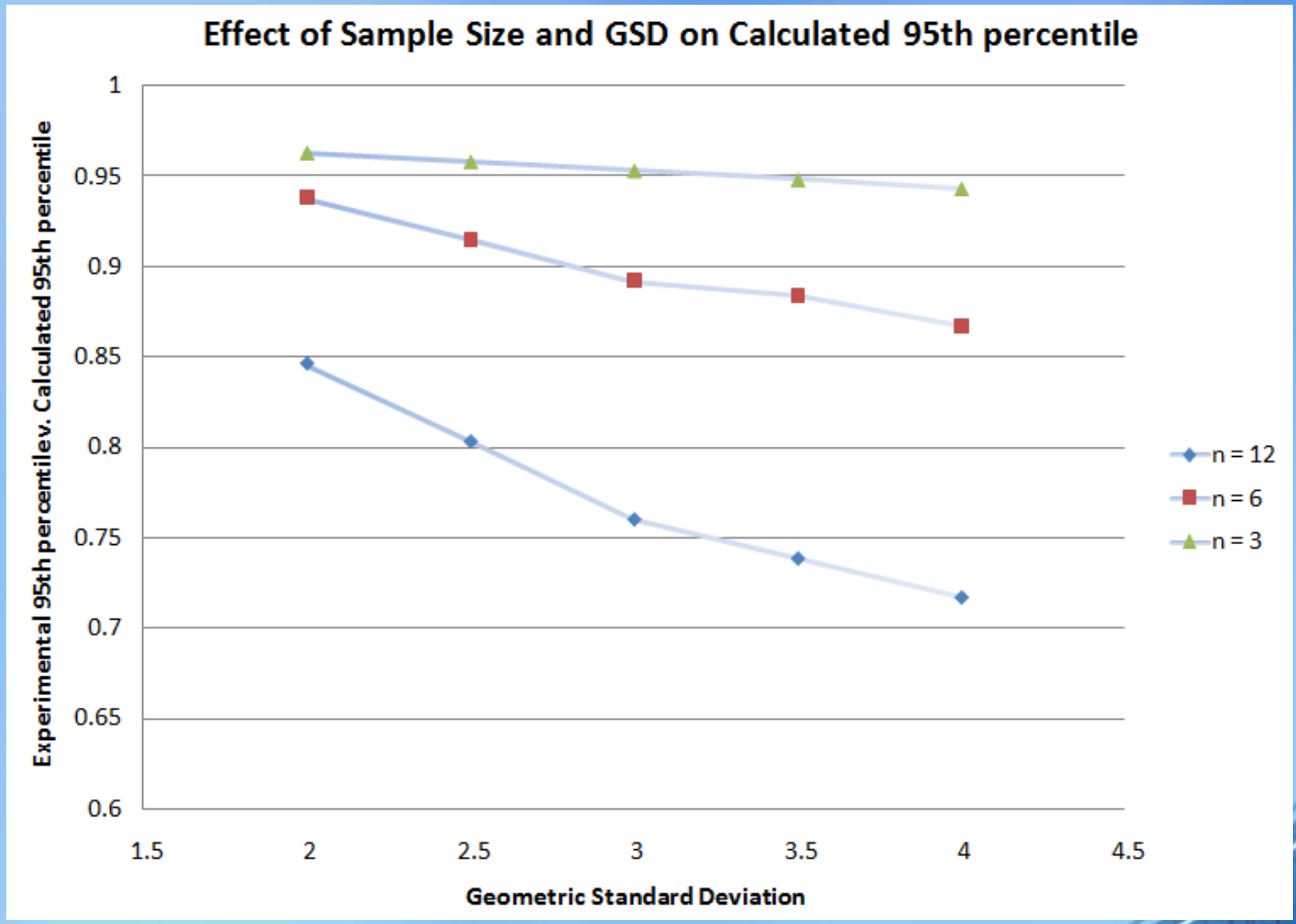
- Calculated $X_{0.95}$ < OEL
- UCL of $X_{0.95}$ < OEL
- UCL of $\overline{X}$ < OEL
- Posterior Bayesian probability of exceeding OEL< 5%
- One (or more) samples looked fine

It depends . . .



Source: http://www.vanbelle.org/presentations/narrative.pdf

Calculated $X_{0.95}$ < OEL



Calculated $X_{0.95}$ < OEL

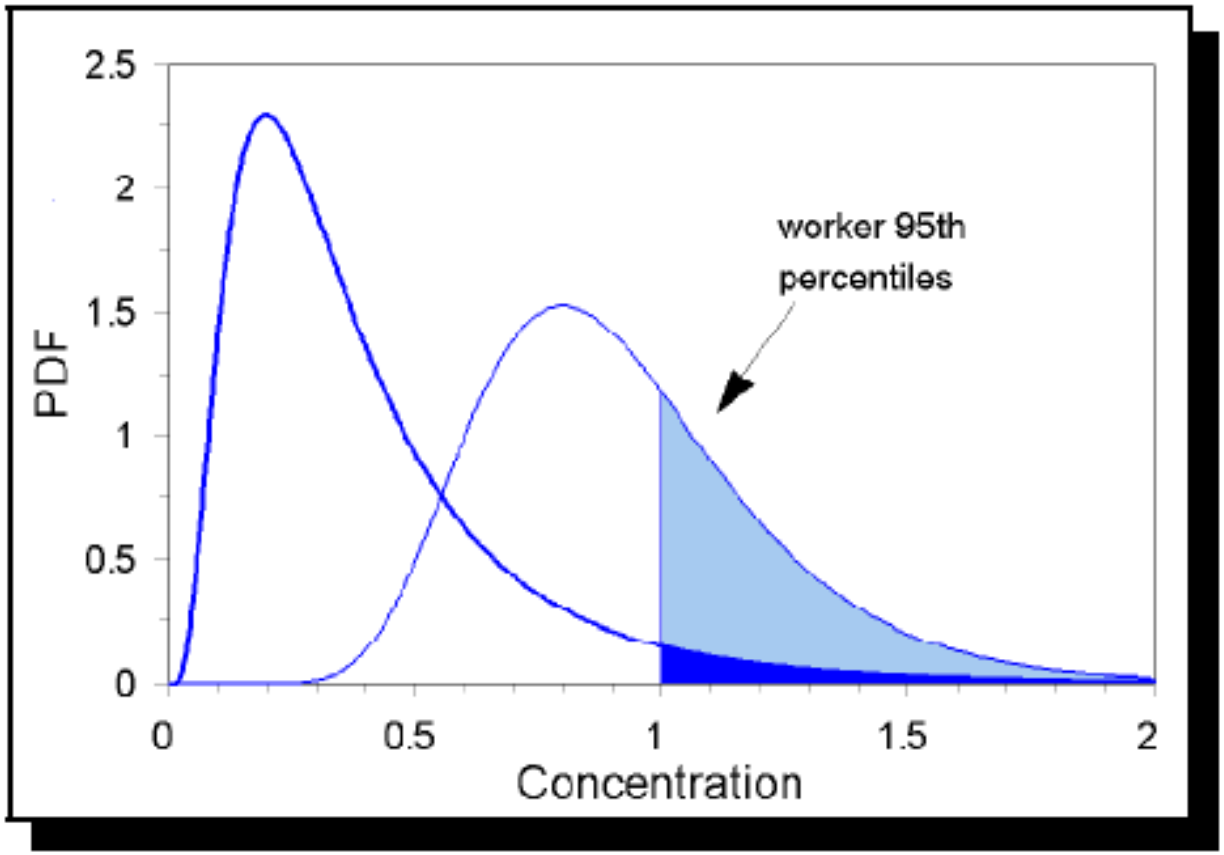


Figure 1: Distribution of worker exposures and distribution of worker "95th percentiles". The geometric mean, geometric standard deviation, and heterogeneity coefficient for the group exposure profile are 0.3197, 2.0, and 0.2, respectively. Exactly 5% of the group exposure profile exceeds the TWA exposure limit of 1 ppm. In contrast, 35% of the workers have individual 95th percentile exposures that exceed the limit.

Source: Hewett, P. Technical Report No. 05-02. January 2005.

Recommendations to account for inter-worker variability

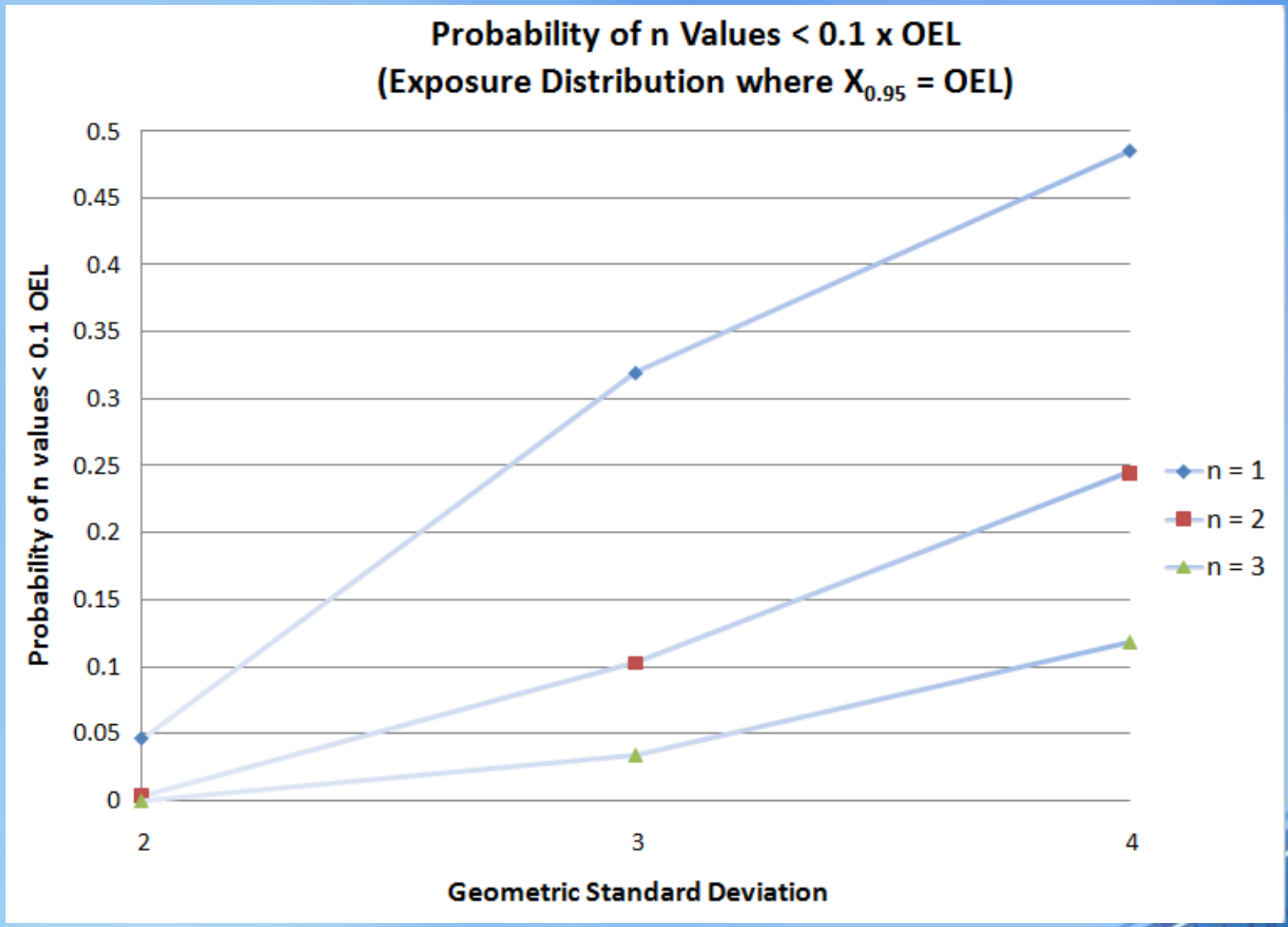
- Group exceedance fraction < 0.01
- $X_{0.95}$ < 0.5 x OEL
- GM < 0.1 x OEL

Source: Hewett, P. Technical Report No. 05-02. January 2005.

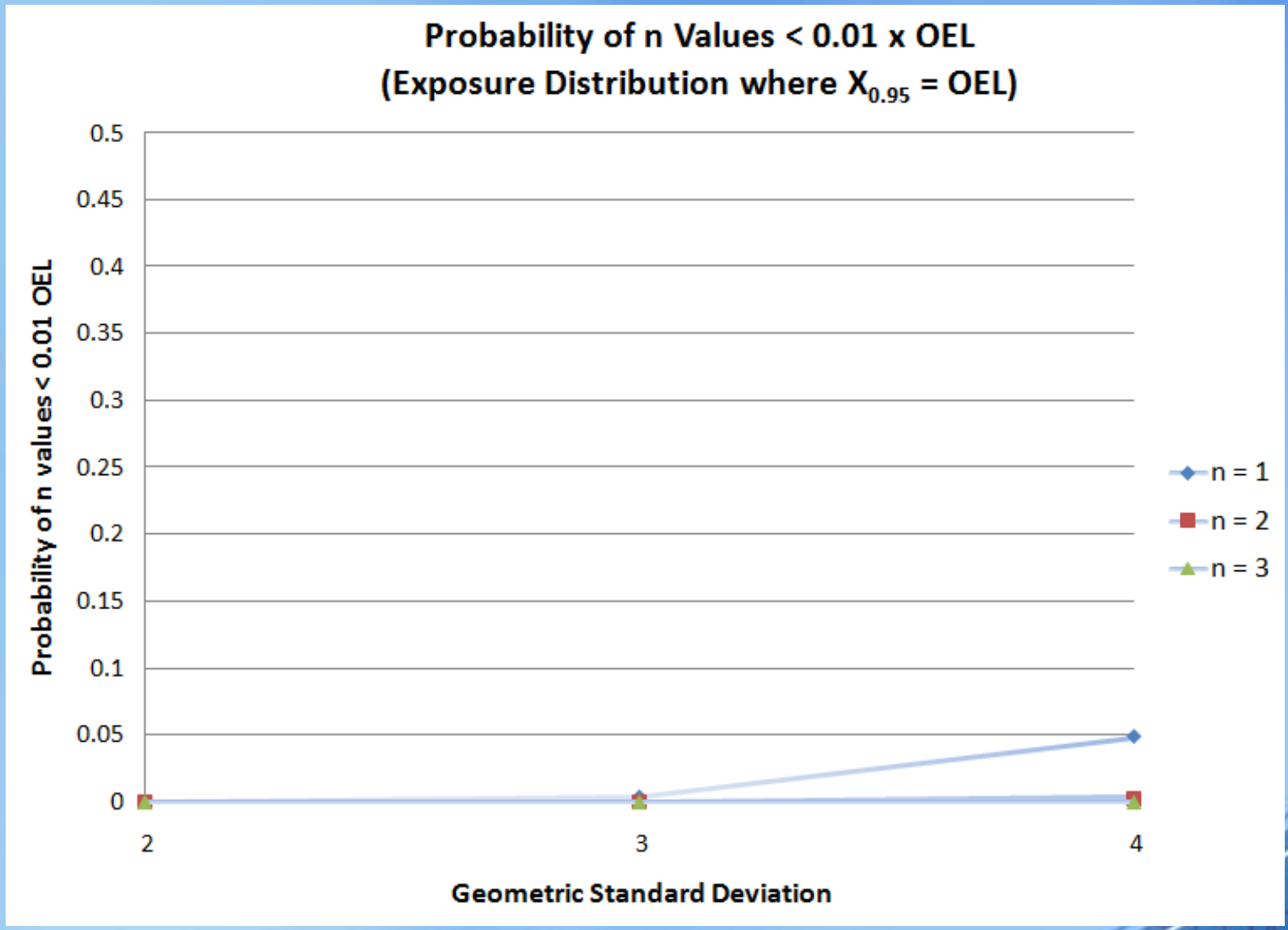
- Another rule of thumb: "The width of the confidence interval decreases rapidly until 12 observations are reached and then decreases less rapidly".

Source: http://www.vanbelle.org Rule 1.10 (August 2003)

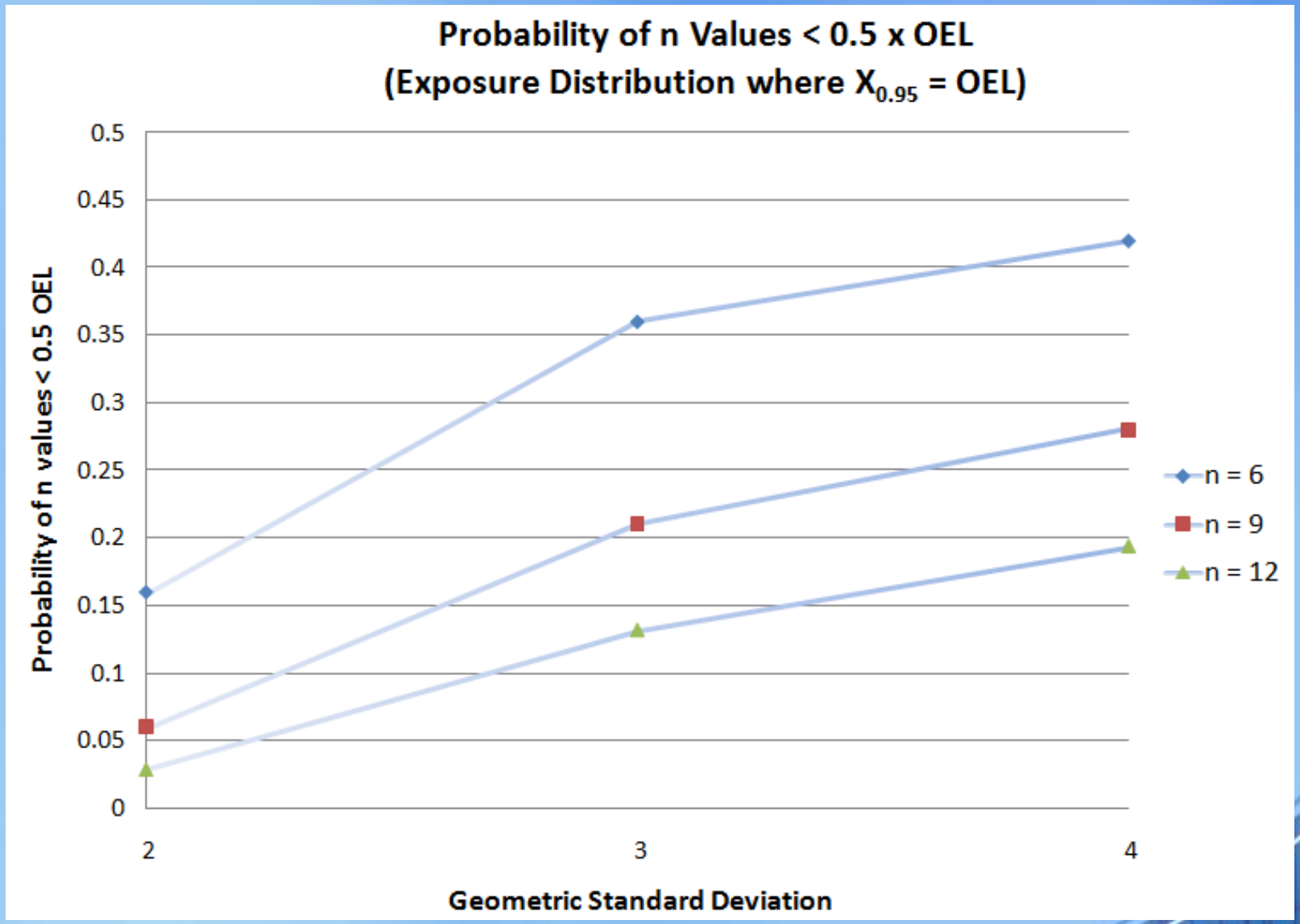
One (or more) samples looked fine



One (or more) samples looked fine



One (or more) samples looked fine



Low Exposure Values

- 3 consecutive random samples < 0.1 x OEL (and none over 0.1 x OEL!) are a good indicator that $X_{0.95}$ < OEL
- Even 1 random sample, but preferably 2 random samples < 0.01 x OEL are a good indicator that $X_{0.95}$ < OEL
- For larger, uncensored data sets and for exposures closer to the OEL, use statistical tools

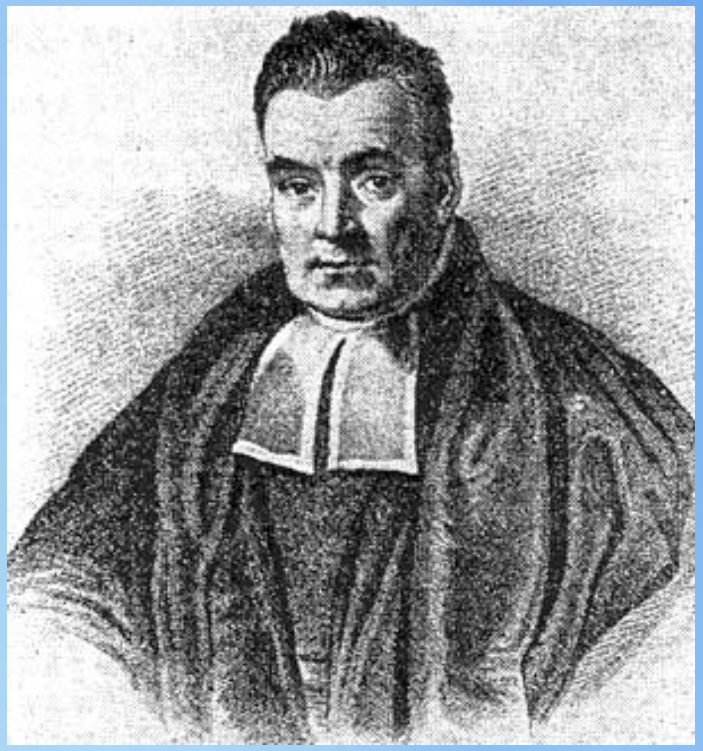
Bayesian Statistics: Importance of accurate priors

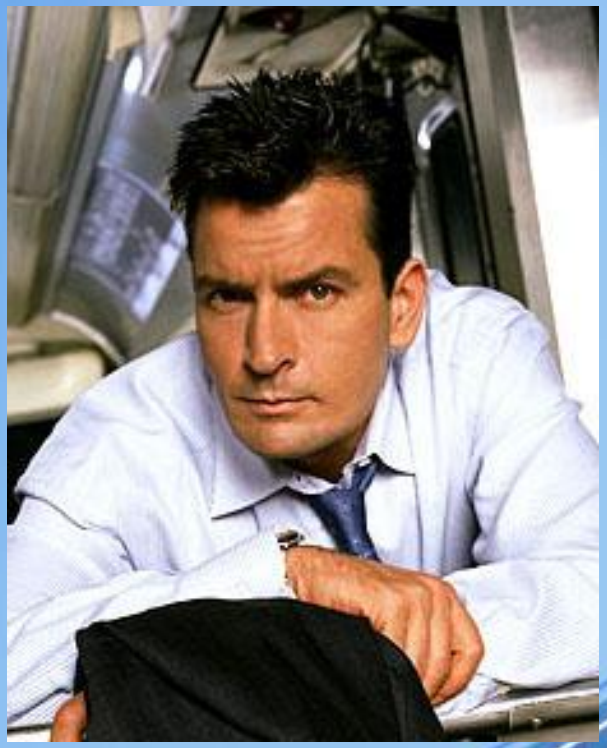
- Bayesian statistics may be very useful in assessing control banding systems – but realistic estimates on which to base prior probabilities are critical

Bayesian Statistics

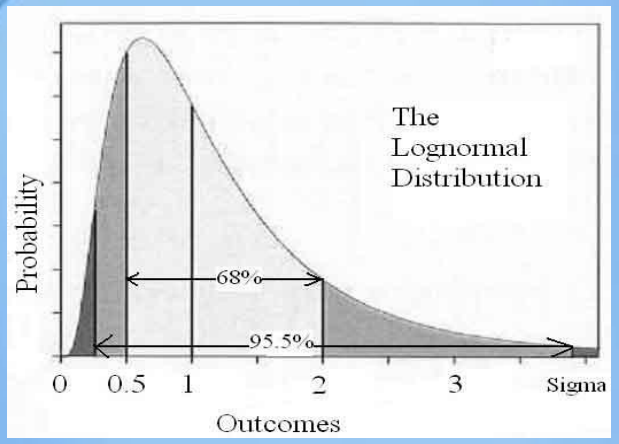
$$P(A|B) = \frac{P(B|A)\,P(A)}{P(B|A)P(A) + P(B|A^C)P(A^C)}.$$

$$f_X(x|Y=y) = \frac{f_{X,Y}(x,y)}{f_Y(y)} = \frac{f_Y(y|X=x)\,f_X(x)}{f_Y(y)} = \frac{f_Y(y|X=x)\,f_X(x)}{\int_{-\infty}^{\infty} f_Y(y|X=\xi)\,f_X(\xi)\,d\xi}.$$



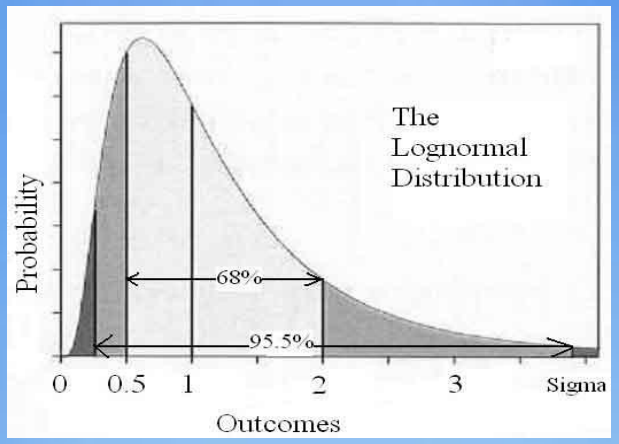


Prior Probability

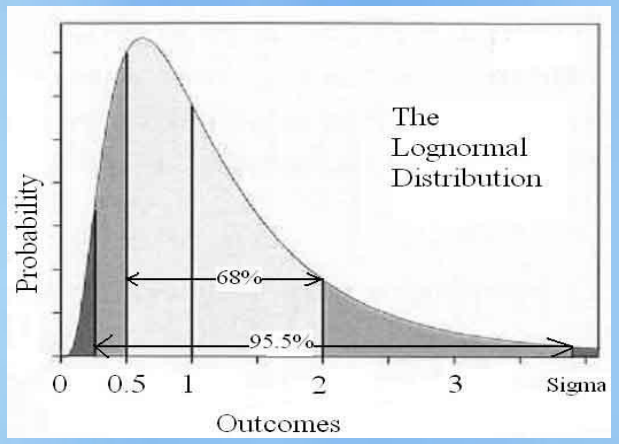


Extract sample
or subject

Likelihood Distribution



Posterior Probability



"Prior" Probabilities

- Are we good at predicting probabilities?

2009 Super Bowl Odds

Posted on Tuesday, February 05, 2008

- New England Patriots: 3:1
- San Diego Chargers: 11:2
- Indianapolis Colts: 12:1
- Dallas Cowboys: 14:1
- Pittsburgh Steelers: 20:1
- New York Giants: 25:1
- Green Bay Packers: 25:1
- Jacksonville Jaguars: 25:1
- New Orleans Saints: 25:1
- Cincinnati Bengals: 28:1
- Philadelphia Eagles: 35:1
- Denver Broncos: 40:1
- Cleveland Browns: 50:1
- Washington Redskins: 50:1
- Chicago Bears: 50:1
- Minnesota Vikings: 50:1
- Detroit Lions: 50:1
- Carolina Panthers: 50:1
- Tampa Bay Buccaneers: 50:1
- Seattle Seahawks: 50:1
- San Francisco 49ers: 50:1
- Arizona Cardinals: 50:1

Bayesian Decision Chart

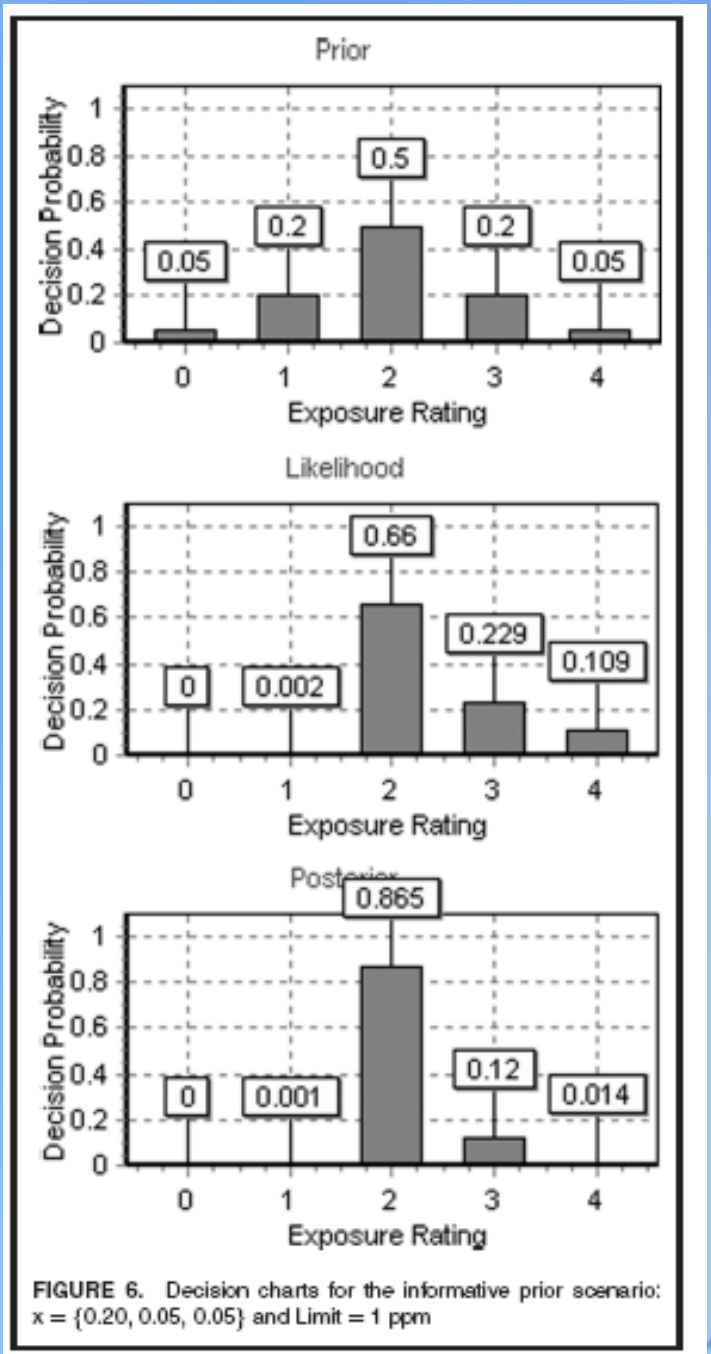
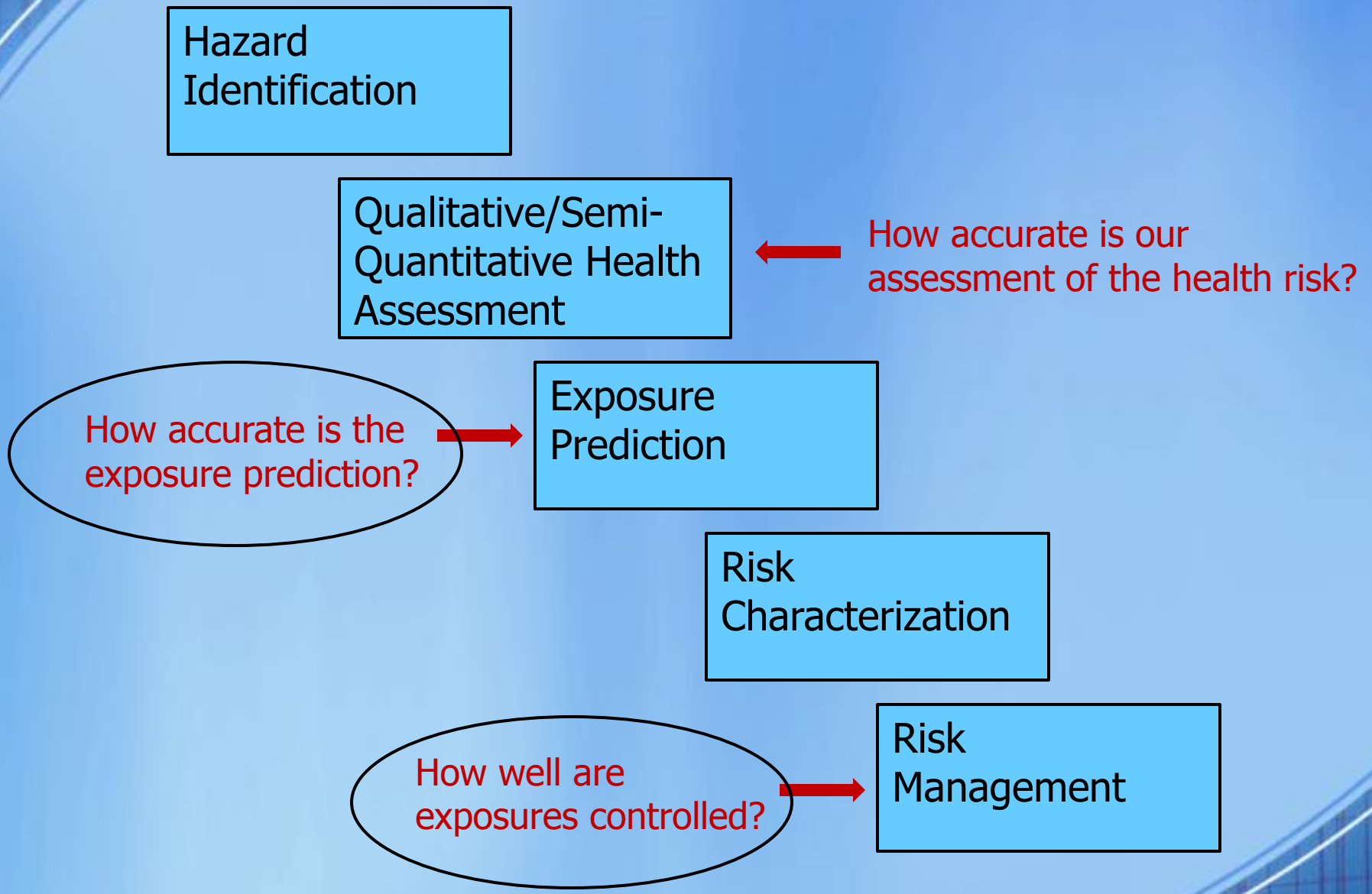


FIGURE 6. Decision charts for the informative prior scenario: x = {0.20, 0.05, 0.05} and Limit = 1 ppm

Control Banding Approach to Managing Risk

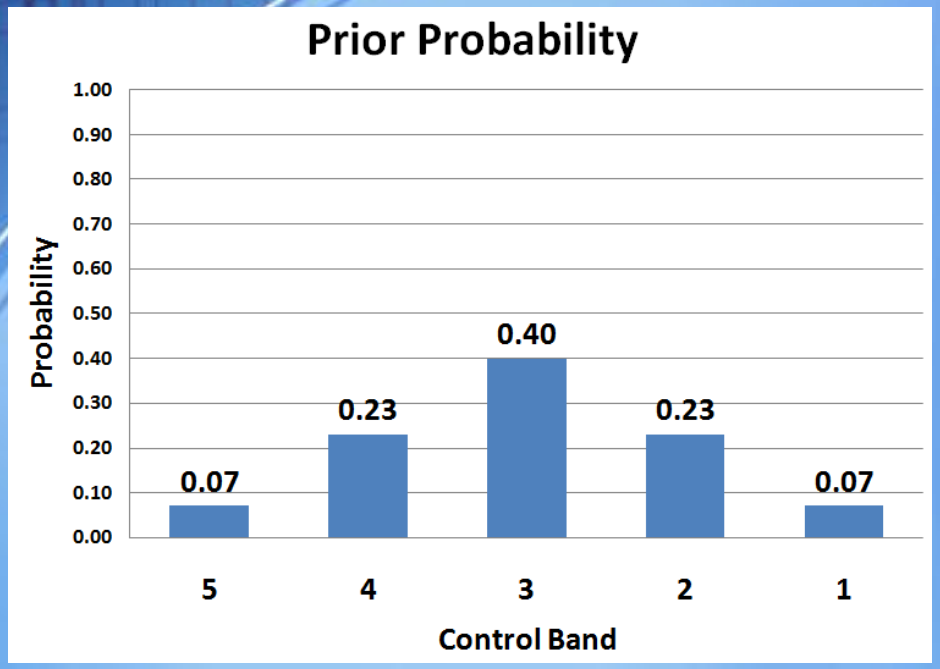


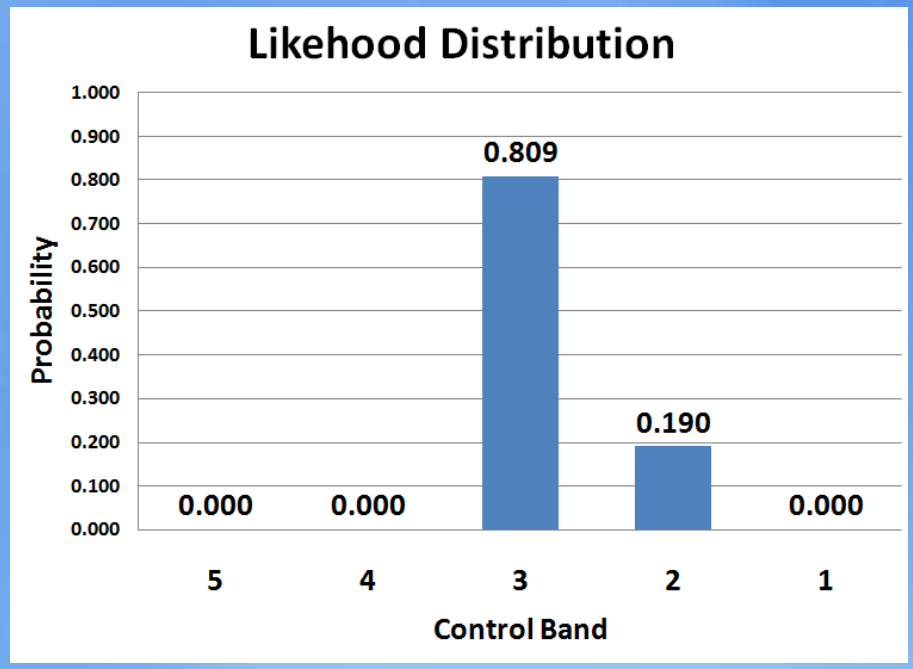
Hypothetical Pharmaceutical Control Banding Scheme

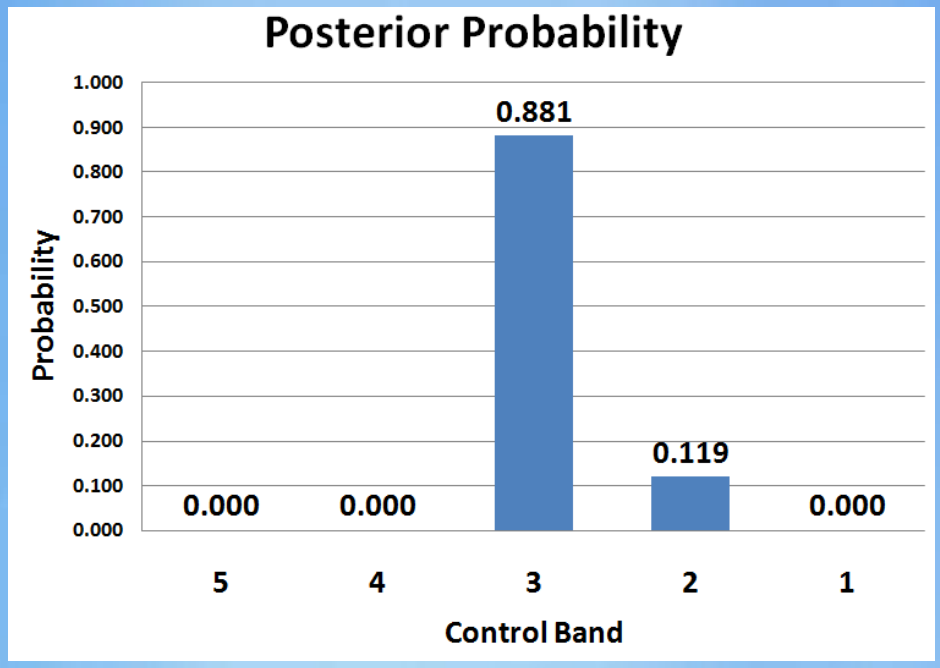
Control Band	Exposure band (µg/m3)
1	> 100
2	20 -100
3	2 - 20
4	0.2 - 2
5	< 0.2

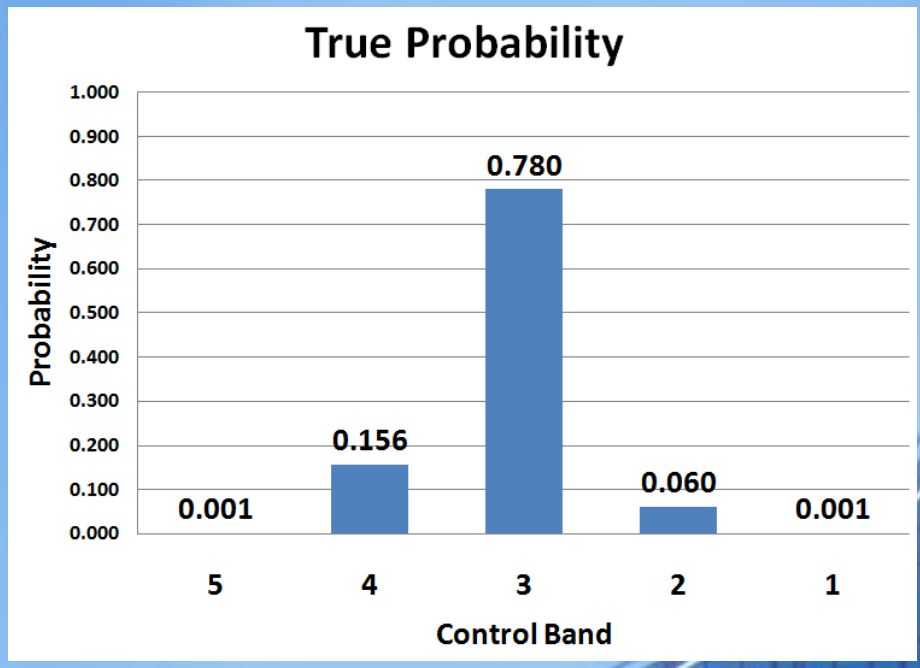
Model Data

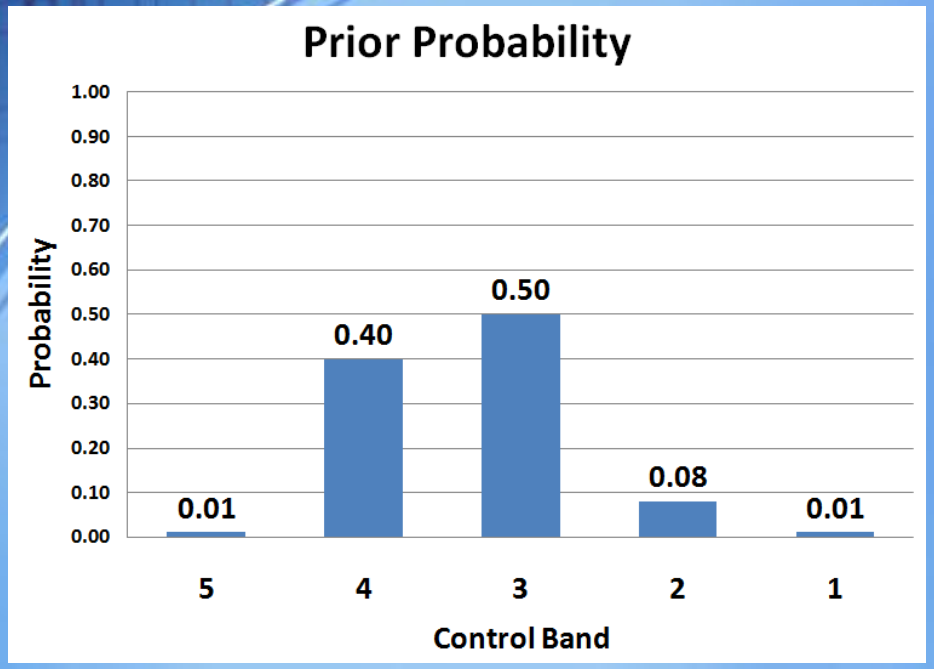
- Control Band 3 Substance (2-20 µg/m^3)
- GM = 5.0 µg/m^3
- GSD = 2.5
- 95th percentile = 22.5 µg/m^3

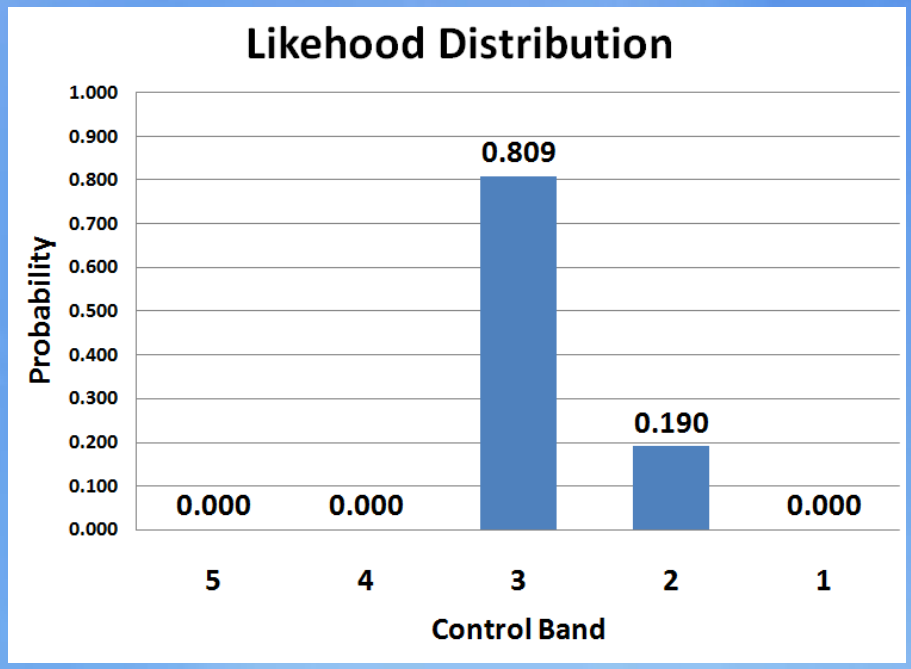

Prior Probability
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.07
0.23
0.40
0.23
0.07
5
4
3
2
1
Control Band

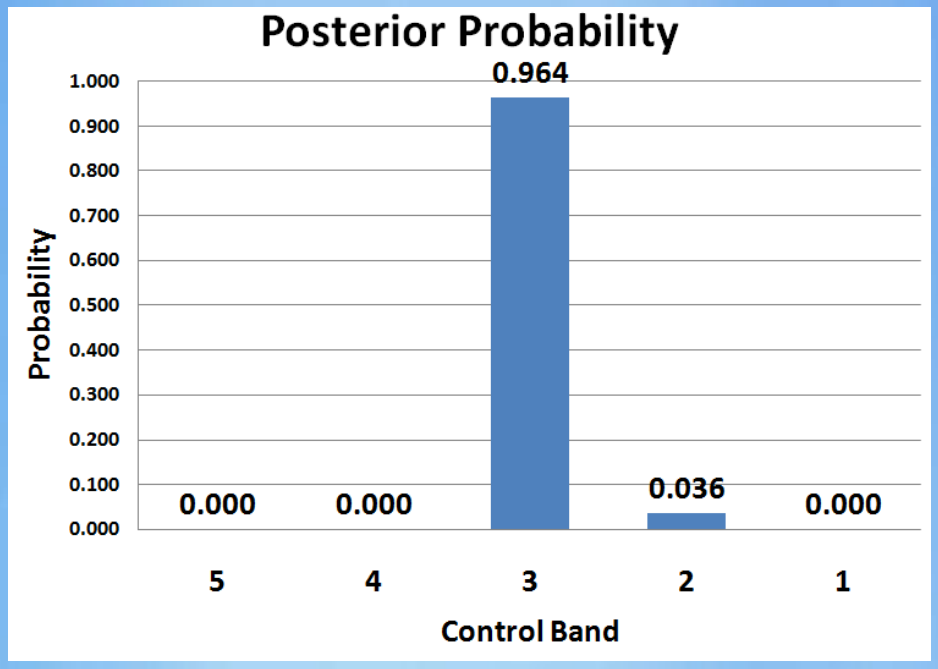

Likehood Distribution
Probability
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.000
0.000
0.809
0.190
0.000
5
4
3
2
1
Control Band

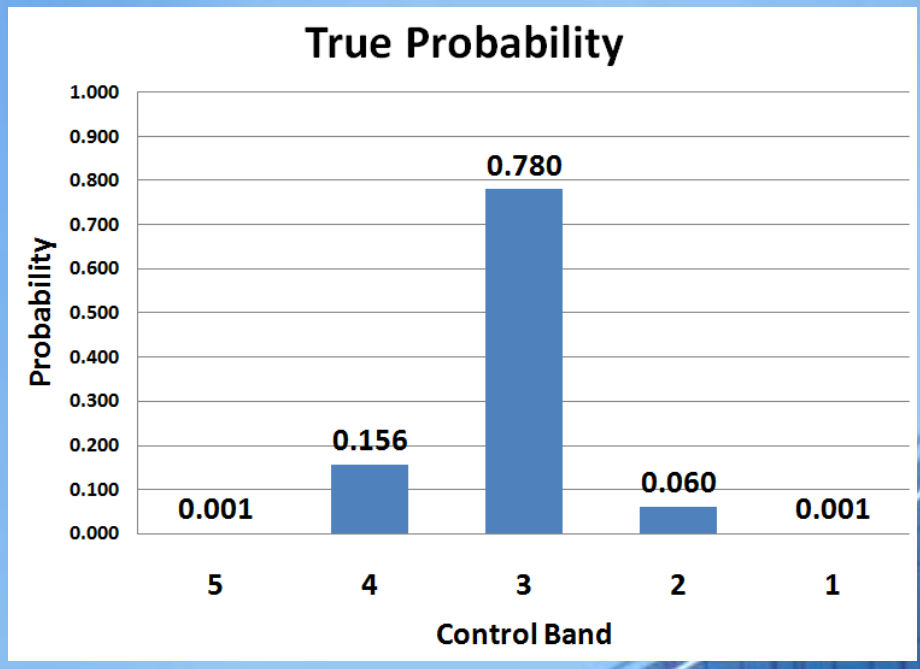

Posterior Probability
Probability
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.000
0.000
0.881
0.119
0.000
5
4
3
2
1
Control Band


True Probability
Probability
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.001
0.156
0.780
0.060
0.001
5
4
3
2
1
Control Band


Prior Probability
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.01
0.40
0.50
0.08
0.01
5
4
3
2
1
Control Band


Likehood Distribution
Probability
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.000
0.000
0.809
0.190
0.000
5
4
3
2
1
Control Band


Posterior Probability
Probability
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.000
0.000
0.964
0.036
0.000
5
4
3
2
1
Control Band


True Probability
Probability
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.001
0.156
0.780
0.060
0.001
5
4
3
2
1
Control Band

Control Banding Assessment

- Data from similar processes with similar chemicals can be used to generate a realistic informative prior
- Verification data should show that acceptance criteria are met …
- But acceptance criteria depend on context – criticality, personal preference, feasibility, size of the data set

Control Banding Implications

- Bands should be at least one order of magnitude wide
- Exposure should be “acceptable” at the top end of the band
- Controls should be designed to achieve the bottom end of the band