Bayesian Approach to Risk, Decisions and Professional Judgment

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3M Corporate Industrial Hygiene Manager
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YUMA Meeting - 2013

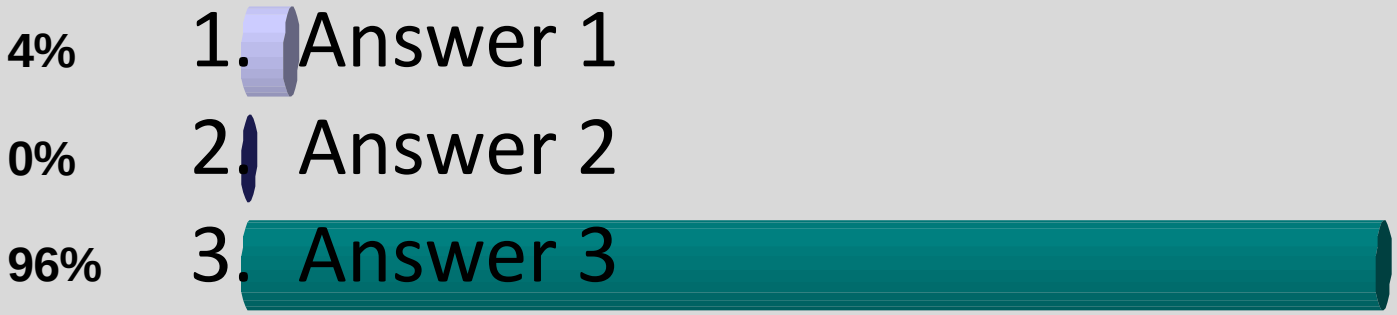
Overview

- Cognition
- Professional Judgment and Industrial Hygiene
- Top 3 Bayesian Benefits for IH
- Path Forward

“We often miss opportunity because it's dressed in overalls and looks like work”

— Thomas A. Edison

Begin Voting – Select Choice “3”



Do this calculation in your head

Quickly!

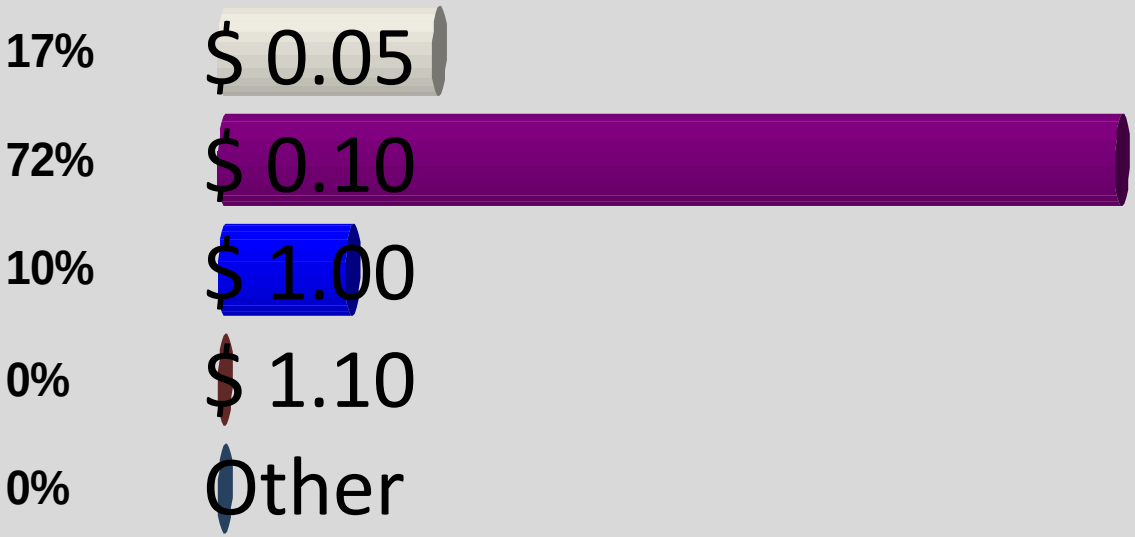
18 X 23 = ?

- Raise you hand when you have the answer

A bat and a ball cost $1.10

The bat costs one dollar more than the ball

How much does the ball cost?



Diagnosing Breast Cancer

- A woman visits a physician for an evaluation of a slight lump in her breast. The physician performs a full physical exam, reviews current and past medical records including family history.
- Given this woman's age and family history the physician estimates there would be a 1% chance that the lump is cancerous.

Diagnosing Breast Cancer

- The physician orders a mammogram
  - If the woman has breast cancer, there is a **79.2%** probability the mammogram will be positive
  - If the woman does not have breast cancer, there is a **90.4%** probability the mammogram will be negative

Diagnosing Breast Cancer

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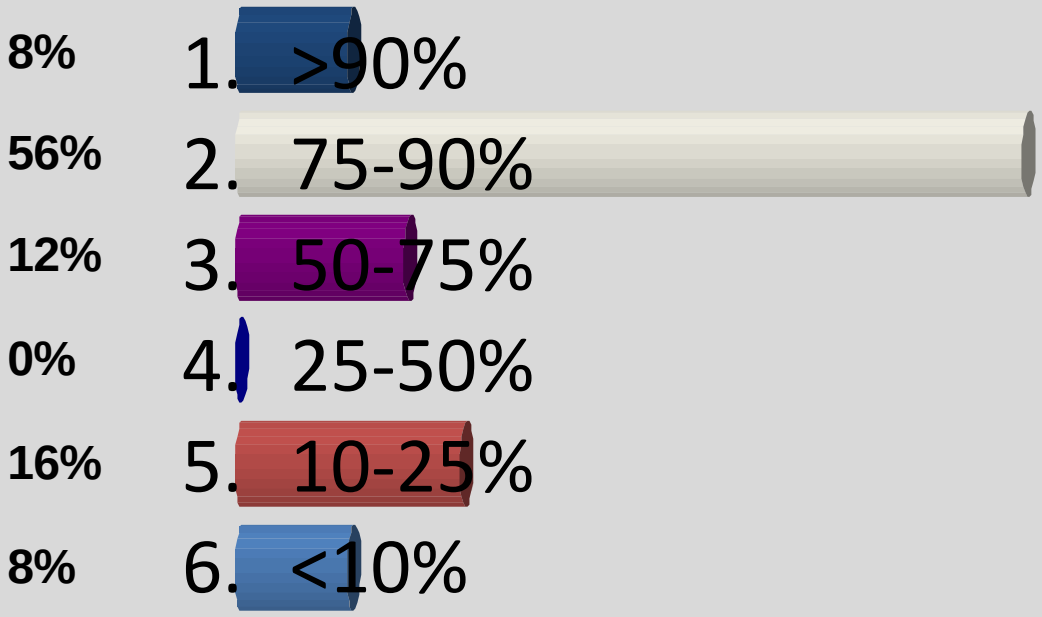
- The woman's mammogram comes back **POSITIVE**.
- Given this positive test, what is the probability that the woman has breast cancer?

- If the woman has breast cancer, there is a **79.2%** probability the mammogram will be positive
- If the woman does not have breast cancer, there is a **90.4%** probability the mammogram will be negative

The mammogram was positive test, what is the probability that the woman has breast cancer?



“Your job as a scientist is to figure out how you’re fooling yourself”

Saul Perlmutter

Lets talk about the results,…

- Are you good at multiplication in your head?
- How much does the ball cost?
- Probability of Breast Cancer?

How much does the ball cost?

- A bat and a ball cost $1.10, the bat costs one dollar more than the ball (See group results!)

Bat + Ball = $1.10

Bat = Ball + $1.00

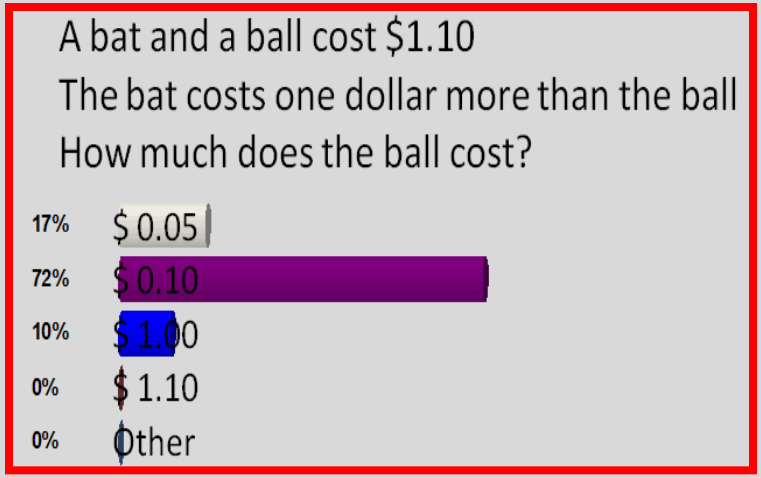
(Ball + $1.00) +Ball = $1.10

2*Ball = $0.10

Ball/2= $0.10/2

Ball = $0.05 (Bat = $1.05)

2013 YUMA Meeting Results (17% Correct)



What is the probability this patient has Breast Cancer?

- What probability did we vote for?
    - <10%, 10-25%, 25-50%, 50-75%, >75%
- Lets see how we can use a ***Bayesian*** approach…

Bayes' Theorem –

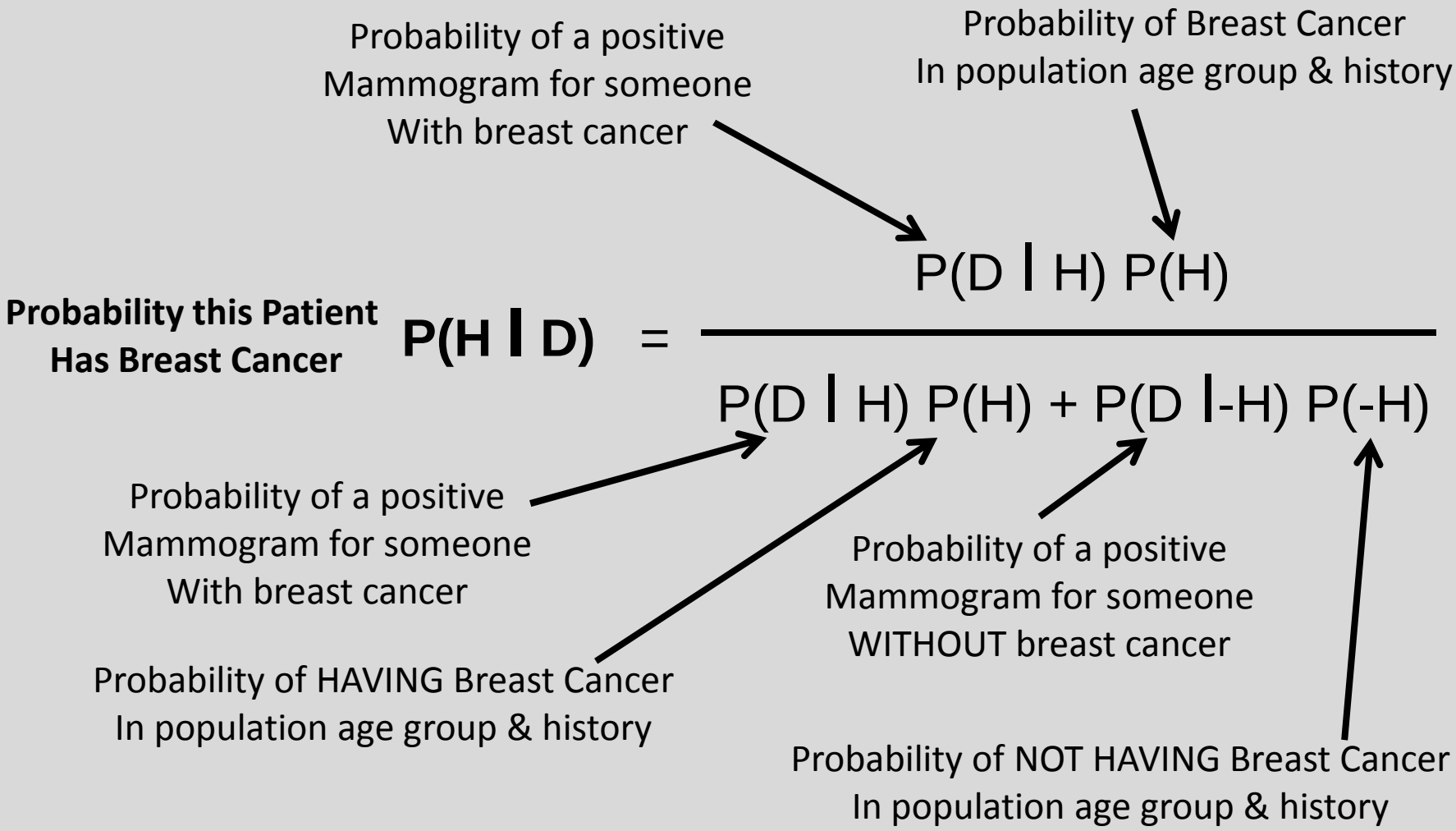
The Foundation of Bayesian Statistics

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 balancing weight of sample data for across likelihood universe

Bayesian Statistical Approach



Bayesian Statistical Approach

Probability of a positive Mammogram for someone With breast cancer

Probability of Breast Cancer In population age group & history

Probability this Patient Has Breast Cancer

$$\mathbf{P(H \mid D)} = \frac{P(D \mid H)\, P(H)}{P(D \mid H)\, P(H) + P(D \mid -H)\, P(-H)}$$

Probability of a positive Mammogram for someone With breast cancer

Probability of HAVING Breast Cancer In population age group & history

Probability of a positive Mammogram for someone WITHOUT breast cancer

Probability of NOT HAVING Breast Cancer In population age group & history

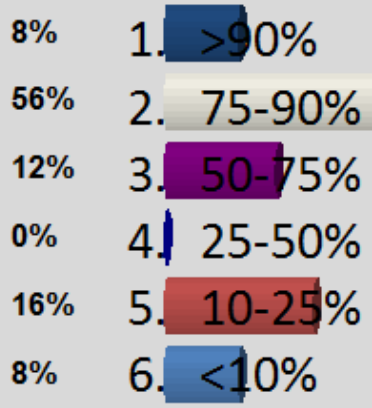
$$P(H \mid D) = \frac{(0.792)\,(0.01)}{(0.792)\,(0.01) + (0.096)\,(0.99)}$$

$$P(H \mid D) = \frac{(0.792)\,(0.01)}{(0.792)\,(0.01) + (0.096)\,(0.99)}$$

$$P(H \mid D) = \frac{(0.00792)}{(0.00792) + (0.09504)}$$

Patient's Probability of Breast Cancer = 0.077 or 7.7%

The mammogram was positive test, what is the probability that the woman has breast cancer?



2013 YUMA Meeting Results (8% Correct)

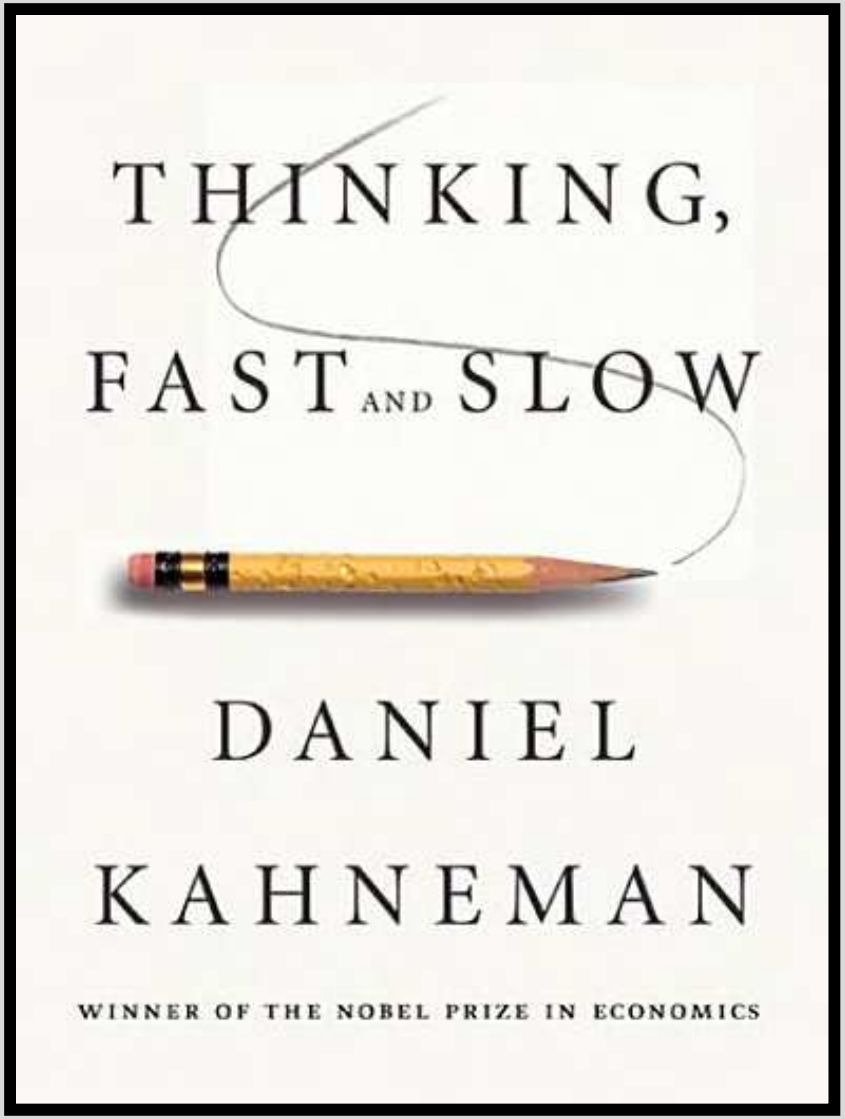
Medical Doctors & OH Professionals

Medical Doctors	Occupational Hygienists
• Diagnose illnesses	• Diagnose exposures to prevent illness
• Prescribe drugs or medical treatment for an illness	• Prescribe exposure controls to prevent illnesses
• Educate people on how to prevent illnesses	• Educate people on how to eliminate or reduce exposures to prevent illnesses

- Are we surprised?
- How much error would we tolerate from our personal physician?
- Do OH Professionals “misdiagnose” exposures in a similar way?
- How can Bayesian tools be used to increase our accuracy of diagnosing exposures?

Daniel Kahneman

- Nobel prize winning psychologist,…in economics
- Defined famous heuristics and decision making processes
- Research has driven changes across many professions.
- Described Decision Making into System 1 & System 2



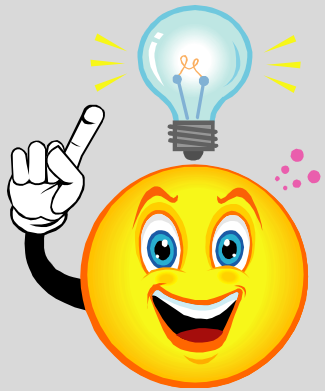
Psychology - Biases and Heuristics

- Kahneman & Tversky proposed three now famous heuristics as to why many biases occur:

  (1) anchoring and adjustment,

  (2) availability

  (3) representativeness.



They have been studied at length in many fields – medicine, law, engineering, economics, psychology,…leading to the description of new heuristics and related biases.

(Kahneman and Tversky, 1982)

- Each decision making system has strengths and weaknesses
  - **System 1 (fast),** less accurate, less energy, intuitive, more efficient, less effective
  - **System 2 (slow),** more accurate, more taxing, cognitive, algorithmic, conscious rules, less efficient, more effective
- How can understanding this help us improve accuracy our decision making?

Relationship between Heuristics and Biases

- Heuristics are the hard coded rules
  - Unconscious (System 1)
    - Driven by emotions – brain stem & hormones
    - Past experience integrated into *"feelings"*
  - Conscious (System 2)
    - Learned algorithms
    - Data analysis

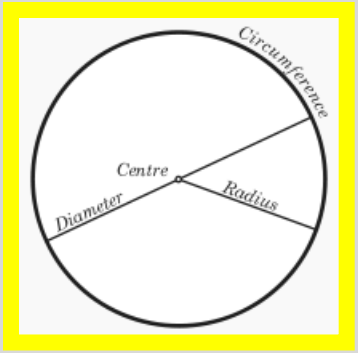
<u>Biases</u> result when there are flaws in the Heuristic(s) used for a given application

3 Common Sources of Bias

- **(1) Cognitive Bias**
  - Selection of wrong heuristic(s)
    - Example – Wrong equation selected

      Area of circle = (4/3) * (pi * radius^3)
  - Inherent flaw in heuristic(s)
    - Example – Error in algorithm or mathematical equation

      Area of circle = pi * diameter^2



- **(2) Self-Serving Bias**
  - Decision based on impact to self or "group"

- **(3) Emotion only based decision (non-rational)**
  - "I'm feeling lucky!"

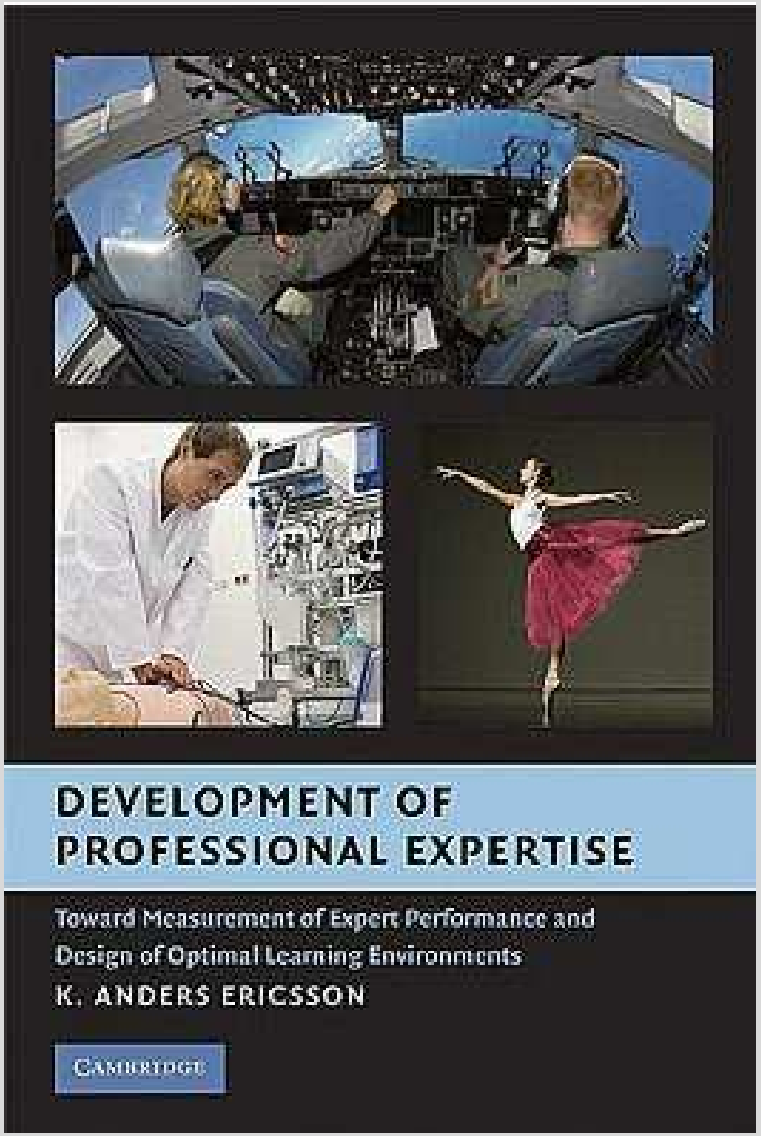
Conclusions from Cognitive Psychology

- Humans are more often biased and inaccurate that we know
  - Your “gut” is wrong much more often that you know (or even want to know)
- As individuals we think we are the accurate one, it is “the person next to us that isn’t so good”
- There are several key strategies and tools which can dramatically reduce bias and increase accuracy

“Now that I know my judgments can be flawed, what can I do?”

K. Anders Ericsson

- Demonstrated the “10 year” or “10,000 hours” rule for Professional Expertise.
- World renowned researcher in
  - **Professional Development**
  - **Superior Memory of Experts and Long-Term Working Memory**



“A wise man will make more opportunities than he finds.”

— Francis Bacon

Bayes' Theorem –

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

Correction Factor balancing weight of sample data for across likelihood universe

Bayesian Approach Applied to Professional Judgments (Exposure)

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Rating Exposure Control Using Bayesian Decision Analysis

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A model is presented for applying Bayesian statistical techniques to the problem of determining, from the usual limited number of exposure measurements, whether the exposure profile for a similar exposure group can be considered a Category 0, 1, 2, 3, or 4 exposure. The categories were adapted from the AIHA exposure category scheme and refer to (0) negligible or trivial exposure (i.e., the true $X_{0.95}$ ≤1%OEL), (1) highly controlled (i.e., $X_{0.95}$ ≤10%OEL), (2) well controlled (i.e., $X_{0.95}$ ≤50%OEL), (3) controlled (i.e., $X_{0.95}$ ≤100%OEL), or (4) poorly controlled (i.e., $X_{0.95}$ >100%OEL) exposures. Unlike conventional statistical methods applied to exposure data, Bayesian statistical techniques can be adapted to explicitly take into account professional judgment or other sources of information. The analysis output consists of a distribution (i.e., set) of decision probabilities: e.g., 1%, 80%, 12%, 5%, and 2% probability that the exposure profile is a Category 0, 1, 2, 3, or 4 exposure. By inspection of these decision probabilities, rather than the often difficult to interpret point estimates (e.g., the sample 95th percentile exposure) and confidence intervals, a risk manager can be better positioned to arrive at an effective (i.e., correct) and efficient decision. Bayesian decision methods are based on the concepts of prior, likelihood, and posterior distributions of decision probabilities. The prior decision distribution represents what an industrial hygienist that either a significant process change has occurred or the industrial hygienist's initial judgment was incorrect. In either case, the industrial hygienist should readjust his judgment regarding this operation.

Keywords Bayesian statistics, exposure assessment, exposure rating

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INTRODUCTION

Industrial hygiene has often been described as both an art and a science. The art component often consists of the application of professional judgment in determining whether occupational exposures are acceptable, relative to some occupational exposure limit (OEL). Professional judgment is

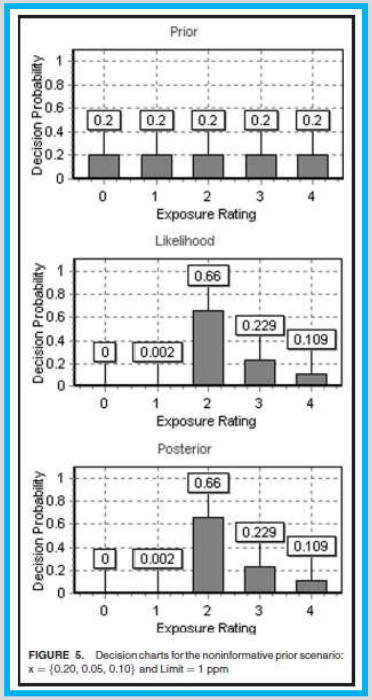

FIGURE 5. Decision charts for the noninformative prior scenario: x = {0.20, 0.05, 0.10} and Limit = 1 ppm

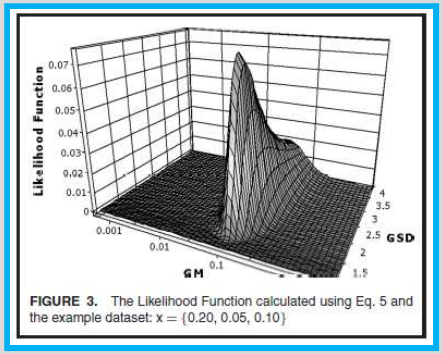

FIGURE 3. The Likelihood Function calculated using Eq. 5 and the example dataset: x = {0.20, 0.05, 0.10}

Top 3 Bayesian Benefits for IH

1. Easily incorporated into the AIHA Strategy Exposure Assessment Control Bands

2. Frames statistical output from sampling data into ***probabilities*** which are more intuitive

3. Transparent framework for ***understanding & strengthening "professional judgment***"

The Annals of Occupational Hygiene

Occupational Exposure Decisions: Can Limited Data Interpretation Training Help Improve Accuracy?

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Accurate exposure assessments are critical for ensuring that potentially hazardous exposures are properly identified and controlled. The availability and accuracy of exposure assessments can determine whether resources are appropriately allocated to engineering and administrative controls, medical surveillance, personal protective equipment and other programs designed to protect workers. A desktop study was performed using videos, task information and sampling data to evaluate the accuracy and potential bias of participants' exposure judgments. Desktop exposure judgments were obtained from occupational hygienists for material handling jobs with small air sampling data sets (0–8 samples) and without the aid of computers. In addition, data interpretation tests (DITs) were administered to participants where they were asked to estimate the 95th percentile of an underlying log-normal exposure distribution from small data sets. Participants were presented with an exposure data interpretation or rule of thumb training which included a simple set of rules for estimating 95th percentiles for small data sets from a log-normal population. DIT was given to each participant before and after the rule of thumb training. Results of each DIT and qualitative and quantitative exposure judgments were compared with a reference judgment obtained through a Bayesian probabilistic analysis of the sampling data to investigate overall judgment accuracy and bias. There were a total of 4386 participant–task–chemical judgments for all data collections: 552 qualitative judgments made without sampling data and 3834 quantitative judgments with sampling data. The DITs and quantitative judgments were significantly better than random chance and much improved by the rule of thumb training. In addition, the rule of thumb training reduced the amount of bias in the DITs and quantitative judgments. The mean DIT % correct scores increased from 47 to 64% after the rule of thumb training ($P < 0.001$). The accuracy for quantitative desktop judgments increased from 43 to 63% correct after the rule of thumb training ($P < 0.001$). The rule of thumb training did not significantly impact accuracy for qualitative desktop judgments. The finding that even some simple statistical rules of thumb improve judgment accuracy significantly suggests that hygienists need to routinely use statistical tools while making exposure judgments using monitoring data.

Keywords: data interpretation training; decision making; desktop study; exposure assessment; judgment accuracy and bias; professional judgment

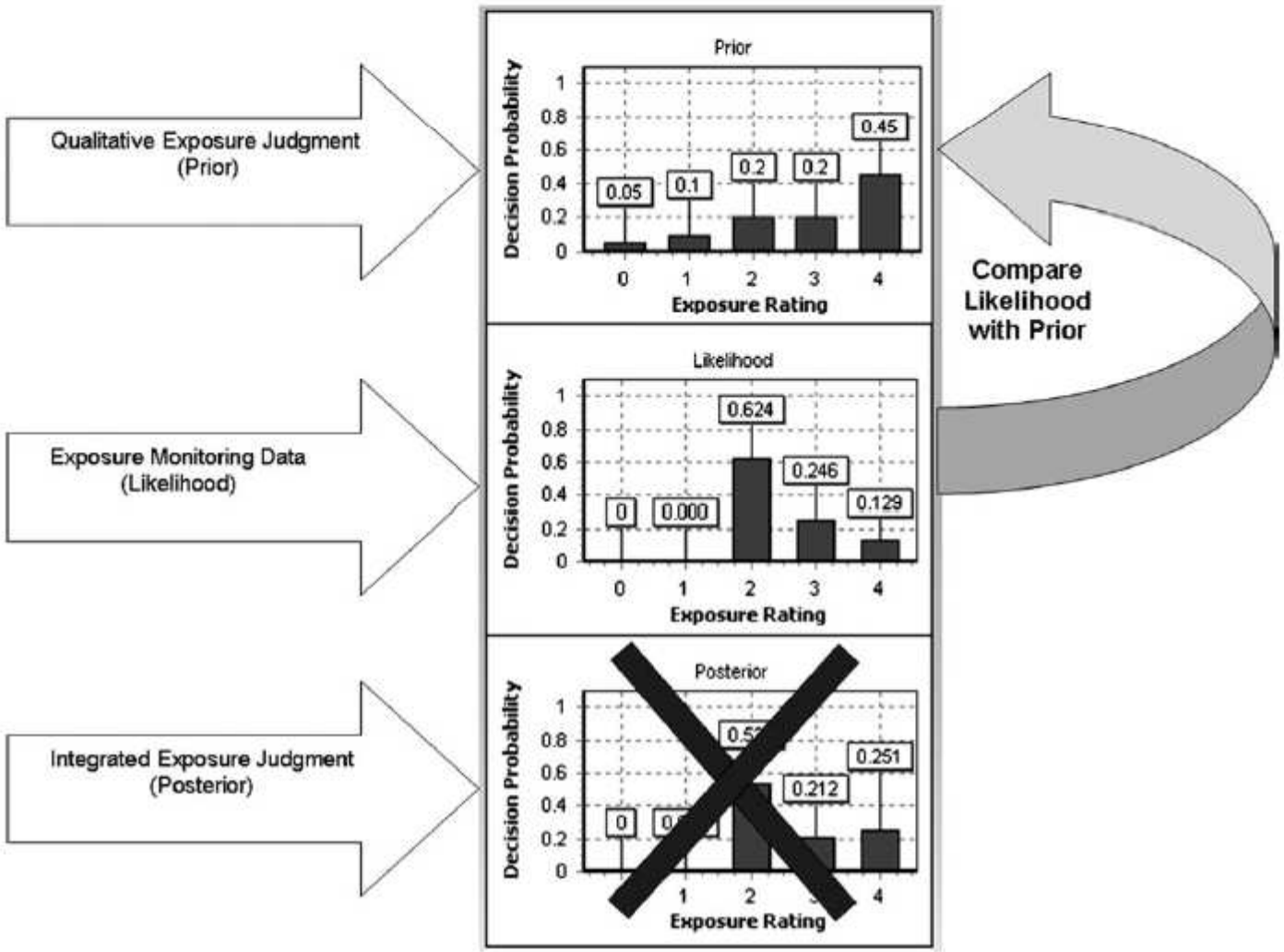


Fig. 2. Bayesian integrated AIHA strategy used to test exposure judgment accuracy. The figure illustrates a method for utilizing the Bayesian integrated AIHA strategy to compare exposure monitoring data analysis (likelihood) with exposure judgments (prior) made by an occupational hygienist for a given SEG.

RESULTS

- Quantitative Pre & Post Training Judgments
  - Accuracy increased from 43% to 63% ($p<0.001$)
  - Appeared to eliminate bias
- Qualitative Pre & Post Training Judgments
  - No statistically significant difference with “Training”
  - **No better than random chance!**

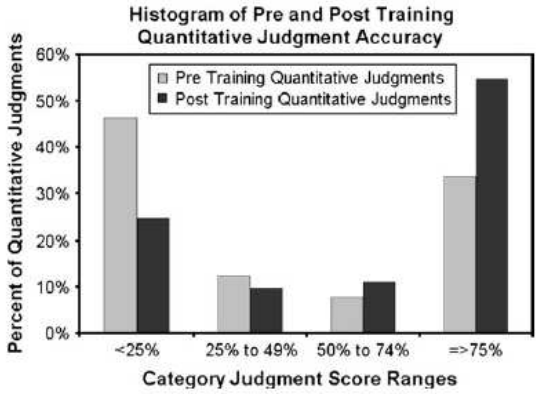
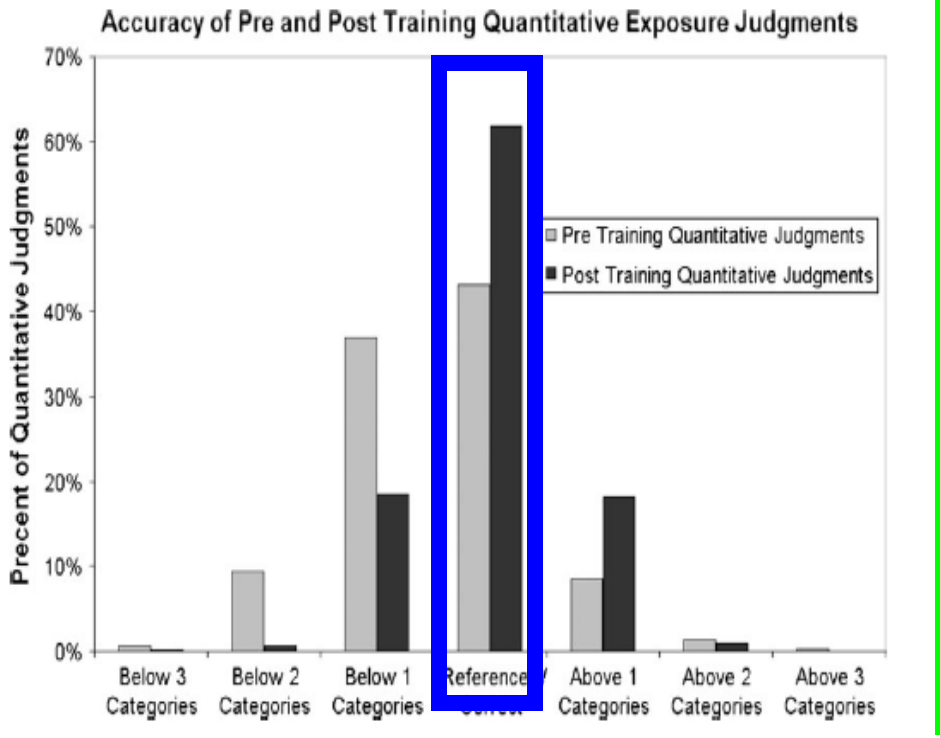
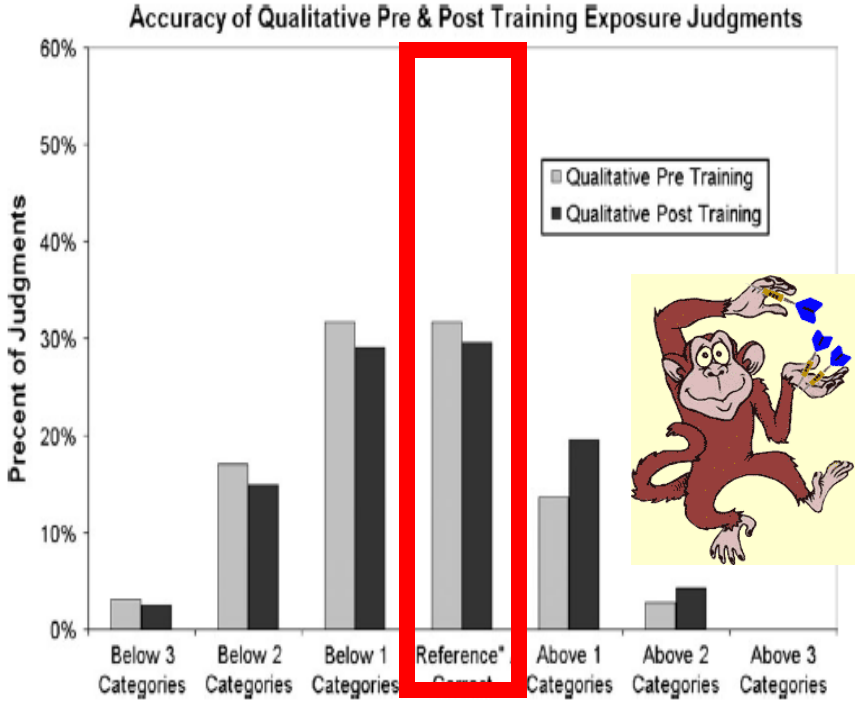


Fig. 8. Histogram of pre- and posttraining task quantitative judgment accuracy.





Key Findings

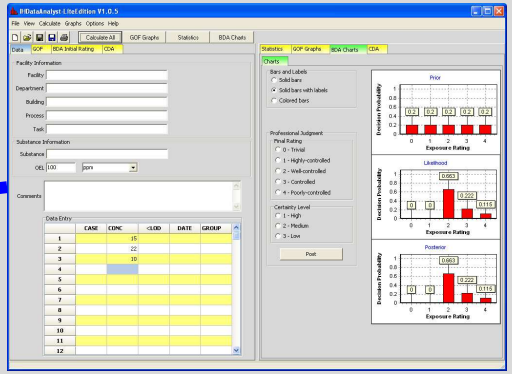
- Exposure judgments are not always accurate and can be biased
- Quantitative judgments were much better than random chance (43% & 63% vs 25%)
- Qualitative judgments statistically were no different than random chance

- More sampling data increased accuracy
- Training or “calibration” significantly helps increase accuracy of judgments ($p<0.001$)
- Need to study the “determinants” of exposure judgment accuracy

Always use statistical tools when interpreting data for exposure judgments!

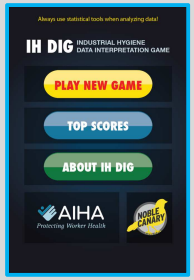
<u>FREE Tools Available – No Excuses!!!</u>

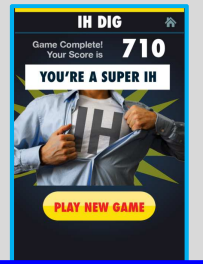
- Exposure Assessment Solutions (IHDA)
  - www.oesh.com

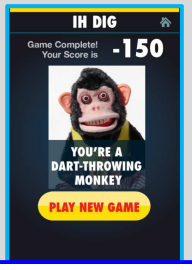


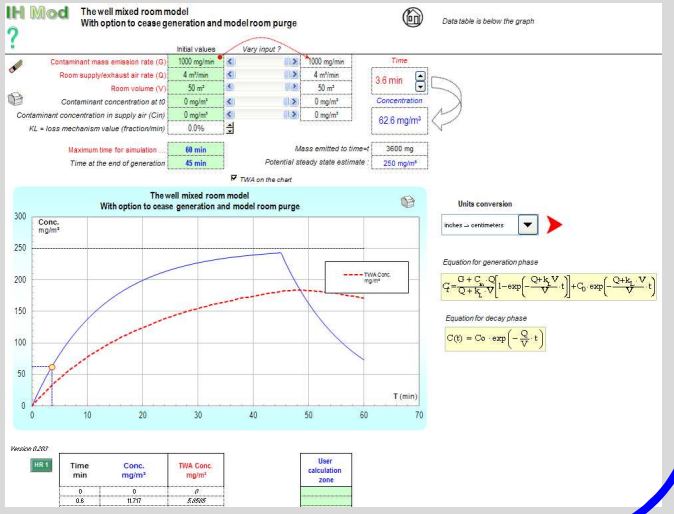
- AIHA Website
  - IHSTAT, IHDIG, IHMOD, IHSkinPerm

http://www.aiha.org/INSIDEAIHA/VOLUNTEERGROUPS/EASC/Pages/EASCTopics.aspx



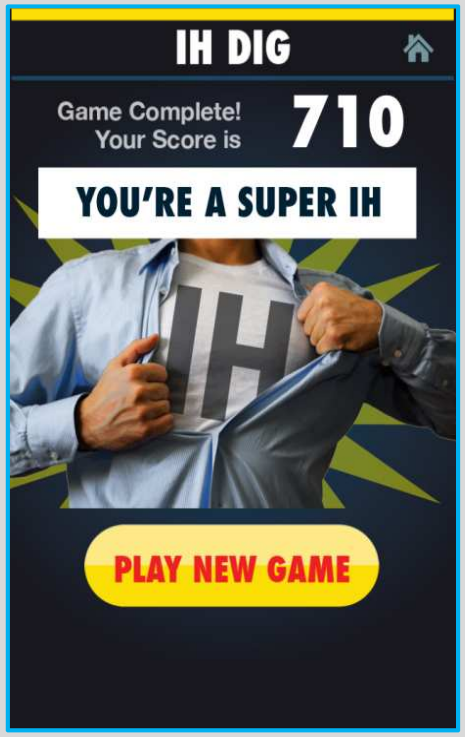


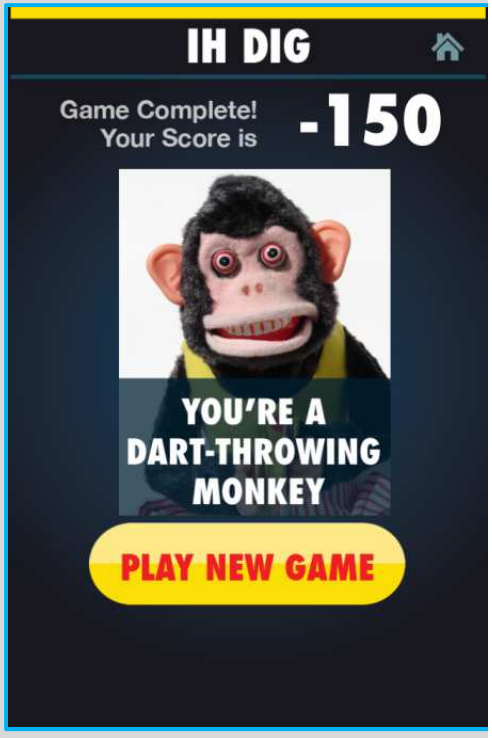




“IH DIG” – IH Data Interpretation Game – Designed to Strengthen IHs System 1 Heuristics for interpreting exposure data and professional judgments based on actual sampling data. (Read “About IH DIG” in App)

Available on Apple iTunes (iPhone, iPad & iTouch) and Android Market place (links on AIHA website)





REFERENCES

American Conference of Governmental Industrial Hygienists. (2005) Threshold limit values and biological exposure indices. Cincinnati, OH: ACGIH.

Baron J. (2000) Thinking and deciding. 3rd edn. Cambridge, UK: Cambridge University Press.

Cock J, Kromhout H, Heederik D *et al.* (1996) Experts' subjective assessment of pesticide exposure in fruit growing. Scand J Work Environ Health; 22: 425–32.

Connolly T, Arkes HR, Hammond KR. (2000) Judgment and decision making: an interdisciplinary reader. Cambridge, UK: Cambridge University Press.

Corn M, Esmen NE. (1979) Workplace exposure zones for classification of employee exposures to physical and chemical agents. Am Ind Hyg Assoc J; 40: 47–57.

Friesen MC, Demers PA, Spinelli JJ *et al.* (2003) Validation of a semi-quantitative job exposure matrix at a Soderberg alu-

Gigerenzer G, Hoffrage U. (1995) How to improve Bayesian reasoning without instruction: frequency formats. Psychol Rev; 102: 684–704.

Gigerenzer G, Hoffrage U. (1999) Overcoming difficulties in Bayesian reasoning: a reply to Lewis and Keren (1999) and Mellers and McGraw (1999). Psychol Rev; 106: 425–30.

Gigerenzer G, Todd PM. (1999) ABC Research Group. (1999) Simple heuristics that make us smart. New York, NY: Oxford University Press.

Gilovich T, Griffin D, Kahneman D. (2002) Heuristics and biases: the psychology of intuitive judgment. Cambridge, UK: Cambridge University Press.

Griffin D, Tversky A. (1992) The weighing of evidence and the determinants of confidence. Cogn Psychol; 24: 411–35.

Hawkins NC, Evans JS. (1989) Subjective estimation of toluene exposures: a calibration study of industrial hygienists. Appl Ind Hyg; 4: 61–8.

Hewett P, Ganser G. (2007) A comparison of several methods for analyzing censored data. Ann Occup Hyg; 51: 611–32.

Hewett P, Logan P, Mulhausen J *et al.* (2006) Rating exposure control using Bayesian decision analysis. J Occup Environ Hyg; 3: 568–81.

Hubbard DW. (2007) How to measure anything—finding the value of "intangibles" in business. John Wiley & Sons.

Ignacio J and Bullock B, editors. (2006) A strategy for assessing and managing occupational exposures. 3rd edn. Fairfax, VA: AIHA Press.

Jayjock MA. (1997) Uncertainty analysis in the estimation of

Kahneman D, Slovic P, Tversky A. (1982) Judgment under uncertainty: heuristics and biases. Cambridge, UK: Cambridge University Press.

Kahneman D, Tversky A. (1973) On the psychology of prediction. Psychol Rev; 80: 237–251.

Kahneman D, Tversky A. (1979) Prospect theory: an analysis of decision under risk. Econometrica; 47: 263–91.

ment between qualitative exposure estimates and quantitative exposure measurements. Am J Ind Med; 12: 551–62.

Macaluso M, Delzell E, Rose V *et al.* (1993) Inter-rate agreement in the assessment of solvent exposure at a car assembly plant. Am Ind Hyg Assoc J; 54: 351–9.

Meyer MA, Booker JM. (2001) Eliciting and analyzing expert judgment—a practical guide. Society for American Statistical Association–Industrial and Applied Mathematics.

Mulhausen J and Damiano J, editors. (1998) A strategy for assessing and managing occupational exposures. 2nd edn. Fairfax, VA: AIHA Press.

Nicas M. (2003) An impractical emphasis. The Synergist; 47–52.

Nicas M, Jayjock M. (2002) Uncertainty in exposure estimates made by modeling versus monitoring. Am Ind Hyg Assoc J; 63: 275–83.

Otway H, von Winterfeld D. Expert judgment in risk analysis and management: process, context and pitfalls. Risk Anal; 12: 83–93.

Plous S. (1993) The psychology of judgment and decision making. McGraw, NY: McGraw-Hill.

Post W, Kromhout H, Heederik D *et al.* (1991) Semiquantitative estimates of exposure to methylene chloride and styrene: the influence of quantitative exposure data. Appl Occup Environ Hyg; 6: 197–204. (ref shows that category judgment accuracy increases with more data).

Ramachandran G. (2008) Toward better exposure assessment strategies—the new NIOSH initiative. Ann Occup Hyg; 52: 297–301.

Ramachandran G, Banerjee S, Vincent JH. (2003) Expert judgment and occupational hygiene: application to aerosol speciation in the nickel primary production industry. Ann Occup Hyg; 47: 461–75.

Rock JC. (1986) Can professional judgment be quantified? Am Ind Hyg Assoc J; 47: A370.

Surowiecki J. (2005) The wisdom of crowds. New York: Random House Anchor Books.

Teschke K, Hertzman C, Dimich-Ward H *et al.* (1989) A comparison of exposure estimates by worker raters and industrial hygienists. Scand J Work Environ Health; 15: 424–9.

Walker KD, Catalano P, Hammitt JK *et al.* (2003) Use of expert judgment in exposure assessment: Part 2. Calibration of expert judgments about personal exposures to benzene. J Expo Anal Environ Epidemiol; 13: 1–16.

Walker KD, Macintosh D, Evans JS. (2001) Use of expert judgment in exposure assessment: Part I. Characterization of personal exposure to benzene. J Expo Anal Environ Epidemiol; 11: 308–22.

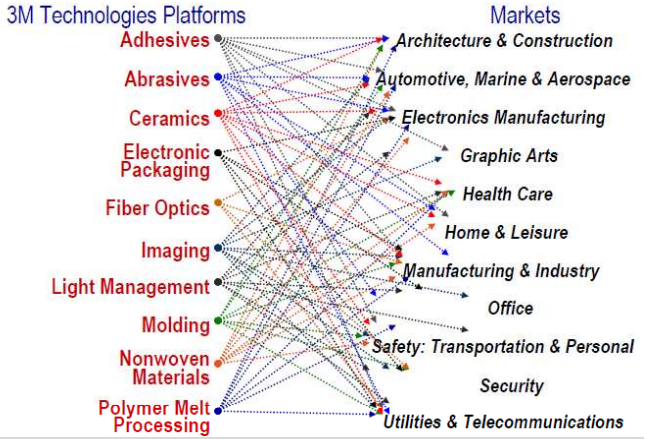
Wild P, Sauleau EA, Bourgkard E *et al.* (2002) Combining expert ratings and exposure measurements: a random effect paradigm. Ann Occup Hyg; 46: 479–87.

Tactical Aspects of Improving Professional Judgment using Bayesian Decision Analysis

3M Overview

- >90,000 employees globally
- >50,000 products
- Many chemistries
- Many technologies
- Many cultures

Technology Platforms…Multiple Markets



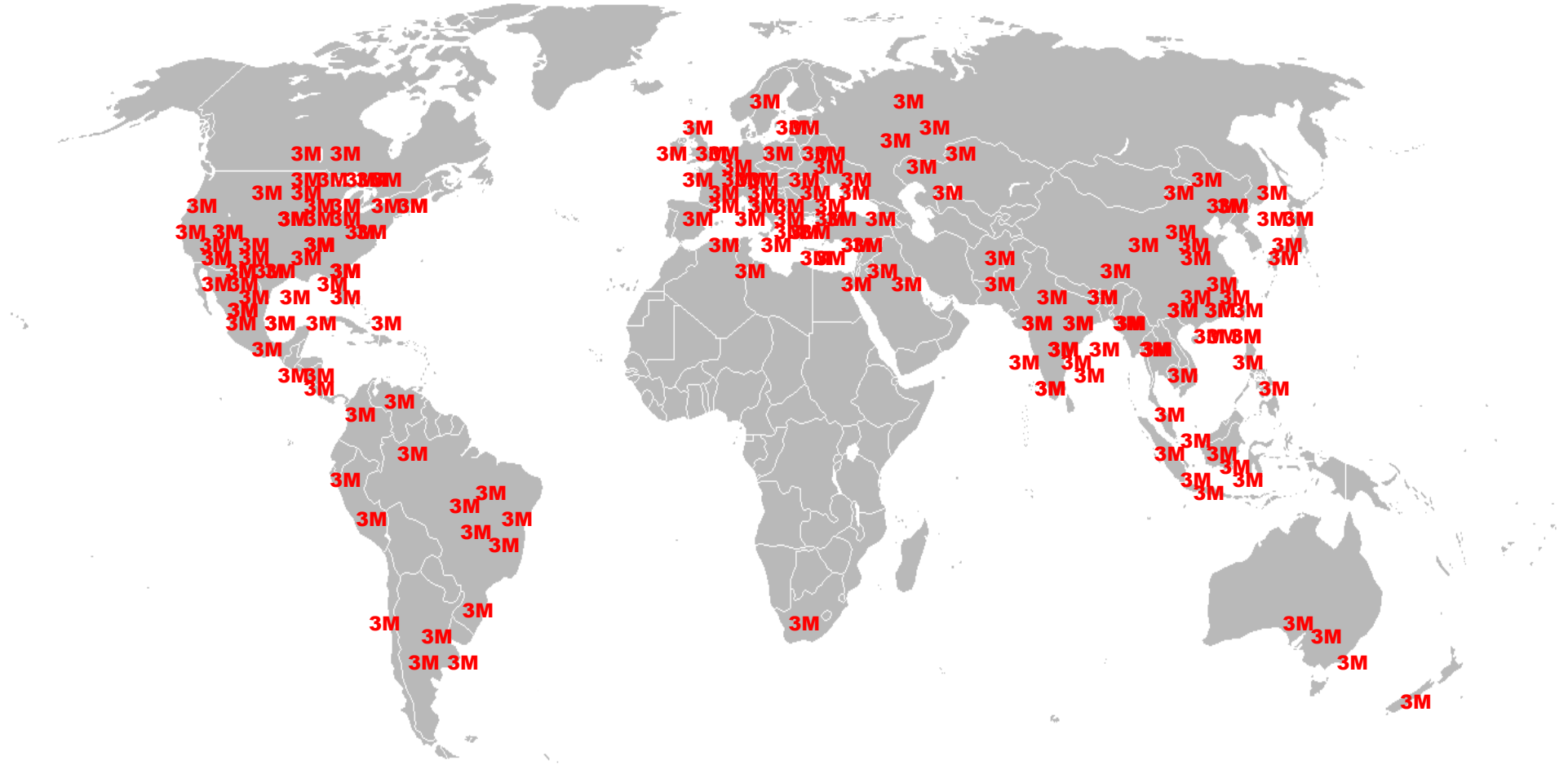
Globalized, Localized R&D

- >3100 technical employees outside U.S.
- Laboratories in 35 countries
- Customer Technology Centers in 25+ countries
- Broad base of technologies leads to customized solutions
- Strong bench-to-bench collaboration
- Localized product and applications development
- Global replication – products, applications, relationships

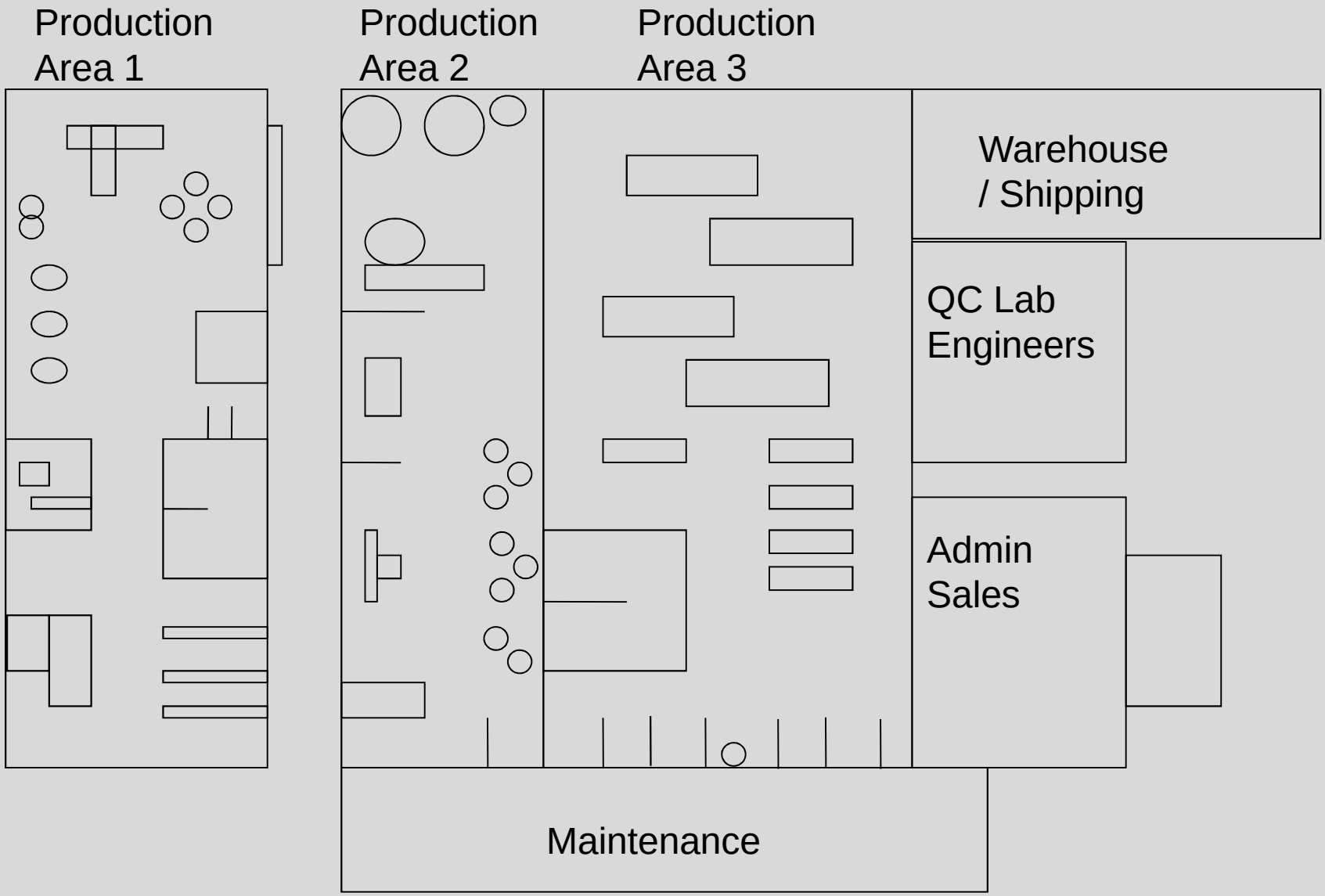
3M's Technology Platforms

Ab Abrasives	Bi Biotech							Pm Polymer Melt Processing	Sm Specialty Materials
Ac Acoustics	Ce Ceramics	Em Electronic Materials					Nt Nano-technology	Po Porous Materials & Membranes	Su Surface Modification
Ad Adhesives	Dd Drug Delivery	Fc Flexible Converting & Packaging				Mi Microbial Detection & Control	Nw Nonwoven Materials	Pp Precision Processing	Tt Track and Trace
Am Advanced Materials	Di Display	Fe Flexible Electronics	Fs Filtration, Separation, Purification	Is Integrated Systems Design	Me Metal Matrix Composites	Mo Molding	Op Opto-electronics	Pr Process Design & Control	Vp Vapor Processing
An Analytical	Do Dental & Orthodontic Materials	Fi Films	Im Imaging	Lm Light Mgmt	Mf Mechanical Fasteners	Mr Micro-replication	Pd Particle & Dispersion Processing	Rp Radiation Processing	We Accelerated Weathering
As Application Software	Ec Energy Components	Fl Fluoro-materials	In Inspection & Measure-ment	Md Medical Data Mgmt			Pe Predictive Engineering & Modeling	Se Sensors	Wo Wound Mgmt

Many Manufacturing, R&D and DC Sites Globally



Consider a Single Production Site



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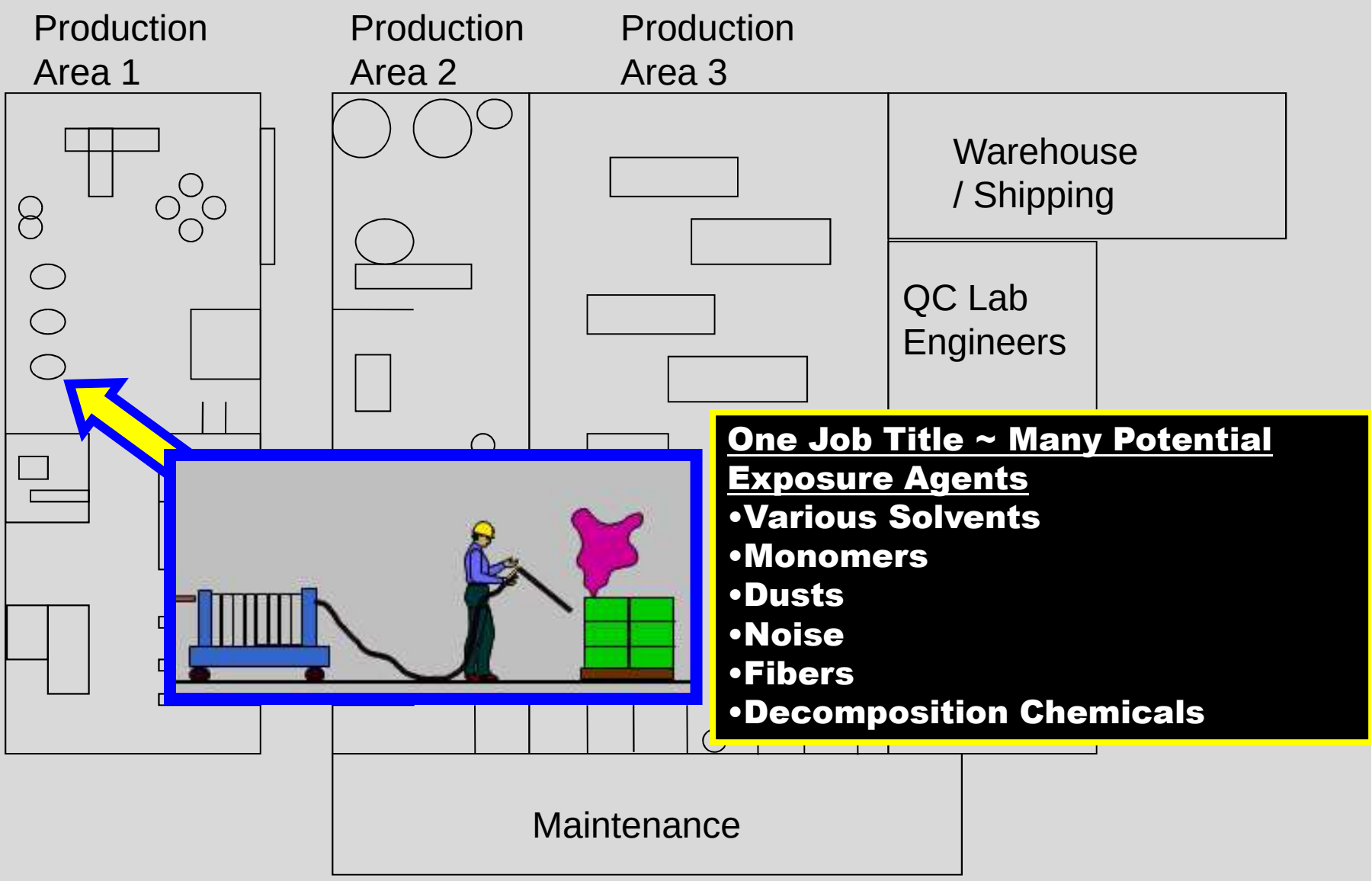
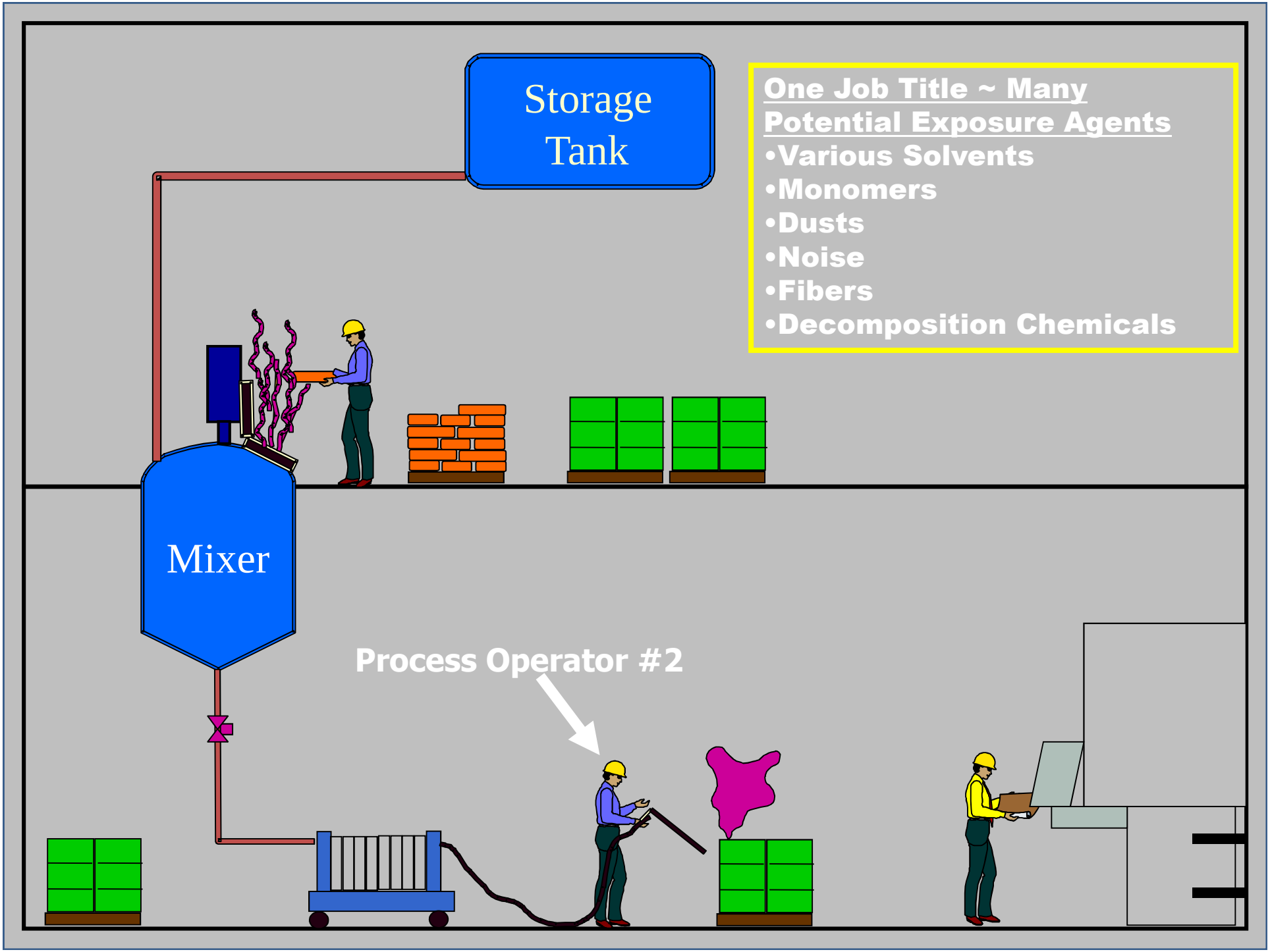
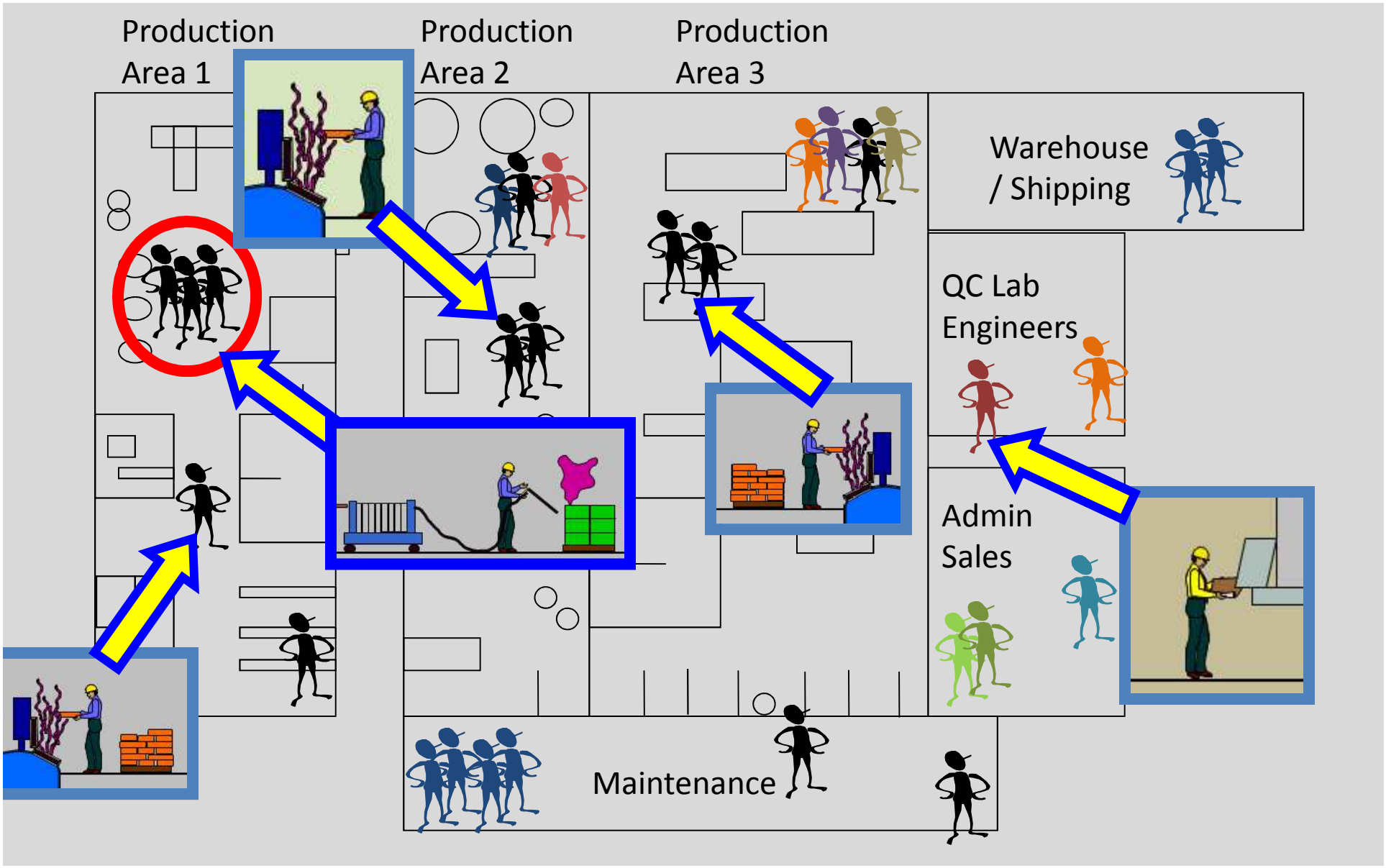
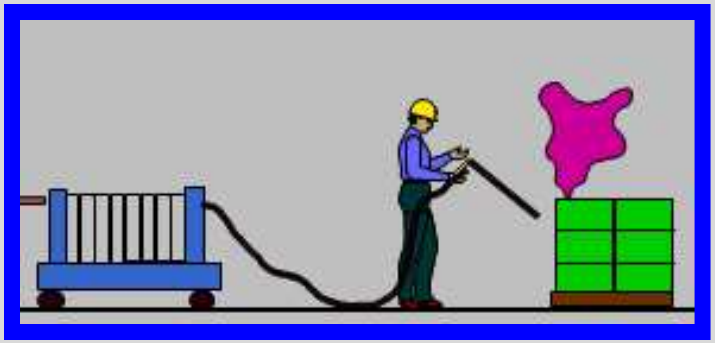



Storage Tank
One Job Title ~ Many Potential Exposure Agents
•Various Solvents
•Monomers
•Dusts
•Noise
•Fibers
•Decomposition Chemicals
Mixer
Process Operator #2

Assess Exposure Risks for All Groups of Workers & All Agents



Comprehensive Exposure Risk Assessment & Management



	1	2	3	4	5	6	7
	Hours / Day	# of Shifts / Day	Total # Employees	# of Chemicals	Average # of Chemicals per Step	# of Different Exposure Jobs / Tasks	# of Chemical - Job/Task Combinations
Production Area 1	12	2	20	220	25	7	175
Production Area 2	12	2	20	140	8	12	96
Production Area 3	8	3	24	30	4	15	60
Maintenance	8	2	12	250	20	20	400
Warehouse / Shipping	8	2	11	10	2	6	12
Quality Control (QC)	8	3	9	120	6	6	36
Engineering	varies	varies	7	180	8	12	96
Administrative	8	1	8	10	1	3	3
Sales	varies	varies	6	60	4	12	48
Contractors	varies	varies	25	250	10	40	400
			142			133	1326

Utilize systems to do efficient accounting for each work group…

Use BDA Framework to Leverage Existing Sampling Data to Strengthen Qualitative Judgments

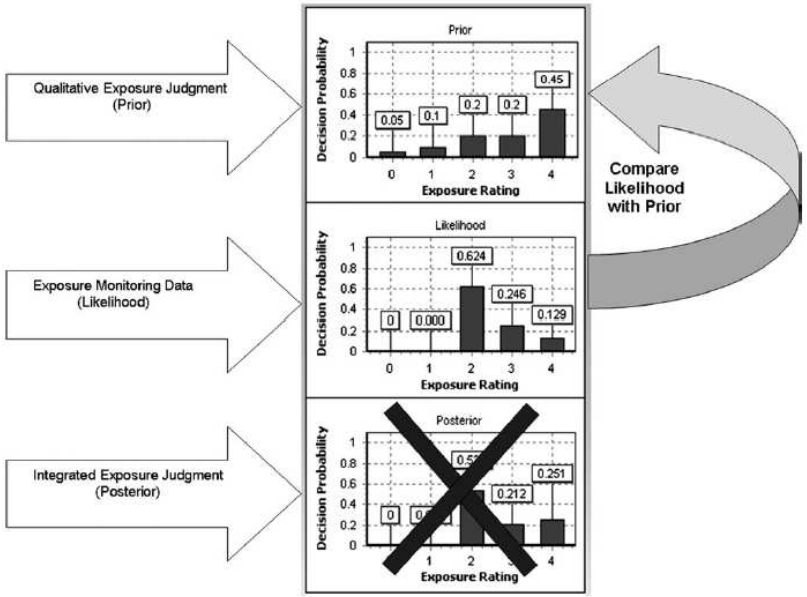


Fig. 2. Bayesian integrated AIHA strategy used to test exposure judgment accuracy. The figure illustrates a method for utilizing the Bayesian integrated AIHA strategy to compare exposure monitoring data analysis (likelihood) with exposure judgments (prior) made by an occupational hygienist for a given SEG.

	1	2	3	4	5	6	7
	Hours / Day	# of Shifts / Day	Total # Employees	# of Chemicals	Average # of Chemicals per Step	# of Different Exposure Jobs / Tasks	# of Chemical - Job/Task Combinations
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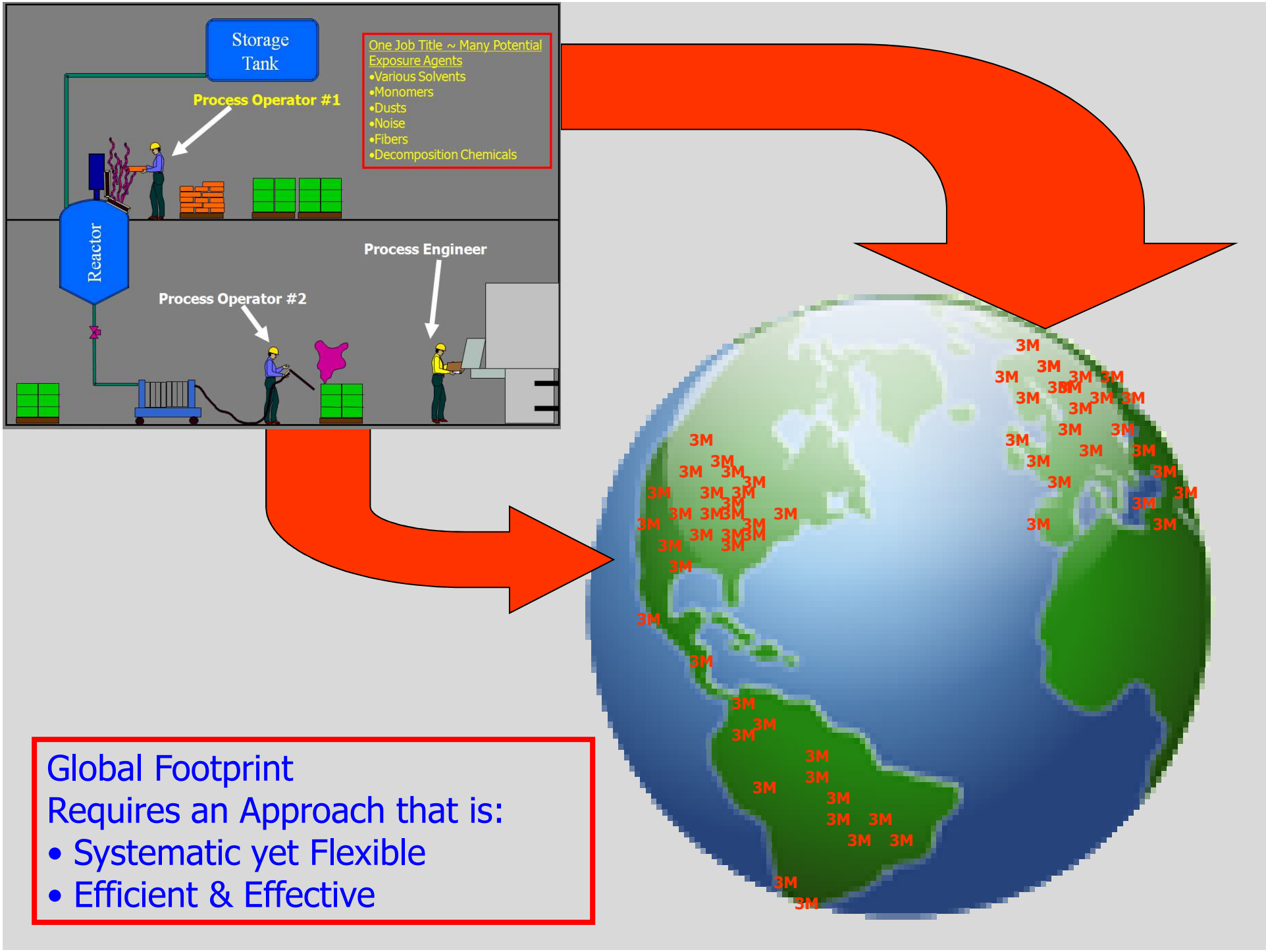
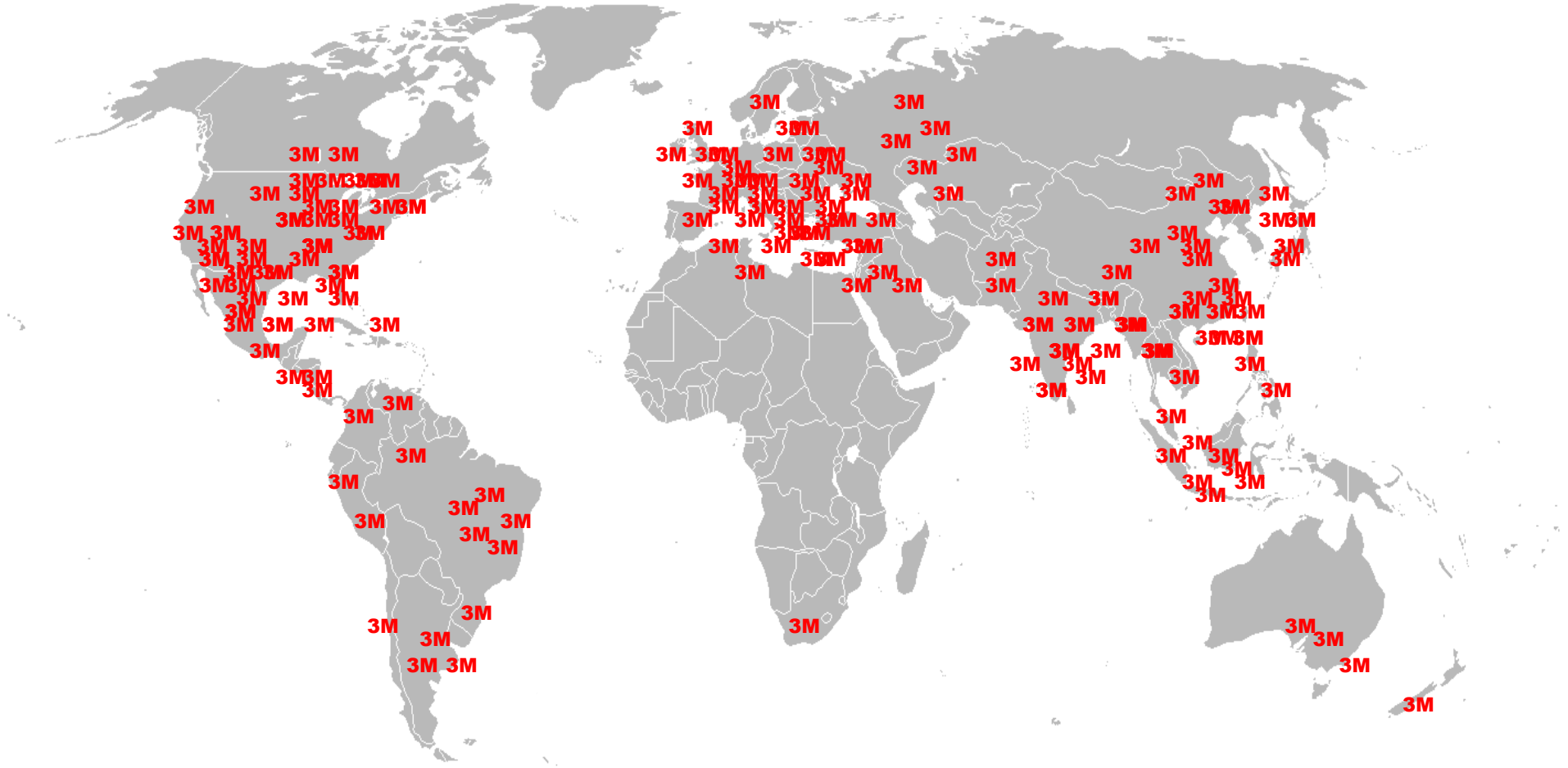
Engineering	varies	varies	7	180	8	12	96
Administrative	8	1	8	10	1	3	3
Sales	varies	varies	6	60	4	12	48
Contractors	varies	varies	25	250	10	40	400
			142			133	1326

1,326 Chemical / Job Task Combinations!


Storage Tank
Process Operator #1
One Job Title ~ Many Potential Exposure Agents
•Various Solvents
•Monomers
•Dusts
•Noise
•Fibers
•Decomposition Chemicals
Reactor
Process Engineer
Process Operator #2
3M
Global Footprint
Requires an Approach that is:
• Systematic yet Flexible
• Efficient & Effective

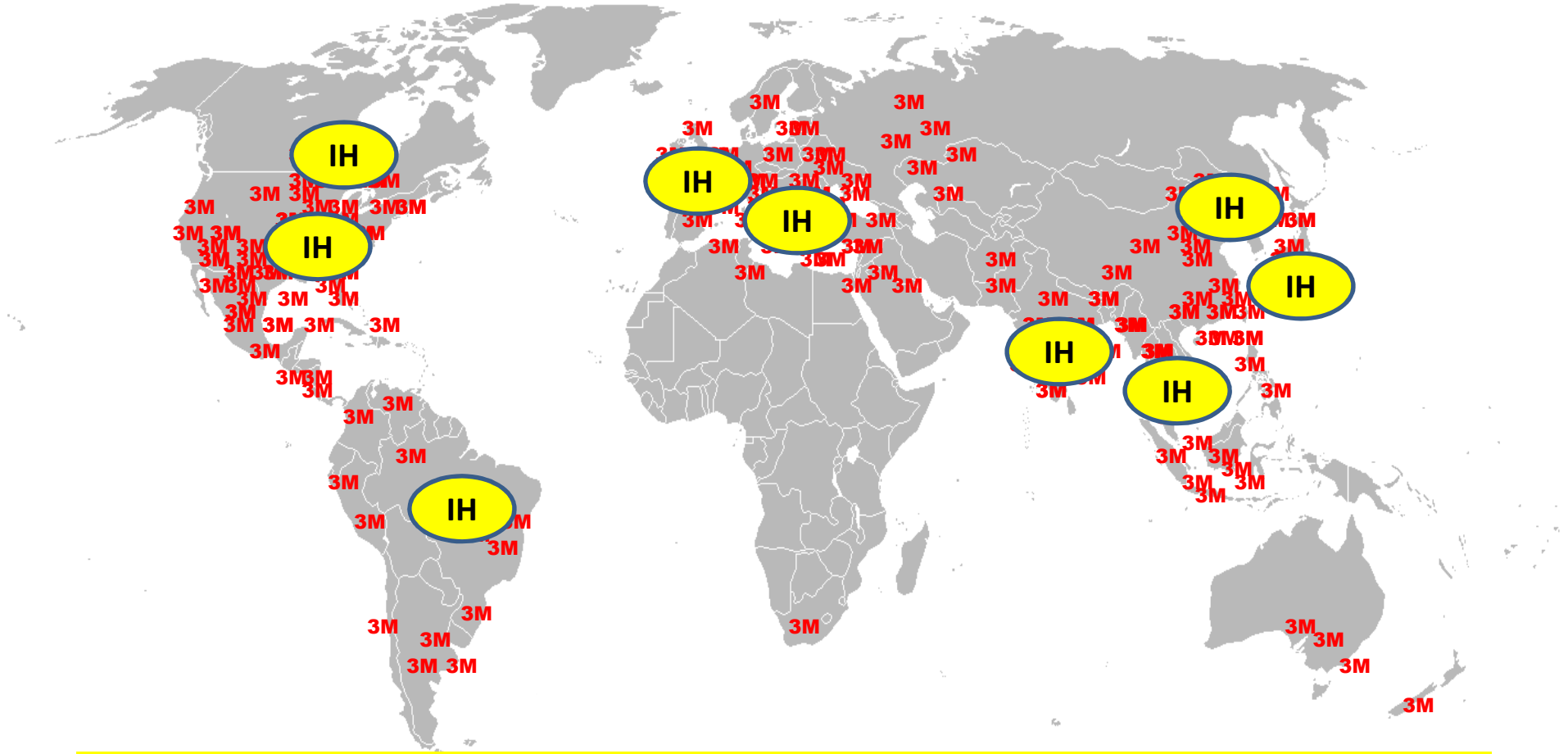
Global IH Success =

1. All EHS Contacts trained to an IH level needed by facility



Global IH Footprint

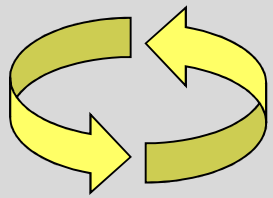
1. **All EHS Contacts trained to a level needed by facility**
2. **Trained IH SME in Critical Locations**

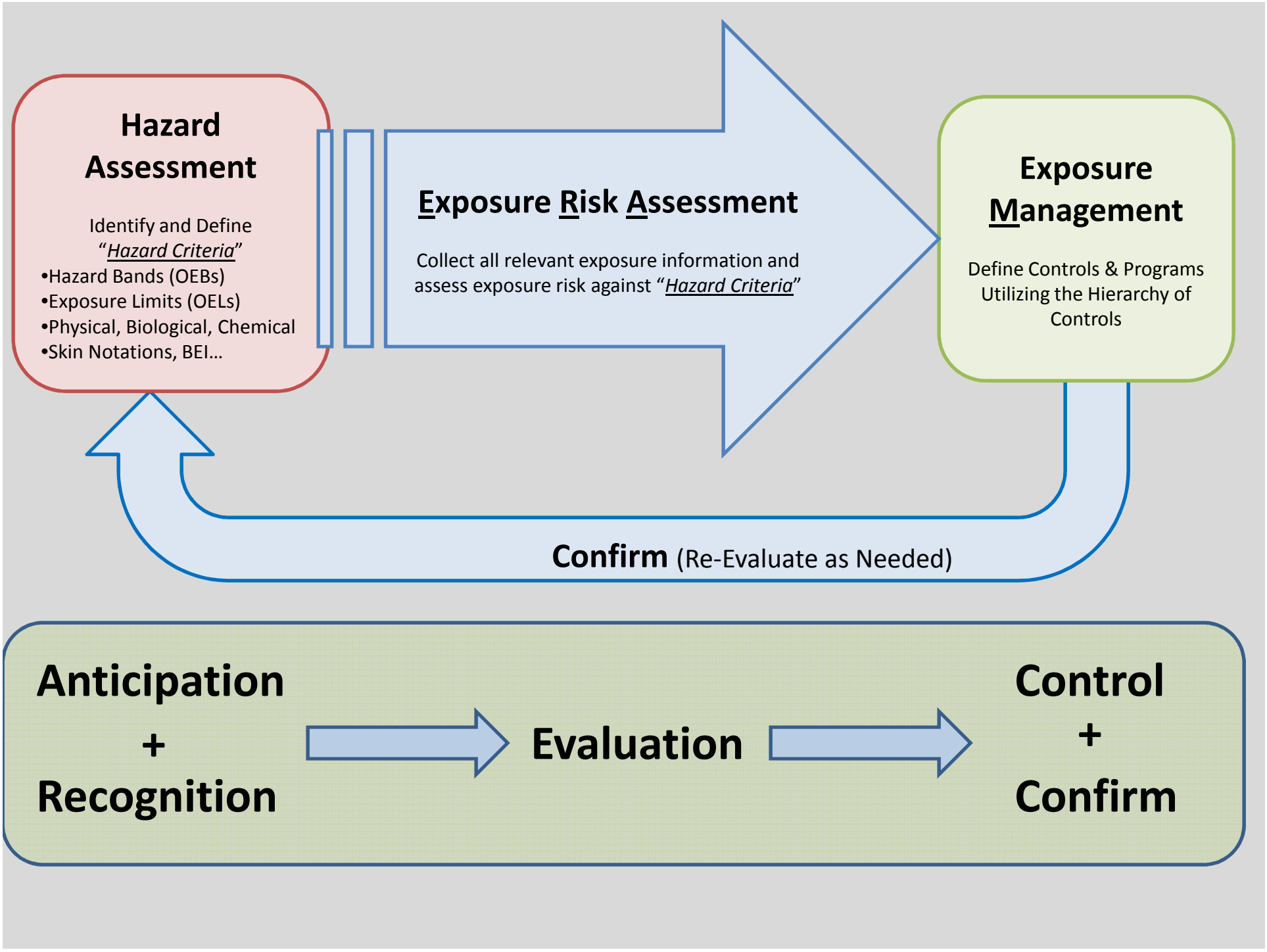


Global IH Team = Network of IH Subject Matter Experts who Support All Sites Globally

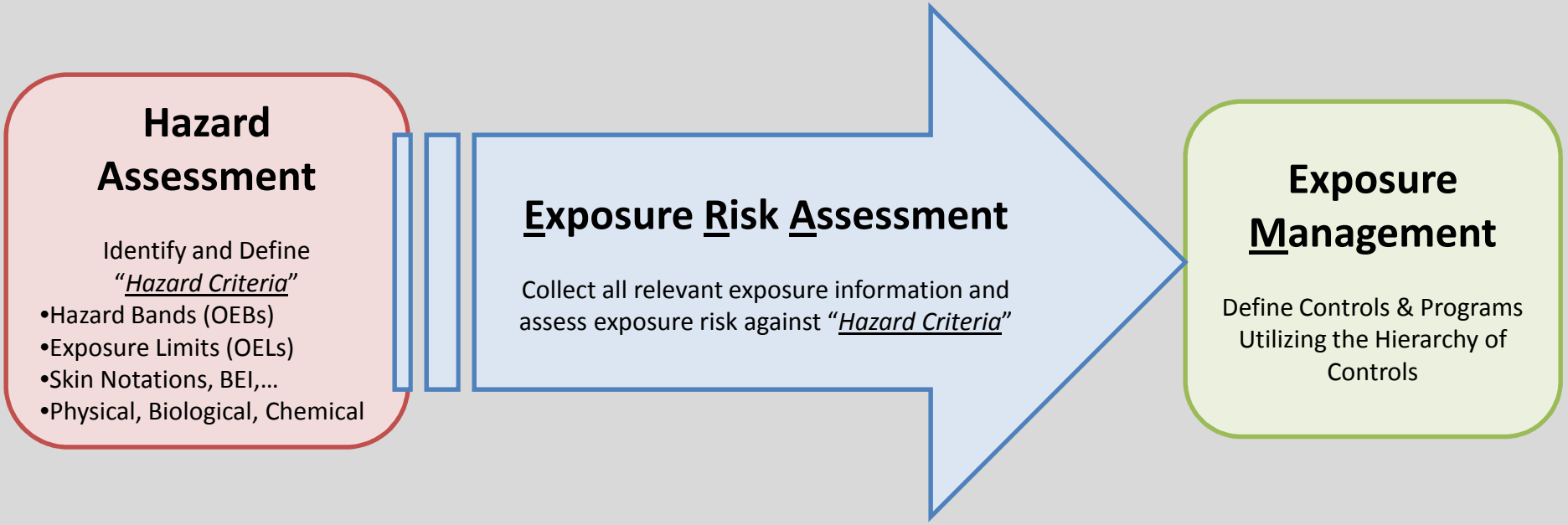
Improving EA Professional Judgments

1. Transparent Feedback Mechanisms
   - **Document judgments & model inputs, use IH BDA tools, DIT Exercises, IH-MOD Modeling Tool, learn from good and bad judgments**
2. Specialized Tools and Training
   - **PDCs, Software Tools, Webmeetings, Workshops, ERAM Apps**
3. Peer & "Expert" Coaching
   - **Workplace Assessment Teams, Peer Networking, "always hang out with people smarter and better looking that you!"**
4. Repeated Practice of Core Judgment Skills
   - **Compare judgments, DIT Exercises, EA Video Games, "Exposure Assessment Training Camps",** Revisit CIH notes, …
   - Enhance skills in chemistry, physics, ventilation, statistics, …




Hazard Assessment
Identify and Define "Hazard Criteria"
•Hazard Bands (OEBs)
•Exposure Limits (OELs)
•Physical, Biological, Chemical
•Skin Notations, BEI…
Exposure Risk Assessment
Collect all relevant exposure information and assess exposure risk against "Hazard Criteria"
Exposure Management
Define Controls & Programs Utilizing the Hierarchy of Controls
Confirm (Re-Evaluate as Needed)
Anticipation + Recognition
Evaluation
Control + Confirm

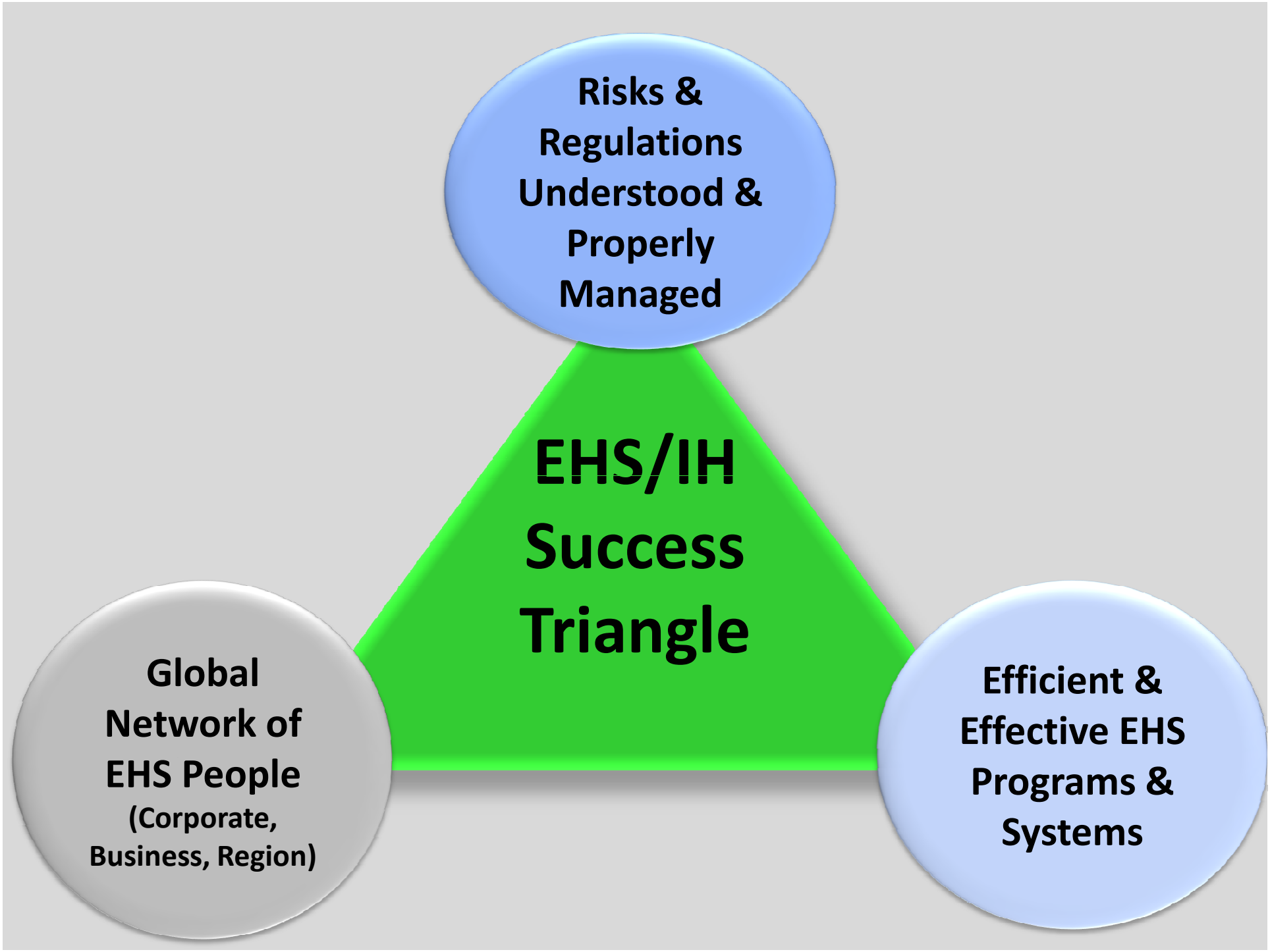
Occupational Hygiene is the Science of Understanding and Managing Exposure Risks



We Must Create Effective Training in CRITICAL Aspects of Each Element

Telewebs, Workshops, ERAM Apps, PDCs, Guidance Documents, White Papers, Synergist Articles, Journal Articles…

Courtesy – AIHA ERAM Working Group


Risks & Regulations Understood & Properly Managed
EHS/IH Success Triangle
Global Network of EHS People (Corporate, Business, Region)
Efficient & Effective EHS Programs & Systems

- “Leadership is needed to take our biggest challenges and turn it into our biggest opportunities…”

Author Unknown

(3) Critical Elements of “Leadership” for Occupational Hygiene

- Technical Leadership Skills
- Individual Leadership Skills
- Organizational Leadership Skills

Thank You!!!

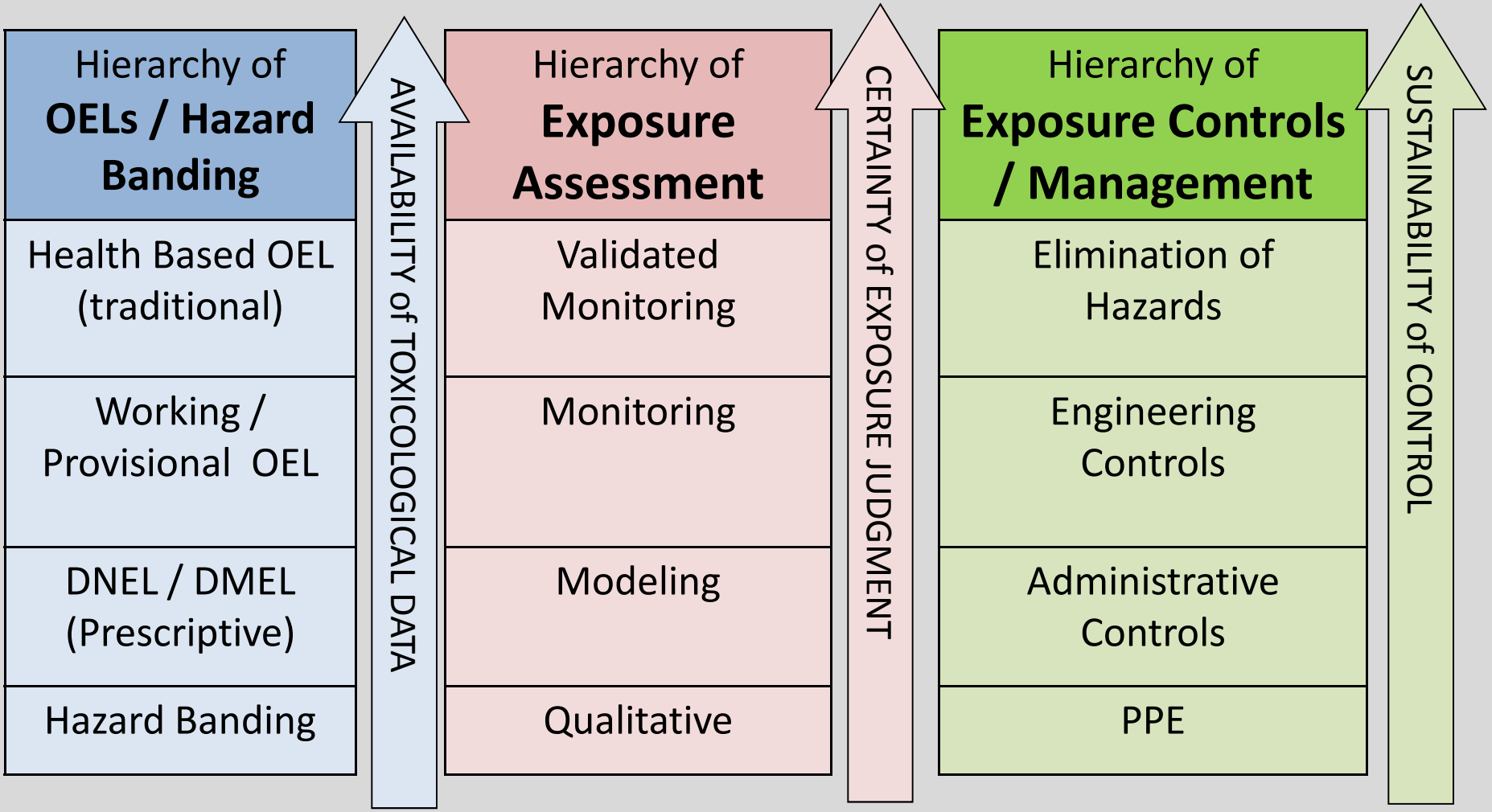
- “Leaders are made, they are not born. “

Vince Lombardi

Hierarchy & Prioritization for Efficient and Effective Exposure Risk Assessment and Management

- Hierarchy of Hazard Information / OELs
- Hierarchy of Exposure Assessment
- Hierarchy of Exposure Controls

Hierarchies for Effective and Efficient Protection of Workers & Communities



Recent "OEL Survey" Illustrates a New Development Opportunity (3rd question)!

We need to create Telewebs, Workshops, PDCs, Apps, …

Response Summary

Total Started Survey: 282
Total Finished Survey: 282 (100%)

PAGE: 2012 AIHCE SCIENCE SYMPOSIUM POLL - USING EXPOSURE LIMITS

1. Does your practice of occupational and environmental health work involve the use of exposure limits (OELs)? Create Chart Download

	ResponsePercent	ResponseCount
Yes, occupational only	73.4%	207
Yes, consumer only	0.7%	2
Yes, occupational and consumer	25.5%	72
No	0.4%	1
AnsweredQuestion		282
SkippedQuestion		0

2. If you answer "yes" to # 1, which of the following limits/guidance do you rely upon? Check all that apply.

Create Chart Download

	ResponsePercent	ResponseCount
ACGIH TLVs	93.6%	264
OSHA PELs	80.5%	227
NIOSH RELs.	57.8%	163
State specific levels	46.5%	131
Hazard banding	7.8%	22
Control banding	13.8%	39
REACH DNELs	11.7%	33
European Union Indicative Limits	15.6%	44
Risk based OELs (often involves modeling)	17.0%	48
None of these.	1.8%	5
	Other (please specify) Show Responses	73
	AnsweredQuestion	282
	SkippedQuestion	0

3. If you responded to more than one item in question #2, do you think you understand the strengths and vulnerabilities of each set of limits/guidance/process?

Create Chart Download

	ResponsePercent	ResponseCount
Yes	57.8%	160
Yes, but I could use more technical training on different types of OELs and their applicability	41.5%	115
No	0.7%	2
AnsweredQuestion		277
SkippedQuestion		5

2012 AIHCE Science Symposium Survey

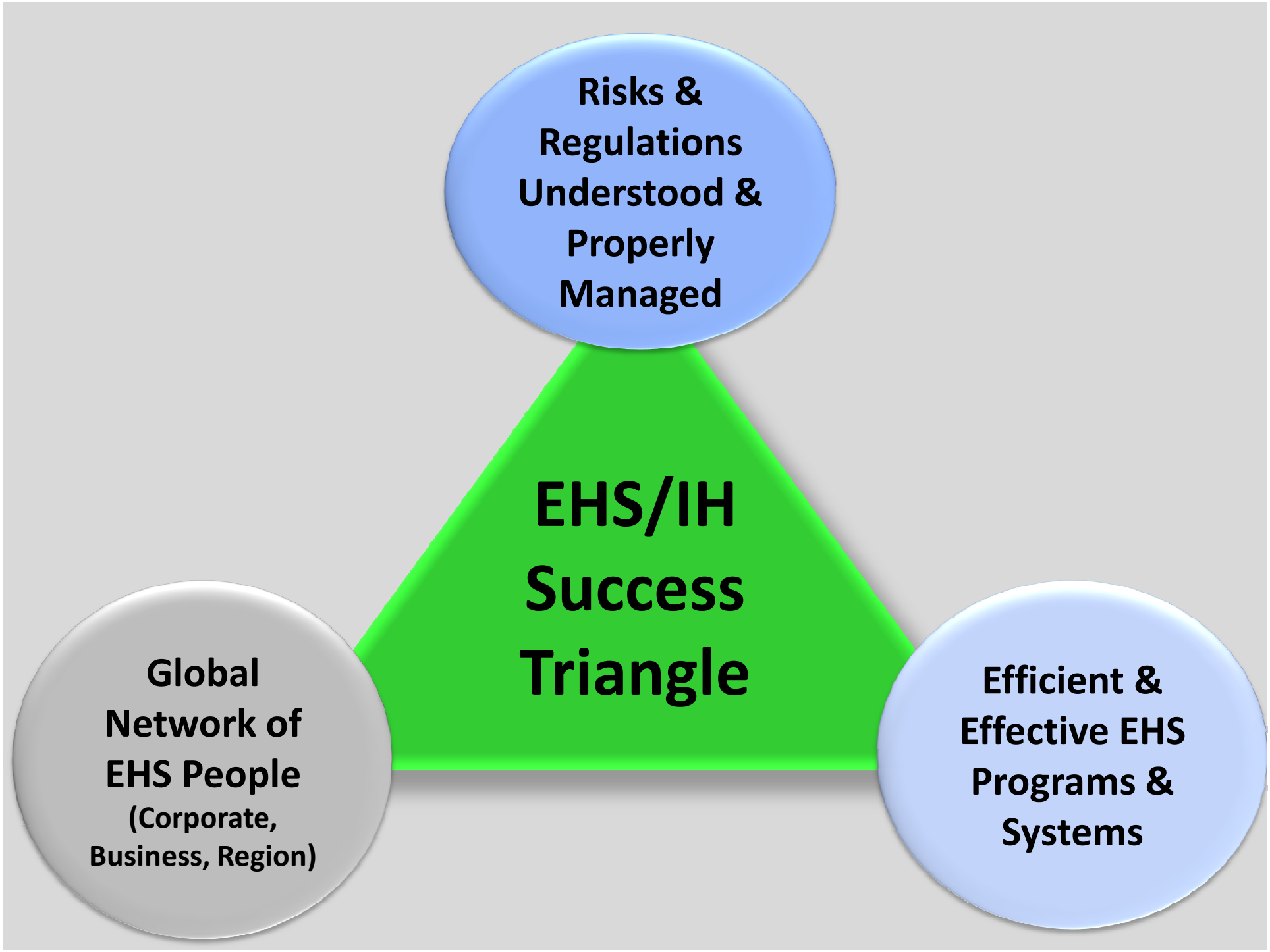
Global Opportunity for Better Understanding OELs!!!

3. If you responded to more than one item in question #2, do you think you understand the strengths and vulnerabilities of each set of limits/guidance/process?

Create Chart Download

	ResponsePercent	ResponseCount
Yes	42.7%	64
Yes, but I could use more technical training on different types of OELs and their applicability	54.0%	81
No	3.3%	5
AnsweredQuestion		150
SkippedQuestion		14

2012 AIOH (Australia) Conference Survey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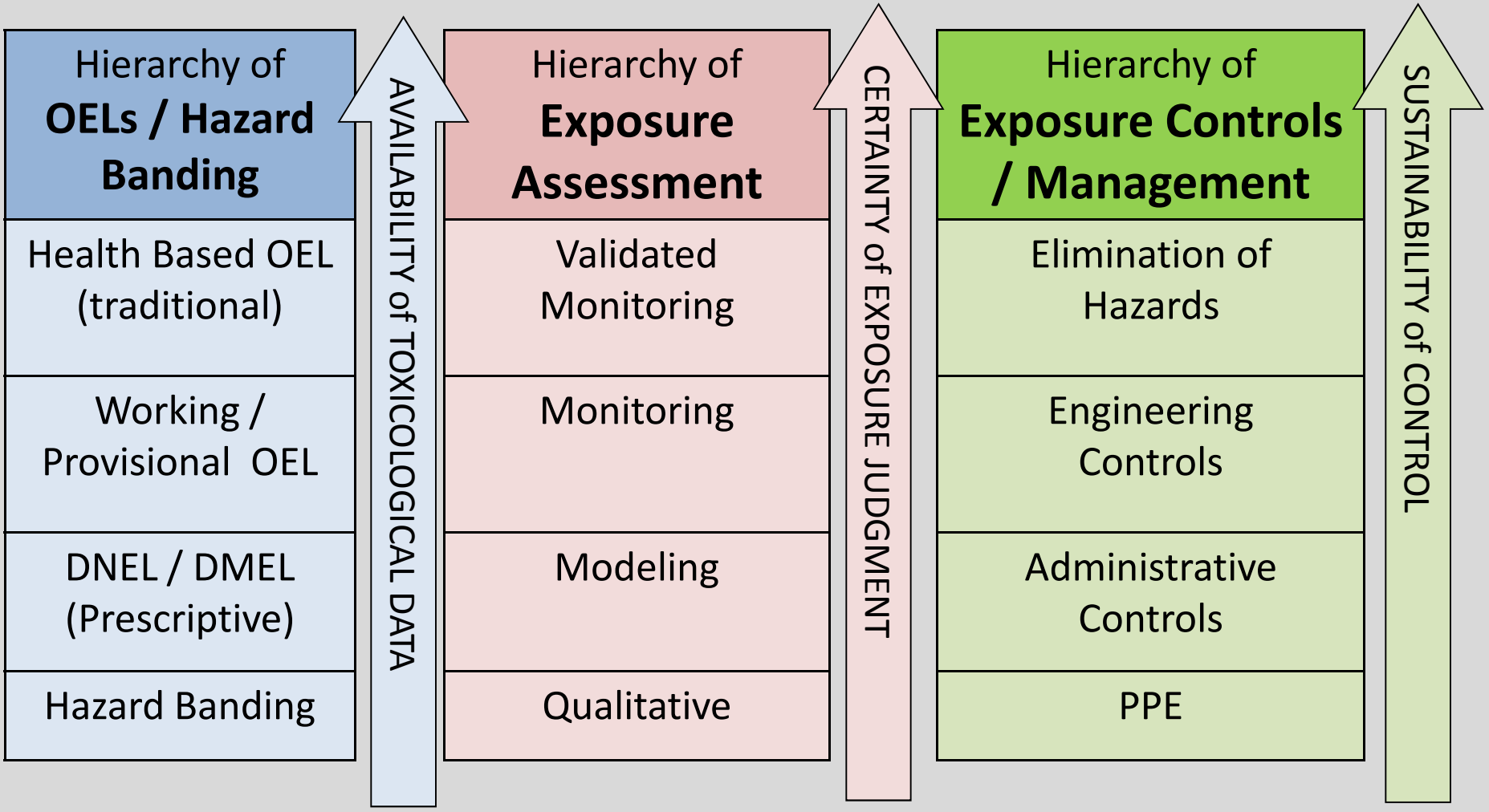
EHS/IH Success Triangle
Global Network of EHS People (Corporate, Business, Region)
Efficient & Effective EHS Programs & Systems

Effective and Efficient
Exposure Risk Assessment and Management (ERAM)

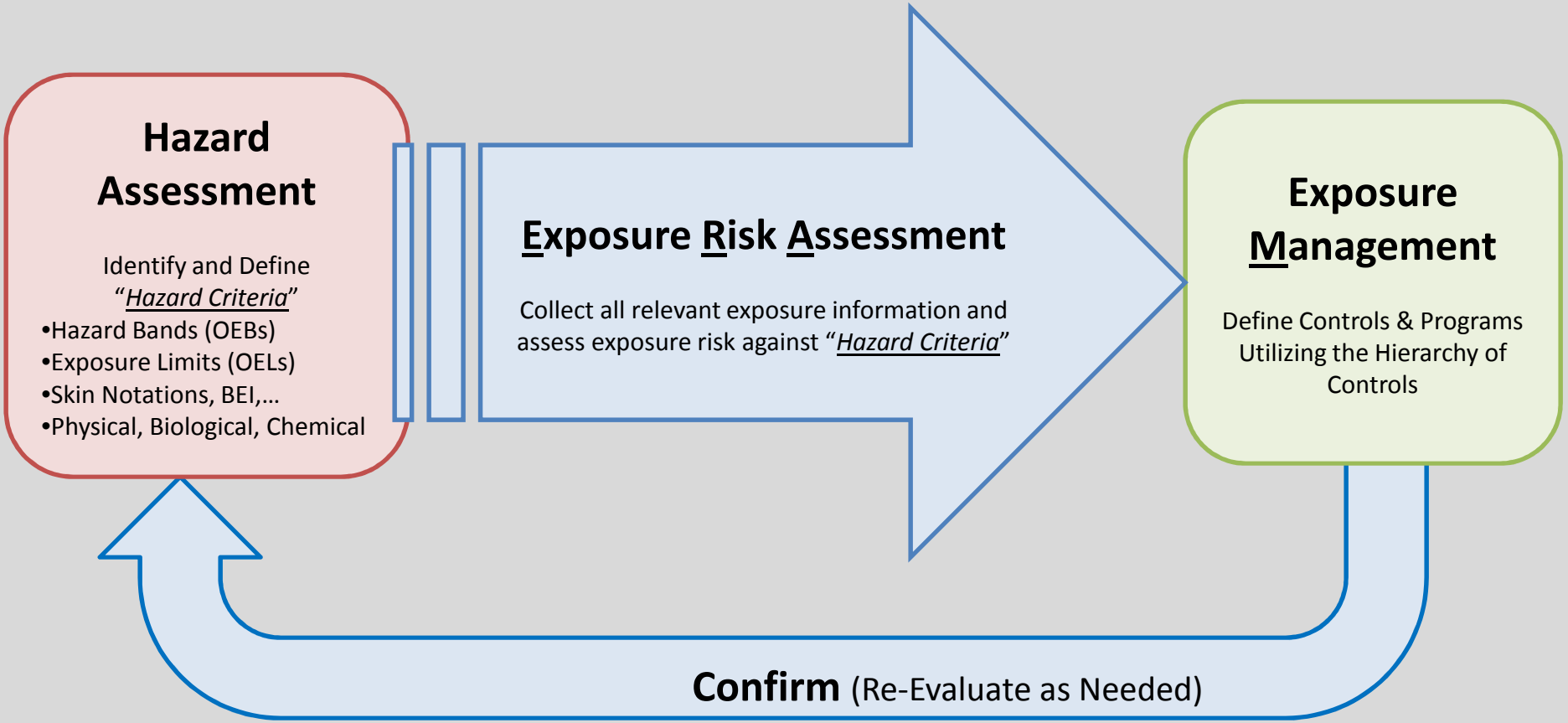
Most Effective / Least Efficient



Least Effective / Most Efficient

Occupational Hygiene is the Science of Understanding and Managing Exposure Risks

(ERAM Model - **E**xposure **R**isk **A**ssessment & **M**anagement)



Courtesy – AIHA ERAM Working Group

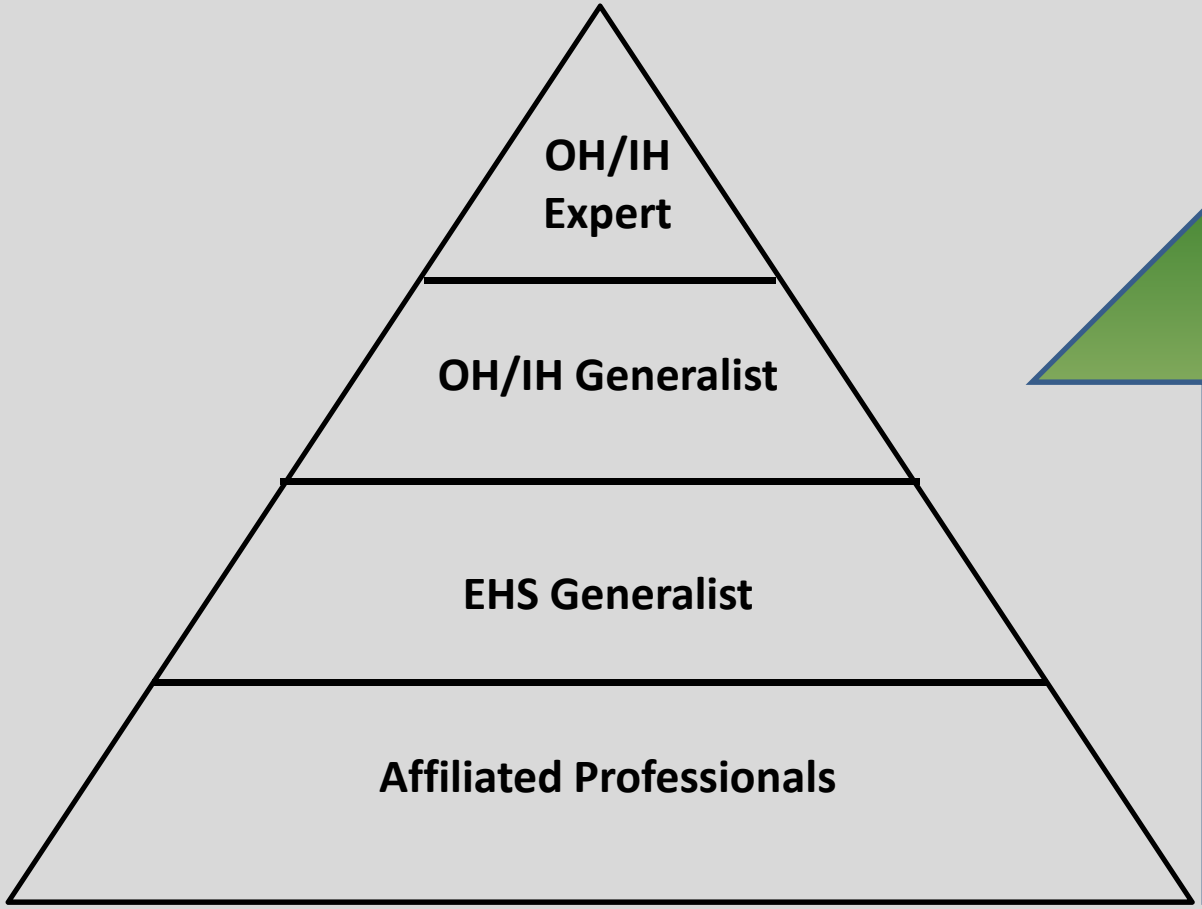
COLUMN | PRESIDENT'S MESSAGE

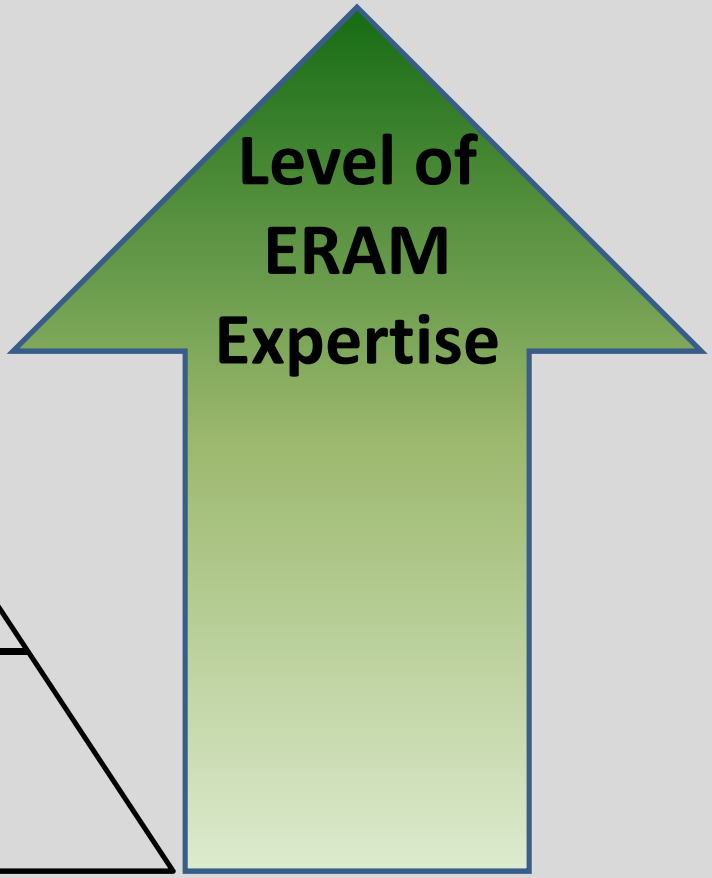
President's Message

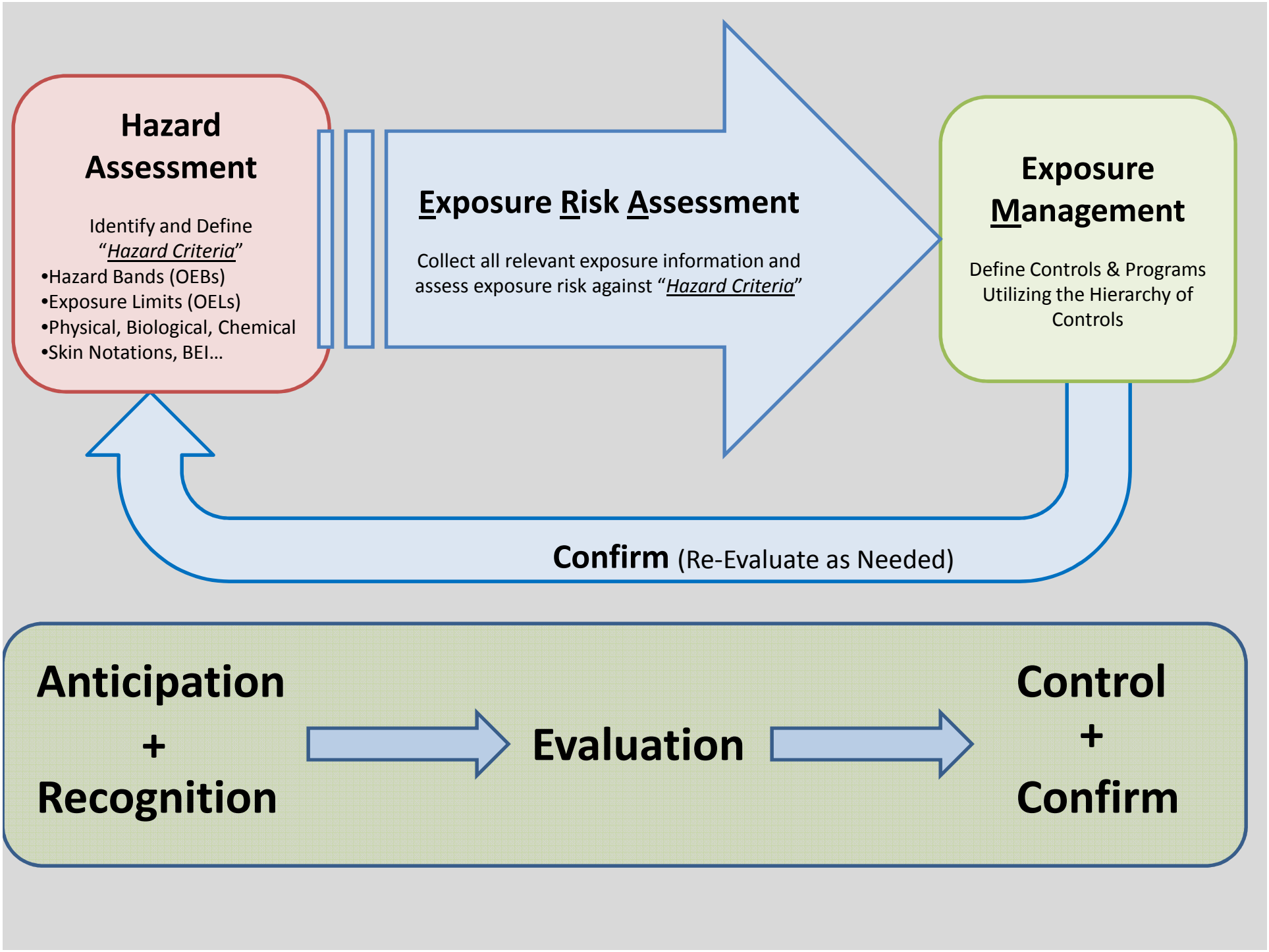
Industrial Hygiene in the 21st Century

BY MICHAEL T. BRANDT, AIHA® PRESIDENT

"OH/IH is an ERAM Discipline Under the Umbrella of Public Health"



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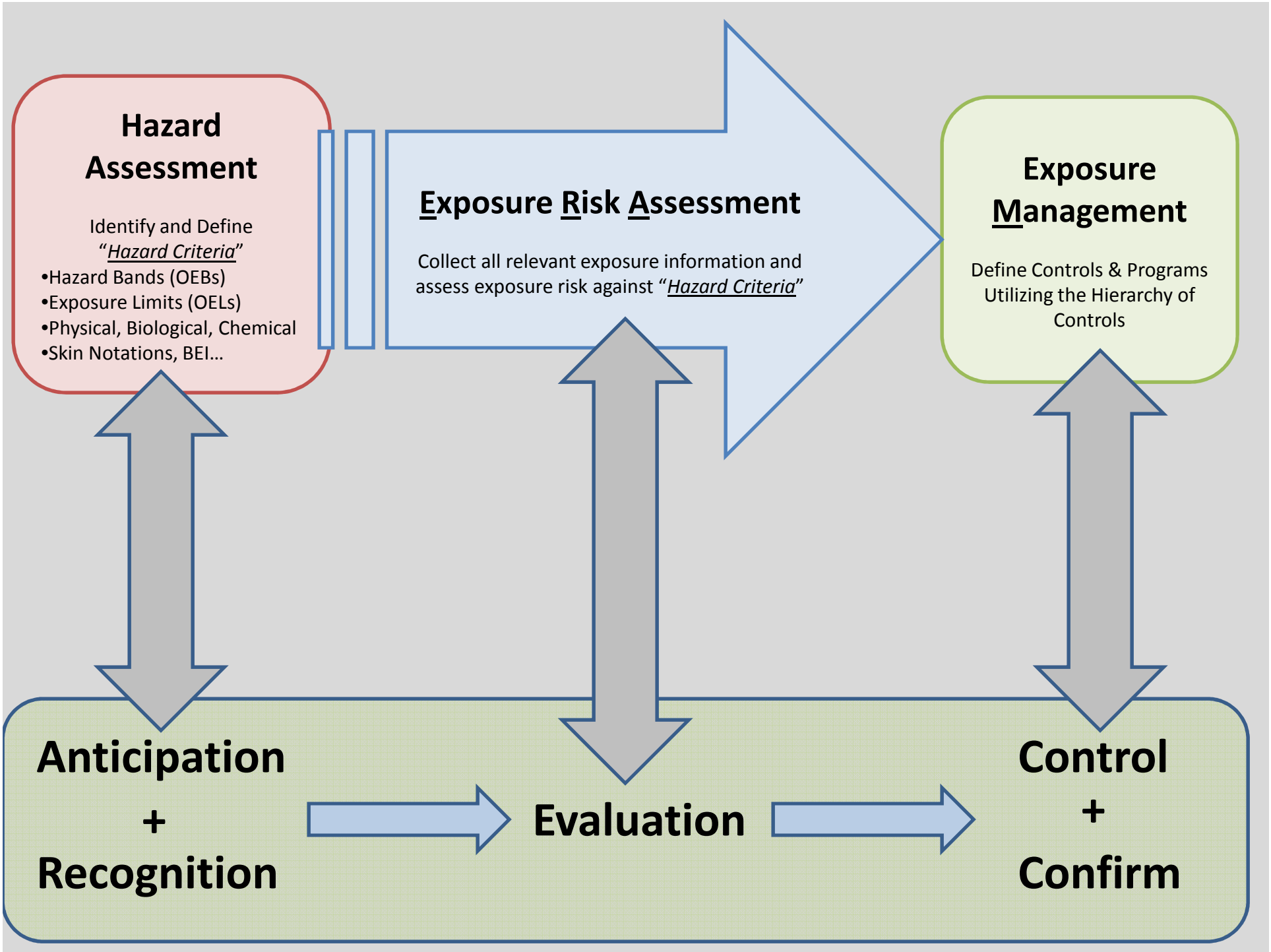
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Top 3 Bayesian Benefits for IH

1. Easily incorporated into the AIHA Strategy Exposure Assessment Control Bands

2. Frames statistical output from sampling data into ***probabilities*** which are more intuitive

3. Transparent framework for understanding & strengthening “professional judgment”

AIHA Strategy
Exposure Assessment Control Bands

	SEG Exposure Control Category**	Recommended Action / Exposure Control Band
	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**

** - Upper Tail Decision statistic = 90^{th}, 95^{th}, 99^{th} percentile

Full Shift Sampling Data (ppm)

25
8
11

Xylene OEL = 100 ppm

Traditional Statistics:

OEL: 100 mg/m^3

Descriptive Statistics

---

mean = 14.7
sd = 9.1
gm = 13.0
gsd = 1.80

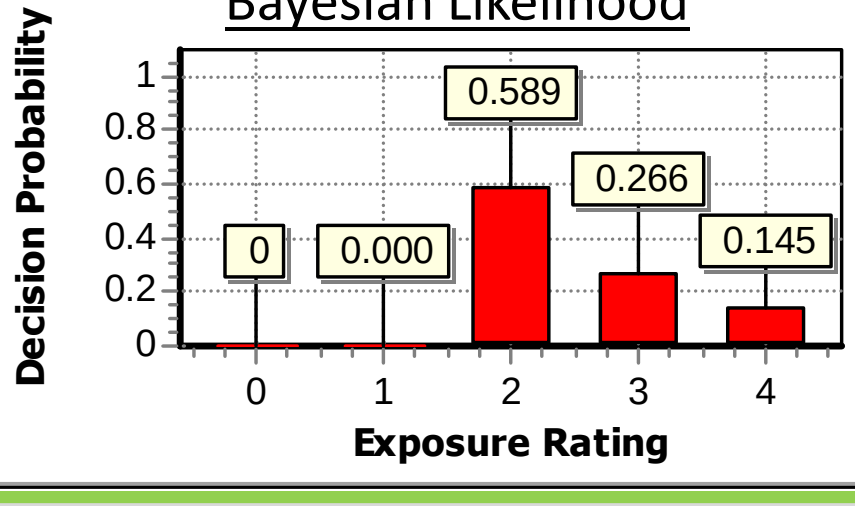
Compliance Statistics (lognormal)

X0.95 = 34.2 95%LCL = 18.9 95%UCL = 1171.8
ExcFrac = 0.00026 95%LCL = <0.001 95%UCL = 0.281

Compliance Statistics (non-parametric)

ExcFrac = 0.000 95%LCL = 0.00 95%UCL = 0.632

Bayesian Likelihood



Bayesian Decision Analysis for IH

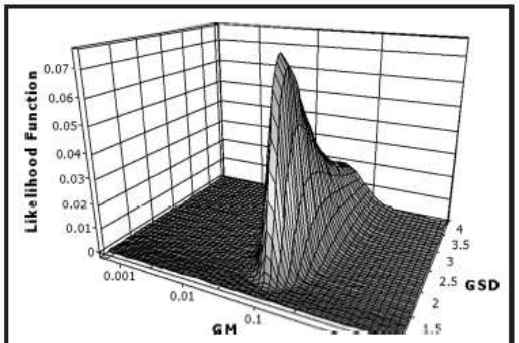


FIGURE 3. The Likelihood Function calculated using Eq. 5 and the example dataset: x = {0.20, 0.05, 0.10}

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DOI: 10.1080/15459620600914641

Rating Exposure Control Using Bayesian Decision Analysis

Paul Hewett,[1] Perry Logan,[2] John Mulhausen,[2] Gurumurthy Ramachandran,[3] and Sudipto Banerjee[3]

[1]Exposure Assessment Solutions, Inc., Morgantown, West Virginia
[2]3M, Minneapolis, Minnesota
[3]University of Minnesota, Minneapolis, Minnesota

A model is presented for applying Bayesian statistical techniques to the problem of determining, from the usual limited number of exposure measurements, whether the exposure profile for a similar exposure group can be considered a Category 0, 1, 2, 3, or 4 exposure. The categories were adapted from the AIHA exposure category scheme and refer to (0) negligible or trivial exposure (i.e., the true $X_{0.95} \leq 1\%$OEL), (1) highly controlled (i.e., $X_{0.95} \leq 10\%$OEL), (2) well controlled (i.e., $X_{0.95} \leq 50\%$OEL), (3) controlled (i.e., $X_{0.95} \leq 100\%$OEL), or (4) poorly controlled (i.e., $X_{0.95} > 100\%$OEL) exposures. Unlike conventional statistical methods applied to exposure data, Bayesian statistical techniques can be adapted to explicitly take into account professional judgment or other sources of information. The analysis output consists of a distribution (i.e., set) of decision probabilities: e.g., 1%, 80%, 12%, 5%, and 2% probability that the exposure profile is a Category 0, 1, 2, 3, or 4 exposure. By inspection of these decision probabilities, rather than the often difficult to interpret point estimates (e.g., the sample 95th percentile exposure) and confidence intervals, a risk manager can be better positioned to arrive at an effective (i.e., correct) and efficient decision. Bayesian decision methods are based on the concepts of prior, likelihood, and posterior distributions of decision probabilities. The prior decision distribution represents what an industrial hygienist that either a significant process change has occurred or the industrial hygienist's initial judgment was incorrect. In either case, the industrial hygienist should readjust his judgment regarding this operation.

Keywords Bayesian statistics, exposure assessment, exposure rating

Address correspondence to: Paul Hewett, Exposure Assessment Solutions, Inc., 1270 Kings Road, Morgantown, WV 26508; e-mail: phewett_2006_07@oesh.com.

INTRODUCTION

Industrial hygiene has often been described as both an art and a science. The art component often consists of the application of professional judgment in determining whether occupational exposures are acceptable, relative to some occupational exposure limit (OEL). Professional judgment is

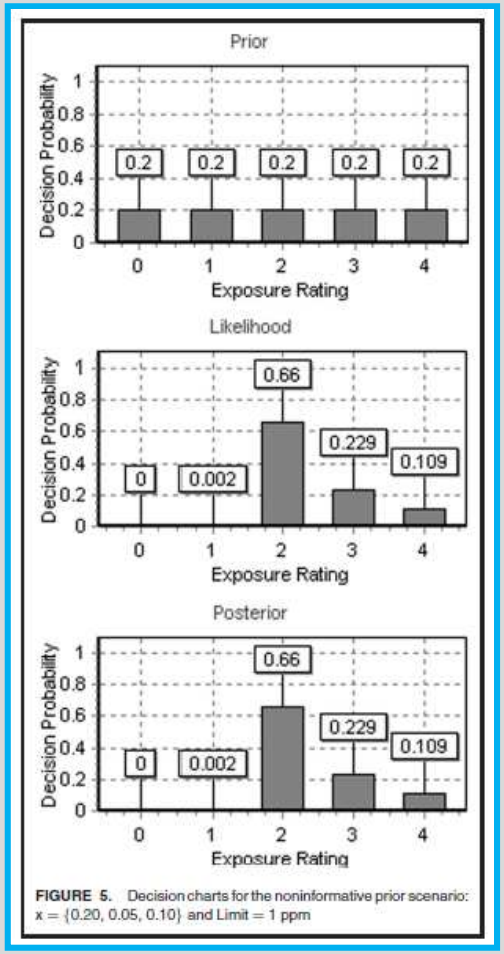


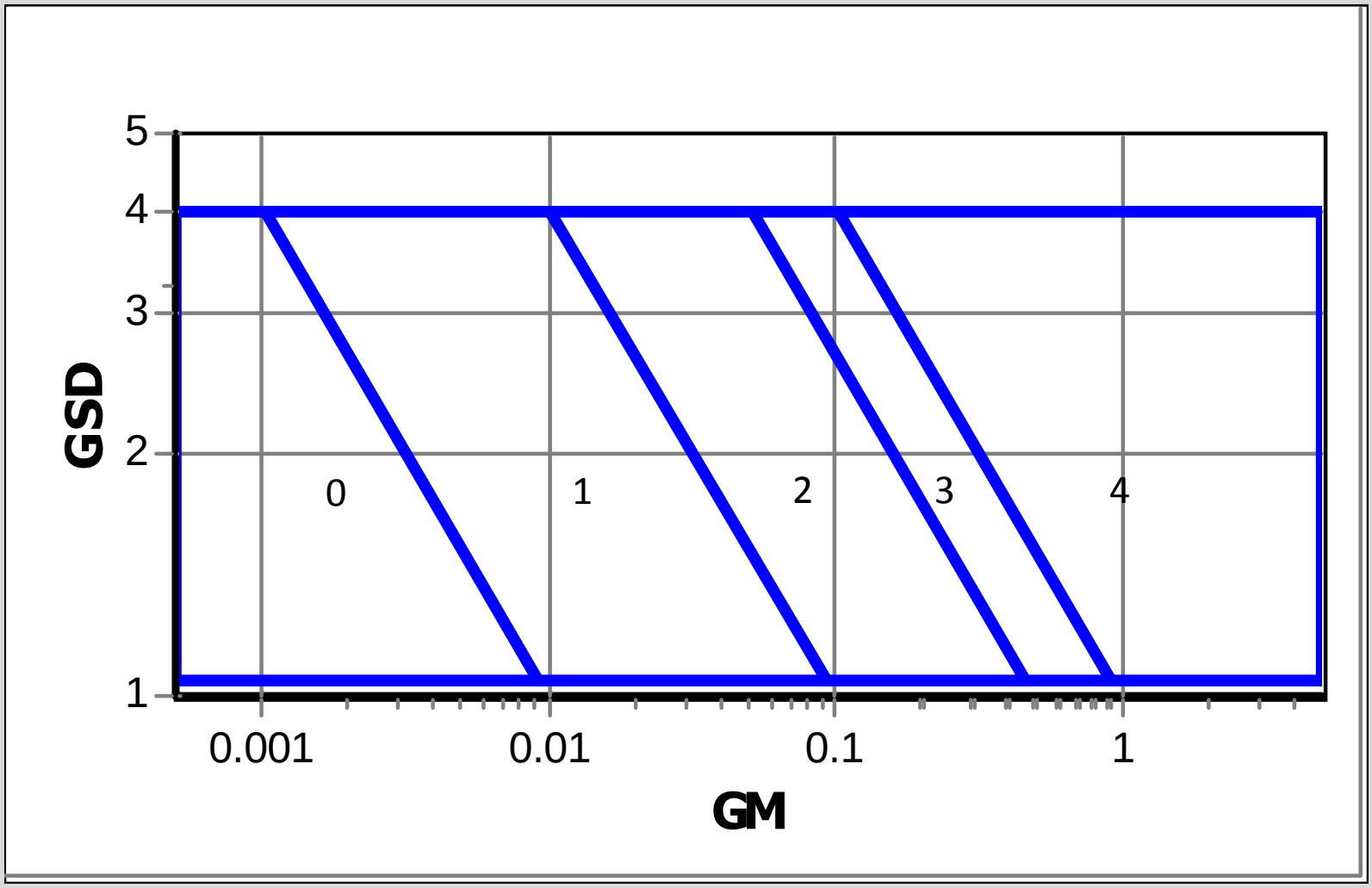
FIGURE 5. Decision charts for the noninformative prior scenario: x = {0.20, 0.05, 0.10} and Limit = 1 ppm

IH Bayesian Decision Analysis

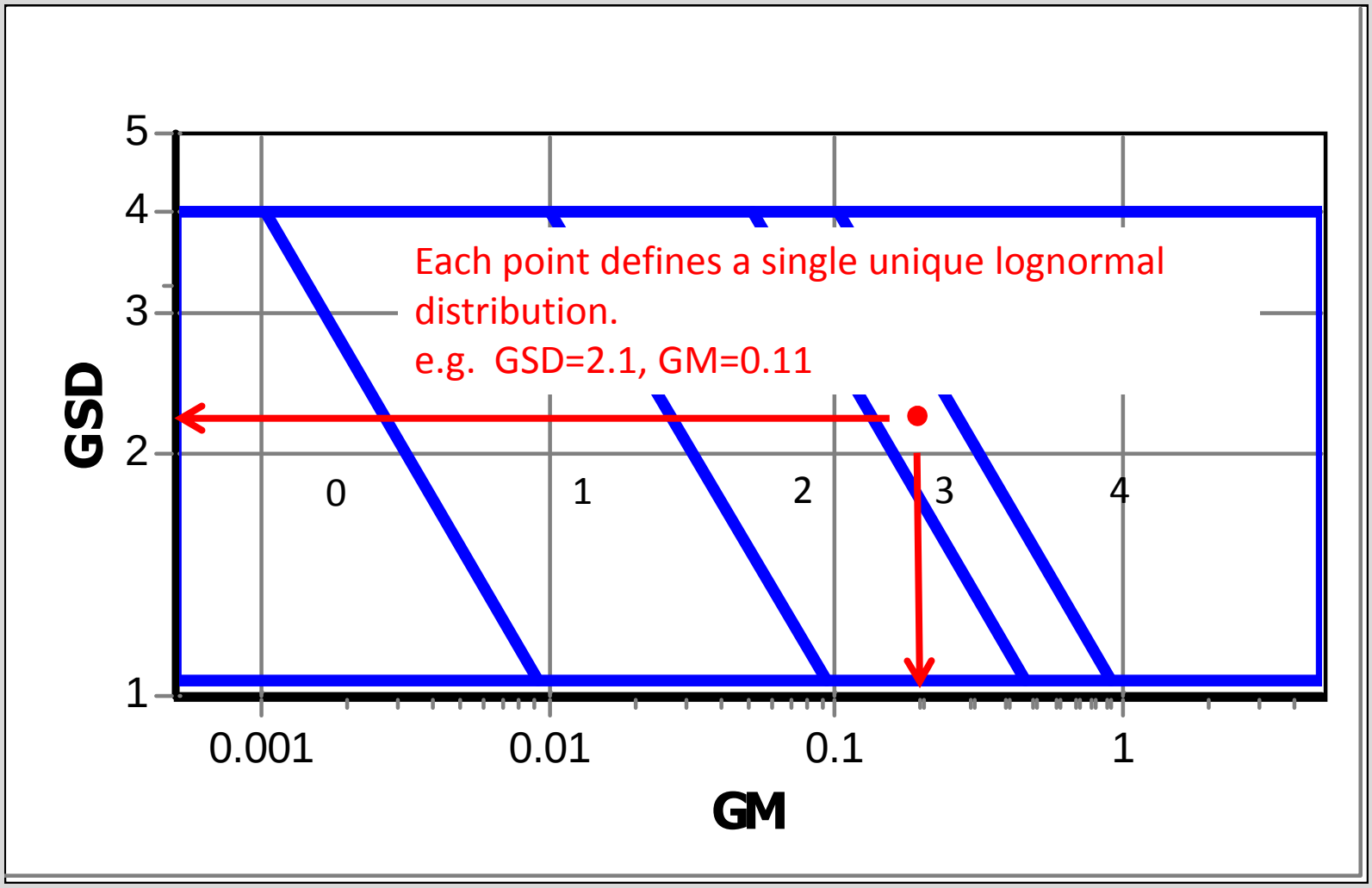
We are interested in distinguishing between five *populations* of exposure profiles: Exposure Zones 0, 1, 2, 3, and 4

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

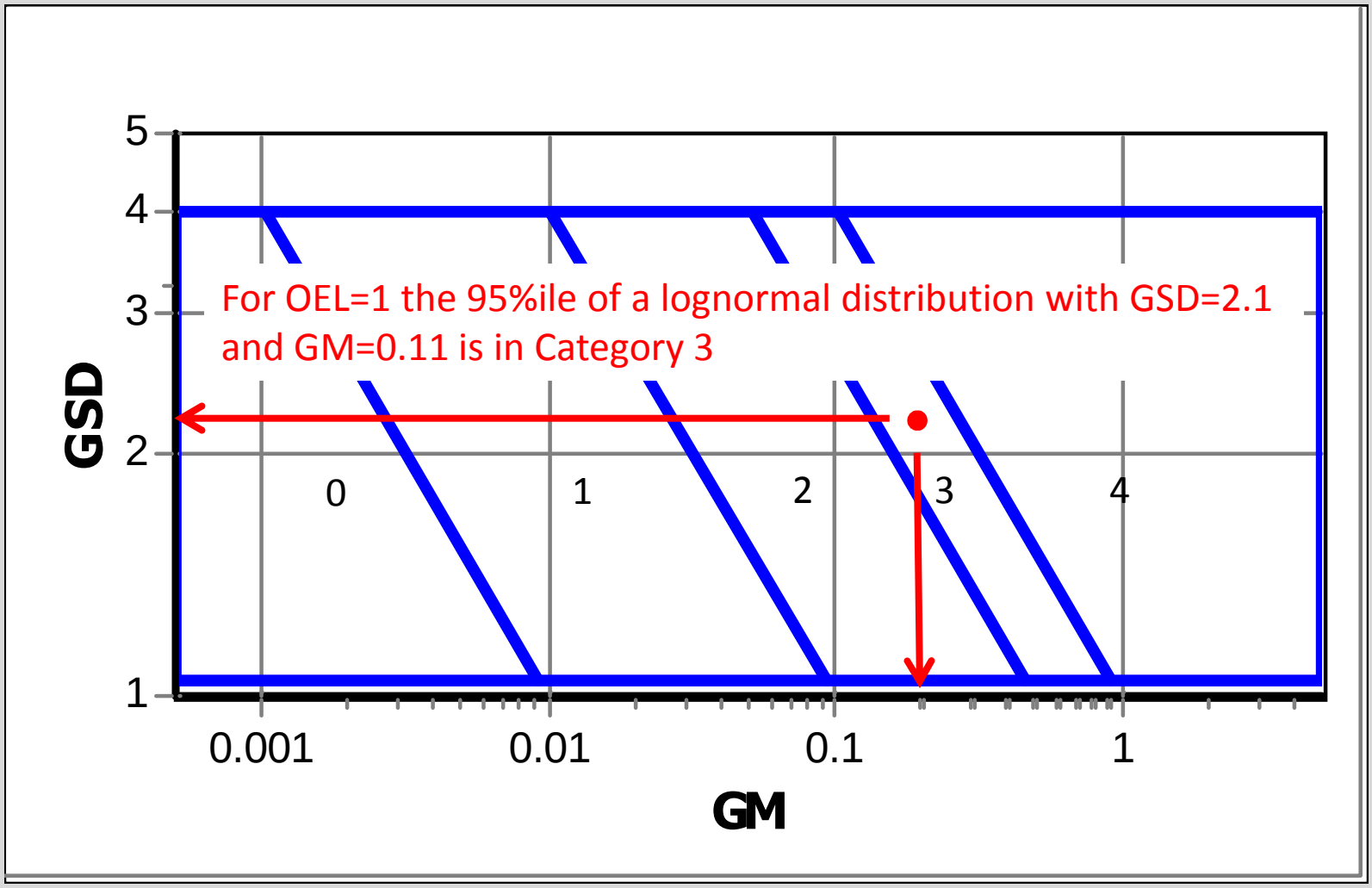
Exposure Ratings translated into *parameter space* for OEL=1ppm

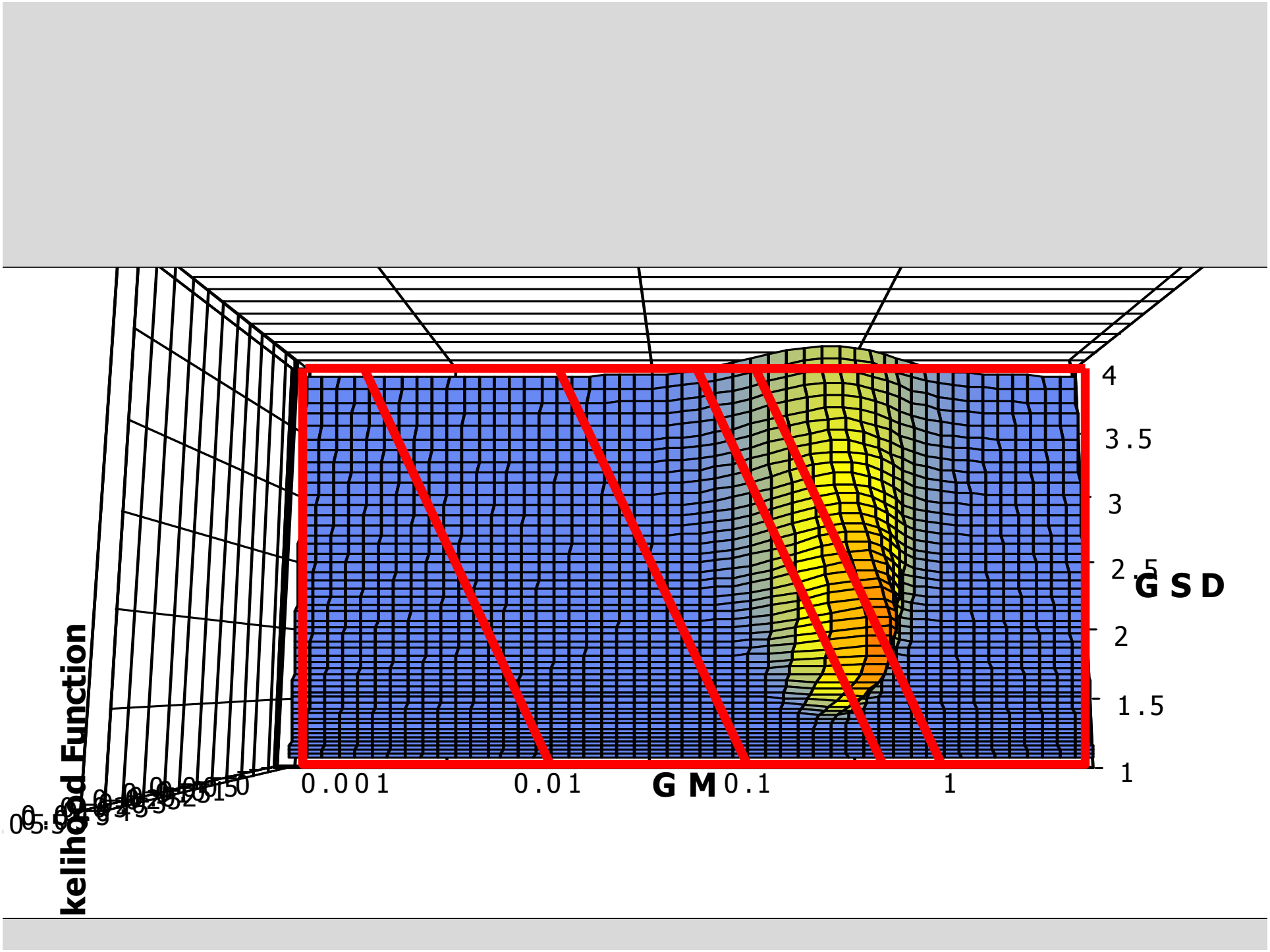


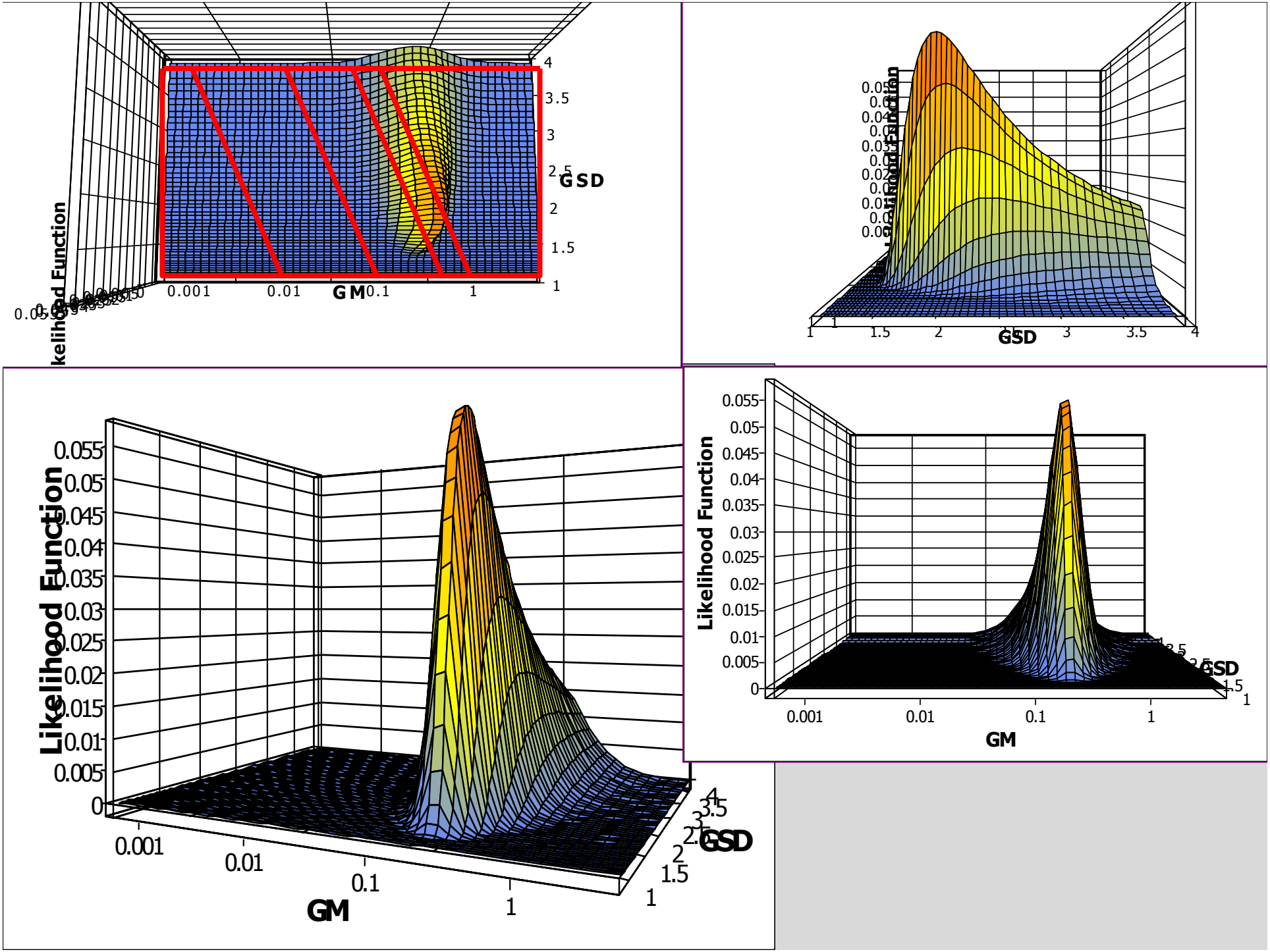
Exposure Ratings translated into *parameter space* for OEL=1ppm



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

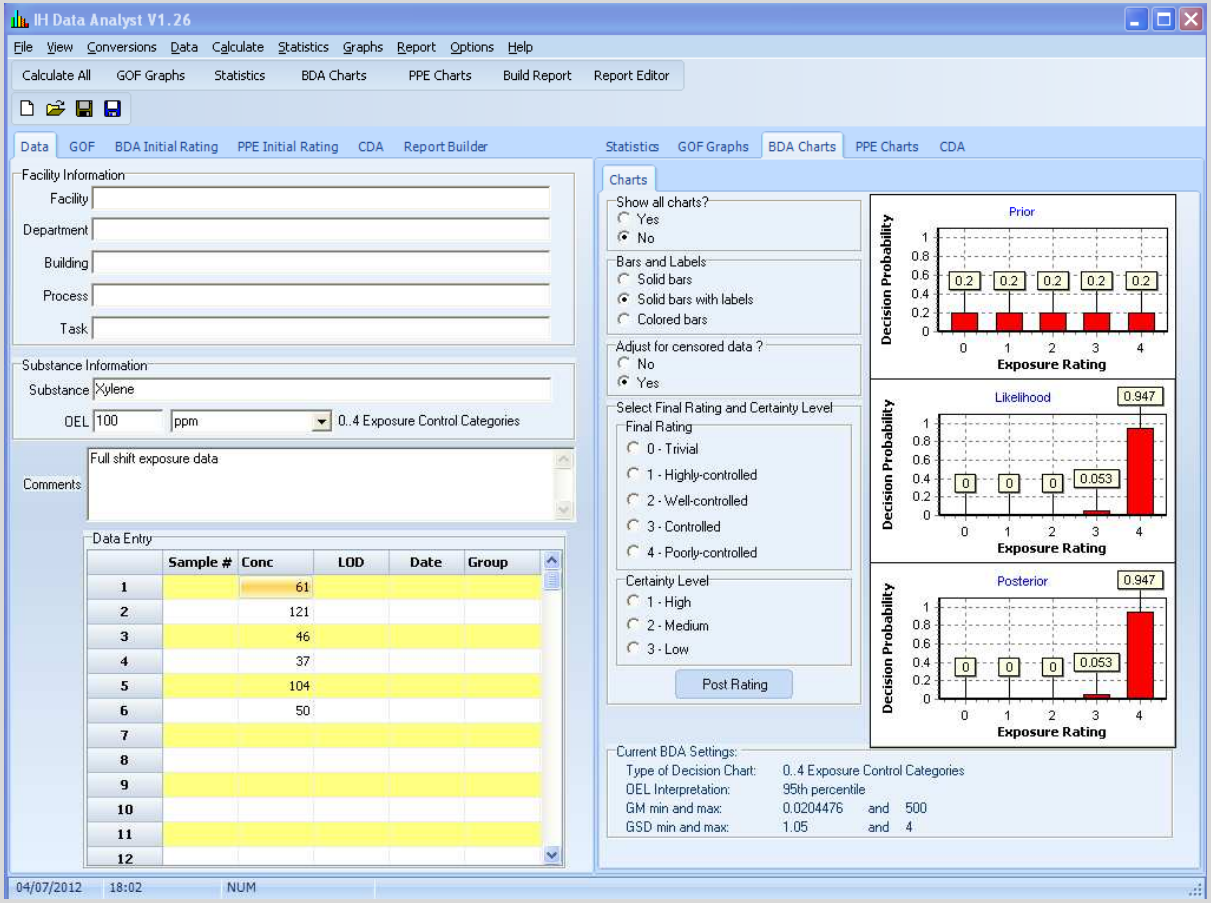


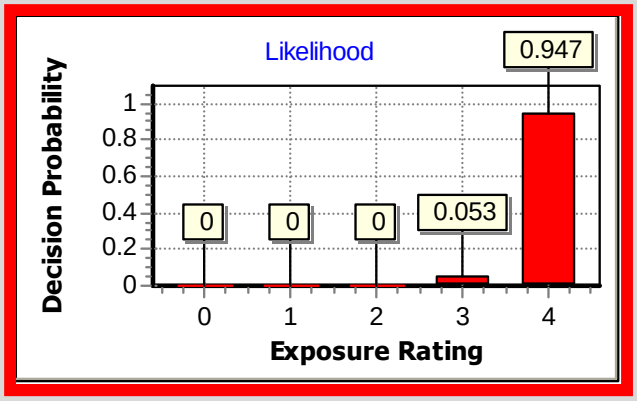

kelihood Function
0.001
0.01
GM
0.1
1
4
3.5
3
2.5
2
1.5
1
GSD


Likelihood Function
0.055
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0.001
0.01
0.1
1
GM
1
1.5
2
2.5
3
3.5
4
GSD

Bayesian Likelihood Analysis

- 94.7% Probability of AIHA Category 4 Exposure ($X_{0.95}$ >100% of OEL)
- Yes, this job <u>requires</u> exposure controls

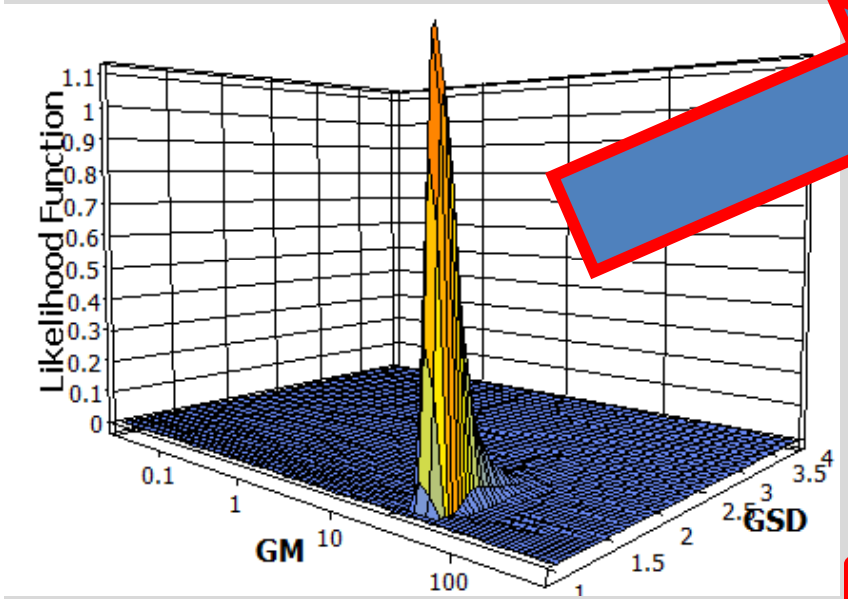


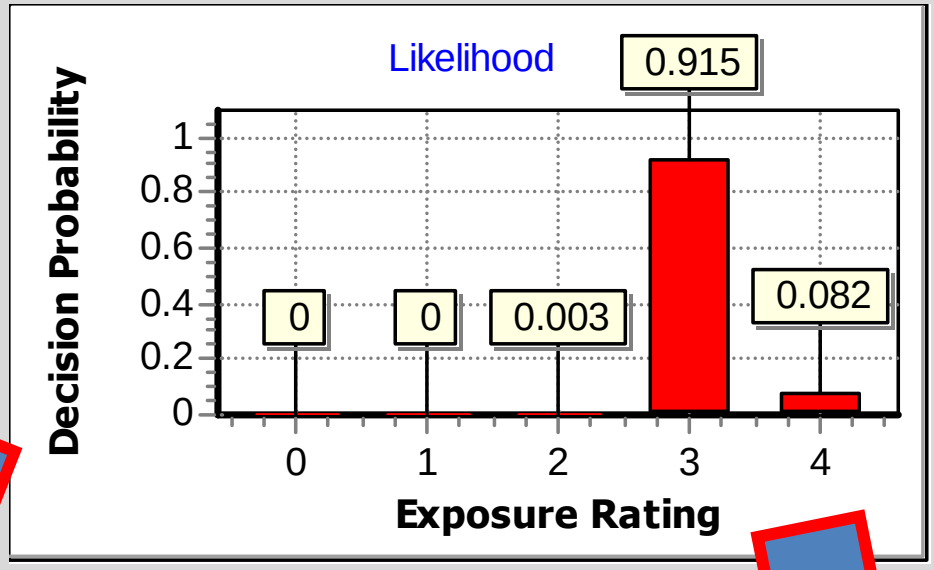


<u>Full Shift Sampling Data (ppm)</u>

61
121
46
37
104
50

Xylene OEL = 100 ppm





	SEG Exposure Control Category**	Recommended Action / Exposure Control Band
	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
	[illegible]	practice controls
	5 (Multiples of OEL; e.g., based on respirator APFs)	+ immediate engineering controls or process shutdown, validate respirator selection

** - Upper Tail Decision statistic = 90th, 95th, 99th percentile