6
Approaches to Improving Professional Judgment Accuracy

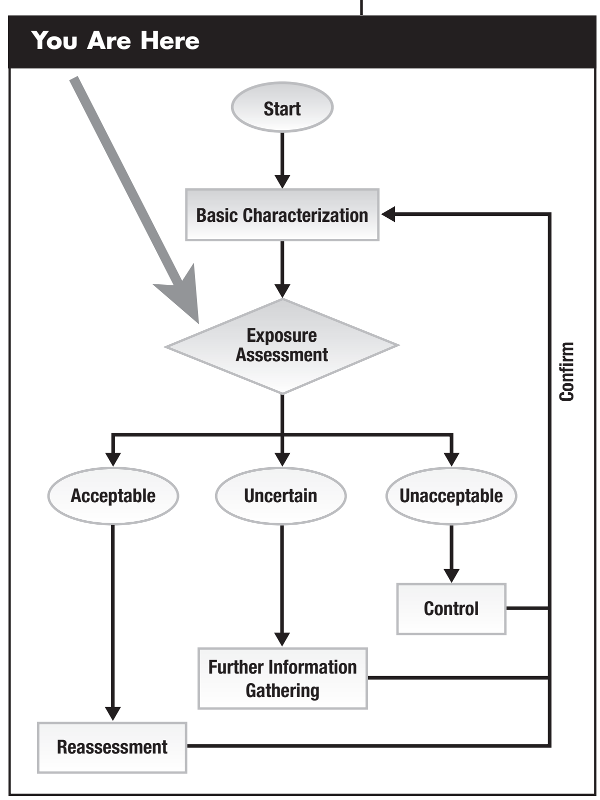
By Susan Arnold, CIH, FAIHA, Mark Stenzel, CIH, FAIHA, and Gurumurthy Ramachandran, PhD, CIH, FAIHA

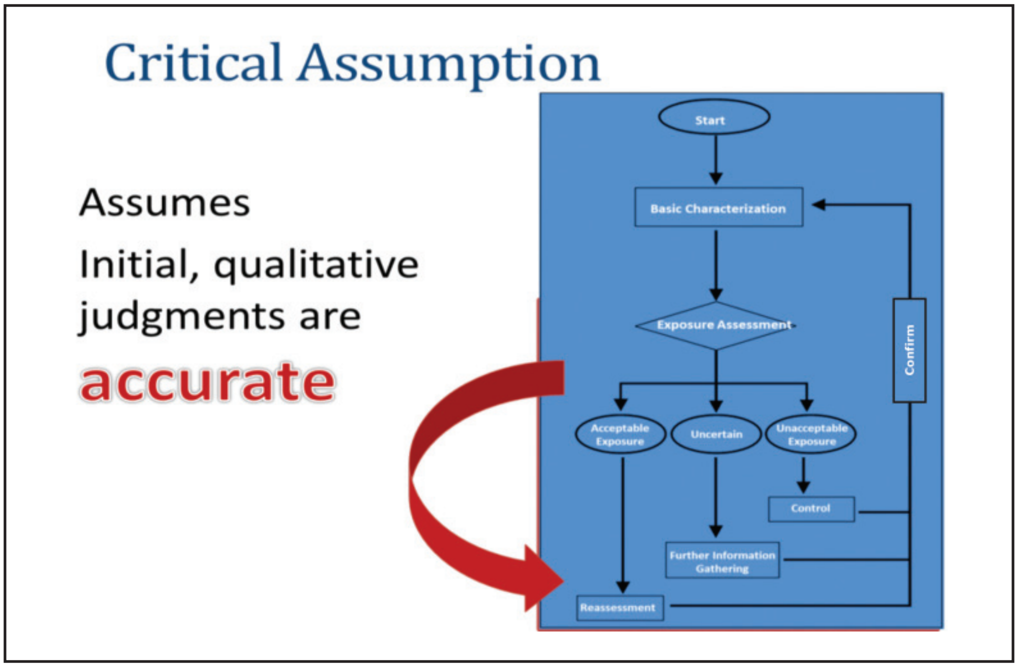
Introduction

Professional judgment plays a critical role in any field in which decisions must be made in the absence of a complete data set. Medical professionals, weather forecasters, financial analysts, and industrial hygienists all use professional judgment to facilitate decision making. Professional judgment, defined as "the application and appropriate use of knowledge gained from formal education, experience, experimentation, inference and analogy that reflects the capacity of an experienced professional to draw correct inferences from incomplete quantitative data, frequently on the basis of observations, analogy and intuition."[1,2] In short, it ensures that in the face of uncertainty, inputs to decision making are considered and weighted appropriately.

When following a comprehensive exposure assessment strategy such as the AIHA's Exposure Assessment Strategy (the Strategy outlined in this text, Chapters 1 through 11), hygienists assess all exposures, to all chemicals, for all workers. Implementation of such a strategy typically occurs at the task-level during all shifts (combination of tasks worked at various frequencies and durations in completing worker job responsibilities), resulting in tens, if not hundreds of thousands of exposure scenarios. The AIHA® Strategy provides an elegant and efficient framework for systematically evaluating all of them. There is a caveat: the strategy assumes that qualitative and quantitative exposure judgments are reasonably accurate.

Exposure judgments are used in a wide range of situations, including retrospective exposure assessments for epidemiology studies[3-6] and current as well as





prospective exposure assessments for managing exposures related to consumer use and manufacturing operations.[7-10] When there are limited or no sampling data available, industrial hygienists (IHs) use a combination of professional judgment, personal experience with a given operation, and review of exposures from similar operations to assess the acceptability of exposures for managing engineering controls, medical surveillance, hazard communication and personal protective equipment programs.[6,8,11-17] In many cases, there is not an opportunity to collect quantitative measurements prior to making an exposure assessment judgment. For example, hazard communication triggered by an exposure assessment must be made prior to the introduction of the agent into the workplaces; similarly, a theoretical technical basis is often the only thing available to define adequate engineering controls related to the introduction of new processes or changes in existing processes.

We use the term “qualitative” to describe judgments or decisions made in the absence of quantitative personal exposure data. This term is further subdivided in our discussion according to the type of inputs from which the judgments are synthesized; subjective qualitative judgments are based on intuition or ‘personal experience’ that is not overtly defined. Objective qualitative judgments are produced using structured approaches.

In the context of this chapter, a decision is represented by a chart showing the hygienist’s assessment of the probabilities that the 95th percentile lies in each of the four categories (Figure 6.1).

The Strategy directs hygienists to conduct initial, qualitative screening assessments to identify those Category 1, 2 or 3 exposures that are clearly acceptable, (i.e. $X0.95 < 10\%$ OEL up to $X0.95 < 100\%$ OEL) or Category 4 exposures deemed unacceptable, (i.e. $X0.95 > \text{OEL}$). These initial judgments may be based on objective strategies such as exposure modeling, or checklists or (more typically) on subjective intuitive approaches. Since the outcome of these initial judgments determine what initial controls and type of follow up, if any, occurs, making accurate qualitative judgments is paramount. Further, since preventing over-exposures and realizing the Strategy’s efficiency occurs when resources are focused on those scenarios truly needing follow up, accurate quantitative exposure judgments are equally critical.

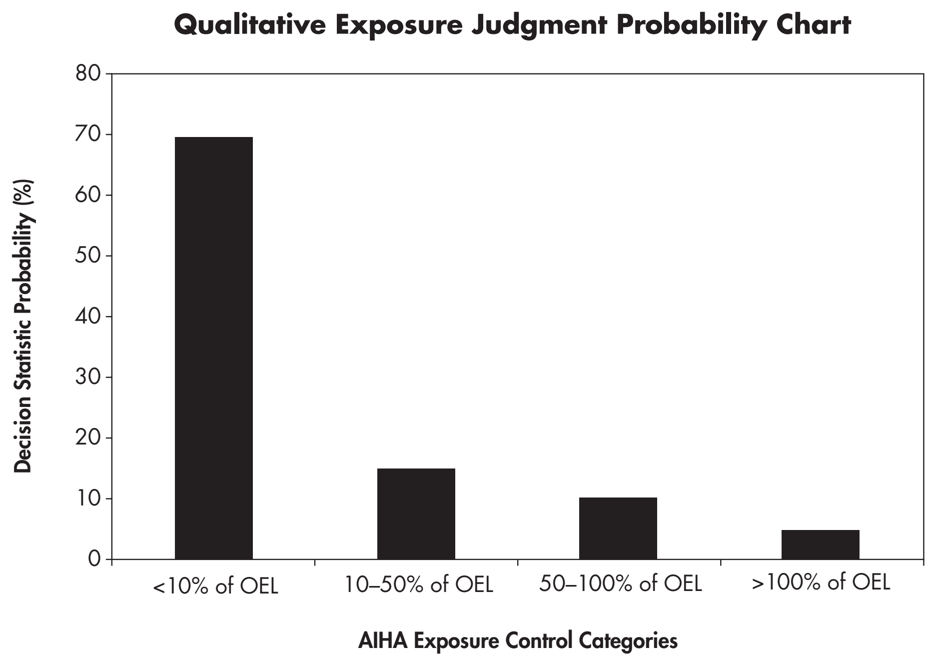


Figure 6.1 – Example qualitative exposure judgment chart illustrating an occupational hygienist's exposure judgment given the information and data available. This chart shows the hygienist's assessment of the probabilities that the 95th percentile falls into each of the four AIHA® Exposure Categories.(14)

Approaches to Decision Making

Subjective judgments focus on the scenario, with each case being treated as if it were unique. They are based on intuition, defined as "the situation has provided a cue; this cue has given the expert access to information stored in memory and the information provides the answer. In short, it is nothing more and nothing less than recognition."(18) Subjective judgments tend to be less structured, considering the information provided from the basic characterization and relying on information that is easily retrievable from memory, experience with situations deemed similar (to the scenario being assessed), and various other inputs. "Intuition can be a useful tool aiding in accurate decision making if, and only if it is followed by the disciplined collection of objective information with disciplined scoring and analysis of that information. In other words, intuitive judgments can be useful when delivered by well-calibrated, experienced professionals operating within their domain of expertise."(18)

Subjective methods for decision making range from the less transparent intuitive approach, to the more disciplined and systematic approaches. A more rigorous, systematic approach may be derived from careful reviews of available information about exposure agents and data related to the work force, jobs, materials, work practices, engineering controls and protective equipment. This is supplemented with worker interviews, review of the technical basis for exposure limits, and when available, personal monitoring data.

When do judgments reflect true expertise?

When the environment is sufficiently regular to be predictable AND the expert has had time and the opportunity to learn these regularities through practice AND the expert can express a judgment accurately in probabilistic terms.

Subjective judgments of exposures for complex scenarios tend to be inaccurate and inconsistent[19] (with the exception of theoretically extreme scenarios, such as those encountered in HAZard and OPerability Analysis [HAZOPs] situations, where one looks at the possible outcomes (worst case, likely case, etc.), considers layers of protection, numbers of people potentially affected, and arrives at a judgment in probabilistic terms). Moreover, assessments based on inadequate or poorly conducted basic characterization tend to be inaccurate and inconsistent.

In fact, research has shown subjective qualitative exposure judgments tend to be no more accurate than random chance, with a significant underestimation bias, i.e., there is marked tendency to assign a lower exposure category than the correct one, thus increasing occupational risk to workers.[14,16,17,19] Logan and Vadali examined qualitative and quantitative exposure judgment accuracy by soliciting exposure judgments for a range of exposure scenarios, initially without revealing personal exposure monitoring data to obtain qualitative judgments, and then presenting the data one data point at a time, with data sets ranging in sample size from n = 1to 8, thus obtaining quantitative judgments. To ensure that a highly confident Reference Exposure Control Category could be computed, only those exposure scenarios with a robust data set of personal exposure data were included in the study. IHs indicated which of the four exposure control categories they believed the 95th percentile of the exposure distribution belonged. Exposure judgments were deemed accurate if the Predicted Exposure Control Category (a "professional judgment") matched the Reference Exposure Control Category.[14,16,19] Study participants were provided with videos of the scenarios[14] or able to visit the facility and observe the operation[16], and yet given basic characterization information including exposure determinant information (as well as given the opportunity to ask the investigators questions about the scenarios), there was little formal consideration of this information. Further, they did not follow any process for arriving at their judgments.

Studies also indicate exposure judgment accuracy of subjective quantitative judgments based on small data sets of personal exposure data (n <6) is also low (< 50%), though better than random chance[14,16], and they improve significantly following training on some simple data analysis rules.

The low accuracy could be due to several factors. Industrial hygienists receive little, if any formal training on how to conduct a basic characterization. If this step of the exposure assessment is not conducted in a systematic way, using physical and chemical principles, and collecting the relevant exposure determinant information, the hygienist may not investigate the exposure that presents the highest exposure potential with sufficient detail, leading to low judgment accuracy.

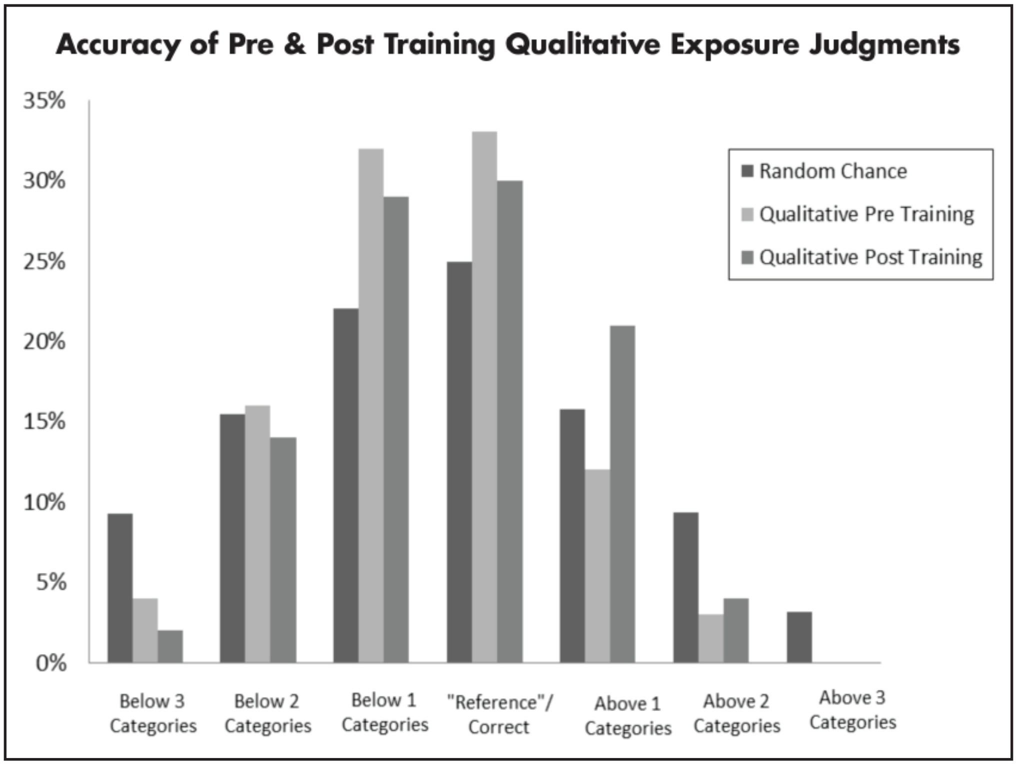


Figure 6.2 – Percentage of pre and post-training qualitative task judgments categorically correct, above and below reference categories in a desktop study, N = 3834.[14] In this case, the differences were not statistically significant.

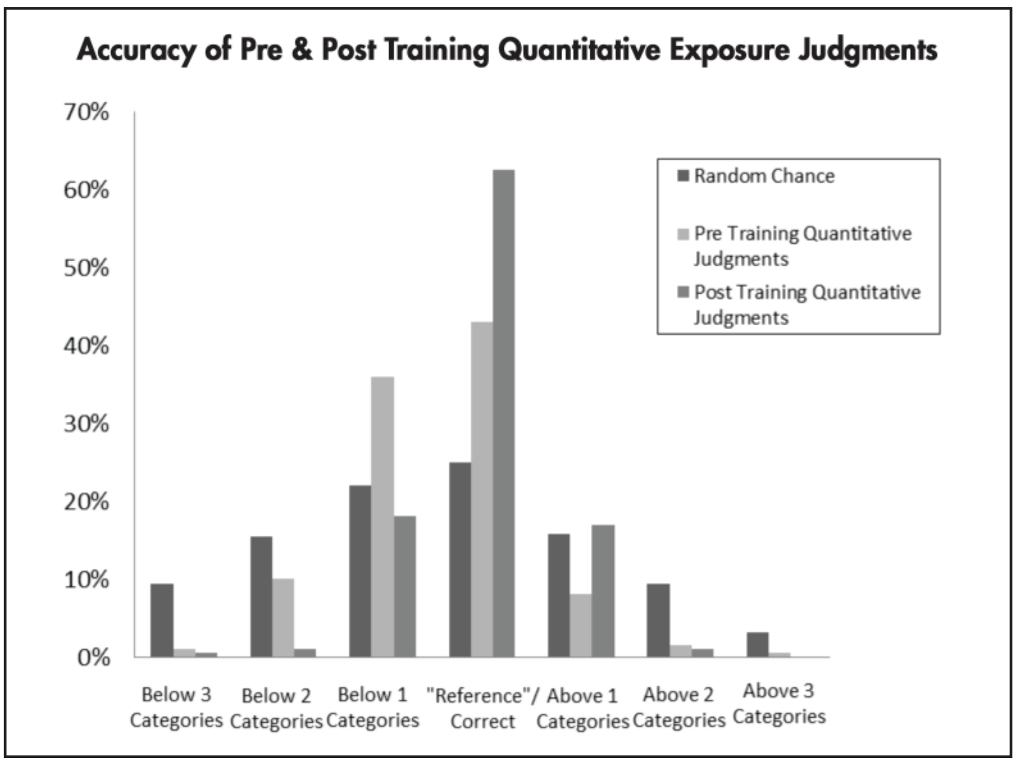


Figure 6.3 – Percentage of pre and post-training quantitative task judgments categorically correct, above and below reference categories in a desktop study, N = 3834.[14]

Another factor may be cognitive biases in understanding skewed lognormal distributions.[14] Cognitive decisions are made in an area of the brain known as the Prefrontal Cortex (PFC). The PFC is easily distracted by stimuli not detected by our conscious self, but which can substantially influence our decisions, making them vulnerable to errors and biases. These stimuli can change moment to moment, which helps explain why subjective intuitive decisions are often so inaccurate and inconsistent.[18] This means that for the practicing exposure assessor, when applied as qualitative judgments initially, regardless of one's age, years of experience or professional credentials, more likely than not the judgment will be incorrect. Mental shortcuts, known as heuristics, are often used, making the decision process efficient but can lead to errors in judgment and introduce bias. Using these heuristics leads to a pattern that, when faced with uncertain prospects, assigns weights to our decisions that differ from the true probabilities of these outcomes. Improbable outcomes are over-weighted, while almost-certain outcomes are under-weighted.

In their research on decision making, Kahneman et al.[20] found these cognitive biases could frequently be attributed to three heuristics: availability, representativeness, and anchoring and adjustment. The availability heuristic reflects the tendency to equate the probability of an event with the ease with which an occurrence can be retrieved from our memory. The degree to which a person's experiences and memory matches the true frequency determines whether these judgments are accurate. Representativeness reflects assignment of an object or event to a specific group or class of events. If the decision maker lacks relevant experience, a surrogate (and less relevant) memory may be used, leading to erroneous conclusions. The anchoring and adjustment heuristic is a strategy for estimating uncertain quantities. When trying to determine the correct value, our minds 'anchor' on a value, and then adjust to accommodate additional information. The degree to which our final answer is anchored to the initial value can be influenced by many factors. For example, when tired, or when our mental resources are spent, we tend to stay closer to the initial value. Within the realm of industrial hygiene decision making, there are many situations where these heuristics can be identified, such as judgments based solely on the "available" information in one's memory. The representativeness heuristic might be invoked when "eyeballing" exposure data, making a judgment modeled on a symmetrical (normal) distribution (which our minds more readily intuit) rather than the skewed, lognormal distribution that more closely reflects most exposure profiles. By modeling the data after a symmetrical, rather than a skewed distribution, the hygienist is likely to underestimate the decision statistic, and consequently underestimate the true exposure. Similarly, when a hygienist 'anchors on a single piece of information', neglecting to take into consideration the most critical factors before making an exposure judgment, can lead one to an erroneous conclusions. Objective, structured approaches, using simple algorithms and exposure modeling are more resistant to these vulnerabilities, focusing the decision maker on the decision making process, and on the critical inputs, while filtering out nonessential information. These approaches have been shown to improve decision making across a broad range of domains, including psychology[18,20], drug delivery and development[21]; predicting transdermal delivery and toxicity[22]; environmental exposure assessment[23]; and aggregate exposure assessment.[24] These same objective approaches can be applied to occupational exposure assessment. In fact, decisions are most accurate in highly uncertain 'low validity' environments, i.e. situations with little or no data, when the final decision is generated from algorithms. The Apgar test is an excellent example. This algorithm, capturing a pattern of behaviors recognized by obstetrical anesthesiologist Virginia Apgar, considers just five basic inputs, with a score assigned to each. The sum of the scores corresponds to the baby's health prognosis. First reported in 1952, this algorithm was better able to predict when medical assistance was needed than individual experts, and is the still the standard in assessing a newborn's transition to life outside the womb.[25,26]

Aids to Decision Making: Use of Algorithms (Checklists) and Models

Algorithms consider critical and consistent inputs and are consistently better at making accurate judgments, while experts try to out-finesse algorithms, thinking outside the box, considering complex combinations of inputs. Humans, however, are inconsistent in making summary judgments of complex information and are therefore less consistent, and less accurate.[18] The algorithms may not be optimal or 100% accurate, but are close enough to be informative and ensure limited resources are used efficiently. Subjective intuitive judgments are, most of the time, no more accurate than random chance. Industrial hygienists should ensure that their judgments are based on proven aids to decision making, eschewing substandard approaches that are not health conservative.

One of the characteristics of algorithms and models contributing to consistent decision making is the consistent order in which information is processed. Checklists provide guidance on the order in which inputs are considered. These simple tools have been the cornerstone of safety excellence in the aviation industry for years. To be sure, checklists and models do not replace knowledge and expertise, and pilots go through rigorous training before they are allowed to fly. The checklists make sure that an IH follows the critical steps at the right time to ensure their own safety, as well as that of their passengers. Likewise, checklists help IHs focus on the critical inputs to decision making in the right order, leading to consistent and accurate exposure judgments, protecting the health and safety of those in their care. The Qualitative Exposure Assessment Checklist Tool to IH judgments will be discussed later in this section.

Model-Based Aids

Several model based tools have been developed and are available to aid decision making. They are introduced here in the context of improving exposure judgment accuracy and so practical application is discussed here, with additional information on the theory and tools covered elsewhere in this book. Additional information is available in other chapters, and these are identified for each of the respective tools, below.

The Industrial Hygiene Exposure Scenario Tool (IHEST) is a freeware spreadsheet tool developed to facilitate consistent and comprehensive basic characterization of a broad range of scenarios. As noted earlier, if the basic characterization is not conducted thoroughly and systematically, exposure judgments are likely to be inaccurate and biased. This tool guides the assessor through the process of collecting general information about the workplace, specific scenario and agent(s), providing cues for measuring or estimating the important determinants of exposure such as generation and ventilation rates. It also prompts the user to specify the type of engineering controls; this information is needed later when making initial judgments by applying the Qualitative Exposure Assessment Checklist. The spreadsheet tool catalogues these values for easy transfer to other AIHA® sponsored Exposure Assessment tools, e.g., the modeling tool IH Mod. IHEST prompts the user for information on the chemical composition (including for mixtures) and physical chemical properties that help identify the potential for inhalation and dermal exposure. Accordingly, there are separate pages in the spreadsheet for capturing inhalation and dermal exposure data. These are identified according to the sample type, sampling method and have specific place holders for capturing pertinent sampling details. Accurate decision making is highly influenced by the quality of the basic characterization, and this tool will be a valuable addition to the exposure assessor's toolkit.

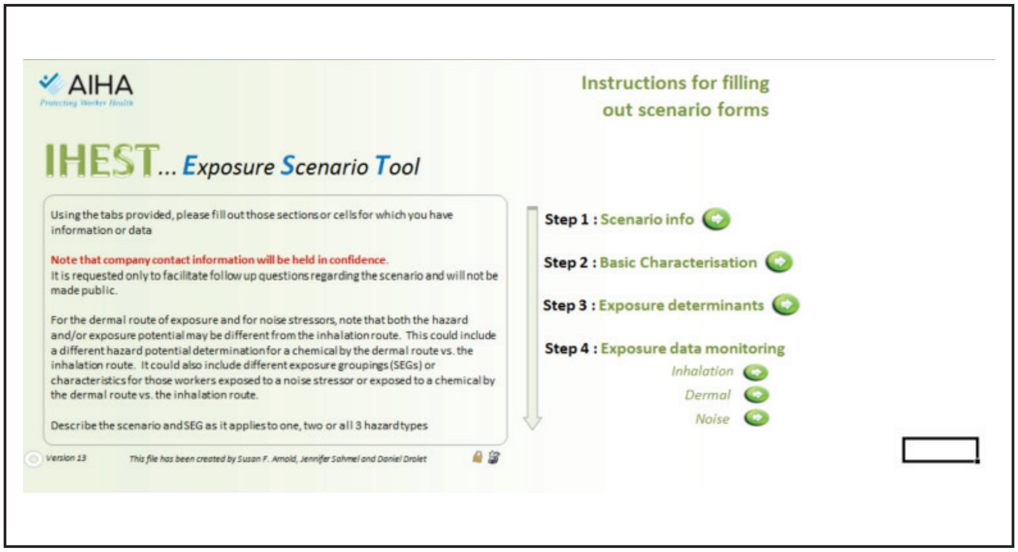


Figure 6.4 – IH Exposure Scenario Tool (IHEST), a tool for conducting a comprehensive basic characterization and transparently documenting exposure determinant data.

The basic characterization provides the information necessary to conduct qualitative and quantitative exposure assessments. The tools presented below will be useful in guiding these exposure assessments.

Checklists

Qualitative checklists, elegant in their simplicity, provide a step-by-step process for applying principles and empirically evaluated practices. One example, The Qualitative Exposure Assessment Checklist, is a tool applicable to vapor, aerosol, fiber and particulate exposure scenarios. It requires only four readily available pieces of information: the Occupational Exposure Limit (OEL), vapor pressure of the pure chemical (VP) when the hazard is in a gas or vapor form, the observed or reported workplace control measures (Obs. Level of Control) and the required level of control (Req. Level of Control) . It can be applied in just a few minutes using readily available information and has been shown to be significantly more accurate than subjective intuitive judgments.(19)

The Checklist guides the application of a set of rules and guidelines or heuristics that are based on physicochemical principles and which were developed empirically. It is divided into three separate sub-checklists; the first two, the Rule of 10 and the Vapor Hazard Ratio, apply to scenarios involving pure or relatively pure volatile and semi-volatile compounds. The Particulate Hazard Ratio applies to aerosol, particulate and fiber scenarios.(28)

The Rule of 10

The Rule of 10 is premised on the incremental reduction in the maximum potential airborne concentration of a volatile chemical resulting from incrementally higher levels of containment. For every step change in containment (through the use of engineering controls), the maximum concentration is reduced by an order of 10. Engineering control types and their corresponding reduction of the airborne concentrations, expressed as a fraction of the Saturated Vapor Concentration (SVC) are presented in Table 6.1 The SVC is calculated from the chemical's pure vapor pressure divided by the atmospheric pressure, in mm Hg. (See Chapter 26 for additional discussion and examples).

Table 6.1 – Checklist for applying the Rule of 10 algorithm

Rule of 10 (ROT)	1. Select the appropriate Occupational Exposure Limit (OEL)
	2. Determine the Vapor Pressure & Saturated Vapor Concentration (SVC)
	3. Identify the Observed Or Reported Level of Control (ObsLC)
	4. Estimate the fraction of the SVC
	5. Calculate the maximum concentration (Cmax)
	6. Compare the Cmax to the OEL
	7. Determine the predicted Exposure Control Category (ECC)

Vapor Hazard Ratio

The Vapor Hazard Ratio (VHR) is the ratio of the SVC, divided by the OEL. A VHR Scale ranging from 1 to 6, reflecting ranges of incrementally increasing VHRs is used to identify the Required Level of Control (ReqLC) (Table 6.2). (See Chapter 26 for additional discussion and examples).

Table 6.2 – Checklist for applying the Vapor Hazard Ratio algorithm

Vapor Hazard Ratio (VHR)	1. Divide VP/OEL to determine VHR Score
	2. Identify ReqLC from VHR matrix
	3. Compare ReqLC with ObsLC
	4. Determine ECC: If Observed Or Reported Level of Control > Req. Level of Control = 1 If Observed Or Reported Level of Control = Req. Level of Control = 2 If Observed Or Reported Level of Control < Req. Level of Control = 4
	5. If the ECC's based on Rule of 10 & VHR differ, use the highest ECC

Particulate Hazard Ratio

The Particulate Hazard Ratio (PHR), similar to the VHR, assigns a PHR Scale value ranging from 1 to 6. The Scale value increases as the OEL value decreases (Table 6.3). (See Chapter 26 for additional discussion and examples).

Table 6.3 – Checklist for applying the Particulate Hazard Ratio algorithm

Particulate Hazard Ratio (PHR)	1. Identify OEL
	2, Identify ReqLC from PHR matrix
	3. Compare ReqLC with ObsLC
	4. Determine ECC: If Observed Or Reported Level of Control > Req. Level of Control = 1 If Observed Or Reported Level of Control = Req. Level of Control = 2 If Observed Or Reported Level of Control < Req. Level of Control = 4

The Rule of 10 and Vapor Hazard Ratio approaches also work for liquid mixtures, but for liquids, the vapor pressure of each component of the mixture is reduced from the vapor pressure of the pure substance following either Raoult's or Henry's Law. Chapter 26 discusses how this adjustment should be made.

With aerosols, fibers and particulates, the expected concentration in air is reduced proportionally to the weight percent of the aerosol, fiber or particulate component in the mixture.

Checklist based judgments were significantly more accurate and less biased, compared to judgments based on subjective inputs in a recently conducted study.(19) Two groups, consisting of practicing IHs (n=39) and novice exposure assessors (n=8) were recruited for the study. Each group was assigned several exposure scenarios and asked to assess worker exposures, before and after receiving Checklist training.

Exposure scenarios to be evaluated were developed from information and data provided by volunteer organizations, with selection criteria specifying that scenarios had to reflect inhalation exposures and had to include at least six personal exposure measurements. Thus scenarios were identified independently of the guidelines to be used in the judgment process. Baseline (subjective) judgment accuracy was low (33%) for both practicing IHs and novice assessors, and was no better than random chance (25.1%). Examining the baseline accuracy separately, however, the novices were more accurate (42%) and showed little bias, meaning they were just as likely to overestimate or underestimate the true exposure. Judgments made by the practicing IH group were biased, tending to underestimate the 'true' exposure with 51% underestimating the 'true' exposure by one (25.4%), two (14.3%) or three (6.3%) Exposure Control Categories. Checklist based judgments accuracy was significantly more accurate (($\chi 2$ (1) = 25.36, p < .000002). Categorical accuracy (defined as an exact match between the reference Exposure Control Category and exposure judgment) was ~ 62%, and categorically-accurate-plus-one, defined as matching or over-estimating the true Exposure Control Category by one category, was ~ 71%. Precision and bias also improved. The qualitative judgments using this model were comparable in accuracy to those achieved with quantitative measurements and corresponding statistical training (Figure 6.5).

Inter-rater agreement, a measure of how frequently two or more IHs assessing the same scenario reach the same conclusion, is an important element of exposure assessment, since the exposure judgment leads to a conclusion regarding the health risk of a worker or group of workers. That conclusion determines what type of risk management occurs and the well-being of that worker (resulting from an appropriate health risk determination) should not depend on who is making the exposure judgment. Thus consistency, evident through inter-rater agreement, is as important as accuracy. Inter-rater agreement of Checklist based judgments was good to excellent.(19)

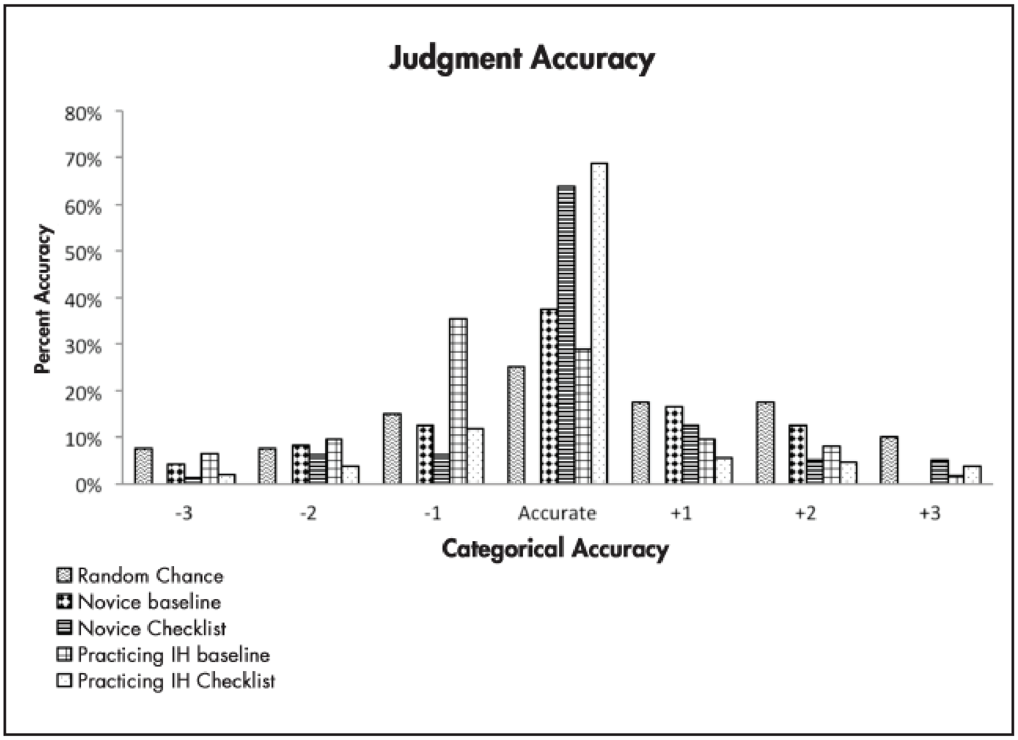


Figure 6.5 – Categorical Judgment Accuracy, showing accuracy attributable to random chance pre-training (Baseline), post-training Checklist-guided judgment accuracy for Novices and Practicing IHs.[19]

The bias observed in the practicing IHs judgments, absent in the judgments made by novices, suggest that the practicing hygienists' feedback loop may be faulty, misinforming their professional judgment leading to bias. Since the distribution of exposures is typically skewed, as we see by the lognormal distribution that best approximates most personal exposure data, the practice of collecting few, if any personal exposure measurements, (and often analyzing them without any statistical rigor) may be one source of this misinformation.

To demonstrate how a faulty feedback loop leads to bias among practicing IH, consider the following example based on the data shown in Table 6.4, which is comprised of summary data from several theoretical personal exposure data sets. The Exceedance Fraction (EF), defined as the proportion of an exposure profile that exceeds a criterion such as an OEL, is presented from top to bottom in the far left column ranges from 50% down to 2%. Focusing on (EF) = 25%, one can see from the "Percentage (%) of time that measurements collected for (N = 1,2,3,4 or 5) will fall below the OEL", even when N = 5, the probability of observing measurements that fall below the OEL, is 23.7%. In these cases, when 'eye-balling' the data, the tendency is to focus on the mean value, rather than the 95th percentile exposure, which is much harder to visualize, intuitively. This means that, while the exposure profile is clearly unacceptable, the IH would erroneously conclude, based on the five measurements, that the exposure was acceptable. The feedback then is incorrect, and may reinforce a trend of underestimating the true exposure.

Table 6.4 – Percentage of the time exposure measurements for sample sizes N = 1 to 5 will be below the OEL, for Exceedance Fractions ranging from 2% to 50%. *Assuming a Geometric Standard Deviation (GSD) = 2.5 and OEL = 10 ppm

EF	*GM*	*95th*	*Percent (%) Distribution < OEL*	*Percentage (%) of time that measurements collected for N = (1, 2 3, 4 or 5) that all n measurements will fall below OEL:*				
				1	2	3	4	5
0.50	10.0	45.15	50.0	50.0	25	12.5	6.25	3.13
0.25	5.39	24.32	75.0	75.0	56.3	42.2	31.6	23.7
0.10	3.09	13.95	90.0	90.0	81	72.9	65.6	59.1
0.05	2.22	10.00	95.0	95.0	90.3	85.7	81.5	77.4
0.02	1.52	6.87	98.0	98.0	96.0	94.1	92.2	90.4

EF = Exceedance Fraction GM = Geometric Mean 95th % = 95th Percentile

The negative bias of qualitative judgments observed in the Checklist study is not limited to estimation of the upper tail exposures. The same negative bias observed in the Checklist study was also observed in a study where hygienists (N = 8) were asked to predict the arithmetic mean in an exposure reconstruction study.[29] Assessments for 77 SEGs were solicited, with participants providing N = 314 qualitative exposure judgments. The same faulty feedback loop thought to contribute to poor calibration of 95th percentile exposures could also misdirect our professional judgment of mean exposures and other measures of central tendency. Thus, subjective estimates of exposure reconstruction are likely to underestimate the true historical exposure.

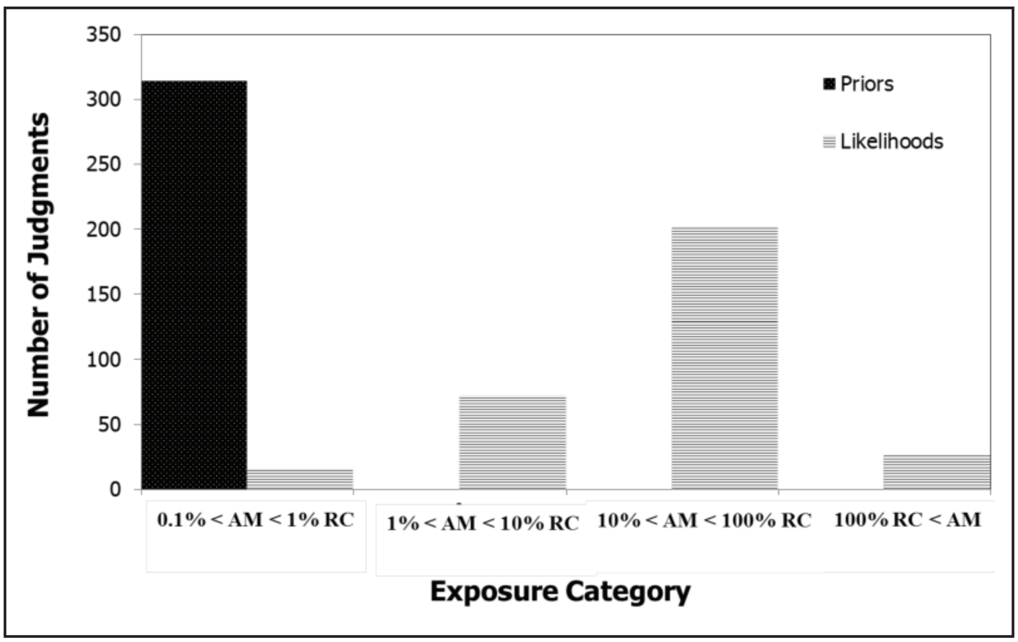


Figure 6.6 – Underestimation bias in exposure reconstruction, N = 314 judgments. AM = Arithmetic Mean, RC = Reference Category.

Exposure models, when used probabilistically, produce more refined, quantitative estimates of the SEG's 95th percentile exposures.[17] Quantitative, rather than categorical exposure estimates are generated by the models in exchange for some specific knowledge about the exposure scenario, such as the ventilation rate and generation rate. When models are selected and applied in a systematic approach, they too lead to exposure judgments that are more accurate than subjective intuitive judgments.[30] An introduction to the models and their application is presented in Appendix I.[31]

Data-Based Aids to Decision Making

Quantitative judgments are also more accurate when analyzed using objective approaches. Algorithms, typically used to test statistical hypotheses, overcome our inherently limited ability to visualize the log normal distribution by which most exposure data can be described. Unlike our subjective intuitive judgments, objective analyses account for this skewed distribution, reducing the probability of underestimating the true exposure. Studies[14,16] show that quantitative judgments based on a simple set of rules or heuristic, even when sample sizes were small, were significantly more accurate, compared to baseline (subjective) estimates. The heuristic guides the categorical classification of exposures.

Decision heuristic:

1. If n is small (e.g. <6) and one or more measurements exceed the OEL, then the exposure rating should be Category 4.
2. Otherwise, estimate the median exposure and use it as a surrogate of the sample GM: sort the data and determine the median (the median is the middle value if n is odd and the average of two middle values if n is even).
3. Multiply the median by three multipliers: 2, 4 and 6.

The results comprise an approximate low, middle and high estimate of true 95th percentile. Compare the low, middle and high estimates to the AIHA exposure control categories, selecting the category, based on these estimates that most likely contains the true 95th percentile.[14]

For example, consider a data set of n = 4. The data are 15, 12, 23 and 9 mg/m3. The OEL is 100 mg/m^3. Following the rules of thumb,

1. reorder the data from lowest to highest 9, 12, 15, 23
2. median value: 12+15/2 = 13.5
3. multiply the median by 2, 4 and 6: 27, 54, 81

The 95th percentiles for low, medium and high estimates correspond to Exposure Control Category 2 and 3.

There are fortunately a number of tools available for assessing quantitative data sets, including the user-friendly and freely available IHSTAT tool. This spreadsheet provides visual and quantitative guidance, leading to accurate exposure assessments. Guidance on applying these statistical algorithms is provided in Chapter 8. Another tool that is especially useful when dealing with small data sets, the Industrial Hygiene Data Analyst – Lite Edition (IDHA-LE, Exposure Assessment Strategies, Inc.) is a free-ware tool that applies the Bayesian Decision logic and delivers a highly intuitive output. This tool also provides a framework for systematically incorporating prior knowledge regarding an exposure scenario, including information generated using qualitative tools such as the Checklist and exposure models. The result is a more robust decision, transparently reporting the appropriate confidence level (or its converse, degree of uncertainty) in the decision, given the data.

Feedback Loops – Calibrating Professional Judgment

Feedback loops are essential for developing excellence in professional judgment, providing the necessary information to validate, refine or correct decision making inputs. Their importance can't be understated, since the skills necessary for evaluating competence in a specialized field are the same skills required for developing competence. In other words, it is by becoming more competent that we improve our ability to identify the presence or absence of competent practice.(32) Feedback loops consist of deliberate, objective data collection and careful analysis, evaluating the degree to which the desired outcome was achieved. In this case, the desired outcome is accurate exposure judgments. This objective feedback is also necessary to calibrate the professional's own judgment, to confirm the exposure assessor is using effective approaches, correctly and consistently. Lacking a documented system to capture earlier judgments and constantly returning to earlier judgments, the professional assessor is doomed to error, usually to the detriment of the worker.

Feedback Loops – A Case Study

The airline industry has learned, sometimes the hard way, that accuracy and reliability means the difference between life and death. Feedback in this industry is swift, obvious, and sometimes tragic. Given the stakes and the criticality of getting it right, every time, airline pilots receive regular simulation training, which includes a post-simulation review of what went right, and what didn't. This approach provides a non-punitive method for learning and calibrating their professional judgments. There are robust data to show that it works; since the inception of simulator training, airline incidents attributable to pilot error dropped 71 percent, making air travel the safest form of travel.(32)

The Future of Exposure Science

The next step towards exposure assessment excellence is incorporating exposure judgment feedback loops to calibrate our judgments and validate our aids to decision making. One way to provide this feedback loop is to select exposure scenarios for which there are at least 6 personal exposure measurements, determining their reference Exposure Control Categories with a reasonable degree of confidence. These will ideally comprise exposures from all four Exposure Control Categories. Then, without revealing the exposure data, instruct hygienists to apply the objective decision making tools and register their qualitative judgments. Next, after revealing the personal exposure data, elicit quantitative exposure judgments, (generated using one of the objective quantitative approaches). Determine the accuracy of their judgments by comparing them to the Reference Exposure Control Categories. If the objective approaches do not lead to accurate exposure judgments, investigate where within the algorithm the error occurred, considering the scenario and any assumptions – incorporated into the algorithms or incorporated by the assessor.

References

1. **Mulhausen, J.D. and J. Damiano:** *A Strategy for Assessing and Managing Occupational Exposures*, 2nd edition. Fairfax, VA: AIHA®, 1998.
2. **Ignacio, J.S. and W.H. Bullock:** (2006). *A Strategy for Assessing and Managing Occupational Exposures*, 3rd edition. Fairfax, VA: AIHA®, 2006.

3. **Esmen, N., T. Hall, R. Stone, G. Marsh, M. Gula, and C. Gause:** An investigation of secondary exposure missclassification effects of lifelong occupational history in exposure estimation. *Am. Ind. Hyg. Assoc. J. 60*:175–81 (1999).
4. **Ramachandran, G.:** Retrospective exposure assessment using Bayesian methods. *Ann. Occup. Hyg. 45(8)*:651–67 (2001).
5. **Ramachandran, G. and S.V. Banerjee:** Expert judgment and occupational hygiene: Application to aerosol speciation in the nickel primary production industry. *Ann. Occup. Hyg. 47(6)*:461–75 (2003).
6. **Friesen, M.D.:** Validation of a semi-quantitative job exposure matrix at a soderberg aluminum smelter. *Ann. Occup. Hyg. 47(6)*:477–84 (2003).
7. **Hawkins, N. C. and J.S. Evans:** Subjective estimation of toluene exposures: A calibration study of industrial hygienists. *App. Ind. Hyg. J. 4*:61–68 (1989).
8. **Teschke, K., C. Hertzman, H. Dimich-Ward, A. Ostry, J. Blair, and R. Hershler:** Comparison of exposure estimates by worker raters and industrial hygienists. *Scand. J. Work Environ. Health 15*:424–29 (1989).
9. **Macaluso, M.D.:** Inter-rate agreement in the assessment of solvent exposure at a car assembly plant. *Am. Ind. Hyg. Assoc. J. 54*:351–59 (1993).
10. **Jones, R.M., C. Simmons, and F. Boelter:** Development and evaluation of a semi-empirical two-zone dust exposure model for a dusty construction trade. *J. Occup. Environ. Hyg. 8*:337–48 (2011).
11. **de Cock, J., H. Kromhout, D. Heederik, and J. Burema:** Experts' subjective assessment of pesticide exposure in fruit growing. *Scand. J. Work Environ. Health 22*:425–32 (1996).
12. **Burstyn, I. and K. Teschke:** Studying the determinants of exposure: A review of methods. *Am. Ind. Hyg. Assoc. J. 60*:57–72 (1999).
13. **Kolstad, H.A., J. Sonderskov, and I. Burstyn:** Company-level, semi-quantitiative assessment of occupational styrene exposure when individual data are not available. *Ann. Occup. Hyg. 49(2)*:155–65 (2005).
14. **Logan, P.R. and P. Hewett:** Occupational exposure decisions: Can limited data interpretation training help improve accuracy? *Ann. Occup. Hyg. 53(4)*:1–14 (2009).
15. **Logan, P., G. Ramachandran, and J. Mulhausen:** Desktop study of occupational exposure judgments: Do education and experience influence accuracy? *J. Occup. Environ. Hyg. 8(12)*:746–58 (2011).
16. **Vadali, M.R.:** Effect of training, education, professional experience and need for cognition on accuracy of exposure assessment decision-making. *Ann. Occup. Hyg. 56(3)*:292–304 (2012).
17. **Vadali, M., G. Ramachandran, J. Mulhausen, and S. Banerjee:** Effect of Training on Exposure Judgment Accuracy of Industrial Hygienist. *J. Occup. Environ. Hyg. 9(4)*:242–56 (2012).
18. **Kahneman, D.:** *Thinking, Fast and Slow*. New York: Straus and Giroux, 2011.
19. **Susan F. Arnold, Mark Stenzel, Daniel Drolet and Gurumurthy Ramachandran:** (In Press) Using Checklists and Algorithms to Improve Qualitative Exposure Judgment Accuracy. *JOEH*.
20. **Kahneman, D., P. Slovic, and A. Tversky:** *Judgment under uncertainty: Heuristics and biases*. Cambridge: Cambridge University Press, 1982.

21. **Lipinski, C., F. Lombardo, B. Dominy, and P. Feeney:** Experimental and computational approaches to estimate solubility and permeability in drug delivery and development settings. *Adv. Drug Del. Rev., 46*:3–26 (2001).
22. **Magnusson, B.M., W.J. Pugh, and M.S. Roberts:** Simple rules defining the potential of compounds for transdermal delivery or toxicity. *Pharm. Res. 21(6)*:1047–54 (2004).
23. **Fristachi, A., Y. Xu, G. Rice, C.A. Impellitteri, H. Carlson-Lynch, and J.C. Little:** Using probabilistic modeling to evaluate human exposure to organotin in drinking water transported by polyvinyl chloride pipe. *Risk Anal. 29(11)*:1615–28 (2009).
24. **Cowan-Ellsberry, C.E. and S.H. Robinson:** (2009). Refining aggregate exposure: Example using parabens. *Regul. Toxicol. Pharmacol. 55(3)*:321–29 (2009).
25. **Apgar, V., D.A. Holaday, L. James, I.M. Weisbrot, and C. Berrien:** Evaluation of the newborn infant-second report. *JAMA 168(15)*:1985–88 (1958).
26. **Gawande, A.:** *The Checklist Manifesto: How to Get Things Right*. New York: Metropolitan Books, 2010.
27. **Stenzel, M.:** Mixtures and Non-Ambient Conditions (Chapter 25). In *A Strategy for Assessing and Managing Occupational Exposures*, 3rd edition. Bullock, W.H. and J.S. Ignacio (eds.). Fairfax: AIHA®, 2006. pp. 279–284.
28. **Chen Y-C., G. Ramachandran, B.H. Alexander, and J.H. Mandel:** Retrospective Exposure Assessment in a Chemical Research and Development Facility. *Environ. Internatl. 39*:111–21 (2011).
29. **Vadali M., G. Ramachandran, and J. Mulhausen:** Exposure modeling in occupational hygiene decision making. *J. Occup. Environ. Hyg. 6*:353–62 (2009).
30. **Keil, C.B., C.E. Simmons, and T.R. Anthony (eds.):** *Mathematical Models for Estimating Occupational Exposure to Chemicals*, 2nd edition. Fairfax, VA: AIHA®, 2009.
31. **Kruger, J. and D. Dunning:** Unskilled and unaware of it: How difficulties in recognizing one's own incompetence lead to inflated self-assessments. J. Personal. *Social Psychol. 77(6)*:1121–34 (1999).
32. **Billings, C.E. and W.D. Reynard:** Human factors in aircraft incidents: Results of a 7-year study. *Aviat. Space Environ. Med. 55(10)*:960–65 (1984).

A Strategy for Assessing and Managing Occupational Exposures

4th Edition

Protecting Worker Health

American Indusgtrial Hygiene Association
Exposure Assessment Strategies Committee

Edited by
Steven D. Jahn, CIH, MBA
William H. Bullock, DHSc, CIH, CSP
Joselito S. Ignacio, CIH, CSP, MPH, REHS/RS

This book was developed by experts with background, training, and experience in exposure assessment and management, working with information and conditions existing at the time of publication. The

American Industrial Hygiene Association (AIHA®), as publisher, and the authors have been diligent in ensuring that the material and methods addressed in this book reflect prevailing occupational health and safety and industrial hygiene practices. It is possible, however, that certain procedures discussed will require modification because of changing federal, state, and local regulations, or heretofore unknown developments in research.

AIHA® and the authors disclaim any liability, loss, or risk resulting directly or indirectly from use of the practices and/or theories discussed in this book. Moreover, it is the reader's responsibility to stay informed of any changing federal, state, or local regulations that might affect the material contained herein, and the policies adopted specifically in the reader's workplace.

Specific mention of manufacturers and products in this book does not represent an endorsement by AIHA®.

ISBN 978-1-935082-46-0
Stock No: AEAK15-327

American Industrial Hygiene Association
3141 Fairview Park Drive, Suite 777
Falls Church, VA 22042
Tel.: (703) 849-8888
Fax: (703) 207-3561
http://www.aiha.org
e-mail: infonet@aiha.org