The construction industry has experienced a fatality rate of 10.2 per 100,000 full-time employees, approximately three times higher than all other industries’ average (CPWR, 2018). These fatalities are, to a large extent, attributed to acute safety incidents or exposure to hazardous substances and materials on construction job sites. However, approximately 95,000 workers died in 2017 from chronic occupational diseases (AFL-CIO, 2019), and up to 50% of occupational cancer deaths are attributed to exposures in the construction industry (Hutchings & Rushton, 2012). National Occupational Research Agenda (NORA) Construction Sector Council (2018) has identified silica, welding fumes, noise, and lead as research priorities in the construction industry. Silica causes a number of chronic illnesses and fatalities among construction workers. OSHA (2016) reported that about 32 of 100,000 construction workers still have elevated levels of lead in their blood, defined as 10 μg/dl or higher (CPWR, 2018). This concerning fact calls for more robust preventive solutions.

Construction safety and health scholars have developed large exposure databases to estimate common health hazards so practitioners can select and use the most effective measures to protect workers. These factors highlight the need for a more comprehensive, intuitive and publicly available system to estimate the probable exposure levels to common health hazards so practitioners can select and use the most effective measures to protect workers. The most effective predictors for the hazards in the ECD, three steps were taken: 1) a literature review; 2) a balloting process; and 3) an iterative review process by the advisory group. A literature review was performed for each hazard, which identified a preliminary list of predictors. Advisory group members ranked the importance of these predictors through a balloting process. Three face-to-face meetings and two conference calls were held with the panel to finalize predictors for each hazard:

- **silica:** task, tool, equipment, material, control method, environment, and project type
- **welding fumes:** type of hot work, consumable (if applicable), base metal, control method and environment;

By Babak Memarian, Sara B. Brooks and Chris Trahan Cain

An Evidence-Based Approach to Estimating Exposure

Key Takeaways
- **Engineering controls** are one of the most effective means of reducing construction worker exposure to health hazards. However, given the variability of construction tasks and the dynamic nature of construction work sites, assessing worker exposure and selecting the most appropriate controls at the outset of a project is challenging.
- This article discusses the development, functionality and application of the Exposure Control Database, an evidence-based solution that estimates construction worker exposure to common health hazards: silica, welding fumes, noise and lead. The database is designed to address the limitations and lack of consistency in air sampling procedures and outlines a new approach to standardize and continuously improve data collection and data sharing processes.

Methods

Industry Advisory Group

An industry advisory group was convened to review the structure, design and functionality of the ECD at various development stages and provide feedback through an iterative process. This advisory group, known as the Engineering Controls Workgroup, comprises 25 subject-matter experts in industrial hygiene, safety and engineering. It was originally established in 1993 by NIOSH and CPWR to identify, implement and evaluate engineering controls in construction.

Exposure Predictors

In existing occupational exposure databases, measurements are most useful when accompanied by a set of predictors of exposure (Beaudry, et al., 2013; Di Marzio, 2016) analyzed hexavalent chromium data from the Information System on Occupational Exposure to Carcinogens (SIREP), a database populated by employer exposure data reported by the national workers’ compensation authority in the United States. Beaudry, et al., 2013; Scarselli, Corfiati and Di Marzio (2016), among others, have suggested that the probable exposure level (Susi & Schneider, 1995). Following a similar approach, other scholars developed exposure databases for additional hazards in the construction industry. For example, Flanagan, Serxas, Becker, et al., (2006), created a database of silica exposures, which was the first to provide broad public access. However, none of these databases are equipped with a mechanism to enable users to search or filter data for a given working condition. This may limit their utility for contractors or practitioners who want to characterize specific work environments for the purpose of selecting the most effective respirator or engineering control.

This issue has been addressed in recent years by incorporating features into the databases that enable users to sort and filter measurements by task, tool and other relevant determinants of exposure. Unfortunately, these systems are only available to policymakers or members (Construction Employers Association, 2016; Ng & Davies, 2016). Although all of the aforementioned databases have limitations to use and availability, they have laid the foundation for building a more comprehensive system.
The database is a practical tool for estimating occupational exposures and has been implemented on a web application. The ECD was developed in response to the demand in the construction industry for a system to estimate the probable hazardous levels of silica, the contractor uses the ECD to estimate the probable exposure level. Selecting the ECD silica tab from the home page, the user selects all of the following options for each predictor from the drop-down menus:

- **Task:** abrasive blasting with silica sand
- **Equipment:** abrasive blasting equipment
- **Material:** concrete
- **Control method:** wet method
- **Environment:** outdoor

Project type: renovation

To renovate the columns of a concrete bridge, a contractor plans to perform the abrasive blasting of a deteriorated coating. To ensure that wet blasting is sufficient to prevent exposure to hazardous levels, the contractor uses the ECD to estimate the probable exposure level. Selecting the ECD silica tab from the home page, the user selects all of the following options for each predictor from the drop-down menus:

- Project type: renovation

The ECD uses 16 measurements matching this condition, which yields an estimated exposure of 68% relative to the current PEL of 50 μg/m³ and requires implementing additional recommended improvements into the system, the ECD database has 16 measurements matching this condition, which indicates that the database is not developed for compliance purposes.

Discussion & Conclusion

The ECD was developed in response to the demand in the construction industry for a system to estimate the probable exposure levels to health hazards so practitioners can select and implement the most effective controls to protect workers. Unlike other existing databases that are typically for a single hazard, the ECD addresses four major hazards on a single platform. More importantly, this intuitive, interactive system is available to the public free of charge. This should be of significant benefit to small- and mid-sized contractors with limited resources to employ full-time safety and health personnel.

The ECD currently contains a total of 1,013 measurements: 350 for silica, 182 for welding fumes, 203 for noise, and 78 for lead. Since its public release, users from a wide variety of organizations such as contractors, universities, nonprofits, labor unions and government agencies have accessed the ECD, and an average of 148 users have visited the website each month. Of the 3,241 inquiries run by users to date, approximately 68% are related to silica. This usage pattern, to a large extent, can be attributed to the concurrent release of the ECD and OSHA’s updated silica standard for construction, which, as the contractors, added this option to comply by using objective data to assess worker exposure. However, note that the ECD was not developed for compliance purposes.

Populating the ECD with a large number of high-quality measurements is an ongoing process that is critical to enhancing its usefulness. However, identifying reliable sources of data has been one of the major challenges throughout the development process. The investigators have been heavily reliant on published sources including peer-reviewed articles and government reports, which limits the

Data Properties & Sources

To provide a clear representation of real-world working conditions, all measured environmental parameters entered into the ECD were collected on active job sites, except for noise. Due to the availability, all noise measurements were taken in a lab setting.

To be considered for inclusion in the ECD, all predictors listed above had to be specified for each measurement. Additional information such as material and task duration, tool, environmental factors, project type and control method were also included.

Finalizing the list of predictors for silica also involved consideration of OSHA’s Table A, which lists the allowable concentration in the new silica standard in construction (OSHA, 2016). Predictors for noise were also informed by NIOSH’s Buy Quiet initiative, which encourages contractors to focus on hearing loss prevention by investing in quieter tool models (Beamer, McCleery & Hayden, 2016).

The goal of this usability testing was to develop an intuitive system that is robust to outliers and the middlemost value in values of occupational exposure measurements, which tend to follow a lognormal distribution (Flynn, 2004; Jia, Hend, Dettod, et al., 2011; U.S. EPA, 1994). Because geometric mean alone does not illustrate the range of data, the ability to view the data distribution and possible outliers lend additional confidence in the results. Research suggests that summary statistics of occupational exposure measurements are not meaningful unless there are a minimum of six data points (Hawkins, Nordwor, Rock; 1999; Patty, 1989). Thus, when a search yields five measurements or fewer, the measurements are displayed individually and geometric mean is not presented.

Construction contractors in the U.S. have a legal obligation to keep exposures below the OSHA permissible exposure limit (PEL) and enact certain protections when exposures reach the OSHA action level (AL) or PEL. For that reason, these two OELs are displayed as the most relevant reference points, and the estimated exposure is plotted against these values. However, PELs and ALs are not available for every hazard, and they are not always comparable to a TWA. For example, there is no OSHA PEL for welding fumes, while particulate, and the PEL for manganese is only available as a ceiling limit. Thus, in similar conditions, the American Conference of Governmental Hygienists threshold limit value, the NIOSH recommended exposure limit and the California OSHA PEL were reviewed. The “worst-case” were also excluded. Worst-case measurements are defined as measurements taken under special conditions where exposure is expected to be much higher than usual (Greim, 2002).

When measurements were small enough to fall below the analytical limit of detection (LOD), a procedure described by Horung and Reed (1990) was used to impute a numeric value. This procedure defines the imputed value as the product of LOD/2, or LOD/2, depending on the geometric standard deviation and percentage of measurements below the LOD. When measurements fell below the limit of quantitation, the same procedure was used.

Database Design & Structure

The goal of this project was to develop an intuitive system so that users with varying levels of computer literacy and technical expertise could use and understand the results. After the advisory group performed multiple iterations and reviews, a three-step, linear process was designed that allows the user to select the hazard of interest and predictors, then view results (Figure 1). After choosing a hazard, the user can select each predictor in a drop-down menu. Menus are dynamic rather than pre-populated, pulling entries directly from the database in real time. This ensures that only predictors associated with available

The database has been used for training and education purposes.
size of the database. In addition, out of 351 total published sources examined at this stage, only 22% contained usable measurements that met the defined criteria for inclusion in the database. This was largely due to 1) the practice of reporting summary statistics instead of individual measurements; 2) lack of sufficient information on one or multiple required predictors; or 3) multiple tasks, tools or control methods used during the sampling period.

Lack of consistency in air sampling procedures and reporting is another major issue that limits the usability of existing measurements. To standardize data reporting practices and streamline the data sharing process, two forms were initially developed for silica and noise, and made available to the public through the ECD. A small number of industry partners have used these forms and shared data with the authors. However, only 45% of the measurements provided by partners met all of the requirements for inclusion in the ECD. This emphasizes the need for a greater number of construction industry stakeholders to contribute data in a standardized format to continuously improve the process. This will help the construction industry more effectively reduce worker exposure to these debilitating and deadly health hazards.

References


Babak Memarian, Ph.D., is director of exposure control technologies Research at CPWR—The Center for Construction Research and Training and the cochair of the NIOSH/CPWR Engineering Controls Workgroup. He holds a Ph.D. in Construction Management from Arizona State University and an M.S. in Civil Engineering with a concentration in Construction Engineering and Project Management from Oklahoma State University. His research interest involves high-reliability construction work systems with a focus on safety, productivity and error management.

Sara B. Brooks, M.P.H., is an industrial hygienist at CPWR. She holds an M.P.H. with a concentration in Environmental and Occupational Health from University of Pittsburgh and a B.A. in Spanish from Carnegie Mellon University. She is also certified in environmental health risk assessment.

Chris Trahan Cain, CIH, is executive director of CPWR. She leads the organization’s construction research, training, service programs and staff in finding synergies among departments to capitalize on programs funded by different federal grants. Cain has been working in construction safety and health for more than 20 years and holds a B.S. in Industrial Hygiene from Clarkson University.

Acknowledgments

This study was funded by NIOSH grant U60OH009762. The authors thank the members of the Engineering Controls Workgroup for their constructive feedback, Ohio Bureau of Workers’ Compensation for sharing silica exposure measurements, and the anonymous construction practitioners who participated in usability testing and provided feedback to improve the ECD.