

NIOSH Construction Program:

Evidence package for 2007-2017

April 2018



**Centers for Disease Control
and Prevention**
National Institute for Occupational
Safety and Health

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Executive Summary

Construction is a high hazard industry that comprises a wide range of activities involving construction, alteration, and/or repair under North American Industry Classification System (NAICS) [code 23](#). It includes not only residential and commercial building construction, but also heavy and civil engineering construction, like water and sewer lines, highways, and bridges. Specialty trades like roofing, plumbing, electrical, drywall, and painting are included in this sector as well. Construction jobs are some of the most dangerous, with the highest fatality rate of all industries. In 2016, the United States (U.S.) construction sector employed 10.3 million workers, a number still rising after employment in the sector declined during the 2009 through 2012 economic recession. More than 40% of construction employees' work for small businesses with fewer than 20 employees, and nearly 30% are of Hispanic origin.

Since it was established in 1970, the National Institute for Occupational Safety and Health (NIOSH) has been addressing occupational safety and health challenges in the construction sector. Based on this extensive research and translation history, subject matter expertise, and available burden and need information at the start of the second decade of the National Occupational Research Agenda (NORA) (2006 through 2016), the NIOSH Construction Program prioritized and focused on several of the 15 NORA construction goals. Consistently, NIOSH construction researchers worked with partners in industry, labor, trade associations, professional organizations, and academia to conduct research and translate it to the construction industry.

NIOSH activities, during the time period of 2007 through 2017, described within this document reflect research conducted by scientists, within NIOSH (intramural), research conducted at academic centers (extramural, funded by NIOSH through grants and contracts), and research and other activities conducted by CPWR—The Center for Construction Research and Training (extramural funded by NIOSH through a cooperative agreement to function as the National Construction Center). The intramural component of the Construction Program has received an annual average of approximately \$9.5 million, and the extramural component, including funding for the National Construction Center, has received an annual average of approximately \$8.3 million. For the purposes

of this review, five topics are described: silica, musculoskeletal disorders, noise exposure, hearing loss prevention, highway work zone safety, and falls.

Silica Research in Construction

Respirable crystalline silica (RCS) is associated with the development of silicosis, lung cancer, pulmonary tuberculosis, chronic obstructive pulmonary disease, autoimmune disorders, and chronic renal disease. NIOSH conducted research to help understand how silica risks can be mitigated or removed from the workplace, developing engineering controls (e.g., using local exhaust ventilation in tuckpointing and concrete drilling operations) and other controls (e.g., spray misting systems installed on crushing machines and conveyors). NIOSH and its partners also conducted extensive research in the area of assessment to ensure the availability of accurate methods for measuring RCS. A significant portion of NIOSH research on sampling and analytic methods, as well as engineering controls is referenced in the 2016 revised Occupational Safety and Health Administration (OSHA) silica standard for construction. Table 1 of the standard includes much of the NIOSH engineering control research for respirable crystalline silica, listing 18 common construction equipment or tasks and effective dust control methods for each (i.e., masonry saws, dowel drilling, milling machines, etc.).

Additionally, NIOSH and stakeholders identified the need to control silica dust exposures during pavement milling in highway construction. NIOSH and partners studied milling machine dust controls, and in 2015 all U.S. and foreign manufacturers of heavy-construction equipment agreed to put NIOSH evaluated silica dust controls on all new milling machines. By 2026, nearly all highway milling machines will have updated silica dust controls.

Musculoskeletal Disorders in Construction

Construction work can lead to musculoskeletal disorders (MSDs) such as back injuries, upper arm disorders, and difficulties stemming from the vibration of tools. The NIOSH Construction Program focuses on the development of evidence-based methods to rigorously measure risk factors associated with awkward working postures, lifting and carrying, and stressful hand-wrist conditions. Measuring and understanding of the

effects of vibration from tools and equipment on the body has been an important component of the Program. Research in this area has been used to develop or improve workplace standards and equipment. NIOSH's seminal research into manual material handling, manifested in the NIOSH Lifting Equation, laid the foundation for much of the subsequent lifting and back injury research conducted at NIOSH and by others. Guidelines and interventions have been developed and implemented in the U.S. and in other countries.

NIOSH researchers and their partners also conducted research addressing health hazards related to drilling and MSDs caused by it. Based on these studies, a NIOSH extramural researcher developed alternative devices for overhead drilling to reduce shoulder load among construction workers.

Noise Exposure and Hearing Loss Prevention

Within the U.S. construction sector, a wide range of sources cause hazardous noise exposures—noise loud enough to cause hearing loss or hearing difficulty—including hand tools, larger machinery, heavy equipment, and generators. NIOSH researchers have addressed key research gaps to improve the understanding of construction noise sources and health impacts and to mitigate the risk. Research projects have examined issues related to hearing loss surveillance, worker training, engineering controls, ototoxicity, impulse noise, and the effective use of hearing protection devices. For example, NIOSH researchers found that noise exposures close to the 85-dBA exposure limit resulted in noise-induced damage to hearing among the construction workers. The study results reinforced the need for enhanced hearing loss prevention programs and noise control efforts in the construction industry, and the need to begin hearing prevention activities as early as possible in the lives of young and early career workers. NIOSH and NIOSH-funded researchers have made substantial contributions towards developing and improving hearing protection devices and in making operating tools quieter.

Advances in smart phone and sound measurement technologies led NIOSH researchers to develop a widely used sound level application, the NIOSH Sound Level Meter

application (app), to assess risks. Industrial hygienists and workers can use the app to make informed decisions about the potential hazards to hearing in the workplace.

Highway Work Zones

Studies show that highway and street construction workers are at a significant risk of fatal and serious nonfatal injuries while working in and around street and highway construction jobsites. NIOSH researchers developed a method for measuring the regions around construction vehicles and equipment not seen from the operator's position (blind areas) and then designed diagrams for those areas. They worked with construction laborers and others to develop internal traffic control plans, which reduce the risk of construction vehicles and equipment striking workers on foot, including runovers and backovers. Additionally, NIOSH developed, tested, and patented a proximity warning system, which alerts equipment operators when they are nearing contact with another object. State departments of transportation have implemented the warning devices in their highway building and improvement operations.

Preventing Falls in Construction

Working at height is dangerous, and for decades, falls have been the leading cause of death and serious injury in construction. NIOSH studies aimed to improve safety in this area, including for guardrail systems, ladders, mast climbers, aerial lifts, and fall protection harnesses. For example, misjudging the ladder angle is a key risk factor for preventable falls from ladders. As a result, NIOSH researchers designed and developed the NIOSH Ladder Safety App for smart phones.

Given the frequency of falls, fall-related deaths, and nonfatal injuries in construction, the NORA Construction Sector Council (which includes NIOSH and many other partners) developed and led the National Campaign to Prevent Falls in Construction. It targets construction contractors, onsite supervisors, and workers to address and reduce falls and fall-related injuries among construction workers nationally. A central event within the Campaign is the National Safety Stand-Down, a voluntary component led by OSHA, which gives construction employers an opportunity to engage directly with their employees about hazards, protective methods, and the company's safety policies, goals,

and expectations. Widespread engagement throughout the construction industry has been a consistent characteristic of the Campaign.

Outlook for the Next Decade

The NIOSH Construction Program has developed goals based on evidence and stakeholder input that fit within the larger NIOSH Strategic Plan for fiscal years 2019-2023. Goals for construction research include reducing hazardous noise exposure, better understanding the risks and benefits of emerging technologies like exoskeletons and robotics for musculoskeletal disorders and traumatic injuries, reducing falls, reducing respirable crystalline silica, and reducing other hazardous respiratory exposures. Finally, the Construction Program plans to do additional research to improve the health and safety of workers in non-standard work arrangements, such as contingent or temporary workers.

Chapter 1: Construction Program Overview

Program History

The evolving history of the National Institute for Occupational Safety and Health's (NIOSH) research activities in the construction sector provides a foundation and context for evaluating its current state. During 1970 through 1990, NIOSH researchers addressed issues relevant for construction and other industry sectors through individual projects and activities. Construction was included in a number of surveillance projects (e.g., the National Occupational Hazard Survey, the National Occupational Exposure Survey, the National Traumatic Occupational Fatalities program). In other projects, NIOSH researchers used analytical methods or engineering controls to measure and reduce construction hazards, such as silica or asphalt fumes. NIOSH also developed scientific evidence supporting a number of Occupational Safety and Health Administration (OSHA) construction standards.

While this research provided valuable information, construction fatalities continued to exceed those in other industries. Construction stakeholders encouraged the United States Congress to target funds for research to address the high rates of occupational injuries, illnesses, and fatalities in the industry. In 1990, Congress authorized and funded \$1 million for NIOSH to “develop a comprehensive prevention program directed at health problems affecting construction workers by expanding existing NIOSH activities in areas of surveillance, research and intervention” [Howard, Stafford et al. 2010].

Congressional funding provided NIOSH with resources to develop and organize a cross-institute program, the Construction Program, to address all occupational safety and health issues in the construction sector. NIOSH organized the Construction Program around a three-pronged structure: NIOSH-wide intramural research and surveillance programs, a large National Construction Center cooperative agreement, and support for investigator-initiated extramural research primarily at universities. From the beginning, the Construction Program worked closely with industry and labor partners to address construction-related injuries, illnesses, and fatalities. The program applies a multidisciplinary ‘research-to-practice’ approach that uses injury and illness data as the

program driver. Stakeholders voiced concerns that spending on construction research was disproportionately lower than spending in other sectors, such as manufacturing and mining. In response, Congress provided budget increases for each of the following four years, 1991 through 1995 (varying from \$1.9 million to \$3.9 million).

During 1995 through 2006, the Construction Program engaged in pivotal research related to a number of topics such as noise, working from height, including elevated workstations, crystalline silica, musculoskeletal disorders, and asphalt fumes. The work continued during 2007 through 2017 as research on these and other topics provided foundational information for construction worker safety.

Review of the Construction Program by the National Academies

In 2005, NIOSH commissioned the National Academies to [review eight of its research programs](#), including the Construction Program. The purpose of the reviews was to assess the impact and relevance of these programs and to identify emerging issues. As "Science Advisors to the Nation," the National Academies and their component organizations, the National Research Council and the Institute of Medicine, provided rigorous, independent expert reviews.

The National Academies reviewed the Construction Program during 2007 through 2008, focusing on construction research and related activities conducted by NIOSH and its National Construction Center during 1996 through 2006. At the conclusion of its review, the National Academies' committee issued a report, [Construction Research at NIOSH](#). The committee awarded research a score of five for relevance and viewed it as high priority in nature. The program was significantly engaged in appropriate activities that transferred research findings to practice in the construction trades and on construction sites [National Research Council U.S. and Institute of Medicine U.S. Committee to Review the NIOSH Construction Research Program 2009]. The committee assigned the program a score of four for impact. NIOSH contributed to construction health and safety as measured by either end outcomes or well-accepted intermediate outcomes.

Committee members differed on whether these contributions could be classified as major contributions across the entire program.

The committee presented six formal Construction Program recommendations to NIOSH:

- Research-to-Practice (r2p) efforts should involve individuals with training or with the experience and skills to create strategic diffusion and social marketing plans for National Institute for Occupational Safety and Health research and to evaluate such plans' effectiveness.
- Consideration should be given to having the majority of research-to-practice efforts of the Construction Research Program conducted through the National Construction Center.
- High-level attention should be given to determine how to provide program resources that are commensurate with a more robust pursuit of the Construction Research Program's goals.
- The Construction Program Coordinator and the Construction Program Manager should both be devoted full-time to the Construction Research Program.
- The National Construction Center should continue to be used as an important component in the Construction Research Program.
- The program should establish a closer connection with the Occupational Safety and Health Administration (OSHA) and other regulatory standards organizations to help ensure that the program's research is applied effectively in rule-making efforts.

In August 2009, in response to the National Academies' recommendations, the Construction Program presented an [initial implementation plan](#) to the NIOSH Board of Scientific Counselors. The BSC commented on the plan and provided an additional recommendation:

An increased focus on developing a specific research-to-practice (r2p) plan for construction in conjunction with the National Construction Center, the National Occupational Research Agenda (NORA) (page 21) Construction Sector Council, and OSHA. The plan should focus on those areas where causes of injuries, illnesses, and

fatalities are known and solutions have been identified and are readily available. Dramatic impacts could be achieved in a relatively short time period [NIOSH 2014].

In its August 2012 [Report to the NIOSH Board of Scientific Counselors](#), the NIOSH Construction Program summarized its progress and impact in implementing five of the six recommendations made by the National Academies, as well as the additional BSC recommendation. A [July 2014 document](#) updated the BSC on the Construction Program's progress toward the same five recommendations.

The National Academies' recommendations were pivotal in two ways. First, they strongly encouraged the National Construction Center to conduct the majority of research-to-practice efforts. Second, they established a leadership structure for construction within NIOSH. In December 2009, the Institute created the Office of Construction Safety and Health (CSH) to provide Institute-wide senior scientific and administrative leadership for all construction research and related activities. CSH actively develops partnerships within NIOSH and among its external stakeholders and coordinates construction research and related activities among NIOSH divisions, labs, and other offices. It extends this coordination within and among the NIOSH-funded National Construction Center; other extramural construction researchers; OSHA's Directorate of Construction; OSHA's public Advisory Committee on Construction Safety and Health; the OSHA Construction Alliance; and with several trade associations.

Program Resources



In 2009, NIOSH created the Office of Construction Safety and Health, located in the NIOSH Office of the Director, to provide Institute-wide senior scientific and administrative leadership for construction research and related activities. Dr. Christine Branche, Principal Associate Director of NIOSH and the Director of CSH, currently manages the Office. Dr. Branche also manages the Construction Program and co-chairs the National Occupational Research Agenda (NORA) Construction Sector Council. The

Coordinator of the Construction Program is Deputy Director of the NIOSH Office of Construction Safety and Health Dr. Scott Earnest. Dr. Earnest joined NIOSH in 1991 and, in 2001, became involved in the Construction Program. As Team Leader and Branch Chief in the Division of Applied Research and Technology (DART), he managed and oversaw multiple construction sector research projects. Dr. Earnest has been the Coordinator since 2015. Mr. Matt Gillen was the first Coordinator and Deputy Director, and served in these roles until his retirement in 2014. The Assistant Coordinator for the Construction Program is CDR Elizabeth Garza an officer in the Commissioned Corps of the U.S. Public Health Service. CDR Garza joined NIOSH in 2009. She first began working for the Office of Construction Safety and Health in 2012. Two years later, CDR Garza took on the role of the Assistant Coordinator for the Office (see Appendix 1 for biographies). CSH also benefits from the input and guidance of an internal steering committee made up of representatives from across NIOSH. Construction activities are an integral part of the mission of NIOSH and its divisions as well as the NIOSH extramural research program.

[NIOSH Office of Extramural Programs](#)

Since 2009, CAPT Steven Inserra, MPH, has served as the Scientific Program Official (SPO) for the NIOSH Construction Program. CAPT Inserra manages construction research grants and the cooperative agreement, authorizing the last two NIOSH program announcements for the NIOSH-sponsored National Construction Center. CAPT Inserra also actively participates in the NORA Construction Sector Council. He holds an MPH, with credentials in institutional and environmental health and injury epidemiology. CAPT Inserra has 28 years of multiple leadership and managerial positions with the Commissioned Corps. Dr. Sharon Chiou is the current SPO overseeing the NIOSH-funded National Construction Center cooperative agreement. She serves as a leading extramural research authority in occupational health and safety science and coordinates the NIOSH intramural research competition. Prior to joining the NIOSH Office of Extramural Programs in 2015, Dr. Chiou was a health scientist with NIOSH's Division of Safety Research (DSR). She has 18 years of experience in developing and executing NORA-funded research projects in the areas of traumatic injury, construction

ergonomics, and personal protective equipment. Her degrees include an MS in industrial hygiene and PhD in occupational ergonomics.

The National Construction Center

NIOSH began funding an external entity to function as a National Construction Center in 1995, using a competitive cooperative agreement mechanism awarded for a five-year period. The cooperative agreement is an integral part of NIOSH's Construction Program, engaging in non-duplicative activities that are complimentary to internal NIOSH Construction Program activities. The National Construction Center focuses on applied research, translational research, and sustainable partnerships with construction stakeholders and intermediaries. Translational research includes both the conduct and study of diffusion, dissemination, education, and outreach on effective safety and health interventions to target audiences. The Center maintains a data and statistical program, materials to support researchers' dissemination efforts, educational materials, and other products. Its translational research is broadly termed research-to-practice (r2p). The Center has extensive communication efforts. These efforts include a database of commercially available and publically-accessible r2p solutions for common worksite safety hazards ([Construction Solutions](#)), the electronic library of Construction Occupational Safety and Health ([eICOSH](#)), and an extensive library of training and other materials for safety managers, safety trainers, and others.

In 1978, the North America's Building Trades Unions (NABTU), formerly known as the Building and Construction Trades Department of the American Federation of Labor and Congress of Industrial Organizations (AFL-CIO), created CPWR -- The Center for Construction Research and Training (CPWR). In 1990, NIOSH awarded the first multi-year cooperative agreement for the National Construction Center to [CPWR](#). Since then, CPWR has competed successfully for the award and continued to serve as the National Construction Center. CPWR is a non-profit (501(c)(3)), dedicated to reducing injuries, illnesses, and fatalities in the construction industry. In partnership with industry stakeholders, health and safety professionals, academics, and key government agencies, CPWR provides research, training, and service programs.

In its capacity as the National Construction Center, CPWR conducts and coordinates a research agenda, manages partnerships, and runs an extensive outreach that includes periodic national webinars, live meetings, seminars, social media, and other activities to promote construction safety and health. It also organizes and hosts an annual meeting in cooperation with NIOSH, collaborates and coordinates with NIOSH, and works closely with CSH. CPWR's relationship with NABTU includes an apprentice and journeymen training programs with construction workers at former Department of Energy (DOE) facilities. This relationship has provided CPWR staff and consortium researchers, as well as internal NIOSH researchers, novel opportunities for participatory collaborative research and its dissemination. In 1993, CPWR began a Small Studies Grant Program to fund pilot and hypothesis-generating research.

Through its cooperative agreement with NIOSH, CPWR has an administrative core that includes all planning and administrative functions for the National Construction Center. Major roles of the administrative core are to coordinate its national research consortium and to build relationships with industry stakeholders. The administrative core links the National Construction Center and NIOSH internal investigators with construction industry stakeholders.

CPWR's 15 current research projects fit into four research program areas that target the second decade NORA of goals: applied research, r2p research, emerging issues research, and support services for industry data and statistics.

The Construction Program expects each research project and activity of the National Construction Center to achieve one or more intermediate outcomes. These outcomes should eventually impact occupational safety and health by reducing illness and injury. Research projects include exploratory projects, as well as ready-for-impact projects. Through a competitive process, CPWR teams with academic organizations. Academic investigators collaborate with CPWR investigators to conduct exploratory research. CPWR actively engages with each project leader and fosters information sharing, collaboration, and application. Responding to two of the National Academies' recommendations that specifically mention the National Construction Center, the Applied Research and r2p Programs conduct ready-for-impact projects. Emerging

research issues have included the growing use of engineered nanotechnology-enabled materials in construction.

In 1992, CPWR established an International Roundtable on Construction Safety and Health to learn from more experienced nations. CPWR now includes 15 countries. From the start, it was evident that the construction industries in many countries had a better safety and health performance than the U.S. It also became clear that the safety and health challenges facing construction are different from any other industry. For this reason, it made sense to share experiences with other countries. This effort has now been combined with the [International Social Security Association](#) Construction Section, to which CPWR is the United States' delegate.

In 1993, CPWR established the [Data Center](#) to identify industry trends. The Data Center responds to data requests for analysis needs from the National Construction Center and other government and construction industry stakeholders. Many government agencies and private organizations collect data on the construction industry, including safety and health data, but the Construction Center's Data Center is unique in two respects:

It uses all of the data collected by other organizations, including NIOSH, OSHA, Bureau of Labor Statistics (BLS), Census Bureau, state agencies, and private sources such as McGraw Hill, Inc. (now Dodge Data & Analytics), to characterize the industry and its workforce (the denominators) and its injury and illness patterns (numerators). The aim is to identify areas of need and measure improvements in national performance.

It services all government agencies, the industry, and researchers. The center responds to requests for information and technical assistance on safety and health issues in the construction industry. The Data Center produces accurate and useful data or findings to a host of end users.

Key products from the Data Center are its data reports and the [Construction Chart Book: The U.S. Industry and Its Workers](#). The Chart Book describes the changing construction industry and its workers in the United States. It monitors the impact of such changes on worker safety and health and identifies priorities for safety and health interventions in the future. Its focus is on construction industry issues important to the decision makers

responsible for worker safety and health, including hazards, exposures, diseases, fatal and nonfatal injuries, and economics data. Thus, the Data Center plays a central role in identifying national trends and tracking national progress in accomplishing NORA research goals.

Founded in 1994, CPWR’s Construction Economics Research Network (CERN) describes the industry and measures the economic impact of safety and health. When the National Construction Center began, there were no economists focused on safety and health in the construction industry. The CERN has evolved into its own non-profit organization, the Institute for Construction Economics Research (ICERES).

Key CPWR Staff

Name	Role
Chris Trahan Cain, CIH	Executive Director and Principal Investigator
Rosemary Sokas, MD, MOH	Interim Deputy Director
Eileen Betit	Director, Translation and Research to Practice Program
Xiuwen (Sue) Dong, MS, DrPH	Director, Data Center
Linda Goldenhar, PhD	Director, Evaluation and Research Program
Bruce Lippy PhD, CIH, CSP	Director, New and Emerging Issues Research Program
Babak Memarian, PhD	Exposure Control Technologies Research
Patricia Quinn	Small Studies Coordinator
Erich (“Pete”) Stafford	Executive Director, 1991–2016
Robin Baker, MPH	Director, Research to Practice, 2010–2015
Janie Gittleman, PhD	Associate Director for Safety and Health Research, 2002–2011
James W. Platner, PhD, CIH	Associate Director for Science and Technology, 1999–2014
Laura S. Welch, MD	Medical Director, 2003–2014

Funding

NIOSH distributes funding in construction across a combination of intramural and extramural activities (Table 1). In fiscal year (FY) 2008, to improve the accuracy of sector specific investment, NIOSH made a change to its instructions for attributing individual projects to programs. This change accounted for a substantial shift in funding and FTE between FY 2007 and FY 2008. For this reason, funding for these two FYs is not included. In FY 2013, a total of 22 intramural construction projects ended, while in FY 2014 only eight new projected were initiated. Due to this net decrease, the net reduction in funding is \$900K. In addition, a total of eight grants ended in FY 2013 (one being a grant for approximately \$1M), and only two additional grants were initiated in FY 2014.

Table 1. Construction Program Funding (in millions) and Staff 2009–2017.

Fiscal Year	Intramural	Extramural	Total	FTE
2007	NA	NA	NA	NA
2008	NA	NA	NA	NA
2009	\$9.5	\$9.7	\$19.2	58
2010	\$9.8	\$10.1	\$19.9	62
2011	\$10.9	\$9.1	\$20.0	70
2012	\$11.2	\$9.6	\$20.8	68
2013	\$9.8	\$9.5	\$19.3	64
2014	\$8.9	\$6.2	\$15.1	59
2015	\$8.4	\$6.6	\$15.0	53
2016	\$8.3	\$7.1	\$15.4	52
2017	\$8.6	\$7.2	\$15.8	52

Facilities

A number of NIOSH divisions, laboratories and offices from across the Institute support the work of the Construction Program, including the following facilities in Cincinnati, Ohio; Morgantown, West Virginia; and Pittsburgh, Pennsylvania.

Cincinnati, Ohio

The Division of Applied Research and Technology (DART) conducts research in three primary areas: (1) exposure sciences to identify and measure chemical, physical, biological, and organizational hazards; (2) interventions and controls to reduce exposure to hazards; and (3) human and social factors including work organization to address musculoskeletal disorders and other health related outcomes. Construction scientists in DART research exposure assessment and methods development in laboratories located in the Taft and Hamilton facilities. Within these laboratories, DART scientists use specialized equipment including high performance liquid chromatography and mass spectrometry, scanning and transmission electron microscopes, and vapor and aerosol generation and measurement systems for the comprehensive characterization of hazardous materials.

The Division of Surveillance, Hazard Evaluations, and Field Studies (DSHEFS) conducts and coordinates surveillance activities and performs health hazard evaluations and industry-wide health and exposure studies to detect and prevent work-related illness. DSHEFS has dedicated exposure assessment and industrial hygiene facilities, including the NIOSH Field Evaluations and Response Vehicle.

The Education and Information Division (EID) develops and transfers information and provides authoritative recommendations in Criteria Documents, Current Intelligence Bulletins, and other document formats to prevent occupational injuries and diseases. Prevention is fostered through targeted information development and dissemination, training research, and the development of qualitative and quantitative risk assessments. EID risk assessments provide the basis for establishing recommended exposure limits (RELs) and other emerging approaches for controlling exposures including occupational exposure banding guidance. EID is also home to the Nanotechnology Research Center and the Prevention through Design (PtD) program.

Morgantown, West Virginia

The Division of Safety Research (DSR) conducts activities aimed at preventing the leading causes of traumatic injuries and fatalities in the workplace. DSR operates three laboratories for research related to construction. The division's human factors laboratory allows DSR researchers to conduct work in the areas of biomechanics, applied physiology, and industrial psychology. DSR's high bay laboratory includes a 37-foot high ceiling with an overhead catwalk and a manikin used to measure biodynamic forces. The DSR virtual reality laboratory contains a fully immersive simulation space. A computer-generated projection gives users the illusion of being fully immersed in a three-dimensional world.

The Health Effects Laboratory Division (HELD) conducts basic and applied laboratory research to establish the causes of occupational disease and injury and contributes to the development of valid strategies of intervention and prevention. HELD's laboratories research a wide range of toxic agents, including respirable crystalline silica. These laboratories provide the division's scientists with the ability to conduct toxicity studies with biological media and to develop new methods for identifying potential biomarkers for assessing exposures to hazardous agents.

The Respiratory Health Division (RHD) seeks to protect workers against work-related hazards and exposures that cause or contribute to respiratory illness, injury, and death and to promote workplace-based interventions that improve respiratory health. As part of its coal miner surveillance program, RHD operates a mobile surveillance laboratory equipped with interview stations, digital X-ray equipment, pulmonary function testing areas, and other medical test capabilities. Spirometry laboratories support the NIOSH field-based pulmonary function and medical testing activities.

Pittsburgh, Pennsylvania

The National Personal Protective Technology Laboratory (NPPTL) conducts timely scientific research on personal protective technology (PPT). The laboratory develops guidance and authoritative recommendations, disseminates information, and responds to requests for workplace health hazard evaluations related to using PPT to keep workers safe. This research includes both the need for and the effectiveness of PPT.

Construction resources at NPPTL include a human factor and ergonomics test laboratory to assess the wearability and performance of self-contained breathing apparatus, closed circuit escape respirators, and closed circuit self-contained breathing apparatus. NPPTL also has approval and research laboratories for assessing the effectiveness of PPT in preventing exposures to hazardous agents.

Pittsburgh Mining Research Division (PMRD) conducts research in support of its mission to eliminate mining fatalities, injuries, and illnesses through research and prevention. The PMRD laboratories include a work physiology laboratory, a motions analysis laboratory, two noise assessment laboratories, two laboratories used for testing diesel emissions sampling and monitoring approaches, three laboratories used for assessing and improving the performance of dust samplers and monitors, a proximity detection laboratory, a mine electrical laboratory, and a virtual immersion and simulation laboratory.

Fatality Assessment and Control Evaluation (FACE) Program

NIOSH's [Fatality Assessment and Control Evaluation \(FACE\) Program](#) investigates workplace traumatic injuries in the U.S. The investigations identify factors that contribute to fatal injuries and use this information to develop comprehensive recommendations for preventing similar deaths. The FACE Program began in 1982, with the primary intent of providing users with access to the full text of fatality investigation reports. Participating states voluntarily notify NIOSH of traumatic occupational fatalities resulting from targeted causes of death that have included confined spaces, electrocutions, falls from elevation, including fatalities in construction and among working youth. In 1989, State FACE included seven state health or labor departments that worked with NIOSH through cooperative agreements for conducting surveillance, targeted investigations, and prevention activities using the FACE model at the state level. State FACE investigations have included fatalities related to renewable energy, incidents involving multiple workers, young workers under 25 years of age, and workers over 60 years of age.

Program Planning

Together the CSH Director and Deputy Director frame the strategic vision and goals, provide logistical support, implement research plans, and co-lead, with an external co-chair, the NORA Construction Sector Council. This collaboration ensures the construction research program is responsive to comments and contributions from emerging research, the National Construction Center, stakeholders, external reviewers, and the NIOSH Director. CSH established the Construction Program Manager and Coordinator positions as dedicated full-time personnel within NIOSH to improve the Institute's ability to align construction resources with national priorities. These positions led coordination among the NIOSH divisions, laboratories, and offices conducting construction research; the NORA Construction Sector Council; and the National Construction Center. Coordination takes place through regular meetings with division representatives on the internal Construction Steering Committee, as well as with direct meetings with construction researchers and division management. This interaction also improves the integration of extramural research supported through the NIOSH Office of Extramural Programs.

The National Occupational Research Agenda (NORA) and the NORA Construction Sector Council

The [National Occupational Research Agenda \(NORA\)](#) is a collaborative initiative to stimulate innovative research and workplace interventions. Unveiled in 1996, NORA has become an occupational safety and health research framework for the nation. Diverse parties identify critical issues in workplace safety and health to develop research objectives to address these issues. NORA council platforms help build partnerships to maximize resources. The information sharing and leveraging efforts promote widespread adoption of improved workplace practices based on research results. The NORA Construction research goals and objectives identify the research, information, and actions most urgently needed to prevent occupational injuries and illnesses in the construction sector. The Agenda provides a vehicle for construction stakeholders to describe the most relevant issues, gaps, and safety and health needs for the sector. NORA runs in [10-year cycles](#): the first decade from 1996 through 2006, the second decade from 2006 through 2016, and the third decade from 2016 through 2026.

The [NORA Construction Sector Council](#) is comprised of academics, trade associations, employer groups, labor unions, insurance companies, NIOSH and other federal and state occupational agencies, and other stakeholders with key interests and activities in the construction sector. [Dozens of individuals](#) participated in the Construction Sector Council during its second decade. The Council has two co-chairs, one is the NIOSH Construction Program Manager and the other currently is the executive director for CPWR, representing stakeholders. Non-NIOSH co-chairs serve for two years. During the second decade of NORA, the NORA Construction Sector Council 2008 developed a sector-based national research agenda. This was the first national effort to create an occupational safety and health research agenda for the construction industry. The key focus was to answer the question: “What information do we need to be more effective in preventing injuries and illnesses in construction?” A description of research needs and information gaps was an important basis for the 2006 through 2016 agenda. Another basis was “research to practice” (r2p), a description of how construction stakeholders could use research findings to bring about needed changes in the industry.

The resulting agenda for 2006 through 2016 consisted of 15 strategic research goals designed to address 10 leading problems in construction safety and health. These included seven “outcome” goals related to important sources of injury or illness and eight “contributing factor” goals related to important influences that affect prevention and control measures throughout the industry. NIOSH adopted these goals to guide its construction research.

The NIOSH Office of Extramural Programs conducted a recent analysis of the NIOSH Construction Program, addressing all 15 strategic goals by extramural and intramural researchers [NIOSH 2017a, b].

Beginning in 2010, NIOSH and the NORA Construction Sector Council selected two of the 15 strategic goals for priority activity. NIOSH and the council selected Strategic Goal 1 (Reduce construction worker fatalities and serious injuries caused by falls to a lower level), for which developing a falls prevention campaign is an intermediate goal. They also selected Strategic Goal 13 (Increase the use of “prevention through design (PtD)” approaches to prevent or reduce safety and health hazards in construction), for which

developing a pilot rating credit with green jobs in construction was a component. All 15 strategic goals were important and relevant; however, making significant accomplishments in all areas within the decade is daunting given fiscal constraints and other considerations. Selecting two goals allowed the NORA Construction Sector Council to make significant progress and bring research accomplishments to the industry within the second decade of NORA.

The NORA Construction Sector Council reviewed all 15 NORA construction strategic goals. The review began in 2011, the halfway point in the decade-long NORA effort. This provided an opportunity to take stock of overall developments; review NORA projects and partnerships; review performance measures; examine the impact of the 2008 through 2012 economic recession on construction generally, and on safety and health developments in construction; and to provide additional directional strategies and fine-tuning. The review culminated in a report [NORA Construction Sector Council 2013]. After the mid-decade review, NORA categorized the following types of goals:

Exploratory – defining problems and solutions for an important issue

Developmental – having some solutions under development for industry impact

Ready for Impact – having sufficient solutions available and ready for industry impact

Table 2. Categorization of Construction goals in the Mid-Decade Review.

Category	Goal Description (Goal number)
Ready for Impact	Falls (1); Struck by (3); Silica (5); Culture (8); Disparities (12); PtD (13)
Developmental	Electrocution (2); Noise (4); Welding Fumes (6); MSD (7); S&H Management (9); Training (11); Surveillance (14)
Exploratory	Industry Organization (10) Engage the Media (15)

In its second decade, categorization proved useful in moving forward, assessing progress, and, more importantly, assessing the impact among the 15 construction strategic goals.

NORA entered its third decade (2016 through 2026) with an improved structure. The 10 sectors formed for the second decade prioritized occupational safety and health research by major areas of the U.S. economy. In addition, it organized seven cross-sectors based on the major health and safety issues affecting the U.S. working population. While NIOSH is serving as the steward to move this effort forward, it is, as always, a national effort. The NORA Construction Sector Council began its third decade by identifying broad occupational safety and health research objectives for the nation, electing to adopt NIOSH's [burden, need, and impact](#) method for considering potential objectives. The proposed research objectives were prepared from advances in knowledge made in its second decade and addressed emerging issues.

In 2017, a draft of the NORA Construction Agenda was published in the [Federal Register](#), allowing for key stakeholder and public commentary. The NORA Construction Sector Council will review all comments provided in the NIOSH docket, address the comments, and prepare the final list of national research objectives that comprise the Agenda. The NORA Construction Sector Council will spend the remainder of the decade working together to address the construction agenda through information exchange, collaboration, and enhanced dissemination and implementation of evidenced-based solutions.

Future Plans

The NIOSH Construction Program collaborates with NIOSH cross-sector programs to develop evidence-based goals to focus and give priority to efforts that will maximize NIOSH's role, investments and impact in the construction industry. The goals are part of NIOSH's larger Strategic Plan. The Construction Program will continue to seek input from experts, stakeholders, and other interested parties, and will carefully consider issues such as burden of injury and illness, size of populations with hazardous exposures, research needed to have an impact, and NIOSH's unique capabilities as it establishes its continuing role in research related to construction.

External Factors

NIOSH has made great strides to promote safe and healthy workplaces in the construction industry sector. Continued efforts to expand and improve the body of knowledge in this area are subject to changes in funding, research priorities, and the availability of knowledgeable and experienced researchers. NIOSH also investigates issues and unplanned opportunities as they emerge.

Organization of the Document

Each of the topics selected in this package of evidence describes scientific exploration conducted from fiscal years 2007 through 2017 by NIOSH researchers, CPWR researchers, or NIOSH-funded researchers, often from academia. These groups frequently collaborate on a particular hazard or exposure in construction. Furthermore, the selected topics are among the research areas found in the second decade NORA Construction Agenda, and had demonstrable impact on the health or safety of construction workers. NIOSH conducts internal research and funds external entities in a number of high burden, high need safety and health areas in the construction sector. Not all areas of research are at the same stage of development, nor have all research outputs had proper time for transference and adoption by organizations or individuals who are able to make changes directly and indirectly in the workplace (e.g., employers, workers, government agencies, manufacturers).

For the purposes of this program review, the panel will be asked to consider only the NIOSH Construction Program's work in the following areas: silica, musculoskeletal disorders, noise exposure and hearing loss, work zone safety, and falls.

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Chapter 2: Silica Research in Construction



Introduction

Silica is a compound of the two most abundant elements in the earth's crust: silicon and oxygen. The chemical formula is SiO_2 [NIOSH 2007b]. Silica is the main constituent of more than 95% of known rocks and can occur in crystalline (crystal) and non-crystalline (amorphous) forms. The transmission of mechanical or blast energy to materials containing crystalline silica (such as blasting, moving, and grinding) produces fine particles that can penetrate the lungs as respirable crystalline silica (RCS). We have known for a long time that exposure to silica dust causes health problems, especially to the pulmonary system. Approximately 2.3 million workers in the United States, many who work in construction, face exposure to RCS [OSHA 2013a, 2016c; CPWR 2018]. Any construction employee who works with materials containing RCS is at risk of exposure to hazardous levels of silica dust. In fact, even persons working near someone generating silica dust may be at risk for silica-related illnesses. An estimated 850,000 or more workers [OSHA 2016c] face exposure to silica levels that exceed the updated permissible exposure limit (PEL, 0.05 mg/m^3) set by the Occupational Safety and Health Administration (OSHA) in 2017 in its new [Respirable Crystalline Silica standard](#) for

construction [OSHA 2016a]. In construction, the most common exposures to RCS come from the disruption of materials containing crystalline silica:

- Chipping, hammering, and drilling of rock
- Crushing, loading, hauling, and dumping of rock
- Abrasive blasting using silica sand as the abrasive
- Abrasive blasting of concrete regardless of the abrasive used
- Sawing, hammering, drilling, grinding, and chipping of concrete or masonry
- Demolition of concrete and masonry structures
- Dry sweeping or pressurized air blowing of concrete, rock, or sand dust
- Operating vehicle-mounted drilling rigs
- Drywall finishing using silica-containing material
- Use of heavy equipment during earthmoving [NIOSH 1996; OSHA 2013a]

RCS exposure is associated with the development of silicosis, lung cancer, pulmonary tuberculosis, chronic obstructive pulmonary disease, autoimmune disorders, and chronic renal disease [Stayner 2007]. Silicosis is a debilitating and sometimes fatal lung disease caused by inhaling RCS particles. These particles can deposit in the lungs and induce pathological inflammatory and fibrotic reactions. Acute silicosis can develop in a matter of weeks to months after very high exposure to silica dust or may occur over time after repeated, lower dose exposures. Silicosis may also occur or worsen years after exposure stops [NIOSH 2002]. Adverse health outcomes from silica exposure commonly require medical treatment, which involves medical disabilities that force workers to spend time away from work. These diseases also negatively affect a person's quality of life and shorten their life span. NIOSH researchers wrote a 2015 Science Blog, Silicosis Update, about the problem of silicosis in the U.S. This blog was very popular and received many comments, questions, and feedback from the public [Mazurek and Weissman 2015].

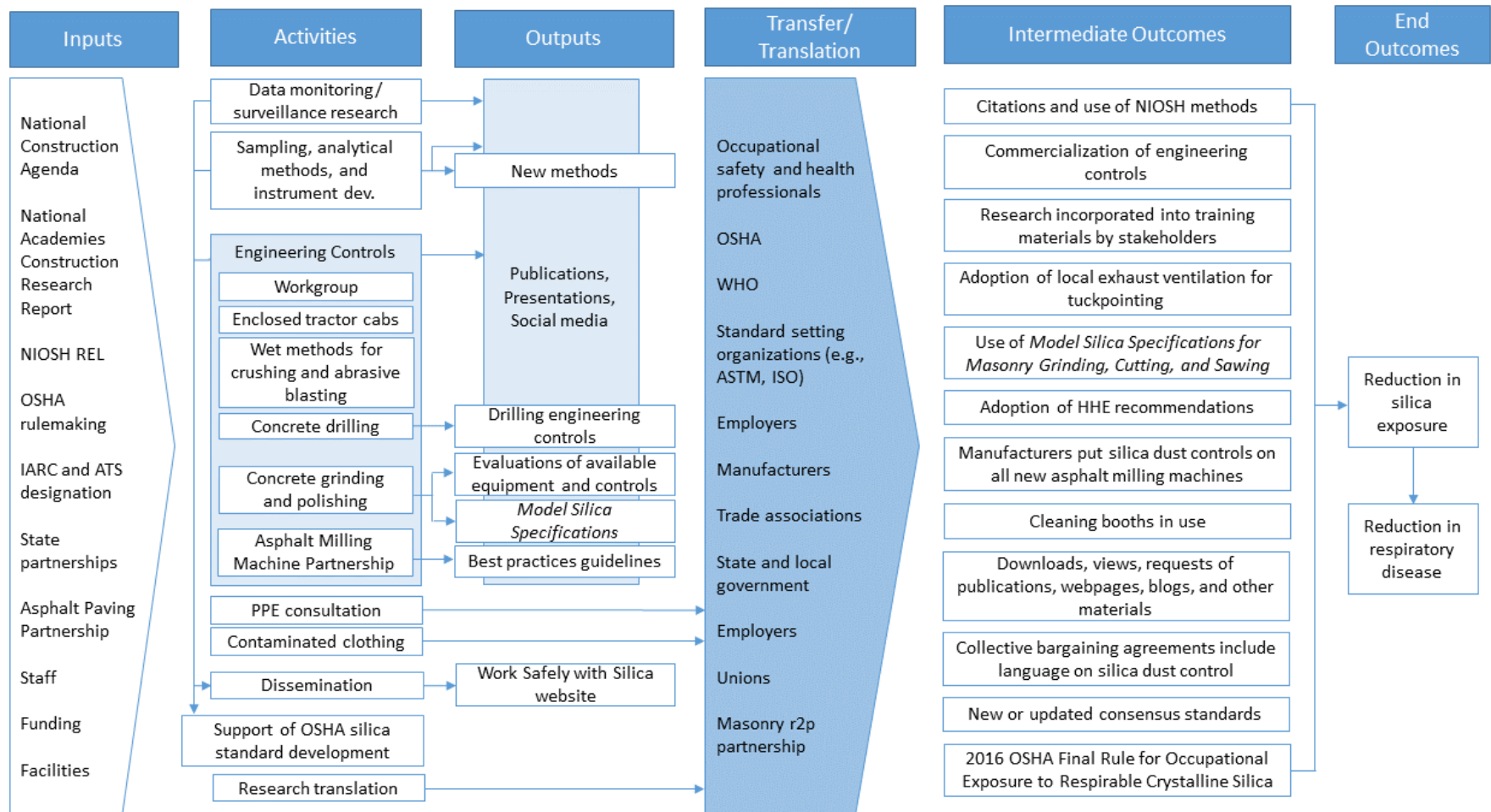
The National Institute for Occupational Safety and Health (NIOSH) has conducted silica research since the early 1970s. NIOSH published its first seminal document on the topic in 1974, the [Criteria for a Recommended Standard](#) [NIOSH 1974]. Because exposure to RCS is associated with lung cancer, in 1988, NIOSH recommended to OSHA the labeling

of RCS as a potential occupational carcinogen. As the NIOSH Construction Program began in 1990, they identified occupational lung disease as a problem. One of the original projects initiated by NIOSH Construction Program researchers was to understand RCS exposure in the construction industry. In 1997, the International Agency for Research on Cancer (IARC) identified “crystalline silica inhaled in the form of quartz or cristobalite from occupational sources” as carcinogenic to humans (IARC Group 1), although the mechanism was not clearly understood at that time [IARC 1997, p. 210]. In 2012, an IARC review of additional epidemiologic studies determined that RCS is a lung carcinogen even in the absence of silicosis [Steenland and Ward 2014]. Through the 1990s, research focused first on surveillance and later on effective intervention strategies. OSHA moved toward rulemaking for RCS exposure in 1997. From that time, NIOSH researchers interacted regularly with OSHA to ensure that OSHA had the most current and relevant research information.

Logic Model

The logic model (Figure 1) illustrates the characteristics of NIOSH’s research and other activities to reduce RCS exposure. Elements of the logic model are Inputs, Activities, Outputs, Transfer and Translation, Intermediate Outcomes and the End Outcome. Each element is described in detail in the sections that follow.

Figure 1. Logic Model for NIOSH Silica Research Efforts for Construction, 2007-2017.



Inputs

Many inputs contribute to the progress of NIOSH's Construction Program in addressing the problem of RCS exposures in the construction industry:

National Construction Agenda

During the second decade of NORA (2006 through 2016), the Construction Sector Council developed the National Construction Agenda that helped drive research on silica in the construction industry. As noted in the Program Overview (page 21), the NORA Construction Sector's national agenda for the construction industry included 15 strategic research goals. The agenda's fifth strategic goal is: Reduce silica exposures and future silica-related health risks among construction workers by increasing the availability and use of silica dust controls and practices for tasks associated with important exposures. In addition, the following five intermediate goals related to this strategic goal were developed:

Intermediate Goal 5.1 - Use existing information supplemented by survey research to develop a baseline on current silica control practices and programs in construction.

Intermediate Goal 5.2 - Increase awareness about silica hazards and known solutions among construction workers, contractors, owners, and suppliers.

Intermediate Goal 5.3 - Increase the availability of engineering and work practice options for reducing silica exposures.

Intermediate Goal 5.4 - Develop model practices and programs and promote their use by construction owners, governmental groups, professional groups, and best practice employers.

Intermediate Goal 5.5 - Evaluate hazard and exposure assessment research gaps associated with silica in construction.

NIOSH used the strategic and intermediate goals for silica to provide direction for extensive work that resulted in significant progress toward reducing silica-related health risks.

National Academies Construction Research Report

The National Academies reviewed the NIOSH Construction Program during 2007 and 2008. The review focused on construction research and related activities conducted by and through NIOSH during 1996 through 2006. The purpose of the review was to assess the impact and relevance of the program and to identify emerging issues. The review included numerous recommendations that influenced the NIOSH Construction Program's work on silica from 2009 until the present. Specifically, the report, [*Construction Research at NIOSH: Reviews of Research Programs of the National Institute for Occupational Safety and Health*](#), recommended that NIOSH establish closer connections with OSHA to help ensure that the program's research is effectively applied in rulemaking efforts. The report also stated that any role that the construction program plays in developing or strengthening standards increases the program's impact [National Research Council (U.S.) and Institute of Medicine (U.S.) Committee to Review the NIOSH Construction Research Program 2009].

NIOSH Recommended Exposure Limit (REL) for Crystalline Silica

In 1974, NIOSH published [*Criteria for a Recommended Standard: Occupational Exposure to Crystalline Silica*](#) recommending that the RCS exposure limit be reduced to a time-weighted average of 50 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) for up to a full shift, ten hours a day, 40 hours a week, over a working lifetime [NIOSH 1974]. The NIOSH criteria document also called for the use of engineering controls, personal protective equipment, and medical monitoring [NIOSH 1974].

OSHA Rulemaking Activities

For many years, the NIOSH REL was significantly lower than the OSHA PEL. The OSHA regulatory agenda included focus on RCS exposure from 1997 through 2016. During that time, OSHA and NIOSH staff discussed the needed research to support this effort. Although NIOSH RCS research occurred in many areas, OSHA wanted additional research on sampling and analytical methods, engineering controls, and risk assessment to address some of the outstanding needs. OSHA needed research support in risk assessment to determine if RCS posed a risk beyond the previous exposure level to demonstrate the need for a new workplace standard. Likewise, OSHA needed to demonstrate that sampling and analytical methods could accurately measure RCS at the airborne level of a new PEL. They also had to show that engineering controls would

allow employers to reach the new PEL in most operations most of the time, meeting their obligation to show that the standard technically feasible (achievable by employers). NIOSH and OSHA signed multiple interagency agreements on research on key aspects of RCS exposure that were important for rulemaking (described later in this chapter).

IARC and ATS Designation for Crystalline Silica

In 1996, the International Agency for Research on Cancer (IARC) reviewed the published experimental and epidemiologic studies of cancer in animals and workers exposed to RCS. IARC concluded that there was “sufficient evidence in humans for the carcinogenicity of inhaled crystalline silica in the form of quartz or cristobalite from occupational sources” [IARC 1997]. IARC reaffirmed their conclusion regarding silica in 2012 [IARC 2012]. In 1997, directors of the American Thoracic Society adopted an official statement that described the adverse health effects of exposure to RCS, including lung cancer. ATS stated, “the available data support the conclusion that silicosis produces increased risk for bronchogenic carcinoma” [Beckett et al. 1997]. ATS noted, however, that less information was available for lung cancer risks among individuals with silicosis who had never smoked and for RCS-exposed workers who did not have silicosis. They also stated that it was “less clear” whether RCS exposure was associated with lung cancer in the absence of silicosis.

NIOSH reviewed the studies considered by IARC and ATS, and during testimony to OSHA, NIOSH concurred with the conclusions of IARC and ATS, in which NIOSH recommended that RCS be considered a potential occupational carcinogen [OSHA 1989]. Because of the significant adverse health effects related to RCS exposure, NIOSH placed greater emphasis on research in this area.

State Partnerships

NIOSH began state partnership programs in 1987 to collaborate with state health departments on surveillance and address limitations in provider-reporting systems (e.g., lack of epidemiologic case definitions, lack of defined networks of sentinel providers, or lack of guidance). Part of this effort involved developing several state-based surveillance and intervention programs for silicosis. As partners for the past 30 years, NIOSH surveillance researchers provide technical support and subject-matter expertise to NIOSH-funded state-level silicosis programs. Through the implementation of active

silicosis surveillance at the state level, New Jersey discovered silicosis among heavy and highway construction workers and identified high-exposure tasks [Valiante et al. 2004]. Other state partners spurred NIOSH research into heavy and highway construction exposures and controls that continued for a number of years. In addition, a state surveillance program played an important role in providing input to NIOSH on areas where more silica intervention and control research was needed. NIOSH work on exposure controls for RCS when fabricating engineered-stone countertops relates directly to state-based surveillance activities for silicosis [Johnson et al. 2017].

Asphalt Paving Partnership

Efforts to develop engineering controls for hot-mix asphalt paving equipment began in 1993 at the National Asphalt Pavement Association (NAPA) annual meeting [Mead et al. 1999]. The resulting National Asphalt Paving Partnership included representatives from labor, industry, government, academia, and all manufacturers that sold asphalt-paving equipment in the United States. The goal of the task force was to improve the working environment and conditions during hot-mix asphalt paving operations by using engineering controls to reduce or eliminate worker exposure to asphalt fumes [Chang et al. 2015]. Under the task force, NIOSH engineers assisted each manufacturer in designing engineering controls for hot-mix asphalt pavers, performing factory and field-testing to optimize the designs. By 1997, all equipment manufacturers who sold highway class pavers to the U.S. market entered into a voluntary agreement with OSHA that a certain class of pavers manufactured after July 1, 1997 would have effective engineering controls [Mead et al. 1999; NIOSH 1997]. The success of the Asphalt Paving Partnership's effort on engineering controls for pavers [Chang et al. 2015; Moran et al. 1997; Welch et al. 2015], and ongoing interaction with key state collaborators [Moran et al. 1994], ultimately led to most of the same industry partners successfully collaborating to reduce RCS exposures from asphalt milling machines (discussed later in this chapter).

Staff

NIOSH conducted construction research in the field as well as in laboratories. Partnerships with industry stakeholders are essential, with industry employers and workers often participating in field projects. NIOSH research resulted in many outputs including publications, conferences, advice to standards organizations, communication

products, and patents. The following individuals have been particularly instrumental in conducting NIOSH silica research:

NIOSH Intramural Researchers

Name	NIOSH Division/Office
Megan Casey, RN, BSN, MPH	Respiratory Health Division (RHD)
Emanuele Cauda, PhD	Pittsburgh Mining Research Division (PMRD)
Andrew B. Cecala, MBA	PMRD
Alan Echt, DrPH, CIH	Division of Applied Research and Technology (DART)
Alberto Garcia, MS	DART
Duane Hammond, MS, PE	DART
Ron Hall, MS, CIH, CSP	DART
Rosa Key-Schwartz, PhD	DART
Bon-Ki Ku, PhD	DART
Pius Joseph, PhD, DABT	Health Effects Laboratory Division (HELD)
Taekhee Lee, PhD	PMRD
Jacek Mazurek, MD, MS, PhD	RHD
Trudi McCleery, MPH	DART
John Organiscak, MBA	PMRD
Robert Park, MS	Education and Information Division (EID)
Chaolong Qi, PhD	DART
Faye Rice, MPH, RHIA, CCS	EID
Patricia L. Schleiff, MS	RHD
Andrea Steege, PhD	Division of Surveillance, Health Effects and Field Studies (DSHEFS)
Kyle Steenland, PhD	DSHEFS (retired)
Elizabeth Ward, PhD	DSHEFS (retired)

CPWR Staff, and Consortium and Small Study Researchers

Name	NIOSH Division/Office
Chris Trahan Cain, CIH	CPWR
Farhang Akbar-Khanzadeh, PhD	University of Toledo
Eileen Betit	CPWR
Xiuwen (Sue) Dong, MS, DrPH	CPWR
Bill Heitbrink, PhD	University of Iowa (retired)

Name	NIOSH Division/Office
Bruce Lippy PhD, CIH, CSP	CPWR
Michael McCann, PhD	CPWR
John Meeker, ScD, CIH	University of Michigan
Babak Memarian, PhD	CPWR
James Platner, PhD	CPWR (retired)
David Rempel, MD, MPH, CPE	University of California, Berkeley
Ruth Ruttenberg, PhD, MCP	Ruttenberg & Associates
Pam Susi, MPH	CPWR (retired)
Laura Welch, MD	CPWR (retired)
Susan Woskie, PhD	University of Massachusetts, Lowell

NIOSH Extramural Grant Researchers

Name	Institution
John Dement, PhD	Duke University
Perry Gottesfeld, MPH	Occupational Knowledge International
Brian Kleiner, PhD	Virginia Polytechnic Institute & State University
Cora Roelofs, ScD	University of Massachusetts, Lowell
Gloria Sorenson, PhD	Harvard University
Deborah Young-Corbett, PhD	Virginia Polytechnic Institute & State University

Activities, Outputs, Transfer and Translation, and Intermediate Outcomes

Published in March 2016, the [OSHA Final Rule for Occupational Exposure to Respirable Crystalline Silica](#), including the standard for construction, 29 CFR 1926.1153, and for

general industry and maritime, 29 CFR 1910.1053, went into effect on June 23, 2016.

Many of the activities, outputs, and research translation efforts described in this chapter support the OSHA silica rule. A significant portion of NIOSH research referenced in the standard related to either sampling and analytic methods or to engineering controls.

Table 1 (Figure 2) of the standard includes much of the NIOSH engineering control research for RCS. The table lists 18 common construction equipment or tasks and effective dust control methods for each (i.e., masonry saws, dowel drilling, milling

machines, etc.). We describe the OSHA Final Rule for RCS and Table 1 in detail later in this chapter.

Figure 2. An excerpt of OSHA Table 1 on exposure control methods.

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employer shall fully and properly implement the engineering controls, work practices, and respiratory protection specified for the task on Table 1, unless the employer assesses and limits the exposure of the employee to respirable crystalline silica in accordance with paragraph (d) of this section.

TABLE 1—SPECIFIED EXPOSURE CONTROL METHODS WHEN WORKING WITH MATERIALS CONTAINING CRYSTALLINE SILICA

Equipment/task	Engineering and work practice control methods	Required respiratory protection and minimum assigned protection factor (APF)	
		≤4 hours/shift	>4 hours/shift
(i) Stationary masonry saws	Use saw equipped with integrated water delivery system that continuously feeds water to the blade. Operate and maintain tool in accordance with manufacturer's instructions to minimize dust emissions.	None	None.
(ii) Handheld power saws (any blade diameter).	Use saw equipped with integrated water delivery system that continuously feeds water to the blade. Operate and maintain tool in accordance with manufacturer's instructions to minimize dust emissions: —When used outdoors —When used indoors or in an enclosed area	None APF 10	APF 10. APF 10.
(iii) Handheld power saws for cutting fiber-cement board (with blade diameter of 8 inches or less)	For tasks performed outdoors only: Use saw equipped with commercially available dust collection system.	None.	None.

Data Monitoring/Surveillance Research

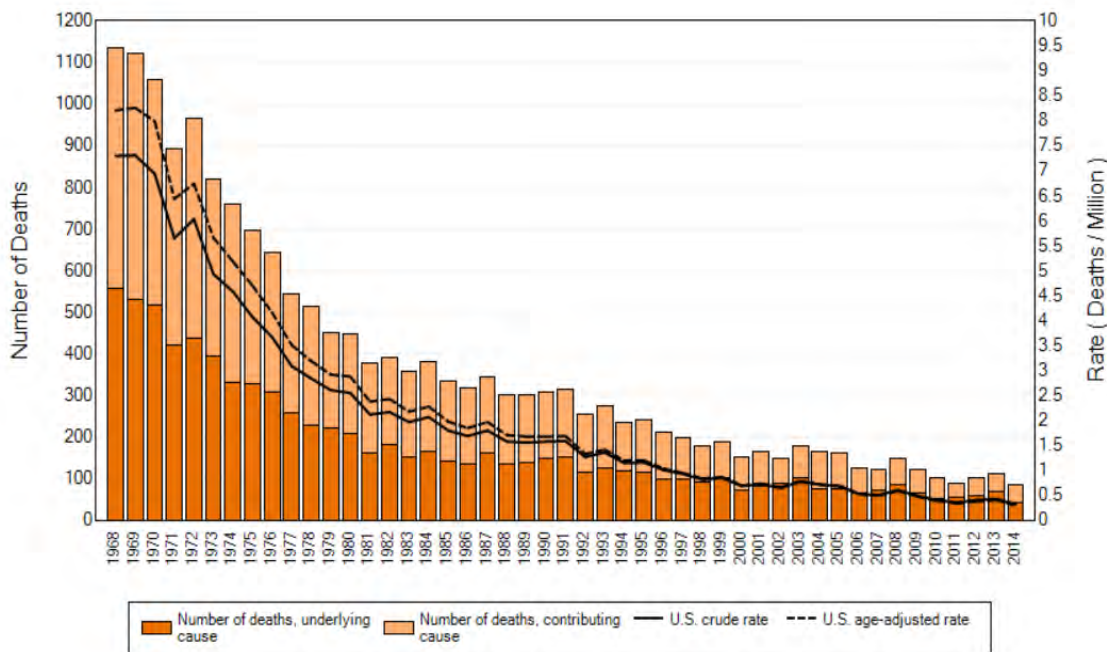
Silicosis Mortality in the United States

Chronic silicosis takes years to develop and is often underreported [Moran et al. 1994]. In 1968, silicosis deaths in the U.S. totaled 1,065, falling to 101 in 2010 (see Figure 3) [CDC 2015b, c; Nasrullah et al. 2011; NIOSH 2008c]. In 2011 and 2012, there were 88 and 103 silicosis deaths, respectively. During 1993 to 2011, the number of hospitalizations with silicosis diagnoses did not decline. NIOSH researchers found that from 2001 through 2010, 1,437 decedents in the U.S. had silicosis as the underlying or contributing cause of death. Of these, 28 (1.9%) were 15–44 years old; 1,370 (95.3%) were males; and 1,236 (86.0%) were white.

Researchers found the overall age-adjusted silicosis death rate for African-Americans (0.87 per 1 million; where silicosis was the primary cause of death) significantly higher than the rate for whites (0.59 per 1 million) and other races (0.16 per 1 million). They found the age-adjusted silicosis death rate for males (1.39 per 1 million) significantly higher than the rate for females (0.05 per 1 million) [CDC 2015c; Mazurek and Weissman 2015]. These estimates show a decline in the total number of deaths with silicosis as underlying or contributing cause as shown entered on death certificates, seen

in Figure 3. Trends in all death rates, including the total number of silicosis-related deaths, continue to fall [CDC 2017].

Figure 3. Silicosis: Number of deaths, crude and age-adjusted death rates, U.S. residents age 15 and over, 1968–2014. (Number of Silicosis deaths, 1968–2014)



Recent contributions to the Centers for Disease Control and Prevention’s (CDC) *Morbidity and Mortality Weekly Report* (MMWR), prepared by NIOSH researchers, report great progress in this area, but silicosis deaths still occur. Silicosis deaths in young adults (aged 15–44 years) are of particular concern, with reports of 55 deaths such deaths during 1999 through 2015 [CDC 2017; Mazurek and Attfield 2008]. These deaths among younger adults likely reflect higher exposures than for deaths among older persons.

To identify an industry and occupation for these young adult decedents, NIOSH researchers translated text entries on each death certificate into North American Industry Classification System (NAICS) and 2010 Standard Occupational Classification codes (SOC) codes using the NIOSH Industry and Occupation Computerized Coding System (NIOCCS). They also reviewed causes of death. With the help of state offices of vital records, during 2015 through 2016, NIOSH researchers requested death certificates from 22 states for 48 young (aged 15 through 44 years) decedents reported for 1999

through 2013 who had pneumoconiosis due to dust containing silica (ICD-10 code J62) assigned as the underlying or contributing cause of death. Seven additional deaths among young adults with the same cause of death code were identified in the National Center for Health Statistics (NCHS) multiple cause-of-death data for 2014 through 2015 (when the new data became available) [CDC 2017].

Based on the records reviewed, the study found during 1999 through 2015, among the 55 decedents, 38 (69%) were assigned pneumoconiosis due to other dust containing silica and 17 (31%) were assigned pneumoconiosis due to talc dust. Thirty-four percent of decedents with pneumoconiosis due to other dust containing silica listed manufacturing or construction industry as the occupation on their death certificates. Among 17 decedents with pneumoconiosis due to talc dust, 13 (76%) involved multiple drug use or drug overdose and none worked in talc exposure-associated jobs.

Intermediate Outcome:

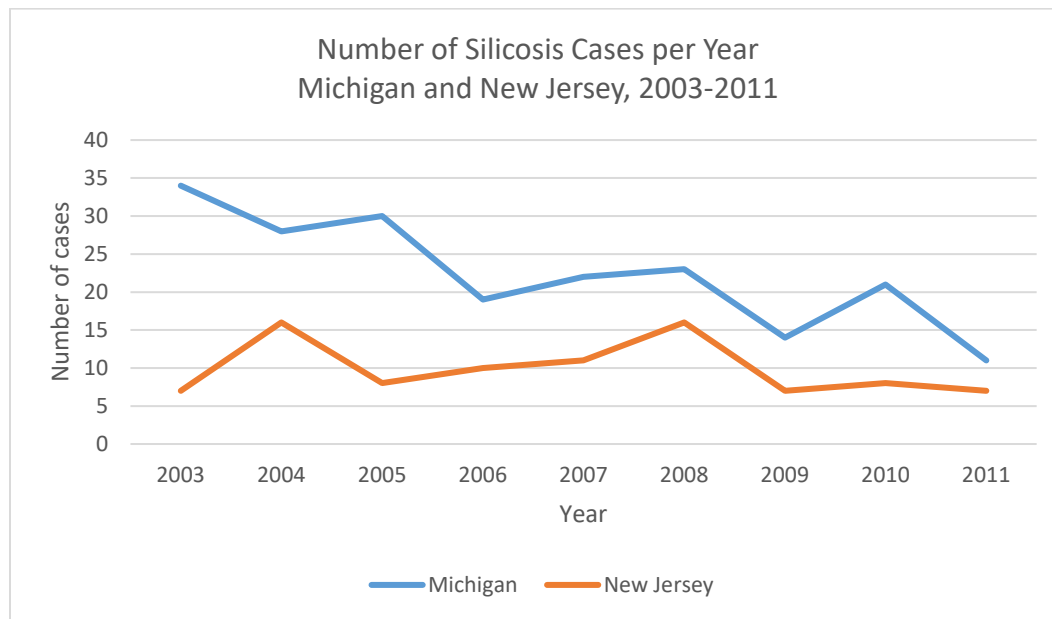
- ❖ Researchers used NIOSH surveillance data on silicosis mortality to support the new [2016 OSHA Silica Standard](#) for the construction industry, cited by OSHA [OSHA 2016c].

State-based Surveillance for Silicosis

NIOSH began state-based surveillance of sentinel events to help with diagnosis and tracking of silicosis and other diseases. Through partnerships with two state-level silicosis surveillance programs within New Jersey and Michigan, NIOSH received sentinel case-based data. Hospital and emergency departments provided the discharge data for identifying and tracking silicosis cases within these two states (See Table 2015-843, Work-Related Lung Disease [eWoRLD] Surveillance System). During 2003 through 2011, Michigan and New Jersey identified and confirmed 292 cases; 28 (9.6%) of the patients had fewer than 10 years of potential exposure to silica dust; and 57 (19.5%) patient identified working in construction (Figure 4) [CDC 2016]. The data collected from NIOSH-funded states support intramural and extramural research for silica-related prevention activities and science-based policy [CDC 2016].

Figure 4. Number of silicosis cases by year—Michigan and New Jersey, 2003–2011.

* N = 292 (Michigan: 202; New Jersey: 90)



A long collaborating relationship exists between NIOSH researchers and silica researchers from New Jersey. The collaborators named the partnership the New Jersey Silica Partnership, changing the name later to the New Jersey Silica Outreach and Research (SOAR) Alliance. Collaboration with the SOAR Alliance consisted of employers, government agencies, and industry and labor organizations working together to prevent silicosis. Much of the interaction concerned surveillance of occupations for New Jersey silicosis cases. The SOAR Alliance assisted CPWR with the development and testing of the [Work Safely with Silica](#) website (described later in this chapter), which provides guidance to construction contractors, workers, and safety professionals.

Intermediate Outcome:

- ❖ The manuscript, *Surveillance for Silicosis—Michigan and New Jersey, 2003–2011*, was published in October 2016 [CDC 2016], and it received 498 views and 49 page downloads as of January 23, 2018.

Silica Exposure and Chronic Obstructive Pulmonary Disease (COPD) Risk

Occupational exposures to silica and other dusts, vapors, gases, and fumes increase chronic obstructive pulmonary disease (COPD) risk. Dement and colleagues at Duke University conducted a CPWR-funded study to estimate the risk of COPD attributable to occupational exposures among construction workers [Dement et al. 2015]. The study

population included 834 cases and 1,243 controls participating in a national medical screening program for older construction workers during 1997 through 2013. Researchers developed qualitative exposure indices based on lifetime work and exposure histories. They found approximately 18% of COPD risk attributable to construction-related exposures, and these are additive to the risk contributed by smoking. Along with a variety of other exposures, researchers found the cumulative exposure indices for silica significantly associated with the risk of COPD. A measure of all exposures combined was a strong predictor of COPD risk. The study found construction workers at increased risk of COPD because of broad and complex effects of many exposures acting independently and interactively. The study concluded that the implementation of control methods would prevent worker exposures, as would the promotion of smoking cessation programs.

Compounding Risks for Lung Disease

Compounding the occupational respiratory health risk of RCS exposure, construction workers have among the highest rates of current smoking (40%) of any occupational group; nearly double that of the general U.S. population (22%). NIOSH-funded researchers, therefore, evaluated the effectiveness of an integrated respiratory health intervention in reducing exposures to silica dust and reducing smoking prevalence as compared with a usual case-control condition [Sorensen et al. 2011]. Using this integrated method, researchers evaluated changes in silica and other dust exposure and smoking prevalence. They then developed feasible, valid, and reliable methods for contractors to conduct on-going assessment and control of silica and other dust hazards including a smoking cessation intervention delivered to construction workers on their jobsites; an approach not tested in prior studies. The model developed in this study indicated that integrated approaches to worker health could positively impact worker health outcomes and provide a valuable tool for future research [Sorensen et al. 2016].

Due to the importance of risk factors at and away from work, NIOSH researchers assisted a heavy-construction company in establishing a respiratory disease prevention program. The program used periodic spirometry and questionnaires to develop individualized interventions addressing all risk factors. This study found a need for respiratory disease prevention actions in this heavy-construction industry workforce [Hnizdo et al. 2011].

Sampling, Analytical Methods, and Instrument Development

NIOSH published the first edition of its NIOSH Manual of Analytical Methods (NMAM) in 1975 [NIOSH 1975], which researchers and industrial hygienists continue to use as a foundation for their practice in the protection of workers from occupational hazards and exposures. NMAM, updated periodically, released the [fifth edition](#) in 2016. Reliable exposure assessment methods enable the effective anticipation, recognition, and evaluation of workplace hazards to better control those hazards. NIOSH and its partners conducted extensive research in the area of assessment to ensure the availability of accurate methods for measuring RCS at very low levels. Helping employers comply with OSHA's PELs drives NIOSH analytical methods research. OSHA's anticipated silica rule sparked NIOSH construction research efforts to improve RCS sampling and analysis as outlined next.

Intermediate Outcome:

- ❖ Citations of NIOSH methods for RCS support the new OSHA PEL for RCS to increase protection of exposed workers [OSHA 2016c].

NIOSH Manual of Analytical Methods Numbers 7603 and 7500

NIOSH construction researchers developed an improved version of the NIOSH 7603 air sampling method (quartz in respirable coal mine dust) that detects a much lower limit of quantitation—near five μg per sample [Farcas et al. 2016; Lee et al. 2013]. This new version, NMAM method 7603, allows industrial hygienists to use current standard equipment and methods to determine respirable quartz exposures at a lower level than in the past. The industrial hygiene analytical laboratory community can adopt the new method and routinely apply it to occupational dust samples in the construction industry. The net result showed a reduction of workers' exposure to RCS at the American Conference of Governmental Industrial Hygienists' Threshold Limit Value (ACGIH TLV) and the new OSHA PEL [Lee et al. 2013].

During the development of NIOSH NMAM 7500 (crystalline silica by x-ray diffraction), NIOSH researchers assessed the inter-laboratory analytical variability down to a limit of quantification of 50 μg on-filter, based on the exposure limits at that time, and found it to be acceptable. (The limit of quantification is the smallest amount of analyte that researchers can measure with precision.)

Intermediate Outcome:

- ❖ The Mining Safety and Health Administration (MSHA) and OSHA cited NIOSH Method 7500 and related NIOSH research in their revised methods for measuring silica and cristobalite [MSHA 2013; OSHA 2016b].

[ASTM Technical Symposium in 2012](#)

A 2012 ASTM technical symposium, chaired by NIOSH construction researchers, provided an important opportunity to discuss air sampling and methods for measurement of silica and associated respirable mineral particles [ASTM 2014]. ASTM International Committee D22 on Air Quality and Subcommittee D22.04 on Workplace Air Quality sponsored the technical symposium. Topics addressed in the symposium included: exposure levels, bulk materials, analysis, sampler differences, measurement precision, high flow rate samplers, and laboratory proficiency. The scientific research presented there concluded that analytical techniques employing appropriate calibration and quality control accurately measure RCS. Conference proceedings from the symposium address different technical sampling and analysis issues related to supporting a lower OSHA PEL for RCS. A variety of air sampling and analysis methods for determining workers' exposures to RCS have been published by NIOSH, OSHA, and MSHA [ISO 2009; ISO 2015a; ISO 2015b; ISO 2017]. Following the symposium, agency representatives discussed how the methods compare and the best way to make an informed decision on which RCS method should be used, and the quality assurance procedures that should be employed to obtain accurate results.

The [ASTM document](#) published selected technical information on sampling and analytical methods used by OSHA and others, supporting the development of the OSHA silica rule. The studies addressed the technical feasibility for measurement of RCS, validating the precision and accuracy of data at the exposure limit through new high-volume samplers, National Institute of Standards and Technology calibration standards, and consistent analytical protocols [ASTM 2014].

Intermediate Outcome:

- ❖ NIOSH's ongoing work with ASTM and the International Organization for Standardization (ISO) resulted in numerous publications (in the conference proceedings) supporting both voluntary consensus and OSHA regulatory

standard development activities. For instance, the International Organization for Standardization (ISO) 24095:2009, [Workplace air—Guidance for the measurement of respirable crystalline silica](#), cited NIOSH air-sampling research [ISO 2009].

International Partnerships for Silica

The World Health Organization (WHO) initiated a project in 2005 focused on the eradication of silicosis in countries that currently have no worker protection. During 2005 through 2009, NIOSH construction researchers initiated relationships with occupational safety managers in South America and Africa and provided on-site facilities consultation and laboratory training for their technical personnel.

Intermediate Outcomes:

- ❖ These efforts led to the establishment of laboratories in Chile and Zambia—countries now active in providing exposure assessment data in support of evidence-based measures to protect respiratory health of workers in the dusty trades. NIOSH and other organizations helped Chile establish its National Program to Eliminate Silicosis by starting a regional silica analytic laboratory, assessing silica-related risks in workplaces, and giving trainings in reading x-rays, testing lung function, and assessing workplace risks [Galloway 2007].
- ❖ The Health and Safety Executive in the United Kingdom published a literature review on hazardous dust control that highlights a significant amount of NIOSH research related to controlling worker exposures to silica [HSE 2012].

Engineering Controls Work Group

Advances in the availability of engineering controls for RCS exposure came about, at least in part, due to relationships between researchers and the manufacturing sector. In 1994, the CPWR-NIOSH Engineering Controls Work Group (formerly the Engineering and Work Practice Controls Work Group), a group of researchers, contractors, labor organizations, and government workers began meeting regularly with the goal of encouraging advances in engineering control research and research-to-practice (r2p) for the construction industry. The work group serves as a forum for government, academic, and industry representatives to share information on control technology research. Initially, the work group focused on identifying needed research and how to get it done;

however, the work group now collaborates with CPWR's r2p staff to get the control technology into practice on construction jobsites. Engineering controls for RCS has been an important priority for the work group. Thus, NIOSH construction researchers and their partners have investigated and developed engineering controls for RCS.

Enclosed Tractor Cabs

Environmental cab enclosures on heavy equipment protect the operators. NIOSH researchers began a group of studies incorporating aerosol test methods (air filtration efficiency, leak identification) to evaluate all phases of cab manufacture and design, auditing, and routine maintenance. Particulate filter efficiency testing and aerosol particle counting methods identified weaknesses in the respiratory protection and the applicability of performance audits during routine maintenance. The researchers found that by increasing filtration efficiency and minimizing air leakage into the cabin using pressurization improves cab design. The work done in this area applies to both newly manufactured equipment and potential retrofits [Organiscak and Cecala 2009; NIOSH 2008d, 2009a].

Intermediate Outcome:

- ❖ Table 1 of the OSHA RCS rule incorporates the findings from this NIOSH research [OSHA 2016a]. The OSHA standard helped to ensure that cabs used near silica include features (such as filtration and pressurization) that significantly improve operator protections. Earlier work in this area had been included in an American Society of Agricultural Engineers standard for tractor cabs that influenced multiple industries including agriculture, mining, and construction [ASAE 1997].

Wet Methods for Crushing and Abrasive Blasting

CPWR consortium researchers at the University of Massachusetts, Lowell, found construction workers exposed to RCS levels above the existing NIOSH REL or the new OSHA PEL of 50 ug/m³ during demolition and crushing operations. The use of crushing machines on construction demolition sites is increasing due to greater debris disposal costs and available Leadership in Energy and Environmental Design (LEED) credits for on-site debris recycling. The findings raised awareness of the need for control measures to reduce the risk of exposures to workers. The study found that spray misting systems installed on crushing machines and conveyors reduced RCS exposures more effectively

than area application with a water cannon. In addition to reducing occupational and environmental exposures on demolition sites, water-based dust suppression methods can also reduce the peak exposures of workers near exposure sources [Shepherd and Woskie 2010].

Findings by CPWR-funded researchers at the University of Iowa supported the use of water-based suppression methods through their evaluation of a water induction nozzle (WIN) (manufactured by Boride Products). For a WIN nozzle, adding water to the abrasive-air mixture suppresses dust during abrasive blasting. Field tests demonstrated that the wet abrasive blasting device resulted in lowered RCS dust levels when compared to exposure data reported in the literature [Old and Heitbrink 2007]. The study recommended that controlled laboratory testing be done to quantify the effectiveness of the water induction nozzle in suppressing dust, separate from the dust control provided by the use of abrasive sand with fine particles removed [Golla and Heitbrink 2004; Old and Heitbrink 2007]. A follow-on study, funded by CPWR, looked at additional water-based suppression methods involving five commercially available products. The study found these technologies reduced concentrations of respirable dust and RCS by a factor of four to seven times [CPWR 2007].

Concrete Drilling

Drilling into concrete is a physically demanding task associated with exposures to hand vibration, noise, silica dust, and high forces to the upper body and back. These exposures are associated with musculoskeletal disorders, hearing loss, and silicosis [Flanagan et al. 2006; Flynn and Susi 2003; Linch 2002; Shepherd et al. 2008]. Workers commonly drill holes into concrete to place anchor bolts in new construction, for setting rebar for retrofitting and seismic upgrades, and to transfer loads across joints in concrete pavement (dowel drilling). Many trades, but especially laborers, brick and cement masons, and carpenters do drilling into concrete or stone. In a series of studies, NIOSH and CPWR researched the various types and aspects of drilling, described next.

Overhead and Horizontal Drilling

CPWR consortium researchers developed a drill rig to reduce musculoskeletal strain and RCS exposures from overhead drilling [Cooper et al. 2012]. The rig offers a safe alternative for drilling overhead into concrete, and the researchers sought feedback from workers across the electrical, plumbing, and sheet metal trades while developing

the device. Using the same technology, the researchers also developed an inverted drill rig so that it could be sold commercially (i.e., the drill press). The inverted rig is attachable to a shroud and dust collection system, which reduced RCS exposures to concentrations to below the NIOSH REL. This effort eventually led to evaluating interventions for lateral drilling into concrete for highways and bridges, which began in 2009. The researchers worked with manufacturers to make the lateral drill rig available commercially. The Musculoskeletal Disorders and Vibration chapter (page 93) also describes this research.

Intermediate Outcome:

- ❖ A U.S. manufacturer, Telpro Inc., produces the [DrillRite™ Overhead Concrete Drill Press](#), a commercial version of the overhead drill rig produced by CPWR research.

Highway, bridge, and building foundation work frequently calls for extensive horizontal drilling to insert dowel bars. CPWR Consortium researchers designed a horizontal drill rig to reduce ergonomic injuries among workers engaged in the heavy task. Researchers also added a dust control device to the new tool. CPWR continued testing the drill's efficacy in reducing workers' RCS exposure, assessing exposures both with and without a dust shroud and vacuum system for dust capture [Cooper et al. 2012]. The drill rig alone, presumably by distancing the worker from the surface, reduced RCS exposure by 55% over conventional pneumatic drilling. However, this level was still six times over the NIOSH recommended exposure limit, so use of a respirator was still necessary. After CPWR researchers outfitted the rig with a shroud and vacuum for dust control, there was a reduction of the operator's exposure to RCS by 94%, to a level below the NIOSH REL.

Intermediate Outcome:

- ❖ A U.S. manufacturer, Ergomek Inc., produces a commercial version of the jig called the [DrillBoss](#) [CPWR 2017a].

Test Bench System and Bit Wear

CPWR consortium researchers at the University of California, Berkeley, built a test bench system designed for concrete hammer drills to evaluate the exposures to RCS, handle

vibration, and handle force. Researchers evaluated hammer drills, bits, dust capture systems, and drilling methods (applied force). The system automatically advanced a drill into concrete blocks while recording potential exposures, allowing for standardized data collection over multiple trials. The test bench system that was developed was different from the system in an existing ISO standard because the ISO standard called for the drilling to occur in a downward direction. [ISO 2011; Rempel et al. 2016].

Drilling into concrete with carbide-tipped bits using a hammer drill is a physically demanding task performed in commercial construction for setting anchors and installing rebar for structural upgrades. Bit wear can decrease productivity (rate of penetration) and increase drill handle vibration, noise, and dust exposure to workers. Carty, building on the earlier CPWR consortium work by Rempel, evaluated the effects of bit wear on RCS, noise, and drilling productivity [Carty et al. 2017]. Researchers wore test bits by drilling holes to different depths. For each trial, an automated test bench system drilled 41 holes into concrete blocks using commercial hammer drills and masonry bits. Increasing bit wear was associated with increasing RCS and noise exposures, as well as reduced drilling productivity. The dull bits generated RCS levels 80% to 114% higher than the sharp bits. The levels of dust and noise produced by these experimental conditions would require dust capture, hearing protection, and possibly respiratory protection. The researchers recommended that construction contractors develop and implement bit replacement programs to improve productivity and reduce potential exposures to noise, vibration, dust, and RCS.

CPWR developed an IMPACT card related to overhead drilling, [*Reducing the Pain and Fatigue of Overhead Drilling*](#), based upon the research discussed previously. IMPACT cards provide brief case studies of completed research projects and how the findings are helping to reduce construction illnesses and injuries.

[*Dowel Drilling*](#)

Workers use local exhaust ventilation (LEV) in concrete dowel drilling operations. Dowel drilling machines (also known as gang drills or dowel-pin drills) drill horizontal holes in concrete pavement (Figure 5), during, for example, new concrete airport runway and highway construction or during full-depth repair of concrete runways and highways to provide load transfer across transverse pavement joints. NIOSH worked with machine manufacturers ([Minnich Manufacturing](#) and [EZ Drill Inc.](#)) and evaluated LEV controls to

reduce worker exposure to hazardous dust during dowel drilling operations. The authors found dust controls reduced concentrations by as much as 90% under controlled conditions but that work practices and maintenance issues adversely affected results [Echt and Mead 2016; Echt et al. 2015]. Both manufacturers discussed dust control options and OSHA compliance on their websites.

Figure 5. Worker performing dowel drilling on a concrete slab.



Concrete Grinding and Polishing

Concrete surface grinding also exposes workers to unacceptable levels of airborne crystalline silica dust. The effectiveness of existing dust control methods and major confounding factors influencing the exposure levels of silica dust were examined by simulating field concrete surface grinding in a laboratory. Akbar-Khanzadeh and his colleagues at the University of Toledo monitored personal air during concrete grinding sessions ranging from five to 90 minutes with approximately 80% grinding and 20% rest time per session. A variety of grinders, diamond grinding cups, and accessories were used on concrete slabs containing $24 \pm 9\%$ crystalline silica. Dust control methods included general ventilation, three types of LEV, and wet-grinding compared with conventional uncontrolled concrete grinding [Akbar-Khanzadeh et al. 2007].

Researchers obtained mean concentrations of silica dust (mg/m^3) by personal monitoring during LEV-, wet-, and uncontrolled grinding. They found levels of silica dust

and RCS significantly lower for smaller grinding cup sizes versus larger. Three factors that did not result in significantly different levels: (1) orientation of grinding surfaces; (2) water flow rates for wet-grinding; or (3) task-specific sampling periods. None of the control methods lowered the 8-hour TWA exposure levels of silica dust to below the ACGIH TLV or the new OSHA PEL, requiring further refinement in engineering control and the use of administrative control or respirator.

Akbar-Khanzadeh and his colleagues found the best conditions for effectively controlling exposure to silica dust and RCS during concrete surface grinding:

- ❖ Using a small grinding cup (4 to 5 inch diameter)
- ❖ Selecting a small (4.5 to 6 and his colleaguesinch diameter) grinder that is either manufactured as a shrouded concrete grinder or is an angle grinder retrofitted with the durable urethane dust shroud
- ❖ Attaching the grinder to the high efficiency particulate air (HEPA) tank or cyclone vacuum
- ❖ Providing a well-ventilated workspace [Akbar-Khanzadeh et al. 2010]

Most walk-behind concrete floor polishers come equipped with local exhaust ventilation or water suppression systems. In 2010, the Operative Plasterers' and Cement Masons' International Association (OPCMIA) and the Association of Equipment Manufacturers (AEM) requested that NIOSH conduct an evaluation of the exposures and controls associated with walk-behind tools used in concrete grinding and polishing operations in response to increased demand for polished concrete floors in residential, commercial, and industrial construction. NIOSH researchers evaluated engineering controls for RCS exposure during concrete polishing operations. Researchers conducted seven field surveys where they studied eight different concrete polishers (including Husqvarna, Prep-Master, HTC, and CPS) and vacuum system combinations (including Pullman Ermator, HTC, and SASE). Of the eight evaluated concrete polishers, six kept exposures below the NIOSH REL of $50 \mu\text{g}/\text{m}^3$ ($0.05 \text{ mg}/\text{m}^3$) while two were consistently above the NIOSH REL. The planetary concrete polishers seem to perform considerably better than the orbital machines in keeping worker exposures below the NIOSH REL [NIOSH 2015b, d]. The study found some equipment more efficient than others at RCS control, directing the way to better worker protection [NIOSH 2015b].

Grinding and Polishing of Stone Countertops

In 2012, an outbreak of silicosis in Israel identified 25 patients who shared an exposure history of working with engineered quartz stone countertops without dust control or respiratory protection [Kramer et al. 2012]. This revelation identified RCS exposure during stone countertop fabrication and installation as an emerging issue. Stone countertop products can contain >90% crystalline silica, and working with this material during fabrication and installation causes excessive exposures to RCS.

The dissemination efforts from NIOSH's state partners led to the identification of the first engineered stone countertop silicosis case in the U.S. [CDC 2015a]. In March 2014, NIOSH construction partners from New Jersey, Michigan, and California, with help from NIOSH staff, posted information about the silica hazards from engineered stone countertops on the [NIOSH Science Blog](#) [Worthington et al. 2014]. An [OSHA/NIOSH Hazard Alert](#) on this topic was also developed, and state partners conducted a significant amount of [outreach](#) [Kamery 2015; OSHA/NIOSH 2015].

Intermediate Outcome:

- ❖ In April 2014, a Texas physician read the blog and responded about a documented case of severe complicated silicosis in a 36-year old worker who was a polisher, fabricator, and cutter of engineered stone countertops. To increase awareness of this emerging issue, the Texas physician co-authored a case report published in a 2015 [MMWR Notes from the Field](#) article [CDC 2015a].

The Texas Department of State Health Services requested that NIOSH perform a [Health Hazard Evaluation](#) (HHE) at a natural stone countertops manufacturer [NIOSH 2016d] because a worker diagnosed with silicosis worked there, performing polishing, laminating, and fabricating. The NIOSH researchers performed air sampling, reviewed spirometry tests, and found overexposures to RCS for workers using pneumatic wet grinders. The researchers recommended engineering controls and the implementation of a medical surveillance program at the facility. CPWR also posted information on the [Work Safely with Silica](#) website. State partners took action by disseminating information about exposure to quartz surfacing materials and the risk for silicosis on their websites.

They informed stone fabrication shops and occupational health practitioners, and spoke at public venues to bring attention to this new source of silica exposure.

Beginning in 2015, partners from New Jersey collaborated with NIOSH construction engineers on a research project on engineering controls. Collaboration between NIOSH researchers and the stone countertop company where the case was initially identified continues [Johnson et al. 2017]. NIOSH researchers also conducted field studies in several other workplaces to measure the effectiveness of wet grinding and polishing in reducing worker exposures. Data collected to date show that existing engineering controls may not sufficiently protect workers' health. These investigations are ongoing [NIOSH 2015a].

Intermediate Outcome:

- ❖ Trade associations such as the Natural Stone Institute now produce [training resources](#) to assist employers in the stone countertop industry in protecting their workers [Natural Stone Institute 2018].

Cutting Masonry Materials (tuckpointing and cutting)

As brick buildings age, the mortar between the bricks falls apart; replacing this mortar prevents water intrusion. Before replacing the mortar, a grinder removes ½ to ¾ inch of the old mortar. The grinder breaks up the mortar, and the mortar turns into airborne dust containing RCS. The crystalline silica dust released during tuckpointing operations is difficult to control. Workers performing tuckpointing experience some of the highest measured construction exposures to RCS, and the clouds of mortar dust make it difficult for them to see the work surface.

Using grinders to remove brick mortar results in worker exposure to RCS that may be 2 to 1,500 times above the NIOSH REL and the new OSHA PEL of 50 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) [OSHA 2013b]. Researchers found that application of local exhaust ventilation with tuckpointing grinders can improve both the health and the safety of these workers. NIOSH construction researchers are also investigating dust controls for RCS exposures for other tools used to remove mortar.

A 2009 CPWR study evaluated the performance of commercially available engineering controls used in dusty construction tasks commonly performed by masonry workers.

Researchers examined LEV controls for a portable abrasive cutter, tuckpointing grinders, and two stationary wet saws at a bricklayers' training center. They collected air samples from personal breathing zones with and without the use of LEV or water suppression during simulated concrete block cutting, brick cutting, and tuckpointing. The study found that the portable LEV unit significantly reduced mean respirable quartz exposures by 96% for block cutting and 91% for brick cutting. Stationary wet saws showed a 91% reduction in exposure. For tuckpointing, the reductions in mean respirable quartz concentrations fell between 91% and 93% with the LEV controls.

In this study, researchers observed reductions of up to 96% in mean respirable quartz concentration between control and no-control scenarios. These reductions with commercially available tools demonstrated the effectiveness of engineering control interventions to reduce crystalline silica exposures in construction. Meeker et al. recommended the need for additional strategies to further improve control performance and approaches for increasing control interventions in construction [Meeker et al. 2009].

Meeker et al. then evaluated a tuckpointing dust control system, in a controlled setting, consisting of a Bosch model 1775E grinder, a Dust Director shroud, and a DustControl 2900c vacuum. Removing mortar with a Bosch grinder without the dust control system resulted in a mean task time-weighted average (TWA) respirable silica exposure 145 times the NIOSH REL of 0.05 mg/m³ for RCS. Use of the same grinder with the dust control system reduced exposures by about 99%; however, exposures measured with the dust control system still exceeded the NIOSH REL [Meeker et al. 2009].

Cooper and Susi at CPWR evaluated a tuckpointing dust-control system used by two workers simultaneously. The system consisted of two Bosch grinders with two Dust Director shrouds attached by duct to a single Ermator S26 vacuum. Researchers conducted randomized trials with and without use of the dust control system in a controlled setting. Removing mortar with the Bosch grinders without the dust control system resulted in a mean task TWA respirable silica exposure 690 times the NIOSH REL. Using the same grinders with the dust control system reduced exposures by approximately 98%. However, exposures measured during the use of the dust control system still exceeded NIOSH REL. Note that the NIOSH REL is based on exposures averaged over a ten-hour workday. The results from this study represent TWAs of the

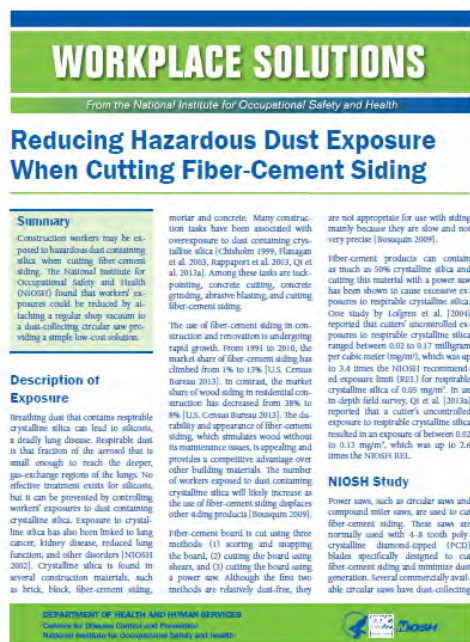
task-based samples [Cooper and Susi 2014]. Based on this research, CPWR developed an IMPACT Card related to tuckpointing: [Research Supports Need, Effectiveness, and Improvements for Engineering Controls](#).

Intermediate Outcome:

- ❖ Case study research demonstrated that at least one major metropolitan city can, in the absence of a Federal regulation, promote the use of engineering controls. Local environmental regulations and major public users in Chicago played a major role in stimulating the early adoption of LEV for tuckpointing [Weinstein et al. 2016].

Fiber cement siding is durable, used in construction and renovation since about 2000. Qi and Echt at NIOSH identified the siding as a source of excessive worker exposure to RCS. Fiber cement products contain as much as 50% crystalline silica so cutting them can put workers at risk of exposure. Researchers found that using simple and low-cost local exhaust ventilation attached to dust-collecting circular saws to be effective in reducing worker exposure [NIOSH 2015f]. The [NIOSH Workplace Solutions](#) publication in Figure 6 presents much of this information.

Figure 6. The NIOSH Workplace Solution publication for cutting fiber cement siding.



Model Silica Specifications

NIOSH construction research has served as a catalyst and as evidence for industry and government to support the use of improved control technology and to create new policies aimed at increasing use of effective engineering controls. A CPWR-NIOSH Engineering Controls Work Group panel, which included researchers, contractors, labor organizations, and government representatives with substantive experience and knowledge of masonry work or engineering controls for silica, developed CPWR's [*Model Silica Specifications for Masonry Grinding, Cutting, and Sawing*](#) [CPWR 2014a]. While designed primarily for protecting workers from occupational exposure to silica, these specifications also provide guidance to those who protect the environment and public from elevated dust levels. Regulators, project managers, building owners, and others can use the language in the specifications to reduce dust generated from construction activities.

Intermediate Outcomes:

- ❖ In 2014, the Philadelphia School District (fifth largest city in the U.S.) used the *Model Silica Specifications for Masonry Grinding, Cutting, and Sawing* in contracts for capital improvement projects for their schools district-wide [CPWR 2014b].
- ❖ Information from the model silica specifications and from the Bricklayers & Allied Craftworkers Local 1 Pennsylvania and Delaware prompted the City of Philadelphia to publish dust control guidance for construction, renovation, and demolition work [City of Philadelphia Department of Public Health 2014].
- ❖ Over 1,200 print copies of the Model Silica Specifications were distributed through requests from organizations and groups such as the NORA Construction Sector Council, Drexel University, the Philadelphia Building Trades Council Safety & Health Committee, the [*Masonry r2p Partnership*](#), and the Mid-Atlantic Safety Council. OSHA Region 3 Compliance Assistance Specialists in 10 area offices and the Eastern PA Chapter of the Associated Builders and Contractors also received PDF copies.

Evaluation of Commercial Vacuum Cleaners for High Exposure Operations

A CPWR-funded laboratory study by Heitbrink at the University of Iowa evaluated how mortar debris generated during tuckpointing affects airflow and pressure losses through four vacuum cleaner filters. Two of the vacuum cleaners used vacuum cleaner bags as a pre-filter while the other two vacuum cleaners used cyclones [Collingwood and Heitbrink 2007; Heitbrink and Santalla-Elias 2009].

To conduct the testing, researchers sucked 35 pounds of mortar removal debris into each vacuum cleaner. Before and after adding each five-pound increment of debris, a venturi meter measured vacuum cleaner airflow; vacuum cleaner static pressures were measured at the inlet to the vacuum cleaner motor, before each filter and after each filter.

Researchers found that the vacuum cleaners equipped with cyclones were unaffected by debris collected in the vacuum cleaner. As debris accumulated in the vacuum cleaners bags, air flow decreased from 80 cfm to approximately 30 cfm due to increased air flow resistance. The researchers concluded that vacuum cleaners equipped with collection bags be used in applications where adequate dust control can be achieved. But where higher airflows are needed, vacuum cleaners should use cyclones in an effort to prevent debris from reaching the vacuum cleaner's final filters [Heitbrink and Santalla-Elias 2009].

Roofing Tiles

During 2003 through 2008, NIOSH construction researchers evaluated RCS exposures and controls from cutting concrete roofing tiles through four Health Hazard Evaluations (HHEs) requested by the United Union of Roofers, Waterproofers, and Allied Workers in Arizona [Hall et al. 2009; Hall et al. 2013]. The union represents members who apply all types of roofing and waterproofing systems, including but not limited to all low-sloped roofing systems (vegetative and solar photovoltaic roofs), structural waterproofing, steep-sloped roofing systems, and air barrier applications. The HHE requests listed silica and noise as potential hazards [NIOSH 2006a, 2008a, b, e].

Workers with over 5 years roofing experience received medical screenings that included a questionnaire, lung function test (spirometry), and a chest x-ray. Most roofers who participated in the medical screening had normal lung function. None of those with

abnormal lung function had moderate or severe impairments. Researchers found that lung function decreased with increasing years of dry cutting concrete tiles, but no workers received a silicosis diagnosis.

Many personal dust samples exceeded the OSHA PEL of 50 mg/m³ for particulates not otherwise regulated. Personal RCS results exceeded the NIOSH and ACGIH limits; one exceeded the old OSHA PEL in force at the time. Construction researchers found that an occupational health hazard from RCS exposures existed for employees.

Recommendations for controlling workplace exposures included reducing or eliminating exposures by implementing engineering controls and enforcing the use of PPE under the OSHA respiratory protection standard. Researchers also recommended medical monitoring and developing a training program on the potential health hazards of RCS exposure.

Intermediate Outcome:

- ❖ Most of these companies improved their training programs, workplace conditions and dust control, medical surveillance, and use of personal protective equipment such as respirators based on NIOSH recommendations [Brueck 2018].

Following the HHEs, researchers conducted a series of field and laboratory evaluations to determine whether the engineering controls (i.e., powered saws with LEV or water suppression systems) could reduce respirable dust and RCS exposures to below occupational exposure limits [NIOSH 2006b, c]. Researchers achieved a 99% reduction in respirable dust concentrations using the water suppression system and a 91% reduction for the LEV cutting concrete roofing tiles with a stationary masonry saw. Results suggest that water is an effective method for reducing RCS exposures. Researchers found that water damage potential, surface discolorations, cleanup, slip hazards, and other factors made the use of water problematic in many situations. Employer concerns with implementing a LEV system to control silica dust exposures included the lack of sufficient capture velocity, additional weight of the saw with the LEV system, access to electricity, and the cost of air handling units [Carlo et al. 2010].

Asphalt Milling Machine Partnership

In 2003, NIOSH and stakeholders identified the need to control silica dust exposures during pavement milling in highway construction (Figure 7). A Silica/Asphalt Milling Machine Partnership formed in 2003 to study milling machine dust controls. This partnership included all manufacturers of pavement-milling machines sold in the U.S.

Figure 7. Asphalt milling machines in use during road construction.



During 2004 through 2016, NIOSH engineers published many documents from the milling machine studies of dust control studies:

- Fifteen technical reports [NIOSH 2004, 2007a, 2009b, c, d, 2011a, b, c, 2012, 2013a, b, c, e, 2014]
- Two peer-reviewed journal articles [Hammond et al. 2016]
- A field guide in collaboration with CPWR [CPWR 2015]
- A NIOSH Best Practices document summarizing the successful dust controls and test procedures; for use when evaluating current and future innovations in dust control technology on milling machines [NIOSH 2015e].

In 2013, NIOSH engineers started collaborating with the French Institut National de Recherche et de Securite (INRS), publishing a summary article on milling machine dust controls in a French occupational safety and health journal [Hammond et al. 2015]. In

2017, researchers from the INRS contacted NIOSH engineers about starting a working group to introduce the 2015 NIOSH Best Practice test procedures into the ISO/AWI 20500-1–[Mobile road construction machinery – Safety](#), similar to a recent international collaboration with the NIOSH asphalt fume engineering control research [ISO/AWI].

NIOSH and partner research showed personal breathing zone air samples all below the NIOSH REL of 0.05 mg/m³ for RCS. The results ranged from below the limit of detection up to 0.024 mg/m³ for the milling machines with well-designed dust controls. NIOSH researchers wrote a NIOSH Science Blog article on this topic in 2015 as the research wrapped up: [The Silica/Asphalt Milling Machine Partnership – All Good Things Need Not Come to an End](#).

Intermediate Outcomes:

- ❖ In 2016, NIOSH engineers collaborated with the INRS to translate the NIOSH 2015 Best Practices document into French so that INRS researchers could use the test procedures to evaluate the effectiveness of dust controls installed on milling machines in Europe [NIOSH 2015e].
- ❖ Because of this research, all U.S. and foreign manufacturers of heavy-construction equipment that sell pavement-milling machines to the U.S. market agreed to put NIOSH evaluated silica dust controls on all new milling machines. The average life of a milling machine is five to 10 years. Therefore, the outcome of this highway construction research is that new silica dust controls will be on at least 50% of milling machines in the U.S. by 2021 and nearly 100% of U.S. machines by 2026. This will affect more than 367,000 U.S. workers employed in highway, street, and bridge construction. The silica dust controls reduced average occupational exposures to RCS to levels well below the NIOSH REL of 0.05 mg/m³ [NIOSH 2015e].
- ❖ RAND estimated a reduction of over 7,000 cases of silicosis in asphalt milling over a 45-year period because of this effort, with an economic benefit ranging from \$304 million to \$1.1 billion on an annualized basis [RAND 2017].

Personal Protective Equipment

NIOSH has a long history of evaluating and certifying respirators used for protection from RCS. [Under Title 42, Public Health—Code of Federal Regulations—Part 84](#), NIOSH is the sole authority for respirators used in U.S. workplaces. Workers generally should not use respirators as the primary means of preventing or minimizing exposure to airborne contaminants such as RCS [NIOSH 1996]. There are times, however, during the development of controls or when exposures remain above the REL that respirators are needed. Construction workers typically use particulate filter respirators to protect against dust. There are three styles of particulate respirators in use: quarter masks, half-masks, and full face-pieces. In addition to particulate filter respirators, NIOSH certifies air-line respirators, made specifically for use during abrasive blasting.

In the absence of a comprehensive standard with engineering controls to reduce silica exposures, the New Jersey Administrative District Council of the International Union of Bricklayers and Allied Craftworkers wanted to provide a union-based training and respirator fit-testing (method to determine mask fit) opportunity for their members. The union recognized that many union workers faced exposure to high silica levels but contractors did not provide either engineering controls or adequate respiratory protection. NIOSH and CPWR provided early consultation to the Bricklayers before they began developing the training program.

Intermediate Outcome:

- ❖ Subsequently, the union piloted a training and respirator fit-testing for their members [Betit 2018]. After a successful pilot test, they provided training, medical evaluation, fit-testing, and respirators to its members. Members received medical evaluations with the assistance of Robert Wood Johnson Medical Center.

Contaminated Clothing

Early studies showed a significant increase in workers' respirable dust exposure from contaminated work clothing [Cecala and Thimons 1986]. The clothes cleaning booth system developed by NIOSH in the early 2000s is an effective technique to clean dust-laden work clothing periodically during the workday to minimize workers' exposure to RCS and other contaminants. The system uses a compressed air nozzle manifold to blow

dust and contaminants from a worker's clothing in an enclosed booth [Cecala et al. 2007, Cecala et al. 2008]. The cleaning booth safely captures and removes the dust and contaminants from the worker's clothing, preventing further exposure of the worker, co-workers, and the work environment.

Intermediate Outcome:

- ❖ Cleaning booths are now in use in many different industries around the world, commercially manufactured by several manufacturers including [SK Bowling Inc.](#) and [Mideco](#) [Cecala 2018].

Dissemination Efforts

CPWR's Work Safety with Silica Website

During 2011 and 2012, the CPWR-NIOSH-OSHA research-to-practice (r2p) work group, with support from labor and management industry stakeholders, developed CPWR's website, [Work Safely with Silica](#), (Figure 8). The content of the website reflects CPWR, NIOSH, and other research findings, translated into tools, materials, and other information for target audiences such as workers and contractors who can use the information on jobsites to reduce RCS exposures.

Figure 8. The CPWR Work Safety with Silica website.



CPWR updates the website with new materials and information, which includes a tip sheet for the proper implementation of the engineering controls and worker practices on Table 1 of the standard, and a guide for employers for implementing the medical monitoring requirements of the silica standard, [Medical Monitoring Under The OSHA Silica Standard for The Construction Industry: Guide For Employers](#) [CPWR 2017b]. In March and April 2014, OSHA hosted informal public hearings, giving stakeholders an opportunity to testify to OSHA staff ([Public hearing notice](#)). The testimony cited the website to demonstrate the availability of dust controls and the feasibility of provisions within the standard, including the requirement for written Exposure Control Plans. In the months following the hearings, OSHA provided opportunities for stakeholders to share comments.

Intermediate Outcomes:

- ❖ Stakeholders cited the Work Safely with Silica website (also called sometimes called the “Silica-Safe website” because the url is www.silica-safe.org) contents and planning tools in their testimony to OSHA:

- [Hearing Transcripts—March 31: International Union of Bricklayers and Allied Craftworkers \(BAC\) Testimony OSHA-2010-0034-3585 Tr. 3093-94](#)

Mr. Ward: ... [he] had a contractor that called and [said] . . . I have a problem. It's a 60-year-old company. They're not used to all this stuff. The general contractor said we want your silica control plan in place tomorrow before you go to work. So help us out, Tom. Thanks to [the CPWR online planning tool] . . . it literally took me 15 minutes to customize [a plan] for the contractor . . . We went out and did a job hazard analysis, looked at what they were doing, came up with some ways to control the hazard . . . and found some productivity improvements too. So there—there's tools out there not just for our contractors but for any contractor across the country to come up with a plan, issue it to the general contractor, and share it with the other crafts on the job.

- [BAC comments: OSHA-2010-0034-2329, p. 5](#)

Using tools like CPWR—The Center for Construction Research and Training's Work Safely with Silica website, creating control plans is simple and cost effective for all contractors.

- [**Hearing Transcripts—March 24: CISC Testimony OSHA-2010-0034-3580 Tr. 1302-1303**](#)

Stuart Sessions: *...OSHA participates in the Silica-Safe website. And this website lists a wide variety of construction materials and then lists a wide variety of activities that get performed on these materials that generate silica. And then if you drill down into the website, it tells the person accessing the website how they can control this activity on this silica-containing material, how they can perform it safely.*

- [**Hearing Transcripts – March 27: IUOE Testimony OSHA-2010-0034-3583 Tr. 2368-2369**](#)

Barbara McCabe: *These sources include OSHA, who has a slide presentation, pocket cards, and an e-tool; NIOSH, who has publications that are available by industry, health hazard evaluations, case studies, and work place solutions; CPWR, that has presentations and PowerPoints, videos, toolbox talks, handouts, training materials, and podcasts.*

- [**Silica Final Rule: Federal Register Vol. 81, No. 58 Friday, March 25, 2016 Rules and Regulations, TR. 16800**](#)

... along with BAC and AFL–CIO, pointed to online tools that are available to help users create written exposure control plans, such as the CPWR–Center for Construction Research and Training (CPWR) tool, available free of charge, on the silica-safe.org Web site (Document ID 2329, p. 5; 4204, p. 61; 4223, pp. 80– 81; 4073, Attachment 5a and 5b)...Requiring a written plan maintains consistency with the majority of OSHA substance-specific standards for general industry and construction, such as lead (29 CFR 1910.1025 and 1926.62) and cadmium (29 CFR 1910.1027 and 1926.1127), which require written compliance plans. A requirement for a written exposure control plan is also consistent with Canadian standards. In addition, it is generally consistent with industry practices, as evidence in the record indicates that some employers in general industry and construction are already developing and using written plans. OSHA

concludes that even for small businesses, preparing a written exposure control plan based on identifying and controlling respirable crystalline silica hazards will not be unduly burdensome, because of the widespread availability of tools and guidance from groups such as CPWR and the Canadian government. In addition, OSHA anticipates that industry associations will provide guidance on developing written exposure control plans for respirable crystalline silica.

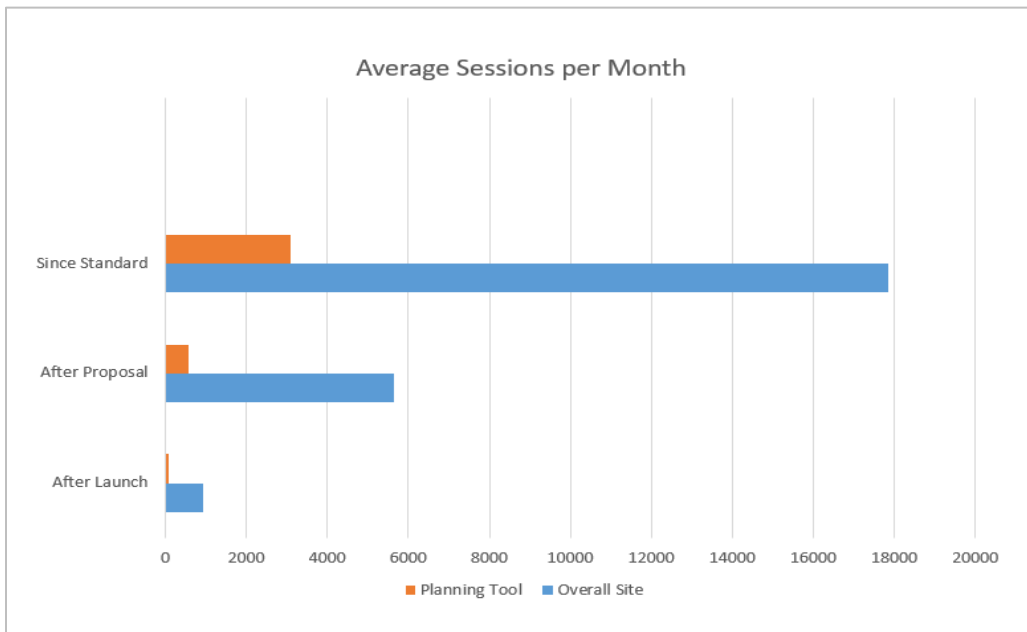
- ❖ From the launch date (November 2012) through the last day of August 2017, users downloaded 31,398 materials (not including CPWR Toolbox Talks or Hazard Alert Cards downloads). In addition to these downloads, thousands of copies of other silica-related materials have been distributed via CPWR websites or distributed in hard copy.

The CPWR Work Safely with Silica website helps employers develop written exposure control plans. Unions, trade associations, and professional groups may offer sample written exposure control plans or other assistance to employers to help to tailor to a particular type of construction work performed [OSHA 2017].

Intermediate Outcomes:

- ❖ Manufacturers and other stakeholders cite CPWR's research and website in marketing materials and as a resource for construction clients, for example:
 - [Bosch](#)
 - [Hilti](#)
 - [International Council of Employers](#)
 - [Sheet Metal and Air Conditioning Contractors' National Association](#)
- ❖ [OSHA's website](#) lists [Silica-Safe.org](#) as a related resource to help with compliance. The website is included in [OSHA's Small Entity Compliance Guide for the Respirable Crystalline Silica Standard for Construction, p. 45](#).
- ❖ Use of the Work Safely with Silica website has increased rapidly since its November 2012 launch. Figure 9 shows data on the average sessions per month at three distinct times: after the website was launched, when the OSHA Silica standard was proposed, and after the standard was disseminated; the last data showing over 15,000 visits per month.

Figure 9. Use of the Work Safely with Silica Website in relation to OSHA rulemaking (November 2012–October 2017).



Hazard Alert Cards

Hazard Alert Cards, which are short pocket brochures, describe common construction hazards and steps that contractors and workers can take to reduce risks and prevent injuries and illnesses. CPWR designed the cards to target construction workers, and employers often hand them out during toolbox talks or training classes. Print copies (43,677) and downloads (2,963) have been available since 2011. The [silica hazard alert card](#) is available in both English and Spanish, accessible at www.cpwr.com or www.silica-safe.org.

Toolbox Talks

Employees working for smaller-sized construction businesses are at greater risk for injuries than those working at larger-sized businesses. Small companies may not have the resources to provide their workers with formal training about on-the-job safety. Many small companies use toolbox talks for their work crews at the worksite to raise worker awareness of potential hazards and preventative measures. Based on NIOSH research, NIOSH and CPWR developed toolbox talks as brief (10 to 20 minute) discussions on safety such as the use of equipment and work practices. The format includes an image illustrating the potential hazard, a description of the hazard and risk, a brief case example, steps to prevent injury or illness, and questions for discussion.

NIOSH researchers use the more effective true narrative case studies in the toolbox talks. CPWR and NIOSH prepared the text and co-branded the documents, and they are available through CPWR's website.

The American Society of Safety Engineers (ASSE) collaborated with CPWR to have the series translated into Spanish. The [silica toolbox talk](#), available in English and Spanish, can be accessed directly on www.cpwr.com; www.silica-safe.org (15,272 downloads since 2012); or through CPWR's electronic Library of Construction Occupational Safety and Health (elcosh.com). Insurance industry representatives added their logo as another level of co-branding with CPWR and NIOSH.

Research Translation Efforts

Collective Bargaining

CPWR is a part of the North America's Building Trades Unions (NABTU). Each of the 14 unions in NABTU have safety and health staff. Through their health and safety offices, CPWR provided the unions with their research findings, as well as findings from NIOSH and NIOSH-sponsored research, as NABTU developed collective bargaining language on the use of dust controls and encouraging new control development.

Intermediate Outcome:

- ❖ In the absence of a comprehensive federal standard, the development of collective bargaining language is an effort to better protect members from silica dust, particularly after the widespread adoption and use of handheld masonry saws and wet/dry diamond blades. Collective bargaining agreements throughout the United States incorporate this language, completely or in part. For example, an excerpt from comments submitted by a member of the International Union of Bricklayers and Allied Craftworkers (BAC) reads
In the absence of a comprehensive federal standard, the International Union of Bricklayers and Allied Craftworkers (BAC) worked at the bargaining table, by supporting federal, state and local legislative and regulatory efforts and through member education to protect our Union brothers and sisters from the dangers of silica. ... many of the Union's affiliates have successfully negotiated language into their collective bargaining agreements promoting the use of engineering controls and work practices to reduce silica exposure. As a result of the collective

bargaining process and the employers' shared interest in the health and safety of their employees, many of BAC's signatory contractors have engaged in heightened safety practices to reduce employee exposure to silica dust. In many areas, particularly in states and localities that have adopted stronger silica protections, and in large metropolitan areas where municipalities, boards and private project owners have put rules in place to reduce workers' and the public's exposure to silica dust, BAC's members and local officers have seen an increase in the use of engineering controls[Boland 2014].

Consensus Standards Activities

NIOSH and CPWR are members of the American National Standards Committee on Standards for Construction and Demolition. As such, they have represented the U.S. on several International Organization for Standardization (ISO) committees. During the second decade of NORA, NIOSH played a significant role in the development of national and international consensus standards related to silica. Many of the contributions were in the areas of air sampling of RCS and control of RCS exposures. Some of the standards NIOSH and its partners contributed to are listed. In most cases, NIOSH staff sat on the consensus standard committee, helped develop the standard, and the standard includes citations to NIOSH research.

Intermediate Outcomes:

RCS Related Consensus Standards

- ❖ ASTM International (formerly the American Society for Testing and Materials)
 - E2625–09 – Standard Practice for Controlling Occupational Exposure to Respirable Crystalline Silica for Construction and Demolition Activities (2009)
 - D4532 – Test Method for Respirable Dust in Workplace Atmospheres (2015)
 - E1132 – Practice for Health Requirements Relating to Occupational Exposure to Respirable Crystalline Silica (2013)
- ❖ American National Standards Institute (ANSI)
 - ANSI /AIHA Z9.2 2012 Fundamentals Governing the Design and Operation of Local Exhaust
- ❖ American Conference of Governmental Industrial Hygienists (ACGIH)
 - Threshold Limit Value (TLV) for crystalline silica is 25 µg/m³ time weighted average (TWA) (2009)

RCS Related Consensus Standards

❖ International Standard Organization (ISO)

- International Standard 24095:2009 “Workplace Air – Measurement of Respirable Crystalline Silica” ISO Technical Committee 146 (Air Quality), Geneva, Switzerland
 - International Standard 19087:2016 “Workplace Air – Measurement of RCS by FTIR” ISO Technical committee 146 (Air Quality), Geneva, Switzerland
 - International Standard 16258-1:2015 (en) “Workplace Air – Analysis of RCS by X-ray diffraction. Part 1: Direct-on-filter method.” ISO Technical Committee 146 (Air Quality), Geneva, Switzerland
-

OSHA Respirable Crystalline Silica Standard

Support of Silica Standard Development

NIOSH supported the Advisory Committee on Construction Safety and Health (ACCSH) recommendation to create a separate silica standard for construction for several reasons: (1) unlike other industries where production conditions are relatively similar day to day, construction conditions change as the building project progresses; (2) work is more temporary in nature and workplaces are shared by multiple employers and trades; and (3) OSHA has a record of successfully tailoring standards for construction with other health hazards such as asbestos, lead, and hexavalent chromium.

In March 2014, when OSHA convened public hearings at the Department of Labor (DOL) for the proposed rule on occupational exposure to RCS, NIOSH and CPWR researchers provided testimony and answered questions in support of the proposed construction standard [OSHA 2013b]. Some of the topics that NIOSH construction researchers addressed were analytical methods for measuring crystalline silica, dust controls, respiratory protection, risk assessment, and medical surveillance and screening.

NIOSH and CPWR construction research on engineering control technologies for grinding concrete, sandblasting, rock drilling, cutting fiber cement siding, tuckpointing, dowel drilling rigs for concrete, using jackhammers and handheld powered chipping tools, occupying enclosed cabs for heavy equipment, and asphalt milling supported the standard and most of these topics are included in Table 1.

NIOSH and CPWR promoted the prevention of silicosis through model partnerships and cooperative agreements with government, industry, labor, and academia. NIOSH methods-research confirmed that techniques to measure the new OSHA PEL are valid, reproducible, attainable with existing technologies, and available to industry and government agencies. The wet methods section of this chapter discusses these techniques (page 45).

Intermediate Outcomes:

- ❖ OSHA published their proposed standard in 2013, *Occupational Exposure to Respirable Crystalline Silica*; Proposed Rule, and their final rule, *Occupational Exposure to Respirable Crystalline Silica*; Final Rule, in 2016. From its conception, OSHA relied on NIOSH research as it considered protective and feasible requirements on the construction industry [OSHA 2013a, 2016c].
- ❖ OSHA published their [Final Rule for Occupational Exposure to Respirable Crystalline Silica](#), including the standard for construction, 29 CFR 1926.1153, and for general industry and maritime, 29 CFR 1910.1053, in March 2016; the rule went into effect June 23, 2016. The OSHA final rule reduces the PEL for RCS to 50 micrograms per cubic meter of air, matching the NIOSH REL. OSHA used NIOSH research in all facets of the rulemaking, including exposure characterization, risk assessment, and controls efficacy.

Engineering controls are part of the new rule, which help to reduce worker exposure. Table 1 includes many controls based upon the extensive silica research of NIOSH and its partners (Figure 2) [Echt and Mead 2016; Echt et al. 2015; Echt et al. 2016; NIOSH 2011c, 2013d, NIOSH 2015a, c, d, f, NIOSH 2016a, c; Qi et al. 2015; Qi et al. 2016].

In the final RCS rule, OSHA proposed specific requirements for laboratories that perform analyses of RCS samples. The rationale is to improve the precision and reduce the variability of results between individual laboratories, increasing sampling reliability. NIOSH research concerning sampling and analytical methods serves as the basis for many of the sampling requirements. OSHA consulted with CPWR to develop a tip sheet to aid compliance, and NIOSH researchers continue to consult with OSHA on silica guidance documents.

- ❖ With engineering controls in place, partially a result from the new OSHA silica standard, several major tool manufacturers now sell grinders and other equipment with integrated dust shrouds. Those manufacturers include, but are not limited to: [Hilti North America](#) (Tulsa, OK), [Bosch Tool Corporation](#) (Mount Prospect, IL), [Makita Corporation of America](#) (La Mirada, CA), and [DeWalt Industrial Tool Co.](#) (Baltimore, MD). Manufacturers now design their tools to meet applicable safety standards (including the OSHA RCS standard). For example, the Underwriters Laboratory mark carried by Robert Bosch and Hilti grinders signifies that their tools meet the requirements of ANSI (American National Standards Institute)/UL/CSA 60745-2-3, which incorporates ANSI B7.1 by reference). Figures 10-13 show webpages from the Hilti, Bosch, Makita, and DeWalt.

Figure 10. The Bosch website with tools that comply with the current OSHA Standard.

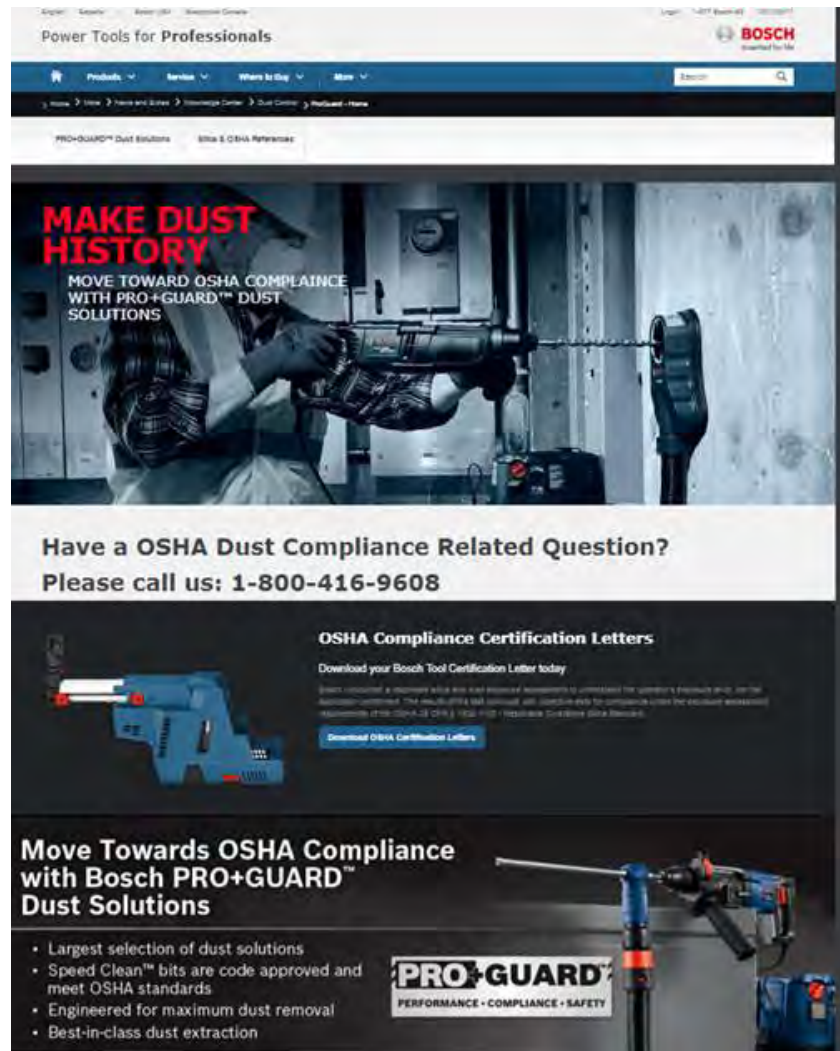


Figure 11. The Makita website with tools that comply with the current OSHA Standard.

OSHA COMPLIANT

COMPLIANT PRODUCTS TO OSHA CRYSTALLINE SILICA RULE 29 CFR 1926.1153

OPTION 1

SPECIFIED EXPOSURE CONTROL METHODS

Employer is required to implement the engineering controls and respiratory protection specified for the tasks on "Table 1" of the OSHA Silica Rule.

OPTION 2

PERFORMANCE (OBJECTIVE DATA) OPTION

Employer may rely on objective data from Makita® providing evidence the exposure level is below the permissible exposure limit when task is performed under the conditions tested by Makita®.

OPTION 1 COMPLIANT

XCVO42
XCVO42 and VC4710 Dust Extractor/Vacuums meet Option 1 Specified Exposure Control Methods when the specified equipment is properly used in accordance with the manufacturer's instruction. See reverse side for details.

OPTION 2 COMPLIANT

XR4011TX
XR4011TX/2094012V2/2094011TX and XCV06Z/22V/PT Dust Extractor/Vacuums meet Option 2 (Objective Data) when used under the conditions tested by Makita®. To see the test procedures, go to makitatools.com/dustmanagement.

XCV06Z

PURSUANT TO OPTION 2, MAKITA HAS PERFORMED TESTING AND PRODUCED OBJECTIVE DATA OF THE APPLICATIONS DETAILED BELOW:

APPLICATION	DUST EXTRACTOR	TESTER TOOL	AIR FLOW (CFM)	APPLICATOR ATTACHMENT	TESTS CONDUCTED
SDS-Plex 5-6 ft bag	XR4011	SD4212	12.3 CFM	5/8" diameter 3.2" depth	Greater than 99%
	XR4011	SD4212	12.3 CFM	5/8" diameter 3.2" depth	Greater than 99%
7" Blasting/ Surface Prep	XR4011	SD4212	12.3 CFM	7" diameter 3.2" depth	Greater than 99%

A SOLUTION FOR ALL YOUR APPLICATIONS
KEY MAKITA DUST ATTACHMENTS LISTED IN OPTION 1 SPECIFIED CONTROL METHODS

DRILLING

CHIPPING/DEMOLITION

SURFACING

CUTTING/TUCK POINTING

makitatools.com/dustmanagement

Figure 12. The DeWalt website with tools that comply with the current OSHA Standard.



DUST SOLUTIONS



ARE YOU COMPLIANT?

The Occupational Safety and Health Administration (OSHA) has issued a final rule to curb lung cancer, silicosis, chronic obstructive pulmonary disease and kidney disease in America's workers by limiting their exposure to respirable crystalline silica. This rule requires engineering controls to keep workers from breathing silica dust.



+



+



TOOLS

Operate and maintain tool in accordance with manufacturer's instructions to minimize dust emissions.

- Read operator's manual provided with tool and accessories.
- To minimize dust emissions use recommended shroud or cowl and dust extractor.

ACCESSORIES AND SHROUDS

Use drill or grinder equipped with commercially available shroud or cowl with dust collection system.

- All DEWALT shrouds and dust collection systems are commercially available.

DUST EXTRACTORS

Dust collector must provide the air flow recommended by the tool manufacturer, or greater, and have a filter with 99% or greater efficiency. Dust collector must have a cyclonic pre-separator or filter-cleaning mechanism. Cleaning/Drilling holes requires a vacuum with a HEPA filter.

- Both DWM10 and DWM12 provide the necessary airflow for drilling and hammering applications.
- Both DWM10 and DWM12 ship with dual HEPA filters, which have an efficiency of 99.97% of all particles greater than or equal to 0.3 microns.
- Both DWM10 and DWM12 have a timed automatic filter-cleaning mechanism.


YOUR FIRST LINE OF DEFENSE.

Figure 13. The Hilti website with tools that comply with the current OSHA Standard.

CUSTOMERS HAVE OPTIONS									
Dust Removal Systems									
Products — Find your tool and accessory below, and then use with any Hilti vacuum. Note that certain solutions have a CFM requirement noted under the tool nomenclature									
Application	Tools with DRS						Dust removal accessory		Universal vacuum cleaners
SDS+ drilling / chiseling	Rotary hammer TE 2	Rotary hammer TE 3-C	Rotary hammer TE 7-C	Comb-hammer TE 30-C	Rotary hammer TE 4-A	Rotary hammer TE 6-A	Cordless combihammer TE 30-A	Hammer drill bit TE-CD	Dust removal system DRS-S
	Item number 3427788	Item number 3553186	Item number 3476284	Item number 3476293	Item number 3482408	Item number 3551238	Item number 3500980	SAFE-ET	Item number 340902
									VC 125 Vacuums
									VC 125-6
SDS-max drilling / chiseling	Rotary hammer TE 4-A	Rotary hammer TE 6-A					Hammer drill bit TE-CD	Dust removal system DRS 4-A	VC 125-9
	Item number 3482408	Item number 3551238					SAFE-ET	(use with TE 4-A)	Item number 2187146
								Item number 2177380	
								Dust removal system DRS 6-A	
Concrete breaking	Comb-hammer TE 50	Comb-hammer TE 60-AVR	Comb-hammer TE 60-ATC	Comb-hammer TE 70	Comb-hammer TE 70-ATC	Comb-hammer TE 80	Hammer drill bit TE-YD	Dust removal system TE DRS-Y	VC 180 X Vacuums
	Item number 3553052	Item number 3554151	Item number 3554152	Item number 3514170	Item number 3514171	Item number 2080438	SAFE-ET	Item number 205718	VC 180-6 X
									Item number 2187146
									VC 180-10 X
Chipping and grinding	Breaker TE 500-AVR	Breaker TE 700-AVR	Breaker TE 800-AVR	Breaker TE 1000-AVR	Breaker TE 1500-AVR		Dust removal system DRS-B		VC 180-10 X
	Item number 3512858	Item number 3484793	Item number 3531084	Item number 3523418	Item number 3455943		Item number 305944		Item number 2187147
									VC 180 XE Vacuums
									VC 180-6 XE
Grinding	Angle grinder AG 450-S	Angle grinder AG 450-D					Cutting hood	Grinding hood	VC 180-6 XE
	Table 1 vacuum requirement: 112.5 cfm	Table 1 vacuum requirement: 112.5 cfm					Item number 2101812	Item number 2102980	Item number 3553060
	Item number 2075613	Item number 2075614							
Grinding	5" Angle grinder AG 500-12D	5" Angle grinder AG 500-11S					Tuck pointing/ cutting	Grinding	VC 180-10 XE
	Table 1 vacuum requirement: 125 cfm	Table 1 vacuum requirement: 125 cfm					Item number 234875	Item number 2102536	Item number 3553061
	Item number 3554553	Item number 3554554							

Silica Standard Compliance Assistance

To help the construction industry better understand and comply with the new OSHA silica standard, nxtMove Corporation, a consultant hired by Hilti North America Inc., approached CPWR to conduct an “OSHA Silica Dust” workshop at Hilti North America’s corporate headquarters in Plano, Texas, on August 23, 2016. The meeting gave construction industry leaders, including 17 general and specialty trade contractors, the chance to learn from OSHA and CPWR about the new construction standard and resources to help with compliance. The meeting gave these stakeholders with a chance to discuss their biggest compliance questions with OSHA, CPWR, and NIOSH researchers.

CPWR and nxtMove, on behalf of the participants, co-authored a white paper, [Understanding the new OSHA standards for Silica dust in the construction industry](#). The paper provides a brief overview of the requirements in the new construction standard as well as responses to key questions and areas of concern raised by participants. These concerns include exposure control methods and medical surveillance requirements. It

also highlights NIOSH and CPWR resources, including the Work Safely with Silica website, and is available in both English and Spanish [CPWR/nxtMove 2017].

Intermediate Outcome:

- ❖ In addition to CPWR's dissemination efforts, Hilti North America distributed the white paper to construction clients nationwide; companies that want to comply with the OSHA silica standard use the paper as a resource [CPWR/nxtMove 2017].

Because of the significant amount of research completed by NIOSH and its partners supporting OSHA's silica rule, NIOSH and CPWR staff conducted numerous silica webinars for the construction industry in 2016 and 2017. These webinars reviewed key provisions in the new standard and shared information and resources available through the [Work Safely with Silica](#) website. The webinars included the availability of research findings, NIOSH Workplace Solutions, and a free planning tool to help contractors comply with the new rule. The webinars also responded to questions and identified related industry research and product needs.

Intermediate Outcomes:

Before OSHA released information on the new silica construction standard, several state and local rules issued used CPWR and NIOSH Silica research as their basis:

- ❖ In September 2008, Cal/OSHA issued the first silica standard for the construction industry: [Control of Employee Exposures from Dust-Generating Operations Conducted on Concrete or Masonry Materials](#) [California 2008; Cal/OSHA 2007, 2018].
- ❖ The [Chicago Department of Public Health](#) issued City Code 11-4-2150-11-4-2190:
To reduce the potential risk of harm to the public's health, safety and welfare or to the environment from releases of dust, debris and other materials occasioned by the demolition, renovation, alteration, repair, cleaning or maintenance of certain types of buildings, facilities or other structures within the City of Chicago Dust generated from any sandblasting, grinding, or chemical washing

operation shall be minimized through the use of dust containment, wetting, vacuum attachments or other such mechanical means as appropriate...

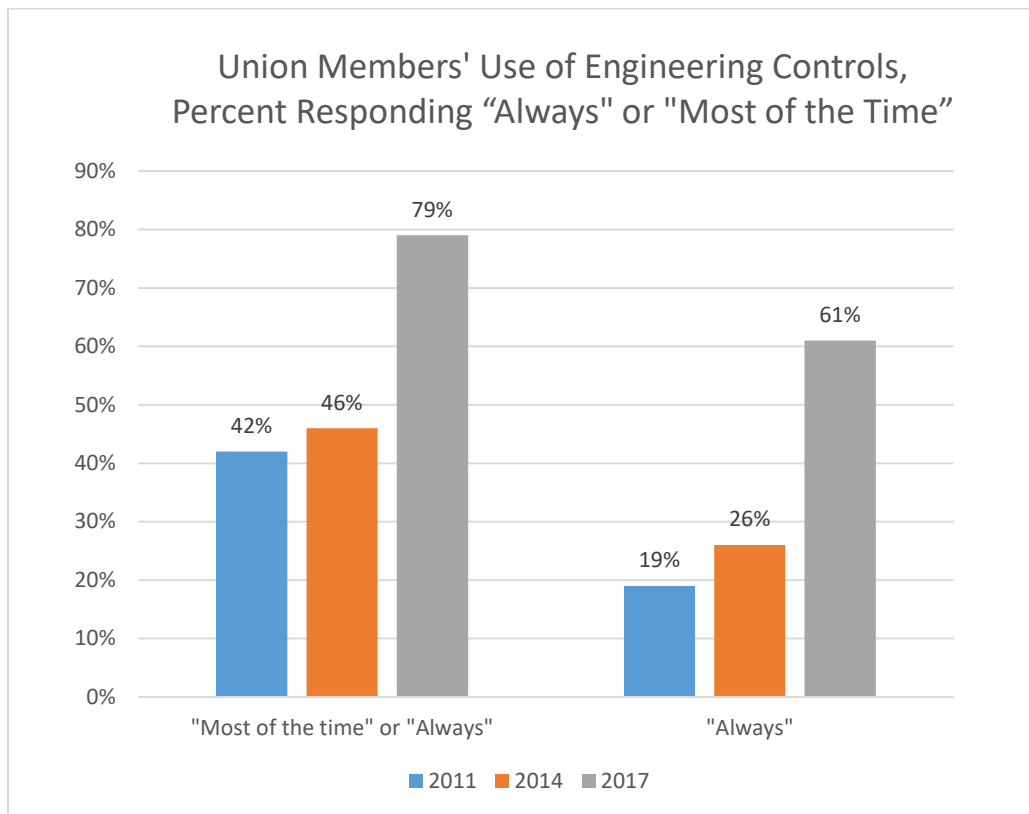
To obtain an Architectural Surface Cleaning Permit in Chicago, a contractor submits, “A written dust minimization-containment plan” [Chicago Department of Public Health 2015; Weinstein et al. 2016].

Masonry r2p Partnership

In 2010, in collaboration with CPWR, the BAC, the International Council of Employers (ICE), and the International Masonry Institute created the [Masonry r2p Partnership](#). The goal of the Partnership is to increase awareness and use of tools, materials, and work practices that have been found to reduce workers’ risk for injury or illness in the masonry industry [CPWR 2017c]. While NIOSH is unable to demonstrate a cause and effect relationship between its research and the end outcome of worker exposure to silica exposure, NIOSH and its funded partners can demonstrate that stakeholders adopt their research. For instance, the Masonry r2p partnership is currently working with NIOSH on tuckpointing, and they were early disseminators of the silica website and planning tool.

The Masonry r2p partnership conducts telephone surveys of BAC union members and union masonry contractors. A third party survey research firm assisted in the development of the surveys, in place since the 1980s. This firm administers the surveys in English and Spanish. The 2017 survey of union members is finished while the contractor survey is underway. For 2017, the union member response rate was 53% (467 union members answered the call and 249 agreed to participate). Historically, in 2011, 214 members participated, and in 2014, 251 participated. The partnership survey data (Figure 14) show an increase (from 19% to 62%) in workers reporting that they “always use” engineering controls for silica-generating tasks.

Figure 14. Survey results showing improved use of engineering controls for silica in 2011, 2014, and 2017.



End Outcomes

OSHA estimates that the new occupational exposure rule will prevent more than 900 new cases of silicosis each year, saving over 600 lives once its effects are fully realized. In OSHA's Final Rule for Occupational Exposure to RCS, the annualized benefits, costs, and net benefits of the Final Rule indicated annualized benefits (number of silica-related cases prevented—morbidity and mortality) of \$8.7 billion [OSHA 2016a]. There has been widespread adoption of new controls on construction equipment, and as employers purchase and employees use this equipment, worker exposures to RCS will lower significantly, reducing the likelihood of new silicosis cases.

Alternative Explanations

When OSHA lowered their PEL from a formula, 0.24 mg/m^3 at 100% quartz, to a much more protective 0.05 mg/m^3 , they reduced the RCS exposure limit in construction almost five-fold. Although much of the technical support for this rule came from NIOSH

and CPWR research, other factors such as the work of our partners in health promotion also played important roles:

- The Laborers' Health and Safety Fund of North America that testified at the OSHA RCS hearings
- The American Conference of Governmental Industrial Hygienists that set an occupational exposure limits for silica
- The American Industrial Hygiene Association that supported OSHA's effort to update the silica rule
- The state health departments that collaborate with NIOSH on silicosis surveillance
- The Hilti company that manufactures tools and equipment used around silica
- The National Asphalt Paving Association that was a key partner in the NIOSH asphalt milling research
- The Masonry r2p partners that collaborated with CPWR and NIOSH on silica research to practice.

Future Plans

The NIOSH Strategic Plan outlines construction and respiratory health priorities for 2019 through 2023. NIOSH activities address a broad range of occupational health and safety hazards affecting construction workers. To decrease silica exposure, reducing the size and weight of continuous personal dust monitors is relevant and essential, as well as developing technology to provide real-time assessment of RCS exposure. Finding ways to demonstrate the effectiveness of other interventions to control exposures is also vital. NIOSH will continue its translation and dissemination research to help construction stakeholders implement requirements of OSHA's new silica rule and advise on collecting objective data. A surveillance need to document exposure reductions related to the OSHA rule also exists. The construction program continues to encourage additional research in these important areas as described next.

NIOSH plans to expand the [National Occupational Mortality Surveillance](#) (NOMS) dataset to allow for specific analyses that will help to identify risks by occupational subgroup (e.g., bricklayers, stonemasons, roofers). The expanded NOMS will also allow for identification for specific groups of workers who may have different or greater

exposures to silica and other agents, such as minority and immigrant workers. This effort, for example, will let us explore risks to female workers in this traditionally male-dominated industry. Data from NOMS are foundational for estimating chronic disease burden for all NORA sectors and several health cross-sectors. Expansion of NOMS will increase the robustness of the chronic disease burden estimates. In addition, because mortality may not occur until years after developing a silica-related disease, there is need for improved surveillance for other important metrics such as RCS exposure and RCS-related morbidity.

Examining the application of various dose-response regression-modeling methods to assess exposure-related risks for RCS-related health outcomes, such as lung cancer, is needed. Researchers plan to apply simulation techniques to assess the performance of various relative rate regression models that specify restricted splines. Researchers used these models in previous assessments of the dose-response association between silica inhalation and lung cancer. When using these models evidence suggests lung cancer development even at low doses of silica inhalation.

NIOSH plans to develop and evaluate field-portable, easy-to-use, and cost-effective sensors (e.g., “lab-on-a-chip” devices) for early detection of biomarkers of exposure in workers exposed to RCS (e.g., at hydraulic fracturing and construction worksites). Sensors for on-site biomonitoring together with aerosol exposure measurements could provide novel approaches for exposure assessment and on-site preclinical screening of worker health effects.

Reducing respirator use for certain types of RCS exposures, for example, during masonry restoration (tuckpointing), is another important area that NIOSH plans to work on. NIOSH research identifying a tool(s) to replace or supplement the use of grinders in tuckpointing would have a significant impact on reducing silica exposures, be useful for those in the masonry construction industry, and could spur tool manufacturers to innovative approaches in this area.

While primary prevention is preferable to secondary or tertiary prevention, they all have important roles. From the standpoint of secondary prevention, new “ultra-low dose” computed tomography (CT) technology, which allows CT scans of the chest using levels of radiation similar to conventional chest x-rays, is now commercially available. NIOSH

plans to evaluate the effectiveness of this technology and develop evidence-based guidelines for its use in the early detection of RCS-related lung diseases, such as silicosis and lung cancer. From the standpoint of tertiary prevention, no specific treatment currently exists for silicosis; management of the disease is symptomatic. Therefore, NIOSH plans to assess the effectiveness of anti-fibrotic therapies recently shown to be effective in treatment of idiopathic pulmonary fibrosis, preventing the progression of silicosis to outcomes such as severe respiratory impairment, lung transplantation, and death.

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Chapter 3: Musculoskeletal Disorders in Construction



[Credit CPWR]

Introduction

Musculoskeletal disorders (MSDs) represent one of the largest classes of occupational illness and injury in the United States (U.S.). Work exposures causing MSDs may be abrupt or ongoing and include high physical exertion, awkward working postures, prolonged static exertion, repetitive tasks, and prolonged, intensive exposure to hand-transmitted vibration (HTV). MSDs include a wide array of injuries, diseases, and painful conditions affecting joints, ligaments, muscles, tendons, and nerves of the human musculoskeletal system, and may cause temporary or permanent disability. The most common MSDs include low back pain, neck pain, osteoarthritis, carpal tunnel syndrome, tendonitis, and epicondylitis (inflammation around the elbow) [SSA 2015]. Sprains and strains represent about 40% of all workplace injuries and illnesses with lost work time—these comprise about 74.4% of all MSDs, while 7.9% of all MSDs with lost work days resulted from non-specific soreness and pain (except low back pain) [BLS 2008].

In the U.S., there are about 700,000 reported workplace injuries due to occupational MSDs and overexertion that result in one or more days away from work (DAFW) per year. Work-related MSDs (WMSD) accounted for about 31% of injuries or illness that resulted in days away from work in 2006 [BLS 2006]. The latest data from the [Medical Expenditures Panel Survey](#) from the Agency for Healthcare Research and Quality (AHRQ) estimated the annual direct and indirect costs for MSDs to be \$213 billion [AHRQ 2014]. The total cost estimate, taking into account all expenses for persons with MSD and related conditions, is nearly \$874 billion per year—this includes the cost of treatment and loss in decreased wages [U.S. Bone and Joint Initiative 2014].

Construction work can lead to MSDs such as back injuries or upper arm disorders and hand-arm vibration syndrome (HAVS). Many construction workers commonly perform work with recognized risk factors. According to CPWR—The Center for Construction Research and Training, some of the trades with the highest rates of MSDs and back injuries include masonry, concrete, drywall, roofing, flooring, and plumbing [CPWR 2013]. The physically demanding nature of construction work, which includes manual materials handling (MMH), awkward and static postures, and often harsh outdoor environments, explain why strains and sprains are the most common type of injury resulting in days away from work [Schneider 2001] and why there is high prevalence of MSDs among construction workers [Engholm and Holmström 2005].

Back injuries are the leading cause of disability in the U.S. for people younger than age 45 years. They are also the most expensive healthcare problem for the 30- to 50-year-old age group. A longitudinal study conducted by CPWR found that nearly 40% of older construction workers (e.g.i.e., over the age of 50 years) suffered persistent back pain or back problems [Dong et al. 2012c]. Length of time working in construction, high physical demands, and job stress significantly increased the odds of back disorders. The Annual Survey of Occupational Injuries and Illnesses (SOII) conducted by the Bureau of Labor Statistics (BLS) indicates that in 2015, back injuries alone accounted for almost 17% of nonfatal injuries resulting in lost work time in construction [BLS 2015]. Lower-back MSDs and injuries related to lifting, pushing, pulling, holding, carrying, or throwing currently cost businesses \$15.1 billion in direct costs and account for approximately 25% of the overall national burden [Liberty Mutual 2014]. Chronic MSDs in the shoulders, neck, elbows, hands, hips, knees, and feet also limit the ability of older construction

workers to reach, push, pull, lift, and carry when compared with white-collar workers [CPWR 2018]. Disability retirement among construction workers strongly correlates with MSDs [Welch et al. 2010; Arndt et al. 2005; Brenner and Ahern 2000]. The extensive research efforts to better characterize the burden and impact of MSDs on construction workers, the specific risk factors for each MSD, effective workplace interventions, barriers to adoption, and efforts to overcome barriers to disseminate solutions are complex but compelling.

Prolonged, intensive vibration exposure to the hands may cause HAVS. The development of the syndrome is usually a complex, long-term process influenced by many factors. The process divides conceptually into two parts: biodynamic responses and biological responses. The study of biodynamic responses pertains to what happens to sub-structures of the human hand-arm system in terms of stress, strain, energy absorption, vibration transmissibility, impedance, and so on in response to exposures to vibration. Sufficient understanding of these two parts and their relationship can lead to better understanding of the mechanisms of HAVS, and help develop effective methods to assess the risk of HTV exposure. Research generally concludes that controlling HTV exposures to a certain level can minimize the prevalence of the HAVS [Griffin 1990].

NIOSH played a leading role in identifying and addressing ergonomic risks to workers for decades. The 1981 NIOSH [Work Practices Guide for Manual Lifting](#) (WPG) and the [Applications Manual for the Revised NIOSH Lifting Equation](#) (RNLE) were two significant early contributions to this effort, described later in this chapter [NIOSH 1981, 1994; Waters et al. 1993]. For many years, these documents were the most heavily cited in ergonomics literature. The public purchased the RNLE, a NIOSH technical report describing how to use the revised equations and recommendations, more than any other NIOSH document bought from the National Technical Information Service during the years 1994 through 2000. Since it became free to the public, it has become the second most requested NIOSH document. Several countries (e.g., European Union and Australia) used the RNLE as a lifting standard [Lu 2016], and the Occupational Safety and Health Administration (OSHA) cites the RNLE in their [Technical Manual](#) and in [interpretations of their standards](#).

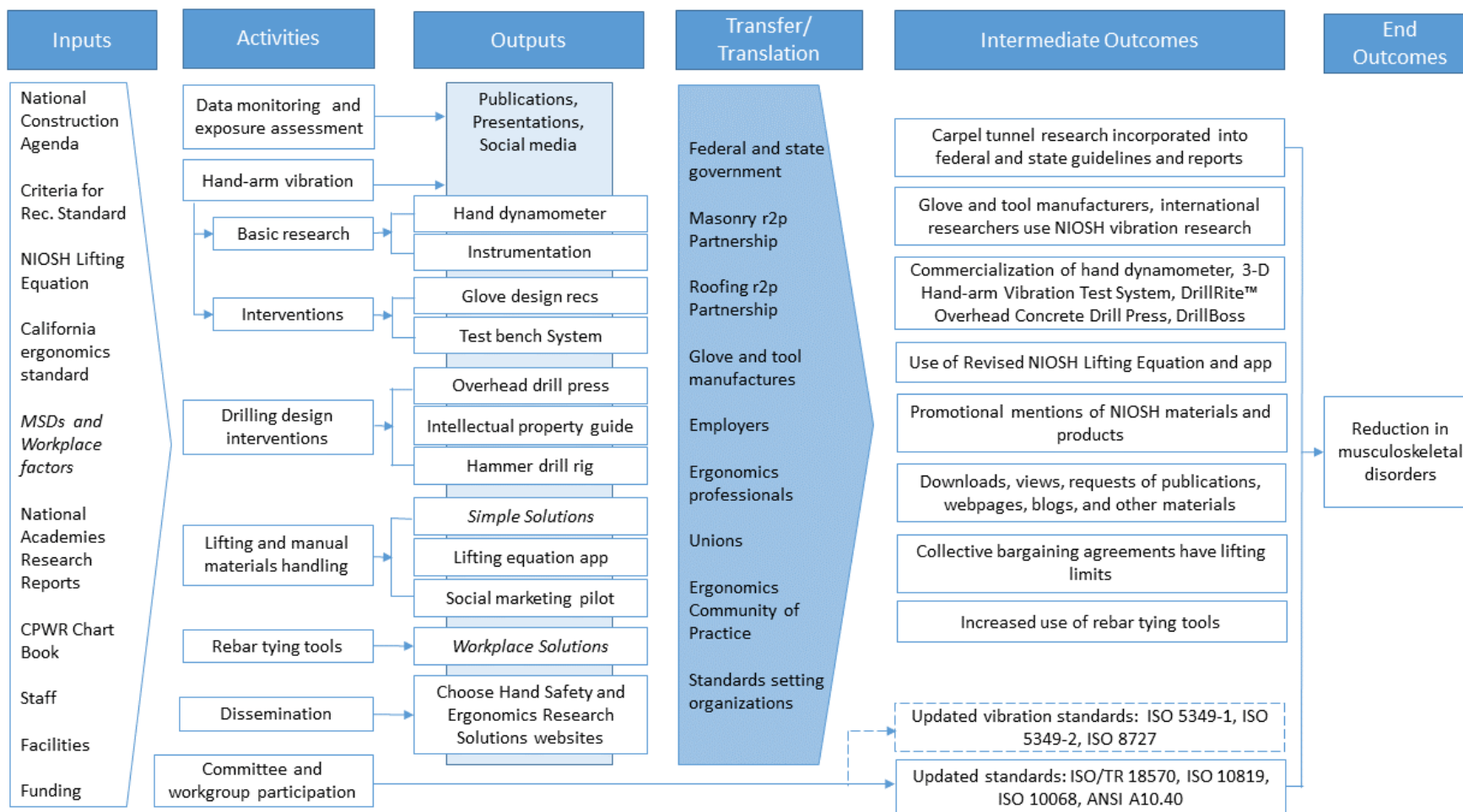
The NIOSH Construction Program focuses on the development of evidence-based methods to rigorously measure risk factors associated with awkward working postures,

lifting and carrying, and stressful hand-wrist conditions. Researchers work to advance the measurement and understanding of the effects of vibration from tools and equipment on the body. These Construction Program efforts promote active researcher-stakeholder collaborations from the beginning of the intervention research process to the evaluation of the interventions. This process ensures the relevance of interventions for construction workers in their work, while considering the effect of potential interventions on productivity.

Logic Model

The logic model (Figure 15) illustrates the flow from initial inputs to end outcome, depicting NIOSH's research and other activities to reduce musculoskeletal disorders among workers in the Construction Sector. A detailed description of each element of the logic model—Inputs, Activities, Outputs, Transfer and Translation, Intermediate Outcomes, and End Outcome—follows in the remainder of this chapter.

Figure 15. Logic Model for NIOSH MSD Research Efforts in Construction, 2007–2017.



Inputs

Many different inputs influenced the NIOSH Construction Research Program in addressing MSDs. Many of these inputs are important and influential documents, described below in chronological order.

National Construction Agenda

A major activity of the NIOSH Construction Program has been to facilitate the work of the National Occupational Research Agenda (NORA) Construction Sector Council (page 21). During the second decade of NORA (2006 through 2016), the Construction Sector Council developed the National Construction Agenda, helping to drive research on MSDs in the construction industry. The Agenda included a strategic MSD goal among its seven “outcome” goals related to important sources of injury or illness.

The agenda’s seventh strategic goal, Reduce the incidence and severity of work-related musculoskeletal disorders among construction workers in the U.S., guided MSD research in NIOSH’s Construction Program. The following six intermediate goals further led NIOSH activities in reducing work-related MSDs:

Intermediate Goal 7.1 – Develop an industry-wide campaign to increase awareness of the human and economic costs associated with construction-industry work-related MSDs and to expand the capability of stakeholders to identify and control recognized risk factors associated with MSDs.

Intermediate Goal 7.2 – Develop, evaluate, and implement recording and tracking systems to more accurately identify the occurrence, characteristics, and costs associated with MSDs in the construction industry.

Intermediate Goal 7.3 – Develop and evaluate practical and valid methods of assessing exposure to risk factors associated with MSDs for use by construction stakeholders in the field.

Intermediate Goal 7.4 – Characterize the association between exposure to risk factors and the development of MSDs among workers in trades and construction divisions in which knowledge gaps exist.

Intermediate Goal 7.5 – Expand the number of workplace solutions to prevent MSDs in the construction industry.

Intermediate Goal 7.6 – Improve the acceptance, diffusion, and adoption of MSD workplace solutions by contractors, owners, suppliers, and workers.

Criteria for a Recommended Standard

In 1989, NIOSH published [Criteria for a Recommended Standard: Occupational Exposure to Hand-Arm Vibration](#) [NIOSH 1989]. This document examined the occupational health problems associated with the use of vibrating tools, including both hand-held vibrating tools and stationary tools that transmit vibration through a workpiece. This publication also provided criteria for reducing the risk of developing vibration-induced health problems. An estimated 1.45 million U.S. workers use vibrating tools, many in the construction industry [NIOSH 1989]. Construction tools commonly associated with HAVS include powered hammers, chisels, chainsaws, sanders, grinders, riveters, breakers, drills, compactors, and sharpeners.

HAVS is a chronic, progressive disorder with a latency period of several months to years. The prevalence and severity of HAVS development depends on many factors, including the level of acceleration (vibration energy) produced by the tool, the length of time the tool is used each day, the cumulative number of months or years the worker has used the tool, and the ergonomics. Use of engineering controls can prevent or greatly reduce the potential for vibration-exposed workers to develop HAVS [NIOSH 1989]. Much of the HAVS-related research described in this chapter occurred, in part, due to many of the findings and recommendations laid out in this criteria document [NIOSH 1989].

NIOSH Lifting Equation

The WPG included a comprehensive summary of scientific literature regarding MMH and the prevention of lifting-related MSDs prior to 1981. The WPG provided two equations—the [Action Limit and the Maximum Permissible Limit](#)—to reduce risk. The equations were widely accepted because they were simple, easy to use, and useful to design safer lifting jobs.

In 1994, NIOSH researchers developed and published [Applications Manual for the Revised NIOSH Lifting Equation](#), a revised version of the two equations that improved upon the earlier approach [NIOSH 1994]. The revised equations—the Recommended Weight Limit (RWL) and the Lifting Index (LI)—are internationally recognized as a standard for safe manual lifting. Health and safety practitioners widely use these

equations. This NIOSH research laid the foundation for much of the subsequent lifting and back injury research at NIOSH [Choi et al. 2012].

California Ergonomics Standard

The California [OSHA-Approved State Plan](#) adopted an [ergonomics standard](#) in 1997 through a legislative mandate. According to the standard, when an employer has more than one employee who experienced a repetitive motion injury or MSD while doing the same task that a physician determined to be work-related, the employer must develop a written MSD ergonomics prevention program. At minimum, the program must include a worksite evaluation, a plan to control exposure, and procedures for training employees. Employers must correct or minimize exposures caused by MSDs in a timely manner. The employer must consider engineering controls, such as workstation redesign, adjustable fixtures or tool redesign, and administrative controls (e.g., job rotation, work pacing or work breaks). California employers must also provide employees with training on topics such as ergonomics and repetitive motion injury exposures, symptoms, and consequences.

The materials from the CA standard supported a Federal OSHA ergonomics standard issued in 2000. However, in early 2001, after about four months, the Congressional Review Act rescinded the federal standard. Consequently, the experience in California provided a U.S.-based example for comparison to the MSD experiences in the rest of the country.

MSDs and the Workplace

In 1997, NIOSH published *Musculoskeletal Disorders and Workplace Factors—A critical review of epidemiological evidence for work-related musculoskeletal disorders of the neck, upper extremities, and low back* [NIOSH 1997]. Despite its age, this is the most comprehensive and authoritative compilation of epidemiologic research on the relationship between selected MSDs and exposure to physical factors. NIOSH concluded that a large body of credible epidemiologic research exists showing a consistent relationship between MSDs and certain physical factors, especially at higher exposure levels.

The document identified overexertion, repetitive motions, and lifting as significant sources of MSD-related injuries. It explained the magnitude of the problem and the

relationships between workplace factors and the development of MSDs. As such, it fed into interventional policies through union contracts and continues to support American National Standards Institute (ANSI) standard setting and MSD research in construction. OSHA cited this document to support their ergonomic standard, issued in 2000, and later rescinded in 2001.

The CPWR Chart Book: The U.S. Industry and Its Workers (Editions 1-6)

The [Chart Book](#) organizes information from many available data sources to explain the burden of work-related illness and injury. It includes information on the prevalence and trends in MSDs and the need for occupational safety and health research in the sector. The Chart Book characterizes the changing construction industry and its workers in the U.S., monitors the impact of such changes on worker safety and health, and identifies priorities for safety and health interventions. CPWR periodically updates the Chart Book through Quarterly Data Reports, which are prepared and disseminated to supplement specific topic areas, such as MSDs, as new data become available [CPWR 2013]. NIOSH and CPWR leadership consult the Chart Book frequently to review the data when conducting strategic planning to establish MSD research goals.

Staff

NIOSH has conducted construction research extensively in its laboratories as well as in the field and with partners. Partnerships with industry and other stakeholders are essential, with employers and workers often participating in field projects. Research has resulted in many outputs including publications, conferences, advice to standards organizations, communication products, and patents. The following individuals have been particularly instrumental in conducting NIOSH MSD research:

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Noah Seixas, PhD	University of Washington
John Shewchuck, PhD	Virginia Polytechnic Institute & State University

Note:* Also participated as CPWR Consortium or Small Study researchers.

Facilities

Cincinnati, OH

The NIOSH Division of Applied Research and Technology (DART) is described in detail in the Program Overview (page 18). Some activities of the division, however, are of particular interest for MSD research. DART maintains approximately 2,800 square feet of flexibly designed space for laboratory studies and field study preparation. The facility houses state-of-the-art instrumentation and apparatuses for biomechanical measurement, including transducers and pressure-sensing technologies. These instruments collect data on hand and arm positions, velocities, accelerations, and forces applicable to workers performing various and intensive arm and hand actions. The flexibility of the laboratory space allows for setup of studies that mimic musculoskeletal exposures observed in fieldwork, for instance, users of pneumatic nail guns and workers who handle materials.

DART also houses facilities useful in evaluating neurobehavioral effects of workplace exposures. The [Ergonomics and Posture Simulation and Lifting Laboratory](#) is designed for prevention research on work-related MSDs. The laboratory includes a human postural simulation system and computer modeling to quantify MSD risk factors. The laboratories are well equipped for research on biomechanics of human interaction and effects on musculoskeletal loading of the worker.

Morgantown, WV

A description of the NIOSH Health Effects Laboratory Division (HELD) in Morgantown, West Virginia, is in the Program Overview (page 19). HELD includes an Exposure Assessment Branch with the mission of researching novel and improved techniques for assessing the exposure of workers to principally chemical, but also to physical and biological hazards. Therefore, some activities of the division are of particular interest for MSD research. Figures 16 -22 show images of some of the HELD laboratories and equipment used to study HAVS and roofer's MSDs.

The hand-arm vibration laboratory (Figure 16) includes the following equipment or devices: One 3-D hand-arm vibration test system (MB Dynamics), seen in Figure 16. Two 1-D hand-arm vibration test systems, seen in Figure 17. One 1-D scanning laser vibrometer that measures the vibration transmitted to the hand-arm system in some experiments, seen in Figure 17. A rented scanning 3-D laser vibrometer that measures the 3-D vibration transmissibility, seen in Figure 16. Brüel & Kjær Data Acquisition Systems (including analyzers) measures vibrations on the vibration test systems, seen in Figure 16. Four tool test stations, some of which are shown in Figure 22. Also in the lab are accelerometers that measure the accelerations on the instrumented handles and tools. Amplifiers are also available, as are three force plates for measuring the hand-applied push or pull force.

Figure 16. The 3-D hand-arm vibration test system.

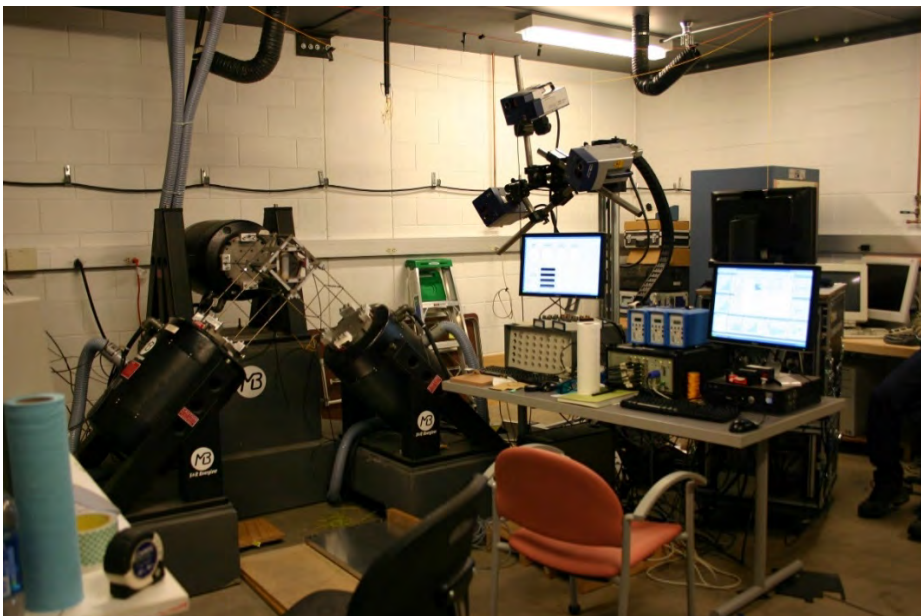


Figure 17. The 1-D hand-arm vibration test system and 1-D scanning laser vibrometer.



Figure 18. Chipping hammer test



Figure 19. Impact wrench test



Figure 20. Rivet hammer test



Figure 21. Simulated riveting test station



Figure 22. A roofing simulator for the study of roofers' MSDs in the HELD facilities in Morgantown.



Activities, Outputs, Transfer and Translation, and Intermediate Outcomes

Data Monitoring and Exposure Assessment Research

CPWR researchers examined MSDs trends among U.S. construction workers, with an emphasis on trades and older workers [Wang et al. 2017]. They identified MSDs during 1992 through 2014 using SOII, estimating employment from the Current Population Survey (CPS) data. Researchers measured MSD risk by number of MSDs per 10,000 FTE (full-time equivalent), taking into account demographics and employment.

Following overall injury trends, the number of MSDs in the U.S. construction industry dropped significantly from 1992 through 2014; however, the rate of MSDs in construction remained higher than in other industries. Median days away from work increased from eight days in 1992 to 13 days in 2014, and the estimated wage loss for private wage-and-salary construction workers was \$46 million in 2014 [Wang et al. 2017]. From 1992 through 2014, the proportion of MSDs for workers aged 55 through 64 years almost doubled. Construction laborers had the largest number of MSDs, while helpers, heating and air-conditioning mechanics, cement masons, and sheet metal workers held the next highest rates, respectively. Researchers found the major cause of MSDs in construction was overexertion, accounting for over 40% of MSDs. Researchers concluded that ergonomic solutions that reduce overexertion—the primary exposure for MSDs, need to be adopted extensively, particularly for workers at highest risk.

Construction Trades

Roofers

Welch et al. at CPWR investigated work demands, chronic medical and musculoskeletal conditions, aging, and the ability to remain on the job in a longitudinal study of older union construction roofers (ages 40 through 59 years) [Welch et al. 2009]. In phone interviews at baseline and one year later, researchers asked participants about medical conditions and MSDs, work limitations, work accommodations, and social and economic functioning. Among the workers for whom a MSD was their most serious condition at baseline, eight percent no longer worked as roofers due to a health condition. Workers with MSDs who received an accommodation (31%) were less likely to leave their roofing occupation compared with workers with a MSD who had no job accommodation.

Musculoskeletal conditions among roofers are strongly associated with work limitation, missed work, and reduced physical functioning, factors that may predict premature departure from the workforce.

Researchers found construction workers less likely to return to work after an injury compared with workers in other sectors [Welch et al. 2009]. In the same study of construction roofers, Welch and colleagues evaluated work demands, chronic medical and musculoskeletal conditions, aging, and disability. Researchers asked participants about medical conditions and MSDs, work limitations, health status, and of the social and economic impact of injury. Medical and musculoskeletal conditions are strongly associated with work limitation, missed work, and reduced physical functioning; these factors are also associated with premature departure from the workforce.

The CPWR Ergonomic Community of Practice¹ used the research results to develop their pilot social marketing program, which focuses on reducing manual materials handling. The [Ergonomics Research & Solutions](#) section of CPWR's website also posted the results. CPWR also established a [Roofing r2p Partnership](#)² that discussed these findings and is considering how best to address them.

NIOSH researchers in HELD, together with their research collaborators (Drs. Fei Dai and Xiaopeng Ning) from West Virginia University, initiated a research program to study roofers' MSDs. As shown in Figure 23, a roofing simulator examines roofers' MSDs and evaluates interventions. Preliminary studies found that the NIOSH lifting equation may not apply to roofer working conditions. However, roofers spend a lot of time in stooping, crouching, and kneeling positions with heavy loads on a slanted surface. This work can cause the development of health conditions, including low back disorders and

¹ The Ergonomics Community of Practice (ECP) was established and facilitated by CPWR at the request of and to bring together researchers and industry stakeholders with a shared interest in addressing ergonomic issues in the construction industry. The ECP includes representatives from research, labor, insurance, and industry that use the research findings as the basis for creating and disseminating translational products—these include commercially available tools and equipment that contractors, workers, and trainers can use on jobsites.

² A National partnership involving the National Roofing Contractors Association (NRCA) and the United Union of Roofers and Waterproofers and Allied Workers that was established in collaboration with CPWR. The partnership engages key decision makers with a national reach in focused research to practice efforts to increase awareness and use of tools, materials, and work practices found to reduce workers' risk for injury or illness in the masonry industry, as well as to identify and support new research needs (practice to research or p2r).

issues with knees and the lower extremities [Wang et al. 2017]. Engineering control technologies or personal protective equipment may reduce some of the unfavorable working conditions [Breloff and Waddell 2017]. A follow-up intervention research project will assess work-related risk factors for knee injuries among roofers and evaluate the use of intervention technologies to alleviate the MSD risk factors among roofers.

Floor Layers

Floor layers have high rates of MSDs; however, few studies have examined their work exposures. A CPWR study used observational methods to describe physical exposures for floor layers during floor-laying tasks [McGaha et al. 2014]. Researchers evaluated 45 videos of 32 floor layers installing flooring (tile, hardwood, and carpet) for tasks, postures, forces, and repetition. They used checklists to define physical exposures across multiple body parts. Findings indicate that most workers (91%) met the threshold for one or more potentially hazardous exposures. Researchers observed prolonged exposures for kneeling, poor neck and low back postures, and intermittent but frequent handgrip forces. Researchers concluded that floor layers experienced prolonged awkward postures and high force physical exposures in several body parts, which possibly contribute to their high MSD rates [McGaha et al. 2014].

Dale et al. at Washington University, St. Louis, studied health insurance claims during 2006 through 2010 for floor layers compared with workers in general industry [Dale et al. 2015]. Data were obtained from a MarketScan database—the largest collection of employer-based health records. Researchers studied MSD claim rates for neck, low back, knee, lower extremity, shoulder and distal arm. They found higher claim rates for floor layers across all body regions with nearly double the rate ratios for the knee and neck regions. The excess risk was greatest for the neck and lower back regions; younger workers had disproportionately higher rates in the knee, neck, low back, and distal arm. Researchers found markedly higher rates of MSD claims for floor layers compared with a general worker population, suggesting a shifting of medical costs for work-related MSD to personal health insurance. The occurrence of disorders in multiple body regions and among younger workers highlight the need for improved floor laying methods and tools [Dale et al. 2015].

The CPWR Ergonomic Community of Practice (of which Dr. Dale is a member) used the Dale et al. study results in the development of their [pilot social marketing program](#)

focused on reducing manual materials handling. The [Ergonomics Research & Solutions](#) section of CPWR's website posted the results, which CPWR established in support of the pilot program. CPWR is currently finalizing the social marketing plan, and the studies will be included in the resources the plan will provide.

Sheet Metal Workers

To address the gap in knowledge of how the transfer of interventions designed to reduce the physical demands of sheet metal workers occurs, CPWR consortium researchers reviewed videos of 15 sheet metal worksite assessments to observe postures and physical loads, and to observe the use of recommended interventions to reduce physical exposures. Workers consistently used material handling devices, but the researchers observed minimal use of recommended interventions to reduce overhead work. Workers spent large amounts of time in awkward shoulder elevation and lower back postures. Dale et al. developed new technologies and system designs to increase the adoption of existing tools and practices that could reduce awkward postures and other MSD risks in sheet metal work [Dale et al. 2016b]. The findings in this study supported the need to intervene at the general contractor level rather than the individual contractor level. The research team used this same intervention approach in subsequent projects.

Sheet metal workers frequently use a cutting tool called "aviation snips" to make curves cuts when fabricating and installing ductwork. CPWR consortium researchers conducted a laboratory simulation to determine the effect of aviation snip design and work height on muscle activity, wrist posture, and user satisfaction [Anton et al. 2007]. Anton et al. examined circular, straight, and offset aviation snip designs when workers place the snips both at waist and shoulder height. Researchers measured upper extremity muscle activity, wrist posture, and user satisfaction; researchers found statistically significant effects for each. Work height had a greater effect on muscle activity and wrist posture than snip design [Anton et al. 2007].

Another CPWR study explored the causes of permanent work disability of sheet metal workers [West et al. 2016]. Researchers used pension records to compare causes of disability among sheet metal workers and the U.S. working population. MSDs (particularly for the spine, shoulder, and knee), circulatory disease, and injuries (47.2%, 13.7%, and 10.9% of pension awards, respectively) were the leading causes of sheet

metal worker disability. These pension award distributions to sheet metal workers differed from the U.S. working population. Higher proportions of disability compensation awards among sheet metal workers are given for work-related injuries and MSDs. The study found that prevention requires task-specific ergonomic innovations and proven participatory interventions [West et al. 2016].

Highway Tunnel Construction

Tak and colleagues at the University of Massachusetts, Lowell, conducted an overview of physical ergonomic exposures in highway construction work across trades and major operations. For each operation, the researchers used the "PATH" (Posture, Activity, Tools, and Handling) observational method to estimate the percentage of time workers spent in specific tasks, awkward postures, and load handling. They observed construction workers in five trades: laborers, carpenters, ironworkers, plasterers, and tilers. Non-neutral trunk postures (forward or sideways flexion or twisting) were observed frequently, representing over 40% of observations for all trades except laborers (28%). Kneeling and squatting were common in all operations, especially tiling and underground utility relocation work. Handling loads was frequent, especially for plasterers and tilers, with most load weights under 15 pounds. This study provided quantitative evidence that highway tunnel construction workers are exposed to significant ergonomic risk factors [Tak et al. 2011].

Aging and Retirement

Dong and colleagues at CPWR assessed chronic back pain and other factors (e.g., employment, job characteristics, and general health status) among older U.S. construction workers by analyzing data from the 1992 through 2008 [Health and Retirement Study](#), a large-scale longitudinal panel survey [Dong et al. 2012c]. The study began with 12,652 participants born during 1931 through 1941. The study aimed to improve understanding of long-term health outcomes based on job history and exposures. Results showed that about 40% of construction workers aged 50 years or older suffered from persistent back pain. Jobs involving high levels of stress or physical effort increased the risk of back disorders—a longer length of time in construction jobs increased the odds of back disorders by 32%. Researchers found that poor physical and mental health strongly correlated with back problems. They established a need for

enhanced interventions for construction workers given the aging workforce and high prevalence of back disorders in construction [Dong et al. 2012c].

A study at the University of Colorado, Denver, funded by CPWR, examined the relationship between age and injury or MSD type on claim costs using Colorado workers' compensation claims filed during 1998 through 2008 among construction workers [Schwatka et al. 2013]. For each one-year increase in age, indemnity and medical costs increased by 3.5% and 1.1%, respectively. For specific injury types, such as strains and contusions, the association between age and indemnity costs was higher among claimants who were 65 years or older, compared to claimants aged 18 through 24 years. Specific injury or MSD types may relate to the higher indemnity costs among older construction workers compared with younger coworkers. A better understanding of how an aging U.S. workforce affects workers' compensation costs is needed, especially for physically demanding industries, such as construction.

Knee Injuries

NIOSH funded Tak et al. at the University of Massachusetts, Lowell, to evaluate risk factors for knee pain in various highway construction trades, operations, and tasks. Over 15,000 discrete observations were made of leg postures and weights handled by 120 workers in five construction trades. Researchers used multilevel random effects models to evaluate the contributions of trade, operation, task, and worker to the variability in work time spent kneeling, squatting, and carrying loads. Construction operation and task explained about 20% to 30% of total variation in kneeling, squatting, and carrying loads. The researchers found that reliable assessments of knee exposures require multiple days to accommodate the high variability of exposures among operations and tasks and over time. They recommended, furthermore, that sources of variability be carefully considered in efforts to estimate exposures to knee loading in subsequent epidemiologic or intervention studies [Tak et al. 2008].

Carpal Tunnel Syndrome (CTS)

Carpal tunnel syndrome (CTS) is a common and disabling work-related upper extremity MSD related to intensive workplace hand use, caused by factors such as forceful grip and repetitive hand activities. NIOSH funded Dale and others at the University of Washington, St. Louis, to conduct a study that provided strong evidence that forceful, frequent hand activity is an independent risk factor for CTS and other MSDs.

Researchers created and validated simplified methods for exposure assessment relevant to upper extremity disorders and validated epidemiologic case definitions for CTS. Workers with CTS were found to be more likely to have long-term hand symptoms and functional impairment, including work disability, than similar workers without CTS. Researchers found work-related MSDs significantly under-reported in workers' compensation insurance, with claims and costs often shifted to private health insurance. This practice impedes surveillance and leads to underestimates of the true burden of MSDs. The researchers also evaluated the practice of post-job offer and pre-job placement screening of workers for CTS using nerve conduction studies. Research findings suggested that this common practice among employers is not a useful or valid preventive measure [Armstrong et al. 2008; Calfee et al. 2012; Dale et al. 2013; Evanoff and Kymes 2010; Evanoff et al. 2012].

Intermediate Outcomes:

- ❖ Study findings from Dale et al. [2013] have been incorporated into federal and state government guidelines and policy reports concerning the diagnosis, treatment, prevention, and compensability of CTS by OSHA [Fagan and Hodgson 2017].
- ❖ Results have been cited in a [U.S. Equal Employment Opportunity Commission lawsuit](#) on post-offer pre-placement screening for CTS [Dale et al. 2016a].
- ❖ Study findings from Dale et al. [2013] influenced the decision of the [Masonry r2p Partnership](#) (page 75) to raise awareness of CTS risks, providing information on interventions to reduce CTS [CPWR 2017]. The Partnership developed the [ChooseHandSafety.com](#) website to provide industry stakeholders with ready access to evidence-based information on how to select and use common masonry hand tools to avoid CTS.

Hand-Arm Vibration Syndrome

HAVS is one of the major MSDs in the upper extremities [Institute of Medicine and National Research Council 2001; NIOSH 1997]. HAVS is characterized primarily by cold-induced blanching of the fingers (often referred to as “vibration white finger” or VWF), a loss of tactile sensitivity in the hands, and reductions in manual dexterity. While many studies and several international and national standards on HTV exposure and health

effects have been published, the exact mechanisms underlying the development of HAVS are not well understood. Researchers do not precisely know the characteristics of the exposure required to cause HAVS, not with respect to vibration magnitude and frequency spectrum, nor with respect to daily and cumulative exposure duration [ISO 2001]. There is no reliable, objective method for the diagnosis of HAVS, and a reliable exposure-response relationship for factors associated with HTV and HAVS is not established. As a result, some studies report that the action limit, a trigger for beginning medical surveillance and other activities, overestimates the risk in some tool operations while other studies state that the established action limit is not low enough to protect workers. NIOSH researchers are studying methods of risk assessment, diagnostic, and vibration exposure control, and specific activities are described in the following sections.

Understanding Health Effect Mechanisms

Researchers developed animal models to assess the various characteristics of vibration exposure and determine which factors increased the risk of developing symptoms of HAVS. NIOSH researchers and their academic partners used an animal model of vibration (a rat tail) to demonstrate that the biodynamic responses of the tail were similar to the biodynamic responses of the human finger. In fact, the study showed that the development of both circulatory dysfunction and hearing loss is related to the frequency of the vibration—the dysfunction developed more quickly with increases in frequency [Dong et al. 2012b; ISO 2017; Krajnak et al. 2012; Krajnak et al. 2016; Xu et al. 2011]. These data support epidemiological and experimental data suggesting the revision of the *Mechanical vibration—Measurement and evaluation of human exposure to hand-transmitted vibration—Part 1: General requirements* ISO 5349-1 standard [ISO 2001] to consider the risk to higher vibration frequencies exposure.

Intermediate Outcome:

- ❖ As the first step of the revision, the ISO 5349-1 Working Group (ISO-TC108-SC4) proposed a Technical Report *Mechanical vibration—Measurement and evaluation of human exposure to hand transmitted vibration—Supplementary method for assessing risk of vascular disorders (the International Organization for Standardization (ISO)/TR 18570)* [ISO 2017]. It takes into account these findings by citing NIOSH research in defining a new frequency weighting for assessing the risk of the vibration exposure.

NIOSH researchers used the rat-tail model to find interventions that may reduce the risk of developing HAVS-like symptoms. They determined that anti-vibration (AV) gloves reduce some of the effects of vibration exposure on the peripheral vascular system. NIOSH researchers then designed a study to determine the length of time it takes for the peripheral vascular system to recover after exposure to vibration in the resonant frequency range [Krajnak et al. 2016]. The results of this study demonstrated that it takes eight to 10 days for the peripheral vascular system to recovery after exposure to vibration. While other factors may play a role in mediating recovery from a single exposure to vibration (e.g., the length of the exposure, ambient temperature, the number of years a worker has used a tool), these data can help employers determine the best work rotation schedule for workers who use vibrating tools.

NIOSH studies also demonstrated that exposure to vibration altered an individual's perception. In particular, the threshold for the detection of mechano-sensory input changed, with animals first becoming more sensitive to the mechanical stimulation, and then with repeated exposures, becoming less sensitive. Changes in skin or ambient temperature do not affect the perception threshold approach, which can reduce the chance of HAVS misdiagnosis.

Based on these findings in animal studies, NIOSH collaborated with the University of Toronto in Canada to assess current perception thresholds in workers diagnosed with HAVS. The researchers found that workers with HAVS had current perception threshold levels that were indicative of peripheral nerve dysfunction or damage [House et al. 2009]. NIOSH collaborated with other researchers to study early, non-invasive physiological or biological markers that could detect vibration-induced injury early on [Eger et al. 2014; House et al. 2011; House et al. 2016; Thompson et al. 2010].

Developing Risk Assessment Methods

The development of HAVS depends on a number of factors such as the characteristics of the vibration exposure, the duration of the vibration exposure (daily and cumulatively), the environment in which the vibration exposure is occurring, and the physical health of the worker, making it a complex process. The current risk assessment method takes into account three major exposure factors in the quantification of risk: vibration magnitude, daily and yearly exposure time durations, and frequency dependency of vibration effect [ISO 2001]. However, researchers lack understanding of the factors and their

quantitative relationships to health. To help improve the standard risk assessment method, NIOSH researchers studied the major issues related to the measurement and evaluation of these three factors. Researchers have also made progress in another important factor—hand force in the vibration exposure assessment. NIOSH researchers conducted studies to resolve technical issues related to the vibration measurement technique, which include practical definition of the coordination systems for vibration measurement, identification and avoidance of baseline offset (dc-shift), and selection and application of an appropriate adapter for the measurement [Dong et al. 2015a; Xu et al. 2014].

Intermediate Outcomes:

- ❖ These studies [Dong et al. 2015a] were cited in comments from the U.S. for revising ISO 8727, *Mechanical vibration and shock—Human exposure—Biodynamic coordinate systems* [ISO 1997], and for revising ISO 5349-2, *Mechanical vibration and shock—Measurement and evaluation of human vibration exposure of hand-transmitted vibration—Practical guidance for measurement at the workplace* [ISO 2001]. The proposed revisions have been submitted to the related work group of the international standards.
- ❖ Some vibration studies published in recent years on grinding, welding, bucking bars, and mechanical assist arms have resulted in technical improvements to reduce vibration based on NIOSH research and technical input [Chen et al. 2017; McDowell 2015]. Several tool and glove manufacturers have communicated to NIOSH scientists how they have applied NIOSH’s experimental results and subject matter knowledge to the development of their product.

NIOSH studies examined alternative measures of vibration exposure (vibration power absorption or VPA) [Dong et al. 2004; Dong et al. 2006a; Dong et al. 2008a; Dong et al. 2008e; Dong et al. 2012a]. NIOSH researchers also identified the major deficiencies associated with using total VPA, which are that the method ignores both the frequency of the vibration power absorption in the hand-arm system and the concentration effect of the vibration hazard. To overcome these deficiencies, NIOSH researchers proposed a new VPA method [Dong et al. 2007; Dong et al. 2012b], which led to the development of

new theories for human vibration biodynamics [Dong et al. 2015b], a major achievement in this area.

Another achievement is the establishment of a novel vibration theorem [Dong et al. 2013a]. This theorem applies to the study of the vibration of not only the human hand-arm system and whole-body system but also any other biomechanical or mechanical systems or machines. Based on this theorem, NIOSH researchers clarified the theoretical basis of a widely used inverse dynamic method for developing human vibration models, proposing a set of new criteria for their validation and evaluation [Dong et al. 2015b]. Researchers outside NIOSH also applied the theorem and criteria [Coyte et al. 2016; Rakheja et al., Forthcoming]. These findings are expected to improve further modeling studies of not only hand-arm vibration but also whole-body vibration.

Modeling can quantify the location-specific vibration exposure using alternative vibration measures such as vibration strains, stresses, and VPA density [Dong et al. 2007; Wu et al. 2010]. These measures are likely to be more directly associated with the biomechanics of injuries and disorders. NIOSH researchers proposed one such alternative [Dong et al. 2007; Kim et al. 2007] for assessing the risk of impulsive vibration exposure and for quantifying the vibration and frequency of biodynamic measures at the hand-tool or hand-workpiece interface [Dong et al. 2007; Dong et al. 2008e]. NIOSH researchers also created a clear and validated method for comparing these alternative exposure measures by deriving their vibration biodynamic frequency weightings [Dong et al. 2008e].

Intermediate Outcomes:

- ❖ These studies advanced the knowledge of human vibration and helped develop new methods and a standard for assessing the risk of the vibration exposure at workplaces (ISO/TR 18570) [Mechanical vibration—Measurement and evaluation of human exposure to hand transmitted vibration—Supplementary method for assessing risk of vascular disorders](#) [ISO 2017].
- ❖ International researchers have adopted NIOSH's method for deriving the VPA frequency weighting not only for hand-transmitted vibration exposure but also for whole-body vibration exposure [Rakheja et al. 2010].

NIOSH researchers are actively working to improve vibration exposure duration measurements. In the past, researchers estimated daily and yearly vibration exposure durations based on workers' subjective recollections. They generally tended to overestimate the actual exposure time, however. NIOSH researchers proposed to use a vibration wristwatch to accurately measure the exposure time, and they developed a prototype of the vibration wristwatch, which is similar to wrist-worn activity trackers. NIOSH successfully validated these alternative measurement devices [Xu et al. 2014].

The hand forces applied in tool operations can be hazardous beyond certain levels. They may also increase the adverse effects of vibration exposure so should be considered in the risk assessment. Theoretically, this requires identifying the health-effects force dependency and establishing a force-weighting factor, similar to the frequency weighting, for the calculation of the vibration exposure dose. To help establish one of the foundations for creating the force weighting, NIOSH studied the effects of hand forces on vibration biodynamic responses [Dong et al. 2008a; McDowell et al. 2012; Pan et al. 2017] and the effect of the feed force on a tool vibration [Antonucci et al. 2017]. This new grip force theory has led to the development of a new hand dynamometer for hand force measurement, *Hand dynamometer with improved configuration for grip strength assessment* [Wimer et al. 2010b]. NIOSH researchers developed a novel method for characterizing the hand grip force [Dong et al. 2008c] that led to the discovery that the grip force applied on a cylindrical handle can be described using an elliptical function. Using the hand dynamometer, NIOSH researchers studied factors influencing grip force [McDowell et al. 2012; Wimer et al. 2010a].

Intermediate Outcomes:

- ❖ NIOSH's and the National Institute of Health's patent offices are currently reviewing a company's licensing application to commercialize the hand dynamometer.
- ❖ Researchers at the University of Connecticut Medical School also used it in their studies [Tornifoglio and Peterson 2012].

While hand forces may affect the vibration responses of the hand-arm system, current national and international standards do not consider hand forces in risk assessment exposure because the relationship between the forces and health is undetermined.

While difficult to identify such a relationship, NIOSH researchers know the association between vibration responses and health effects—they proposed a draft measure to quantify the relationship between the hand forces and vibration responses of the hand-arm system. They proposed, furthermore, to use the measure as an alternative approach for conducting risk assessment [Krajnak 2012; Krajnak et al. 2010; Krajnak et al. 2012; Pan et al. 2017; Welcome et al. 2008; Wu et al. 2006]. Based on this research and for the first time, researchers identified the direct relationship between grip force and vibration transmissibility of the hand-arm system [Pan et al. 2017]. The data from these studies provided important evidence for reviewing and evaluating a proposed revision of ISO 15230. Further studies are planned to help revise this standard.

Development of Instrumentation

Instrumented handles are critical for experiments of hand-arm vibration exposure and health effects. Several such handles in use did not provide accurate measurements of the vibration biodynamic responses of the hand-arm system. Some of the handles could not measure major resonances, the most important characteristics of the system [Dong et al. 2006b]. To overcome problems with these devices, NIOSH developed novel instrumented handles with several different sizes and shapes [Dong et al. 2008b]. Besides their greatly improved accuracy, these handles are unique in that they separately measure the biodynamic responses distributed on the fingers and the palm of the hand. This makes it possible to consider the fingers as a separate structure in the biodynamic analysis. Because of this invention, the biodynamic frequency weighting of the fingers is included, helping to assess the risk of vibration-induced white finger.

Intermediate Outcomes:

- ❖ International researchers used some of the instrumented handles [Shibata et al. 2008].
- ❖ One of the instrumented handles is included in the current standardized anti-vibration glove test, ISO 10819 [Mechanical vibration and shock—Hand-arm vibration—Measurement and evaluation of the vibration transmissibility of gloves at the palm of the hand](#) [ISO 2013].
- ❖ NIOSH developed technical specifications and basic structural design for a 3-D Hand-arm Vibration Test System (Figure 24). MB Dynamics in Ohio constructed

and commercialized the test system. They also adopted a 3-D instrumented handle (Figure 25), which is a critical component of the test system.

Figure 24. 3-D Hand-arm vibration test system. Figure 25. 3-D instrumented handle.



Interventions to Reduce Vibration

Vibration-reducing gloves can reduce some vibration, especially the vibration transmitted to the palm-wrist-arms. NIOSH researchers studied the gloves, including the mechanisms identified for reducing the transmitted vibration and health effects [Dong et al. 2009b; Krajnak et al. 2015; Wu et al. 2012]. They also examined developing and improving the glove test, the evaluation method, and related standards [McDowell et al. 2012]. Researchers also studied glove effectiveness [Dong et al. 2013b; Dong et al. 2014; Dong et al. 2016; Welcome et al. 2014; Xu 2011] and potential adverse effects [Krajnak et al. 2016; Wimer et al. 2010a].

Intermediate Outcome:

- ❖ Dong et al. [2009b] was cited in substantial revisions to the standard on the glove test and evaluation [ISO 2013], providing valuable information on further improvements of glove designs, their selection, and their appropriate application. Several glove developers and manufacturers (Impacto, Chase Ergonomics, and Eureka Safety) took NIOSH suggestions in account for additional glove development [Welcome 2010, 2011, 2018; Welcome et al. 2014].

NIOSH researchers continue to develop and evaluate new anti-vibration technologies. Analysis should consider the impedance of the hand-arm system because it may

influence the tool handle or hand-held workpiece vibration. Researchers developed several biodynamic models for analyzing the designs of tools, tool handles, and anti-vibration devices [Dong et al. 2008d; Dong et al. 2009a, 2013b]—these models may help develop tool test apparatuses. NIOSH researchers proposed a set of intervention methods to reduce the vibration exposure of workers who use handheld tools to grind [Chen et al. 2017; Dong 2016]. The general concepts and principles developed in these studies applies to vibration exposure control in construction settings such as cutting handheld tile and wood. In collaboration with the U.S. General Services Administration (GSA), NIOSH evaluated several anti-vibration gloves and powered hand tools used in construction and recommended design improvements to the manufacturers (e.g., Impacto, Ergodyne).

Intermediate Outcomes:

- ❖ These studies are included in an international standard, ISO 10068 [Mechanical vibration and shock – Mechanical impedance of the human hand-arm system at the driving point](#), developed primarily based on NIOSH research [Dong et al. 2009; ISO 2013].
- ❖ The low-vibration tools and certified anti-vibration gloves are available to government agencies for purchase and may help protect workers exposed to hand-arm vibration [Dong et al. 2009b]. The U.S. Air Force and U.S. Navy have been purchasers [Dong 2016].

Pneumatic percussive power tools are used extensively in construction and can cause HAV disorders such as pain, numbing, and blanching of the fingers. NIOSH evaluated a chipping hammer for vibration, acoustic, and fluid characterization. NIOSH researchers developed a numerical model, conducted a preliminary study of vibration control approaches, and developed impact vibration absorber prototypes. The results demonstrated a 63% reduction of the impulses produced by the tool. Technologies identified in this project could substantially reduce pneumatic tool vibrations with minimal impact on performance [Kadam et al. 2005; Kadam et al. 2006; Schwartz 2006].

Workers may be exposed to high levels of hand vibration when drilling into concrete or rock using hammer drills. Building on their earlier work, CPWR consortium researchers developed a robotic test bench system for measuring handle vibration on drills to compare differences in drill designs, power sources, bit designs, and drilling methods.

The Silica and Noise chapters also describe this research (pages 47 and 187, respectively). The test bench is a departure from the ISO method for measuring drill handle vibration, *Hand-held portable power tools—Test methods for evaluation of vibration emission—Part 10: Percussive drills, hammers and breakers (ISO 28927-10)* [ISO 2011], which requires drilling by people. Researchers designed the test bench system to drill repeatedly into concrete blocks under force control while measuring productivity and handle vibration. This study validated the new robotic test bench system for measuring handle vibration against ISO methods and demonstrated dynamic properties similar to human drilling [Rempel et al. 2017]. Researchers also explored the effect of bit wear on drill handle vibration and drilling productivity using the test bench system. The tests showed that bit wear led to a small but significant increase in vibration and had a large effect on productivity—the time to drill a hole increased by 58% for the worn bit compared to a new bit. The effect on productivity will influence a worker's allowable daily drilling time if exposure to drill handle vibration is near the ACGIH Threshold Limit Value (1), as well as encourage construction contractors to implement a bit replacement program [Antonucci et al. 2017].

Dissemination

CPWR created two Hazard Alert cards (page 65) addressing vibration and MSD injuries: [*Hand Tools: Tips to Choose and Use Them Safely and Back Injuries: You Are at Risk*](#). Users can access the cards, available in English and Spanish, directly from the [CPWR website](#) and [eLCOSH](#).

Intermediate Outcome:

- ❖ CPWR received 20,241 requests for printed copies of the Hazard Alert cards from 2009 through 2017 and 5,455 downloads from 2013 through 2017. The hazard cards received 6,122 views on eLCOSH from 2009 through 2017.

Drilling Design Interventions

NIOSH researchers and their partners conducted substantial amounts of research addressing health hazards related to drilling. The chapter focuses on how drilling can cause MSDs; researchers examined other drilling hazards such as silica and noise exposures described in other chapters (pages 47 and 187, respectively). The following sections describe a series of studies funded by CPWR to address the MSD hazards.

Overhead Drilling

CPWR researchers identified and characterized overhead drilling into concrete (Figure 26) as a strenuous task associated with shoulder, arm, neck, and back MSDs resulting from the forceful and awkward work. Workers from several trades use overhead drilling to hang pipes, ducts, and trays. Rempel and colleagues at the University of California, Berkeley, worked iteratively with employers and workers from a range of trades, including electrical, plumbing, and sheet metal work, to develop alternative devices for overhead drilling to reduce shoulder load. The research team conducted field studies of two intervention devices: an inverted drill press and a foot lever design. Researchers evaluated and modified these alternative devices for usability, productivity, and user fatigue through testing with construction workers [Rempel et al. 2007; Rempel et al. 2009].

Using a participatory intervention model, feedback from construction workers guided the development of a new intervention design that incorporated a wheeled tripod base and a unique method of aligning the drilling column to vertical. The final design resulted in less fatigue in the neck, shoulders, hands, arms, lower back, and legs; it reduced force to the body by 90% from 50 lbs. with the traditional method to just 6 pounds with the intervention. In comparison with traditional overhead drilling, the field tests of the intervention showed similar productivity. The design suggestions and field-testing by experienced construction workers on real construction tasks helped to improve the safety and usability of the new drilling [Rempel et al. 2010]. Additional benefits extended beyond reducing the risk for MSDs. The intervention also reduced the fall risk by eliminating the need for a ladder to mark the ceiling and reduced silica dust exposure when using the intervention with a vacuum system because the drilling takes place farther from the worker's breathing zone.

Figure 26. Construction worker performing traditional overhead drilling.



Figure 27. Adjustable Castor Base Drilling Intervention.



Intermediate Outcome:

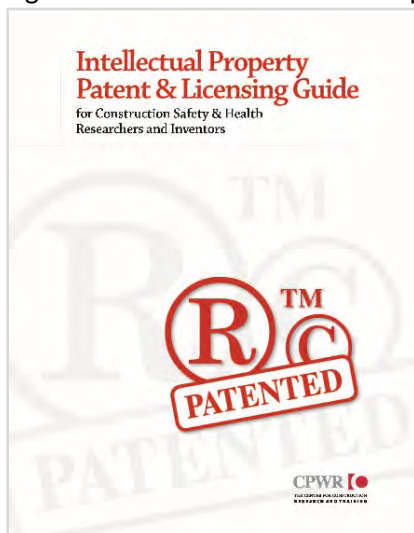
- ❖ U.S. Manufacturer, Telpro Inc., developed and marketed [DrillRite™ Overhead Concrete Drill Press](#) (Figure 27), a commercial version of the tool, now available for use on construction projects.

To help researchers address the types of technology transfer challenges encountered by Rempel and other researchers, CPWR developed an [Intellectual Property Patent and Licensing Guide for Construction Safety & Health Researchers & Inventors](#) (Figure 28), with accompanying materials, including a case study and technology transfer roadmap for researchers.

Intermediate Outcome:

- ❖ Since 2014, CPWR distributed more than 600 copies of the guide in print or downloaded from CPWR's website. The types of requestors include business (e.g., insurance companies, construction contractors, etc.), labor (e.g., unions and workers), academic, and government agencies. Specific users include, for example, International Union of Painters and Allied Trades, BAC, Teamsters, Kelpe Contracting Inc., Helix Environmental, Latino Workers' Resource Center, Old Republic Construction Program Group, the American Road and Transportation Builders Association, ISO, Construction Ergonomics, LLC, AGC of Missouri, Xcel Energy, the (U.S.) National Institutes of Health, and the Minneapolis Community and Technical College.

Figure 28. CPWR's Intellectual Property Patent and Licensing Guide.



Rig for Large Hammer Drills

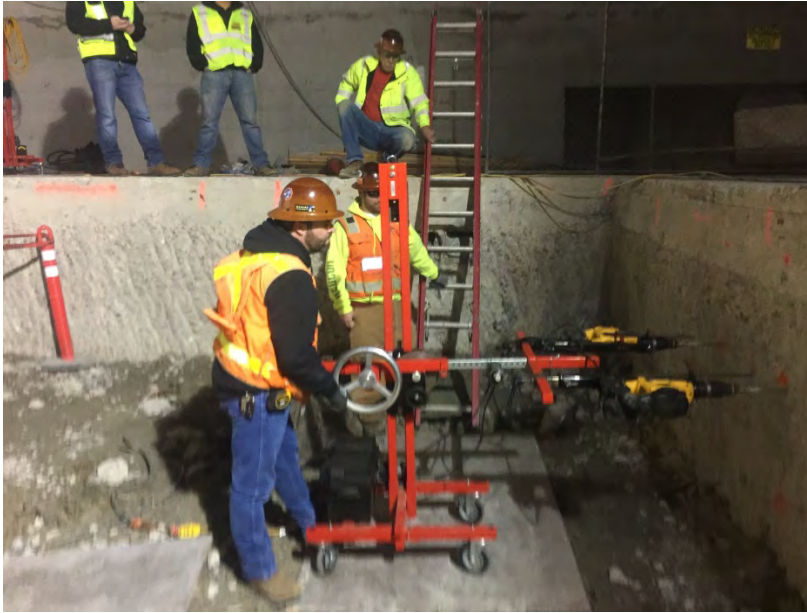
The relationships developed between contractors, unions, and the research team during the overhead drill press project led to a new one by Rempel, funded by NIOSH, to address the challenges presented by rotary impact hammer and rock drills, which can weigh up to 40 lbs. and are used in highway, bridge, and building foundation work. Drilling holes into concrete with heavy hammer and rock drills is one of the most physically demanding tasks performed in commercial construction. Rempel and Barr [2015] used a participatory intervention model, as in the development of the overhead drill press, to develop a support rig for pneumatic rock drills or large hammer drills to reduce the risk of MSDs and improve usability of the rig.

Researchers developed and modified seven prototype rigs based on feedback from commercial contractors and construction workers. Laborers and electricians evaluated the final design comparing the usual method and the new rig. Workers experienced a significant reduction in neck, shoulder, hand, arm, and lower back fatigue when using the new rig. In addition, usability ratings for the rig were significantly better on stability, control, drilling, accuracy, and vibration compared with the usual method—and drilling time reduced by about half. These results show the support rig as a viable tool for use by commercial construction contractors, laborers, and electricians who use large hammer drills for drilling many holes [Rempel and Barr 2015].

Intermediate Outcomes:

- ❖ Ergomek Inc., a U.S. manufacturer, produces and distributes a commercial version of the drill rig, called the [DrillBoss](#) (Figure 29). Large civil and commercial construction contractors purchase the DrillBoss. A short article and video about the support rig is available on the website [Toolsofthetrade.net](#).
- ❖ The United Association Union of Plumbers, Fitters, Welders, and Service Techs (UA) distributed an article describing the research and benefits of the drill jig to approximately 340,000 members in its December 2017 newsletter, Safety News [United Association 2017].

Figure 29. Image of the DrillBoss



Lifting and Manual Materials Handling

Ergonomic Guidelines

Construction workers commonly perform manual materials handling (MMH). Researchers have conducted many projects addressing MSDs, such as low back pain, which develop because of MMH tasks. NIOSH Program researchers in collaboration with external study partners developed new risk assessment methods for quantifying physical risk factors for LBP to address the limitations of the revised NIOSH Lifting Equation (RNLE). The new methods included risk assessments for variable lifting tasks, tasks involving job rotation, and video analyses for estimating postural risk information without interfering with the worker's job. Researchers also conducted projects to estimate the association between the lifting index and low back pain.

NIOSH researchers, along with Cal/OSHA, developed and wrote a high impact NIOSH publication relevant to construction ergonomics, [*Ergonomics Guidelines for Manual Material Handling*](#) [NIOSH/Cal/OSHA 2007]. The document details work methods that can minimize the risk of MSDs in a variety of work conditions. It discusses benefits to improving work tasks and many different improvement options such as changing work practices or using certain equipment. It also provides some resources such as administrative improvements, work assessment tools, and analysis methods.

NIOSH researchers also assisted in writing or revising ergonomic standards for MMH, such as the ISO Technical Group 159 Sub-Committee 3 [Anthropometry and Biomechanics](#) standard and the U.S. military ergonomics standard (MIL-STD-1472G-2012), [Design Criteria Standard: Human Engineering](#). RNLE adopted these new standards as the main risk assessment method for manual lifting. The new risk assessment methods, the risk information of the RNLE, and recent guidelines on pushing/pulling work are highly relevant to preventing MSDs in construction workers because of the significant manual material handling activities that occur in construction. The revisions of both standards expect publication dates in 2018. The forthcoming ISO standard cites NIOSH work [Dick et al. 2017; NIOSH 1994; Waters et al. 2007].

In response to a stakeholder request for expanded procedures for assessing complex manual lifting jobs, NIOSH and international collaborators developed two new methods for assessing complex lifting jobs—the sequential lifting index (SLI) and variable lifting index (VLI) [Waters et al. 2007; Waters et al. 2016].

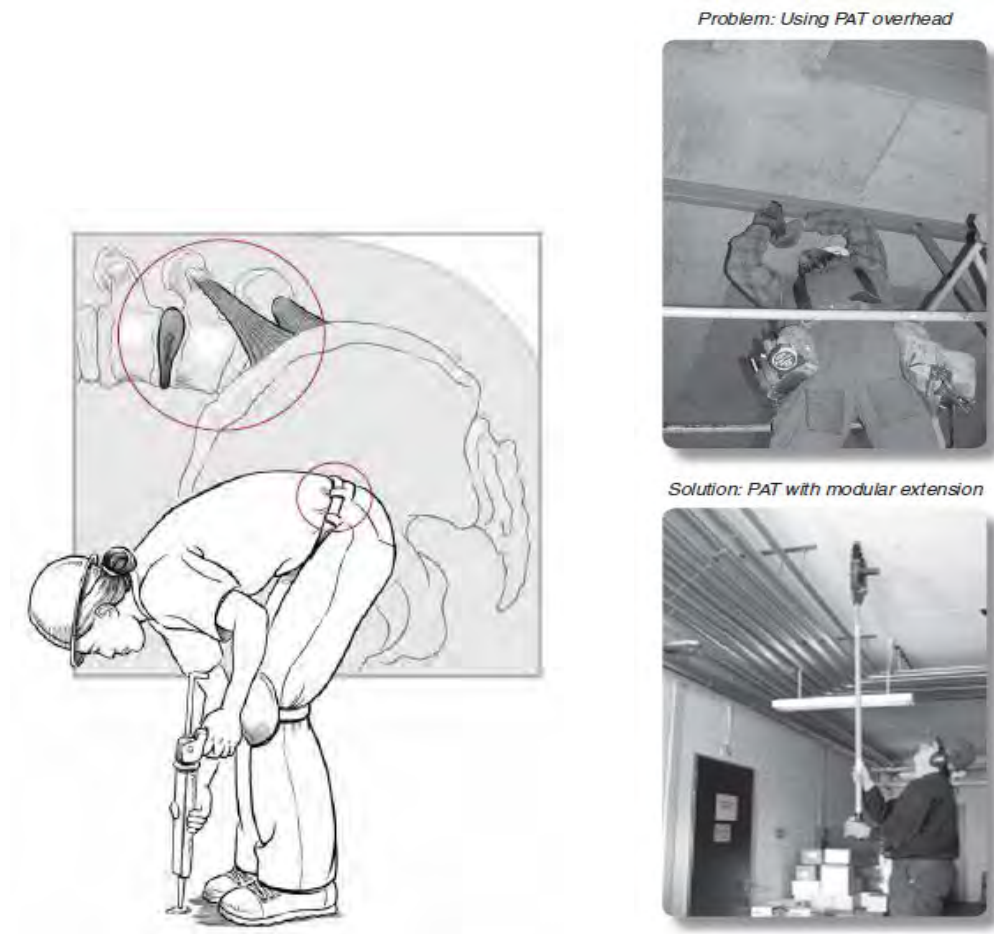
Intermediate Outcomes:

- ❖ The NIOSH document, [Ergonomics Guidelines for Manual Materials Handling](#), has received more than 65,000 downloads since 2007.
- ❖ The equations have been widely duplicated for other assessment tools, such as the Strain Index, which is used to assess jobs for the risk of work-related MSDs in the upper extremities [Garg et al. 2017a, b; Moore and Garg 1995].
- ❖ Litigation involving lifting injuries use this documentation, equations, and recommendations extensively ([Taylor v. TECO Barge Line Inc., 642 F. Supp. 2d 689 - Dist. Court, WD Kentucky, 2009](#); [COPING v. ELEMENTIS SPECIALTIES INC., Dist. Court, SD West Virginia, 2013](#)).
- ❖ Certified Professional Ergonomists use the NIOSH RNLE assessment tool frequently for most MMH guidelines [Dempsey et al. 2005].
- ❖ Many companies and labor groups base their weight limits on the NIOSH RNLE [Lu et al. 2016], such as General Motors, Automotive Industry Action Group [AIAG 2007], [Laborers' Health and Safety Fund of North America](#) and the [United Automobile Workers of America](#).

Simple Ergonomic Solutions

NIOSH construction intervention research for MSD prevention focused on engineering control technologies that reduce exposures to force, non-neutral work posture, and repetition. NIOSH developed two “Simple Solutions” publications, one for construction workers and the other for home building workers; both significantly influenced the construction sector. The first, [*Simple Solutions: Ergonomics for Construction Workers*](#) (Figure 30), provides many simple and inexpensive ways to make construction tasks easier, more comfortable, and better suited to the needs of the human body [NIOSH 2006]. This product was one of [six finalists](#) in the Training and Education category of the [2008 Ergo Cup® Competition at the Annual Applied Ergonomics Conference](#). CPWR added “Simple Solutions” to their [Construction Solutions](#) database, the [Choose Hand Safety](#) website, developed as a project of the Masonry r2p Partnership, and the [Ergonomics Community of Practice online resources](#).

Figure 30. Examples of the photos and illustrations in the NIOSH Simple Solutions-Ergonomics for Construction Workers.

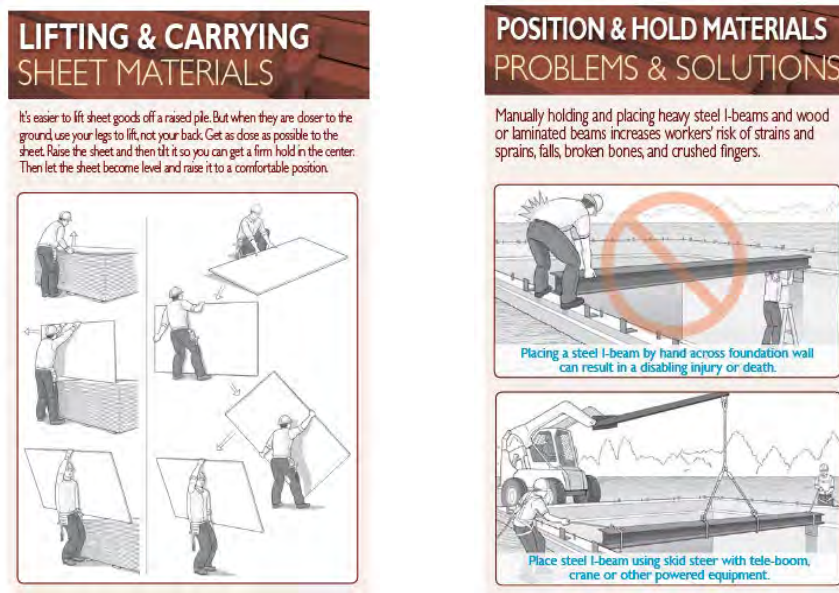


Intermediate Outcomes:

- ❖ The [Laborer's Health and Safety Funds website](#) and the [OSHA website](#) both refer to the Simple Solutions document. The Simple Solutions document received over 21,000 downloads from the NIOSH website.

NIOSH-conducted reviews of construction safety and health research, ergonomic and intervention literature, and construction print and electronic trade publications to identify potential work-related MSD risk factors and interventions. NIOSH researchers translated the results of this review, which included NIOSH-supported extramural research in residential construction into the second publication. The second document, [Simple Solutions for Home Building Workers](#) (Figure 31), describes how individual workers and groups of workers (e.g., crews) can take action and use readily available procedures and equipment to reduce the risks of developing MSDs [NIOSH 2013]. Written specifically to appeal to new and experienced residential construction workers, contractors, and builders, and available in English and Spanish, it includes many illustrations as appropriate for lower-literacy workers. In addition to the worker engagement information provided, the document describes additional actions that subcontractors and builders may take to reduce further the risks of MSDs.

Figure 31. Images from the NIOSH Simple Solutions for Home Building Workers publication.



Intermediate Outcome:

- ❖ This document received about 3,935 downloads since its 2013 publication.

Lifting Equation App

The NIOSH MSD Program researchers teamed up with the NIOSH Communications Office to develop a RNLE [mobile application \(app\)](#). The app (Figure 32) helps to: (1) raise worker awareness about risks associated with manual lifting; (2) inform workers about the potential hazards to their musculoskeletal health; and (3) serve as a job design guide for manual lifting tasks. The app provides instant information to help workers or their managers effectively control risks associated with the lifting task. The mobile app became available through [Apple iTunes](#) and [Google Android](#) stores in August 2017. CPWR's pilot social marketing program on [Manual Materials Handling program](#), initiated as part of the Center's ECP (page 108), incorporated the app into their program.

Intermediate Outcome:

- ❖ In just the first two months, the mobile app received more than 5,000 downloads from the NIOSH website. The app has been featured in many occupational safety and health websites, including
 - [Safety and Health: The Official Magazine of the National Safety Council Congress and Expo](#)
 - [Environmental Resource Center](#)
 - [Occupational Health and Safety Magazine](#)
 - [Gallaway Safety and Supply](#)
 - [Construction Executive: Tech Trends](#)
 - [Worker Health and Safety Centre](#)
 - [National Safety Council Nebraska](#)
 - [Connection Signs](#)

Figure 32. Website for the NIOSH lifting equation app.

ERGONOMICS AND MUSCULOSKELETAL DISORDERS



NIOSH Lifting Equation App: NLE Calc

The National Institute for Occupational Safety and Health (NIOSH) Lifting Equation mobile application, NLE Calc, is a tool to calculate the overall risk index for single and multiple manual lifting tasks. This application provides risk estimates to help evaluate lifting tasks and reduce the incidence of low back injuries in workers.



Download NLE Calc today!

[Apple iTunes](#)

[Google Play](#)

Key Benefits

- Calculates the composite lifting index (CLI) for multiple lifting tasks
- Uses equations approved by NIOSH ergonomists, who were the original creators of the NIOSH Lifting Equation (NLE)
- Promotes better musculoskeletal health
- Raises workers' awareness about their job tasks
- Helps workers make informed decisions about the potential hazards to their musculoskeletal health
- Serves as job design guidelines for manual lifting tasks
- Can be used as a research tool to collect manual lifting data

Send Us Your Feedback or Request Help



In 2014, NIOSH collaborated with the Canadian Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD) to prepare a research to practice (r2p) translational product related to preventing MSDs. The document, [Observation-Based Posture Assessment: Review of Current Practice and Recommendations for Improvement](#) [NIOSH 2014], parallels a [position paper by Canadian Centre of Research Expertise for the Prevention of Musculoskeletal Disorders](#) [Andrews et al. 2016] which shows international collaboration on an important MSD topic: posture.

Intermediate Outcome:

- ❖ Users downloaded this NIOSH document 8,385 times since publication in 2014.

Manual Materials Handling in Key Construction Trades

CPWR partnership activities identified construction work involving significant MMH, including tasks in masonry, drywall, framing, and carpentry, which frequently require heavy lifting and awkward postures. A description of several research partnerships and r2p activities follow.

Bricklayers

Bricklayers are at high risk for MSDs because of frequent lifting of bricks and concrete blocks. They can lift approximately 4,000 kg (over 8500 pounds) of materials on a typical workday [Moraski and Watters 2009]. In a NIOSH-funded study, apprentice bricklayers constructed walls with concrete blocks alone (one person) and in two-person lift teams to evaluate trunk and upper extremity kinematics and muscle activity [Anton et al. 2013]. Working in lift teams required less trunk flexion but more side-bending than working alone. Overall, working in lift teams helped to reduce trunk flexion and lower back activity when bricklayers work at heights between the knees and waist.

Intermediate Outcome:

- ❖ These study results support the use of two-man lift teams and weight limits in collective bargaining agreements: see examples for BAC in St. Louis, MO and Boston MA [BAC and Mason Contractors Association of Massachusetts 2017]:
 - The Bricklayers and Allied Craftsmen (BAC) Local Union No. 3 in Eastern Massachusetts and the Mason Contractors Association of Massachusetts agreed to the following contract language in Section 16: *On all masonry when blocks are used, whether said blocks be of cement, cinders or terra cotta, and are in sizes 8 x 8 x 16 inches, 8 x 12 x 16 inches, 12 x 12 x 12 inches, and also where any substitutes are used for the materials mentioned above, which are equal in size or weight or larger, two bricklayers shall work as a team in lifting and laying of all said materials starting with the first course of masonry. Scaffolding for these materials shall be no higher than four (4) feet (for scaffolding height). Walls shall not exceed four (4) feet eight (8) inches in height except for units over 8 x 8 x 16 inches, which shall not exceed four (4) feet.*
 - The Bureau of National Affairs nationally reported the St. Louis agreement, [BNA Construction Labor Report](#):

According to the Local 1 statement, the union was able to hold firm on one MCA proposal that the contractors had pushed for early on, that the weight limit on blocks to be lifted by one worker be increased from 30 pounds to 40 pounds. The contractors argued that the most common block in use for load-bearing masonry weighs 40 pounds, and that increasing the weight limit

would help the mason contractors increase their market share. But in the final deal, the 30-pound weight limit remained in place [Bloomberg BNA 2011].

This research also influenced the content of the CPWR Hazard Alert [Back Injuries](#) and the NIOSH-CPWR co-branded toolbox talk [Lifting and Carrying Materials](#), which both show the use of two-person lift teams. In addition, CPWR developed a video, [Advantages of a Two-Mason Lift Team](#). Both [eLCOSH](#) and the [Ergonomics Research & Solutions](#) of CPWR's website established by the ECP (page 108) posted the video. CPWR also publishes the infographic, [How much does a bricklayer lift?](#), available through the CPWR website.

Intermediate Outcomes:

- ❖ The International Union of Bricklayers and Allied Craftworkers (BAC) posted the [video on their website](#)—they present the [video at BAC workshops and training programs](#).
- ❖ Users downloaded *How much does a bricklayer lift?* over 200 times since 2016. The International Union of Bricklayers and Allied Craftworkers [District Council of West Virginia' Training Center](#) and the [Minnesota/North Dakota Training Centers](#) both posted the infographic on their Facebook pages.

Concrete Masonry Units vs. Autoclaved Aerated Concrete

CPWR consortium researchers conducted an ergonomic evaluation of autoclaved aerated concrete (AAC), a lightweight, foam concrete building material, to determine if it could reduce the risk of shoulder and back injury to masons. AAC is purported by manufacturers to have many construction benefits because it potentially lowers building costs by saving on building materials (e.g., no need for drywall) and labor, environmentally friendly to manufacture and 33% lighter weight, provides thermal and acoustic insulation, and possesses excellent fire and termite resistance.

The study evaluated shoulder exposure parameters, low back stress, and worker perceptions in two groups of journey-level masons: one group using concrete masonry unit (CMU) and the other group using AAC block. Results indicate that CMU masons had significantly greater shoulder and low back pain, and they held block significantly longer

than AAC masons. Lower back compressive forces were high for both materials. Masons handling AAC demonstrated less left upper extremity stress compared with CMU masons, but researchers estimated both materials to be hazardous to the low back [Hess et al. 2010b]. CPWR developed a [return on investment \(ROI\) calculator example for lightweight block](#), such as AAC (Figure 33).

Figure 33. Return on investment calculator example for lightweight block.

(Current File: CMU - Based on Unit of Material) Load an example Help Getting Started

Project Description
(e.g. number of units installed, times equipment is used, or tasks performed, and time period if it impacts cost)

Install 255,000 lightweight and 255,000 heavyweight CMU

	Lightweight CMU	Heavyweight CMU
Name of equipment, material, or work practice	Lightweight CMU	Heavyweight CMU
Cost to purchase or lease & maintain	\$ 318,750.00 Edit	\$ 255,000.00 Edit
Cost to train & deploy	\$ 0.00 Edit	\$ 0.00 Edit
Worker productivity	\$ 405,819.06 Edit	\$ 501,300.00 Edit
Injury costs	\$ 0.00 Edit	\$ 6,397.00 Edit
Total cost:	\$ 724,569.06	\$ 762,697.00

Comparison: Lightweight CMU is \$38,127.94 less expensive than Heavyweight CMU.

Notes:
This example compares the time it takes to install 255,000 lightweight blocks to the time it takes to install 255,000 heavyweight blocks. Click on any section you want to alter.

Email Print Log in to Save and Load Files Start Over

CPWR added the ROI example to [CPWR's Construction Solutions](#) website, and CPWR's [Ergonomic Community of Practice](#) (page 108) used the ROI example in the development of their pilot social marketing program focused on reducing manual materials handling.

Intermediate Outcome:

- ❖ The Masonry r2p Partnership included findings of this study in their [Safety Intervention Sheet: Reducing Back Injuries in Masonry](#), which has been distributed at the Labor-Management Craft Committee meetings and posted on

the [International Council of Employers of Bricklayers and Allied Craftworkers](#) website [Betit 2013; Hess et al. 2010a; Hess et al. 2012].

Alternatives to Lifting Concrete Masonry Blocks onto Rebar

Another CPWR-funded study by Hess et al. at the University of Oregon involved a biomechanical and perceptual evaluation of two alternatives to lifting concrete masonry blocks onto vertical rebar: H-block and high lift grouting (Figure 34). Masons place H-block around rebar instead of lifting over it rebar; high lift grouting, where rebar is threaded through the cells, reduces lifting. Researchers evaluated peak and cumulative shoulder flexion, adoption barriers, costs, and stakeholder (contractor) perceptions. Results indicated that using the alternatives significantly decreased peak shoulder flexion. Findings found building costs higher with H-block but not enough to affect total costs. Contractors reported important differences in perceptions, work norms, material use, and practices. Contractors should consider using H-block or high-lift grouting methods to reduce awkward upper extremity postures, though cost and stakeholders' perceptions present barriers to be aware of when developing diffusion strategies for these alternatives. This study provides information from several perspectives about ergonomic controls for a high-risk bricklaying task, information beneficial to occupational safety experts, health professionals, and ergonomists [Hess et al. 2012].

Figure 34. Three approaches to building concrete masonry block walls.



(a) Placing conventional CMU



(b) Placing H-block



(c) High-lift grouting

Social Marketing Pilot

In 2016, CPWR established an ECP (page 108) to identify new ways to advance the use of ergonomic interventions and reduce MSDs in construction. The ECP conducted formative research to understand the extent to which construction contractors take action to reduce MMH-related injuries, the barriers to engaging in safer practices, and how safety-minded contractors successfully overcame common barriers and the associated risks on their job sites.

First, CPWR conducted a national survey of a convenience sample of construction contractors to learn the extent taken to reduce MMH on their jobsites [Betit et al. 2017]. The majority (85%) of respondents considered themselves “very” or “somewhat” knowledgeable about hazards that cause MSDs and how to prevent them (79%). When asked about the extent they incorporate strategies to minimize MMH into their site plans, 57% reported doing this both during pre-planning and when the project was underway. The remaining respondents reported incorporating strategies only during pre-planning (21%), only while the project was underway (11%), or they do not plan for MMH (11%).

When surveyed about specific strategies they use to manage MMH, roughly half of the respondents said they set lifting limits and store materials between knee and waist height—half said they do not. However, when provided with a list of common MMH strategies and asked to select all that they use, respondents did not often include strategies related to setting lifting limits and storing materials between knee and waist height. Respondents reported that the top motivators for adopting safer MMH strategies were workers’ compensation incentives, job contract requirements, and efforts to protect materials. Perceived barriers to adopting safer MMH strategies centered on not knowing the weight limits to set, a lack of awareness or access to equipment or simple structures for safe storage, no planning experience, and the perception that planning is too difficult [Betit et al. 2017].

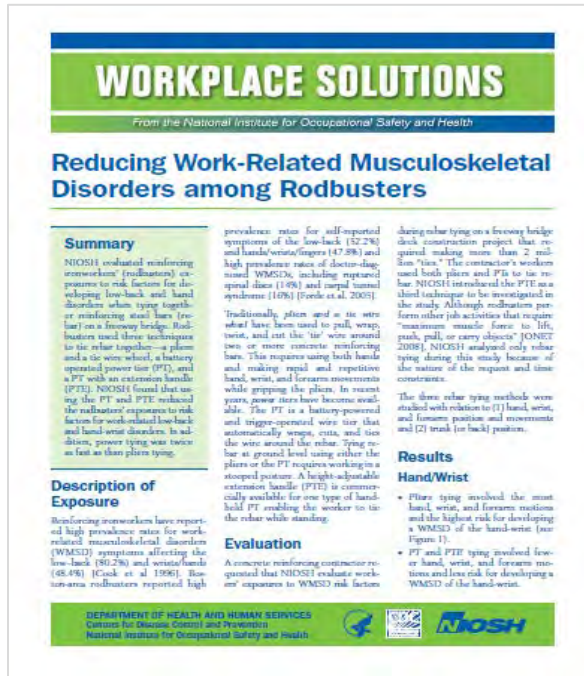
Based on the survey results, Betit and colleagues conducted additional qualitative research to examine how safety-minded contractors overcame common barriers to safer MMH practices. The researchers interviewed 12 contractors identified by others in their areas of construction as engaging in safer MMH practices. The interview results found that all of the contractors considered how to minimize MMH within routine job

scoping, bidding, project operations and execution, and job hazard analyses. Researchers found the results consistent regardless of the size of the contractor, their trade, or their chosen approach to mitigate MMH risks. The survey results and the information from the 12 contractors suggest promoting safer MMH through a program that focuses on positioning safer MMH practices as a core element of contractors' project planning and "good construction business practices." This can provide contractors with the knowledge, resources, and research findings to support their planning activities [Betit et al. 2017].

Rebar Tying Tools

NIOSH researchers studied ironworkers' risk for developing back and hand injuries from hand-tying reinforcing steel bar (also called 'rebar') to determine whether power tying tools can be an effective intervention for the prevention of work-related MSDs [Albers and Hudock 2007]. They conducted a field investigation of biomechanical loading when using three common techniques to tie together rebar while measuring employees' wrist and forearm movement. Manually tying rebar with pliers at ground level involved sustained deep trunk bending and rapid, repetitive, and forceful hand-wrist and forearm movements. Using a power tier, which automatically cuts, wraps, and ties the rebar, significantly reduced the hand-wrist and forearm movements. The powered device also allowed the ironworkers to use a free hand to support their trunk posture while tying; furthermore, it was twice as fast as using pliers. Adding an extension handle to the power tier allowed the ironworkers to tie rebar while standing erect, further minimizing sustained trunk flexion. Research related to rebar tying ergonomics and the benefits of powered rebar tying tools resulted in an important output, [*Workplace Solutions: Reducing Work-Related Musculoskeletal Disorders among Rodbusters*](#) [NIOSH 2010] (Figure 35).

Figure 35. The NIOSH Workplace Solutions for the rebar tying document.



Intermediate Outcomes:

- ❖ The dissemination of the study results through secondary channels helped [Max USA Corp.](#) communicate health and safety benefits to tool users. These activities and products resulted in increased use of powered rebar tying tools in the industry, reducing risk factors related to rebar tying [Earnest 2018].
- ❖ A number of trade magazines highlighted NIOSH studies of rebar tying risk factors and rebar tying tool intervention including [For Construction Pros](#) online magazine and [Public Works](#) online magazine [For Construction Pros 2013, Public Works 2016].

Dissemination Efforts

It is important to disseminate MSD-related research with construction stakeholders and encourage r2p [Choi et al. 2016]. To accomplish this, significant communications efforts occur. CPWR accomplishes this effort using several key web-based systems.

Toolbox Talks

CPWR's toolbox talks (page 65), designed for brief discussion sessions on jobsites, raise worker awareness of potential hazards and preventative measures. There are five

toolbox talks with this format related to MSDs or vibration: *Carpal Tunnel Syndrome*, *Materials Handling: Drywall; Hammer; Lifting and Carrying Materials*; and *Vibration* (Figure 36). The toolbox talks are available in English and Spanish, accessible directly on the [CPWR website](#); or through CPWR's [Electronic Library of Construction Occupational Safety and Health \(eLCOSH\)](#). Users can access three other CPWR toolbox talks in an earlier format—*Vibration*, *Ergonomics in Construction*, and *Selecting Hand Tools*—through the [Choose Hand Safety](#) website. These toolbox talks received 72,232 downloads and 12,157 page views from August 2013 through August 2017.

Figure 36. The CPWR toolbox talk on vibration.



Webinars

CPWR conducted webinars on ergonomic research and interventions to provide researchers an opportunity to share their research findings and get direct input from industry stakeholders—the target audiences for their research. Two CPWR webinars and one for an insurance company's construction clients have addressed MSDs:

- ❖ As of August 31, 2017, 142 stakeholders attended or viewed [Health and Safety Risk Reductions Using Pre-fabricated Concrete Formwork Systems](#).
- ❖ As of August 31, 2017, 111 stakeholders attended or viewed [Health and Safety Considerations for Powered Hand-tools Used in Construction](#).

- ❖ *How to Integrate Ergonomics into Your Construction Health and Safety Management*, part of the [Marsh Insurance Company's](#) Quarterly Construction Webinar Series presented on March 3, 2016 [Moore 2016].

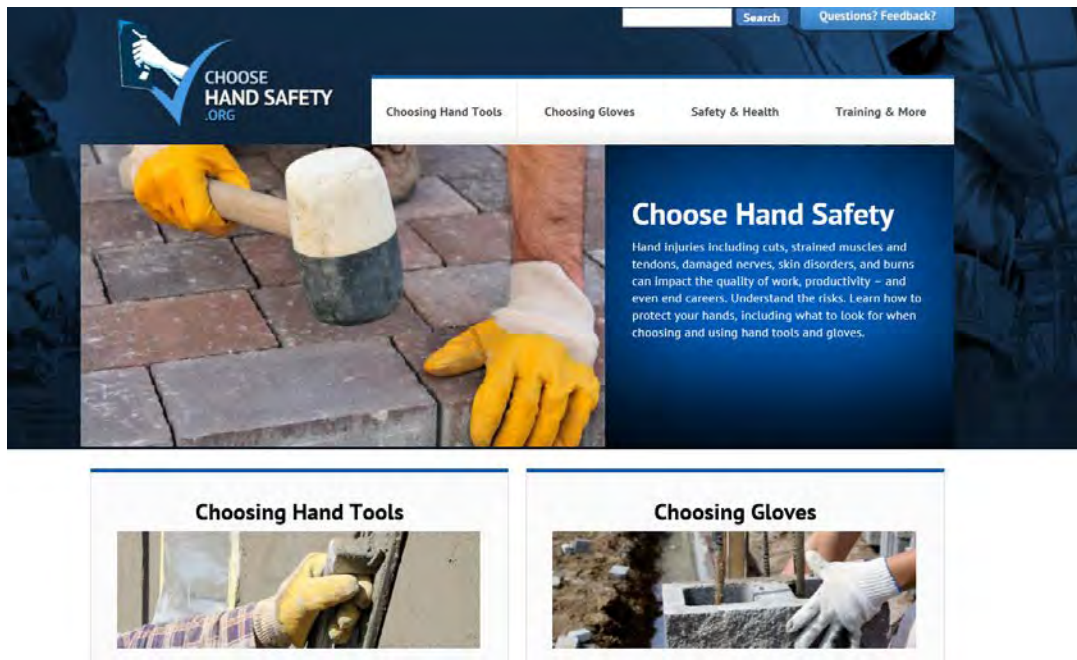
Hand Safety Website

CPWR and the Masonry r2p Partnership (page 75) collaborated to develop CPWR's [Choose Hand Safety](#) website (Figure 37) in 2014. The website focuses on reducing carpal tunnel syndrome by promoting safe use of hand tools and appropriate gloves to prevent vibration and chemical injuries/illnesses. The website serves as a vehicle to disseminate related research findings, interventions, and translational products. It includes unique features and online tools to identify ways to prevent MSDs and other hand injuries.

Intermediate Outcome:

- ❖ While developed with a focus on the masonry industry, other trades in the construction industry also use the website. The BAC has promoted the use of the Choose Hand Safety website on their [website](#).

Figure 37. Images from the Choose Hand Safety website.



Consensus Standard Activities

NIOSH participation in the development and revision of standards and regulations ensures timely transfer of NIOSH and Construction Center MSD findings, as well as the acquisition of new knowledge. MSD researchers participated in several workgroups and committees on MSDs, human vibration, and wearable robots, including International Standards Organization (ISO), Acoustical Society of America (ASA), ANSI, American Conference of Governmental Industrial Hygienists (ACGIH), and Society of Automotive Engineers (SAE). Various conferences and journal article publications presented the findings and knowledge from these activities. This work not only influenced the studies of other researchers, but workplace practitioners and consultants also adopted their findings. NIOSH researchers led or played a critical role in the development, review, and revision of many of the national and international standards associated with MSDs and human vibration including coordinating the U.S. reviews of the international standards associated with hand-arm vibration exposure.

Intermediate Outcome:

- ❖ ANSI published a consensus standard on sprain and strain injuries in construction in 2008 (renewed in 2013), ANSI/ American Society of Safety Engineers (ASSE) [*A10.40 Reduction of Musculoskeletal Problems in Construction*](#) [ANSI 2013]. This standard references information from both NIOSH and CPWR on how to prevent MSDs in construction—the most common and costly injuries in the industry. The standard summarizes best practice and establishes criteria for assessing if a construction jobsite uses responsible safety practices. The standard recognizes sprain and strain injuries as a major problem in construction and identifies an employer’s duty to review jobsites for ergonomic dangers, assess significant risks, and work with employees to reduce risk exposures.

NIOSH researchers are also contributing to activities on the following committees:

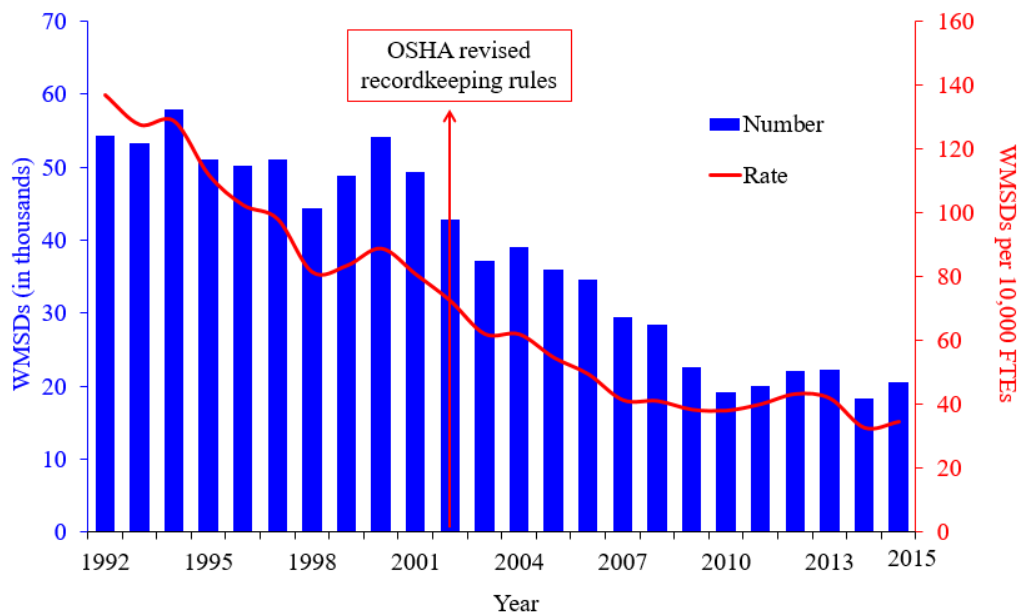
- ANSI-Accredited Standards Committee S2/Working Group 39 – Human Exposure to Mechanical Vibration and Shock
- Accredited Standards Committee Sub-Committee 2 (Mechanical Vibration and Shock), and the U.S. Technical Advisory Groups to 108/SC4 (Human Exposure to Mechanical Vibration and Shock)

- SAE International Technical Committee EG-1B1 for Powered Hand Tools - Productivity, Ergonomics and Safety
- Technical committee for the revision of military standard MIL-STD-1472H Section 5.5.5 – Vibration & Shock.
- Robotic Industries Association ANSI R15.08 Subcommittee on Industrial Mobile Robot Safety
- Robotic Industries Association ANSI R15.06 Subcommittee on Industrial Robot Safety
- ASTM F48: Exoskeletons and Exosuits; Executive Subcommittee F48.90 and Subcommittee F48.02 – Human Factors and Ergonomics

End Outcomes

The number of work-related MSDs in construction (Figure 38) dropped significantly from 2007 through 2015, following the overall trend from 1992. MSD rates also decreased during the same time, although by a lesser amount. In 2015, the number of MSDs in construction increased slightly to 20,510, which was still 40% of the 1992 level. The 2015 rate of 34.6 per 10,000 FTEs was 25% of the 1992 rate. Despite the reduction, the rate of MSDs in construction was still 16% higher than the rate of 29.8 per 10,000 FTEs for all industries combined in 2015. Both, the number and rate of MSDs resulting in days away from work dropped to a record low in 2014, even lower than the recession-related drop in 2010. Researchers consider these numbers underestimated due to problems with determining the work-relatedness of MSDs as well as underreporting [BLS 2015; CPWR 2018].

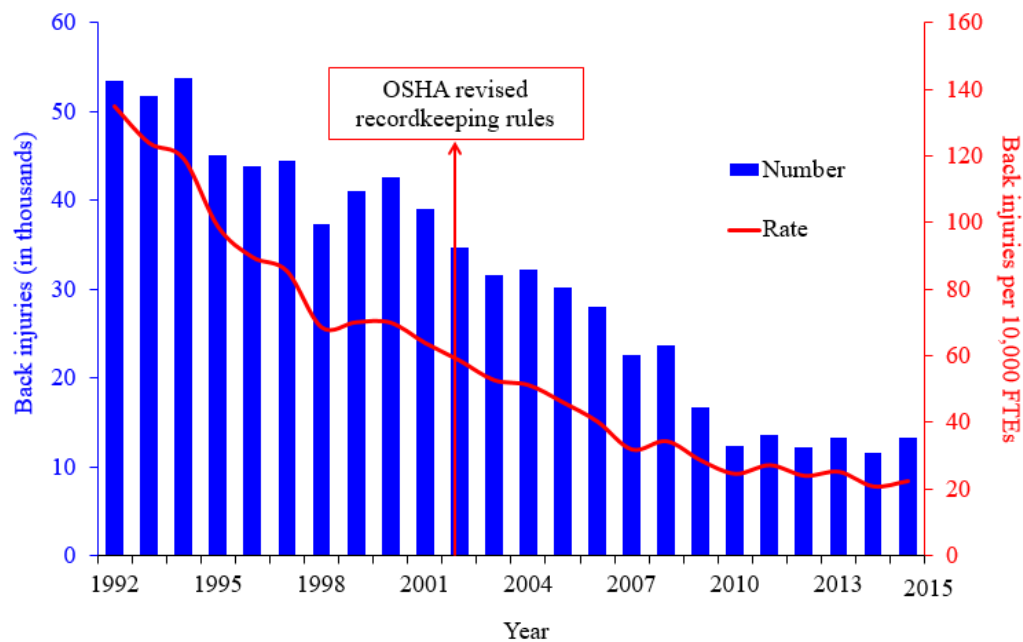
Figure 38. Number and rate of work-related MSDs in construction [CPWR 2018].



Source: U.S. Bureau of Labor Statistics. Survey of Occupational Injuries and Illnesses. Data obtained from the BLS by special request.
Calculations by the CPWR Data Center.

The number of reported back injuries in construction (Figure 39) declined over the past two decades. In 1992, there were more than 50,000 back injuries among construction workers reported to the BLS, but just over 13,000 such cases in 2015—a greater than 60% decrease. During 2003 through 2015 both number and rate of back injuries each year declined approximately 58%. Despite these changes, construction workers still had a higher rate of back injuries in 2015 than in all industries combined (22.3 versus 16.2 per 10,000 FTEs); and the fourth highest rate among major industry groups [BLS 2015; CPWR 2018].

Figure 39. Number and rate of back injuries resulting in days away from work in construction, 1992–2015 (Private wage-and-salary workers) [CPWR 2018].



Source: U.S. Bureau of Labor Statistics. 1992–2015 Survey of Occupational Injuries and Illnesses, <http://www.bls.gov/data/#injuries>.

Alternative Explanations

Many factors, including NIOSH research, played a role in the significant reduction of MSDs and back injuries in the construction sector. While a regulatory framework for addressing MSDs does not exist in most states, Washington and California are exceptions. In anticipation of the implementation of the Washington ergonomics standard, a significant amount of effort, both in Washington and neighboring Oregon, was directed towards identifying MSD risk factors and assessing control technologies to reduce hazardous exposures. The Washington State ergonomics standard, however, was rescinded in 2004. The California ergonomics standard, which took effect in 1997, raised awareness of MSDs among contractors and trades people, perhaps playing an important role by influencing work in this area [Jewell and Bero 2006]. The OSHA ergonomics standard, implemented in 2000 but rescinded soon after, may have positively influenced the work and safety trends by bringing additional attention to MSDs and ergonomics in general [Seo and Blair 2003].

A possible increase in the underreporting of MSDs could be another factor—research shows construction and other industries commonly underreport work-related injuries.

The safety culture in construction dissuades workers from reporting minor injuries and encourages them to deal with the pain as just part of the job. Frequent reasons for not reporting MSDs relate to perceptions of injuries as “small” and “part of the job” as well as fear of negative consequences, which may follow injury reporting. As more construction workers are Hispanic workers or in nonstandard work arrangements, these factors could also play a reporting role. All of these psychosocial, economic, and cultural factors likely influence the WMSD numbers and rates.

Future Plans

The NORA Construction Sector Council (which NIOSH co-chairs) developed a draft National Occupational Research Agenda for Construction that identifies needed MSD-related research. This research area was included in NIOSH’s new Strategic Plan for fiscal years 2019 through 2023. Some of the current MSD-related efforts discussed next will continue for the next several years.

The average age of construction workers increased from 36 to 41.5 years within the last decade. To address the health and safety needs of aging construction workers, there needs to be greater emphasis on MSDs. The burden of MSDs on aging construction workers warrants the development of a broader range of Workplace Solutions (WPSs) and other NIOSH products. According to Silverstein’s healthy aging model, there are four strategic dimensions for meeting aging workers’ needs—work environment, organization of work, employees, and social support [Silverstein 2008]. Researchers gain information on possible product development by analyzing the MSDs-related claims and focus group feedback from construction employers and workers of various ages.

As NIOSH research places more attention on automation and robotics, researchers have begun studying the use of exoskeletons to address MSDs in construction and other industries. While this research is in its infancy at NIOSH, researchers have been participating in standard-setting committees on this topic and have produced several NIOSH Science Blogs related to the potential benefits and challenges of exoskeleton use including [Wearable Exoskeletons to Reduce Physical Load at Work](#) [Lowe et al. 2016] and [Exoskeletons in Construction: Will they reduce or create hazards?](#) [Zingman et al. 2017].

There is a need to provide a foundation for improved HTV assessment methods and new intervention strategies for reducing occupational HTV exposures. This, in turn, may lead

to better recommendations, criteria, guidelines, and standards relating to occupational HTV exposures and their consequences. Therefore, NIOSH researchers are also evaluating using exoskeletons as an intervention for minimizing occupational HTV exposures. This effort will investigate the effects of awkward postures, armloads, and their exposure durations on the biomechanical loads and physiological effects related to muscle fatigue in the shoulder. This knowledge will help researchers formulate the combined force and duration of exposures to reduce WMSDs, evaluate the effectiveness of exoskeleton system interventions for reducing shoulder disorders by examining intervention effects on the daily exposure dose, and improve and optimize the exoskeleton system by supporting tool weight and reducing hand forces.

Work-related physical risk factors are the main source of lower back problems (LBP). These physical risk factors include heavy and repetitive manual lifting, awkward posture, and long work hours. Combinations of these factors may lead to an increasing risk of developing LBP. The main goal of ergonomic interventions is to reduce the physical risk factors. Researchers also need accurate risk assessment methods to evaluate the effectiveness of the interventions. Many risk assessment methods quantify physical risk factors of MSDs including LBP, but the majority used by practitioners are checklists or subjective ratings, which have numerous limitations. Researchers are developing an objective risk-assessment tool, which is an inexpensive wearable system, capable of automatically measuring multiple LBP physical risk factors associated with manual lifting. MSD risk data collected with the proposed wearable system will advance scientific knowledge about the cumulative effects of work-related risk factors.

Masons have the highest rate of overexertion injuries among all construction trades and rank second for occupational back injuries in the U.S. The SAVE program, Safety Voice for Ergonomics, which is a coordinated project between the Masonry r2p Partnership and CPWR consortium researchers, will integrate evidence-based health and safety training strategies into masonry apprenticeship skills training to teach ergonomics, problem solving, and communication to reduce MSD risk. The central hypothesis is that the combination of ergonomics training and safety voice promotion (soft skills like responsibility and speaking up to co-workers and supervisors about unsafe conditions) will be more effective than no training, or either ergonomics training alone or safety voice training alone. Researchers will evaluate SAVE training in controlled trials at

selected U.S. masonry training centers. Researchers expect a vetted intervention for masonry apprentices to reduce MSDs [Kincl et al. 2016].

The construction sector employs approximately 1.8 million Spanish-speaking workers, and Hispanic workers are injured and killed at rates two to three times higher compared with non-Hispanic construction workers. Over 40% of Spanish-speaking construction workers work for small businesses with limited resources for OSH training. CPWR successfully disseminated the toolbox talk series throughout the construction industry. NIOSH and CPWR have collaborated, with input from subject matter experts, to further refine and update the content and co-brand the series. CPWR's research found that Spanish-language versions of the toolbox talks that are culturally relevant and use more visuals might experience higher acceptance by small construction contractors and young, immigrant Latino workers than factual narrative formats. Two new microgames on manual materials handling will supplement toolbox talk content on MMH and will be accessible in English and Spanish. Microgames are very brief, interactive, and highly visual training tools for use on smartphones or tablets.

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Chapter 4: Noise and Hearing Loss



[Credit: SNC-Lavalin/Earl Dotter/CPWR]

Introduction

Hearing loss is one of the most common work-related illnesses in the United States (U.S.) [Themann et al. 2013a]; more than 11% of the working population has hearing difficulty. Occupational exposures account for 24% of worker hearing difficulty [Tak and Calvert 2008], which include hazardous noise and ototoxic chemicals (e.g., chemicals causing damage to the inner ear). In the U.S. workplace, 17% of workers (approximately 22 million) are exposed to hazardous noise each year [Tak et al. 2009].

Within the U.S. construction sector, a wide range of sources cause hazardous noise exposures, including hand tools, larger machinery, heavy equipment, and generators. Many construction workers risk exposure to impulse or impact noise and hazardous noise levels. One study by Tak and others, using National Health and Nutrition Examination data, found that 44% of construction workers reported hazardous noise

levels at work; about 31% of construction workers reporting this hazardous noise also reported not wearing hearing protection [Tak et al. 2009]. Another study found that almost three-quarters (73%) of construction workers were exposed to noise levels above the NIOSH recommended exposure level (REL) of 85 dBA [CPWR 2010a]. (Decibels, dB, are unweighted sound pressure levels, and dBA levels are A-weighted—similar to how the human ear hears sound.)

These exposures can cause significant hearing impairment—defined as hearing loss that affects day-to-day activities. Using anonymous audiograms collected by the National Institute for Occupational Safety and Health (NIOSH) for hearing loss surveillance, Masterson and others found that 25% of construction workers have a hearing impairment in at least one ear [Masterson et al. 2015], 16% have hearing impairment in both ears, and seven percent have tinnitus (hearing ringing, roaring, or buzzing sounds) [CDC 2016]. During 2001 through 2010, 21% of construction workers incurred at least one standard threshold shift [Masterson et al. 2014]. A significant threshold shift is when the hearing threshold (lowest level heard 50% of the time) changes (relative to the baseline audiogram) an average of 10 dB or more at 2000, 3000, or 4000 Hz in either ear.

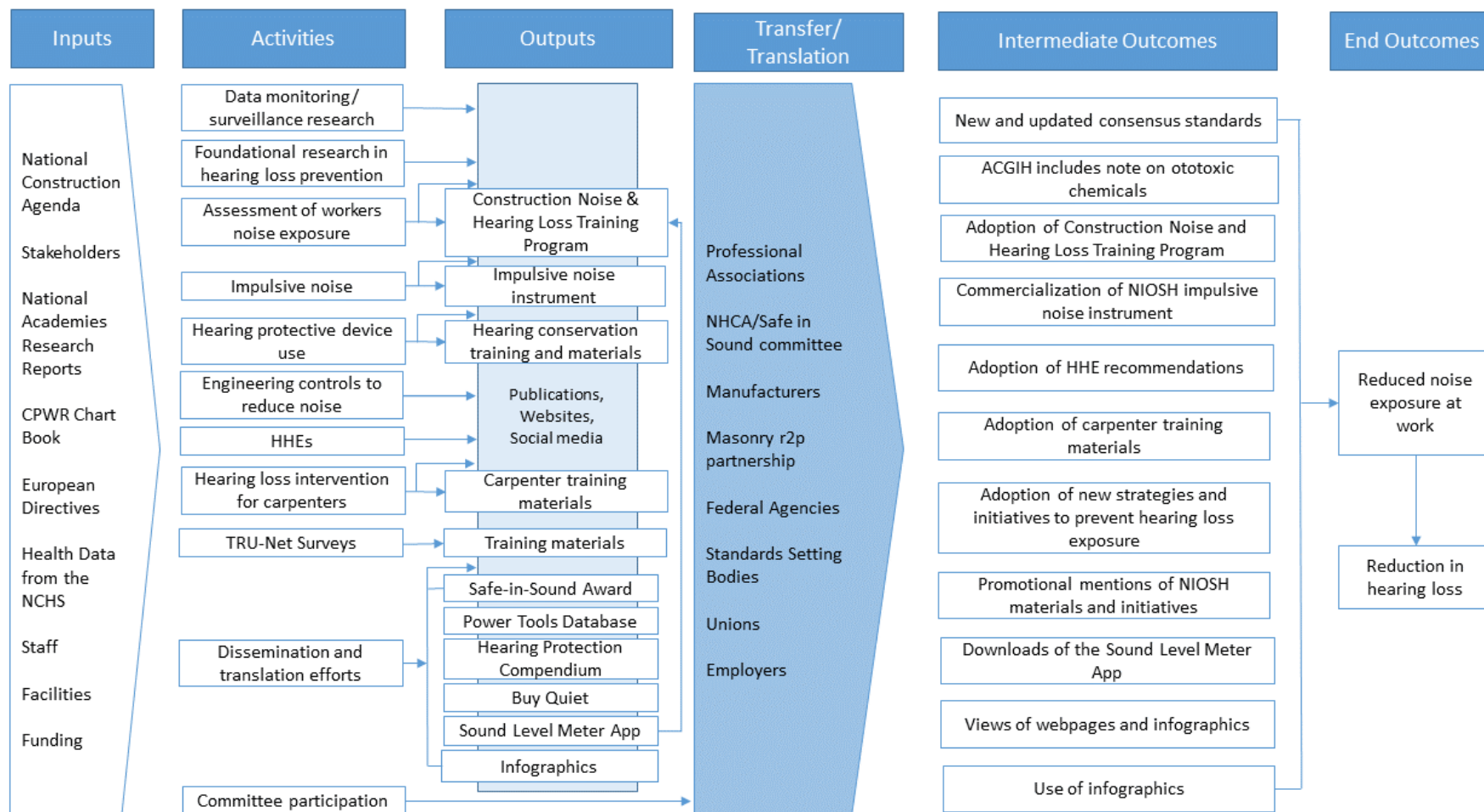
Construction trades with the highest prevalence of hearing loss include welders, iron workers, laborers, boilermakers, carpenters, sheet-metal workers, and brick masons [CPWR 2010b]. Many workers have an elevated or disproportionate risk, including foreign-born workers and workers with limited English-language skills, workers in small businesses, temporary workers, and younger (teenage) and older (over 64 years) workers [Themann et al. 2013b]. Hearing loss can significantly impact quality of life. It is associated with cognitive decline [Chien and Lin 2012] and adverse cardiovascular outcomes such as hypertension [Themann et al. 2013a]. Hearing loss is also strongly associated with depression [Hétu and Fortin 1995; Themann et al. 2013a]. Tinnitus, which often co-occurs with hearing loss, can disrupt sleep and is associated with both depression and anxiety [Shargorodsky et al. 2010]. Annually, construction workers lose about 3.1 healthy years per 1,000 noise-exposed workers, the second highest loss among industries [CDC 2016].

Researchers within the NIOSH Construction and Hearing Loss Prevention Programs have addressed key research gaps to improve the understanding of construction noise sources and health impacts. Research projects have examined issues related to hearing loss surveillance, worker training, engineering controls, ototoxicity, impulse noise, and the effective use of hearing protection devices (HPDs). The NIOSH Construction Program provides the evidence basis for employers, workers, and safety and health professionals to increase the use of HPDs, and the use, development, and commercialization of engineering controls to reduce the burden of hearing loss among construction workers. This research supports proactive companies and provides the scientific basis for potential standard setting and regulatory action for the construction industry.

Logic Model

In order to visually depict and characterize NIOSH efforts to prevent occupational hearing loss for the construction sector, a logic model was developed (Figure 40). The logic model depicts the flow from initial inputs to final outcomes in determining priorities for construction hearing loss prevention and establishing research and partnerships that result in the reduction of hearing loss among workers in the Construction Sector. The logic model comprises six different topics: Inputs, Activities, Outputs, Transfer and Translation, Intermediate Outcomes, and End Outcomes.

Figure 40. Logic Model for NIOSH Hearing Loss Prevention Efforts for Construction, 2007-2017.



Inputs

National Construction Agenda

The National Occupational Research Agenda (NORA) National Construction Agenda emerging from the NORA Construction Sector Council included a hearing loss goal among its seven “outcome” goals related to important sources of injury or illness. Four intermediate goals related to activities were developed from the strategic goal.

Strategic Goal 4 – Reduce hearing loss among construction workers by increased use of noise reduction solutions, practices, and hearing conservation programs by the construction community.

Intermediate Goal 4.1 – Use existing information supplemented by survey research to develop a baseline on current noise control and hearing loss practices in construction.

Intermediate Goal 4.2 – Increase awareness about noise hazards and solutions among construction workers, contractors, owners, and suppliers.

Intermediate Goal 4.3 – Increase the availability and adoption of quieter tools and equipment in the construction industry via research and implementation of a “Buy Quiet” campaign.

Intermediate Goal 4.4 – Develop and promote the use of model programs and practices by construction owners, governmental groups, professional groups, and best practice employers.

Extensive work was conducted and progress made in response to the strategic and intermediate goals for noise. This work is the focus of the current chapter.

Stakeholders

New York City Department of Environmental Protection

Representatives from the New York City Department of Environmental Protection (NYDEP) partnered with NIOSH in developing strategies for creating quieter construction sites. In January 2007, NYDEP adopted [rules](#) for citywide construction noise mitigation. These new rules reward contractors who use tools and machinery with the best available noise control technologies, those designed for quieter performance, or known to be the quietest available models of their type. NYDEP released a products and vendor guidance sheet to assist contractors in achieving compliance with the New York City

Noise Regulations. Consultation with NYDEP representatives about their program helped in the development of the NIOSH Buy Quiet Program and the Power Tools Database, each described later in this chapter.

U.S. Navy Occupational Health and Safety

The extensive United States Navy Occupational Health and Safety program covers construction-related activities performed by Navy personnel and Navy contractors. Stakeholders from the Navy program partnered with NIOSH with the common goal of preventing noise-induced hearing loss. A U.S. Navy Defense Safety Oversight Council Project working to reduce occupational hearing loss and initial work by the Navy Undersea Medical Research Facility and Center for Naval Analysis furthered NIOSH activities. Navy safety and health personnel collaborated with NIOSH on a variety of projects, such as conducting joint webinars for construction stakeholders and working on ways to encourage the purchase and use of quieter tools and equipment. The Navy also shared information supporting the link between noise exposure, hearing loss, and associated costs with NIOSH. This chapter describes these projects more fully including the Navy's role in facilitating transfer and intermediate outcomes.

National Academies Research Reports

In 2006, the National Academies conducted a program review of the NIOSH Hearing Loss Prevention Program, [*Hearing Loss Research at NIOSH: Reviews of Research Programs of the National Institute for Occupational Safety and Health \(2006\)*](#) [National Research Council (U.S.) and Institute of Medicine (U.S.) Committee to Review the NIOSH Hearing Loss Research Program 2006]. The review assessed the impact and relevance of the program and identified emerging issues. The National Academies review focused NIOSH efforts in hearing loss prevention through the development of a strategic plan that targeted the Construction, Manufacturing, and Mining sectors, which altogether hold the greatest prevalence of workers with hearing loss. Intramural and extramural goals focused on identifying engineering noise controls with possible dual application in mining and construction. The reviewers believed interventions for education and personal protective equipment to be applicable to all sectors, and suggested the health communication message needed adjusting for the different audiences.

During 2007 through 2008, the National Academies reviewed the NIOSH Construction Program, described in more detail in the Program Overview (page 9). The review,

[Construction Research at NIOSH: Reviews of Research Programs of the National Institute for Occupational Safety and Health \(2009\)](#), included recommendations that influenced the NIOSH Construction Program's work on hearing loss prevention in construction from 2009 until the present [National Research Council (U.S.) and Institute of Medicine (U.S.) Committee to Review the NIOSH Construction Research Program 2009].

CPWR Chart Book

The [CPWR Chart Book - The U.S. Industry and Its Workers](#) categorizes available data sources to explain the burden and needs for occupational safety and health research in the sector. The Chart Book characterizes the changing construction industry and workforce in the U.S., monitors the impact of such changes on worker safety and health, and identifies priorities for safety and health interventions in the future. The Chart Book contains significant amounts of data concerning noise-induced hearing loss in the construction industry. NIOSH construction leadership developed and updated its research priorities using this valuable information as its basis.

European Directives

The main European Directive on noise exposure to workers is [Directive 2003/10/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents \(noise\)](#) (Seventeenth individual directive within Article 16(1) of Directive 89/391/EEC). The directive establishes minimum requirements to protect workers from health and safety risks arising from noise exposure, specifically, the risk to hearing. This directive influenced NIOSH construction research on impulsive noise and jackhammers used in construction.

Another influential European Directive pertinent to construction is [Directive 2000/14/EC](#) about noise and outdoor equipment. It improves the control of environmental noise emissions by stipulating that manufacturers' equipment bears the "CE Marking" (European Conformity marking), an indication of the guaranteed sound power level, and carries the EC Declaration of Conformity. The Declaration is a special document, which the manufacturer signs to say that the product meets all of the requirements of the applicable directives. It must be issued by the manufacturer, or by the person placing the product on the European Union (EU) market if the manufacturer is not based in Europe. The directive fed into NIOSH's efforts to develop its Buy Quiet program and a noise control database. The European directive requires the measurement of noise

levels for construction tools; the [NIOSH Power Tools Database](#) contains some of that data.

Health Data from the National Center for Health Statistics

The Bureau of Labor Statistics (BLS) publishes the national surveillance data on Occupational Hearing Loss (OHL) from a sample of workplace illnesses and injuries documented on Occupational Safety and Health Administration (OSHA) 300 forms ([Log-of-Work-related Injuries and Illnesses](#)) and shared with the BLS through the Survey of Occupational Injuries and Illnesses program. Though important, these incidence counts may underestimate hearing loss rates by as much as an order of magnitude (value that is 10 times lesser or greater) [Hager 2006] due to the exclusion of certain types of employers, economic disincentives to reporting, and the level of hearing impairment required before an OSHA Standard Threshold Shift is reported [Azaroff et al. 2002; Leigh and Miller 1998].

Since 1957, the [National Health Interview Survey](#) (NHIS), a nationally representative in-person health survey, has monitored the health of the nation. NHIS collects data through personal household interviews on a broad range of health topics. Survey results provide instrumental data to track health status, health care access, and progress toward achieving national health objectives. NHIS cross-sectional data help NIOSH research and surveillance efforts that target prevalence rates for hearing difficulty, tinnitus, occupational noise exposure, and related health outcomes (e.g., cardiovascular conditions) among workers.

The [National Health and Nutrition Examination Survey](#) (NHANES) is a nationally representative in-person, cross-sectional survey of the health of persons within the U.S. Annually, about 5,000 persons participate in the NHANES survey, providing nationally representative estimates of various health conditions. Since 1997, NIOSH has supported the audiometric component of the NHANES survey, which tests hearing for both workers and non-workers. NIOSH characterizes hearing protection use among noise-exposed workers by industry using the NHANES data. NIOSH also uses these data to develop updated age correction tables for use in the OSHA Occupational Noise Exposure Standard and to develop an American National Standards Institute (ANSI) age correction standard.

Staff

Staff involved in NIOSH's intramural hearing loss prevention research include researchers and other staff at NIOSH; staff at CPWR—The Center for Construction Research and Training (CPWR) and its network of university-based consortium partners and a small grants program; and researchers funded through NIOSH's extramural grants program. They collectively have considerable expertise in hearing loss prevention, having contributed both to the body of knowledge and the application of that knowledge. The following individuals have been particularly instrumental in these efforts:

NIOSH Intramural Researchers

Name	NIOSH Division/Office
Bryan R. Beamer, PhD, PE	DART
David C. Byrne, PhD	DART
Rickie R. Davis, PhD	DART (retired)
Pamela S. Graydon, MS	DART
Charles S. Hayden, MS	DART (retired)
Chuck A. Kardous, MS, PE	DART
Elizabeth Masterson, PhD	DSHEFS
Thais C. Morata, PhD	DART
William J. Murphy, PhD	DART
Mark R. Stephenson, PhD	DART (retired)
Christa L. Themann, MS	DART
Edward L. Zechmann, MS, PE	DART

CPWR Staff, and Consortium and Small Study Researchers

Name	Institution
Anila Bello, PhD	University of Massachusetts, Lowell
Eileen Betit	CPWR
Sergio Caporali, PhD	University of Puerto Rico
Xiuwen (Sue) Dong, MS, DrPH	CPWR
Linda Goldenhar, PhD	CPWR
Oisaeng Hong, PhD	University of California, San Francisco
Bruce Lippy, PhD, CIH, CSP	CPWR
Babek Memarian, PhD	CPWR

Name	Institution
David Rempel, MD	University of California, San Francisco
Knut Ringen, PhD	CPWR
Pam Susi, MPH, CIH	CPWR (retired)
Susan Woskie, PhD	University of Massachusetts, Lowell

NIOSH Extramural Grant Researchers

Name	Institution
Roger P. Hamernik, PhD	State University of New York at Plattsburgh
Donald Henderson, PhD	State University of New York at Buffalo
Brian Kleiner, PhD	Virginia Polytechnic Institute & State University
Noah Seixas, PhD	University of Washington
Richard L. Neitzel, PhD	University of Michigan
Anthony Brammer, PhD	University of Connecticut Health Science Center

Facilities

Hearing loss researchers for construction use space and equipment in the Division of Applied Research and Technology (DART) and the Division of Surveillance Hazard Evaluations and Field Studies (DSHEFS) to conduct their research. NIOSH facilities are described extensively in the Program Overview (page 18). These facilities include

- ❖ A hearing protector test laboratory that includes a reverberation room, software, and computers. From 2008 through 2014, the laboratory was accredited by the National Voluntary Laboratory Accreditation Program (NVLAP) for the measurement of real-ear attenuation of hearing protector devices in accordance with test standard ANSI 12.6-1997 R2002 *Methods for Measuring the Real-Ear Attenuation of Hearing Protectors*. Due to the expense of continuing accreditation and lack of volume of testing, the accreditation was allowed to lapse. The quality control methods remain in place.
- ❖ A clinical audiometric suite containing a clinical audiometer with high frequency capability, middle ear analyzer, otoacoustic emission measurement system, and a hearing aid analyzer. A small audiometric test room, similar to those commonly found in occupational settings, allows the evaluation of test strategies in an occupational environment.

- ❖ The collaborative use of a 172 m² anechoic chamber at the University of Cincinnati equipped with a 24-channel computerized data acquisition system. A ten-microphone arrangement in an essentially free-field over a reflecting plane collects engineering-grade sound power and sound energy measurements of electric-powered hand tools. This laboratory was accredited from 2008–2014 by the NVLAP for testing of the International Standards Organization (ISO) 3744 *Sound Power over a Reflecting Plane* [ISO 2010]. Due to the expense of continuing accreditation and lack of volume of testing, the accreditation was allowed to lapse. The quality control methods remain in place.
- ❖ An impulse noise lab designed to facilitate the testing of hearing protection devices at high noise levels. An air-powered acoustic shock tube creates the impulse noise, and a variety of acoustic anthropometric manikins with ear simulators test the hearing protection.
- ❖ Field study capabilities that includes instrumentation for noise level assessments of complex noise exposures, impulsive noise (sudden bursts of noise) recording and analysis, audiometric testing (measures the range and sensitivity of a person's hearing), hearing protector fit-testing, and audiometric database analysis.

Although the main use of the Pittsburgh Mining Research Division (PMRD) facility in Pittsburgh is for mining research, construction researchers may use the facilities for assessing engineering noise controls developed commercially or through NIOSH research efforts. The PMRD facilities consist of a large (1300 cubic meters) reverberant acoustic testing chamber for conducting sound power measurements and a large (1200 cubic meter) hemi-anechoic chamber for noise source identification. Construction researchers use the acoustic testing chamber, accredited according to the ISO 3741 testing standard, for precision-grade sound power measurements of large machinery. Researchers use the hemi-anechoic chamber to localize noise sources on equipment with a 2.5-meter diameter beamforming array. Researchers used these facilities in 2010 to assess the effectiveness and noise controls of several jackhammers, described later in this chapter.

Activities, Outputs, Transfer and Translation, and Intermediate Outcomes

Data Monitoring and Surveillance Research

As mentioned, BLS, NHANES, and NHIS datasets are cross-sectional samples: only the NHANES survey collects audiometric data for workers, but for limited age ranges and sample sizes, precluding analyses by industry. DSHEFS Surveillance Branch scientists realized the limitations in these data sources for studying longitudinal trends in hearing loss.

NIOSH Surveillance System for Occupational Hearing Loss

In 2009, the [NIOSH Occupational Hearing Loss Surveillance Project](#) developed a national surveillance system for OHL. As of 2017, the project partners with 21 audiometric service providers, hospitals, clinics, and others who test noise-exposed worker hearing to collect anonymously their worker audiograms and related data. This approach allows NIOSH to collect nearly 12 million de-identified audiograms from thousands of workplaces across the U.S. while protecting the identities of workers, companies, and providers.

Researchers use the North American Industry Classification System (NAICS) to classify the industry associated with each audiogram. The [project webpage](#) includes findings and industry sector-specific statistics, as well as the data set for download and analysis. The information allows users to better understand the demographics of workers impacted by occupational hearing loss and how to reduce the impact. These data can be used to focus hearing loss prevention research or to directly address hearing loss in the workplace. From these results, the surveillance program developed burden estimates showing noise-exposed construction workers as having a 25% prevalence rate of hearing loss, greater than the rate of all other sectors such as manufacturing or services [Masterson et al. 2015].

National Health and Nutrition Examination Survey (NHANES)

NHANES evaluated many different age groups since 1997, when NIOSH and NHANES began their partnership. The NHANES data are an important data source because they are representatively sampled from the entire population of the U.S. As such, the data help to establish new standards for hearing as a function of age, gender, and ethnicity,

as well as document the investigation of different risk factors for hearing loss. An evaluation of data from 1999 to 2010, and comparisons with earlier NHANES surveys, found that hearing improved slightly among Americans [Hoffman et al. 2017].

The current [OSHA age-correction tables](#) for audiometry are based upon 1970's data developed by NIOSH [OSHA 2018; NIOSH 1972; NIOSH 1973]. These tables provide options for employers to apply age corrections to employee audiograms when determining if a standard threshold shift occurred. NIOSH derived the tables largely from a white male population, so they are not representative of the U.S. population. Accordingly, NIOSH participates on the age-correction task force with members of the National Hearing Conservation Association. The estimates from the age-correction tables take into account factors like smoking, diabetes, and hypertension—all which affect hearing—to better account for these effects when considering the age correction for what is normal hearing. NIOSH researchers are working to publish updated age-corrected tables.

Intermediate Outcome:

- ❖ In 2013, the International Standards Organization ISO 1999 standard for estimation of occupational noise-induced hearing loss was updated, and it included data from the NHANES survey. ISO 1999:2013 [Acoustics—Determination of Occupational Noise Exposure and Estimation of Noise-induced Hearing Impairment](#) allows estimation of expected hearing loss due to varying intensities and durations of noise exposure during employment [ISO 2013]. ISO 1999 provides hearing experts with normative data against which to compare a particular exposed population. Researchers used the NHANES data to update the hearing tables for unscreened normal populations and to expand the tables to include data at 8000 Hertz (Hz).
- ❖ In 2014 and 2015, NIOSH worked with the ANSI Subcommittee 3 for bioacoustics to have the ISO 1999:2013 standard adopted as a modified national standard: American National Standards Institute (ANSI) S3.44-2016 [Acoustics - Estimation of Noise-induced Hearing Loss](#) [ANSI 2016], which combined the American standard with the ISO standard, helped to replace older, less representative data. Because the ANSI S3.44 standard was adopted in 2016, it

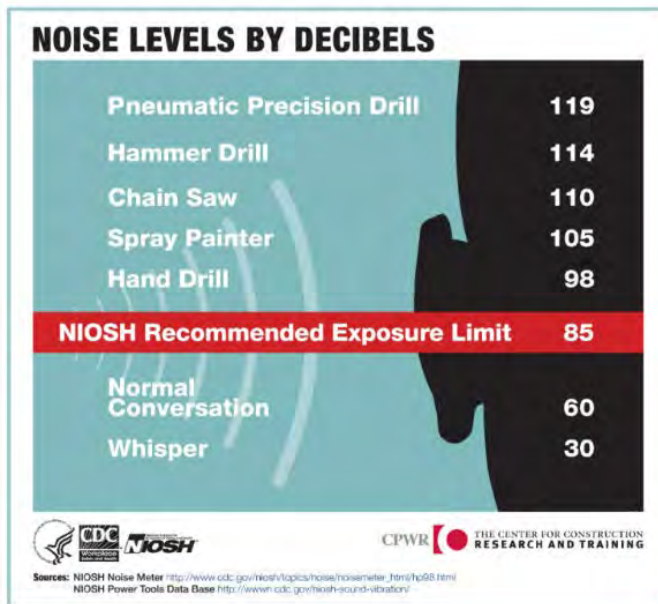
has few citations. The ISO standard, however, has been used to assess the hearing loss of workers in multiple countries in a variety of industries including construction. NIOSH researchers use the ISO standard to assess the hearing loss relative to a normative data set [NIOSH 2016].

Longitudinal Study of Construction Workers' Hearing

While noise exposure is well known to cause hearing damage, the change in hearing with each increment of exposure over time has not been described well. This is true particularly for construction workers, who experience a high degree of intermittent and peak noise exposures, and who often do not wear hearing protection devices [Tak et al. 2009]. In addition, standard hearing tests conducted with pure-audiograms may not be as sensitive as extended high frequency audiometry, therefore, missing signs of early hearing loss. High frequency audiometry tests hearing at frequencies above 8000 Hz, which are more susceptible to noise exposure due to the sensitivity of the high frequency regions of the cochlea to noise-related damage [Flamme and Williams 2013; Flamme et al. 2014; Liberman et al. 2016].

To address these issues, Seixas et al., at the University of Washington and funded by NIOSH, conducted a longitudinal study of noise exposures and hearing from 2000 through 2009. They assessed the effects of noise exposure on hearing by following a relatively inexperienced cohort of construction workers just entering the trade, conducting up to eight annual hearing tests over a 10-year period. They collected a database consisting of more than 1,300 full-shift personal noise dosimetry measurements. Researchers found that nominally hazardous noise exposures close to the 85-dBA exposure limit (dB sound pressure levels are unweighted and dBA levels are A-weighted similar to how the human ear hears) resulted in noise-induced damage to hearing among the construction workers [Seixas et al. 2012]. The effect was consistent with or exceeded that predicted by the prevailing model for noise-induced hearing loss by the ISO 1999:1990 standard. The results reinforced the need for enhanced hearing loss prevention programs and noise control efforts in the construction industry, and the need to begin hearing prevention activities as early as possible in the lives of young and early career workers. Figure 41 shows the decibels levels from various sources, along with the NIOSH recommended exposure limit (REL).

Figure 41. Noise decibel levels from various types of construction equipment (compared to the NIOSH REL).



Foundational Research in Hearing Loss Prevention

Noise exposures of construction workers have many descriptors. *Noise level* characterizes the potential for immediate damage, and *spectrum* characterizes frequencies that have greater risk of producing hearing loss [NIOSH 1998].

Hearing Hazards Associated with Industrial Noise Exposure

NIOSH funded animal research evaluating kurtosis (a statistical measure of the peak sharpness of a frequency distribution curve) of noise exposure related to fluctuations in the noise level due to impacts (objects colliding) or impulses (explosions). Through animal studies, NIOSH researchers demonstrated the increased risk for hearing loss for exposures at high levels (>85 dBA) and high kurtosis greater than 10 [Goley et al. 2011; Hamernik et al. 2003; Zhu et al. 2009].

NIOSH funded researchers at the State University of New York Plattsburgh to investigate a cohort of construction workers exposed to noise in China [Zhao et al. 2010]. The Chinese cohort worked for years in the same job, and researchers reconstructed historical noise exposures to determine noise-induced hearing loss. Researchers found a greater incidence of hearing loss in the workers with a higher level of kurtosis compared with other workers. This study was significant because it helped to improve our

estimate of the risk of hearing loss and reaffirmed that construction workers experienced an elevated risk of hearing loss [Xie et al. 2016; Zhao et al. 2010].

Ototoxic Chemicals

NIOSH researchers and their partners studied the auditory effects of occupational chemical exposures because certain chemicals called ototoxic chemicals are hazardous to hearing. When combined with noise, some of these chemicals may exacerbate noise effects on hearing. Approximately ten million workers, including construction workers, are exposed to ototoxic solvents [NIOSH 1998]. In addition to solvents, other ototoxic substances include heavy metals, asphyxiants, and pesticides. Ototoxicant research focuses on identifying ototoxic chemicals and their risk, bringing the risk to the attention of workers and public health professionals, and developing and disseminating recommendations to reduce exposures.

For example, Henderson and colleagues, at the State University of New York and funded by NIOSH, studied the ototoxicity of toluene and styrene using an animal model, measuring hearing before and after solvent and noise exposure. They also examined the effects of various drugs on preventing or reducing the ototoxic effects of solvents. Henderson et al. found that although the mechanism of styrene-ototoxicity was different from noise trauma, styrene at a nontoxic level increased the likelihood of noise-induced hearing loss and hair cell loss [cited in Chen et al. 2008; cited in Śliwiska-Kowalska et al. 2007]. These studies improved our knowledge of ototoxicity and clarified how styrene and toluene interact with noise.

Sufficient animal study data exist to conclude that several specific organic solvents cause hearing loss [Morata 2010; Morata et al. 2011]. Epidemiologic studies in humans exposed both to combined solvents and to individual solvents identified as ototoxic in rat studies confirmed the results of animal experiments, finding effects on hearing from combined solvents as well. A document produced jointly in 2010 by NIOSH and the [Nordic Expert Group](#), which is a collaboration among the Institutes of Environmental and Occupational Health in Norway, Finland, Denmark, Iceland, and Sweden, summarizes ototoxicity research.

Based on the research of NIOSH and its partners, the U.S. Department of Labor's Advisory Board on Toxic Substances and Worker Health recommended updates to the

existing DOL, Office of Workers Compensation Programs Solvent and Hearing Loss Policy. This recommendation, approved by this Board at their [June 2017 meeting](#), but pending DOL action, would assist construction workers with obtaining compensation for hearing loss [DOL Advisory Board on Toxic Substances and Worker Health 2017].

Intermediate Outcome:

- ❖ After consulting with NIOSH experts and based on NIOSH studies by Morata and others [Fuente et al. 2009; Morata and Johnson 2012; Morata et al. 2011], the American Conference of Governmental Industrial Hygienists (ACGIH), in its *Threshold Limited Values and Biological Exposure Indices* (TLVs® and BEIs®) publication [ACGIH 2016], included a note in the Noise Section, which was expanded and updated in 2017 [Morata 2016]:

“The designation OTO for hearing disorders in the “Notations” column highlights the potential for a chemical to cause hearing impairment alone or in combination with noise, even below 85 dBA. The OTO notation is reserved for chemicals that have been shown, through animal studies or human experience, to adversely affect auditory capacity, usually manifested as a permanent audiometric threshold shift (difficulty in detecting sounds) as well as difficulties in processing sounds. Certain solvents, predominantly aromatic hydrocarbons, but also some halogenated solvents, metals and chemicals that cause anoxia, have been shown to cause hearing disorders. Some solvents appear to act synergistically with noise, whereas carbon monoxide potentiates noise effects. The OTO notation is intended to focus attention, not only on engineering controls, administrative controls and personal protective equipment needed to reduce airborne concentrations, but also on other means of preventing excessive combined exposures with noise to prevent hearing disorders. Specifically, affected employees may need to be enrolled in hearing conservation and medical surveillance programs to more closely monitor auditory capacity. Please refer to the TLV for Physical Agents Documentation on Audible Sound section on Ototoxicity [ACGIH 2018, p. 74].”

Developed by ACGIH as guidelines, TLV is a daily exposure level without adverse effects, and BEI is a biological indicator of the uptake of a substance into the human body.

Assessment of Workers Noise Exposure

While studying working-life estimates of risk for dust-related occupational lung disease, chronic obstructive pulmonary disease, and hearing loss based on 11,793 audiograms, NIOSH funded researchers, Ringen et al., found that over a 45-year working life, an estimate of 73.8% construction workers develop hearing loss [Ringen et al. 2014]. Although detecting hearing loss early and preventing further loss in noise-exposed individuals or older adults is critical, accurate measurement tools may be unavailable. Research widely uses self-reporting because it is often the only possible measure to evaluate hearing ability [Hong et al. 2011].

In their assessment of hearing status, Hong et al. at the University of California, San Francisco, and funded by CPWR, established the level of validity of self-rated hearing by comparing it with the results of audiograms. They found a single-item question about an individual's hearing ability to be moderately valid to assess hearing loss, with good specificity at higher frequencies and good sensitivity in the speech frequencies [Hong et al. 2011]. While not a substitute for audiometric measurement, a single question, like the one used in the Hong et al. study, can be recommended for population-based studies when audiograms are unavailable.

The Hong et al. study also provided support for subsequent CPWR noise surveys of construction trainees and trainers. In surveys conducted by CPWR, as part of the inter-agency CPWR-NIOSH-OSHA research-to-practice (r2p) Work Group's focus on noise, more than 200 [trainers](#) and 4,000 workers responded to questions about their hearing. The results have been shared with industry stakeholders and researchers through presentations at meetings and conferences, including North America's Building Trades Unions' (NABTU) Safety and Health Committee, CPWR's Trainer Enhancement Program, American Public Health Association Conference, and CPWR's r2p Seminar. The surveys identified training gaps, and in response, a new [Construction Noise & Hearing Loss Prevention Training Program](#) was developed, presented to trainers for input, and then released in February 2018. The program incorporates findings from both NIOSH and CPWR research, and includes a series of in-class and hands-on exercises using the [NIOSH Noise Sound Level Meter App](#), a mobile application to measure sound levels. The program's evaluation includes both direct follow up with union trainers on their use of

the program and materials and an online survey to capture feedback from users who access and download the program directly from CPWR's website.

Impulsive Noise

In construction, most of the millions of workers exposed to hazardous noise levels are also exposed to impulsive noise on worksites. Tools and equipment used in construction, such as jack hammers, nail guns, powder-actuated tools, pile drivers, and other equipment, all produce significant amounts of impulsive noise. Considerable research shows that impulsive noise is more likely to cause noise-induced hearing loss than continuous noise. Currently, no universally-accepted standard defines impulsive noise accurately nor does a standard method exist to measure impulses. Most research scientists or industrial hygienists involved in measuring and studying human exposures to impulsive noise rely on bulky, nonstandard, and often outdated equipment to collect exposure data. Field studies are especially challenging due to the size, portability, and the performance requirements of such equipment. These issues, along with the lack of standards and regulations, hinder the collection of empirical evidence to document human exposures to impulsive noise and its effects on hearing [Kardous et al. 2005].

To address some of these issues, NIOSH researchers developed and patented a [new instrument](#) to collect and characterize exposure to impulsive noise ([U.S. Patent 7,401,519 --System for Monitoring Exposure to Impulse Noise](#)) [Kardous 2009]. In addition to the new instrument, these researchers are developing occupational guidelines for exposure to impulse noise. NIOSH's instrument is the only one of its kind capable of measuring and characterizing exposure of construction workers to impulsive noises. NIOSH used the instrument in field studies by the U.S. Army, U.S. Navy, U.S. Air Force, U.S. Department of Energy, the Federal Bureau of Investigation, the Massachusetts Institute of Technology Lincoln Research Laboratory, and researchers from various academic and government institutions (such as the State University of New York and the Department of Interior) [Davis 2018, NIOSH 2013, 2014, 2018].

Current occupational standards for high-level noise exposures prohibit exposures above 140 dB, however impulse noise can exceed this limit. In the construction sector, impulse noise can be generated by impacts such as jackhammers, pneumatic tools, and powder-actuated nail guns. NIOSH research by Murphy et al. demonstrated that the Noise Reduction Rating (NRR) does not adequately describe the performance earplugs and

earmuffs that use a nonlinear valve or filter [Murphy et al. 2012]. The noise reduction rating (NRR) is a single-number, laboratory-derived rating that the U.S. Environmental Protection Agency (EPA) requires to be shown on the label of each hearing protector sold in the United States. The ANSI/ASA S12.42-2010 standard specifies an acoustic test fixture with approximately 60-dB acoustic isolation and realistic surfaces for the head and ear canal contacting the protector. Therefore, NIOSH worked with two manufacturers to develop acoustic test fixtures that satisfied the S12.42 specifications and a small microphone suitable for measuring impulses between 130 and 170 dB. NIOSH evaluated different types of protectors, passive, nonlinear, and electronic, to better understand the measurements according to the standard [ANSI/ASA 2010].

Intermediate Outcome:

- ❖ Since 2013, Structural Dynalysis Ltd. has commercially manufactured and sold NIOSH's impulsive noise instrument.

Hearing Protection Device Use

A large body of research exists on occupational HPD use, and much of it relies on workers' self-reported use of hearing protection. Recent studies, however, indicate that self-reported HPD use may be inaccurate for industries (like construction) with variable noise exposure. Researchers from the University of Washington, funded by NIOSH, compared workers' self-reported use of hearing protection with their observed use in three workplaces with two types of noise environments: one construction site and one fixed industry facility, each with a variable noise environment; and one fixed industry facility with a steady noise environment. The researchers found that workers in the steady noise environment self-reported HPD use more accurately on the surveys than workers in variable noise environments. They also found workers tend to over-report HPD use, and noise exposure variability is a factor influencing reporting accuracy [Griffin et al. 2009].

Griffin et al. [2009] also assessed the effectiveness of a three-component intervention in motivating construction workers to effectively wear HPDs during high noise exposure. The intervention components were (a) a standard hearing conservation training program; (b) reinforcement of HPD use with a novel personal noise level indicator; and (c) weekly reinforcement training on HPD use. This study also assessed the impact of a

"train-the-trainer" and expert trainer approach [Trabeau et al. 2008]. The study found that training improved beliefs regarding HPD use, increased workers' hearing protection knowledge, and increased self-reported HPD use; last, the effectiveness of the training was not dependent on the training approach.

To promote HPD use in construction and to evaluate strategies to increase their use, the University of Washington researchers conducted a large-scale four-year study, from July 2005 to May 2009, with 268 construction workers across eight construction sites in Washington State [Edelson et al. 2009; Trabeau et al. 2008]. Researchers evaluated safety climate and used a health promotion model. They developed training materials as part of this study, including [hearing conservation training](#) and toolbox (page 65) training materials for [supervisors](#) and [workers](#).

HPD-use evaluation was limited to 176 construction workers who completed exposure assessments throughout the entire length of the study. The study observed a significant increase in HPD use. Overall, the fraction of time HPDs used in high noise increased from 35% pre-intervention to almost 50% at the end of the two-month intervention period of the four-year study. Researchers found that trade, education level, years in construction, and several health promotion components were related to HPD use. Site safety climate was also found to be a significant factor [Neitzel et al. 2008; Seixas et al. 2011].

Hearing Protection Device Use and Signal Detection in Roadway Construction

Casali at Virginia Polytechnic Institute & State University (Virginia Tech) evaluated construction noise with emphasis on road construction using heavy excavation vehicles and paving equipment [Casali 2010; Fitch et al. 2007; Lancaster et al. 2007]. The purpose of this NIOSH-funded study was to determine the impediments to workers' hearing of warning signals and speech in construction noise and to evaluate hearing protection and ground worker-vehicle separation distances to improve safety.

The work at Virginia Tech built upon previous NIOSH research that examined the noise made by heavy construction equipment [Spencer and Kovalchik 2007; Spencer and Yantek 2005]. Researchers conducted a comprehensive sampling of noise emissions from approximately 50 construction vehicles and powered hand tools. The researchers found high noise exposures above OSHA limits for road construction workers in certain

jobs and vehicles. Furthermore, road construction workers rarely wore hearing protection at many construction sites [Spencer and Kovalchik 2007; Spencer and Yantek 2005].

HPDs rely on either active or passive noise reduction. Passive HPDs use noise isolating or absorbing materials, but active HPDs reduce sound using a power source to cancel the unwanted noise. Laboratory experiments showed that sound-transmission technology in active HPDs adversely affected persons with hearing impairment when compared with passive devices. An analysis was performed to test auditory signals that construction workers needed to hear to work safely. While certain vehicle-specific, nonverbal auditory signals were found (e.g., crane boom signals, in-cab signals of vehicle systems status), the most common signal was the backup (i.e., reverse) alarm that is present on most construction vehicles to warn those behind the vehicle.

Some passive pre-molded earplugs provide backup alarm detection equivalent to the open ear in some noisy conditions and better than detection from deeply-inserted foam earplugs. NIOSH research showed that as background noise increased, listeners experienced much greater difficulty in hearing backup alarms from vehicles. Significant improvements in backup alarm localization could be realized when using a modified (i.e., with additional low [400 Hz] and high [4000 Hz] frequencies) backup alarm signal when compared with the standard backup alarm (dominant frequencies from 1250–2500 Hz) [Lancaster 2007].

In the same study, NIOSH researchers tested backup alarms in an anechoic room. Based on discussions with heavy construction equipment manufacturers, researchers evaluated a 97 dBA alarm (per Society of Automotive Engineers J994b Type C) for use in signal detection/localization experiments, because this backup alarm was reported to be the most “typical” standard alarm for the equipment. Evaluations of electronic, sound-transmission hearing protection devices indicate a potential for improving construction workers’ hearing in the bandwidth that encompasses speech and warning signal frequencies (i.e. 1000–4000 Hz). Field-based backup alarm detection experiments resulted in a formula that predicts the distance that normal-hearing workers wearing HPDs should be kept from a reversing construction vehicle (of various backing speeds) to allow them time to avoid being struck-by the vehicle. This study showed that sound-transmission technology in currently available and active HPDs have no advantage over

conventional passive HPDs for detecting a backup alarm signal in various levels and types of noise [Lancaster 2007].

Evaluation of Ear and Eye Protection

In construction, many loud tasks like drilling, cutting, and grinding require that workers use eye protection along with ear protection. Studies suggest, however, that the combination of earmuffs and eye protection can reduce the effectiveness of earmuffs by breaking their “seal” around the ear. In a CPWR-funded small study, Caporali Filho at the University of Puerto Rico measured earmuff performance (measured as Noise Insertion Loss [NIL]) and neck posture for different commercially available earmuffs by exposing participants to noise from four different power tools while wearing a variety of eye protection models [Caporali Filho 2015].

Researchers found that earmuff, protective eyewear, and neck posture had a statistically significant effect (five percent) on earmuff NIL while only the first two, earmuff and protective eyewear, were statistically significant for the discomfort rating ($p < 0.05$). Researchers identified several meaningful results:

- The eyewear that least impacted earmuff performance;
- The earmuff with the best performance when used together with eye protection;
- The most comfortable sets of earmuff and eyewear combinations; and
- The earmuff and eyewear combinations least affected by neck posture.

The results established proof of the concept for the NIL metric and for comfort ratings. Of note, the loss of hearing protection when using safety eyewear was consistently less than predicted by previous estimates. Researchers disseminated this information to construction stakeholders through a small study report.

Engineering Controls to Reduce Noise

While NIOSH and other researchers have invested substantially in developing and improving hearing protection devices, another area for research is making operating tools quieter.

Noise Controls for Jackhammers

NIOSH researchers studied controlling noise from several construction tools including pneumatic (air) nail guns, jackhammers, and circular saws. NIOSH collaborated with the University of Cincinnati, Iowa State University, Penn State University, and Michigan Technological University to perform some of the noise control research, while other research were done by NIOSH staff.

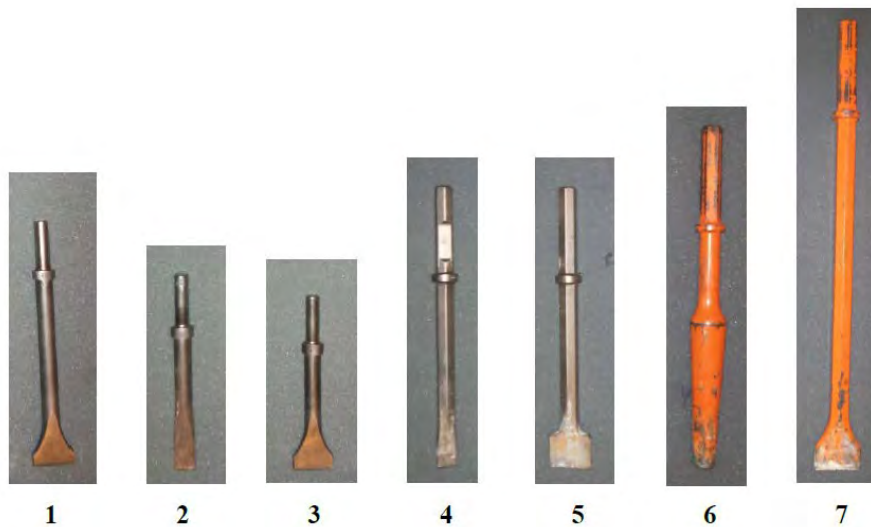
NIOSH researchers evaluated several controls on four types of jackhammers used for chipping concrete blocks in a NIOSH Pittsburgh laboratory (Figure 42) [Murphy 2016]. The most significant jackhammer noise sources came from the interaction of the chisel with the concrete and the pneumatic exhaust. Researchers tested a jackhammer shroud (jacket) and bellows (expanding tube) to reduce the noise radiating from the jackhammer body. A retractable shroud over the chisel reduced noise levels, with the controls (the jacket and bellows) reducing noise up to 4 dB for some jackhammers (a 3 dB reduction is a 50% reduction in sound pressure level). Researchers found that some jackhammers produced significantly less noise than others and that the best approach to reduce noise levels should include the use of all available controls [Zechmann et al. 2011].

Figure 42 Testing jackhammer noise controls in the NIOSH Pittsburgh laboratory.



In another set of experiments, NIOSH researchers evaluated the noise levels of seven jackhammer and chipping hammer chisels with and without damping material (Figure 43). Researchers milled grooves into the sides of the chisels, and then strips of constrained-layer damping material (quiet steel) were affixed in the grooves. The damping material reduced noise levels and tonal components from 3–4 dB to as much as 40 dB, but the strips of damping material had durability issues under working conditions [Zechmann and Hayden 2012].

Figure 43. Hammer chisels evaluated in jackhammer noise-level testing.



Noise Controls for Pneumatic Nail Guns

NIOSH researchers collaborated with the University of Cincinnati to investigate noise controls for pneumatic nail guns. Preliminary measurements showed that major contributors of pneumatic nail gun noise were the impact noise transmitted through the gun and exhaust-related noise. Applying a noise-absorbing foam on the outside of the nail-gun body was a simple and effective noise-reduction technique. Researchers also designed and applied small mufflers to the exhaust side of the nail gun, which reduced both the exhaust noise and the impact noise. This result indicated an overall noise level reduction by as much as 3.5 dB, suggesting that significant noise reduction is possible in construction power tools without any significant increase in cost. Construction workers using nail guns may not perceive the short duration impulses as being loud, however, peak sound pressure levels can exceed 120 dBA; therefore, workers should use hearing

protection [Jayakumar et al. 2015]. The nail gun research motivated NIOSH's participation in a [nail gun topic page](#), co-branded with OSHA.

Noise Controls for Chipping Hammer

Vibration from these hand-held power tools can lead to hand-arm vibration disorders such as pain, numbing, and blanching of the fingers, commonly known as “white finger” [Dong et al. 2008]. To address noise and vibration simultaneously, NIOSH researchers performed an in-depth vibration, acoustic, and fluid characterization of a chipping (or demolition) hammer a widely used construction tool. This effort gave valuable physical insight used to develop the other noise and vibration controls described later.

From the acoustic characterization, researchers found that the dominant noise source is the high-pressure exhaust, which they expected. More importantly, the fluid measurements indicated that the exhaust velocity was sonic over a small fraction of the operating cycle of the tool. This suggested that slowing the exhaust velocity and dissipating energy at the peak exhaust velocities should lead to significant noise reductions. Researchers performed experiments using a commercially available small silencer; the silencer reduced the noise 10 dB overall without a noticeable reduction in the tool performance [Molisani and Burdisso 2010; Preidikman 2009].

Hammer Drill and Rotary Bit Wear

As discussed in the Silica and MSD chapters (pages 47 and 122, respectively), in commercial construction, workers use hammer drills and rotary hammers extensively for drilling into concrete for rebar installation, anchor bolt installation, and other jobs. When a drill bit is worn down, it decreases productivity (rate of penetration) and increases drill handle vibration and noise (and silica dust as well). Studies conducted by CPWR consortium researchers Rempel and colleagues at the University of California, San Francisco, used an automated laboratory test bench system, called Rempel's test bench after the researcher who created it, to evaluate drill bit wear and rate of penetration [cited in Botti et al. 2017].

Carty et al., funded by CPWR, used Rempel's test bench system to evaluate the effects of bit-wear on respirable silica dust, noise, and drilling productivity [Carty et al. 2017]. Researchers wore down test bits to three worn states by drilling consecutive holes to different cumulative drilling depths. For each trial, using the automated test bench, a

commercially available hammer drill and masonry bits drilled holes into concrete block at a rate of one hole per minute. During each trial, researchers used a noise dosimeter to take noise samples. When comparing noise level results for the sharp (0 cm) versus dull drill bit (1560 cm), the mean noise levels increased from 112.8 to 114.4 dBA, respectively. The findings demonstrate that increased bit wear significantly increases noise and respirable silica dust while reducing drilling productivity. Reducing exposures to noise and respirable silica dust requires dust capture, hearing protection, and possibly respiratory protection. The findings support construction contractors adopting a drill bit replacement program [Carty et al. 2017]. A drill bit replacement program is a program that contractors set up to ensure regular replacement of dull drill bits with new sharp ones. The cost of the program would depend on how it is set up by each contractor.

Sound Dampening Mats

In a NIOSH and CPWR funded study, Saleh et al., at The University of Massachusetts at Lowell, evaluated the performance of sound barriers to test their effectiveness and practicality in reducing noise exposures for construction equipment operators. Researchers installed commercially purchased sound-dampening mats (SDMats) inside three heavy-equipment engine compartments, measuring sound pressure levels before and after the installation, while the equipment idled, and while on full-throttle settings where it normally operates. The SDMats installations reduced sound pressure levels inside the heavy-equipment operator cabs significantly, by 5.6–7.6 dBA on the full-throttle setting ($p < 0.01$). This simple to install and affordable intervention significantly reduced the engine noise reaching the construction heavy-equipment operator, potentially reducing reliance on hearing-protection devices [Saleh et al. 2017].

Health Hazard Evaluations: Noise Exposures to Roofers

From 2007 through 2017, researchers completed or published several [Health](#) Hazard Evaluation (HHE) Reports about hearing loss prevention for construction workers [NIOSH 2006, 2008a, b, c]. For example, during 2003 through 2008 on hazardous exposures from cutting cement roofing tiles. The Silica chapter, page 56, also discusses these studies. The United Union of Roofers, Waterproofers, and Allied Workers in Arizona requested four HHEs with silica and noise reported as potential hazards.

Noise dosimeters collected daily noise measurements for workers installing roofs to monitor their noise exposures. Researchers asked all monitored employees questions about general health symptoms, work practices, and use of personal protective equipment. Many workers with over five years of roofing experience received medical screenings.

The HHEs concluded that roofers faced an occupational health hazard due to noise exposure. The results showed that many of the employees' exposures exceeded the NIOSH REL and many exceeded the OSHA Action Level, defined as an 8-hr time-weighted average of 85 dBA or a dose of 50%. Some exposures exceeded the OSHA Permissible Exposure Limit (PEL) for noise.

Recommendations from the HHEs for controlling noise exposures included implementing engineering controls and enforcing the use of personal protective equipment. In addition, employers should develop a training program about the potential health hazards from excessive noise exposure.

Intermediate Outcome:

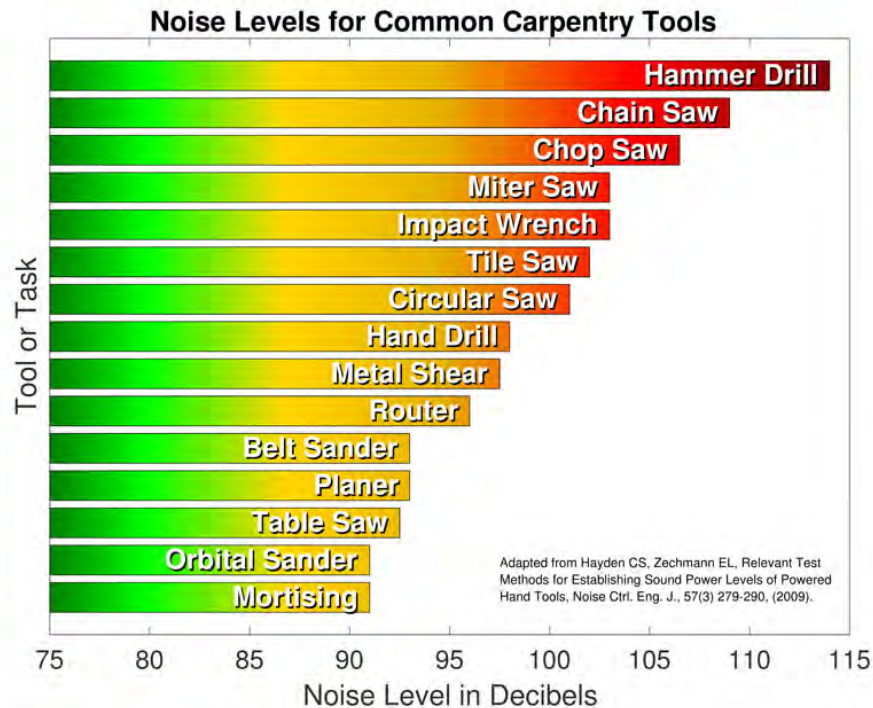
- ❖ Based on followup with company representatives, most of these roofing companies improved their noise-related training programs, workplace conditions, and use of hearing protection devices [Hall et al. 2009; Hall et al. 2013].

Hearing Loss Intervention for Carpenters

Carpenters are exposed to noise from a variety of tools (Figure 44). NIOSH researchers worked with carpenters and their union to assess noise-induced hearing loss, evaluate the effectiveness of the interventions, and develop a model hearing loss prevention program for carpenters [Stephenson and Stephenson 2011; Stephenson et al. 2011]. This work began as an HHE request by the United Brotherhood of Carpenters (UBC) and Joiners of North America to assess hearing loss among its members. Data show that carpenters begin to develop occupational hearing loss soon after entering the trade, and the hearing loss continues until they are substantially hearing impaired. An HHE of over 600 carpenters revealed that by age 25 years, carpenters' hearing equal that of a 50-year-old non-noise exposed worker; by age 55 years, most carpenters need hearing aids [Stephenson 2009]. NIOSH and CPWR, through its r2p efforts, shared these findings with other construction stakeholders, both union and non-union (i.e., sheet metal workers,

operating engineers, pile drivers, bricklayers, and laborers), as well as with service providers working in the construction industry.

Figure 44. Noise levels from various types of construction tools.



The UBC estimated a cost of one-half billion dollars to provide the first pair of hearing aids to their members who need them. So they determined it more cost effective to prevent noise-induced hearing loss among their 500,000 members than pay rehabilitation and hearing aid costs.

NIOSH staff completed and pilot-tested elements of a theory-driven program specifically focused on teaching carpenter apprentices how to prevent occupational hearing loss, emphasizing topics that may affect attitudes and beliefs, such as worker susceptibility, severity of hearing loss on quality of life, and benefits of prevention [Stephenson and Stephenson 2011; Stephenson et al. 2011]. As part of this effort, researchers developed education and training materials. A three-year intervention study determined the effectiveness on how the program positively influenced hearing health behaviors. The training focused on addressing worker attitudes and beliefs and on barriers to HPD use

that workers mentioned. The training presented the increased risk from impulse noise, prevalent in construction, and the benefits of noise control and buy quiet programs.

The study used NIOSH's existing partnerships with labor-management organizations within the construction industry to field test and evaluate the program. Apprentice carpenters who received the NIOSH model hearing loss prevention program training were compared with a control group who received only the current OSHA compliance approach.

Intermediate Outcome:

- ❖ The training materials used by the UBC Joint Apprenticeship Training Centers at several locations in the U.S. resulted in an increase from 45% to 94% of the workers who indicated that using HPDs could protect their hearing and that of their coworkers [Stephenson and Stephenson 2011; Stephenson et al. 2011].

TRU-Net Surveys (2015–2017)

The CPWR-owned [Trainers and Researcher United Network \(TRU-Net\)](#) is an invitation-only forum designed to encourage construction safety and health researchers and trainers to work together to advance the cause of reducing injury and fatality in the construction industry. In 2014, as part of CPWR's own r2p activities, and with the support of the National Institute of Environmental Health Sciences, the link between CPWR's consortium of safety and health researchers and extensive training network was formalized.

The goal of TRU-Net is to improve the quality and relevance of health and safety research and to advance the use of effective research-based solutions in the field. It provides an online forum where union trainers and CPWR and NIOSH researchers can discuss industry events, ask questions, suggest research ideas, share experiences, and learn about new research initiatives and ways to become involved. Interested members of CPWR's research consortium or training network must register to access the forum.

TRU-Net also has a research component that involves outreach to a broader cross-section of trainers to participate in specific research projects, including, for example, participating in and conducting surveys, assisting with the interpretation of research findings, and evaluating interventions, including equipment, work practices,

and materials. The TRU-Net pilot research project supported the CPWR-NIOSH-OSHA research-to-practice (r2p) Work Group's effort to distribute research and interventions related to noise and identify research and dissemination gaps and needs.

Within TRU-NET two surveys were conducted to identify possible gaps in awareness of noise hazards, understand the use of administrative controls and hearing protection, recognize barriers to use, learn about types of noise-related training that trainers conducted and workers received, and discover how survey participant self-reported their own hearing [Betit 2015, 2017b; Betit et al. 2017; Fletcher 2017a, b]. A total of 248 trainers from nine national unions participated in the trainer survey conducted in 2015, a response rate of roughly 21%. A total of 4,195 union workers from a cross-section of the trades participated in the worker survey conducted between October 2106 and February 2017, a response rate of 84% [Betit 2015, 2017b; Betit et al. 2017; Fletcher 2017a, b].

The preliminary findings from the surveys showed a lack of knowledge of engineering and administrative controls (engineering controls isolate people from the hazard while administrative change the way people work), with less than 39% accurately identifying these types of controls. Findings from the self-reported hearing assessment showed that the level of self-reported hearing difficulty differed significantly by years working in construction. The surveys identified a need for ongoing training on noise hazards and hearing loss prevention. Recently developed training programs and materials facilitate this ongoing training and integrate noise awareness and control training into skills training, as well as safety and health training programs. The new training program was presented at the 2017 CPWR Trainer Enhancement Program, used by CPWR and NABTU trainers, and made available to other industry safety and health professionals. The Trainer Enhancement Program is an annual program that brings together instructors in construction OSHA 500/502, environmental hazards, and health & safety from across the country to learn about new training requirements and programs they can incorporate into their OSHA 10- and 30-hour classes, as well as into environmental hazards and skill training programs they conduct.

Researchers presented the trainer and preliminary worker survey results at approximately five stakeholder meetings from 2015–2017 [Betit 2015, 2017b; Betit et al.

2017; Fletcher 2017a, b]. Several papers are in progress for submission to peer-reviewed journals on the survey results and the survey data collection methods.

Voluntary Consensus Standards Committee Participation

NIOSH researchers have a long history of working with the American National Standards Institute (ANSI) and the Acoustical Society of America (ASA) to develop and evaluate acoustic standards from testing and measurement.

From 2010 through 2013, NIOSH worked with the American Society of Safety Engineers (ASSE) to develop another standard, ANSI/ASSE A10.46 *Hearing Loss Prevention for Construction and Demolition Workers* [ANSI/ASSE 2013]. The standard aims to help employers prevent occupational hearing loss among construction and demolition workers with potential noise exposures (continuous, intermittent, and impulse) of 85 dBA and above. NIOSH consulted with the working group about the critical elements for a hearing loss prevention program, providing input included in the standard. The standard also references several NIOSH documents and data relevant to construction including Buy Quiet.

A joint project among the U.S. Department of Defense (DOD), General Services Administration (GSA), and NIOSH initially addressed procurement criteria for powered hand tools, elicited involvement of the Society of Automotive Engineers (SAE) EG1-B Hand Tools committee, their affiliated industry participants, and producers of powered hand tools (many used in construction). NIOSH partners in the U.S. Navy Occupational Safety and Health program led much of this effort with significant help from several NIOSH construction researchers.

Intermediate Outcome:

- ❖ Committee efforts focused upon development of an SAE International Standard that considers productivity, hand-arm vibration, noise, other safety and health factors, and life-cycle costs in procurement criteria for powered hand tools. Aerospace Standard, [*AS 6228 Safety Requirements for Procurement, Maintenance and Use of Hand-held Powered Tools*](#), [SAE 2014] was published in September 2014 [Geiger and Ster 2015]. This standard references NIOSH research on noise, vibration, and ergonomics. It also references and builds on

other NIOSH efforts including the NIOSH Power Tools database, Buy Quiet Initiative, and Prevention through Design.

Concurrently, a new committee, EG1-B1, Powered Hand Tools, Productivity, Ergonomics, and Safety, evolved from the EG1-B subcommittee initially formed to address this topic. GSA adapted Aerospace Standard 6228 in an evaluation of powered hand tools, currently making approximately 140 quieter, lower-vibration, ergonomic tools available to federal users and Aerospace Original Equipment Manufacturers, while identifying new products based on customers' supply support requests.

Outreach to industry and DOD followed the publication of the standard, with the development of a [technical report](#) describing application of the AS 6228 standard and extending the processes to other commodities and industrial processes [SAE 2012]. NIOSH conducted several CPWR/NIOSH webinars (involving the committee chair and several NIOSH construction researchers) in July and August 2016 focusing on this new standard and its relationship to construction noise from powered hand-tools; and most importantly, how the standard protects workers. More than 100 construction industry stakeholders participated in or viewed the webinars on demand [Geiger et al. 2016].

Dissemination and Translation Efforts

Safe-in-Sound Program

In 2006, to promote implementation of effective hearing loss prevention programs, NIOSH partnered with the National Hearing Conservation Association to create the [Safe-in-Sound Excellence in Hearing Loss Prevention Award™](#). The initiative aims to obtain and disseminate information about successful hearing loss prevention programs and public health practices used in industry. By distributing evidence-based strategies, Safe-in-Sound enables other groups to effectively advance proven approaches in hearing loss prevention. NIOSH construction funds, in part, supported the creation of this award.

Initially, NIOSH restricted the Safe-in-Sound Excellence in Hearing Loss Prevention awards to applicants from construction and two other sectors. Today, NIOSH considers applicants from all industries. In addition, the establishment of an award for "Innovation in Hearing Loss" recognizes individuals and business entities, regardless of industry. In the past ten years, two awards for Excellence in Hearing Loss Prevention have been in the construction industry.

The first award for Excellence in Hearing Loss Prevention was presented in 2010 when the New York City Department of Environmental Protection (NYCDEP) and Parsons Brinckerhoff Inc. established a partnership to update New York City's Noise Code, creating a new law with rules for construction noise. These rules were developed primarily to reduce community noise by establishing noise emission limits and requiring noise mitigation measures for all construction work occurring within New York City. Because of NYCDEP and Parsons Brinckerhoff's insight, the rules proactively address work-related exposures, thereby extending its reach and benefits.

In 2013, Vulcan Materials Company (VMC), a major producer of construction aggregates (such as asphalt, gravel, and concrete), was the second recipient for Excellence in Hearing Loss Prevention in construction. VMC operates 323 construction aggregate production and distribution facilities, which serve 19 states, the District of Columbia, the Bahamas, and Mexico. VMC was recognized by the Safe-in-Sound program for their commitment and implementation of a quality data-driven hearing loss prevention program that extends beyond simple regulatory compliance to highlight best practices in hearing loss prevention.

Additionally, the 2012 recipient for Innovation in Hearing Loss Prevention in construction was Bechtel National Inc., BSII, Waste Treatment & Immobilization Plant Project in Richland, WA. NIOSH recognized the project for its comprehensive integration of their hearing loss prevention program components, innovative strategies to address industry specific challenges in the areas of noise monitoring, risk evaluation and risk communication, and for adopting the NIOSH REL of 85 dB with the 3 dB exchange rate.

While only three of the 22 awards given in the 10-year period were specific to construction companies, the awards facilitate the extension of successful hearing loss prevention activities and strategies toward workers from different sectors, including construction. The Safe-in-Sound awards establish credibility, especially for those award winners who stretch traditional boundaries with novel approaches, further motivating winners to pursue additional program improvements and to reach higher goals.

Intermediate Outcomes:

- ❖ OSHA's August 2013 [OSHA Technical Manual](#) highlights Safe-in-Sound in Section III: Chapter 5 – Noise. The chapter provides technical information and guidance

to help Compliance Safety and Health Officers evaluate noise hazards in the workplace. An appendix on [alternatives for evaluating benefits and costs of noise control](#) cites Colgate-Palmolive—a winner of the Safe-in-Sound award—as an example.

- ❖ Citations of project work by others show considerable uptake of the deliverables of this project. OSHA, DOD, and other professional organizations promote the Safe-in-Sound awards by announcing the applications and by referencing the program and its principles in other literature (e.g., the AIHA Synergist, NHCA Spectrum, and Hearing Center of Excellence) [AIHA 2018; HCE, no date].
- ❖ In 2009, Pratt & Whitney received a [Safe-in-Sound Award](#) for the implementation of Buy Quiet in their facilities. In 2015, United Technologies, the parent company of Pratt & Whitney, received an award for their efforts in applying Buy Quiet concepts to reduce noise exposures for more than 8,000 workers [Murphy 2016].
- ❖ Implementation of the prevention award winning initiatives can be found under Testimonials from past award recipients and leaders in the field, at [Safe-in-Sound Outcomes](#).
- ❖ Online traffic to the award website, monitored since inception, increased steadily from 14,000 visits in 2009 to 55,000 visits in 2017.

In 2016, NIOSH hearing loss researchers produced a [Workplace Solution](#) document that discussed preventing hazardous noise and hearing loss through project design and operation. This document highlighted information from a Safe-in-Sound Award relevant to construction. It specifically addressed reducing noise from compressed air lines (in air tools) and in the tractor cabs of air-rotary drill rigs using a Prevention through Design approach.

[NIOSH's Noise and Hearing Loss Prevention](#) topic page promotes infographics related to construction and hearing-loss-related products. In 2016, NIOSH and CPWR actively promoted these products, with many available in both English and Spanish.

Intermediate Outcome:

- ❖ In 2016, [NIOSH's Noise and Hearing Loss Prevention](#) topic page received between 1,000 and 4,000 times visits per month, with the highest visits in February through March of that year.

Power Tools Database

From 2007 through 2012, NIOSH researchers tested construction industry power tools to make sound measurements for users and purchasers of specific tools. Researchers conducted testing at the NIOSH-University of Cincinnati Acoustical Testing Facility in a hemi-anechoic chamber. In all, researchers tested 166 power tools including belt sanders, circular saws, drills, impact wrenches, jig saws, miter saws, orbital sanders, reciprocating saws, and screwdrivers.

Based on these tests, NIOSH developed an online resource, the [Power Tools Database](#). The database incorporates some existing databases into one—resulting in an inclusive, accessible resource on noise-producing machinery, equipment, and tools. Included in the Power Tool Database is the noise level data on thousands of pieces of equipment from the European Union's [Machinery Directorate and the Noise Pollution Clearinghouse](#) database. Thus, the Power Tools Database was intended as a comprehensive resource both for customers seeking to buy equipment and for manufacturers seeking to market their products.

The product information available on the database can be sorted by power, sound level, brand, and other characteristics. It includes detailed noise emission data, including sound power level, sound pressure level, vibration information, product loading, and more. Although archived in 2017, the data are no longer maintained or updated, the database serves as a proof of concept demonstration on thousands of available power tools for other organizations to build upon. The database is still available online and is referenced in the SAE Standard for Power Tools Safety Aerospace Standard, [AS 6228 Safety Requirements for Procurement, Maintenance and Use of Hand-held Powered Tools](#) [SAE 2014].

Hearing Protector Device Compendium

One of NIOSH's cornerstone products on hearing protection device research is the [Hearing Protector Device Compendium](#) (Figure 45), a comprehensive searchable

database of hearing protection devices. NIOSH researchers created it to help workers and safety professionals select the best product for their particular environment. The Compendium allows users to search for devices by type, manufacturer, and noise exposure level. It also explains essential product features, including desired noise reduction ratings, mean attenuations, standard deviations of attenuations, protector construction and materials, and other features that aid in selecting protectors for specific situations. In the pursuit of completeness, all manufacturers can submit their data.

Figure 45. An example page from the NIOSH Hearing Protector Device Compendium webpage.

The screenshot displays the NIOSH Hearing Protector Device Compendium interface. On the left, a sidebar titled 'Narrow Results By' allows filtering by 'Device Class' (Pre-Molded (1), Semi-Insert (1)), 'Noise Reduction' (10-20 dB (2), 20-30 dB (64), 30-40 dB (5)), and 'Brand' (Aegisound LLC (2), David Clark Company Incorporated (11), E-A-R (2), Elvex Corporation (9), Howard Leight (7), Moldex-Metric, Inc. (6), North Safety Products (4), Peltor (11), Sensesar (4), Tasco Corporation (15), Compatibility). The main content area, titled 'Hearing Protector Device Compendium', shows 'Search Results (71)'. Two results are visible: 'Black Hawk' (Model: 2400, Basic NRR: 24) and 'BlackHawk' (Model: 2700, Basic NRR: 27). Both are manufactured by Tasco Corporation and feature earmuff design with various compatibility options like hard-hat and safety eyewear.

NIOSH Buy Quiet Initiative

The construction industry uses millions of pieces of noise-producing machinery and equipment. However, businesses in construction often lack the technical expertise or resources to effectively implement engineering noise controls after putting equipment and machinery in the field for use. Instead, it is more effective to buy or rent quieter models of equipment. To this end, NIOSH sponsored the development of a “Buy Quiet” Initiative. Over the last decade, the NIOSH Buy Quiet Initiative developed while working closely with the NYDEP and the U.S. Navy, with an aim to reduce occupational and community noise exposure by obtaining and using tools and machinery with the lowest noise emissions [SAE 2014; NYDEP 2007]. The European Directives (page 168)

mentioned earlier influenced this effort by providing guidelines on noise emissions from tools and equipment. The prevention initiative accomplishes several goals:

- Encourages companies to buy or rent quieter machinery and tools to reduce worker noise exposure when new businesses start up or when older equipment is replaced.
- Inspires manufacturers to design quieter equipment by creating a demand for quieter products.
- Provides information on equipment noise levels, so companies can buy quieter products that make the workplace safer.

The [NIOSH Buy Quiet](#) webpage houses the communication products developed to support the initiative. A [YouTube video](#) gives an overview of Buy Quiet for construction company owners, employees, subcontractors, purchasers and suppliers of power tools and equipment, and to the general community. NIOSH also developed a [series of posters](#) for construction companies to use at their worksites. These four posters provide information to workers about hearing loss and also communicate their organization's efforts and commitment to reducing noise levels in and around those worksites.

In efforts to reduce hearing loss in construction and bring NIOSH's research to practice, NIOSH, working through the OSHA-NIOSH-CPWR research-to-practice (r2p) Work Group, co-authored and co-branded with CPWR a series of noise infographics, including some focused on [Buy Quiet and Noise](#). These infographics pull information from existing resources: the [NIOSH's Power Tools Database](#), the results of the earlier research with carpenters (page 189), and the CPWR [Construction Chart Book](#). NIOSH redesigned the [Noise and Hearing Loss Prevention](#) topic page, and CPWR created a [Preventing Hearing Loss](#) topic page with a link to a [Noise Infographics](#) page to help promote the infographics. In 2016 and 2017, NIOSH and CPWR worked collaboratively, actively promoting the infographics to draw attention to NIOSH Buy Quiet resources and to CPWR's resources related to noise in the construction industry, including Spanish-language materials.

One series of seven infographics (in both English and Spanish) provide information on Buy Quiet (Figure 46). Each has its own page on the NIOSH website where a user can easily copy the html code to use on their website or download the infographics to print

and display. The infographics can also be downloaded from the CPWR website, for use on social media and in presentations and print materials.

Figure 46. NIOSH-CPWR Buy Quiet and NIOSH SLM app (discussed next) Infographics.



Intermediate Outcomes:

- ❖ The [NIOSH Buy Quiet Infographics](#) page received an average of 48 monthly views for a total of 578 total views in 2016. The [Buy Quiet construction video](#) has received more than 7,800 views during the same time period.
- ❖ The [CPWR Noise infographics](#) page received an average of 97 monthly views for a total of 1200 views from September 2015 through August 2016. The public downloaded the infographics seen in Figure 46, 1,117 times.

NIOSH Sound Level Meter App

The common use of smartphones and the sophistication of current sound measurement applications present an opportunity to revolutionize current noise data collection and surveillance practices. Through crowdsourcing techniques, workers world-wide can

collect and share workplace (or task-based) noise exposure data using their smartphones. Scientists and occupational safety and health professionals can use this shared data to build job exposure databases and promote better hearing health and prevention efforts. In addition, getting and displaying real-time noise exposure data raises workers' awareness about their work (and off-work) environments, allowing them to make informed decisions about potential hearing hazards. Advances in smartphone and sound measurement technologies led NIOSH researchers to develop a widely used sound level application, described next.

Health and safety professionals can use the [NIOSH Sound Level Meter \(SLM\) application](#) (or app) to assess risks, similar to how they use a professional sound level meter; workers can use the app to make informed decisions about the potential hazards to their hearing in the workplace (Figure 47). The NIOSH SLM app provides a readout of the sound level using the built-in microphone (or external microphone if used) and reports the instantaneous sound level in A, C, or Z-weighted decibels.

Figure 47. The NIOSH Sound Level Meter App webpage.

NIOSH Sound Level Meter App

The NIOSH Sound Level Meter mobile application is a tool to measure sound levels in the workplace and provide noise exposure parameters to help reduce occupational noise-induced hearing loss.

Key Benefits

- Raises workers' awareness about their work environment
- Helps workers make informed decisions about the potential hazards to their hearing
- Serves as a research tool to collect noise exposure data
- Promotes better hearing health and prevention efforts
- Easy to use

[Download the free app today](#)



[Read our NIOSH Science Blog on the Sound Level Meter app](#)



NIOSH developed two videos that [summarize the app](#) and [demonstrate its features](#). The frequency weighting response is user-selectable and found in the "Settings" screen. The app also reports the main metrics of importance for proper occupational noise measurements: the run time (total time), the A-weighted Equivalent Sound Level (LA_{eq}), the Maximum Level measured during the current run time, the C-weighted Peak Sound

Pressure Level (LC_{peak}), the Time-Weighted Average (TWA), and Dose (find more information in the online [SLM user manual](#)).

The app also contains some basic information on noise and hearing loss prevention. In addition, it allows the user to save and share measurement data using the smartphone's other communication and media features. If location services are enabled, the app uses the global positioning system (GPS) to provide an exact geospatial location of the noise measurement. The NIOSH Office of Construction Safety and Health and CPWR invested a substantial amount of time publicizing and distributing information about this new app to its many stakeholders, and construction stakeholders expressed a great deal of interest in the app. The NIOSH project officer gave a presentation on the app to the NIOSH Construction Sector Council, and the [NIOSH Science Blog](#) wrote a post on the app.

Several different construction-related websites and other publications provide information about the app. Some of the most relevant articles and dissemination are below.

- The NIOSH Office of Construction Safety and Health and the OSHA Construction Directorate coordinated to promote the NIOSH app in the [OSHA Quick Takes](#) on March 1, 2017.
- NIOSH published two YouTube videos related to the Sound Level Meter App in response to stakeholders (some in construction) asking for instructional how-to videos for the app. These are accessible from the NIOSH SLM webpage.
 - [The NIOSH Sound Level Meter app for iOS Devices – Short Summary](#)
 - [The NIOSH Sound Level Meter app for iOS Devices – Features & Instructions](#)

Intermediate Outcomes:

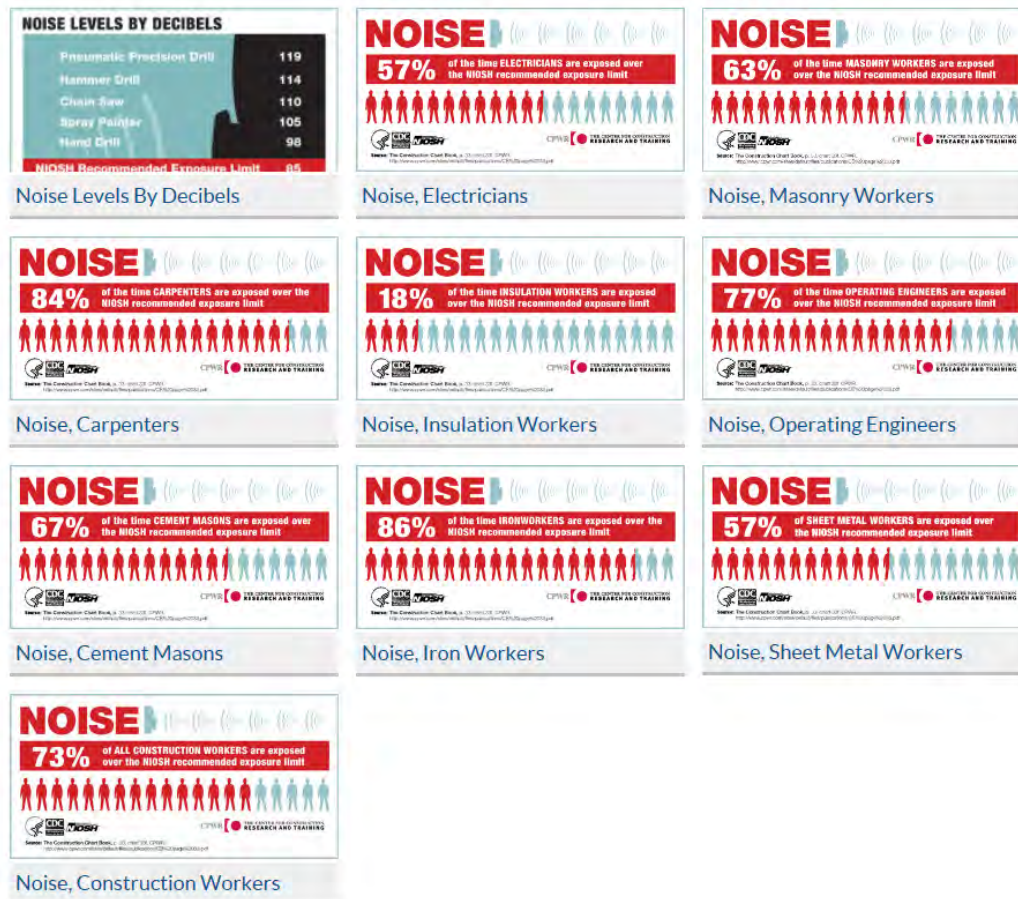
- ❖ Since its release in January 2017, users downloaded the NIOSH SLM app over 106,000 times.
- ❖ A [union publication](#), published quarterly, promoted the SLM app, reaching more than 20,000 stakeholders in print and online [Vitkovich 2017].
- ❖ The newsletter of the Laborers' Health & Safety Fund of North America, [Lifelines](#), included the SLM app in an article on free safety apps [LHSFNA 2017].

- ❖ Many construction and other organization’s websites or their publications highlighted the SLM app and its potential for use in construction:
 - The [Construction Junkie blog](#) features news about developments in the construction industry.
 - [Constructionequipment.com](#) serves as a buyer’s guide for managers of construction fleets and includes news and information about the construction industry.
 - Calling themselves the “voice of the electrical construction industry,” the [National Electrical Contractors Association](#) has 119 local chapters across the U.S.
 - The official magazine of the National Safety Council, [Safety and Health Magazine](#), seeks to reduce preventable injuries, including those at construction workplaces.
 - As the blog of the National Association of Home Builders, [NAHB NOW](#) attracts a large and diverse construction audience.

Infographics

In addition to the [Buy Quiet](#) and [Noise Sound Level Meter app infographic](#), NIOSH and CPWR developed and co-branded another group of infographics on the hazard, risk by trade, and noise decibels of different tools (Figure 48) in support of the OSHA-NIOSH-CPWR research-to-practice (r2p) Work Group’s noise and hearing loss dissemination priority. Users can find these infographics, in English and Spanish, on both [NIOSH](#) and [CPWR](#) webpages. A web publication, [EHS Today](#), also publishes the infographics on their “noise infographics” page.

Figure 48. NIOSH-CPWR Construction Noise Infographics.



Intermediate Outcomes:

- ❖ In 2016, the NIOSH noise infographics page received an average of 218 views monthly for a total of 2,624 total views. Users downloaded this group of infographics, hosted on CPWR's website, 633 times from September 1, 2015, to August 31, 2017. The same group of infographics on NIOSH's noise infographics page received 561 downloads.
- ❖ CPWR distributed 566 copies of an infographic flyer with noise and Buy Quiet infographics. CPWR also promoted the noise-related infographics through social media posts (Twitter, Facebook, and LinkedIn) over 250 times. As part of their CPWR Update, an e-newsletter article with noise infographic information received 779 views through a listserv of 2,667 subscribers.
- ❖ Union and trade publications use the infographics to raise awareness and promote safe practices. For example, the Bricklayers Union used them in

publications, potentially reaching about 100,000 industry stakeholders through print and [online](#). Their survey results show that use of hearing protection among its members has increased [Betit 2018a].

In 2013, a group of partners including CPWR, OSHA, and NIOSH collaborated to create toolbox talks (page 65). One toolbox talk topic is on hearing protection (Figure 49).

Figure 49. Cover of the toolbox talk on hearing protection.



Intermediate Outcomes:

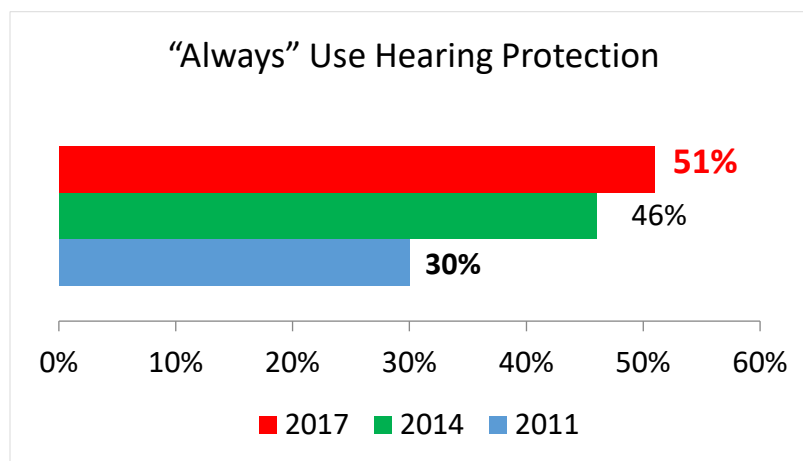
- ❖ Users viewed the [noise toolbox talk](#) 903 times and downloaded it 15,192 times between September 2013 and the end of August 2017; 176 copies of the noise toolbox talk have been distributed during that time.
- ❖ An insurance company, [Haylor, Freyer & Coon, Inc.](#), is co-branding both the toolbox talks and hazard alert cards—including the ones on noise. This company plans to distribute the materials to clients (small to mid-size contractors) and then post them on their website and share the metrics with NIOSH. Other insurance companies have shared the talks and cards with their clients. Habitat for Humanity's safety team expressed interest in using the toolbox talks and hazard alert cards and possibly co-branding them [Betit 2017a]. The Painters and Allied Trades expressed the same interest [Betit 2018b].

Masonry r2p Partnership

One of the Masonry r2p Partnership's (page 75) original priorities was to raise awareness of noise hazards and use of protective measures by distributing CPWR and NIOSH translational products through their communications channels, including websites, newsletters and magazines, and social media; and to fill product gaps as needed. To fill one of the earlier identified gaps, the partnership developed a [Safety Intervention Sheet: Noise and Hearing Loss](#) for masonry contractors who relied heavily on CPWR and NIOSH research and products. This intervention sheet highlights NIOSH and CPWR noise research, including the Power Tools Database and the Buy Quiet Initiative.

To gauge their progress with workers and contractors on noise and other priority topics, the partnership conducted telephone surveys of union members who belong to the International Union of Bricklayers and Allied Craftworkers (BAC) and of union masonry contractors. The 2017 union member survey is completed while the union masonry contractor survey is still underway. For 2017, the union member response rate was 53% (467 union members answered the call and 249 agreed to participate). Historically, in 2011, 214 members participated, and in 2014, 251 participated. The union member survey data (Figure 50) shows an increase (from 30% to 51%) in worker-reported use of hearing protection since the partnership's noise-related dissemination effort began [Betit 2015; Betit 2017b; Fletcher et al. 2017].

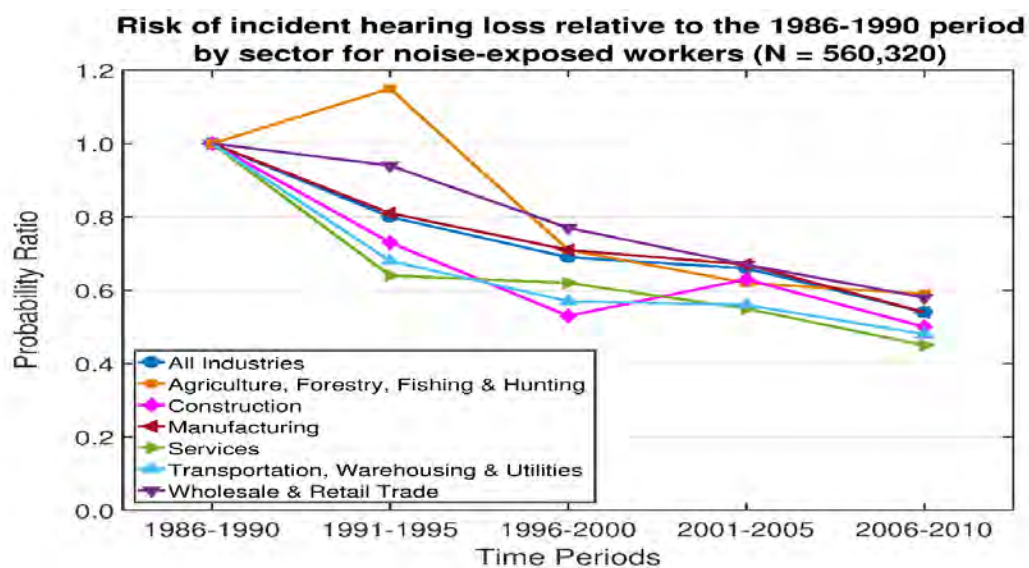
Figure 50. Results of telephone survey conducted of union members, 2011, 2014, and 2017.



End Outcomes

NIOSH has had some success in controlling noise exposures in the workplace and reducing the burden of hearing loss, although it is difficult to show a cause and effect relationship. As reflected in Figure 51, the risk of incident hearing loss decreased by 46% overall from the 1986 through 1990 to 2006 through 2010 time periods [Masterson et al. 2015]. Still, an estimated 22 million workers are exposed to hazardous noise levels above 85 dBA (not considered as a time-weighted average) [Tak et al. 2009].

Figure 51. Risk of incident hearing loss relative to the 1986–1990 period by sector for noise-exposed workers (N=560,320). Figure adapted from Masterson et al. [2015].



Alternative Explanations

A number of organizations and government agencies have played important roles in preventing hearing loss prevention in construction, whether developing products or helping to disseminate information. Standards for hearing protection devices are available because of efforts by the American Society of Safety Engineers (ASSE) and the American National Standards Institute (ANSI). The U.S. Department of Defense funded research in the hearing loss prevention and noise exposure area, contributing information and additional products to the body of knowledge.

The American Industrial Hygiene Association (AIHA), the International Safety Equipment Association (ISEA), the Institute for Noise Control Engineering (INCE), the National

Hearing Conservation Association (NHCA), the Laborers' Health & Safety Fund of North America (LHSFNA), and Association of Union Constructors (TAUC) are examples of professional organizations, non-profit organizations, contractors, and labor unions instrumental in disseminating hearing loss prevention information to construction contractors, workers, and others interested in this area. The efforts of all these stakeholders, including NIOSH, drove changes in regulation, standard and technology adoption, industry practice, and worker knowledge. It is difficult to imagine any outcome separate from this collaborated effort.

Future Plans

Hearing loss prevention in the construction industry is a topic that NIOSH will continue to address, along with a broad range of occupational health and safety hazards affecting construction workers. NIOSH researchers will develop and evaluate quieter equipment and noise controls for construction, because prevention through design (PtD) and engineering controls through the [hierarchy of controls](#) are the most effective methods to reduce noise exposures.

NIOSH will continue to prioritize impulsive noise generated by pneumatic tools and other construction equipment, collaborating with other industries such as mining, which could lead to more technology transfers suitable for construction applications.

Researchers found that hearing loss interventions may be ineffective due to improper and inconsistent use of hearing protection coupled with inadequate training [Byrne et al. 2017]. Therefore, NIOSH will continue efforts to educate employers and workers about noise and hearing protections. Trainers and workers need more information about the use of administrative controls to limit worker exposure to hazardous noise, allowing for various exposure time and noise intensity levels. Fit-testing systems that can measure a personal attenuation rating of hearing protectors and provide opportunities to aid in the proper selection of hearing protection may help reduce hazardous noise exposure. Translational research for fit testing methods is also needed.

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Chapter 5: Highway Work Zones



[Credit NIOSH]

Introduction

Highway work zones are hazardous both for motorists who drive through the signs, barrels, and lane changes, and for the workers who build, repair, and maintain streets, bridges, and highways. Studies show that highway and street construction workers are at a significant risk of fatal and serious nonfatal injuries while working in and around street and highway construction jobsites. Highway maintenance workers had the highest rate of struck-by fatalities (road worker deaths resulting from being struck by vehicles, equipment, or objects), while helpers had the highest rate of nonfatal struck-by injuries struck-by injuries [Wang et al. 2017].

The U.S. Federal Highway Administration (FHWA) reports the number of deaths from crashes in construction and maintenance work zones, and the Bureau of Labor Statistics (BLS) reports workers fatalities at road construction sites. According to the FHWA, 24,745 individuals (about 750 per year) lost their lives in work zone crashes from 1982 through 2014 [FHWA 2018]. Since the peak year of 2002—when 1186 died in construction and maintenance zones—the number of deaths has declined steadily to an

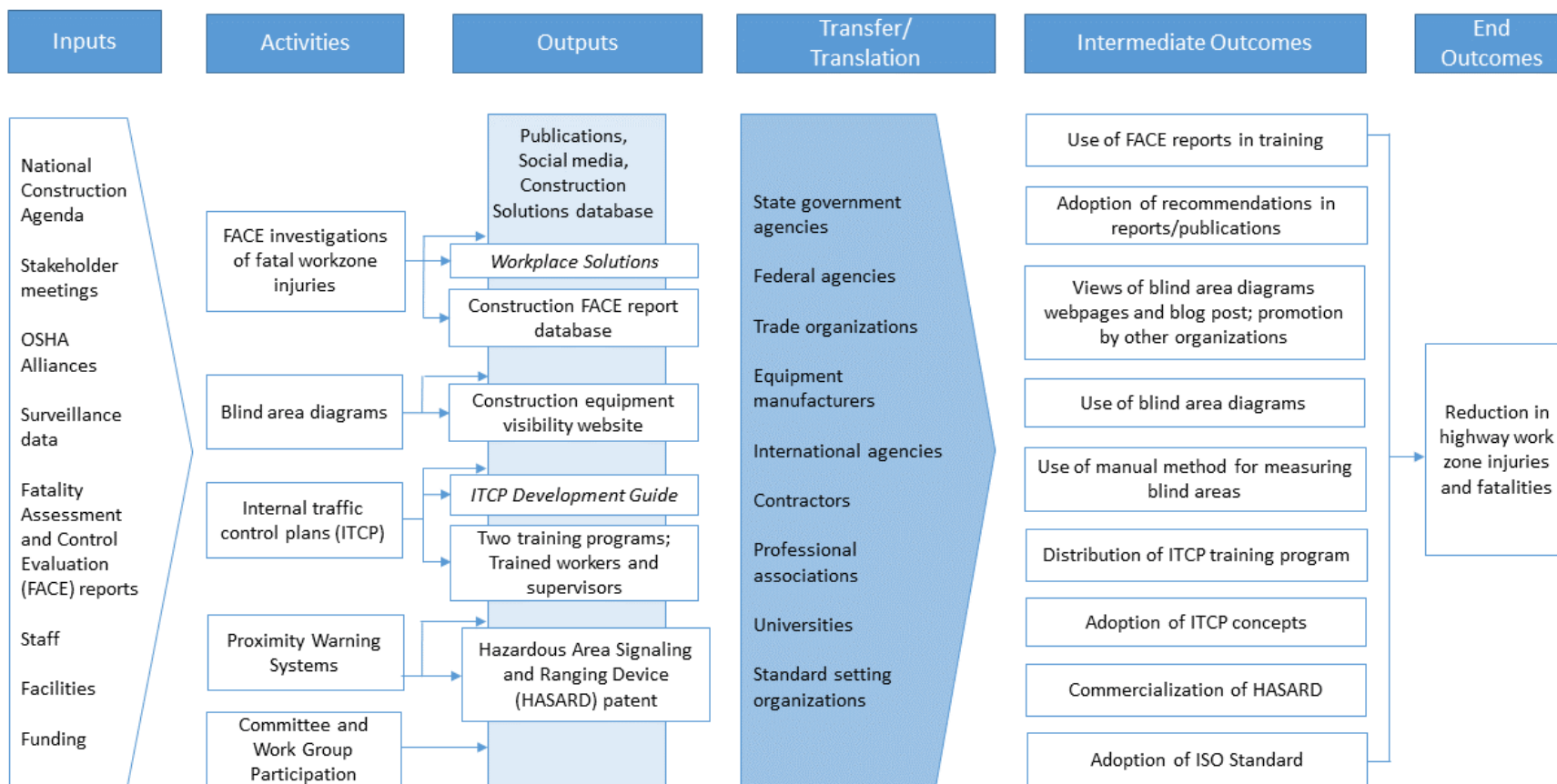
average of 591 during 2008 through 2014. During 2003 through 2015, BLS reports 1571 workers died at road construction sites. During 2003 through 2015, the largest share of work-related deaths in work zones (68%) occurred among construction laborers, tractor-trailer drivers, construction equipment operators, first-line supervisors of construction and extraction workers, and highway maintenance workers [BLS 2018].

Added to the risk of injury from passing motor vehicle traffic outside the work zone, there is an equally hazardous risk from construction vehicles and equipment moving within the work zone. Limited visibility around construction equipment contributes to collision incidents [Hinze and Teizer 2011]. The National Institute for Occupational Safety and Health (NIOSH) Construction Program examined these risk factors, and with partners, developed and tested interventions to make work zones safer for workers. The Construction Program continued working with partners to introduce and share these interventions into the field.

Logic Model

The Logic Model (Figure 52) illustrates the characteristics of NIOSH's research and other activities to reduce work zone injuries and fatalities. Elements of the logic model are Inputs, Activities, Outputs, Transfer and Translation, Intermediate Outcomes, and End Outcome. A detailed description of each element follows.

Figure 52. The Logic Model for NIOSH Work Zone Research, NIOSH, 2007–2017.



Inputs

Highway construction research needs come from a combination of fatal injury data analysis, input from individuals representing a wide-range of stakeholders in the road construction industry, and collaborative partnership activities. NIOSH began developing work zone safety projects in 2000 based on these identified research needs.

National Construction Agenda

The NIOSH Construction Program collaborates with a wider segment of the construction industry by facilitating the NORA Construction Sector Council [Gillen 2010]. The second decade NORA Construction Strategic Goal 3 and the related intermediate goals summarized existing NIOSH work zone research activities and identified needs for more work zone safety research.

Goal 3: Reduce fatal and serious injuries associated with struck-by incidents associated with objects, vehicles, and collapsing materials and structures.

Intermediate Goal 3.3 – Vehicles: Evaluate strategies to reduce worker exposure to being run over by heavy construction vehicles and equipment.

Intermediate Goal 3.4 – Vehicles: Promote the availability and use of operator-visibility-limit information for road construction equipment.

Intermediate Goal 3.5 – Vehicles: Evaluate worker injury risks associated with the expanded use of night work in the road construction industry.

Intermediate Goal 3.6 – Vehicles: Gain widespread usage of effective prevention measures in the road construction industry.

NIOSH used the intermediate goals to guide research activities in construction work zone safety with the aim to reduce safety risks for highway workers.

Stakeholder Meetings

In 1997, NIOSH held a series of three public meetings to understand the causes of fatal injuries in the construction industry. NIOSH invited stakeholders from three construction

sectors: roofing, residential construction, and highway and street construction. The highway and street construction meeting included participants from FHWA, the U.S. Occupational Safety and Health Administration (OSHA), and state transportation departments, labor unions, industry trade associations, paving contractors, and construction insurers.

Researchers shared analyses from the NIOSH National Traumatic Occupational Fatalities (NTOF) surveillance system, highlighting the leading causes of death (motor vehicle, machinery, and falls) in the highway and street construction industry, the high number of fatal injuries in highway and street construction compared with other sectors of the construction industry, and the number of pedestrian deaths in work zones. Participants suggested that NIOSH look beyond the obvious issue of motorists striking flaggers and focus on measures to prevent work zone injuries associated with all types of vehicles and equipment. These stakeholder meetings led NIOSH to hold a three-day workshop in 1998, which resulted in the publication of [*Building Safer Highway Work Zones: Measures to Prevent Worker Injuries from Vehicles and Equipment*](#) [NIOSH 2001]. The process of analyzing data and discussing roadway construction hazards with industry stakeholders helped NIOSH identify research needs and develop a multidisciplinary research project in 2001 to develop and evaluate intervention measures.

OSHA Alliances

NIOSH and OSHA each partake in partnerships with industry, labor, and trade organizations to address research and intervention needs. NIOSH formally joined the [*OSHA Work Zone Safety and Health Coalition Alliance*](#) in 2003, and NIOSH continues to join in the expanded [*OSHA Roadway Work Zone Safety and Health Partners Alliance*](#). Through Alliance activities, NIOSH researchers increase their understanding of road construction operations and the injury risks workers face daily. Alliance partners provide communication channels throughout the industry that NIOSH researchers use to share findings to ensure that interventions and best practices in training and outreach activities come from the best-available scientific data. Alliance partners also give feedback on research activities, publications, and other products.

Surveillance Data

Almost half of the 802 construction workers killed by vehicles or equipment from 1995 through 2002 worked on highway and street construction projects [NIOSH 2007a]. Analyses from the NTOF and the BLS Census of Fatal Occupational Injuries (CFOI) clearly defined the risk of pedestrian workers (referred to as *workers on foot*) getting struck by motor vehicles passing through the work zone and by construction vehicles and equipment operating inside the work zone. The initial analysis of NTOF data, published in *Accident Analysis and Prevention*, focused on 2,144 work-related motor vehicle fatalities in the U.S. construction industry from 1980 through 1992 [Ore and Fosbroke 1997]. During that time, construction workers had a crude mortality rate (2.3/100,000) twice the rate for the average worker in the U.S. The largest proportion of deaths (40%) in construction were to workers on foot. The analysis showed that the worker tasks of flagging and surveying were identifiable worker-on-foot hazards. CFOI data analyses from 1992 through 1998 found that of 492 work zone fatalities in highway and street construction, 465 involved vehicles or equipment—318 of these deaths were to workers on foot. Victims were as likely to be struck by a construction vehicle as by passing traffic [NIOSH 2001].

NIOSH Fatality Assessment and Control Evaluation (FACE)

Individual case reports from the [NIOSH Fatality Assessment and Control Evaluation \(FACE\) Program](#) also contributed to the development of work zone research. The FACE Program collects information on factors that contribute to occupational fatalities and make recommendations for preventing similar future fatalities. By 2001, NIOSH completed 29 fatality evaluations of workers in highway construction or maintenance and utility work from investigations conducted during the 1990s [NIOSH 2001]. NIOSH used the investigation results in project development and as a foundation for future research activities in work zone safety. The fatal injury investigations included various causes of death: workers struck by dump trucks and other equipment inside the workspace (part of work zone that workers occupy), vehicles intruding into the workspace, equipment overturns, and falls from equipment and structures (e.g., bridge deck).

Staff

Staff involved in work zone safety research and intervention efforts include NIOSH researchers located in Morgantown, Pittsburgh, and Spokane; staff at CPWR—The Center for Construction Research and Training, including its network of university-based consortium partners and a small grants program; and researchers funded through NIOSH’s extramural grants program. NIOSH construction researchers have extensive expertise, having helped to develop the body of knowledge and the application of that knowledge. Their collective focus on work zone hazards and risks position NIOSH to address research needs effectively, to better characterize the problem, and to develop interventions for the occupational safety and health community. The following individuals have been particularly instrumental in these efforts:

NIOSH Intramural Researchers

Name	NIOSH Division/Office
David Fosbroke, MSF	Division of Safety Research (DSR)
Mathew Hause	Division of Safety Research (DSR)
Jennifer E. Lincoln, MS	Division of Safety Research (DSR)
Gary Mowrey, PhD	Pittsburgh Mining Research Division (PMRD) (retired)
Stephanie Pratt, PhD	Division of Safety Research (DSR)
Todd Ruff, MS, PE	Spokane Mining Research Division (SMRD)
William Schiffbauer, AS	Pittsburgh Mining Research Division (PMRD) (retired)

CPWR Staff, and Consortium and Small Study Researchers

Name	Institution
Eileen Betit	CPWR
Chris Trahan Cain, CIH	CPWR
Xiuwen (Sue) Dong, DrPH	CPWR
Yong Kwon Cho, PhD	Georgia Institute of Technology
Babak Memarian, PhD	CPWR
James Platner, PhD	CPWR (retired)
Erich Stafford	CPWR (retired)
Pam Susi, MPH	CPWR (retired)

NIOSH Extramural Researchers

Name	Institution
Dulcy M. Abraham, MS, PhD	Purdue University
Lesley Strawderman, MS, PhD	Mississippi State University

Activities, Outputs, Transfer and Translation, and Intermediate Outcomes

Given the inputs described, the research during the period of this program review focused on developing and adapting interventions to the road construction environment; defining and developing measures and methods for collecting data on worker exposure at road construction sites; and implementing interventions and collecting intervention efficacy data on highway paving projects. Research-to-practice (r2p) efforts stemming from this research included developing methods for distributing information on areas of reduced visibility around equipment and for reducing hazardous worker exposure to operating construction equipment. NIOSH also funded work zone safety research on a variety of supporting topics, including the safety of nighttime construction activities, hearing loss in road construction, and design criteria for work zone signage.

Preventing Injuries and Deaths in the Work Zones

During 2007 through 2014, the NIOSH FACE Program published reports of investigations of 19 fatal injuries to workers in highway work zones. Eight cases involved a worker struck by traffic in a work zone; ten cases involved a worker struck by a construction vehicle; nine cases involved a backing vehicle; two cases occurred during work at night; and one case involved a worker struck by part of a tire from a passing semitruck. In 2014, the FACE Program published a workplace solution document, [Preventing Worker Deaths from Backing Vehicles and Equipment at Roadway Construction Worksites](#) [NIOSH 2014]. In 2017, CPWR launched a new [Construction FACE Database](#) to facilitate use of NIOSH FACE report information.

Intermediate Outcomes:

- ❖ Construction companies and safety instructors frequently use FACE reports as training tools. Trade media outlets also re-published FACE report information for their readers. For example, [Equipment World](#) used six construction-related FACE reports on highway work zones to create *Safety Watches*. A *Safety Watch* is a short article formatted for use in safety training and toolbox talks (page 65) that highlights specific safety hazards. In 2015, the American Road and Transportation Builders Association's Development Foundation created [eight digital videos using NIOSH and State FACE reports](#). These videos describe the fatality event and work zone safety recommendations.
- ❖ In 2016, a Pennsylvania company developed a prototype device that provides real-time communication between construction site spotters and truck drivers. The promotional literature for the prototype device quotes the NIOSH Workplace Solutions, [Preventing Worker Deaths from Backing Vehicles and Equipment at Roadway Construction Worksites](#) [NIOSH 2014].

During 2005 through 2011, Abraham et al. at Purdue University evaluated the safety of nighttime construction by analyzing working and safety practices (including safety management and traffic control planning) during nighttime construction and maintenance work. They also analyzed lighting at night construction sites. There were several key findings: construction and maintenance workers expressed concern that traffic in work zones pose a risk; the presence of law enforcement and public awareness campaigns are important traffic control strategies; and changeable message signs were a less effective speed reduction strategy than using law enforcement at road construction sites.

The Purdue researchers made specific recommendations [cited in Miller et al. 2009; Mostafavi et al. 2012; Valentin et al. 2010]:

- Develop methods to raise public awareness of nighttime construction
- Make professionals who design nighttime work zones aware of new lighting references
- Use good task lighting (as provided by balloon lighting)
- Wear high-visibility apparel maintenance and classification

The researchers shared their findings through presentations, graduate student theses, and professional journal articles.

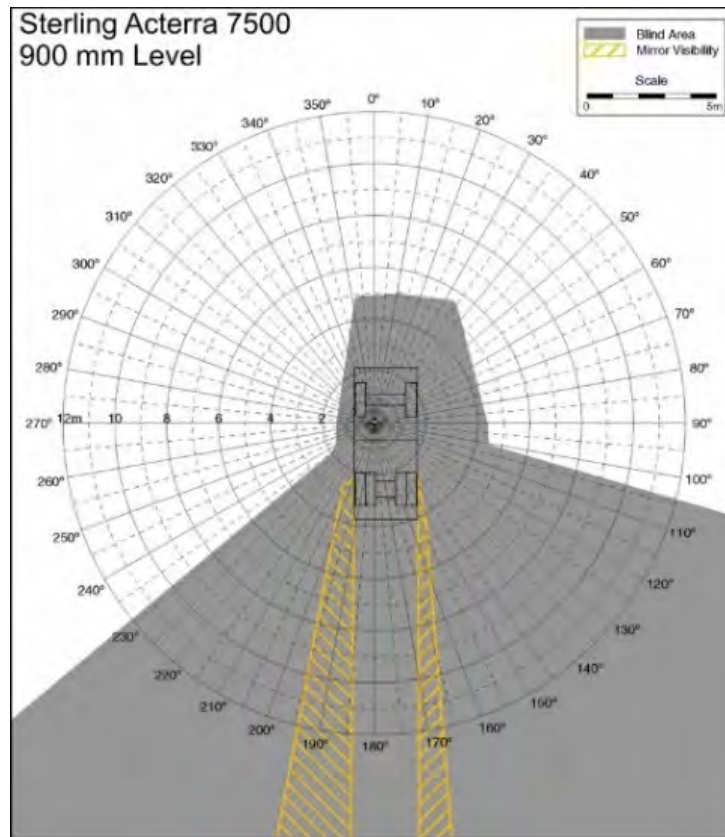
Mississippi State University researchers evaluated the criteria for work zone sign design. Specifically, during 2013 through 2016, Strawderman et al. examined the design of changeable message signs and the impact of design options on driver compliance and worker safety. This was a high-fidelity driver simulation study with an integrated eye-tracking system. Based on their findings, the researchers recommended using dynamic message signs during nighttime construction, using a longer refresh rate (three seconds vs two seconds) for the changing message, and mentioning of workers in the message *if* workers are present on the construction site [Strawderman et al. 2013].

Blind Area Diagrams

Blind areas are the regions around construction vehicles and equipment not seen from the operator's position. To assess the effectiveness of safety interventions on roadway construction sites, NIOSH researchers defined the blind areas around construction equipment based on visibility limits and equipment movements during roadway construction. One activity focused on developing a [manual method](#) for measuring blind areas. NIOSH funded a project to develop blind area diagrams (Figure 53) for 38 pieces of construction equipment and five pieces of mining equipment. Workers use the [diagrams](#) in the detailed construction vehicle list to help recognize the blind areas around heavy equipment.

For each construction vehicle, three different blind-area diagrams are available to represent the ability of the operator to see an object at three different elevations: ground level, 900 mm (3'), and 1500 mm (4' 11"). The 900-mm plane represents the average height of construction barrels (channelizing devices) commonly used in road construction to guide traffic, and the 1500-mm plane corresponds to the height of a 4' 11" person. Safety personnel and instructors can use this resource as a training aid to increase awareness about the blind areas near construction vehicles and equipment. These diagrams are based on the International Organization for Standardization (ISO) 5006 standard for Earth-moving machinery—Operator's field of view—Test method and performance criteria [ISO 1993].

Figure 53. NIOSH Blind Area Diagram



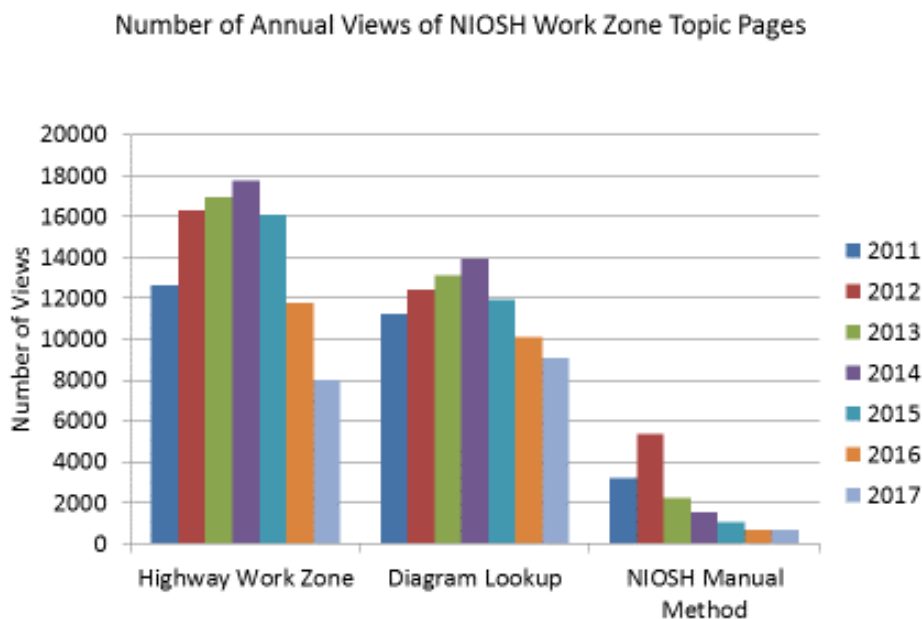
Though developed for use by NIOSH researchers, industry stakeholders suggested that blind area diagrams could be a valuable training resource for road construction companies and labor unions [Fosbroke 2011b]. As a result, NIOSH developed a [Construction Equipment Visibility](#) webpage based on two contract reports provided to NIOSH by Caterpillar, Inc., and one contract report provided by John Steele, PE [Hefner 2003, 2004; Steele 2006]. A link to the [Construction Equipment Visibility](#) page is on the [NIOSH Highway Work Zone Safety](#) topic page.

Intermediate Outcomes:

- ❖ Established in late 2010, the [NIOSH Highway Work Zone Safety](#) page has received more than 101,000 views through 2017, an average of approximately 14,100 per year (Figure 54). The [Diagram Lookup](#) page serves as the portal to selecting the specific vehicle or equipment of interest and viewing its blind-area

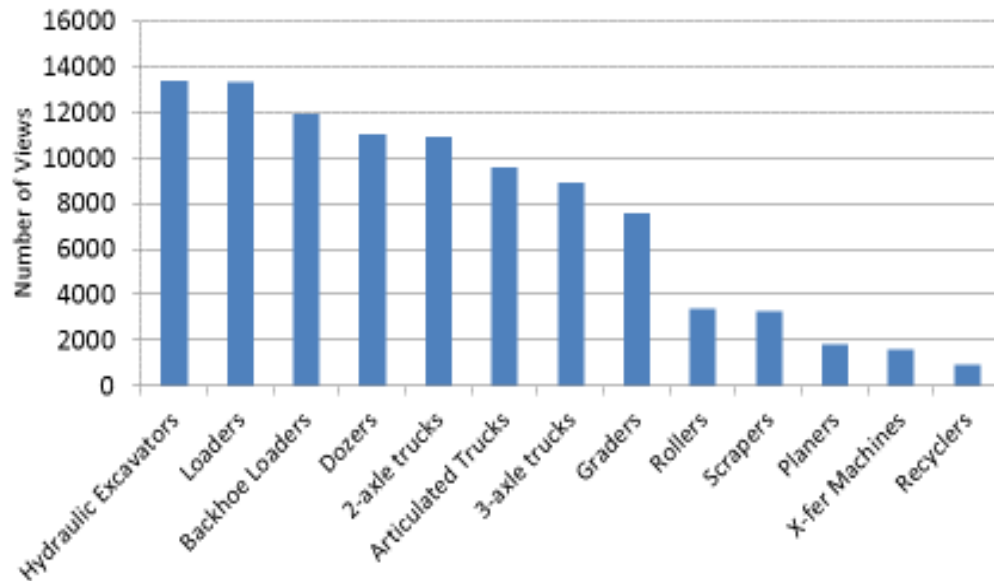
diagrams. The [Diagram Lookup](#) page was accessed more than 85,000 times from 2010 through 2017.

Figure 54. The number of annual views of NIOSH work zone topic pages, 2011–2017.



- ❖ A 2011 [NIOSH Science Blog post](#) discussed how companies could use blind area diagrams to raise worker awareness of the hazards of working around construction vehicles and equipment [Fosbroke 2011b]. The blog received modest feedback (23 comments), but the content was widely distributed through a variety of construction media outlets, including industry magazine articles [Moore 2014] and the National Work Zone Safety and Health Clearinghouse—The [American Road Transportation Builders Association](#) (ARTBA) hosts the Clearinghouse, a library of resources about roadway safety organized by the FHWA. The blog increased traffic to the [Diagram Lookup](#) page by 300% after the distribution through construction media outlets. The blind area diagrams for hydraulic excavators, loaders, backhoe loaders, dozers, and dump trucks receive the most views (Figure 55).

Figure 55. Number of annual views for specific construction equipment visibility diagrams, October 2010–December 2017.



- ❖ A variety of outlets reproduced or referenced NIOSH blind area diagrams: [Know the Blind Spots](#) is a poster developed by ARTBA. Through the National Work Zone Safety Information Clearinghouse, ARTBA and FHWA distributed approximately 11,000 posters.
- ❖ The Roadway Safety Consortium, a group of construction industry stakeholders who work together to craft safety training programs and documents, incorporated information on blind areas into the safety training DVD, [Roadway Safety +](#) (Figure 56).

Figure 56. DVD cover of Roadway Safety+ DVD Training Program.



- ❖ The highway agency in the United Kingdom used the blind area diagrams and other NIOSH work zone safety research to improve work zone safety for their workers and passenger vehicle drivers [Smythy 2010].
- ❖ In 2012, a major construction equipment manufacturer notified NIOSH that they began including “restricted visibility” diagrams in equipment operators’ manuals.
- ❖ Also in 2012, the French government research agency for occupational safety and health (Institut National de la Recherche et de la Sécurité -French National Research and Safety Institute) incorporated NIOSH blind area diagrams into one of their [publications](#) [Marsot 2011].
- ❖ Knowledge of other companies using blind area diagrams to increase hazard awareness comes from conversations with company safety and health directors:
 - In 2011, Lane Construction Company had a safety Stand-Down to focus field personnel on preventing injuries from backing-up vehicles. They used blind area diagrams as part of the Stand-Down exercise [Fosbroke 2009]. A Stand-Down is a term taken from the military, reused here as a name for an upbeat safety awareness event. See page 297 for a description of a similar effort for construction falls.
 - In 2013, an ecologist for a design-build firm contacted NIOSH about using blind area diagrams for project-specific safety plans, safety

briefings, and presentations focused on general construction safety [Fosbroke 2013].

- In 2009, Corman Construction in Annapolis, Maryland, launched a company-wide program to raise awareness of the hazards created by blind areas [Fosbroke 2009].
 - Also in 2009, Ledcor Industries in Vancouver, British Columbia, contacted NIOSH with interest in creating blind area diagram decals for installation in the cabs of company equipment [Fosbroke 2009].
- ❖ In 2013, a mine in Minnesota used NIOSH blind spot diagrams to create their own diagrams for mobile equipment on their worksites [CDC Info 2013].
- ❖ In 2014, M-C North America, a company that specializes in developing exterior visual systems for large transportation vehicles, developed a [line of mirrors for heavy equipment](#) that eliminates the distortion levels typical of convex mirrors. M-C North America used the NIOSH definition of blind areas on their website where they explain the development of the new mirror system.
- ❖ In 2015, South Korean researchers from the Department of Biosystems Machinery Engineering at Chungnam National University, LS Matron Research and Development Center, Gunpo Korea Research Institute, and Kukje Machinery Company LTD used the NIOSH manual method of measuring equipment blind areas to evaluate visibility for agricultural tractor operators [Kabir et al. 2015]. The article noted, “The manual method recommended by NIOSH was helpful to define the exact nature of the blind, or non-visible areas, and mirror visibility can also be determined by that method” [Kabir et al. 2015].

Internal Traffic Control Plans

In 1998, the Laborers’ International Union of North America (LIUNA) introduced the concept of organizing the workspace, the worker-occupied area of the work zone, to lessen the risk of construction vehicles and equipment striking workers on foot. During 2000 through 2005, NIOSH funded two researchers, Graham and Birch, to prepare reports on how NIOSH could define an internal traffic control plan (ITCP) at this

workspace organization. The researchers included examples of ITCPs on asphalt [CL Williams Consulting Inc. 2003a, c] and concrete paving [CL Williams Consulting Inc. 2004a, b] and a guide on how to develop ITCPs [CL Williams Consulting Inc. 2003b]. Graham and Birch also published a conference paper and a peer-review article on the preparation of ITCPs, which included observations from asphalt and concrete paving operations [Graham et al. 2005; Graham and Burch 2006].

Next, NIOSH worked with construction contractors to refine the ITCP concept by preparing an [ITCP Development Guide](#), piloting ITCPs with a construction company, and developing an ITCP training program for supervisors responsible for work crews on hot-mix asphalt (a combination of stone, sand or gravel with asphalt that is heated to complete the binding process) paving operations. NIOSH implemented ITCPs at hot-mix asphalt paving operations. Researchers collected data at control and intervention study sites on worker exposures to construction vehicles and equipment [Graham et al. 2005; Graham and Burch 2006].

During these field intervention trials, NIOSH researchers worked with officials and staff from state departments of transportation and road construction companies. NIOSH trained agency and company staff on the principles of internal traffic control, worked with staff during data collection, and provided updates to agency and company leadership. Arizona, North Carolina, and Vermont helped obtain pilot sites before conducting the field trials, while Idaho, Indiana, Oklahoma, and West Virginia participated in the field trial. Application of ITCPs were mixed, with two of seven sites experiencing a significant decrease in exposures [Fosbroke 2011a]. NIOSH co-branded an ITCP brochure [The Roadway Safety Alliance 2005] with the [OSHA Work Zone Safety and Health Coalition Alliance](#) and presented ITCP concepts at many labor and industry safety conferences.

Working with the OSHA-NIOSH Safety and Health Partners' Alliance during 2003 through 2008, NIOSH contributed to several modules of the [Roadway Safety+ Training Program](#) and three toolbox talk brochures (page 65), which Alliance partners distributed through DVDs and internet downloads. NIOSH contracted with ARTBA to develop a series of three-minute video clips focused on preventing backovers and runovers (workers hurt

or killed by vehicles backing or running over them), covering [dump trucks](#), [equipment](#), and [technology](#). These videos covered blind areas around construction vehicles and equipment, use of mirrors and backup alarms, availability of proximity warning technology, the need to separate workers on foot from moving equipment, and maintaining windows and mirrors to maximize equipment operator visibility. Using NIOSH funding, ARTBA incorporated the videos into a training program, [Preventing Runovers and Backovers – Internal Traffic Control Plans](#) [ARTBA 2011].

ARTBA also developed a field guide with student and instructor workbooks on preventing runovers and backovers. ARTBA trained nearly 7,000 construction workers and on-site supervisors on ways to reduce workers' risk of being hit by operating equipment in work zones. During the training, approximately 2,300 of the student workbooks were distributed. NIOSH delivered the training program to the construction industry with funding from OSHA and FHWA, and developed a guidance document, [Guidance: Developing Internal Traffic Control Plans \(ITCPs\) for Work Zones](#) using FHWA funding [ARTBA 2016]. The guidance document includes information from the NIOSH work zone project.

In 2009, NIOSH contracted with the [North American Association of Transportation Safety and Health Officials](#) (NAATSHO) to develop a training program on DVD called *Work Zone Employee Safety Awareness and Internal Traffic Control Planning* [North American Association of Transportation Safety & Health Officials 2009]. This training program introduces state and local transportation workers to the concept of internal traffic control. NIOSH researchers presented at NAATSHO annual meetings and participated in discussions on many topics, including selection of high-visibility apparel, backing safety, construction visibility limits, internal traffic control, motorists' intrusion into work zones, safety and health data-system management, and hearing conservation.

NIOSH researchers and industry stakeholders trained company and transportation personnel about internal traffic-control concepts. Researchers shared information with several construction companies, including the seven companies that participated as data collection sites [Fosbroke and Beaupre 2008a]. NIOSH staff held trainings and workshops at annual trade-association meetings (e.g., World of Asphalt, ConExpo) and

work zone safety meetings [Fosbroke and Beaupre 2008b; Fosbroke 2009; Fosbroke 2012]. In 2011, the Idaho Department of Transportation (IDOT) and the Idaho Contractors' of America arranged for NIOSH staff to conduct a four-hour work zone safety workshop at their Annual Safety Fest of the Northwest for construction companies, county road departments, and IDOT staff [Fosbroke and Lincoln 2011]. In 2017, an insurance company with about 20 roadway construction companies in its portfolio organized a NIOSH presentation to 17 corporate safety directors to discuss how ITCPs are developed [Fosbroke 2017].

Intermediate Outcomes:

- ❖ At the request of the Iowa State Department of Transportation, Iowa State University incorporated ITCP principles into their integrated traffic control risk management system [Shane et al. 2012].
- ❖ NAATSHO distributed the work zone internal traffic control program to its members to train highway department workers in their states. The Minnesota Department of Transportation inquired to NIOSH about using the included video in their internal safety training [CDC Info 2010].
- ❖ The ANSI American Society of Safety Engineers (ASSE) consensus standard, A10.47-2015 Work Zone Safety for Highway Construction, and the Safety Certification for Transportation Project Professionals both incorporated ITCP concepts. More than 100 people have passed the Safety Certification for Transportation Project Professionals exam, and about 200 others are scheduled or now registering for the exam [Fosbroke 2017].

Proximity Warning Systems

Sensor technologies offer a new way to add safety features to construction equipment. These proximity warning systems alert equipment operators when they are nearing contact with another object. NIOSH took two approaches to adapting sensing technology to construction equipment: purchasing off-the-shelf systems and developing a new system. Researchers tested the potential of four types of sensing technology (camera, sonar, radar, and electromagnetic field) for use on highway construction

equipment. Related activities included developing test methods for measuring the detection area of sensing technologies; developing temporary processes for installing sensing technology on highway equipment; and developing and patenting an electromagnetic field-based proximity detection and warning system.

NIOSH developed, tested, patented (U.S. patent No. 5,939,986: Mobile Machine Hazardous Working Zone Warning System [Schiffenbauer and Ganoe 1996] and 6,810,353: A Non-directional Magnetic Field Based Proximity Receiver with Multiple Warning and Machine Shutdown Capabilities [Schiffenbauer 2001]) and licensed a prototype proximity warning system, the [*Hazardous Area Signaling and Ranging Device \(HASARD\)*](#) shown in Figure 57. This system uses the basic concept of electromagnetic fields for proximity warning and detection and includes an electromagnetic field generator, loop antenna, transceiver worn by workers on foot, and a receiver/display unit mounted in the equipment cab.

In collaboration with the Georgia Institute of Technology and through a CPWR-funded small study project, NIOSH evaluated other technology for detecting workers around operating equipment, developing a prototype safety sensing system and alerts based on off-the-shelf Bluetooth low-energy technology [Cho et al. 2017]. NIOSH demonstrated the installation of this technology on construction equipment and published the study results [NIOSH 2003; Ruff 2004], circulated the [*key findings*](#), and recommended methods for selecting and testing proximity warning systems for mining equipment that work equally well with construction equipment [NIOSH 2007b].

NIOSH researchers worked in the field with officials and staff from state departments of transportation and road construction companies, training agency and company staff on the principles of proximity detection, working with staff during data collection, and giving updates to leadership. Arizona, North Carolina, and Vermont assisted with obtaining pilot sites before conducting the field trials, while Idaho, Indiana, Oklahoma, and West Virginia participated in the field trial. Results suggested that installing proximity-warning devices at a worksite decreased unsafe worker risk to moving equipment, but the decrease was not statistically significant [Fosbroke 2011a].

Figure 57. Hazardous Area Signaling and Ranging Device (HASARD)



The Idaho Department of Transportation, the Washington State Department of Transportation, and the Vermont Agency of Transportation (VAOT) requested presentations from NIOSH. Researchers also presented the results to OSHA Alliance members, the U.S. Department of Labor's National Advisory Committee for Construction Safety and Health, the Association of Equipment Manufacturers, the North American Transportation Safety and Health Officials, and to others at a variety of research and industry annual meetings.

NIOSH provided stakeholders (e.g., Washington State Department of Transportation and VAOT) and federal agencies (e.g., U.S. Department of Transportation and its National Highway Traffic Safety Administration) with recommendations and information on proximity-warning technology effectiveness, limitations, and installation procedures.

Intermediate Outcomes:

- ❖ Frederick Mining Controls licensed NIOSH's HASARD concept into a product called HazardAvert® for use on highway construction haul trucks, surface mining haul trucks, and forklifts. [Strata Worldwide](#) markets the HazardAvert® system surface and underground proximity detection system, which incorporates the HASARD technology.
- ❖ The development of ISO standard 16001:2008—*Earth moving machinery—Hazard detection systems and visual aids - Performance requirements and tests*

[ISO 2008], cited previous NIOSH research regarding collision warning systems [NIOSH 2000a; b; 2002].

Construction Solutions Database

Ready-to-use, commercially available solutions to [work zone-related hazards](#) are available online to construction superintendents, occupational safety and health consultants and workers through CPWR's Construction Solutions database. The database is designed as an easy-to-use tool for construction firms seeking quick answers to their health and safety questions while at the worksite. The database contains analyses of workplace hazards that have been synthesized for quick review and application. The public accessed the work-zone related solutions listed below 6503 times as of December 7, 2017:

- [Automated Flagging Assistant Devices](#)
- [Building Information Modeling for Safety Planning](#)
- [Crash Cushion](#)
- [High-Visibility Safety Apparel](#)
- [Illumination Ring for Hard Hats](#)
- [Movable Longitudinal Barriers](#)
- [Object Detection and Camera System for Heavy Equipment](#)
- [Rumble Strips](#)
- [Self-Adjusting and Directional Backup Alarms](#)
- [Temporary Longitudinal Barriers](#)
- [Temporary Traffic Control Devices](#)
- [Truck-Mounted Attenuator](#)
- [Work Zone Lighting](#)

Committee and Work Group Participation

Committee and work group participation allows NIOSH researchers further understand industry needs and how industry partners could help NIOSH in moving work zone research into practice. NIOSH researchers join in many work zone safety activities:

- Provide input into educational materials, training programs, guidance documents, and other safety materials developed by industry and other partners.
- Present at many organizations safety meetings representing labor, contractor and trade associations, transportation departments, manufacturers, and insurers.
- Participate in work groups and two consensus standards committees.

American National Standards Institute (ANSI) Committees

- *ANSI/ASSE A10.47-2015 American National Standard for Work Zone Safety for Highway Construction*—NIOSH provided information and expertise on blind area diagrams, ITCs, proximity warning systems, and field observations to the A10 subcommittee as they drafted this standard.
- *ANSI/ISEA 107-2015 American National Standard for High-Visibility Safety Apparel and Accessories*—While NIOSH is not a member of this consensus-standard committee, NIOSH staff discussed high-visibility apparel with members of the committee at construction industry meetings and presented the video of the high-visibility vest test burn. Because of this input, the current ANSI/ISEA standard on high-visibility safety apparel and accessories specifies labeling requirements for flammability.

OSHA Work Zone Safety and Health Partners' Alliance

Working together, OSHA, NIOSH, and the Roadway Work Zone Safety and Health Partners give members and others with information, guidance, and access to training resources to help protect the health and safety of workers, as well as promote a better understanding of worker rights and the responsibilities of employers under the 1970 Occupational Safety and Health Act (OSH Act). The Alliance promotes a culture of safety and health within the roadway-construction industry, including non-English and limited-English speaking employees. The Alliance aims to reduce workplace incidents and prevent worker exposures to runaway/backover and struck-by hazards, excessive noise, sprains and strains, and illnesses associated with silica exposure. At quarterly meetings, members discuss activities related to promoting safer work zones throughout the United States. Many large organizations are in the Alliance:

- American Association of State Highway Transportation Officials
- American Road and Transportation Builders Association
- Associated General Contractors of America
- International Union of Operating Engineers
- Laborers' International Union of North America
- Laborers' Health and Safety Fund of North America
- LIUNA Education and Training Fund
- National Asphalt Pavement Association
- National Institute for Occupational Safety and Health
- Occupational Safety and Health Administration

Work Zone Safety Consortium

FWHA's work zone safety grant program developed highway work zone safety training and guidelines to prevent and reduce work zone injuries and fatalities. In 2007, FHWA awarded funds for a joint grant to the Laborer's Health and Safety Fund of North America (LHSFNA) and ARTBA, among others. NIOSH provided subject-matter expertise to LHSFNA and ARTBA to develop a series of guidelines for highway construction. NIOSH recommended adding safe access and egress topics to the workspace of a work zone based on field trial experience at highway paving sites. NIOSH assisted LHSFNA and ARTBA with the development of the following guideline documents:

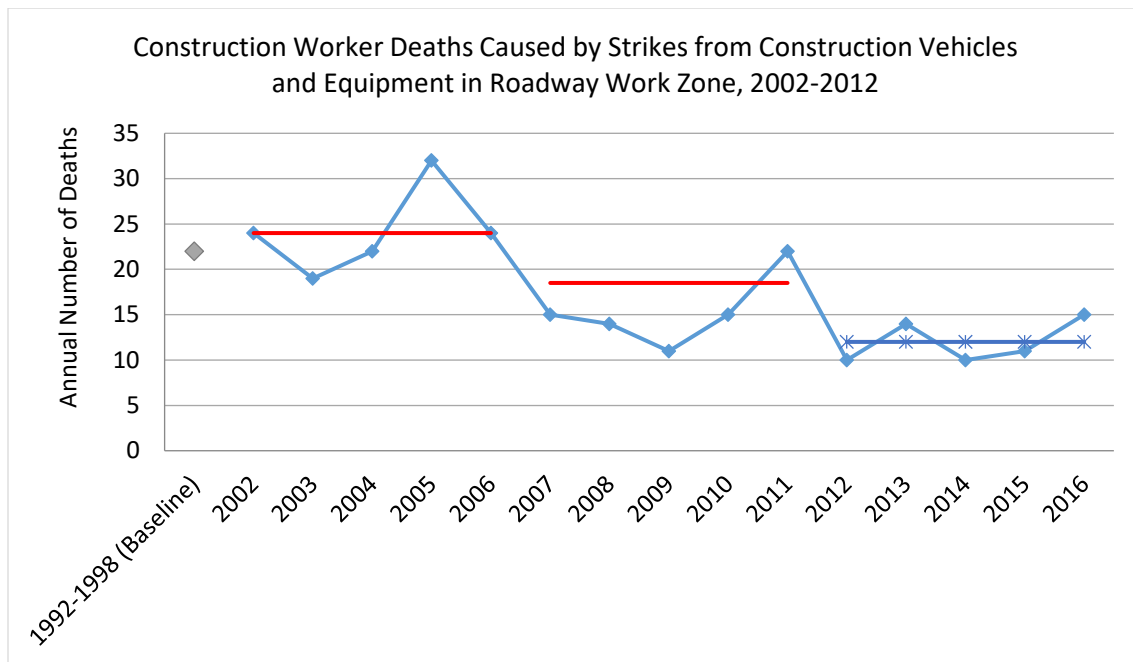
- [Guidelines for managing speeds in work zones](#) (2010)
- [Guidelines on ensuring positive guidance in work zones](#) (2011)
- [Guidelines on work zone access and egress](#) (2011)
- [Guidelines for developing internal traffic control plans \(ITCPs\) for work zones](#) (2016)

End Outcomes

A decline in occupational injuries and fatalities in the work zone in the U.S. is the desired outcome of interest. Currently the number of workers killed in work zones by construction vehicles or equipment serves as the best, if imperfect, measure of the end outcome. After peaking at 32 deaths in 2005 (Figure 58), these struck-by fatalities fell to a three-decade low of 11 in 2009 (2012 data are preliminary). The five-year average

declined 23% from 24 deaths (2002–2006) to 12 (2012–2016). The coordinated activities of key industry groups, NIOSH, and other partners resulted in policy, regulation, consensus standards, and industry practice changes that likely influenced the lower fatality rate.

Figure 58. The number of construction worker deaths caused by strikes from construction vehicles or equipment in roadway work zones, from 2002–2012. The gray diamond on left is the baseline average from 1992–1998; red lines mark five-year averages.



Alternative Explanations

The economic downturn during 2008–2012 reduced the number of highway and road construction projects, making it difficult to interpret the impact of NIOSH research activities on the reduction of work zone struck-by injuries and fatalities. Many organizations and government agencies have played critical roles in the level of work zone safety in the U.S. today. State and federal transportation agencies strongly encourage work zone safety for the companies and workers operating in their jurisdictions, and they have the authority and funding to regulate activities. The American Road and Transportation Builders Association, the National Asphalt Pavement Association, the Associated General Contractors of America, the International Union of

Operating Engineers, the Laborers' International Union of North America, and Laborer's Health and Safety Fund of North America are professional association and labor partners, respectively, who have played pivotal roles in identifying, funding and disseminating work zone safety information. The collaborative and coordinated activities of all these stakeholders, including NIOSH, drove changes in policy, regulation, consensus standards, technology adoption, and industry practice. It is difficult to imagine any outcome separate from this coordinated effort.

Future Plans

NIOSH and CPWR researchers will continue to analyze data, publish findings, and work with industry partners and translate research into practice on roadway construction sites. NIOSH anticipates continuing to work with industry stakeholders to promote worker safety in roadway construction, primarily through participation in the OSHA-NIOSH Roadway Work Zone Safety and Health Partners' Alliance.

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Chapter 6: Preventing Falls in Construction



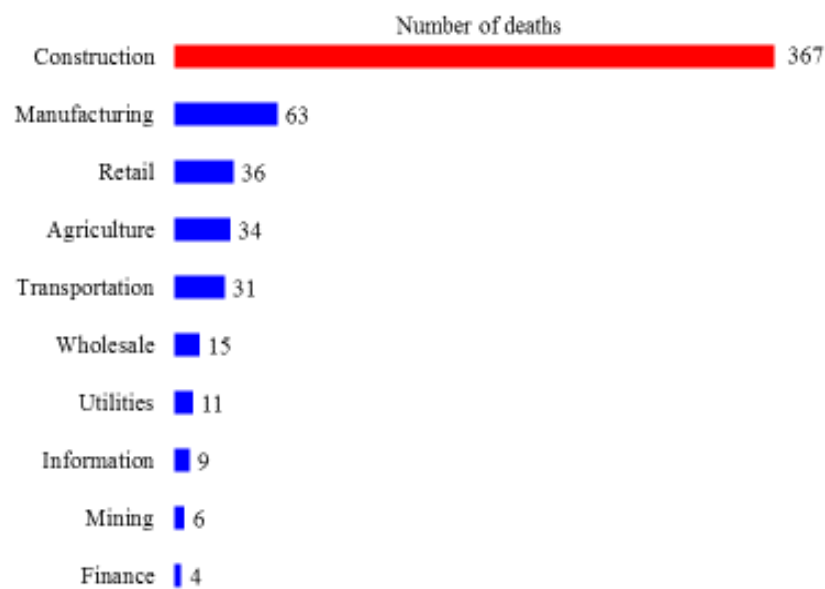
[Credit Turner Construction/Earl Dotter/CPWR]

Introduction

For decades, falls have been the leading cause of death and serious injury in construction. Fatal falls are far more common in construction than other industries (Figure 59). Because most of these injuries and deaths are preventable, fall prevention research is a critically important area of occupational safety research. Since the mid-1990s, the National Institute for Occupational Safety and Health (NIOSH) has recognized fall prevention as a strategic research priority and has conducted a collection of laboratory- and field-based research to identify fall risks, develop prevention strategies and technologies, and produce, evaluate, and distribute a variety of products and strategies based on this research. Specifically, NIOSH has developed and updated strategic research goals for construction to address the national occupational fall burden [Stout 2010]. NIOSH has funded grants and cooperative agreements with external researchers and other partners addressing fall prevention, including research to practice (r2p).

Our discussion in this chapter will include falls to a lower level, falls to the same level, and slips and trips. Job hazards that pose risks for falls include unstable and slippery working and walking surfaces, cluttered work areas, unprotected floor and wall openings, unprotected edges, improperly positioned ladders, and misused fall protection equipment.

Figure 59. Number of Fatal Fall Injuries by Major Industry, United States, 2015 (all employment).



Source: U.S. Bureau of Labor Statistics, 2015 Census of Fatal Occupational Injuries. Numbers were from the online CFOI database.

From 2003 through 2015, there were between 267 and 448 fatal falls in construction each year [Dong et al. 2017a]. There were about six times as many fatal falls in construction as compared with manufacturing, the industry with the second highest number of fatal falls. Construction accounted for 46% of fatal falls in all industries that year (Figure 60). In 2015, falls accounted for 353 (36%) of the 985 recorded fatalities among construction workers [BLS 2016a; Dong et al. 2017a]. During 2011 through 2015, the number of fatal falls in construction increased by 36.4%, from 269 to 367, with falls from roofs, scaffolds, and ladders as the primary cause of death. Examining 1,533 fatal

construction falls between 2011 through 2015, nearly 33% were from roofs, 24% were from ladders, and 15% were from scaffolds or staging [Dong et al. 2017a].

The economic recession during 2007 through 2009 had a large impact on the United States (U.S.) construction industry [Wang et al. 2015]. Construction projects that were underway stopped, and planned projects did not begin. Thousands of construction workers lost their jobs (Figure x). Recovery in the construction industry paralleled the economic recovery in the U.S. as a whole, with dollars spent on construction projects and employment following the fall and rise seen in construction fatalities (Figure 61) [Dong et al. 2017a].

Figure 60. Construction Employment in the United States, 2003–2016 (all employment).

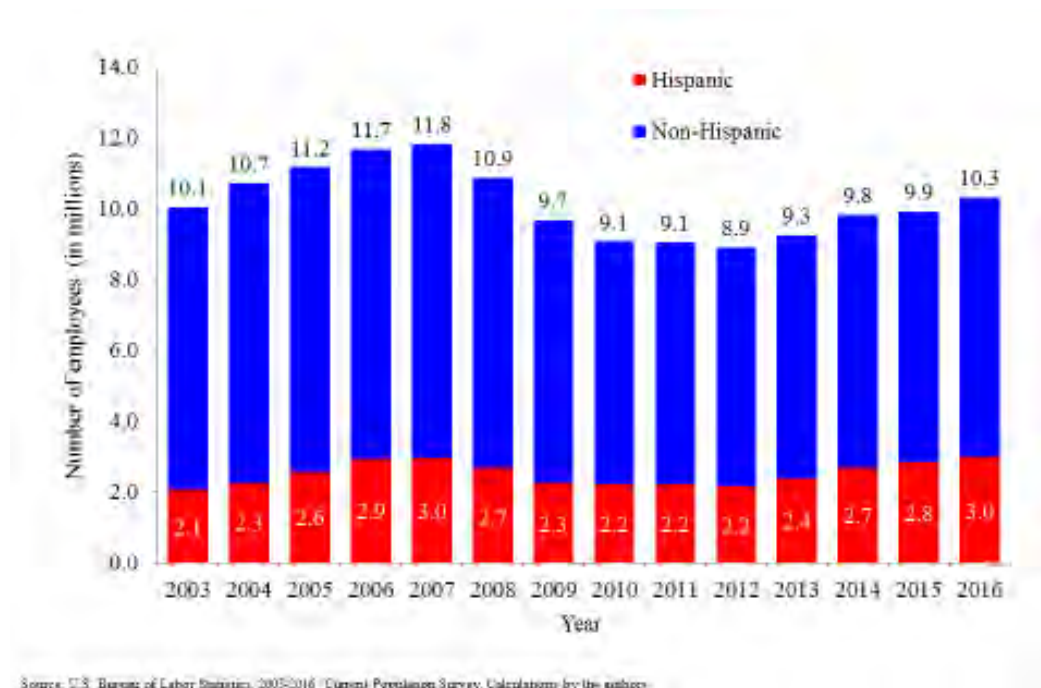
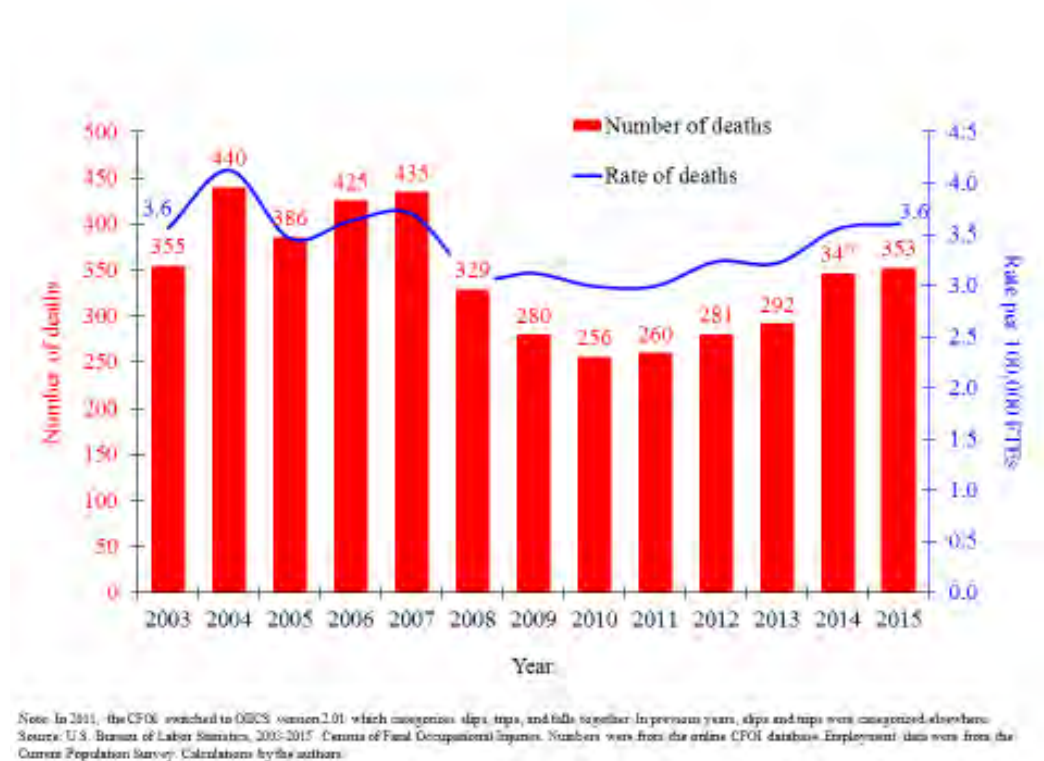


Figure 61. Number and Rate of Fatal Falls to a Lower Level in United States Construction, 2003–2015 (all employment).



Construction falls have consistently ranked among the leading cause of nonfatal injury among all industries in the U.S. The Bureau of Labor Statistics (BLS) data for 2015 show construction workers sustained 40,300 nonfatal injuries from falls, slips, and trips that resulted in one or more lost workdays [BLS 2016b]; note, however, that nonfatal injury data in construction are widely considered under-reported. Data from the U.S. Consumer Product Safety Commission (CPSC) estimated that during 1999 through 2005, U.S. emergency departments treated as many as 555,700 nonfatal fall-related injuries among construction workers [Shishlov et al. 2011]. In a separate study of nonfatal construction injuries treated in emergency departments, the injury rate was twice as high among the youngest workers, those 24 years and younger, compared with those 45 years and older. Workers older than 50 years had the most serious injuries and a higher proportion of falls resulting in fractures [Shishlov et al. 2011].

Based on 2014 data from BLS and the National Academy of Social Insurance, and on information from Liberty Mutual, Liberty Mutual's Workplace Safety Index ranks the

leading 10 causes of disabling work-related injuries and their direct costs. In the 2017 rankings for all industries, falls on the same level and falls to a lower level ranked second and third and were responsible for direct costs of \$10.6 billion and \$5.5 billion dollars, respectively [Liberty Mutual 2017]. Estimates for the total cost of fatal and nonfatal injuries in the construction industry were \$11.5 billion in 2002, which is 15% of the costs for all private industry. The average cost per case of fatal or nonfatal injury is \$27,000 in construction. Falls to a lower level and overexertion are the two most costly events in construction, each generating \$950 million in days-from-work (DFW) costs. Falls to a lower level accounted for 13.8% of the cost of all construction DFW injuries in 2002, which is proportionate to their share of DFW injuries. These falls also rank highly in severity of cases, ranking ninth in per case costs with \$58,000 per DFW case [Waehrer et al. 2007].

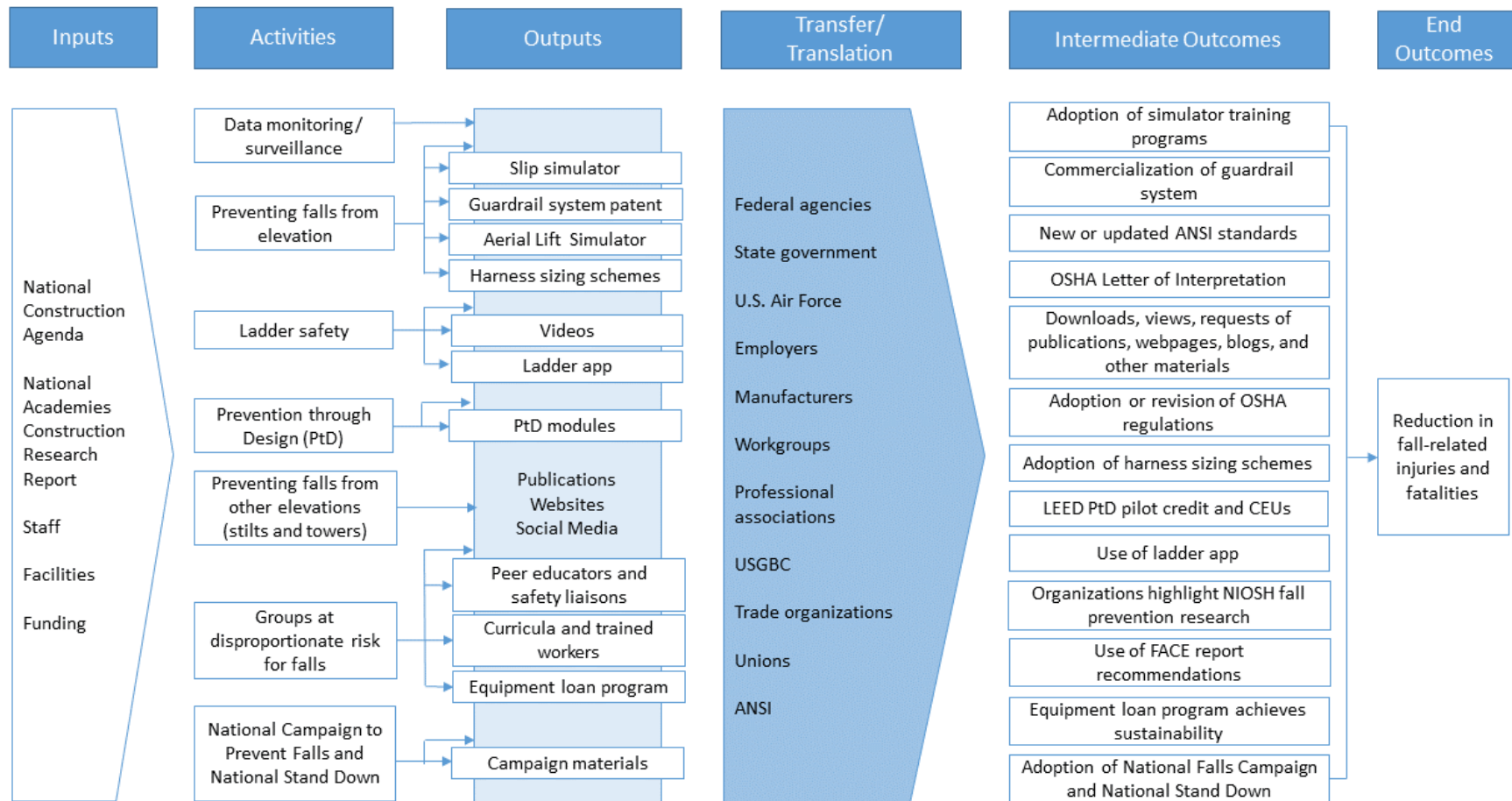
Risks for falls in construction differ among construction subgroups: 323 construction laborers suffered fatal falls to a lower level from 2011 through 2015 (4.8 per 100,000 full-time equivalents (FTEs)), the largest number of all construction occupations. Other occupations at increased fall risk included iron workers, sheet metal workers, welders, and power-line installers. Roofing contractors, however, experienced the highest rate of fatal falls to a lower level during 2011 through 2015, at 34.2 per 100,000 FTEs. That rate was greater than 10 times the rate of all construction occupations combined (3.3 deaths per 100,000 FTEs) [Dong et al. 2013; Dong et al. 2017a].

During 2011 to 2015, fatal falls to a lower level increased faster among Hispanic workers compared with their white, non-Hispanic counterparts. Hispanic construction workers experienced a 28% increase in fatal falls, the rate increasing from 4.0 to 4.9 per 100,000 FTEs from 2014 to 2015; a greater than 20% increase in one year. On the contrary, among white non-Hispanic workers, construction fall deaths decreased 10%, the rate decreasing from 3.4 to 3.0 deaths per 100,000 FTEs during the same period [Dong et al. 2017a]. Foreign-born workers (3.7 per 100,000 FTEs), workers who are self-employed, older workers (28.2% of construction workers who died from falls to a lower level were ages 45 through 54 years), workers in small businesses, and contingent workers experience elevated risks of fatal falls in the construction industry [NIOSH 2015; Dong et al. 2017a].

Logic Model

The logic model (Figure 62) illustrates the characteristics of NIOSH's research and other activities to reduce construction fall-related injuries and fatalities. Elements of the logic model are Inputs, Activities, Outputs, Transfer and Translation, Intermediate Outcomes, and End Outcome. A detailed description of each element follows.

Figure 62. Logic Model for NIOSH Construction-related Falls Prevention Research, 2007–2017.



Inputs

Many inputs contribute to the progress of NIOSH's Construction Program in addressing the problem of falls in the construction industry:

National Construction Agenda

For more than two decades, NIOSH's Construction Program has focused on the leading fatal injury and death contributors to falls. The evaluation of NIOSH's Construction Program in 2008 describes this foundational work [NAS 2009]. The NIOSH Construction Sector Program Manager and Coordinator for the second decade of the National Occupational Research Agenda (NORA) were instrumental in crafting the ready for impact, developmental, and exploratory categorization scheme (page 23) helped combine efforts and speed progress in developing falls interventions for the construction industry. The NORA Construction Sector Council, which included academics, federal and state occupational safety agencies, trade associations, labor unions, insurance companies, and construction contractors with key interests and activities in the construction sector, provided meaningful insight in selecting priorities, and guidance for accomplishing the NORA second decade goals related to falls. With NORA Goals 1 and 13 selected as priorities, the Sector Council helped develop a campaign targeting falls intervention.

The agenda's first strategic goal, Reduce construction worker fatalities and serious injuries caused by falls to a lower level, was instrumental in guiding construction falls research and intervention efforts in NIOSH's Construction Program. NIOSH used the intermediate goals to engage in critical activities to reduce the risk of falls:

Intermediate Goal 1.1 – Partner with construction stakeholders and safety professionals to identify the top three fall-related problems requiring technical engineering solutions, and develop and evaluate options to fill these gaps.

Intermediate Goal 1.2 – Partner with construction stakeholders to expand awareness and use of existing effective fall prevention and protection solutions by construction employers and workers.

Intermediate Goal 1.3 – Partner with construction stakeholders to provide the industry with the information and tools to reduce portable ladder fall injuries.

Intermediate Goal 1.4 – Partner with architects, engineers, and construction organizations to expand the use of “safe-by-design” [The term used by the NORA Construction Sector goal for this topic on design is “Construction Hazard Prevention through Design” or CHPTD] practices for fall prevention via demonstration projects and guidance.

Intermediate Goal 1.5 – Work with construction partners to develop and implement a national campaign to reduce fatal and serious injuries associated with construction falls to a lower level.

NIOSH used Strategic Goal 13, Increase the use of “Prevention through Design (PtD)” approaches to prevent or reduce safety and health hazards in construction, to address green or sustainable construction. Efforts in sustainable construction include addressing fall hazards through design. Specifically through Intermediate Goal 13.3, which is, Evaluate opportunities to develop potential incentives for encouraging architects and engineers to embrace CHPTD, NIOSH introduced a credit to a sustainable building rating system.

The NORA Construction Sector Council reviewed progress on NORA goals throughout the decade. With its support, under Strategic Goal 1, a national campaign addressing construction falls was developed. The Sector Council also participated heavily in the development of a PtD Pilot Credit for the Leadership in Environmental and Energy Design (LEED) (page 282).

Staff working on falls and prevention strategies include researchers and other staff at NIOSH; staff at CPWR—The Center for Construction Research and Training (CPWR), as well as its network of university-based consortium partners and a small grants program; and researchers funded through NIOSH’s extramural grants program. This collective focus on fall hazards and risks position NIOSH to address research needs effectively, to better characterize the problem of falls in construction, and to develop interventions for the occupational safety and health community.

Staff

NIOSH has conducted construction research related to falls both in the field and in laboratories. Partnerships with industry stakeholders are critical. Research has resulted in many outputs including publications, conferences, advice to standards organizations, communication products, and patents. The following individuals have been particularly instrumental in conducting NIOSH falls research:

NIOSH Intramural Researchers

Name	NIOSH Division/Office
Thomas G. Bobick, PhD, PE, CSP	Division of Safety Research (DSR)
Sharon Chiou, PhD	Office of Extramural Program (previously with DSR)
Hongwei Hsiao, PhD	DSR
Christopher Pan, PhD	DSR
Nancy T. Romano, MS, CSHM	DSR
Peter Simeonov, PhD	DSR
CDR Elizabeth P. Garza, MPH, CPH	Office of Construction Safety and Health (CSH)

CPWR Staff, and Consortium and Small Study Researchers

Name	Institution
Thomas J. Armstrong, PhD	University of Michigan
Robin Baker, MPH	CPWR
Eileen Betit	CPWR
Brady Bratcher	Iron Workers Regional District Council & Iron Workers Local 84
Jessica Bunting	CPWR
Chris Trahan Cain, CIH	CPWR
Xiuwen Sue Dong, DrPH	CPWR
Bradley Evanoff, MD, MPH	Washington University in St. Louis, School of Medicine

Name	Institution
Janie Gittleman, PhD	CPWR
Vicki Kaskutas, OTD, MHS, OT/L	Washington University in St. Louis
Eric Marks, PhD, PE	University of Alabama
Michael McCann, PhD	CPWR
Babak Memarian, PhD.	CPWR
Michele Ochsner, PhD	Rutgers-New Labor
Melissa J. Perry, ScD, MHS	The George Washington University Milken Institute School of Public Health, formerly at Harvard University
James Platner, PhD	CPWR
Ruth Ruttenberg, PhD, MCP	Ruttenberg & Associates
Rosemary K. Sokas, MD, MOH	University of Illinois at Chicago
Erich Stafford	CPWR
Pam Susi, MSPH	CPWR
Todd Wolfson, PhD	Rutgers University (with PhilaPOSH)

NIOSH Extramural Researchers

Name	Institution
Linda S. Forst, MD, MPH	University of Illinois-Chicago
Daniel P. Hindman, PhD	Virginia Polytechnic Institute & State University
Hester Lipscomb, PhD	Duke University
Thurmon E. Lockhart, PhD	Virginia Polytechnic Institute & State University
Brian Kleiner, PhD	Virginia Polytechnic Institute & State University
Michael L. Madigan, PhD	Virginia Polytechnic Institute & State University
Cora R. Roelofs, PhD	University of Massachusetts-Lowell
Huiyun Xiang, MD, PhD	Children's Research Institute

National Academies Construction Research Report

Finally, the Construction Program also considered findings and recommendations from the National Academies 2008 evaluation report, [Construction Research at NIOSH](#) (page 9), in its planning efforts [National Research Council U.S. and Institute of Medicine U.S. Committee to Review the NIOSH Construction Research Program 2009]. In [2012](#) and [2014](#), NIOSH's Board of Scientific Counselors evaluated the Program's progress in implementing the National Academies' recommendations. These inputs were critical in ensuring NIOSH's falls research efforts were sound.

Activities, Outputs, Transfer and Translation, and Intermediate Outcomes

Extensive research activities on preventing falls in construction continue in four NIOSH divisions, at CPWR, and among researchers funded through NIOSH's Office of Extramural Programs. These important, innovative efforts help us to better understand and improve the problem of falls in construction. This section describes major projects, and their outputs and intermediate outcomes.

Data Monitoring and Surveillance Research

Many research activities have focused on enumerating the type and severity of construction safety and health topics, or on improving data collection generally. Monitoring external national occupational safety and health data sources for fall-related injury and death information allows NIOSH to examine and compare such information across industrial sectors. The Construction Program relies on CPWR to provide a thorough assessment and analysis of national databases for injuries and deaths related to construction falls. The Construction Program uses this information in making data-driven decisions regarding its priorities.

Construction researchers also use CPWR's analyses as the basis for their work. For example, CPWR's data analysis helped the NIOSH Construction Program identify Hispanic workers as the construction workers with the highest risk for falls. Hispanic workers who represent about 17% of the U.S. population and over 25% of the construction workforce experience more fatal falls than non-Hispanic construction

workers (Figure 63). The proportion of fatal falls among Hispanic construction workers increased from about 37% of all fatal falls during 1992 through 2002 to 40% of all fatal falls in 2006 [Dong et al. 2009]. The risk of fatal falls was higher for Hispanic workers not born in the U.S. Nearly 80% of the Hispanic workers who died from falls during 2003 through 2006 were foreign-born, and many were young and inexperienced. Nearly 65% of Hispanic workers who died from a fall were employed for less than a year, compared with about 53% of white, non-Hispanic workers who died [Dong et al. 2009]. Analyses by

Figure 63. CPWR's data analysis revealed that Hispanics have a higher risk for fatal falls than their non-Hispanic counterparts. [Credit SNC-Lavalin/Earl Dotter/CPWR]



CPWR's Data Center have also been helpful in characterizing fall events, injuries, and deaths in construction. For example, CPWR studied trends in fatal falls from roofs in U.S. construction during 1992 through 2009 using BLS Census of Fatal Occupational Injuries (CFOI) data and the Current Population Survey (CPS). They found that falls from roofs accounted for one-third of fatal falls in construction. The analysis also showed that nearly 67% of deaths from roof falls occurred in small construction businesses (i.e., those having 10 or fewer employees), with roofers, iron workers, and residential

construction workers most at risk of fatal roof falls. Workers under 20 or older than 44 years of age, Hispanic workers, and immigrants experienced higher rates of roof fall fatalities. This study recommended that prevention strategies target these high-risk workers [Dong et al. 2013].

NIOSH also recognizes, however, that the construction industry commonly underreports falls. Kleiner et al., at Virginia Polytechnic Institute & State University (VA Tech) (2009 through 2015), funded by both NIOSH and CPWR, compared patterns of work-related injuries and illnesses among union carpenters in Washington State from BLS data and state workers' compensation claims over a 20-year period (1989 through 2008) [cited in Lipscomb et al. 2013]. They found the rate of injury and illness claims higher than those reported by BLS.

Preventing falls from Elevation

Working at height is dangerous. Equipment meant to improve efficiency and productivity while working at height (e.g., aerial lifts, ladders) adds more complexity to an already challenging work environment. NIOSH studies conducted during 2007 through 2017 aimed to improve safety in these environments. Research includes guardrail systems, ladders, mast climbers, aerial lifts, and fall protection harnesses (Figure 64X). Reports from NIOSH's [Fatality Assessment and Control Evaluation](#) (FACE) investigations offer insight into how the construction industry uses recommendations stemming from NIOSH's research.

Figure 64. NIOSH research includes guardrail systems, ladders, mast climbers, aerial lifts, and fall protection harnesses. [Credit Turner Construction/Earl Dotter/CPWR]



Characterizing Fall Risks

Fall risks exist at different types of elevations (from a roof, scaffold, etc.), however, other factors contribute and must be understood to reduce risk. For example, a NIOSH-funded researcher at Virginia Tech, Lockhart (2009 through 2014), investigated how localized muscle fatigue and its effect on gait and balance increased fall risks [cited in Parijat et al. 2015; cited in Wen-Ruey et al. 2016]. Lockhart conducted two laboratory studies to quantify the effects of localized muscle fatigue on slip tendency and balance recovery. The first evaluated the effects of localized muscle fatigue on the slip initiation process while walking over a non-slippery surface. The second experiment evaluated the effects of localized muscle fatigue on the balance recovery process following slips caused by walking on an unexpectedly slippery surface. Results showed that, in

comparison with values during normal walking, lumbar kinematics, lumbosacral kinetics, lumbar muscle activations, and lumbosacral reaction forces all substantially increased during a slip event. These observed levels of muscle activity and lumbosacral reaction forces suggest the potential for low-back injury during a slip event. Thus, in addition to causes following a slip (e.g., contact with the ground from a fall), low-back injury could result from high levels of forces generated during the slip.

Based on this research, Lockhart developed a slip simulator-training program to improve the ability to recognize and take proper actions to prevent various fall hazards at workplaces. The results suggest a beneficial effect of slip simulator training in reducing fall accidents.

Intermediate Outcome:

- ❖ The Iowa-Illinois Safety Council is currently one of two companies within the entire state of Iowa to own a slip simulator [Iowa-Illinois Safety Council 2018].

Roofs and Platforms

Frequent fatalities and severe injuries result from workers falling through roof and floor openings, and existing skylights. Bobick et al. at NIOSH worked with residential carpenters to design, develop, and patent a multifunctional guardrail system for use in residential and commercial-industrial work sites to prevent workers from falling to lower levels [Cantis et al. 2009; Bobick et al. 2010; Bobick and McKenzie 2011]. This two-edge protection guardrail system can provide protection to personnel working near (1) unguarded roof surfaces—flat and seven different residential slopes, (2) unguarded skylights, (3) unguarded roof and floor holes, and (4) on stairs where handrails are not installed yet. The fall-prevention system meets all Occupational Safety and Health Administration (OSHA) safety requirements for guardrails. In fact, the final design supports more than twice the OSHA 200-pound top-rail strength requirement for a worker falling against it, and it is easy to install.

Intermediate Outcome:

- ❖ In 2014, Reese Wholesale began to manufacture the NIOSH's guardrail system and make it commercially available. The system sells commercially as [The Protector Guardrail System](#).

A mast climbing work platform (MCWP) helps construction workers perform tasks at height more safely. A MCWP is a power-driven work scaffolding surface that climbs a vertical tower mast, allowing both work at height and work at positions that reduce bending and reaching. A MCWP can also carry larger loads to higher elevations compared with traditional scaffolds [CPWR Work Group on Mast Climbing Work Platforms 2010]. The construction industry, particularly the masonry industry, uses them to increase efficiency and to reduce risks for musculoskeletal injuries. Nearly 50,000 workers use the 22,000 MCWPs in the U.S.

When installed and used correctly, mast climbers are considered safe, or safer, than other scaffolds [CPWR Work Group on Mast Climbing Work Platforms 2010]. When they fail, however, multiple deaths and serious injuries may occur. For example, using OSHA and media reports, CPWR identified 12 incidents between 1990 and 2010 that resulted in 18 deaths and a number of serious injuries. In each case, either workers fell or parts of the MCWP struck them.

CPWR established a work group made up of representatives from industry, government, and labor, to examine problems associated with MCWPs and to discuss solutions to improve safety. The work group identified the lack of mandatory, standardized training tailored for this type of scaffold as a major underlying reason for these preventable MCWP-related injuries and deaths. Their work culminated in a series of recommendations to reduce the risks of MCWP failure. These recommendations targeted regulators, individuals, and entities responsible for training workers who assemble, disassemble, or work on mast climbers, and those who specify and contract construction work for mast climbers [CPWR Work Group on Mast Climbing Work Platforms 2010].

Intermediate Outcomes:

- ❖ The Mast Climbing Platforms work group published [*Reaching Higher: Recommendations for the Safe Use of Mast Climbing Work Platforms*](#), which addresses mast climbing scaffold use, hazards, and training needs. The work group recommended that OSHA and the American National Standards Institute (ANSI) A92.9 Committee strengthen their standards to address the unique design and safe use of mast climbers. In response, OSHA determined that the scope of the existing Cranes and Derricks standard covers hoists attached to mast climbers and posted their determination in a 2011 Letter of Interpretation ([Applicability of OSHA's Cranes and Derricks standard to hoists attached to mast climbing platforms](#)). Statutes, standards, and regulations determine OSHA requirements, and interpretation letters explain the requirements and their application in specific circumstances.
- ❖ The Masonry r2p Partnership established an [online resource on mast climber safety](#). Since its release, the report has more than 3,700 requests and downloads. In addition, more than 700 copies of a related [IMPACT Card](#) summarizing the report's findings, recommendations, and follow-up activities.

With an interest in reducing fall hazards and musculoskeletal disorders associated with MCWPs, in 2016 Pan and colleagues at NIOSH began designing a mechanical intervention—a production table that removes the need for lower level access to materials and reduces the potential for overloading the MCWP—and testing mechanical loads, including anchorage conditions [Pan et al. 2012]. The study aims to improve worker safety, productivity, and ergonomics by decreasing exposures to material handling hazards (for masons), by improving work efficiency (number of bricks laid per hour), and by finding the anchor conditions (bolts, wall conditions) that cause MCWP anchors to fail. In the latter, Pan et al. are conducting computer model simulations to recreate circumstances that cause failures, and they are designing an ultrasonic testing program with funding from Builders Mutual's Jobsite Safety Institute. In the former, NIOSH researchers are working with a key MCWP manufacturer (Fraco) in the study, but other manufacturers are very interested in this type of intervention. NIOSH will make

changes to the adaptations it is developing to accomplish the goal of improving worker posture while working on MCWPs.

Aerial Lifts

Another choice for working at height is the aerial lift; a powered, mobile platform used to elevate workers to various heights (Figure 65). Pan et al. [2007] at NIOSH analyzed 306 fatalities in the BLS CFOI database related to aerial lifts (228 boom lifts and 78 scissor lifts) that occurred between 1992 through 2003. Researchers found that lift height and the vertical position of the worker correlated with incidents as typically the higher the lift, the less vertical the worker. Tip-overs accounted for 44%–46% of boom-lift and 56%–59% of scissor-lift fatalities. Falling from a height accounted for 72% of the scissor-lift fatalities. Pan et al. also examined data from 173 fatalities investigated by OSHA in 1990 through 2003 and the 12 investigated by the NIOSH FACE Program in 1985 through 2002. They found that 83% of cases involved falls, collapses, or tip-overs.

Figure 65. A NIOSH study showed that fall arrest systems on aerial lifts offer effective fall protection. [Credit Turner Construction/Earl Dotter/CPWR]



The CFOI, OSHA, and NIOSH data suggest the majority (72%–74%) of scissor-lift fatalities occurred in construction, yet fall protection equipment use on scissor lifts was not universally accepted as effective by safety experts [Pan et al. 2007; Pan et al. 2012]. In light of this finding, NIOSH conducted a laboratory study using a commercially available 19-foot electric scissor lift. Researchers dropped manikins wearing fall arrest systems from the fully extended scissor lift [Pan et al. 2012]. A computer model simulated movements, falls, and biomechanical impact. The study showed that fall arrest systems offer effective fall protection on scissor lifts. Further study showed that to work safely on a lift, the fall arrest system must anchor to the floor of the lift rather than to a railing [Harris et al. 2010].

Figure 66. [Aerial Lifts Educational Poster](#)



Understanding that anyone using aerial work platforms and equipment needs training, NIOSH developed an educational tool and other products to create awareness about common workplace hazards when using aerial lifts. One such tool is NIOSH's [Aerial Lift Hazard Recognition Simulator](#). Employers, trainers, safety professionals, and other users

can download this step-by-step guide designed to help potential aerial lift operators acclimate to aerial lift operation. While not a substitute for required training to operate an aerial lift, the Simulator aids in finding common occupational hazards during aerial lift use (e.g., depressions [potholes], crushing hazards, and tip-over hazards).

As part of the process for developing the Simulator, NIOSH contacted the aerial lift work groups within the ANSI A10.29 and A92.9 standard committees, asking for feedback. The Simulator was then refined using this feedback to ensure that it would accurately reflect and meet the expectations of aerial lift industry manufacturers and safety professionals to help reduce injury and deaths to aerial lift users. Members of the Scaffold and Access Industry Association, an organization that includes aerial lift manufacturers, rental companies, safety consultants, and trade associations, received information and flyers ([Aerial Lift Simulator flyer](#)) (Figure 66) about the Simulator through email messages. Employers, trainers, safety and health professionals, and aerial lift operators can use this and other information to help prevent work-related falls.

Intermediate Outcome:

- ❖ The NIOSH topic page with the description of the Simulator ([Aerial Lifts](#)) received more than 14,000 views.

Lateral buckling occurs in unbraced joists when a vertical load is applied. For example, when a person walking along the joist exceeds the critical buckling load, the joist can begin to sway and wobble. As the worker moves towards the center of the joist, the amplitude of this sway and wobble become larger, possibly causing a loss of balance or fall. Concerned about this fall hazard, Hindman at VA Tech received NIOSH funds to evaluate construction worker loadings and the mechanical behavior that causes lateral buckling of wood composite I-joists [Hindman et al. 2011]. This study allowed researchers to formulate prevention strategies to enable workers to complete their task while reducing the occurrence of lateral buckling. It also led to the development of the temporary joist stabilizer, a temporary brace that workers use to latch onto the joists in front of them to create a safe walking area. This new invention helps workers avoid situations where joists may become unstable.

Personal Fall Protection Systems, Including Harnesses

Fall protection harnesses are an essential part of personal fall arrest systems; however, for many years, we knew little about how well they fit workers. Poor harness fit can cause suspension trauma injuries after a fall. Symptoms of suspension trauma, or orthostatic intolerance, are light-headedness, palpitations, tremulousness, poor concentration, fatigue, nausea, dizziness, headache, sweating, weakness, and occasionally fainting during upright standing. Suspension trauma can be life-threatening [OSHA 2011].

NIOSH began a series of studies in 2003 examining the harness fit of male and female construction workers. Hsiao et al. [2007, 2009, 2012] determined that approximately 40% of those evaluated while standing or suspended needed a redesign of harness components. Guidelines emerged for the development of improved sizing systems and strap lengths for whole body fall arrest harnesses to accommodate diverse populations in the construction industry (Figure 67). In addition, Hsiao et al. [2012] extended their study on the impact of harness fit on suspension tolerance. The latter research evaluated human-harness interfaces and their effect on the development of suspension trauma after a worker falls and the harness successfully arrests the fall. This research helped harness manufacturers to develop improved harness configurations to fit construction workers. It also helped to develop recommendations for optimum rescue times to prevent suspension trauma after a worker (wearing a harness) falls.

Figure 67. NIOSH research found the need for harness redesign to fit the diverse construction population. [Credit SNC-Lavalin/Earl Dotter/CPWR]



The researchers recommended (a) developing a self-deployable accessory or mechanism integrated into the harness design; (b) fit-testing to reduce the risk of injury during a fall (with two sizes for women and three sizes for men instead of a unisex system); and (c) establishing a nine-minute rescue plan by employers and workers to reduce the risk of suspension trauma.

Intermediate Outcomes:

- ❖ In 2016, OSHA updated its [*General Industry Regulations on Fall Protection Systems*](#) using this NIOSH research to justify requirements that employers should ensure proper harness sizing and configurations to accommodate diverse body shapes and sizes in the workforce, and that fall arrest systems should be capable of safely suspending the worker without impacting their neck and chin area [OSHA 2016].
- ❖ Fall protection harness manufacturers are formulating harness-sizing schemes for various populations, especially women and minorities, to maximize

protection, productivity, and comfort using NIOSH's research. They are using the research also on harness fit as the criterion for real-world torso-angle-of-suspension tests. Specifically, MSA, a harness manufacturer and NIOSH study partner, used study results to develop a new generation of fall protection harnesses, EVOTECH ([*Sizing and Fit of MSA's EVOTECH Fall Protection Harness*](#)). Findings from the harness study are helping to update guidelines for rescuing construction workers whose fall protection harnesses engage during a fall. The ANSI Z359 Fall Protection Standards Committee, where several harness manufacturing industry representatives serve as members, received copies of the study results.

Bethancourt and Cannon, funded through CPWR, confirmed that conventional wood-framed structures and trusses in residential construction can serve as anchor points for personal fall arrest systems, with no need for special modifications, and still satisfy OSHA's fall protection standard [Bethancourt and Cannon 2015]. Unfortunately, while PFAS proved effective in preventing injuries and deaths, they are not always used. Of the 768 construction fatalities investigated through FACE investigations, one-third of the falls were from heights greater than 30 feet where PFAS were unavailable to 54% of the workers [Dong et al. 2017b]. This shows the need for research to examine the adoption of interventions by employers. Studies of employer and worker attitudes about working from elevations and following fall safety regulations help us understand potential barriers to using fall arrest and protection systems.

Hindman, from Virginia Tech, received a grant from NIOSH to examine a fall protection system for residential construction considering usability and worker attitudes after a change in OSHA policy. Until 2013, OSHA policy allowed residential construction employers to let employees work on roofs and elevated surfaces using "alternative fall protection measures," which are less protective than traditional fall protection designed to prevent or arrest a fall. That year, OSHA modified its policy, now requiring employers in residential construction to use traditional fall arrest or fall prevention systems when working over six feet above a lower level, as specified in the regulation, unless they prove infeasibility on that particular jobsite. Hindman [2011] administered a safety climate questionnaire among residential construction workers (unfamiliar with fall

protection) and post frame workers (familiar with fall protection); conducted an engineering analysis of the truss structure considering a worker falling; and assessed the usability of fall arrest systems for both indoor and outdoor scaled world models. From the questionnaires, researchers found an incongruence between contractors and workers about pressure to work faster—workers felt more pressure while contractors did not.

Intermediate Outcome:

- ❖ In 2016, OSHA updated its [Walking-Working Surfaces and Fall Protection Standard](#) using this NIOSH research to justify requirements that employers should ensure proper harness sizing and configurations to accommodate diverse body shapes and sizes in the workforce, and that fall arrest systems should be capable of safely suspending the worker without impacting their neck and chin area [OSHA 2016]. This update also requires that fall arrest systems be capable of suspending the worker within the system or strap configuration without making contact with the worker’s neck and chin area.

Ladder Safety

Falls from ladders are an important source of preventable construction injuries. In the U.S., more than 500,000 people per year receive medical treatment for ladder-related injuries, and more than 300 people die from those injuries [CPSC 2014; CDC 2017]. The estimated annual cost of ladder-related injuries in the U.S. is \$24 billion, including expenses from work loss, medical, legal, liability, and pain and suffering [CPSC 2014].

Characterizing Hazards

Three surveillance systems analyzed by NIOSH in 2011 showed that work-related ladder fall injuries in the U.S. resulted in 113 fatalities, with an estimated 15,460 nonfatal injuries resulting in days away from work, and an estimated 34,000 nonfatal injuries treated in emergency departments [CDC 2014]. Workers who were male, Hispanic, older, self-employed, working in smaller establishments, and doing construction, maintenance, and repair experienced higher ladder fall injury rates [CDC 2014].

In a laboratory-based study, Armstrong, from the University of Michigan, received CPWR funds to examine traits associated with fixed ladder climbing that might increase the risk of falls in an effort to develop design interventions. A modified adjustable ladder recorded the hand and foot forces of a climber on the side rails and first, second, seventh, and eighth rungs. The study examined postures and forces workers might face when operating ready-mix trucks. Armstrong found that climbing with a toolbox yields the greatest overall peak forces on the hands [Armstrong et al. 2008].

In 2004, Perry and colleagues received funding through CPWR to explore fatal falls from ladders [cited in Dennerlein et al. 2009]. The researchers interviewed workers who experienced an injury from a ladder fall and received treatment at one of 65 hospital emergency departments sampled by the National Electronic Injury Surveillance System. These individuals were primarily from construction, installation, maintenance, and repair professions. Researchers found that 51% of fall injuries occurred on step or trestle ladders and 40% on extension ladders. The most frequent injuries were to the arm, elbow or shoulder, and to the head, neck, or face. Diagnoses were primarily fracture, strain, sprain, contusion, or abrasion, and these injuries occurred most often while workers were standing or sitting on a ladder while installing, hanging an item, or performing a repair. Ladder movement was the mechanism in 40% of falls; environmental conditions played a role in fewer than 10% of cases. There was a significant association between fracture risk and fall height while working on the ladder, a finding influenced by worker age [Lombardi et al. 2011].

The researchers then explored the extent users follow ladder-use best practices by developing an audit tool to assess compliance with best practices for portable step and extension ladders in the construction industry. The tool, usable on a hand-held device, consists of four categories of checklists: ladder condition, setup, moving on a ladder, and completing tasks from a ladder. The tool offers a practical method to quantify best practices associated with ladder use that can inform targeted intervention efforts [Dennerlein et al. 2009].

The study by Perry et al. provided an opportunity to circulate a product from an earlier part of this project [cited in Dennerlein et al. 2009]. Funded by CPWR, the [*Don't Fall for*](#)

[It!](#) video, developed with input from labor and industry partners, features first person accounts of workers who survived a ladder fall as well as interviews with family members of those who died. This video helps reinforce the need for using safer alternatives and work practices to prevent ladder falls.

Intermediate Outcomes:

- ❖ Available in English and Spanish, the 11-minute *Don't Fall for It!* video has been widely adopted as a safety training tool by construction contractors, trainers, and apprenticeship programs. Since its release in May 2006, 5,176 copies were distributed, and the video has more than 22,000 views and 1,000 downloads online and on YouTube.

In addition to direct distribution through CPWR, the video has reached many underserved workers through the federal Susan Harwood Training Grant program, administered by OSHA and through state-level initiatives. The Minnesota OSHA Consultation program showed the video to more than 1,000 workers and contractors, including hundreds of small residential contractors who employ a high-risk, hard-to-reach population. The California State Building and Construction Trades Council used the video with more than 100 participants in multi-craft, train-the-trainer classes; giving participants copies to use for training thousands of workers. Roughly 770 Spanish- and English-speaking workers viewed *Don't Fall For It!* as part of a newly-required OSHA 10-hour training program offered through a University of Nevada-Las Vegas program funded through a Harwood Grant. In addition, the Massachusetts Department of Health worked with the State Department of Education to send *Don't Fall For It!* to 51 vocational-technical high schools. The State's Department of Public Health and Division of Occupational Safety and Health jointly promoted the video in a mailing to 384 public works and public utility departments, resulting in video requests from 38 municipalities. Furthermore, more than 1,000 copies of an IMPACT Card describing the video have been distributed or downloaded.

- ❖ A three-minute animated video entitled, [A Simple Task: Fatal Ladder Fall](#), available in English and in Spanish, is part of the *Lessons to Go Home Safe* short-

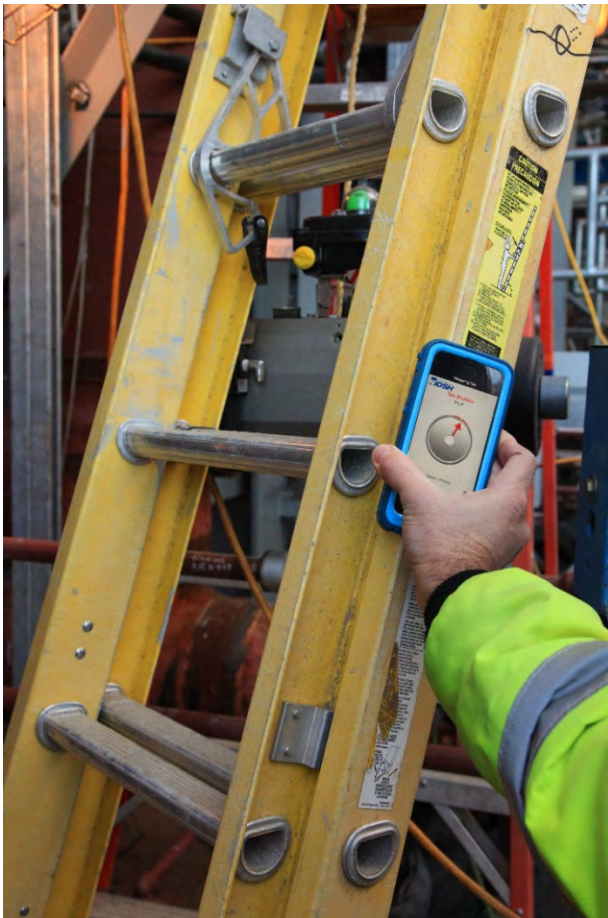
video collection. The video portrays a fatal ladder fall described in a NIOSH FACE report. In 2014, this series won the Construction Writers Association's Robert F. Boger Award for best video and the Silver Telly Award for Internet/Online Programs, Segments, or Promotional Pieces for Safety and Use of Animation. Since posting online and on YouTube in 2014, the video has 56,751 views and more than 2,150 downloads.

Ladder Safety App



Misjudging the ladder angle is a key risk factor for a fall. If the ladder is set too steeply, it is more likely to fall back or slide away during use, and if it is set too shallow, the bottom can slide out. To reduce this risk, NIOSH researchers designed and developed the first NIOSH construction-related smart phone application: the *Ladder Safety App* (Figure 68). The app targets construction workers who regularly use extension and step ladders. Designed to improve ladder safety, the app has a number of interactive tools, checklists, and graphic guides that quickly and easily assist construction workers in ladder selection, inspection, accessory, and safe use. It provides immediate access to easy-to-use ladder safety tools and graphic-oriented ladder safety information, and therefore is an excellent “ladder safety tool-box” and convenient training aid. Importantly, it has the potential to reach small construction contractors who account for more than 80% of the industry and are at high risk for fall injuries. Furthermore, the app can help workers across many other industries, such as manufacture, services, wholesale, and retail, as well as for homeowner use.

Figure 68. NIOSH's Ladder Safety App is a comprehensive tool for portable ladder selection, accessory, inspection, position, and use. [Credit SNC-Lavalin/Earl Dotter/CPWR]



The basis of the app is a NIOSH-patented technology that uses a multimodal indication (multiple signals through visual, sound, and vibration) [Simeonov et al. 2012b]. In a separate study, Simeonov and colleagues showed multimodal signals as more accurate and efficient (requires less time) than other available methods for ideal ladder positioning [Simeonov et al. 2013]. First released in June 2013, this free and popular app, used widely in the field as a training tool, is available in both English and Spanish. The NIOSH [Falls in the Workplace](#) webpage provides links for downloading the app for the [Apple](#) and [Android](#) operating systems. The science that led to the development of the app received an honorable mention in the [2014 U.S. Department of Health and Human Services \(HHS\) Innovates award](#) competition.

Intermediate Outcome:

- ❖ The ladder app has received many positive reviews from ladder users and safety professionals, including the American Society of Safety Engineers and Industrial Hygiene and Safety News. Since its release in 2013, the app has more than 214,224 downloads. Because the tool is free and easily accessible at the worksite, it is especially helpful for small construction businesses that have limited safety resources. State officials, industry leaders, and safety professionals have promoted the app, and many companies have incorporated using the app as part of their safety practices. The governor of Maine, the Washington State Department of Labor, the Ohio Bureau of Workers' Compensation, DISH Network, LeBlanc Building Company, SRS Distribution Inc., the New York Department of Public Health, OSHA, Utah Labor Commission, and Connecticut Department of Labor recommend the app to their employees and to the public [Maine Department Of Labor 2013; Ohio Bureau of Workers' Compensation 2017; Advanced Technologies and Laboratories International, Inc. 2013; Simeonov 2018; New York State Department of Health 2017; OSHA 2015; Utah Labor Commission 2013; Connecticut DOL 2016]. Based on email communications, Twitter comments, and CDC-IFO requests, the app has also received considerable international attention from more than 20 countries, including Canada, Singapore, the United Arab Emirates, and New Zealand [Simeonov 2018; Dubowksi 2015; Chong 2013; Oxley et al. 2014].

Other Ladder Safety Interventions

When setting up an extension ladder, the current standard method for angular positioning involves grasping the rung in front with outstretched arms. NIOSH researchers studied and found a better method: Grasping the side rails of the ladder instead of a rung offers a more natural placement of the outstretched hands and a safer ladder angle [Simeonov et al. 2012a].

Intermediate Outcome:

- ❖ ANSI A14 committee on Ladder Safety used NIOSH research to adopt the new method and modified the extension ladder standard safety labels (ANSI A14.2

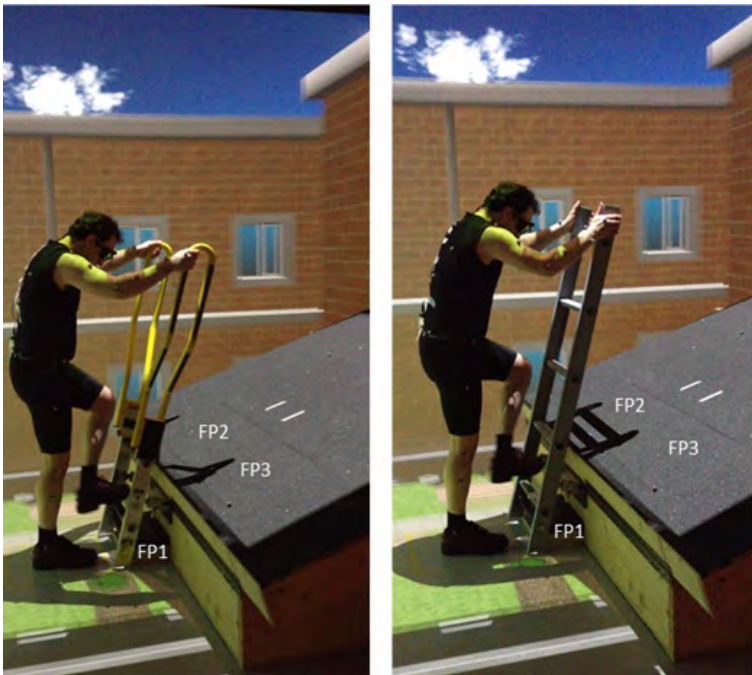
and A14.5). The committee approved the standards, now released for public review.

To help stabilize the top and the base support of extension ladders, NIOSH researchers worked with SRI International to evaluate the use of electroadhesion technology, which uses electrostatic forces between surfaces (e.g., a wall and electroadhesive pads on a ladder) to increase stability [Simeonov et al. 2010]. The description of an invention using electroadhesion technology with an extension ladder, where power to each adhesive pad comes from a small battery pack, is in a published patent application [Prahlad et al. 2010].

To improve ladder safety during transitioning tasks at elevation, NIOSH researchers proposed the concept of a convertible multipurpose ladder top accessory, which included a walk-through configuration (Figure 69) [Hsiao et al. 2010]. NIOSH researchers then evaluated the effectiveness and safety of the walk-through top accessory in ladder-roof transitioning tasks [Simeonov et al. 2017]. Conducted in the NIOSH virtual reality lab, the study used a real ladder top and roof structure sections with visually simulated height. NIOSH gave the published study results to the American Ladder Institute (ALI) and the ANSI A14 committee to assist them in making decisions for future updates of the Ladder Accessory standard (ANSI A14.8).

A NIOSH 2008 paper outlined and analyzed the gaps and needs in ladder safety research, which also set specific research directions and goals [Hsiao et al. 2008]. NIOSH summarized consecutive ladder safety innovation, research, and development efforts in a special chapter of a NIOSH-edited book on fall prevention and protection [Simeonov 2016].

Figure 69. Images from the NIOSH Virtual Reality Laboratory showing a subject moving to a sloped roof frame from a walk through ladder, left, and from a regular ladder, right. [Credit NIOSH]



Prevention through Design (PtD)

The mission of NIOSH's [Prevention through Design Program](#) is to prevent occupational injuries, illnesses, and fatalities by including prevention principles in all designs that affect workers. The key aim is eliminating hazards and controlling risks to workers “at the source” or as early as possible in the life cycle of items or workplaces includes the design, redesign, and retrofit of work premises, structures, tools, facilities, equipment, machinery, products, substances, work processes, and the organization of work.

In 2013, NIOSH developed and released free education modules intended to increase awareness of construction hazards for students enrolled in university engineering courses (each with an instructor's manual, education manual, and a slide deck). Each module outlines the motivations for PtD, encourages inclusion of worker health and safety considerations early in design processes, and identifies hazards associated with the construction industry. A brief description of each modules follows:

- [Architectural Design and Construction Education Module](#): This covers site planning and excavation, specific building elements such as skylights, solar

panels, and green roofs, general safety considerations, and hazards associated with decommissioning a building.

- [Reinforced Concrete Design Education Module](#): This covers concrete design, detailing, fabrication, and erection processes. Examples enable structural engineers and detailers to incorporate PtD into their reinforced concrete designs.
- [Structural Steel Design Education Module](#): This contains steel design, detailing, fabrication, and erection processes.
- [Mechanical-Electrical Systems Education Module](#): This describes electrical hazards for working with electricity. A wind farm case study shows useful PtD solutions for preventing falls. A research facility case study identifies PtD concepts applied to mechanical-electrical systems safety.

Following a PtD approach when designing or redesigning a building or other structure minimizes the risks of fall-related injuries and fatalities to construction workers and users of the completed structures. Workers risk falling during new construction, but they risk falling also during the operation and maintenance phase of a facility's life cycle, during renovation, and during the demolition phase. Facility features that present fall hazards include floor and roof edges, elevated platforms, ledges, atria, skylights, machine rooms, and ladders and stairways. Falls can occur from temporary structures used in construction and maintenance such as scaffolds or ladders, or from permanent locations such as roofs. In May 2014, NIOSH published a Workplace Solution, [*Preventing Falls from Heights through the Design of Embedded Safety Features*](#), which offers practical occupational safety and health recommendations based on NIOSH PtD research. The embedded features of interest include concrete straps, anchor points for use with the correct personal fall arrest systems and lifelines, and guardrail support. In this document, NIOSH recommends that facility designers, owners, constructors, and safety and health professionals work together to perform safety design reviews, allowing them to explore and address hazards likely to occur over the life cycle of the facility. This approach incorporates safety features into the building's design, addresses fall hazards in construction plans, establishes safety criteria for buying equipment, and

communicates risks to building owners and facilities personnel rather than relying on other forms of protection such as personal protective equipment (PPE) or administrative controls [Behm 2005]. In fact, because of a fatality investigation result, FACE evaluators illustrated the importance of and proper installation of embedded anchors and encouraged designers to consider first the need for permanent fall protection features in the facility to protect construction workers, future occupants, and repair workers from falls.

In an effort to address construction worker safety, especially falls, NIOSH worked with the U.S. Green Building Council (USGBC) and the NORA Construction Sector Council to integrate PtD in their Leadership in Energy & Environmental Design (LEED) building rating system. LEED is a certification system for green buildings, and an environmental rating system that plays an important role in promoting and implementing green and sustainable practices. Buildings qualify for different levels of LEED certification based on acquiring a sufficient number of “credits” demonstrating that the building is efficient, cost-effective, and better for occupants and the environment. USGBC uses pilot credits to test new and innovative concepts. In 2015, USGBC published a PtD Pilot Credit, developed by NIOSH.

Intermediate Outcomes:

- ❖ The USGBC adopted and published the LEED PtD Pilot Credit, making it a part of its addressing construction, operations and maintenance [NIOSH 2017]. The PtD Pilot Credit describes the criteria for addressing worker safety issues early on in a building’s life cycle—and to design out worker hazards for the construction, operations, and maintenance phases of a building’s life cycle. It is available through the USGBC site and is applicable to multiple rating systems ([v4](#) and [v2009](#)).
- ❖ NIOSH developed a topic page on [safe, green construction](#), as well as the content and narration for two webinars for LEED users that describe the pilot credit. The [first](#) gives a general overview and the [second](#) offers specifics about the credit requirements. A 2017 [NIOSH Science Blog](#) further describes the pilot credit and webinars. As of this writing, the architect or designer of 102 building

projects globally registered to include the PtD Pilot Credit (e.g., 21 projects in the U.S.; 50 in Ireland; 2 in Malaysia; 4 in Qatar). Furthermore, participants earned 664 continuing education units for the first webinar (released in July 2015) and 81 CEUs for the second webinar (released in May 2017).

Understanding that data on final credit accrual for completed projects is difficult to obtain, the USGBC confirmed that, as of January 2017, two completed projects in Europe included the pilot credit in their final LEED certification [Metalitz 2017].

The findings of Kleiner et al., funded through a NIOSH extramural grant (2009 through 2015), support the PtD Pilot Credit. The researchers compared safety strategies between the U.S. and Australia (Australia's safety record is twice as good as that of the U.S.) [Saunders et al. 2016]. The researchers determined that making decisions to address hazards earlier, in the design process or pre-construction phase, as opposed to later, during construction, can have a major impact on safety. This finding suggests the need for architects, engineers, and construction contractors to work together in pre-construction. The researchers used a PtD approach in developing a decision support system for panelized construction. The researchers examined trends and barriers in adopting PtD technologies in the concrete, masonry, asphalt roofing, and welding industries. They found that safety, government regulations, and insurance incentives motivated the adoption of safer technology; and that productivity, job performance, and cost were barriers.

Preventing falls from Other Types of Elevations in Construction

Not all fall hazards occur on roofs, platforms, and ladders. Relevant research findings are available from NIOSH research on stilts and communication towers as well.

Characterizing Injuries from Stilts

Stilts enable workers to move from one location to another without erecting scaffolds or repositioning ladders. Workers on stilts often perform drywall finishing, taping, and sanding, and other interior tasks such as painting, plastering, and insulation installation. A NIOSH study of BLS data reported that drywall installers are at a high risk of overexertion and falls to a lower level [Chiou et al. 2000]. Subsequently, NIOSH

investigators conducted computer simulations and laboratory studies demonstrating stilt injury mechanisms. As the work from this first study continued, Wu et al. [2009] developed two stilt-walking models to investigate the musculoskeletal loadings imposed on workers using stilts and to study fall scenarios and gait-related issues with stilts, which induce the re-distribution of force among the muscles. The force redistribution creates an increase in muscle loadings when walking on stilts, which in turn places demands on balance and speeds muscle fatigue. In another NIOSH study, Chiou et al. [2008] found that as stilt height increases, joint flexibility decreases. Unexpected environmental changes (e.g., slippery surfaces, negotiating a turn) further challenged the dynamic balance of stilted workers. Foot clearances for workers on stilts are lower than for those not using them, making workers more likely to trip on objects. A separate study by Pan et al. [2009] recommended that users keep stilts at the lower height settings whenever possible and adopt proper standing posture with feet parallel, directly beneath the body, and shoulder-width apart.

Characterizing Injuries from Communication Towers and Other Elevations

The growing demand for wireless and broadcast communications has prompted an increase in communication tower construction and maintenance. Common hazards in this work include falls from heights, falling objects hazards, electrical hazards, and the structural collapse of towers. Workers who construct or maintain communications towers regularly climb structures in excess of 1,000–2,000 feet using fixed ladders [OSHA, no date-a]. In 2013, OSHA recorded 13 communication tower-related fatalities, 12 in 2014, three in 2015, and six in 2016. In June 2015, NIOSH supported OSHA's effort to prevent injuries and fatalities during tower work by [providing feedback](#) on OSHA's Request for Information on communication tower safety. NIOSH's comments exist as examples of FACE-related communication tower safety issues.

In 2008, New Jersey FACE investigated the [death of a 55-year-old male communications tower](#) worker who died instantly after falling 60 feet while performing structural upgrades to a 280-foot-tall self-supported communication tower [NJ FACE Project 2010]. The FACE investigation findings led to a recommendation that tower workers use a separate fall protection system when employing vertical lifelines or controlled descent

devices, and that they receive training on the proper use of tower climbing and fall protection equipment.

A 2007 New Jersey FACE investigation of a [fall from a temporary bridge catch platform](#) involved a laborer falling through a temporary bridge catch platform [NJ FACE Project 2011]. In addition, during 2008 through 2010, California's FACE program, using funds from NIOSH, completed three fall-related fatality investigation reports of Solar Panel Installations [CA FACE 2008, 2009, 2010]. From these investigations, CA FACE prepared a [digital story](#) to warn solar workers and employers of the potential fall hazards.

Intermediate Outcomes:

- ❖ In March 2016, the U.S. Federal Communications Commission began to align the use of broadcast airwaves with 21st century consumer demands for video and broadband services, forcing television to modify or replace their existing broadcast antennas to transmit on a different frequency for a specific time [OSHA, no date-b]. This, in turn, caused a large increase in crews working at heights on communication towers and with other unique and complex hazards on the towers to complete the work as scheduled. OSHA and the FCC worked together proactively to raise awareness about safety in advance of the increased workload, providing information and resources to help ensure that crews complete this work safely. In 2017, the two agencies jointly published their [Communication Tower Best Practices](#) document for which NIOSH gave evidence-based comments on falls, fall protection, and prevention through design, based on NIOSH research and several FACE investigations.
- ❖ In 2016, the American National Standard (ANSI) A10 Committee developed the ANSI American Association of Safety Engineers (ASSE) consensus A10.48 standard (*Criteria for Safety Practices with the Construction, Demolition, Modification, and Maintenance of Communication Structures*), which establishes the minimum criteria for safe work practices and training for working on communication towers and similar structures [ANSI/ASSE 2016]. The standard draws on NIOSH's research as well as CPWR's and the construction industry's experience in construction falls. NIOSH, CPWR, and OSHA participated as

members, and provided relevant expertise, including in research-to-practice, as the Committee prepared the standard. The standard is comprehensive in nature with a deliberate effort to place all of the communication tower processes, procedures, and protocols in one location, making it easier for all companies with a role at a tower site to find best practice information.

- ❖ In 2013, the California State Building and Construction Trades Council incorporated the California FACE digital story, [Preventing Falls in the Solar Industry](#), into their statewide Train-the-Trainer Fall Prevention Training curricula and their [Construction Case Study Prevention Guide](#) featured the CA FACE investigation reports [Styles 2013]. The digital video has more than 19,000 views and won an American Public Health Association (APHA), Occupational Health Section, Digital Technology Award (October 2012) [Industrial Safety and Hygiene News 2012].
- ❖ During 2014 and 2015, *Equipment World*, a news and e-commerce website for construction contractors, construction equipment manufacturers, and dealers, used state FACE reports to create several *Safety Watches* (shown below) to highlight construction hazards. *Safety Watches* have a monthly circulation of about 100,000 heavy highway and civil engineering contractors and others who are engaged in a wide variety of construction activities. *Safety Watches* are used in safety training and toolbox talks, and their combined print, web, and social media circulation is about two million:

Safety Watch Title	Report	FACE Report Title and Link
Deadly Drops – Collapses Aren’t The Only Source of Danger When Performing Demolition	92MA007	Demolition Laborer Dies in Fall Through Roof Opening in Massachusetts

Safety Watch Title	Report	FACE Report Title and Link
Disastrous Drops – Falls Are The Number One Cause Of Death In Construction Accidents	10KY043	Steel Worker Falls from Highway Bridge and Dies in Kentucky
Unsafe Openings – Don’t Risk Falling When Working Above Ground	07CA009	A Hispanic Ironworker Dies When He Falls 50 Feet Through a Floor Opening in California
Up In The Air – Sacrificing Safety For Convenience Could Cost You	08NJ052	55-Year-Old Communications Tower Worker Killed After Falling 60 Feet in New Jersey

- ❖ In 2009, the [Philip Poynter Construction Safety website](#) in the United Kingdom featured the New York FACE report, [Construction Laborer Dies after Falling off Collapsed Precast Concrete Floor Slab](#) [NY FACE 2007]. Philip Poynter Construction stated that the NY FACE report offered more detail and insight than similar reports available in Great Britain, and that it would be of interest to all those involved with the design and installation of precast concrete floors.

Groups at Disproportionate Risk for falls in Construction

Workplace, technical, and personal characteristics can place workers at greater risk of injuries. Immigrant workers, with possible language barriers, who are new to the job or to the U.S.; workers who are younger, older, or overweight; and workers who receive little or no training are risk factors that NIOSH’s Construction Program explored.

Immigrant Workers

Immigrant workers comprise a sizable proportion of the total U.S. workforce. Through a NIOSH-funded study, Xiang, from the Children’s Research Institute (2006 through 2010), compared the nature, frequency, and risk factors for nonfatal work-related injuries between immigrant (foreign-born) and U.S.-born workers using data from three national surveys. Xiang also examined the medical expenditures associated with nonfatal work-

related injuries for the two groups, and described the sources of payments for the medical treatment of nonfatal work-related injuries by size of employer and type of industry [cited in Zhang et al. 2009]. Xiang found that although immigrant workers reported a significantly lower rate of work-related injuries, they may have suffered more severe injuries.

While language barriers are presumed to cause some of the documented increased risk for fatal workplace falls among immigrant workers, most observers cite exploitative or tenuous work arrangements. In a study funded by CPWR, Sokas et al. reported similar increases in knowledge and attitude scores among U.S.-born union apprentices compared with Spanish-speaking apprentices who had been observed to peer-translate during an OSHA hazard awareness training program conducted in English when the evaluation was conducted in the preferred language [Sokas et al. 2009]. Furthermore, in this union-based sample, foreign-born Latino workers were as likely to report having identified fall hazards and having taken action to reduce them as their U.S.-born counterparts; both groups did significantly better if they had received prior training or had been in the trade longer. Union membership is less common among foreign-born Latino workers, however, and immigrant worker centers have emerged as alternative institutions where peer support and peer training are available.

Occupational safety and health researchers and immigrant worker center organizers developed peer-education materials to foster hands-on training (Figure 70). Ochsner and others at Rutgers University, funded through CPWR (CPWR Consortium grants [2004 through 2014]), developed and evaluated peer-education tools in collaboration with the New Labor immigrant worker center.

Figure 70. The New Labor immigrant worker center collaborated with CPWR-funded researchers to develop bilingual materials and outreach to train Latino construction workers in health and safety. [Credit SNC-Lavalin/Earl Dotter/CPWR]



Adapting a CPWR curriculum for the OSHA 10-hour health and safety awareness program for construction, the partners developed bilingual worksheets and activities in a comprehensive workbook, [*The Day Laborers' Health and Safety Workbook*](#). Developed by and for low-literacy Spanish-speaking immigrant workers, the workbook design includes adult learning techniques that allowed workers to build from their own experiences. The team also conducted additional educational outreach on falls prevention and other topics through street-corner outreach. The formal OSHA 10-hour hazard-awareness training utilized the workbook to engage workers through adult participatory, peer-led mechanisms; OSHA-authorized instructors trained peer educators; peer educators, in the presence of OSHA certified instructors, trained immigrant workers [Williams et al. 2010; Ochsner et al. 2012]. More than 30 trained peer educators and facilitators offered classroom training to about 450 immigrant construction workers in New Jersey. More than 500 immigrant workers in New Jersey and New York earned the OSHA 10-hour hazard awareness card.

An evaluation of this participatory training program found improvements in worker's safety and health knowledge, attitudes, and work practices. Follow-up interviews with participants showed that the training empowered the workers to ask employers for

safety equipment or to take actions to work safer. In addition, post-training focus groups revealed that participants were teaching their co-workers about safe practices.

Two later projects deepened this work. Through further CPWR funding, the Rutgers-New Labor team matured the concept of peer education by developing worker center leaders who became certified to deliver OSHA hazard awareness training and to engage in work-site outreach, forming a group of safety liaisons to visit active residential construction sites and offer safety consultation to workers and site supervisors where feasible. Worker center leaders reported safety violations to the area OSHA office when necessary. Twenty-nine immigrant workers underwent intensive training to become safety liaisons, with 10 to 12 liaisons active at any given time conducting outreach education and informal evaluations at more than 200 construction sites. Worker evaluations provided a snapshot of health and safety needs: in half the sites, workers did not wear hard hats and did not receive fall protection devices for work at height. In two-thirds of the visits, liaisons spoke with co-workers, and in 35% of the visits, they approached the site supervisor to spot hazards and request remediation. In eight instances, they referred the concerns for OSHA investigation [Ochsner 2014].

The projects resulted in the dual-language publication, [*Bending Towards Justice*](#), which offers an overview of immigrant worker vulnerabilities and approaches to reducing vulnerability through interventions that offer contextual support.

At the same time, researchers at the University of Illinois-Chicago, working with the Interfaith Worker Justice worker center network and the National Day Laborer Organizing Network, obtained NIOSH funding to partner with the Rutgers-New Labor team to expand this model of peer education for occupational safety and health to new locations. Forst and her team at the University of Illinois-Chicago updated and adapted the workbook for different locations and partnered with worker centers in seven cities to train worker-leaders to deliver the OSHA 10-hour hazard-awareness construction health and safety program. The goal of the project was to prevent occupational injuries, including falls, by increasing hazard awareness and self-efficacy among foreign-born, Hispanic construction workers and by expanding the agenda of worker centers to include occupational health and safety. Thirty-two worker leaders (peer educators)

trained 463 workers in 25 sessions over three years, totaling 4,545 worker-hours of training. Eight participating worker centers in seven cities issued 446 OSHA 10-hour cards. Program evaluations revealed strong consistency in course delivery, good worker learning, and an overall strengthening of the worker center's stability and engagement with safety and health [Forst et al. 2013; Ahonen et al. 2014].

Intermediate Outcome:

- ❖ The free [Day Laborers' Health and Safety Workbook](#) developed by Ochsner et al. has been used at worker centers affiliated with the Interfaith Justice Network and National Day Laborer Organizing Network in cities such as Cincinnati, Houston, Austin, Memphis, Milwaukee, and Phoenix [CPWR 2011].

Kleiner at Virginia Tech, funded through a NIOSH extramural grant, found no significant differences in safety knowledge and behavior among Latino construction workers when given education about fall protection and prevention by a lay health advisor or community health worker [cited in Grzywacz et al. 2012; cited in Arcury et al. 2014; cited in Arcury et al. 2015]. Study findings confirmed, however, that workers were hesitant to take part in an educational program fearing alienation from their employers. To address the latter, education programs need to address workers' values surrounding the need for employment and income.

Supported by CPWR, Bratcher et al. worked with the Iron Workers Regional District Council & Iron Workers Local 846 to develop and administer a survey to Spanish-speaking unrepresented iron workers employed by 17 different companies in the western and southwestern U.S. The researchers found that these workers thought their jobs were dangerous, and they were afraid of getting hurt on the job, including from slips, trips, and falls. They complained of a lack of personal protective equipment (PPE) and poorly constructed scaffolds. Few of those surveyed had received safety and health training, but all wanted it. Nearly all workers felt that a union would improve their working conditions [Bratcher et al. 2010].

Preventing falls with Latino Construction Workers (2007 through 2013) was the subject of Roelofs' NIOSH-funded community-based participatory research project, based in a

historic Latino-majority city in Massachusetts [Shrestha and Menzel 2014]. The research addressed the disproportionate rate of injuries and illnesses that Hispanic construction workers experience. It focused on preventing falls in residential construction by developing a construction supervisor training program to improve the safety climate. Focus groups, surveys, and a community consultation process produced findings that resulted in the Hispanic Safety Climate Model for construction workers.

Figure 71. To address the higher fatal fall risk for Latinos, a NIOSH-funded research project focused on giving safety training to supervisors and contractors. [Credit SNC-Lavalin/Earl Dotter/CPWR]



The findings contained the most critical factors of the work environment contributing to poor conditions that could be modified to reduce exposures to hazards and reduce the risk for injuries and illnesses. The results included these factors: availability of training, equipment, social support from co-workers and supervisors, non-retaliation for reporting hazards and injuries, clear roles and responsibilities for safety, and a focus on safety in the face of time pressures. The researchers developed a training intervention, “Leaders in Safe Construction,” which targeted the knowledge, skills, and attitude shortfalls identified through their focus group and survey assessments. They trained

over 100 supervisors and contractors (in English and Spanish) in safety planning, fall prevention regulations and equipment, communication strategies for multilingual workforces, and hazard identification and control. Pre-, post-, and six-month follow-up surveys showed significant improvements in the safety leadership potential of trainees (Figure 71).

Wolfson and Rahke, at the Philadelphia Area Project on Occupational Safety and Health (PhilaPOSH), received funding through CPWR to explore the use of selected social media approaches (email, text messaging, and Facebook) to reach Latino construction workers with safety messages related to the *Construction Falls Prevention Campaign*. Findings suggest that social media messages sent during work hours were most effective, particularly when augmented with face-to-face interactions with safety experts and others engaged in building relationships, conducting interviews, and offering training and information. Researchers learned that Latino construction workers preferred to receive text messages about safety and health because they are brief and to the point. Traditional media also worked well with workers who use their smart phones to stream online or to listen to radio programs on safety and health topics. Workers wanted messages that gave them information about how to report hazardous worksites without jeopardizing their own jobs, about safe tools and equipment, and about rights and responsibilities under workers' compensation [Wolfson and Rahke 2015].

In another study funded by CPWR, Teran, Blecker, and colleagues concluded that targeting Latino construction workers is not enough to increase the adoption of fall protection. Additional research may find what incentives might influence contractor behavior to facilitate the adoption of fall protection measures [Teran et al. 2015].

Young and Older Workers

As the construction workforce ages, attention to health and safety risks for older workers becomes more important. Older construction workers are at increased risk of injury and death during falls, just as are younger workers (Figure 72). In a CPWR study examining fatal construction falls during 2003 to 2008, about one-fifth were among workers aged 55 and older [Dong et al. 2012]. Compared with workers younger than 55 years, deaths among older workers were 50% more likely to be from falls. The highest

risk of fatal falls for both older and younger workers occur in the occupations of roofer, iron worker, and power line installer.

Figure 72. Studies find that both younger and older workers are at an increased risk of fatal falls on a construction site. [Credit SNC-Lavalin/Earl Dotter/CPWR]



Madigan, through a NIOSH grant, characterized the effects of obesity on balance and fall risk, focusing on falls caused by slips and trips and on young and older adults, given the potential for differential effects of obesity by age. The researcher's overarching hypothesis stated that obesity, age, and their interaction adversely influenced balance and risk of falls from slips, trips, and a loss of balance. Researchers assessed balance and fall risk by estimating the risk of losing balance (due to slipping or tripping) as well as the ability to recover balance once it is lost (after slipping or tripping). Madigan found that neither obesity nor older age increased the risk of slipping but older obese adults were at higher risk of tripping over obstacles in the range of 2.4–4.2 cm in height, due, at least

in part, to a deficient stepping response. The study recommended the use of fall prevention interventions focused on improving the stepping response to reduce the fall rate among older, obese workers [Wu 2015].

Training

In construction, falls from heights are more common among inexperienced workers. CPWR funded a series of projects with consortium researchers from Washington University in St. Louis and Duke University who teamed up with CPWR researchers to study approaches to developing and evaluating training intervention effectiveness. These studies have included both large projects and small studies. While they have shown that well-developed safety training can help to prevent falls, challenges remain [Kaskutas et al. 2010; Kaskutas et al. 2013].

In a study of fall prevention training among carpenters funded by CPWR, Evanoff, from the Washington University in St. Louis, conducted a comprehensive needs assessment of fall safety training for apprentice carpenters in St. Louis, Missouri, in partnership with the St. Louis Carpenters' Apprenticeship Training Program. In the needs assessment phase, investigators identified risk factors for falls among apprentices to include recent residential work experience, crew behavior, and lower journeyman carpenter to apprentice ratio. Curriculum development, implementation, and evaluation followed. The researchers found that training, attitudes, and safety behaviors at worksites improved. The training curriculum is available through CPWR's [Electronic Library of Construction Occupational Safety and Health](#). A partnership with the regional Carpenters' District Council as well as with the faculty of the Carpenters' Joint Apprenticeship Training Program and local homebuilders formed [Evanoff et al. 2012].

In the same CPWR-funded study by Evanoff, residential construction worksites often did not implement classroom safety training, resulting in apprentices continuing to be exposed to fall hazards. The investigators identified meaningful deficiencies in the level of safety training foremen received before they trained or supervised others. In response, the researchers developed, adapted, implemented, and evaluated falls prevention training (e.g., videos, an instructor's manual) for foremen and other site supervisors who incorporated safety climate messages and measures.

Under the cover of the Evanoff study, Kaskutas and colleagues established a website describing more than 150 fall protection devices used at residential construction sites along with a regional fall prevention equipment loan program, which lent out the equipment. The researchers used their substantial experience in construction fall prevention research and their wide network of industry contacts to develop the web-based inventory, which is searchable either by the type of fall prevention device or by the stage of construction it is used [Kaskutas 2014]. Despite the stricter enforcement by OSHA of relevant standards, many residential construction contractors have limited knowledge of the array of fall protection devices commercially available: this website helps overcome that barrier to using fall prevention technologies in residential construction.

Additional resources stemming from the Evanoff study included a Facebook page, case study, and trade articles. Study outcomes include improvements in foremen and crewmember safety practices following safety and communication training aimed at foremen. Both foremen and crewmember surveys documented an increase in worksite fall prevention practices following foremen training, with these effects maintained six months after the training. Statistically significant increases in personal and crewmember use of fall prevention methods, availability of fall prevention equipment, and crewmember familiarity with their company's fall prevention plan were noted both at post-training and at extended follow-up, as were increases in observed practices, including safe step and extension ladder set up and use by foremen and crewmembers.

Intermediate Outcome:

- ❖ Outcomes from this study include improvements in foremen and crew member safety behaviors following safety and communication training aimed at foremen. The partnership initially established through the grant continues to maintain and use the equipment loan program following completion of that funding. Twelve regional contractors continue using the loan program. The website created through the Kaskutas small study logged more than 6,000 unique visitors in its initial six months. It continues to be active, and partners continue to lend the equipment despite the end of grant money.

In 2008, Lipscomb et al. studied residential fall prevention through a series of focus groups with union apprentice carpenters at various levels of training. Their findings suggest that apprentices often do not apply safety principles taught to them at work because of a lack of support for implementing them; without adequate training, fall prevention programs and equipment are less effective. These findings illustrate how training alone can fall short, demonstrating the importance of measuring more than just knowledge when evaluating how well training works [Lipscomb et al. 2008].

The National Campaign to Prevent Falls in Construction and the National Safety Stand-Down

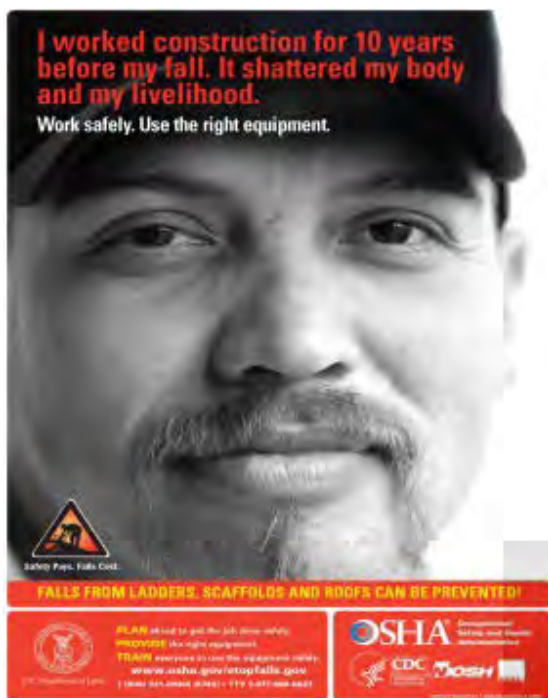
Given the frequency of falls, fall-related deaths, and nonfatal injuries in construction, the NORA Construction Sector Council developed and led a campaign to prevent falls among construction workers to address this major, persistent, yet preventable public health problem. The National Campaign to Prevent Falls in Construction (Campaign) addresses NORA Intermediate Goal 1.5, Work with construction partners to develop and implement a national campaign to reduce fatal and serious injuries associated with construction falls to a lower level. The Campaign targeted construction contractors, onsite supervisors, and workers to address and reduce falls and fall-related injuries among construction workers nationally. NIOSH's Office of Construction Safety and Health (CSH) and CPWR led the development of the Campaign within the NORA Construction Sector Council. An information committee within the Sector Council explored how to use various regional and national campaigns to advance general safety and health efforts; gathered basic questions and information for planning and implementing a construction falls campaign; and prepared options for discussion by the full NORA Construction Sector Council. The Campaign is a remarkable accomplishment among NIOSH, CPWR, OSHA, and the NORA Construction Sector Council.

CPWR hired a social marketing firm to prepare an environmental scan of existing occupational safety and health campaigns in the U.S. and abroad. CSH hired the same firm to prepare a social marketing plan. CSH and CPWR worked with the social marketing firm to prepare draft messages and conduct focus groups to test potential messages for the campaign. NIOSH, OSHA, and CPWR teamed up to finalize the Campaign theme and messages. Because the Campaign relies heavily on completed

research, it is a major r2p effort. The Campaign, which began in April 2012, focuses on reducing the number and severity of falls from ladders, scaffolds, and roofs. The motto of the Campaign is “Safety Pays, Falls Cost.”

The Campaign uses a variety of strategies to reach the construction industry through a three-part message—*Plan, Provide, and Train*—Plan ahead to get the job done safely, Provide the right equipment for workers, and Train everyone to use the equipment safely. Materials and resources are available on the main [Campaign website](#), hosted by CPWR. OSHA’s [Campaign website](#) is where to order free Campaign posters (Figure 73) and fact sheets (available in English, Spanish, Polish, Portuguese, and Russian). NIOSH supports a [topic page](#) and used CDC’s [Morbidity and Mortality Weekly Report](#) to feature announcements. The NIOSH Science Blog ([2015](#), [2016](#), and [2017](#)) and social media carry messages about the Campaign, and the OSHA, CPWR, and NIOSH Campaign websites or pages link to each other. Electronic newsletters and live webinars, tailored each year to target specific topics in construction falls, are effective at engaging external partners about the Campaign each year [Macario et al. 2015].

Figure 73. The Prevent Falls in Construction Campaign is a significant research to practice (r2p) event to reduce the number and severity of fatal falls.



A central event of the Campaign is the National Safety Stand-Down (Stand-Down), introduced in 2014. The Stand-Down continues yearly, along with the Campaign, due to higher than anticipated participation and overwhelmingly positive feedback. Employers voluntarily participate in the Stand-Down, giving them an opportunity to talk directly to employees about hazards, protective methods, and the company's safety policies, goals, and expectations. Each year, CPWR creates and posts on the Campaign website an easy, free, day-by-day list of suggested activities that individual jobsites can tailor for their needs. Data from the Campaign website show that during September 1, 2011, through July 10, 2017, there were 368,248 sessions and 596,968 products downloads. A variety of products—developed and shared in print, online, and through social media—raise awareness of the Campaign and resources available to support Campaign and Stand-Down activities. New products such as the [2017 Stand-Down video](#) and outreach activities continue to contribute to its ongoing viability and success:

- NIOSH posted the video, [A construction framer talks about protecting his crew from falls](#), which NIOSH staff took during a visit to a residential construction site in Phoenix, Arizona, to the NIOSH website in May 2014. The contractor who invited NIOSH, LeBlanc Building Company Inc., requires all their employees to use fall protection when working at heights.
- In 2016 and 2017, CPWR hosted three informational webinars related to the Campaign. One reviewed findings from a *CPWR Quarterly Data Report on Fall Injuries and Prevention*, and two promoted the Stand-Downs (2016 and 2017).
- Four of CPWR's Hazard Alert Cards (page 65) largely or entirely focus on fall hazards: Aerial Lifts, Fall Protection Harnesses, Ladders, and Scaffolds. Contractors and workers can access cards on [CPWR's website](#) or [the Stop Construction Falls website](#).

Eight of the toolbox talk (page 65) titles are largely or entirely focused on fall hazards: Falls from Moving Machinery, Falls: Extension Ladders, Falls: General Protection & Awareness, Preventing Falls from Roofs, Preventing Falls from Scaffolding, Preventing Falls through Holes, Roof Collapse, and Step Ladders. Workers access toolbox talks on CPWR's [website](#), the [Campaign website](#), and through CPWR's [electronic Library of Construction Occupational Safety and Health](#).

Intermediate Outcomes:

- ❖ Outreach by the National Association of Counties, through their April 2013 newsletter, helped to get information about the Campaign to city and county officials across the country who in turn made the information available to others, for example, to permit and registration offices frequented by construction contractors.
- ❖ The research to support the strategic planning and execution of the National Campaign to Prevent Falls in Construction received the prestigious 2012 Thoth Award in the category of Research and Evaluation from the Public Relations Society of America. Campaign partners and stakeholders spread the Campaign's message to thousands of construction employers (the primary target audience) and construction workers through blast e-mails, radio and television broadcasts, webinars, publications, trainings, and outreach events. The initial results from a social network analysis still underway shows that Campaign partners who responded to the survey and identified as contractors and related associations reported reaching anywhere between 100 and 100,000 individuals, reaching an estimated 222,300 individuals (n=8) altogether [Betit 2018]. Union partners reported reaching between 500 and 100,000 individuals, reaching 208,500 individuals around the Falls Campaign total (n=5) altogether. As far as promoting the Campaign to their specific audiences, 75% of all Campaign partners who responded to the survey said that they have conducted "a fair amount" or "a great deal" of promotion over the past year. These are the most commonly reported activities :
 - Distribution or posting of Campaign materials (79% of all respondents)
 - Newsletter articles or blog posts (70% of all respondents)
 - Email promotions (70% of all respondents)

In terms of the roles of NIOSH, CPWR, and OSHA, and the Campaign leaders, the top outcomes that partners reported when working with these lead organizations include these results:

- Increased organizational capacity to address falls (83% of partners)

- Improved relationships between their organization and the lead organizations (80% of partners)
- Increased organizational knowledge around fall prevention (66% of partners) [Varda 2018]

Participation in the Campaign by 157 partners (as of July 2017) [Betit 2018], representing a broad cross-section of the construction industry, reflects the firm commitment of government, industry, labor, trade groups, and professional stakeholder organizations to end falls from heights. An early evaluation of the Campaign suggested that information was not adequately reaching small construction contractors, the original primary target audience. Since then, increased efforts to reach them have been put in place, and in 2013, the goal of the Campaign expanded to preventing falls in all types of construction. By 2016, 25.42% of all residential construction entities in OSHA's Stand-Down Certificate Database were for Stand-Downs held with 10 or fewer workers, indicating participation by small construction contractors. In contrast, in both 2014 and 2015, less than 2% of residential entities were Stand-Downs of that size. During 2014 through 2016, Stand-Down activities alone reached more than 10,000 construction employers and almost 4.5 million workers [Bunting 2015, 2017]. The actual number of construction workers participating in Campaign activities and events is expected to be well-over 5 million when the 2017 campaign data is evaluated (Figure 74).

Intermediate Outcomes:

- ❖ Several local areas made the Campaign a priority and created innovative ways to spread Campaign messages. Boston, Massachusetts, and Montgomery County, Maryland, for example, worked with their public transportation systems to post Campaign posters on busses, metro-rail trains and highway digital billboards. State agencies, encouraged to support the Campaign, spearheaded their state's efforts in collaboration with NIOSH's FACE program [Fiore 2013; OSHA 2013].
- ❖ All of the U.S. Air Force Occupational Safety units, which support ground operations for air bases in the U.S. and abroad, participated in the Campaign (year 3) and Stand-Down activities. This included training, audits, internal newspaper articles, internal television network, posters, and briefings at the Air Force Occupational Safety Commander's calls. All 2,000 Air Force occupational

safety professionals focused on fall protection awareness during the week of the Stand-Down, with an expectation that all 650,000 Air Force Occupational Safety staff would be reached [United States Air Force 2016].

- ❖ [Safeway](#), the largest supplier of construction access equipment (e.g., scaffolds) in North America, became a partner with the Construction Falls Prevention Campaign in 2014 [Safeway 2014]. They invested approximately \$100,000 to adapt existing material or develop new company-specific Campaign materials (e.g., mailers, promotional items) for their staff, trainees, and business partners.

Figure 74. May 1, 2017 National Safety Stand-Down Kick-off, the Wharf site, Washington, DC. [Credit NIOSH]



- ❖ An analysis of OSHA's compilation of certificate of participation data for the Stand-Down shows that participants increased from 770,193 in 2014 through 1,041,307 in 2015. Companies that received OSHA Campaign certificates shared how they incorporated training and awareness efforts for other hazards into their fall prevention Stand-Downs [Bunting 2017]. Initial data from OSHA for the 2017 Stand-Down show more than 5,000 certificates (covering more than 500,000 employees) and 11.2 million OSHA website page views [Mckenzie 2017].
- ❖ Turner Construction, a large global construction contractor, hosted Stand-Downs at 1,000 of their global projects, covering 50,000 employees. Werner

Ladder, a manufacturer, hosted 125 events nationally covering roughly 25,000 employees and sponsored announcements about the Stand-Down on ESPN Radio in early May 2017. Estimates show that the radio feature reached more than 9.3 million listeners. [OSHA 2017; Werner Co 2017]

- ❖ Lamar Advertising Company hosted 200 electronic billboards at key road intersections nationally, generating 17.5 million views. Ladder Safety Month, first hosted in March 2017 by the ALI, models the National Construction Falls Prevention Campaign and the National Safety Stand-Down [ALI, no date].
- ❖ On May 11, 2017, more than 150 building material trade workers participated in the 2017 Safety Stand-Down awareness event at the American Buildings Company plant in Carson City, Nevada [CPWR 2017a]. UCOR, which has participated in the National Safety Stand-Down for the last three years, reported reaching about 1,500 employees on five different work sites in 2017 alone. The company conducted a variety of activities over several days, including having visits by Tennessee OSHA Compliance Officers on two different days [CPWR 2017b].
- ❖ Milicia Electric Corporation participated in the 2017 Safety Stand-Down by holding a Stand-Down of 20 workers at a New York Power Plant project, including toolbox talks on each of the five days—two talks focused on fall prevention, two on ladder safety, and one on respirable silica awareness [CPWR 2017c].
- ❖ Builders Mutual partnered with the North Carolina Department of Labor and Little Giant Ladders to take OSHA Stand-Down events to three job-sites. The events included ladder, scaffolding, and fall protection safety training [Schaffner 2017].
- ❖ Campaign and Stand-Down products reached a wide audience (4,812 downloads, 20,120 reached through Facebook, 17,829 reached through LinkedIn). The CPWR-NIOSH-OSHA r2p work group developed a series of eight infographics (images or charts conveying a brief message), available in English

and Spanish, to support the Campaign. These infographics addressed fall hazards, the NIOSH aerial lift simulator, new ladders apps, sound-level (noise) safety, and how to join the [Campaign website](#) or on CPWR's website. The infographics have been used in various places:

- Published in print materials (e.g., *The Journeyman Roofer & Waterproofer* 1st quarter 2017 magazine, with distribution to roughly 20,000 workers and hundreds of roofing contractors, contractor associations, insurers, and other stakeholder organizations) [United Union of Roofers, Waterproofers and Allied Workers 2017]
- Displayed on websites (e.g., [Washington State Department of Labor & Industries](#), [National Safety Inc.'s blog](#), a [NY law firm's blog](#), and [Weeklysafety.com's Pinterest list of top safety infographics](#))
- Developed into posters and other materials by stakeholders (e.g., Babcock & Wilcox Construction co-created a poster) [Betit 2017]

The three Campaign-related webinars hosted by CPWR in 2016 and 2017 received notable participation with 1,240 participants and on-demand views from February 16, 2016, through July 10, 2017.

CPWR's Hazard Alert Cards have been distributed both in print and electronically more than 145,000 times (114,631 print copies distributed; 31,141 downloads). In 2017, more than 70,000 Hazard Alert Card requests came through an order form developed by CPWR for the campaign.

CPWR's toolbox talks, with eight talks focusing specifically on falls, have been accessed more than 133,000 times (127,560 downloads; 6,315 views on Elcosh). These downloads reach further than web metrics notes because of their potential for multiple uses on multiple projects. In 2017, Haylor Freyer & Coon Inc., which is one of the top 100 independently owned insurance agency in the U.S., asked to co-brand the toolbox talks and distribute them directly to its construction clients.

End Outcomes

A decline in fall-related injuries and deaths in the United States is an end outcome of interest. The economic recession in 2008 through 2009 impacted the construction industry, increasing unemployment and lowering injury and fatality numbers and rates. The number of fatal falls to a lower level among roofers (Figure 75) decreased from 68 in 2014 to 60 in 2015, while the rate dropped from 39.9 to 31.4 deaths per 100,000 FTEs during the same time period; a 21% decrease within one year [Dong et al. 2017a].

Figure 75. Number and Rate of Fatal Falls to a Lower Level among Roofers, United States, 2011–2015.



The increase in fatal falls observed in 2011 and 2012 accompanied an increase in construction activities in the initial phases of the economic recovery. During those years, however, there were no overt efforts to address construction falls by regulators or researchers. NIOSH's research and interventions to prevent falls and fall-related injuries in construction have contributed to the decline observed beginning in 2015, including the guardrail system for roofers, improved harnesses and other personal fall arrest

systems, the National Campaign to Prevent Falls in Construction, and the National Safety Stand-Down.

Alternative Explanations

The number and rate of fall deaths in construction began to increase by 2015, likely explained, at least in part, by the economic recovery [Dong et al. 2017a]. The decline in the number and rate of fatal falls among roofers in 2015, while of keen interest, is only for a single year, and may be simply a statistical aberration. Additional years of data are needed to confirm a trend.

Another explanation could be that during the economic recession, the lack of work prompted many experienced construction workers to permanently leave or retire from the industry. Once the economic recovery began in the industry, union apprenticeship programs trained fewer apprentices. As a result, many of the new workers to the construction workforce, filling positions created through new construction projects, lack industry experience.

Many organizations and government agencies play roles in addressing construction falls. Federal OSHA, state-based occupational safety and health agencies, and other regulatory agencies, for example, have the authority to regulate and enforce policies designed to prevent falls. Hosts of professional and trade associations and labor unions have designed information and training tools to address falls in construction. The Associated General Contractors of America and the American Road and Transportation Builders Association (ARTBA) are examples of two organizations addressing aggressively construction falls for their members. LeBlanc Building Company Inc., a commercial, residential, and specialty-framing contractor based in Arizona, is one example of a small contractor and insurance company that has integrated falls prevention into its daily activities for all of their workers and on every project.

Future Plans

Factors to reduce fall risks include dry, stable working surfaces; safety training with proper supervision and guidance; fall arrest systems and other personal protective equipment; a safety culture and climate; and worksite ergonomics. Multidisciplinary

research on these factors, involving engineering and design, education and training, behavior, and administrative issues, continue to be important.

The frequency of deaths and injuries related to roofs, scaffolds, and ladders should mandate dedicated efforts to develop intervention programs and evaluate their effectiveness. For example, incentive systems, work organization, and other managerial and organizational issues related to falls receive scarce attention and could be opportunities for study. Furthermore, few studies evaluate fall intervention programs in the real world. While feasibility and study design require researchers to simplify this complex picture, research offers a holistic picture to evaluate interventions. A dynamic model for fall prevention is needed to provide feedback for construction stakeholders to aid in safety planning and fall prevention.

The NIOSH Strategic Plan outlines construction and falls prevention priorities for 2019 through 2023. NIOSH and construction researchers, funded through NIOSH extramural grants, will continue to address a broad range of occupational health and safety hazards affecting the changing population of construction workers. Future fall prevention research should consider improvements in work environment, construction materials, and work methods, procedures, and practices. Furthermore, intervention and translation research stemming from research findings discovered during 2007 through 2017 will be important to explore, especially among laborers, workers at disproportionate risk, and for workers employed by small businesses.

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Appendix A: Abbreviations

AAC	Autoclave Aerated Concrete
ACCSH	Advisory Committee on Construction Safety and Health
ACGIH	American Conference of Governmental Industrial hygienists
AEM	Association of Equipment Manufacturers
AFL-CIO	American Federation of Labor and Congress of Industrial Organizations
AIHA	American Industrial Hygiene Association
ALI	American Ladder Institute
ANSI	American National Standards Institute
ARTBA	American Road and Transportation Builders Association
ASA	Acoustical Society of America
ASAE	American Society of Agricultural Engineers
ASSE	American Society of Safety Engineers
ASTM	American Society for Testing and Materials
BAC	International Union of Bricklayers and Allied Craftworkers
BLS	Bureau of Labor Statistics
CDC	Centers for Disease Control and Prevention
CERN	Construction Economics Research Network
CFOI	Census of Fatal Occupational Injuries
CMU	Concrete Masonry Unit

COPD	Chronic obstructive pulmonary disease
CPS	Current Population survey
CPSC	Consumer Product Safety Commission
CPWR	Center for Construction Research and Training
CRE	Canadian Centre of Research Expertise
CSH	Construction Safety and Health
CT	Computed Tomography
CTS	Carpal Tunnel Syndrome
DAFW	Days Away From Work
DART	Division of Applied Research and Technology
DOD	Department of Defense
DOE	Department of Energy
DOL	Department of Labor
DSHEFS	Division of Surveillance, Hazard Evaluations, and Field Studies
DSR	Division of Safety Research
ECP	Ergonomics Community of Practice
EID	Education and Information Division
eLCOSH	Electronic Library of Construction Occupational Safety and Health
EPA	Environmental Protection Agency
FACE	Fatality Assessment and Control Evaluation

FHWA	Federal Highway Administration
FTE	Full Time Equivalents
GPS	Global Positioning System
GSA	General Services Administration
HASARD	Hazardous Area Signaling and Ranging Device
HAVS	Hand-Arm Vibration Syndrome
HELD	Health Effects Laboratory Division
HHE	Health Hazard Evaluation
HPD	Hearing Protection Device
HTV	Hand-Transmitted Vibration
IARC	International Agency for Research on Cancer
ICE	International Council of Employers
ICERES	Institute for Construction Economics Research
IDOT	Idaho Department of Transportation
INCE	Institute for Noise Control Engineering
INRS	Institut National de la Recherche et de la Sécurité (French National Research and Safety Institute)
ISEA	International Safety Equipment Association
ISO	International Organization for Standardization
ITCP	Internal Traffic Control Plans
LEED	Leadership in Energy and Environmental Design

LEV	Local Exhaust Ventilation
LHSFNA	Laborer's Health and Safety Fund of North America
LIUNA	Laborers' International Union of North America
MCWP	Mast Climbing Work Platform
MMH	Manual Material Handling
MMWR	Morbidity and Mortality Weekly Report
MSDs	Musculoskeletal Disorders
MSHA	Mining Safety and Health Administration
NAATSHO	North American Association of Transportation Safety and Health Officials
NABTU	North America's Building Trades Unions
NAICS	North American Industry Classification System
NAPA	National Asphalt Pavement Association
NCHS	National Center for Health Statistics
NHANES	National Health and Nutrition Examination Survey
NHCA	National Hearing Conservation Association
NHIS	National Health interview Survey
NIL	Noise Insertion Loss
NIOCCS	NIOSH Industry and Occupation Computerized Coding System
NIOSH	National Institute for Occupational Safety and Health
NOMS	National Occupational Mortality Surveillance

NORA	National Occupational Research Agenda
NPPTL	National Personal Protective Technology Laboratory
NRR	Noise Reduction Rating
NTOF	National Fatal Occupational Injuries
NVLAP	National Voluntary Laboratory Accreditation Program
NYDEP	New York City Department of Environmental Protection
OHL	Occupational Hearing Loss
OPCMIA	Operative Plasterers' and Cement Masons' International Association
OSHA	Occupational Safety and Health Administration
PATH	Posture Activity Tools and Handling
PEL	Permissible Exposure Limit
PMRD	Pittsburgh Mining Research Division
PPE	Personal Protective Equipment
PtD	Prevention through Design
RCS	Respirable Crystalline Silica
REL	Recommended Exposure Limit
RHD	Respiratory Health Division
RNLE	Applications Manual for the Revised NIOSH Lifting Equation
r2p	Research to Practice
SAE	Society of Automotive Engineers

SAVE	Safety Voice for Ergonomics
SMRD	Spokane Mining Research Division
SOAR	Silica Outreach and Research
SOC	Standard Occupational Classification
SPO	Scientific Program Official
TAUC	The Association of Union Constructors
TLV	Threshold Limit Value
TRU-NET	Trainers and Researchers United Network
TWA	Time Weighted Average
UBC	United Brotherhood of Carpenters
USGBC	U.S. Green Building Council
VAOT	Vermont Agency of Transportation
VMC	Vulcan Materials Company
VPA	Vibration power absorption
VWF	Vibration White Finger
WHO	World Health Organization
WIN	Water Induction Nozzle
WMSD	Work-related MSDs
WPG	Work Practices Guide

Appendix B: NIOSH Office of Construction Safety and Health Biographies

Dr. Christine Branche, Director

Principal Associate Director of NIOSH and the Director of the NIOSH Office of Construction Safety and Health, Dr. Branche has been involved in NIOSH's Construction Program for many years. She first contributed as a member of the Technical Advisory Board for CPWR—The Center for Construction Research and Training (1994–2007), which serves as the NIOSH-funded National Construction Center. Dr. Branche also manages the Construction Program and co-chairs the NORA Construction Sector Council. Prior to joining NIOSH, Dr. Branche worked for the National Center for Injury Prevention and Control in the Center for Disease Control, first as an Epidemic Intelligence Service (EIS) Officer and later as the Director of the Division of Unintentional Injury Prevention. Before coming to the CDC, Dr. Branche worked extensively in occupational and environmental epidemiology. With a research expertise in occupational and non-occupational injury prevention, her degrees include a BA in biology and an MSPH and PhD in epidemiology. She is currently a Fellow in the American College of Epidemiology.

Dr. Scott Earnest, Deputy Director

Deputy Director of the NIOSH Office of Construction Safety and Health, Dr. Scott Earnest coordinates the Construction Program. Dr. Earnest joined NIOSH in 1991 to lead research in the control of occupational exposures to air contaminants. In 2001, he became involved in the Construction Program. As team leader and branch chief in the Division of Applied Research and Technology (DART), Dr. Earnest managed and oversaw multiple construction sector research projects. He played an important leadership role in preparing for the National Academies' review of the Construction Program. Since 2015, Dr. Earnest has been the Deputy Director of the Office of Construction Safety and Health and the Construction Coordinator. He also leads the NIOSH Construction Steering Committee. With a research expertise in air filtration, industrial ventilation, and indoor

air quality, Dr. Earnest degrees include a BS, MS, and PhD in industrial and mechanical engineering. He is currently a registered Professional Engineer and Certified Safety Professional.

CDR Elizabeth Garza, Public Health Analyst

Assistant Coordinator for the Construction Program, CDR Elizabeth Garza is an officer in the Commissioned Corps of the U.S. Public Health Service. CDR Garza joined NIOSH in 2009. In 2012, she began working for the Office of Construction Safety and Health. In 2014, CDR Garza took on the role of the Assistant Coordinator for the Office. Her public health expertise and fluency in Spanish have enabled her to take the lead on disparities issues in construction. She provides programmatic assistance, conducts outreach activities, develops r2p approaches, and serves as the lead for social media and communication. Her degrees include a BS in biology and international relations as well as an MPH. She currently holds the Certified in Public Health credential.

Matt Gillen, Former Deputy Director

Former Deputy Director, Matt Gillen coordinated the NIOSH Construction Program from 2000 until retiring from NIOSH in 2014. As Construction Program Coordinator, Mr. Gillen played an important role in transitioning the program from the first decade of NORA to the sector-focused second decade. Under his leadership, the Construction Program was the first NIOSH sector to complete development of NORA goals at the start of the second decade. Mr. Gillen coordinated discussions between construction stakeholders and scientists to develop national construction goals. He also oversaw the preparation of a decade's worth of NIOSH Construction Program activities for the National Academies review. Mr. Gillen's degrees include a BA in biology and sociology as well as an MS in environmental health. He is an industrial hygienist and a Fellow of the American Industrial Hygiene Association. Prior to joining NIOSH, he worked for the Environmental Protection Agency (EPA), OSHA, and several non-profit organizations before retiring from NIOSH in 2014.