Improving Exposure Judgments in Industrial/Occupational Hygiene

Through the Strategic Use of IH Tools, focusing on the Structured Deterministic Model (SDM) 2.0 | Susan Arnold, PhD, CIH FAIHA

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SCHOOL OF PUBLIC HEALTH
UNIVERSITY OF MINNESOTA

Logistics

- Agenda
- Technology (Poll Everywhere)
- Case for Improvement
- Introduction to the Structured Deterministic Model (SDM 2.0)
  - Algorithms and decision logic
  - Navigating SDM 2.0
  - License & download: https://license.umn.edu/product/structured-deterministic-model-sdm-20
- Case studies

Practice - using Polling

Using your computer or cell phone to respond!

- From web: https://pollev.com/susanarnold390
- Join by Text: Send **susanarnold390** to **22333**

If someone paid for you to study any subject, what would you study?

0

Nobody has responded yet.

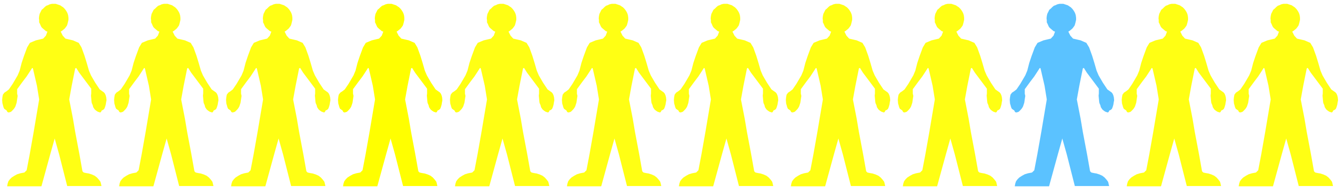
Hang tight! Responses are coming in.

Occupational Exposure Assessment Strategies

- The design of an exposure assessment strategy should be driven by the reason for obtaining samples
- Routine monitoring of worker exposures to chemicals in a workplace and comparing them against occupational exposure limits (OELs)
- To determine a relationship between exposure and the health outcome in an occupational epidemiology study, which in turn might lead to the establishment of new standards

IH Effectiveness Goal:

Ensure that no worker has unacceptable exposures

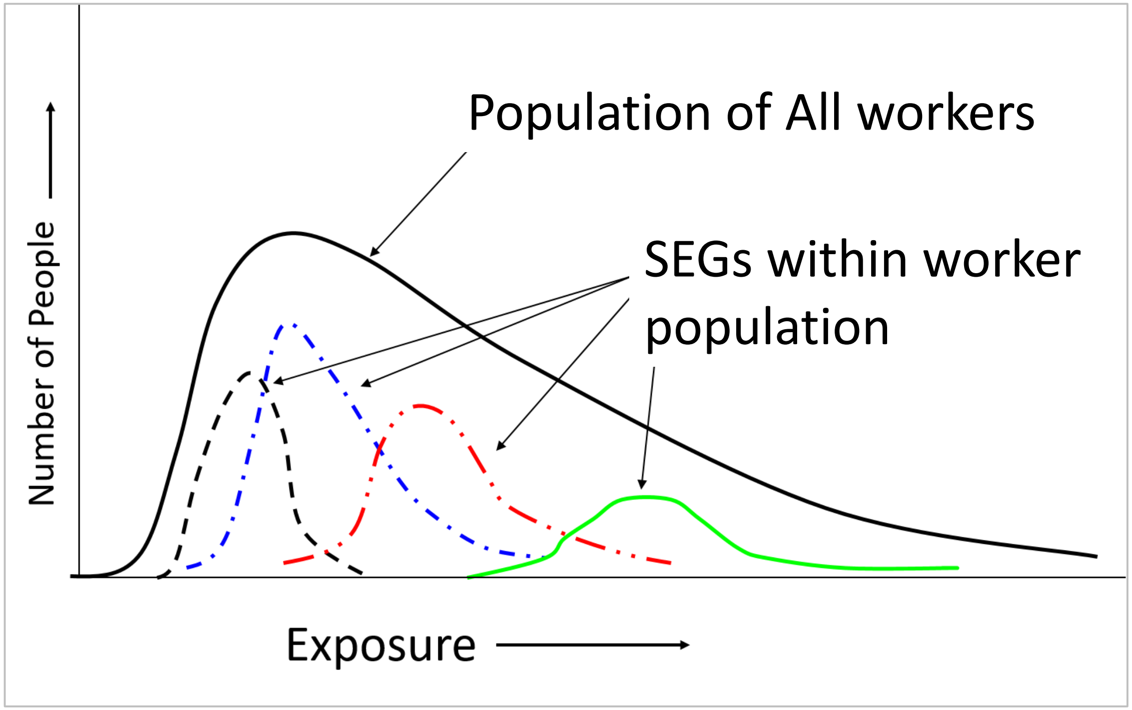


Occupational Exposure Assessment Strategies

- Exposures vary between workers, over time, shift, and location
  - The sampling strategy should be effective in capturing this variability
- At the same time, the strategy must be feasible and efficient in that it should not require an inordinately large number of samples
  - Occupational hygienists usually operate with limited resources that preclude large sample sizes

The Observational Approach to Creating Similar Exposure Groups (SEGs)

Exposure Distributions within the Worker Population in a Workplace



Between and Within-Worker Variability

- The classification of workers into similar exposure groups (SEGs) facilitates the efficient exposure assessment of large numbers of workers
- By randomly sampling workers within each SEG, the exposure distribution for each SEG can be estimated

Examples of Decision Strategies

Exposures are judged to be acceptable:

- If all the measurements in a dataset are below the OEL
- If all the measurements in a dataset are below the Action Level (AL)
- When the exposure metric (e.g., 95th percentile) is below the corresponding OEL or AL
- When the exposure metric falls into the desired exposure band.

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?

0

0 samples	0%
1 sample	0%
5 samples	0%
10 samples	0%
25 samples	0%
50 samples	0%

Most common number of air samples used to make a judgment about exposure?

0

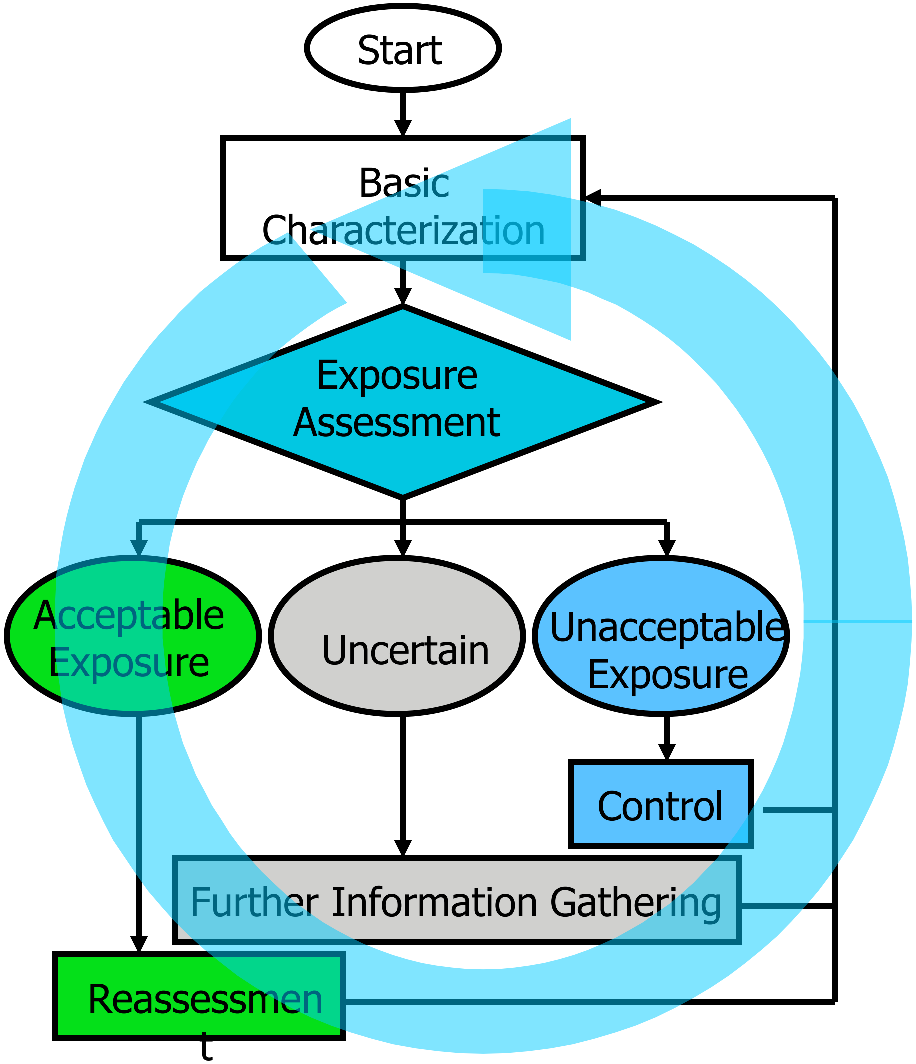
>10	0%
6 to 10	0%
3 to 5	0%
1 or 2	0%
0	0%

Exposure Scenario: OEL
OEL = 10 ppm, GSD = 2.5, AL=5 ppm

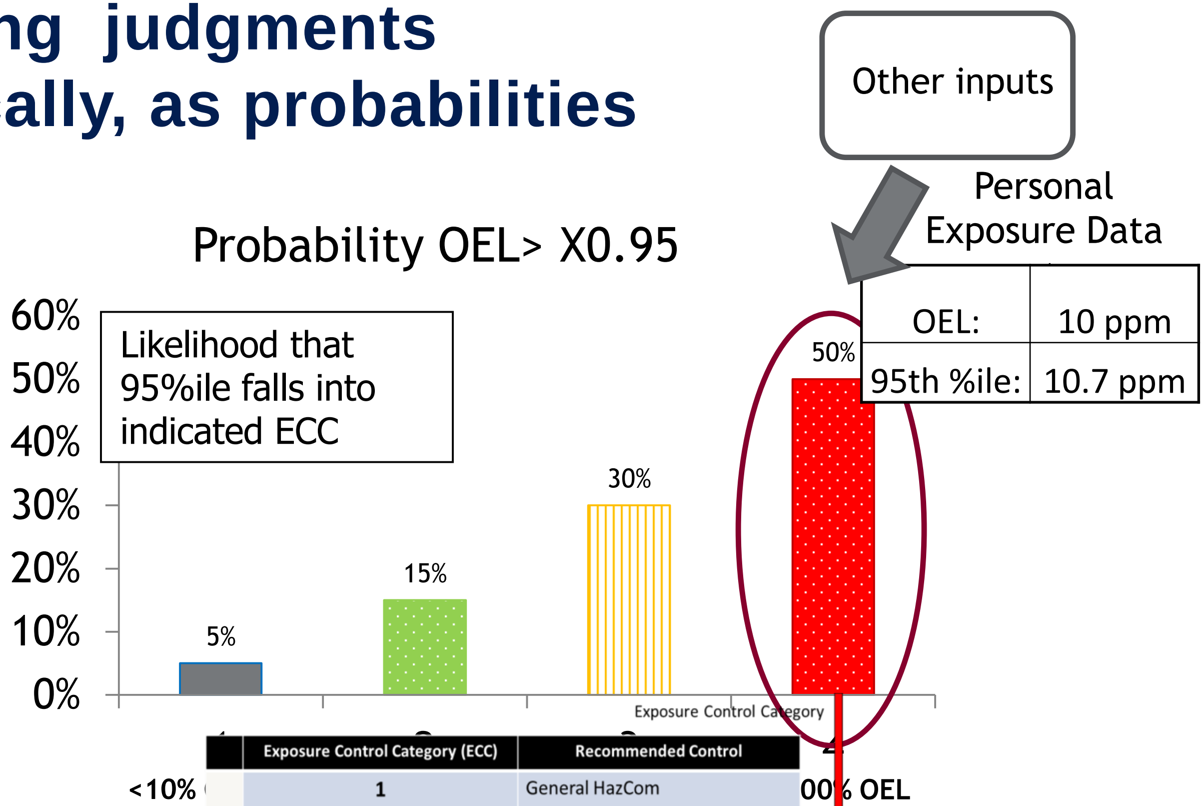
EF	GM	95th % (ppm)	Distri-bution <OEL	Percentage of Time that All Measurements of Dataset Size N (N=1, 2, 3, 4, or 5) Will Fall Below the OEL (%)				
				1	2	3	4	5
0.50	10.0	45.15	0.500	50.0	25.0	12.5	6.25	3.13
0.25	5.39	24.32	0.750	75.0	56.3	42.2	31.6	23.7
0.10	3.09	13.95	0.900	90.0	81.0	72.9	65.6	59.1
0.05	2.22	10.00	0.950	95.0	90.3	85.7	81.5	77.4

EF = Exceedance Fraction ***GM = Geometric Mean***
95^{th} % = 95^{th} Percentile ***AL= Action Level***
GSD = Geometric Standard Deviation

Decision Making using the AIHA Exposure Assessment Strategy



Expressing judgments categorically, as probabilities



	Exposure Control Category (ECC)	Recommended Control
	1 X0.95 < 0.10 OEL	General HazCom
	2 0.10 OEL < $X_{0.95}$ < 0.5 OEL	+ chemical specific HazCom
	3 0.5 OEL < $X_{0.95}$ < OEL	+ exposure surveillance, medical surveillance, work practices
	4 OEL < $X_{0.95}$	+ respirators & engineering controls, work practice controls

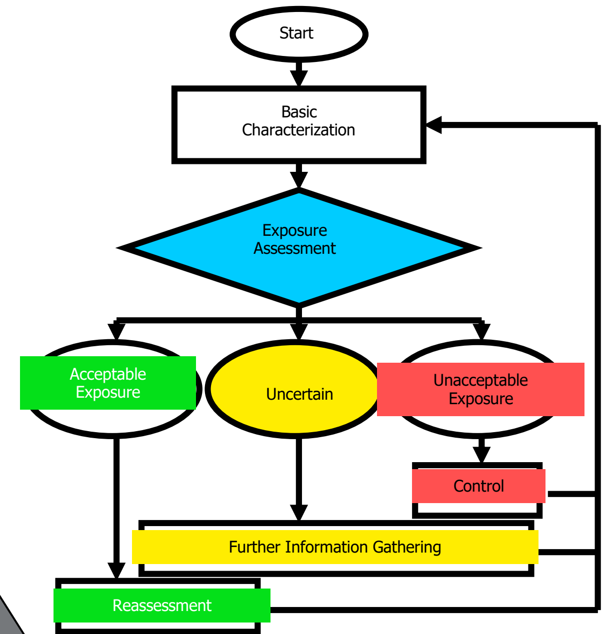
Effectiveness and Efficiency of Strategies for Decision Making

- **Effectiveness** - the ability to reach a correct decision;
- **Efficiency** - the ability of an exposure assessment strategy to reach a decision with a minimum or tolerable expenditure of resources;
- **Goal**: a <u>high probability</u> of detecting a clearly unacceptable group exposure profile. To minimize the number of workers whose upper percentile exposures are greater than the OEL.

How Does One Fix the Exposure Assessment Paradigm?

- Give comparable weight to quantitative measurements, modeling (mathematical, statistical and determinist), rules-of-thumb and professional judgment.

AIHA EA Strategy



Define Exposure Using All Available Information

Conditions

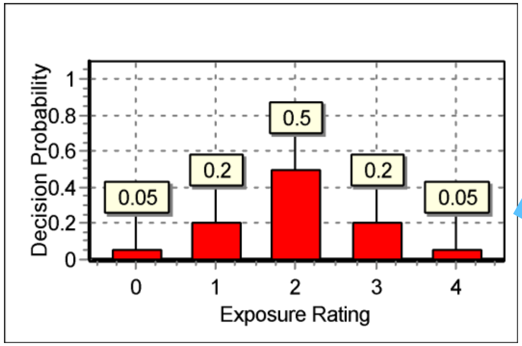
Qualitative
Modeling
Monitoring

EA Tools

Exposure Profile

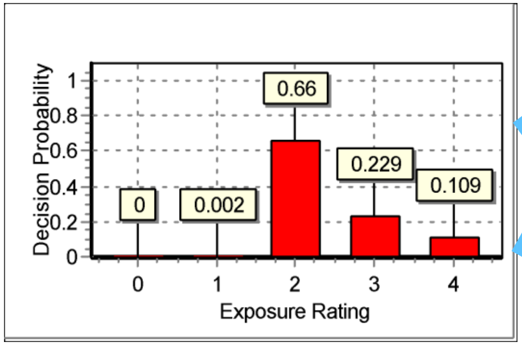
Qualitative
Modeling
Monitoring

Qualitative Assessment or Validated Model



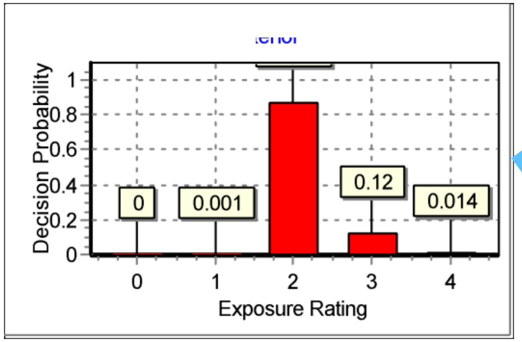
Qualitative
Modeling
Monitoring

Monitoring Results



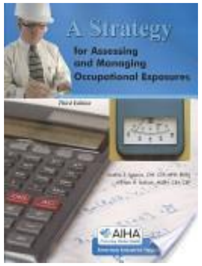
Qualitative
Modeling
Monitoring

Integrated Exposure Assessment



What is "Professional Judgment" ?

- The application and appropriate use of knowledge gained from the formal education, experience, experimentation, inference, and analogy. The capacity of an **experienced professional** to draw **correct inferences** from incomplete quantitative data, frequently on the basis of observations, analogy and intuition.



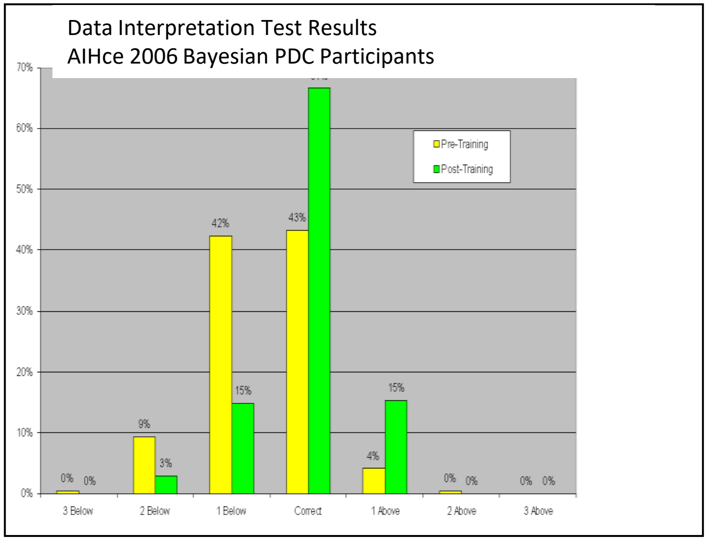
Experienced professional **Correct inferences**

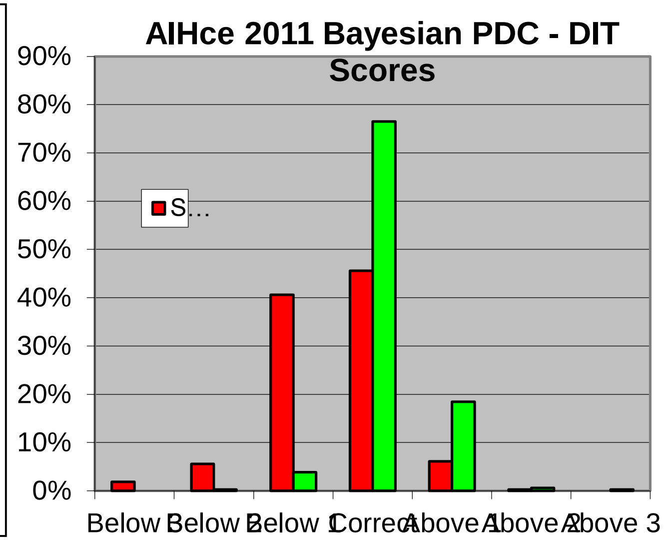
- Ref: Bullock. W.H. and Ignacio, J.S: (editors)
  A Strategy for Assessing and Managing Occupational Exposures,
  Third Edition. Fairfax, VA: American Industrial Hygiene Association (2006).

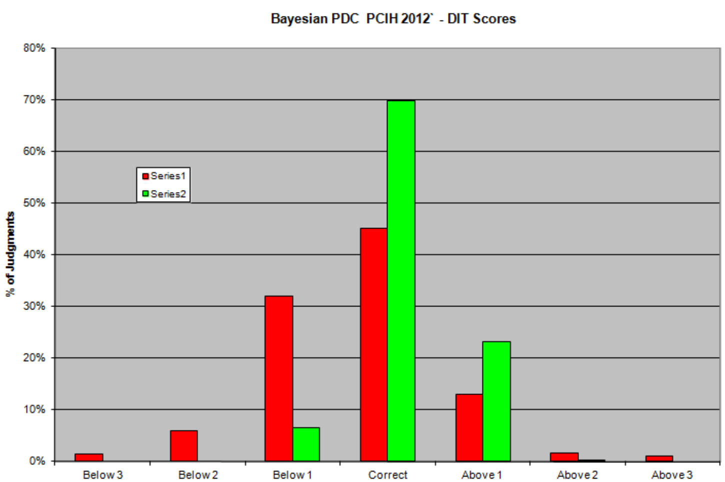
The Motivator

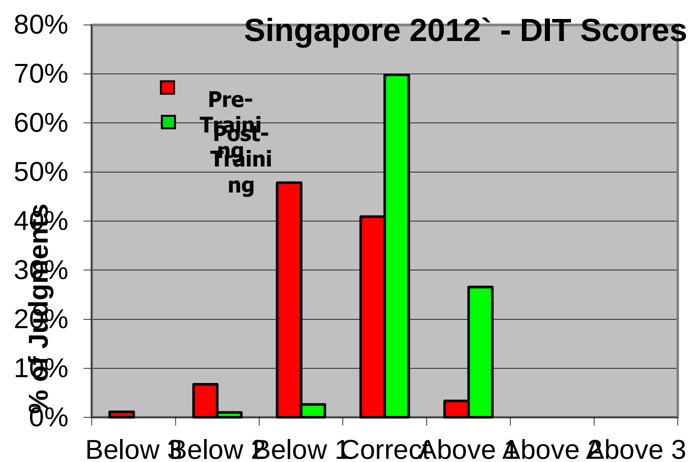
- Majority of exposure judgments are qualitative (have data for only ~ 2-5%)
- AIHA EA Strategy relies on accurate qualitative assessments
- Judgments based on intuitive professional judgment are INACCURATE and UNDERESTIMATE exposure

Professional judgment accuracy with monitoring data


Data Interpretation Test Results
AIHce 2006 Bayesian PDC Participants
70%
60%
50%
40%
30%
20%
10%
0%
Pre-Training
Post-Training
0%
0%
9%
3%
42%
15%
43%
4%
15%
0%
0%
0%
0%
3 Below
2 Below
1 Below
Correct
1 Above
2 Above
3 Above


AIHce 2011 Bayesian PDC - DIT Scores
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
S…
Below 3
Below 2
Below 1
Correct
Above 1
Above 2
Above 3

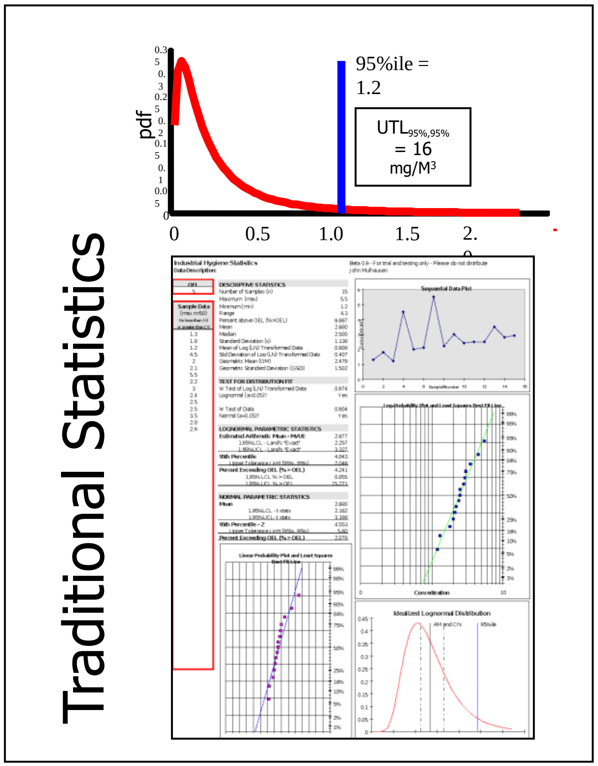

Bayesian PDC PCIH 2012` - DIT Scores
% of Judgments
80%
70%
60%
50%
40%
30%
20%
10%
0%
Series1
Series2
Below 3
Below 2
Below 1
Correct
Above 1
Above 2
Above 3

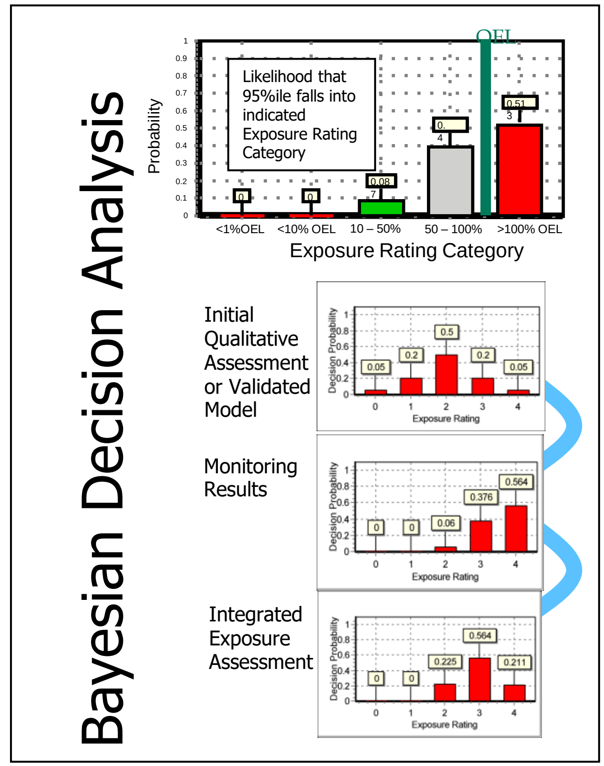

Singapore 2012` - DIT Scores
% of Judgments
80%
70%
60%
50%
40%
30%
20%
10%
0%
Pre-Training
Post-Training
Below 3
Below 2
Below 1
Correct
Above 1
Above 2
Above 3

Rules of Thumb for Estimating the 95th Percentile

- IHs typically don't use statistical tools to interpret monitoring data; instead they "eyeball" the data.
- Simple **Rules of Thumb** based on lognormal statistics improved judgment accuracy significantly.

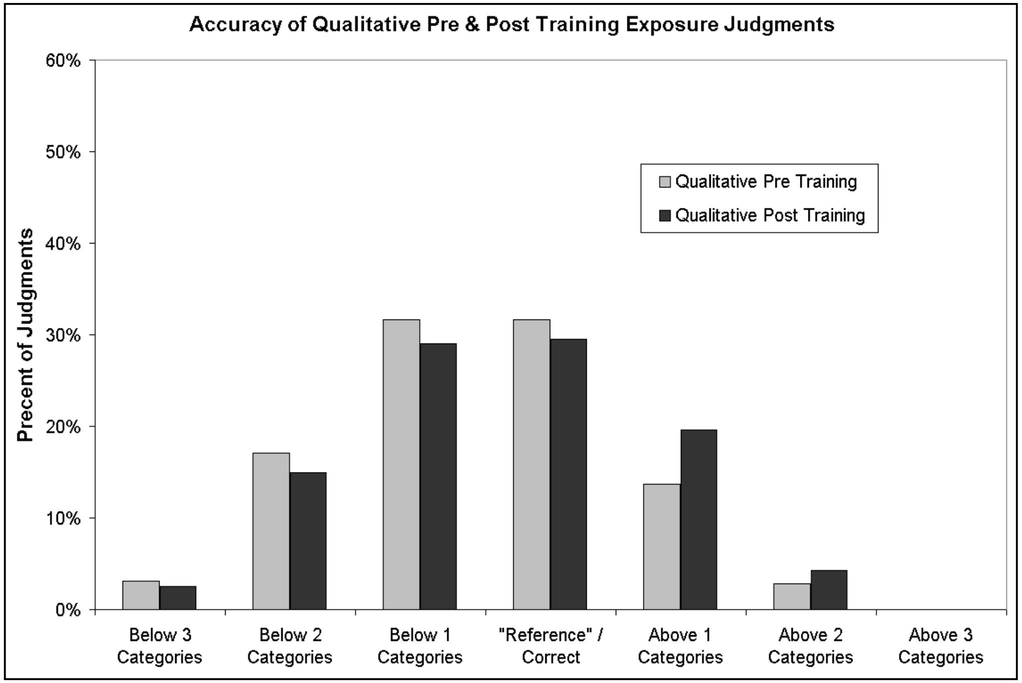
Use statistical tools!!





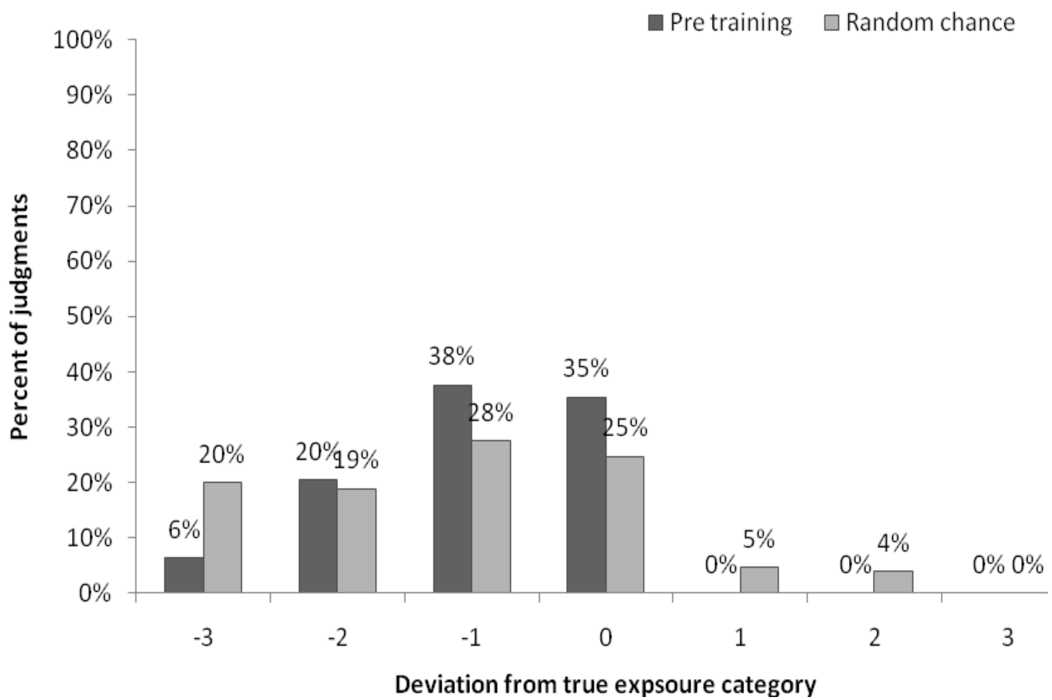
Professional judgment accuracy without monitoring data

Qualitative Judgments not better than random chance - Video 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

Qualitative Judgments not better than random chance - Real Workplace Judgments



Vadali, Monika, et al. "Effect of Training on Exposure Judgment Accuracy of Industrial Hygienists." *Journal of Occupational and Environmental Hygiene* 9, no. 4 (April 2012): 242-56. https://doi.org/10.1080/15459624.2012.666470.

When poll is active, respond at **pollev.com/susanarnold390**

Text **SUSANARNOLD390** to **22333** once to join

How do we define 'acceptable' exposures?

- No exceedences (100 percentile < OEL)
- Less than 1% exceedance
- Less than 5% exceedance
- Less than 10% exceedance

External Sources for Inconsistent Judgments

- 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.

Structured Approaches to Decision Making

Rule of 10 (ROT): Pure chemicals & Chemical Mixtures

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

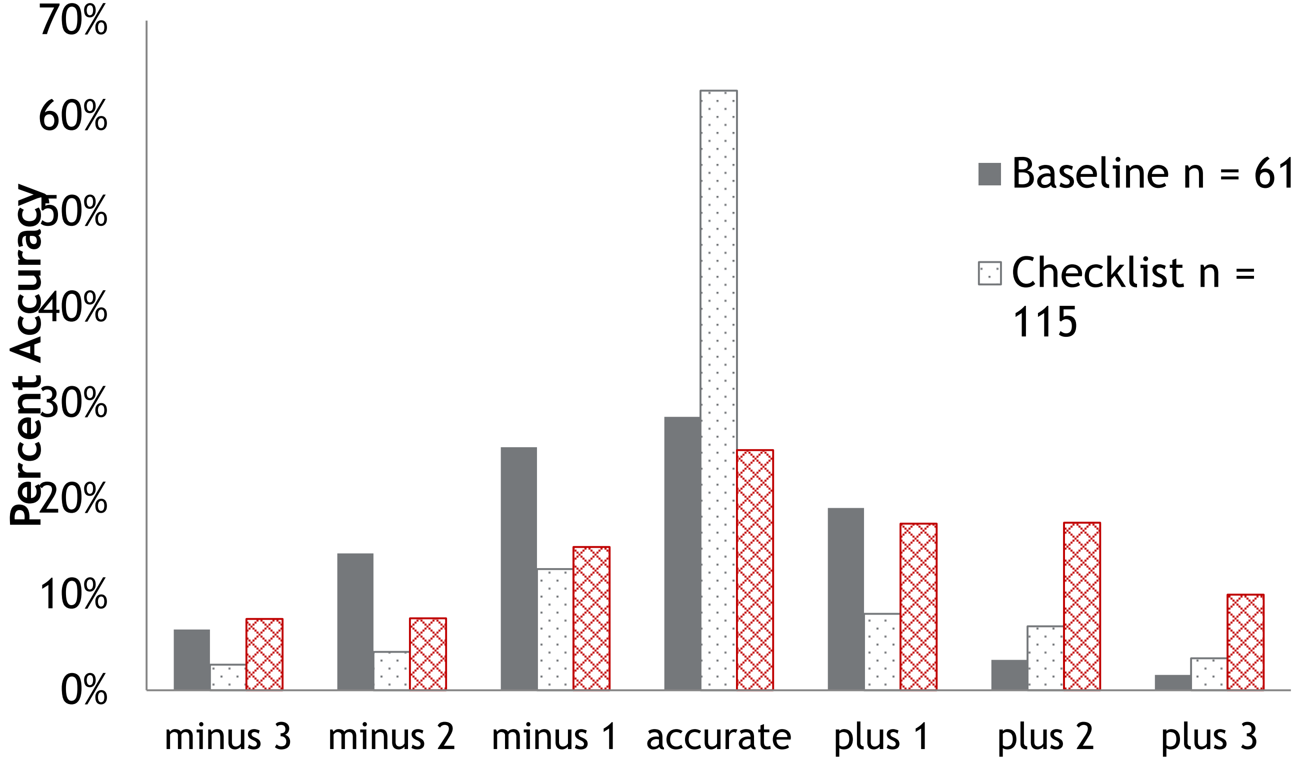
How does the Checklist Tool (SDM) Improve Exposure Judgment Accuracy?

- ✓Uses OBJECTIVE inputs
- ✓Produces ACCURATE & consistent outputs
- ✓Applies to a broad range of scenarios
- ✓Is easy to use
- ✓Even easier with ‘the **Structured Deterministic Model** (SDM) 2.0 Tool’

The Structured Deterministic Model

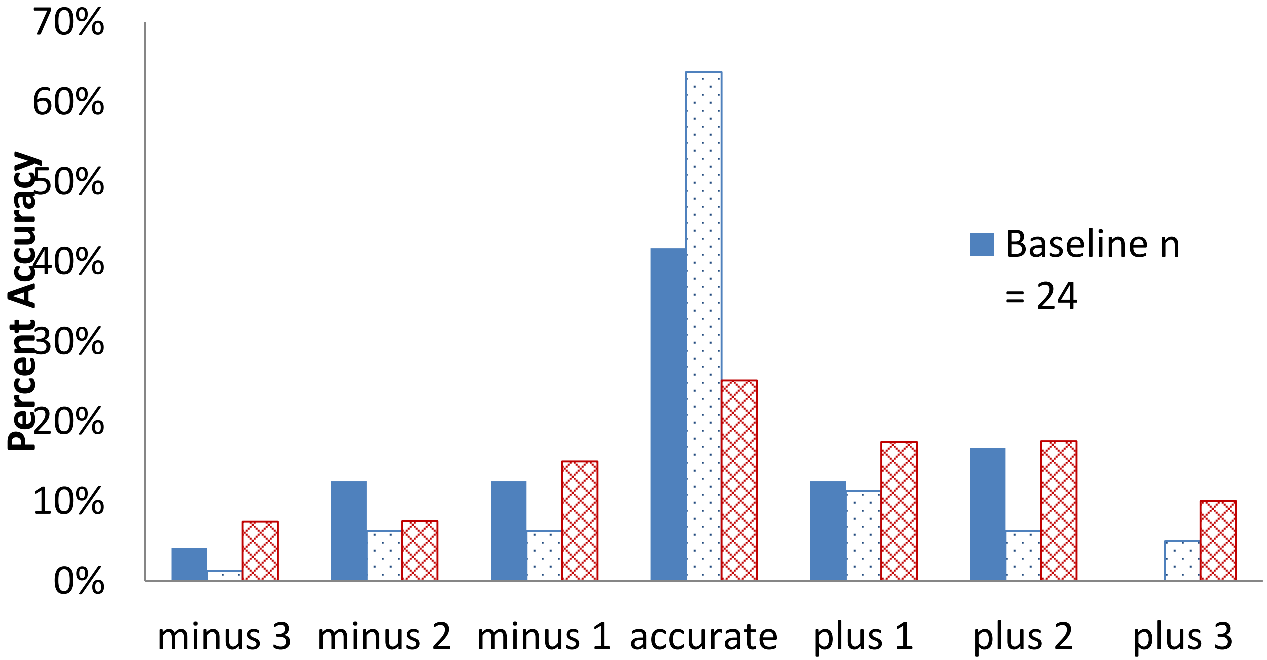
- Applying simple algorithms or heuristics to improve judgment accuracy
- Algorithms based on physical chemical principles, developed empirically, through experience
- Structured, like a checklist that ensures consistent application, every time

Results - Post-Checklist Training Accuracy, Practicing IHs



Arnold SF, Stenzel M, Drolet D, et al. Using checklists and algorithms to improve qualitative exposure judgment accuracy. J Occup Environ Hyg 2016; 13: 159-168. DOI: 10.1080/15459624.2015.1053892.

Results – Post-Checklist Training Accuracy, Novice IHs



Arnold SF, Stenzel M, Drolet D, et al. Using checklists and algorithms to improve qualitative exposure judgment accuracy. J Occup Environ Hyg 2016; 13: 159-168. DOI: 10.1080/15459624.2015.1053892.

Using the Structured Deterministic Model (SDM) 2.0

Recommended for agents that are:

- ✓Pure or relatively pure volatile or semi-volatile chemicals and chemical mixtures
- ✓Fibers, particulates or aerosols

Glossary

ECC: exposure control category

OEL: occupational exposure limit

ObsLC: observed or reported level of control

PHR: particulate hazard ratio

ReqLC: required level of (engineering) control

SVC: saturated vapor concentration

VP: vapor pressure (mmHg)

VHR: vapor hazard ratio

ESSI Exposure Science and Sustainability Institute

SDM 2.0
Structured Deterministic Model

AIHA | Exposure Assessment Strategies COMMITTEE

Introduction

Zoom
768
1080
1440
2160

This tool is a deterministic model that provides point estimates of the 95th percentile airborne concentrations as a predictor of inhalation exposure to chemicals. It applies to pure, or relatively pure, volatile and semi-volatile chemicals and chemical mixtures (Checklist #1), and fibers, particulates and aerosols (Checklist #2).

SDM 2.0 is not appropriate for assessing scenarios involving thermal decomposition, polymers or chemicals under pressure.

Checklist #1
for assessing pure, relatively pure agents, or chemicals contained in mixtures comprised of volatile and semi-volatile agents

Checklist #2
for assessing particulates, fibers and aerosols

Disclaimer
Credits
Comments

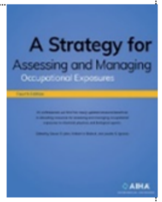
Before using :

Read the Support File documentation, and be sure you understand how this tool works. Your judgments, and any tool that informs your judgment should be calibrated using exposure measurement data.

Link

More information about the algorithms can be found in the Support File, and in the AIHA Publication:

Jahn, S.D., William H. Bullock, Joselito S. Ignacio:
A Strategy for Assessing and Managing Occupational Exposures
AIHA Press, 2015, Chapters 6, 23, 26.



Link

Version 1,00 : May 2022

Conception: Susan F. Arnold, Mark Stenzel, Puleng Moshele and Daniel Drolet

Arnold S.F, Stenzel M. R., Mushele P. and D. Drolet, (2022).
SDM 2.0. Structured Deterministic Model. (Version 1,0)
Software available from University of Minnesota and AIHA.org

Checklist 1.

Evaluating volatile chemical exposures
Using the Rule-of-10

Vapor Pressure (VP)—1

- Pressure exerted by the gaseous phase of a two phase—gas/liquid or gas/solid system
- Pressure that is formed above its liquid or solid
- If a substance is in an enclosed place, the two phase system will arrive at an equilibrium state
  - Dynamic, balanced condition with no change of either phase
  - For a specific temperature, VP measured at equilibrium state is called equilibrium or **saturated vapor pressure**
- Fraction of the total pressure, which is equal to 760 mmHg at sea level

Vapor Pressure VP—2

- Vapor pressure changes (increases) with temperature
- When comparing VP, must use some comparable temperature (e.g. 25 °C)
- VP at agent's boiling point = 760 mm of Hg (atmospheric pressure)
- VP of specific agents in mixtures is lower than agent's VP in its pure state
- VPs and BP usually reported on SDS or are available in standard sources (e.g., PubChem, HSDB, NIOSH Pocket Guide)

1. Rule of 10

Saturation (SVC) = Vapor Pressure (VP) (mm Hg)/760 mm Hg X 10^{6}

	Level of Control	Fraction of Saturation Vapor Concentration (SVC)	Example/Description
1	Very Limited	1/10th of Saturation	Example: Confined space with virtually no mechanical ventilation (< 1 air change/hour (ACH))
2	Poor	1/ 100th of Saturation	Example: Confined space with limited ventilation (1- 3 ACH); or if there is ventilation > 3 ACH, the ventilation is not configured properly to result in 1 – 3 ACH in the workers breathing zone. Note that there may be fans in the workplace, but there is limited makeup air resulting in the fans only circulating air, not supplying fresh or uncontaminated air.
3	Good – General Ventilation – [illegible]rs (or in protected outdoor areas whe[illegible]re is minimal wind) - Displaced ai[illegible]	1/300th of Saturation	Where typically, indoor work areas are designed to have ~ 3 to 6 ACH in a manufacturing work setting, where displaced air also occurs, it can negatively impact on the effectiveness of the designed control. Displaced air refers to air that is being introduced into the air from a source under greater pressure that of the rest of the area. An example is a release of contaminated air that occurs when worker opens a tank while the tank is being filled. Because of the limited space in the tank, the air in the tank headspace becomes saturated and then is released.
4	Good – General Ventilation – [illegible]rs (or in protected outdoor areas whe[illegible]re is minimal wind)	1/1,000th of Saturation	Typically, indoor work areas are designed to have ~ 3 to 6 ACH, typical design criteria for a manufacturing work setting.
5	Good General Ventilation – ([illegible]) – Displaced air	1/1,000th of Saturation	Air movement outdoors under what would be considered still area is at least 1 to 2 mph. Under conditions what generate displaced air (see the 3rd example above), the effectiveness of good ventilation is lowered.
6	Good – General Ventilation– [illegible]s (or in protected outdoor areas whe[illegible]re is minimal wind) high ACH	1/3,000th of Saturation	The work area is indoors but ACH are in the range of 6 to 12 ACH. Some work areas have auxiliary fans in addition to the good general ventilation to clear an area where there may have been a spill or in situations where the chemicals used in the process have high volatility.
7	Good General Ventilation– O[illegible]	1/3,000th of Saturation	Outdoors where the wind is at least 1 to 2 mph.
8	Capture – Local Exhaust Vent[illegible]	1/10,000th of Saturation	Mechanical ventilation is available to collect the vapor release at the source. It should be determined if the location of the hood is close enough to capture the vapor, which is dependent on the type of hood such as slot, flanged slot, plain opening, etc. Also, the air velocity in the ventilation piping must be adequate to capture the vapor. In the case of a canopy hood configuration the worker cannot be between the source of the vapor and the hood entry.
9	Containment – Local Exhaust Ventilation	1/100,000th of Saturation	The source of the vapor is contained within an enclosure with sufficient face velocity to assure that vapors do not escape but not so high of a face velocity to cause turbulence.

Basis of the Rule

- Rule was developed from empirical observations of exposure scenarios where quantitative measurements are available.
- Outcome of applying the rule is a point estimate of the 95th Percentile

Steps - Application of Rule of 10

1. Select appropriate Occupational Exposure Limit (OEL)
2. Determine Vapor Pressure (VP) & Saturated Vapor Concentration (SVC)
3. Identify Observed Level of Control (ObsLC)
4. Estimate the fraction of the SVC
5. Calculate the maximum concentration (C_{max})
6. Compare C_{max} (~95^{th} percentile) to OEL
7. Determine Exposure Control Category (ECC)

Group Exercise – Rule of 10

- Using hypothetical case study of pure chemical
- ‘Acetic Acid’

1. Select Appropriate OEL

- ACGIH TLV: TWA **10 ppm**

2. Determine VP & SVC

- Using VP (pure chemical):

$$SVC = \frac{11.25\ mm\ Hg}{760} \times\ 10^6 \text{ ppm}$$

$$= 14800\ ppm$$

3. Identify ObsLC

- good general ventilation – (~ 5-6 ACH)

* ObsLC = Observed Level of Control

4. Estimate the fraction of the SVC

Factor	Fraction of the saturation vapor concentration "SVC"
10	Very Limited
100	Poor
300	Good General Ventilation - Displaced Air*
1000	Good General Ventilation – Indoors
3000	Good - Outside***
10000	Capture LEV
100000	Containment

5. Calculate C_{max}

Example:

Good – General → 1/1,000th of Saturation

$$C_{max} = \frac{14800}{1000}$$

$$= 14.8\ ppm$$

6. Compare C_{max} to OEL

-

$$X_{0.95} = \frac{14.8\ ppm}{10\ ppm}$$

$$= 1.48\ or\ 148\%$$

7. Determine ECC

Cat	Min	Max	Exposure Control Category (ECC)	Recommended Control	Respirator Assigned Protection Factors
0	0	0.01	less than 0,01		
1	0.01	0.1	0,01 to 0,1		
2	0.1	0.5	0,1 to 0,5		
3	0.5	1	0,5 to 1		
4	1	2	1 to 2		APF-10
5	2	5	2 to 5		APF-10
6	5	10	5 to 10		APF-10
7	10	25	10 to 25		APF-25
8	25	50	25 to 50		APF-50
9	50	1000000	more than 50		APF- >50

Using SDM 2.0- Part 1


ESSI Exposure Science and Sustainability Institute
SDM 2.0
Structured Deterministic Model
AIHA Exposure Assessment Strategies COMMITTEE
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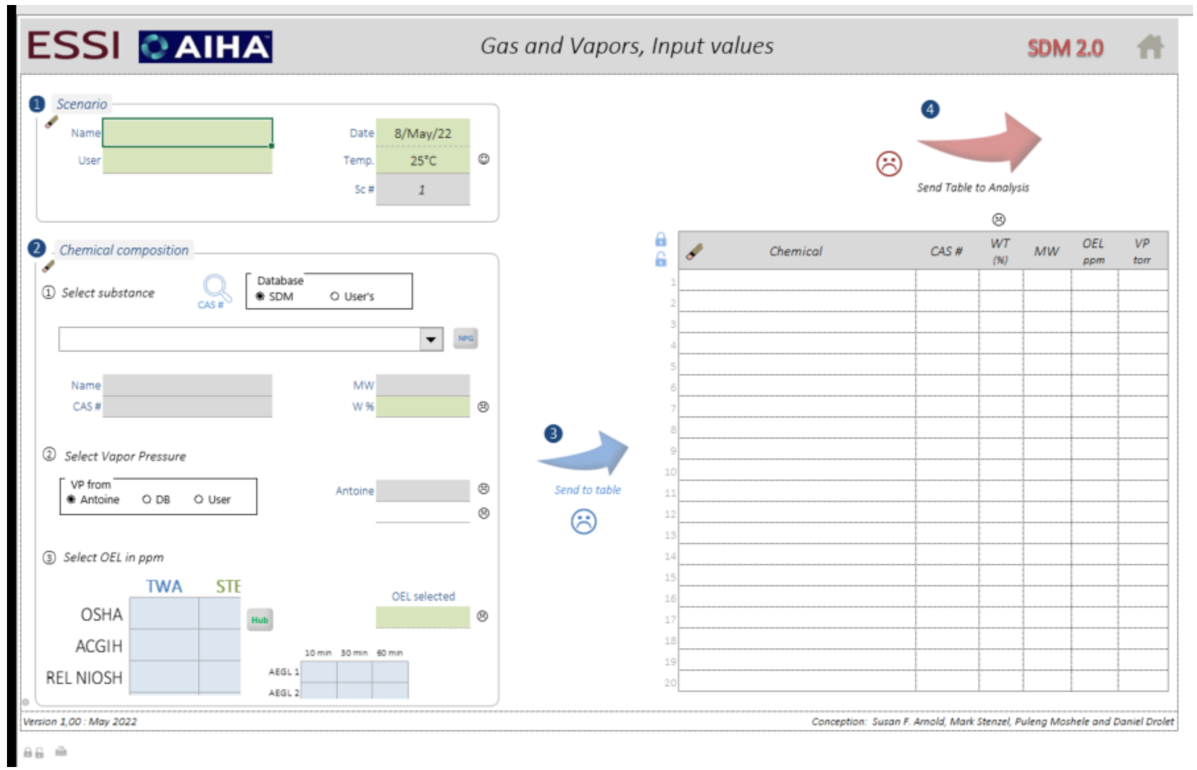
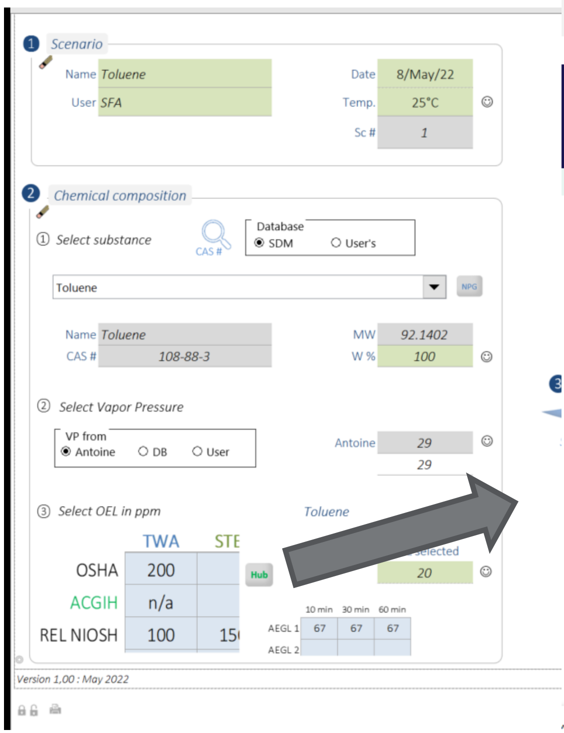
Jahn, S.D., William H. Bullock, Joselito S. Ignacio:
A Strategy for Assessing and Managing Occupational Exposures
AIHA Press, 2015, Chapters 6, 23, 26.
Link
A Strategy for Assessing and Managing Occupational Exposures
Version 1,00 : May 2022
Conception: Susan F. Arnold, Mark Stenzel, Puleng Moshele and Daniel Drolet
Arnold S.F, Stenzel M. R., Mushele P. and D. Drolet, (2022).
SDM 2.0. Structured Deterministic Model. (Version 1,0)
Software available from University of Minnesota and AIHA.org
© Regents of the University of Minnesota, Exposure Assessment Applications, LLC, Daniel Drolet All rights reserved. If you use this tool, please cite as following

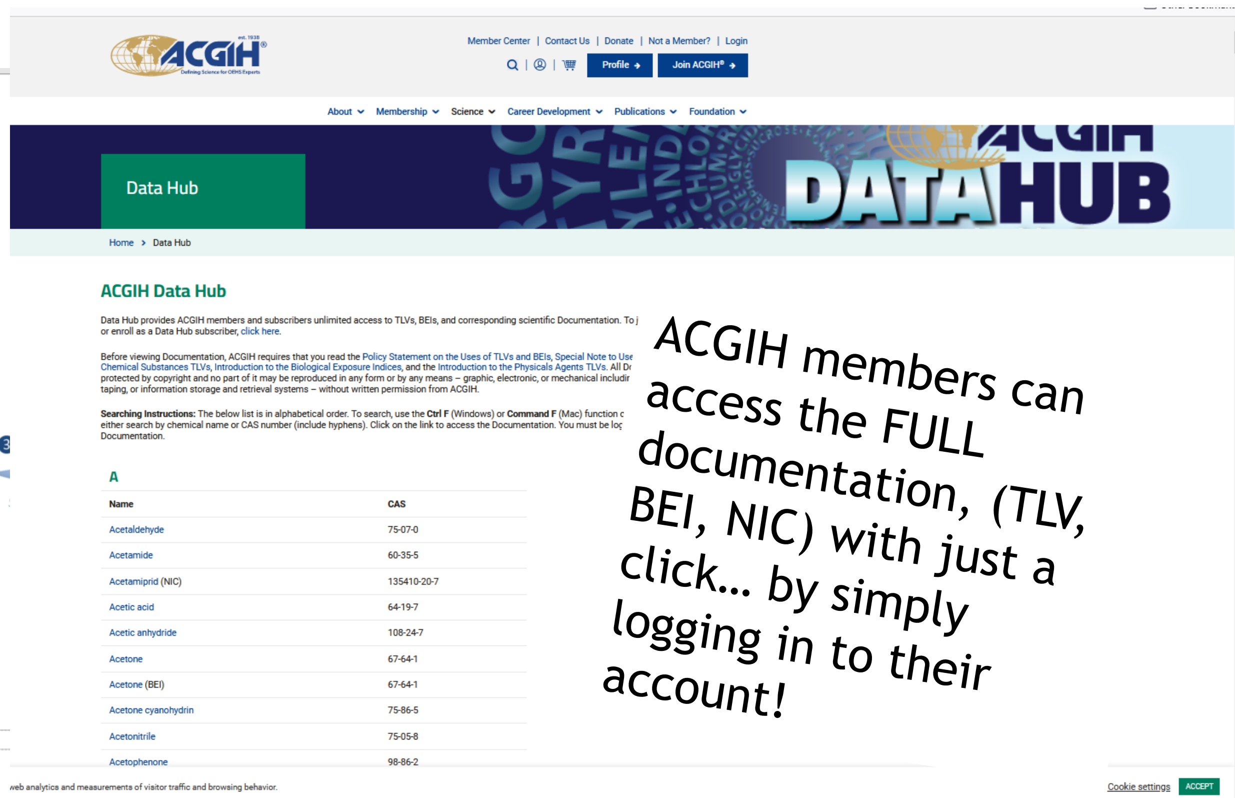
Checklist 1 - input tab

- For volatile & semi-volatile chemicals
- Input steps are numbered to guide process
- Input cells are green
- Drop down menu to access database
- Select 'user' option for customized database



Checklist 1 - input tab - link to ACGIH datahub!

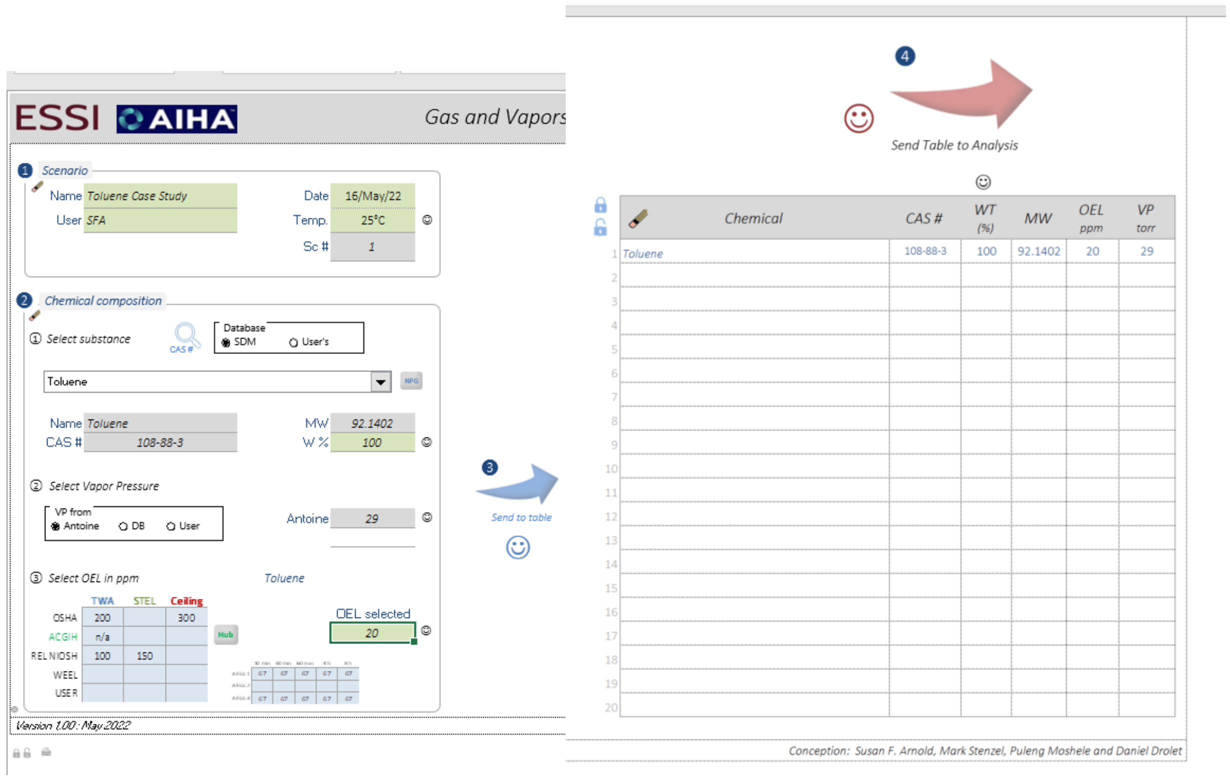




ACGIH members can access the FULL documentation, (TLV, BEI, NIC) with just a click… by simply logging in to their account!

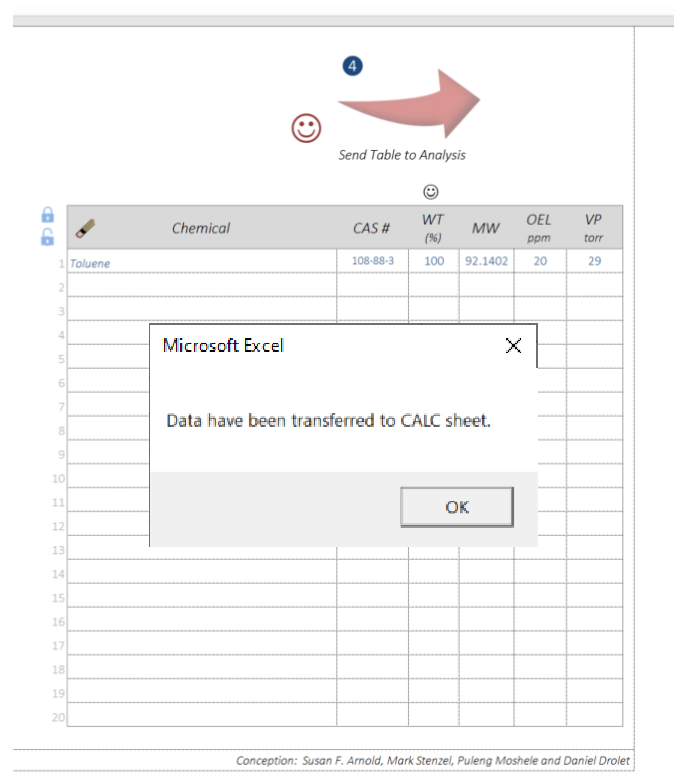
Checklist 1 - input tab

- Visual cues ☺ confirm input is complete and you are ready to go to the next step



Checklist 1 -transfer to report tab

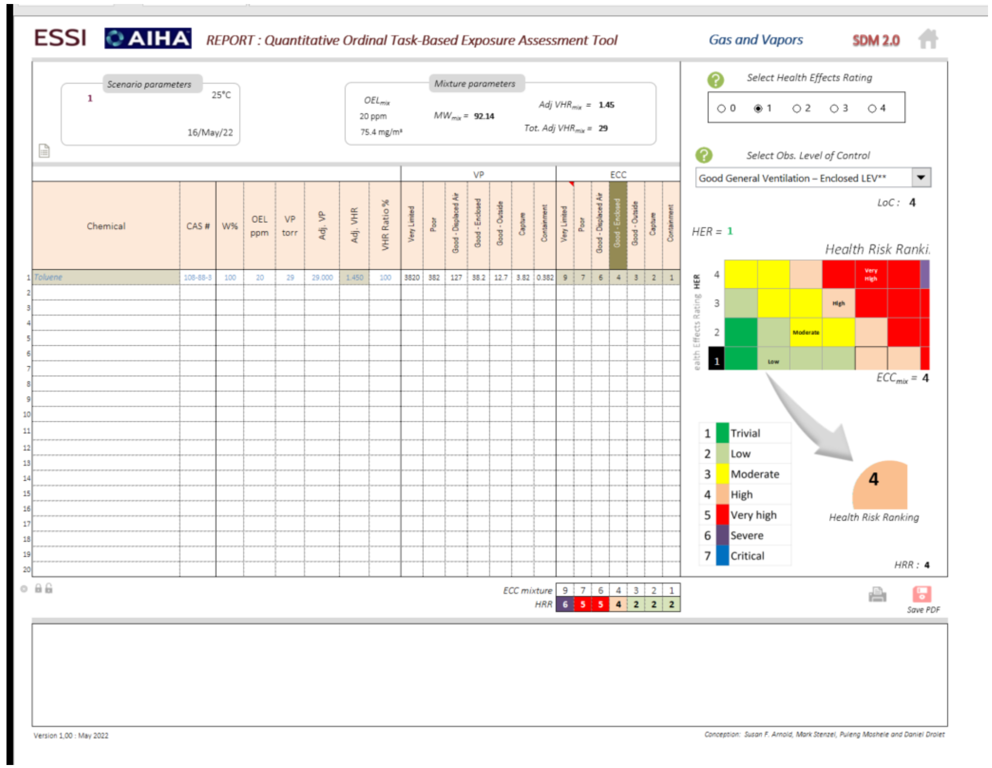
- When all the inputs have been entered, the data are transferred to the report tab by clicking on the red arrow
- A message will appear, confirming the transfer
- Click ‘OK’ to go to the report tab



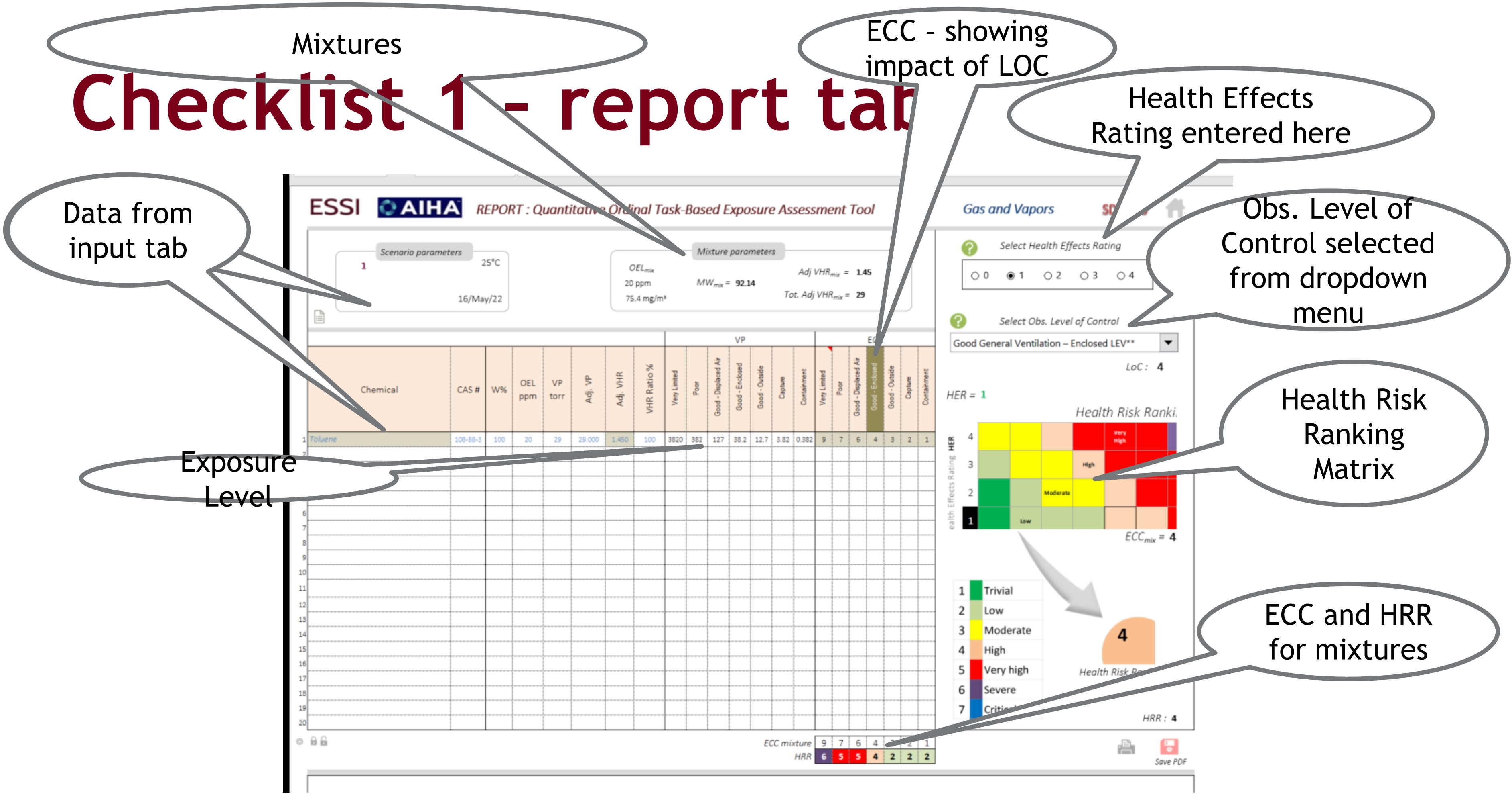
Checklist 1 - report tab

- Single page format can be saved as pdf, printed
- Inputs *and* outputs captured
- Free text space at the bottom of the page
- Let’s take a closer look!

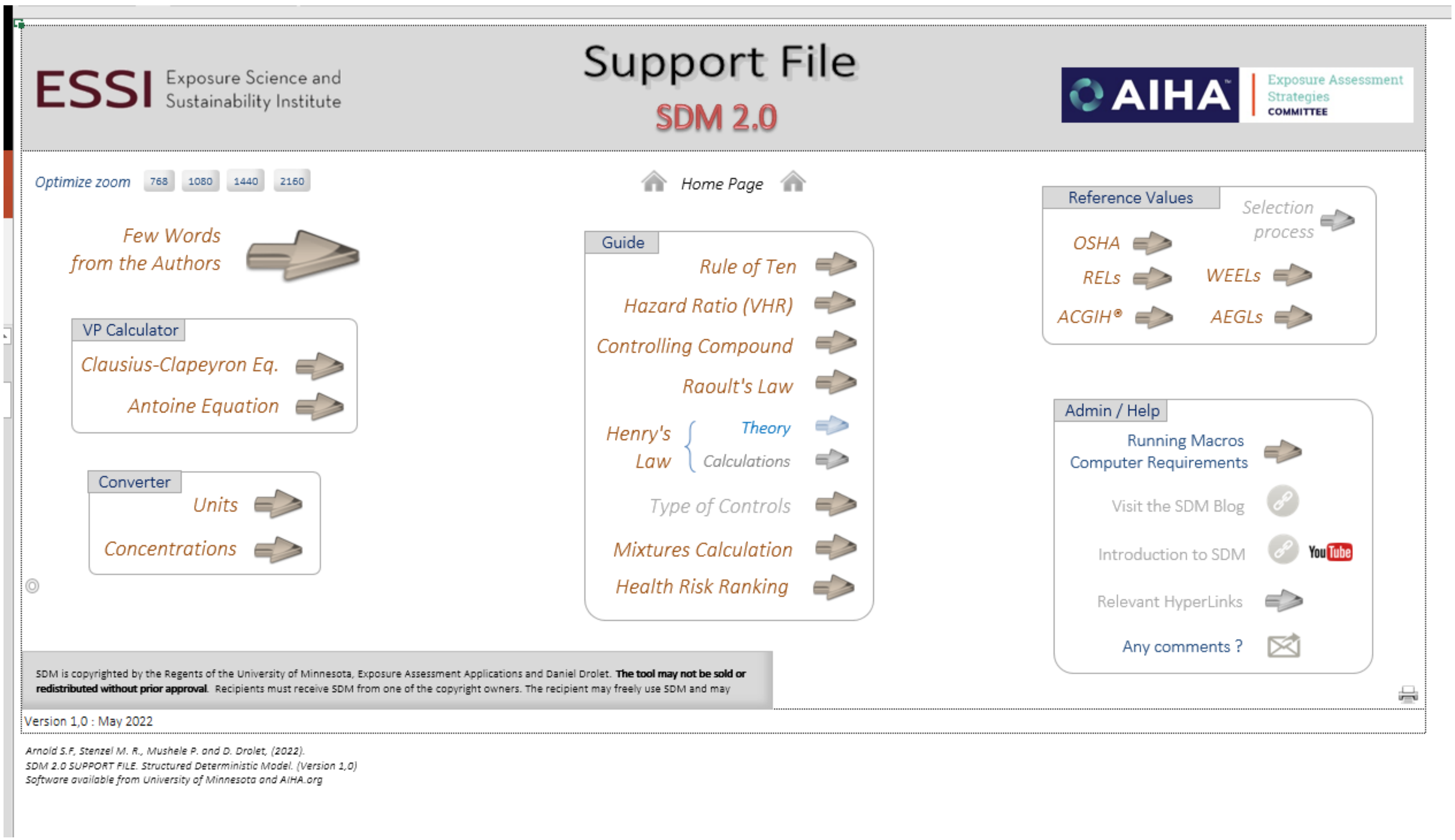
* note: VP should be Concentration



Checklist 1 - report tab



SDM 2.0 Support File-overview


ESSI Exposure Science and Sustainability Institute
Support File
SDM 2.0
AIHA Exposure Assessment Strategies COMMITTEE
Optimize zoom 768 1080 1440 2160
Home Page
Few Words from the Authors
VP Calculator
Clausius-Clapeyron Eq.
Antoine Equation
Converter
Units
Concentrations
Guide
Rule of Ten
Hazard Ratio (VHR)
Controlling Compound
Raoult's Law
Henry's Law
Theory
Calculations
Type of Controls
Mixtures Calculation
Health Risk Ranking
Reference Values
Selection process
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Version 1,0 : May 2022
Arnold S.F, Stenzel M. R., Mushele P. and D. Drolet, (2022).
SDM 2.0 SUPPORT FILE. Structured Deterministic Model. (Version 1,0)
Software available from University of Minnesota and AIHA.org

Case studies to Apply the SDM 2.0 checklist 1 for pure chemicals & mixtures

Case Study 1: Foundry Shell Core - Phenol

Scenario Description:

Phenolic resins are combined with a sand mixture and then heated to make a sand mold that will be used to shape metal parts in a foundry operation. Your exposure judgment should be based on inhalation exposure to phenol, as an 8 hour TWA exposure.

Tasks:

The operator fills the molds with the sands/phenolic resin, which are then heated to form the shell core. After a few minutes, he takes the shell core out of the mold and modifies or repairs its shape, as necessary. To do this, he holds the shell core in one hand, and using the other hand, files it with a hand file. This task is repeated for the entire 8 hour shift.

Environmental conditions:

- The shell core area is approximately 5m x 5m x 5 m = 125 m^3
- Air flow (Q) ~ 5-6 ACH or 10.4 m^3/min was estimated, using area measurements and local air velocity data.

Agent Characterization: Phenol is used as part of the resin that holds the mold together.
CAS 101-6808 According to the msds, it is present at 1 – 5%. The estimated generation rate for phenol is 16 mg/m^3. Vapor Pressure (mm Hg): 0.35 mm Hg @ 25 deg C

ACGIH TLV: Phenol TWA 5 ppm (19 mg/m^3)

VHR in SDM2.0

Vapor Hazard Ratio (VHR)

Measure of a chemical's potential to exceed it's OEL.

$$\text{VHR} = \frac{VP\ (mm\ of\ Hg)}{OEL\ (ppm)}$$

Mixture Heuristics

Mark Stenzel

Background

Assume the following mixture:

Chemical	Weight %
Toluene	40
Xylene	20
Ethyl acetate	20
Benzene	2
Methylene chloride	3
Carbon tetrachloride	15

Now what do I do?

- Is it valid to assume that the chemical that is the largest component, will have the highest exposure?
- Or should I look at the chemical with the lowest OEL?
- Or should I look at the chemical that has the most significant adverse health outcome?
- Or should I evaluate the most volatile component?
- Or do I have to look at all of the above?
- Or do I give up and because the problem is too complicated?

What data and information will I need to assess exposure of a mixture?

Chemical	Weight %	OEL (ppm)	Molecular Weight (MW)	Pure Vapor Pressure (VP) in mm of Hg at 25°C
Toluene	40	20	92.1	28.4
Xylene	20	100	106.2	8.74
Ethyl acetate	20	400	88.1	93.2
Benzene	2	0.5	78.1	94.8
Methylene chloride	3	25	84.9	435
Carbon tetrachloride	15	5	153.0	115

Applicable chemical and physical laws

Liquids & Vapors

- Raoult's Law
- Henry's Law

Raoult's Law

Raoult's Law: The vapor pressure of each specific component of a mixture is reduced proportional to the mole fraction of the component in the mixture

$$P_A = X_A \, P^0_A$$

Where:

- P_A is the vapor pressure of component A in the mixture
- X_A is the mole fraction of component A in the mixture, and
- P^0_A is the vapor pressure of the pure component A at 25°C

Henry's Law

Henry's: The vapor pressure of each specific component of a mixture is reduced by a constant times the components molar concentration.

$$P_A = k_{H,A} * c_A$$

Where:

- P_A is the vapor pressure of component A in the mixture
- $k_{H,A}$ is the Henry's Law constant for component A
- c_A is the molar concentration (molarity) of component A in the mixture

Controlling Component

Which component is controlling?

That is, in a mixture which component has the highest potential to exceed its’ corresponding OEL?

Mixture Calculations - Raoult's Law

	A	B	C	D	E	F	G	H	J
Chemical	WT (%)	OEL (ppm)	MW	VP (torr)	Mole Fraction	Mole % in Liquid	Adjusted VP	Adjusted VHR	VHR Relative %
					A/C	E/total E	F* D	(G/B)	(H/Max H)* 100
toluene	40	20	92.1	28.4	0.434	0.431	12.20	0.612	12.7%
xylene	20	100	106.2	8.74	0.188	0.187	1.63	0.016	0.3%
ethyl acetate	20	400	88.1	93.2	0.227	0.225	21.00	0.052	1.1%
benzene	2	0.5	78.1	94.8	0.026	0.025	2.41	4.814	100.0%
methylene chloride	3	25	84.9	435	0.035	0.035	15.20	0.610	12.7%
carbon tetrachloride	15	5	153	115	0.098	0.097	11.20	2.236	46.4%
Total	100				1.009	1.000	63.64	8.340	

Interpretation and Exposure Control

- VHR of the mixture = 8.3 that corresponds to Vapor Hazard Ratio Scale of 3 or GGV with capture Local Exhaust Ventilation (LEV) at emission points.

Checklist 2.

Particulate Hazard Ratio

for fibers, particulates, aerosols

PHR Required Level of Control (ReqLC)

OEL Range (mg/m³)	PHR Scale	Required Levels of Control
> 5	1	General ventilation ~ 2 to 4 air turnovers/hr.
≤ 5 to 1	2	Good – General + fans ~ 4 to 6 air turnovers/hr.
≤ 1 to 0.1	3	Good – General + fans ~ 6 to 8 air turnovers/hr.
≤ 0.1 to 0.01	4	Capture
≤ 0.01 to 0.001	5	Containment
≤ 0.001	6	Secondary containment

*PHR = Particulate Hazard Ratio

Aerosols – Particulate Hazard Ratio (PHR)

1. Select appropriate OEL
2. Identify ReqLC from PHR matrix
3. Compare ReqLC with ObsLC
4. Determine ECC:

   If ObsLC> ReqLC = Cat 1

   If ObsLC= ReqLC = Cat 2

   If ObsLC < ReqLC = Cat 4

*OEL = Occupational Exposure Limit *ReqLC = Required Level of Control
*ObsLC = Observed Level of Control *ECC = Exposure Control Category

Group Exercise #3

Case study:

- Cobalt exposure while weighing Lithium Cobalt Oxide powder
- Ingredients are weighed before being transferred to a blender for mixing.

Cobalt exposure while weighing Lithium Cobalt Oxide powder

- Weighing and mixing tasks were conducted in a clean room area where contaminants were removed by a large slot hood.
- The air exchange rate ~ 2 hr^{-1}

1. Select Appropriate OEL

- The ACGIH Short Term Exposure Limit for Cobalt is 0.02 mg/m^3

2. Identify ReqLC from PHR matrix

OEL Range (mg/m3)	PHR Scale	Required Levels of Control
> 5	1	General ventilation ~ 2 to 4 air turnovers/hr.
≤ 5 to 1	2	Good – General + fans ~ 4 to 6 air turnovers/hr.
≤ 1 to 0.1	3	Good – General + fans ~ 6 to 8 air turnovers/hr.
≤ 0.1 to 0.01	4	Capture
≤ 0.01 to 0.001	5	Containment
≤ 0.001	6	Secondary containment

3. Compare ReqLC with ObsLC

The **ReqLC** is Capture
The **ObsLC** is ‘General ventilation’

*ReqLC = Required Level of Control
*ObsLC = Observed Level of Control

4. Determine ECC

If ObsLC > ReqLC, = Cat 1

If ObsLC = ReqLC, = Cat 2

If ObsLC < ReqLC, = Cat 4

*ReqLC = Required Level of Control
*ObsLC = Observed Level of Control
*ECC = Exposure Control Category

More information

- License for SDM 2.0:
- https://license.umn.edu/product/structured-deterministic-model-sdm-20
- Recorded videos: https://essi.umn.edu/interacct/training/#mod7
- 2-day PDC: AIHA Connect PDC 704
- https://ww6.aievolution.com/aih2401/index.cfm?do=ev.viewEv&ev=1046

Questions: Susan Arnold arnol353@umn.edu