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Defining Science for OEHS Experts

Defining the Science Research Agenda

Practice to Research to Practice™

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Version 2 | March 17, 2025

Introduction

The members of AIHA and ACGIH are occupational and environmental health and safety (OEHS) professionals, including industrial hygienists, who protect workers by practicing the art and science of anticipating, recognizing, evaluating, controlling, and confirming protection from hazardous workplace conditions that may cause injury or illness. The members of AIHA and ACGIH have engaged in a process aiming to establish a research agenda that will benefit the organizations' shared mission to protect worker health and safety. This research agenda reflects the needs of both organizations' members and seeks to address science and practice gaps that hinder full worker protection. It is intended to stimulate ideas among academic, government, and private researchers. AIHA and ACGIH will use the agenda to advocate for occupational health research proposals that will present opportunities for the funding organizations to fulfill their research missions.

Defining the Science

The success of OEHS as a profession depends on cutting-edge research, training, and practical application-elements of a self-improving, evolving system. The mission of the Defining the Science Advisory Group (DTS-AG) is to develop and maintain a national OEHS research agenda endorsed by the AIHA and ACGIH boards of directors.

DTS-AG has been tasked to address such matters as:

- Identifying areas of practice that do not hold up to current scientific evidence so that AIHA, ACGIH, and other stakeholders may improve OEHS practice through focused outreach, promotion, and training.
- Identifying research initiatives that are needed to advance the state of OEHS science and address gaps in practical knowledge.
- Identifying opportunities to answer OEHS research questions through studies of at-risk workers.
- Defining a transparent, open process across volunteer groups, local sections, and allied stakeholders for creating and sustaining a living research agenda on behalf of the profession and prioritizing project ideas for future funding.
- Advising the AIHA and ACGIH boards and staff members on where they should focus their internal resources to advance the state of OEHS research.
- Defining the roles of AIHA and ACGIH as facilitators of OEHS scientific research—both for funded research opportunities that come to the organizations and as "bundlers" of partners, needs, and ideas to bring before funding organizations.
- Determining how AIHA and ACGIH may leverage their volunteer representatives who have been recently appointed to NIOSH National Occupational Research Agenda (NORA) councils. NORA is an important source of funding for research and training and helps inform NIOSH's strategic plan.

Development of a Research Agenda

This research agenda follows the Practice to Research to Practice™ (P2R2P) model. The inaugural version of the research agenda is based on ideas suggested by AIHA and ACGIH members through the DTS submission process. More about the process of submitting and evaluating research ideas may be found in AIHA and ACGIH's Defining the Science guide for members (PDF). Updated versions of the agenda will be issued periodically as new ideas are submitted, reviewed, and prioritized. Readers who wish to review the original submissions or provide comments on research ideas may access and comment via AIHA's DTS webpage.

The research agenda is divided into two main sections. First, the Practice to Research section encompasses research required to address barriers to practice that exist due to lack of knowledge. Second, the Research to Practice section addresses the dissemination of new knowledge that has the potential to improve industrial hygiene (IH) practice or OEHS practice more generally.

Practice to Research

Research required to address barriers to practice due to a lack of knowledge.

Occupational Safety and Health Surveillance: The value of protecting occupational health lies in preventing the onset of new occupational disease and the exacerbation of existing disease following occupational exposures. The difficulty of measuring the human and financial costs associated with occupational diseases creates a barrier to supporting research focused on understanding and preventing these diseases. Illnesses and injuries that are not readily associated with single exposure events tend to go unrecognized. Since the causes of illnesses do not affect treatment decisions, medical care providers do not ascertain or report them.

The National Academies of Sciences, Engineering, and Medicine (NAS) published an authoritative report on this issue in 2018.[1] The findings and recommendations of this report present opportunities to advocate for changes in public policy that will lead to wider recognition of the important role that protection of occupational health plays in improving the health and welfare of the American people. The NAS report counters the perceptions of the public and health practitioners by highlighting the large and growing burden of occupational illnesses on people's overall health and the country's economy.

According to the Centers for Disease Control and Prevention (CDC), public health surveillance is "the ongoing, systematic collection, analysis, and interpretation of health-related data essential to planning, implementation, and evaluation of public health practice."[2] Unexpected patterns or trends raise questions that trigger investigation and research. The U.S. Bureau of Labor Statistics (BLS) collects recordable injury and illness data from employers through workers' compensation insurance claims and summarizes lost workday rates by industry; however, BLS' methods miss data for health outcomes that are covered by health insurance or occur after a person's separation from employment. Methods used in academic studies for estimating this lost data could be used to improve surveillance to manage health risks.

Quantifying the Health and Economic Burden of Occupational Disease: Occupational epidemiology and toxicology studies establish causation and dose-response relationships that provide technical bases for health and safety protection standards. For some time, workplaces have played a leading role in environmental health science research. Employers may support OEHS professionals who provide valuable insights into the contributions by work environments to unacceptable exposures that arise from production processes. OEHS professionals have a unique perspective on occupational health issues through the services they provide to protect workers, such as anticipating hazards, establishing administrative and engineering control measures, selecting personal protective clothing and equipment, collecting and interpreting exposure measurements, and investigating unexpected health outcomes.

Workers are an identifiable, genetically diverse group of people who are the first to be at risk of exposure to new materials entering commercial use. Toxicity testing, including the tests required by the 2016 Frank R. Lautenberg Chemical Safety for the

[1] National Academies of Sciences, Engineering, and Medicine. 2018. A Smarter National Surveillance System for Occupational Safety and Health in the 21st Century. Washington, DC: The National Academies Press. https://doi.org/10.17226/24835.

[2] Centers for Disease Control and Prevention, Introduction to Public Health Surveillance. Accessed July 29, 2022, at https://www.cdc.gov/training/publichealth101/surveillance.html.

21st Century Act, takes time and may not always identify relevant human health effects. As new materials and processes are introduced at an increasing pace, identifying workers who produce and use these materials opens up research opportunities that may provide technical bases for health protection programs. Because occupational health protection remaining on alert for unexpected health effects and high exposure levels, the OEHS profession will continue to have an important role in generating hypotheses for testing and topics for study.

Estimates of the morbidity and mortality attributable to workplace exposures indicate a significant and growing problem. In a 2019 publication, the International Labor Organization (ILO) estimated that "diseases are the cause of the great majority of work-related deaths (2.4 million deaths or 86.3 percent), in comparison to fatal occupational accidents (which make up the remaining 13.7 per cent)." ILO concluded that work-related disease and accidents combined "account for 5 to 7 percent of deaths globally."[3]

Based on an in-depth literature review, the American Thoracic Society concluded that "workplace exposures contribute substantially to the burden of multiple chronic respiratory diseases," such as asthma, chronic obstructive pulmonary disease, chronic bronchitis, idiopathic pulmonary fibrosis, hypersensitivity pneumonitis, and sarcoidosis.[4] Furthermore, the COVID-19 pandemic has highlighted the role of occupational exposures in the spread of infectious diseases. Researchers at the University of Washington reported "approximately 10% (14.4 M) of United States workers are employed in occupations where exposure to disease or infection occurs at least once per week." This study has also found about 18.4 percent of all U.S. workers to work in occupations where they may be exposed to disease or infection at least once per month.[5]

Leading causes of death are increasingly the chronic diseases of old age. Occupational and environmental exposures increase people's probability of developing these diseases, exacerbate disability, and decrease life expectancy. There are also hidden socioeconomic costs associated with uncontrolled occupational health risks. The trades and industries that put workers at risk are increasingly shunned by people unwilling to accept those risks, even for jobs that are among the highest paying in a given community. Those who are willing to take on these risky roles typically represent a more vulnerable segment of society with fewer resources to cope with the increased risks and adverse outcomes. Studying occupational health risks presents opportunities to reduce morbidity and mortality and reduce uncertainties about safe workplace conditions, thus providing individuals the freedom to pursue careers that reward their labor and ingenuity.

Exposure Surveillance: The existence of large, government-owned electronic databases of occupational exposure monitoring information creates possibilities to use the data in ways analogous to public health surveillance. Federal and state compliance requirements, small business consultations, and field studies have generated millions of exposure monitoring results. OEHS programs at government-owned research, development, testing, manufacturing, and medical care sites are other potential sources of information.

3 International Labour Organization (2019): "Safety and Health at the Heart of the Future of Work: Building on 100 Years of Experience."

4 Blanc, P.D., I. Annesi-Maesano, J.R. Balmes, K.J. Cummings, D. Fishwick, D. Miedinger, N. Murgia, R.N. Naidoo, C.J. Reynolds, T. Sigsgaard, K. Torén, D. Vinnikov, and C.A. Redlich (June 1, 2019): "The Occupational Burden of Nonmalignant Respiratory Diseases: An Official American Thoracic Society and European Respiratory Society Statement." *Am. J. Respir. Crit. Care. Med. 199(11)*, 1312–1334.

5 Baker, M.G., T.K. Peckham, and N.S. Seixas (April 28, 2020): "Estimating the Burden of United States Workers Exposed to Infection or Disease: A Key Factor in Containing Risk of COVID-19 Infection." *PLoS One.* 15(4).

However, there is no routine collection, analysis, interpretation, and dissemination of occupational exposure monitoring data in the way that BLS routinely publishes analyses of reportable injury and illness data. OEHS professionals must know this information for project planning. Summary data would provide technical bases for recommending controls and prioritizing organizations' health protective efforts. In addition, exposure surveillance supports hypothesis-forming research that could identify areas to investigate or reduce uncertainties regarding exposure mitigation strategies.

Research on methods of collecting, analyzing, and interpreting existing government-owned exposure monitoring data has a high likelihood of success. There is a body of literature that employs government-owned data to support useful analyses. Most recently, the University of Michigan released a Noise JEM website that is populated with measurements from government databases, private industry, and the published literature and that supports queries for summary data by industry codes or occupation codes.[6]

Routinely publishing summary data would also promote standardized data reporting and recordkeeping. Organizations could use published summaries as baseline information to set occupational health goals. Progress in meeting their goals would require analyzing exposure monitoring results to create metrics comparable to published estimates. Over time, this would incentivize employers and organizations to create and follow standardized methods.

Improving Exposure and Risk Assessment: Preventing occupational illness requires using observations and exposure monitoring results to guide decisions on interventions needed to assure working conditions are protective. Current risk assessment and management practices and programs vary greatly across workplaces in their ability to recognize, evaluate, and control risks that are associated with exposure. Some workplaces take a comprehensive approach, such as the strategy advocated by AIHA, working to evaluate and control exposures for all workers, on all days, and for all environmental agents.[7] Other workplaces focus only on regulatory compliance and incident or complaint follow-up. Many workplaces have no systematic practices or programs in place at all. These varying approaches could result in unacceptable health risks due to inadequate or nonexistent exposure assessment and management practices and programs. Workplaces are dynamic environments in which constantly evolving tasks, materials, and tools result in large variation in exposure levels. Exposure assessment programs of sufficient quality to account for the uncertainty in exposure levels support continuous improvement that will also compensate for the uncertainties in our understanding of the degree of health risk associated with exposure.

It is necessary to make a systematic and comprehensive survey of the prevalence and efficacy of exposure assessment and management practices and programs implemented in workplaces across various sectors (e.g., heavy and light manufacturing, resource extraction, chemical manufacturing and refining, healthcare, government entities, etc.). The results of this survey would inform OEHS practitioners and regulators on program and practice attributes that ensure adequate worker protection from occupational exposures.[8]

[6] University of Michigan: "Noise Job Exposure Matrix." Accessed July 29, 2022, at https://noise-jem.shinyapps.io/NoiseJEM.
[7] Jahn, S. D., W. H. Bullock, and J. S. Ignacio (Eds.) (2015): *A Strategy for Assessing and Managing Occupational Exposures*. AIHA.
[8] DTS Submission List. Row 18. https://app.smartsheet.com/b/publish?EQBCT=57736221c0db461a8bec3c7c264bbab5.

The Athena Heuristic is a set of data processing algorithms developed by a community consensus of practice.[9] It is intended to be a demonstration of The Athena Conjecture: that there exists a set of systematic data processing and calculation rules (an algorithm) that allows an exposure data set of small or big size to be determined as acceptable or unacceptable for simple specified parameters.

Electronic sensors create second-by-second to minute-by-minute records of measured contaminant or energy levels. These records are electronic files. The sensors might be installed in a fixed array or worn by an individual. They might be substance-specific or responsive to a range of similar substances. Sensors are especially useful as alarms that annunciate when some protective action is needed. When combined with observation, measuring the variation in levels during a work shift can help identify likely sources or causes of exposure.

Exposure monitoring results collected primarily for alarm or diagnostic purposes can be put to secondary use in comparing the distribution of results to occupational exposure limits (OELs.) Heuristics currently in use are tailored to interpreting exposure monitoring results either from a full-shift or a short-term task within a shift, but not both, and not beyond single shifts or shift aliquots. The granularity of sensor data with both full-shift and short-term levels are proving to be surprisingly difficult to interpret for exposure assessment purposes. Heuristics that would simplify data analysis require assumptions about the mathematical relationship between the full-shift and shorter time periods within the shift. In addition, it is possible to make predictions of workers' exposure levels based on results from an array of fixed monitors, additional experiential modeling details, and the application of correlation and correction factors. The ever-increasing use of sensors makes research on these topics both important and highly likely to succeed. Questions that would benefit from further research include:

- Many substances have both full-shift and short-term OELs. For any given exposure distribution, one will be more stringent than the other. Theory predicts that if the distance between the two is less than a factor of 3, then the short-term limit will be more stringent and the full-shift limit adds little protection. If the distance is greater than 5, the full-shift limit will be more stringent.[10,11] However, there is little empirical data verifying this relationship. Research is needed to verify these theories are valid.
- Design principles for dilution ventilation predict that concentrations in air exhausted from the general area will be lower than concentrations in worker's breathing zone because of mixing. In theory, these mixing factors should hold for results from fixed sensors, however there are very few published studies validating the use of mixing factors for interpreting results from fixed sensors.[12]
- Industrial hygiene exposures are generally assumed to be lognormal. However, much of this research is based upon full-shift exposure measurements. Additional research to validate lognor-

[9] Spencer Pizzani & Marina Jabsky (2022) The Athena heuristic: The need for a system of algorithms for standardized evaluation of big exposure. *Journal of Occupational and Environmental Hygiene*, 19:12, 691-695.

[10] Tuggle RM. The relationship between TLV-TWA compliance and TLV-STEL compliance. *Appl Occup Environ Hyg*. 2000 Apr;15(4):380-6.

[11] Shinji Kumagai, Ichiro Matsunaga & Yukinori Kusaka (1993) Autocorrelation of Short-Term and Daily Average Exposure Levels in Workplaces, *American Industrial Hygiene Association Journal*, 54:7, 341-350.

[12] ACGIH. (2019). Industrial Ventilation: A Manual of Recommended Practice for Design (30th ed.). ACGIH.

mality within and among direct-reading instrument results for shorter periods within a shift.[13,14]

Mercury Detection on Metal Surfaces

Members of the Oil and Gas Working Group expressed a concern that the current instruments used in industry to detect mercury on metal surfaces do not pick up any reading unless the surface is heated. This situation leads to false negative findings in the field.

Traditionally, surface mercury analysis of metal samples has been performed by laboratory analysis. Atomic absorption spectroscopy (AAS) is one such laboratory method, but this takes time and is not always practical.

An instrument is needed to detect mercury that does not require heating of the surface first. One type of instrument is described in the literature: 'Recent progress in detection of mercury using surface enhanced Raman spectroscopy — A review'.[15]

Concerns over exposure to mercury have motivated the exploration of cost-effective, rapid, and reliable method for monitoring Hg2+ in the environment. Recently, surface-enhanced Raman scattering (SERS) has become a promising alternative method for Hg2+ analysis. SERS is a spectroscopic technique which combines modern laser spectroscopy with the optical properties of nano-sized noble metal structures, resulting in substantially increased Raman signals. When Hg2+ is in a close contact with metallic nanostructures, the SERS effect provides unique structural information together with ultrasensitive detection limits. This review introduces the principles and contemporary approaches of SERS-based Hg2+ detection. In addition, the perspective and challenges are briefly discussed.

> "*Challenge*: The substantial enhancement in detectable Raman signal coupled with the unique NP-based approach has made SERS a powerful tool for Hg2+ sensing. However, the optimization of the sensing system is needed to meet the demands of environmental applications. As we summarized throughout the review, the detection limit of the Hg2+ sensors spans from nanomolar to picomolar. Therefore, sensitivity and reproducibility of the SERS substrates are still the major concerns in Hg2+ detection. In particular, the development of efficient sensors to detect Hg2+ in complex biological fluids such as urine, serum, and blood remains a great challenge. In addition, efforts should be made to develop SERS sensor for methyl mercury such as CH3Hg+ , which is much more toxic than Hg2+. The recent progress in the synthesis of multifunctional metal nano-structures with tailored size and shape, as well as the development of portable separation techniques is expected to overcome the present limitations and advance the application of the technique."

It is unknown whether SERS is a commercially available sampling method. More research is needed to determine the viability and feasibility of this method.

[13] Kumagai,S., Kusaka, Y., & Goto, S., (1997). Log-normality of distribution of occupational exposure concentrations to cobalt. *The Annals of Occupational Hygiene*, Volume 41, Issue 3, June 1997, Pages 281-286. https://doi.org/10.1016/S0003-4878(96)00043-9.

[14] Lyles, R., Kupper, L., & Rappaport, S., (1997 January). A lognormal distribution-based exposure assessment method for unbalanced data. *The Annals of Occupational Hygiene*, 1997. Jan;41(1):63-76. doi: 10.1016/S0003-4878(96)00020-8.

[15] S Zhenli Sun, Jingjing Du, Chuanyong Jing, Recent progress in detection of mercury using surface enhanced Raman spectroscopy — A review, *Journal of Environmental Sciences*, Volume 39, 2016, Pages 134-143, ISSN 1001-0742, https://doi.org/10.1016/j.jes.2015.11.009. (https://www.sciencedirect.com/science/article/pii/S100107421500457X)

A recent research paper entitled 'Nanozyme-based sensing platforms for detection of toxic mercury ions: An alternative approach to conventional methods' was published in 2020[16] shows promise in the development of technology to achieve low detections limits for mercury.

Evaluating Emissions from Thermal Processes

Industrial Hygiene labs are often asked to provide guidance to field practitioners regarding possible exposure monitoring because of high odor or irritating materials being generated during high heat processes involving plastics or surface coatings. These high heat processes might be a component of a manufacturing process, such as melting or extruding; or a destructive process such as grinding, sanding, laser cutting or torching. Workers often express concerns because of irritation or odors they experience, which might not be associated with their usual tasks. The field industrial hygienist is concerned that there might be an unacceptable exposure to an airborne contaminant and is looking for guidance on what to sample for and what sampling procedure to use. The Industrial Hygiene lab is often left to provide very general guidance that is often not helpful because the request is for short-term response, versus a longer-term qualitative investigation.

Environmental and Industrial Hygiene labs have characterized the airborne contaminants generated by the heating or thermal decomposition of several different types of plastics, thermoplastics, and coating materials, for the purpose of identifying key volatile emissions.[17,18,19] These studies are usually conducted under research conditions that involve carefully controlled test environments and sophisticated measurement methods. Unfortunately, not all Industrial Hygiene labs have the ability to conduct broad characterization studies on an ad hoc basis using tools such as dynamic headspace GC-MS analysis to identify volatile contaminants being generated during thermal degradation or destruction of a material. Additionally, most of the studies published on evaluating volatile emissions from thermal processes use sophisticated on-line, real-time measurements or whole-air samplers that might not be readily available to the field IH. In either case, the information gained from the first step to identify contaminants of interest might not satisfy the request from the field IH of 'what should I sample for and how?" as the exposure event is occurring.

General guidance is needed for the Industrial Hygiene lab on how to approach this exposure scenario with helpful information. If the lab is familiar with and has the ability to support the sampling and analytical requirements of broad screening approach such as NIOSH Method 2549 using thermal desorption GC-MS, this would be a basic starting point. More helpful, however, would be guidance that states "if you

[16] Anwarul Hasan, Nadir Mustafa Qadir Nanakali, Abbas Salihi, Behnam Rasti, Majid Sharifi, Farnoosh Attar, Hossein Derakhshankhah, Inaam Ahmad Mustafa, Shang Ziyad Abdulqadir, Mojtaba Falahati, Nanozyme-based sensing platforms for detection of toxic mercury ions: An alternative approach to conventional methods, Talanta, Volume 215, 2020, 120939, ISSN 0039-9140, https://doi.org/10.1016/j.talanta.2020.120939. (https://www.sciencedirect.com/science/article/pii/S0039914020302307)

[17] Patel, S.H. and Xanthos, M. (2001), Environmental issues in polymer processing: A review on volatile emissions and material/energy recovery options. Adv. Polym. Technol., 20: 22-41. https://doi.org/10.1002/1098-2329(200121)20:1<22::AID-ADV1002>3.0.CO;2-O.

[18] Yamashita, K., Yamamoto, N., Mizukoshi, A., Noguchi, M., Ni, Y., & Yanagisawa, Y. (2009). Compositions of Volatile Organic Compounds Emitted from Melted Virgin and Waste Plastic Pellets. *Journal of the Air & Waste Management Association*, 59(3), 273–278. https://doi.org/10.3155/1047-3289.59.3.273.

[19] Stefaniak, A. B., LeBouf, R. F., Yi, J., Ham, J., Nurkewicz, T., Schwegler-Berry, D. E., ...Virji, M. A. (2017). Characterization of chemical contaminants generated by a desktop fused deposition modeling 3-dimensional Printer. *Journal of Occupational and Environmental Hygiene*, 14(7), 540–550. https://doi.org/10.1080/15459624.2017.1302589.

heat or thermally disrupt material X, you can expect to encounter airborne contaminants Y, which can be sampled using methods Z". What would allow the creation of such guidance? Some basic steps include:

- Critical review of the literature already published on characterizing emissions
- Compile an index of key contaminants generated by thermal processes by common materials that might be involved
- Generate a guidance document for IH laboratories that lists the most common contaminants along with recommended air sampling and analytical methods
- List the odor thresholds for key contaminants that have been identified to assist the labs and the IH in responding to the concern that there is still an odor even though samples return 'non-detect' results.

Input and review from the Sampling and Laboratory Analysis and the Exposure Assessment Strategies technical committees will assist in defining the need and getting feedback from IH laboratories and exposure assessment practitioners on the types of Practice to Research to Practice outputs would be most helpful.

Using Monitoring Data to Improve Decision-Making:

- **Worker Self-Monitoring:** Typically, an OEHS professional observes exposure monitoring to prevent failed samples and capture job and task information associated with monitoring results. The considerable time and expertise required to collect monitoring data severely constrains robust exposure evaluation and results in health risks remaining uncharacterized and poorly managed. Research to develop easy-to-use sensors, badges, and other monitoring devices that workers can use to participate more directly in the exposure assessment process would provide a partial solution to the problem.[20] Additional research is also needed to determine straightforward and effective approaches that workers could use during self-monitoring, either on their own or with virtual support from an OEHS professional, to document the sample, exposure, and concentration information needed to complete a robust data set that permits proper documentation and interpretation of exposure monitoring results.
- **Aerosol Mixtures:** Exposure monitoring results are difficult to interpret for complex particulate aerosol mixtures such as welding fumes, concrete dust, and wildfire smoke, even when constituents have been fully characterized. Conservative rules for interpreting gravimetric or particle counting results would simplify monitoring and reduce the chance of misinterpretation.
- **Bioaerosol Monitoring:** Assessing exposures to spores, endotoxins, and infectious agents is often confounded by the diversity of bioaerosol agents in the environment. Methods for monitoring exposure to antigens and organisms that are hard to cultivate have been developed. Applied research focused on developing a measurement system to produce interpretable monitoring results for risk management decisions has a high likelihood of success.[21]
- **Commercially Available High-Flow Inhalable Samplers:** Current personal sampling methods for high-hazard particulate aerosols (e.g., beryllium, manganese, etc.) have laboratory reporting limits near occupational exposure limits (OELs), which often results in non-detect values that can com-

[20] DTS Submission List. Row 5. https://app.smartsheet.com/b/publish?EQBCT=57736221c0db461a8bec3c7c264bbab5.
[21] DTS Submission List. Row 24. https://app.smartsheet.com/b/publish?EQBCT=57736221c0db461a8bec3c7c264bbab5.

plicate evaluation of workplace compliance with these OELs. High-flow-rate, size-selective air samplers that provide actionable information related to the appropriate OELs must be developed to address this concern.[22]

Improving Decision-Making When Exposure Monitoring Data Are Not Available:

- **Improve Qualitative Judgement Accuracy:** Decisions made without the benefit of formal modeling or exposure monitoring data, also referred to as "professional judgements" or "qualitative assessments," are by far the most common approach to decision-making about health risks. Yet studies have shown that the accuracy of qualitative exposure assessments is often very poor, sometimes not statistically different from random chance, and tends to be biased towards low values.[23,24,25,26,27,28] Various approaches have been suggested for improving the accuracy of qualitative exposure risk decisions, including accurate feedback loops, group discussion, practice, and models that provide structured characterization of determinants and decision rationale.[23,24,25,26,27,28,29] However, little research has been conducted to determine the most efficient techniques for improving qualitative exposure risk judgements.[30]
- **Exposure Predictor Model Development:** Properly validated mathematical models can efficiently estimate exposure with reasonable accuracy, even outperforming exposure monitoring when sample sizes are very small.[31] They hold promise for integration into Bayesian exposure estimation approaches and, when monitoring is not possible, they may be the only option available aside from applying professional judgment.[28,32,33] Research is needed to develop new modeling approaches and tools that are accurate and efficient.
- **Exposure Model Validation:** Mathematical models have potential to vastly improve the effectiveness and efficiency of risk decision-making but

[22] DTS Submission List. Row 8. https://app.smartsheet.com/b/publish?EQBCT=57736221c0db461a8bec3c7c264bbab5.
[23] Arnold, S. F., M. Stenzel, D. Drolet, and G. Ramachandran (2016): "Using Checklists and Algorithms to Improve Qualitative Exposure Judgment Accuracy." *J. Occup. Environ. Hyg. 13(3)*, 159–168.
[24] Logan, P., G. Ramachandran, J. Mulhausen, and P. Hewett (2009): "Occupational Exposure Decisions: Can Limited Data Interpretation Training Help Improve Accuracy?" *Ann. Occup. Hyg. 53(4)*, 311–324.
[25] Logan, P.W., G. Ramachandran, J.R. Mulhausen, S. Banerjee, and P. Hewett (2011): "Desktop Study of Occupational Exposure Judgments: Do Education and Experience Influence Accuracy?" *J. Occup. Environ. Hyg. 8(12)*, 746–758.
[26] Vadali, M., G. Ramachandran, and S. Banerjee (2012): "Effect of Training, Education, Professional Experience, and Need for Cognition on Accuracy of Exposure Assessment Decision-Making." *Ann. Occup. Hyg. 56(3)*, 292–304.
[27] Vadali, M., G. Ramachandran, J.R. Mulhausen, and S. Banerjee (2012): "Effect of Training on Exposure Judgment Accuracy of Industrial Hygienists." *J. Occup. Environ. Hyg. 9(4)*, 242–256.
[28] Vadali, M., G. Ramachandran, and J. Mulhausen (2009): "Exposure Modeling in Occupational Hygiene Decision-Making." *J. Occup. Environ. Hyg. 6(6)*, 353–362.
[29] Friesen, M. C., J. B. Coble, H. A. Katki, B. T. Ji, S. Xue, W. Lu, and P. A. Stewart (2011): "Validity and Reliability of Exposure Assessors' Ratings of Exposure Intensity by Type of Occupational Questionnaire and Type of Rater." *Ann. Occup. Hyg. 55(6)*, 601–611.
[30] DTS Submission List. Row 4. https://app.smartsheet.com/b/publish?EQBCT=57736221c0db461a8bec3c7c264bbab5.
[31] Nicas, M. and M. Jayjock (2002): "Uncertainty in Exposure Estimates Made by Modeling Versus Monitoring." *AIHA J. 63(3)*, 275–283.
[32] Gurumurthy, R. (April 2019): "Progress in Bayesian Statistical Applications in Exposure Assessment." *Ann. Work Exp. Health. 63(3)*, 259–262.
[33] Jayjock, M. and N. C. Hawkins (June/July 2022): "Exposure Modeling: The Next Generation." *The Synergist*. AIHA https://synergist.aiha.org/20220607-exposure-modeling.

are currently limited. Validation of these models is essential to their use, but it is typically not done or performed inconsistently because there are no standard, scientifically vetted approaches to doing so.[23,34] Research is needed to determine the most effective and efficient approaches to validating models' abilities to accurately predict exposures in various types of operations and scenarios.[33,35]

- **Define Appropriate Bayesian Priors:** Bayesian statistical approaches show promise in improving exposure judgments, and their use is becoming more widespread.[36,37] One of the greatest advantages of Bayesian approaches is their ability to formally combine qualitative judgements or model results with measurement data to reach a decision based on the integrated information.[28,32] For Bayesian approaches to reach their full potential, research is needed to determine the best means of incorporating qualitative judgments and modeling results into Bayesian priors without introducing undue inaccuracies and biases, which are known to exist in both qualitative judgments and modeling results.[38]

Control Validation: Effective and efficient approaches to risk assessment and management rely on understanding control effectiveness for both characterizing risk and determining appropriate follow-up for exposure risk management.[7,34] Research is needed to efficiently and consistently characterize the performance of specific types of controls used in various operations for the purposes of defining accurate control bands, improving qualitative judgments, and efficiently choosing exposure controls.[39]

- **Validation of WELL Health-Safety Rating for Buildings:** Unbiased assessment is needed of the International WELL Building Institute's (IWBI) WELL Building Standard approach to rating a building's ability to "deliver more thoughtful and intentional spaces that enhance human health and well-being" (https://v2.wellcertified.com/en/wellv2/overview). Research must ensure that the approach is grounded in robust science and determine its credibility and utility as a mechanism for improving indoor environments.[40]
- **Developing Ventilation Systems for Welding and Cutting:** Metal fabrication involving welding and cutting remains a major occupational health protection challenge. The effectiveness of general dilution or local exhaust ventilation systems is limited, especially for large work pieces. Capturing fumes at the point of generation can affect the quality of welds by removing shield gas or reducing the heat of the electrode. Studies to develop methods to reduce both near- and far-field exposures while maintaining weld quality are needed.[41]
- **Validating the Efficacy and Safety of New Infection Control Technologies:** New approaches for general indoor infection control are being developed and marketed with such as ultraviolet irra-

[34] Waters, M., L. McKernan, A. Maier, M. Jayjock, V. Schaeffer, and L. Brosseau (2015): "Exposure Estimation and Interpretation of Occupational Risk: Enhanced Information for the Occupational Risk Manager." *J. Occup. Environ. Hyg. 12(sup1)*, S99–S111.
[35] DTS Submission List. Row 16. https://app.smartsheet.com/b/publish?EQBCT=57736221c0db461a8bec3c7c264bbab5.
[36] Hewett, P., P. Logan, J. Mulhausen, G. Ramachandran, and S. Banerjee (2006): "Rating Exposure Control Using Bayesian Decision Analysis." *J. Occup. Environ. Hyg. 3(10)*, 568–581.
[37] Lavoué, J., L. Joseph, P. Knott, H. Davies, F. Labrèche, F. Clerc, et al. (2019): "Expostats: A Bayesian Toolkit to Aid the Interpretation of Occupational Exposure Measurements." *Ann. Work Exp. Health. 63(3)*, 267–279.
[38] DTS Submission List. Row 15. https://app.smartsheet.com/b/publish?EQBCT=57736221c0db461a8bec3c7c264bbab5.
[39] DTS Submission List. Row 3. https://app.smartsheet.com/b/publish?EQBCT=57736221c0db461a8bec3c7c264bbab5.
[40] DTS Submission List. Row 13. https://app.smartsheet.com/b/publish?EQBCT=57736221c0db461a8bec3c7c264bbab5.
[41] DTS Submission List. Row 11. https://app.smartsheet.com/b/publish?EQBCT=57736221c0db461a8bec3c7c264bbab5.
[42] DTS Submission List. Row 22. https://app.smartsheet.com/b/publish?EQBCT=57736221c0db461a8bec3c7c264bbab5.

diation, ozone generation, ultra-filtration, bipolar ionization, and hydroxyls. Independent studies are needed to validate the effectiveness and safety of these new approaches.[42]

- **PPE and Respiratory Protection:** While control strategies at the top of the Hierarchy of Controls are preferred and every risk management program should have robust processes for continuously improving its controls, there are many instances when personal protective equipment (PPE) and respiratory protection are used as primary controls. However, according to NAS, "the science and research foundation for understanding the successful implementation of respiratory protection programs for all workers (implementation science) is relatively sparse."[43]

Furthermore, both workers and members of the public heavily rely on respiratory protection against unexpected threats such as wildfire smoke or SARS-CoV-2. Because respiratory protection programs are primarily driven by known workplace exposure risks, most workers and members of the public are not covered by respiratory protection programs when those unexpected threats suddenly appear. Research is needed to better understand the strengths, limitations, and risk management performance of various respirator protection approaches for workers and the public from both known and unanticipated airborne hazards.

Effective Respiratory Protection for Bioaerosols During Pandemics: The COVID-19 pandemic highlighted the limitations of the OEHS field's knowledge regarding the use of respirators and other face coverings as strategies for preventing disease transmission, by both protecting uninfected workers and acting as effective source control for infected people. Research is needed in both areas, and the COVID-19 pandemic offers significant opportunities to conduct retrospective epidemiological studies to identify real-world factors influencing strategy effectiveness.[44]

Need for Well-Trained OEHS Professionals: The lack of well-trained OEHS practitioners presents an important ongoing barrier to the broad implementation of risk management practices needed to attain AIHA's vision of "a world where all workers and their communities are healthy and safe." While the current lack of up-to-date and comprehensive data prevents making definitive statements about imbalances between supply and demand for well-trained OEHS practitioners, AIHA's public policy agenda states that the organization "can say with certainty that unmet OEHS needs do exist."[45]

The last comprehensive analysis of professional OEHS staffing needs was commissioned by NIOSH in 2010 and concluded that the number of occupational health and safety professionals employers expected to hire in 2011–2016 was "substantially higher than the number estimated to be produced from [OEHS] training programs." The study also found that there was an overall decline in OEHS program funding during the previous five years.[46]

A recent survey of OEHS professionals by the Na-

[43] National Academies of Sciences, Engineering, and Medicine (2022): *Frameworks for Protecting Workers and the Public from Inhalation Hazards*. The National Academies Press. Accessed Oct. 3, 2022, at https://nap.nationalacademies.org/catalog/26372/frameworks-for-protecting-workers-and-the-public-from-inhalation-hazards.

[44] DTS Submission List. Row 21. https://app.smartsheet.com/b/publish?EQBCT=57736221c0db461a8bec3c7c264bbab5.

[45] 2021 AIHA Public Policy Agenda. Accessed Oct. 7, 2022, at https://aiha-assets.sfo2.digitaloceanspaces.com/AIHA/resources/2021-AIHA-Public-Policy-Agenda-FINAL.pdf.

[46] McAdams, M.T., J.J. Kerwin, V. Olivo, and H.A. Goksel (Oct. 3, 2011): "National Assessment of the Occupational Safety and Health Workforce." Westat. Accessed Oct. 7, 2022, at https://www.cdc.gov/niosh/oshworkforce/pdfs/NASHW_Final_Report-508.pdf.

tional Safety Council (NSC), published in April 2022, indicated at least anecdotal evidence of an increased need for well-trained OESH professionals, with 55 percent of respondents saying they had personally observed a shortage of qualified OEHS professionals.[47] In addition, 24 percent of respondents indicated their departments had increased staff in the past six months, and 37 percent of respondents anticipated their departments would add additional staff in the 12 months following the survey. Seventy percent of respondents believed that more employers would look within their organizations to fill OEHS roles, even if the person who filled the role had little or no safety experience.

Research is needed to update the OEHS field's understanding of current and future needs for well-trained OEHS professionals so that plans and resources can be put in place to meet those needs.[48]

Research to Practice:

The dissemination of new knowledge with the potential to improve OEHS practice.

Routine Use of Statistical Tools: Without a basic understanding of lognormally distributed data and the use of traditional or Bayesian statistical tools to aid judgment, OEHS professionals frequently make inaccurate judgments about risks that are associated with exposure.[24,28]

Accelerate Exposure Predictor Model Use: Properly validated mathematical models can efficiently estimate exposures with reasonable accuracy and even outperform exposure monitoring for very small sample sizes.[49] Modeling tools show promise for integration into Bayesian exposure estimation approaches and, when monitoring is not possible, they may be the only option available to OEHS professionals beyond exercising professional judgment.[28,32] Work is needed to accelerate the widespread adoption of existing modeling tools.

Including Psychosocial Disorders and Mental Health in Total Worker Health: Psychosocial health is impacted by issues ranging from social factors to hazardous tasks in the work environment. The Canadian Centre for Occupational Health and Safety (CCOHS), in conjunction with Simon Fraser University, has identified thirteen psychosocial risk factors that impact organizational health, the health of individual employees, and the financial bottom line. In recognition of the importance of psychological health, the International Organization for Standardization (ISO) has made two additions to the 45000 series of standards: ISO 45003, *Occupational health and safety management— Psychological health and safety at work—Guidelines for managing psychosocial risks* and ISO/PAS 45005, *Occupational health and safety management—General guidelines for safe working during the COVID-19 pandemic*.

It significantly impacts well-being in the workplace but is often an area in which many health and safety practitioners feel unqualified to take on leadership roles. Enhanced collaboration between AIHA, ACGIH, and professional societies representing industrial and organizational psychologists could promote collaboration at the organizational level to address the psychological stress created by occupational health risks and psychological barriers to behaviors that minimize those risks. In addition, research

[47] Ferguson, A. (April 24, 2022): "2022 Job Outlook." *Safety + Health. National Safety Council*. Accessed Oct. 7, 2022, at https://www.safetyandhealthmagazine.com/articles/22457-job-outlook-2022?page=1.
[48] DTS Submission List. Row 10. https://app.smartsheet.com/b/publish?EQBCT=57736221c0db461a8bec3c7c264bbab5.
[49] Nicas, M. and M. Jayjock (2002): "Uncertainty in Exposure Estimates Made by Modeling Versus Monitoring." *AIHA J. 63(3)*, 275–283.

is needed to improve understanding of the complex interactions between environmental and psychosocial hazards experienced at and outside of work so that better guidance and tools can be developed to manage those hazards.

Heat Stress Management: According to OSHA, the effective management of heat exposures and resulting heat stress has come under increasing attention as "the danger of extreme heat increases each year due to continuing effects of climate change" and "workers suffer over 3,500 injuries and illnesses related to heat each year."[50]

Although the factors influencing health impacts on individuals working in hot environments are relatively well understood, there is opportunity to better understand heat exposures and the relative effectiveness of various heat stress management programs across different industries and types of operations.[51,52] Collaboration between AIHA, ACGIH, and professional societies representing exercise physiologists who do original research on thermal stress can help assure that authoritative guidelines continue to be informed by the latest research findings.[53,54,55]

Impulse Noise Measurement and Assessment: Impact and impulse noises, defined as the instantaneous change in sound pressure over a short period of time, are not being adequately monitored in numerous workplaces. Generated by the collision of solid objects (impact) or the rapid release of compressed gases (impulse), many of measuring and monitoring challenges are due to the lack of guidance on the recognition, evaluation, and control of high intensity short duration noises. Most OEHS practitioners do not have access to specialized equipment currently required for surveying these types of noise exposures (i.e., NIOSH Impact Noise Measurement Kit).[56] Education is needed to assure practitioners understand the limitations of commonly deployed equipment such as personal noise dosimeters and sound level meters and to use equipment and software capable of measuring impulse noise accurately. Additionally, providing regularly accessible guidance on which dosimetry parameters (LASmax, LZpeak, etc.) to use and comparative thresholds for compliance and worker protection is paramount.[57]

[50] OSHA National Emphasis Program on Outdoor and Indoor Heat Hazards Factsheet. Accessed Oct. 7, 2022, at https://www.osha.gov/sites/default/files/heat-nep-factsheet-en.pdf.

[51] DTS Submission List. Row 24. https://app.smartsheet.com/b/publish?EQBCT=57736221c0db461a8bec3c7c264bbab5.

[52] DTS Submission List. Row 25. https://app.smartsheet.com/b/publish?EQBCT=57736221c0db461a8bec3c7c264bbab5.

[53] Workers' health and productivity under occupational heat strain: a systematic review and meta-analysis. Flouris AD, Dinas PC, Ioannou LG, Nybo L, Havenith G, Kenny GP, Kjellstrom T. *Lancet Planet Health. 2018 Dec;2(12)*:e521-e531. doi: 10.1016/S2542-5196(18)30237-7. https://www.ncbi.nlm.nih.gov/pubmed/30526938

[54] Levi M, Kjellstrom T, Baldasseroni A. Impact of climate change on occupational health and productivity: a systematic literature review focusing on workplace heat. *Med Lav. 2018 Apr 24;109(3)*:163-79. doi: 10.23749/mdl.v109i3.6851.

[55] Nunfam VF, Adusei-Asante K, Van Etten EJ, Oosthuizen J, Frimpong K. Social impacts of occupational heat stress and adaptation strategies of workers: A narrative synthesis of the literature. *Sci Total Environ. 2018 Dec 1;643:1542-1552.* doi: 10.1016/j.scitotenv.2018.06.255

[56] CAPT Chucri (Chuck) A. Kardous, MSEE, PE, and CAPT William J. Murphy, PhD. How Can we Measure Impulse Noise Properly? (NIOSH Science Blog). 2018. https://blogs.cdc.gov/niosh-science-blog/2018/07/18/impulse-noise/

[57] Bender, C. A Deaf Spot for Industrial Hygiene: The Problem of Impulse Noise. *AIHA Synergist*. January 2017.; Roberts, Abby. An Immersive Inventory of Impulse Noise. AIHA Synergist Blog. February 2024.