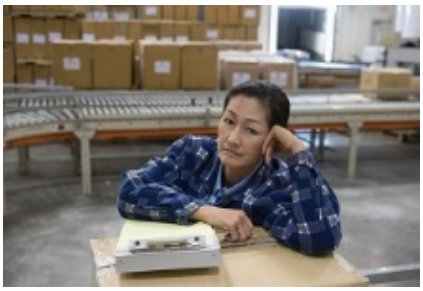
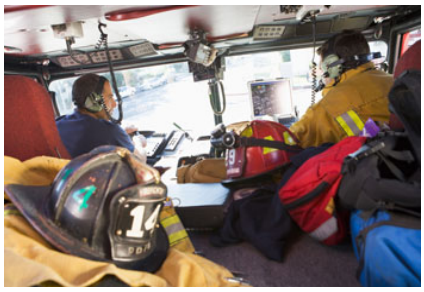
NIOSH Strategic Plan: FYs 2019–2023

Version 4: October 2019






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

Contents

Changes for Version 4: October 2019

New Goals

Four goals were added to specifically address *Total Worker Health®* within the Healthy Work Design and Well-Being Cross-Sector.

- CONxHWD 7.11 (See pg. 163)
- HCSAxHWD 7.12 (See pg. 168)
- PSSxHWD 7.14 (See pg. 177)
- SRVxHWD 7.15 (See pg. 183)

Three goals were added to address the opioid overdose epidemic, specifically prescription drug (incl. opioids), illicit drug, and substance use/misuse.

- CONxTIP 6.19 (See pg. 127)
- PSSxTIP 6.20 (See pg. 146)
- OGExHWD 7.13 (See pg. 174)

Finally, one goal was added in response to gaps identified by the Respiratory Health Program on mixed exposures.

- SRVxRHP 5.13 (See pg. 117)

Revisions to goals

The burden and need narratives for several goals were lightly revised to address one of the recommendations made by an expert panel that reviewed the Construction Program:

- CONxHLP 2.1 - Engineering controls to reduce noise exposure (See pg. 41)
- CONxHLP 2.2 - Hearing loss prevention education for employers and workers (See pg. 42)
- CONxMUS 4.2 – MSD interventions (See pg. 76)
- CONxRHP 5.2 – Exposures to mineral dusts (See pg. 94)
- CONxRHP 5.3 – Mixed exposures (See pg. 96)
- CONxTIP 6.2 – Falls (See pg. 123)
- CONxTIP 6.3 - Injuries related to emerging technologies (e.g., robots) (See pg. 125)
- CONxHWD 7.1 – Non-standard work arrangements (See pg. 161)

The following goals have been revised to highlight research needs around prescription drug (incl. opioids), illicit drug, and substance use/misuse:

- CONxMUS 4.2 – MSD interventions (See pg. 76)
- MINxMUS 4.4 – MSD risk factors (See pg. 84)
- PSSxTIP 6.12 – Violence (See pg. 145)
- TWUxTIP 6.14 – Transportation incidents (See pg. 152)
- CONxHWD 7.1 – MSD interventions (See pg. 161)
- PSSxHWD 7.4 – Work organization (See pg. 176)

Introduction

The National Institute for Occupational Safety and Health (NIOSH) studies occupational safety and health through scientific research. The Institute then transforms its research into cost-effective, global work practices. The Occupational Safety and Health Act of 1970 established NIOSH and it is now part of the Centers for Disease Control and Prevention in the U.S. Department of Health and Human Services. NIOSH works with public and private sectors to make work safer, healthier, and more productive for workers, employers, and the nation.

The NIOSH Strategic Plan reports research and service goals for fiscal years 2019-2023. These goals address a broad range of occupational health and safety hazards, affecting an ever-changing workforce. Jobs in the U.S. economy continue to shift from manufacturing to services. Longer hours, compressed workweeks, an aging workforce, reduced job security, and part-time and temporary work have also changed the workforce. These changes represents a major challenge for NIOSH as it manages limited resources to address its research portfolio priorities.

The NIOSH Strategic Plan introduces strategic, intermediate, and activity goals that guide occupational health and safety research priorities and service work. NIOSH's unique portfolio of research programs includes sector, cross-sector, and core and specialty research programs. These programs perform research that covers a wide range of activities, from basic to applied research. Service work covers non-research work that supports NIOSH's mission or fulfills a legislative mandate. Service work can also support research work within NIOSH and outside with external partners. For example, the Surveillance Program provides data and analysis as a service to both NIOSH's programs and to external partners, while the Health Hazard Evaluation Program provides an external service. NIOSH awards funding priority to outside researchers conducting extramural projects that address the research goals identified in the NIOSH Strategic Plan. NIOSH will also lead new intramural projects to address the goals stated within this plan.

NIOSH recognizes that new issues may emerge or become more important during the five-year plan. Goals may be retired because they have been achieved. Priorities may shift in response to changing conditions. NIOSH will add or remove issues based on current or anticipated burden, need, and impact and allocate resources to address these changes.

The next section explains how NIOSH develops and organizes its research goals and the section after that focuses on how NIOSH develops and organizes service goals.

Part I: Research Goals

NIOSH's sectors, cross-sectors, and core and specialty programs share research goals to promote collaboration, avoid duplicative efforts, and maximize impact.

NIOSH Research Programs

NIOSH organizes its research into sector and cross-sector programs based on the framework provided by the National Occupational Research Agenda (NORA). Stewarded by NIOSH, NORA is a public-private partnership program that aims to stimulate innovative research and improve workplace practices stewarded by NIOSH. Now in its third decade, NORA is comprised of 17 councils that bring together diverse stakeholders. These stakeholders meet to develop a research agenda for the nation in industry sectors on crosscutting health and safety issues. NIOSH also has core and specialty programs that that represent core activities, mandates, special emphasis areas, and methodological approaches. .

Burden, Need and Impact

NIOSH determines research priorities based on the Burden, Need, and Impact Method (BNI Method). *Burden* is a measure of the health and safety or economic or potential economic burden of workplace risks and hazards. *Need* describes the knowledge gap the proposed research will close and considers the comparative advantage that NIOSH with its unique resources has over other organizations. *Need* also considers the stakeholders' occupational research priorities. *Impact* is the assessment of how individual research projects are likely to address *Burden* and *Need*. When identifying research priorities, the plan excludes *impact* from the BNI equation. NIOSH assesses the *impact* of each individual research project after identifying the broader research priorities.

Goal Hierarchy

The NIOSH Strategic Plan has three hierarchies of goals: Strategic, intermediate and activity goals. Strategic goals are broad in scope and based on health and safety outcomes identified by NIOSH's portfolio of research programs. Intermediate goals flow from strategic goals, and activity goals flow from intermediate ones. Figure 1 provides a description for each goal level.

Strategic Goal	Desired change in work-related illness, injuries, or fatalities.
Intermediate Goal	Actions organizations and individuals should take using NIOSH research findings or products to contribute to stated strategic goals.
Activity Goal	A research activity that moves the research through the research to practice (r2p) continuum. NIOSH organizes its research into four categories: 1) basic/etiologic, 2) intervention, 3) translation and 4) surveillance research.

Figure 1. Goal Definitions

Goal Development Process

NIOSH sector and cross-sector programs reviewed the NORA draft objectives to decide which objectives or parts of objectives it is well suited to take on. Programs considered additional factors, such as mandates from congress and the executive branch, stakeholder input from other sources, innovative ideas, and emerging issues.

Strategic Goals

Representing the health and safety issues facing the U.S. workforce, NIOSH established seven strategic goals:

1. Reduce occupational cancer, cardiovascular disease, adverse reproductive outcomes, and other chronic diseases.
2. Reduce occupational hearing loss.
3. Reduce occupational immune, infectious, and dermal disease.
4. Reduce occupational musculoskeletal disorders.
5. Reduce occupational respiratory disease.
6. Improve workplace safety to reduce traumatic injuries.
7. Promote safe and healthy work design and well-being.

Intermediate Goals

Only with the assistance of its partners can NIOSH improve occupational safety and health. Thus, intermediate research goals specify desired actions on the part of external stakeholders using NIOSH research findings and outputs. Achieving an intermediate goal often takes years and the combined effort of multiple research projects. The process unfolds as scientific research progresses from basic to applied research, to its translation and adoption.

Intermediate goals in this plan were developed through a series of facilitated meetings among sector, cross-sector, and core and specialty program representatives. Programs identified priority areas using the BNI Method criteria listed in Appendix A, weighting burden and need equally, omitting impact as mentioned.

NIOSH's portfolio of research programs uses a grid of sectors and cross-sectors, infused with core and specialty programs. Intermediate goals are shared by sector, cross-sector, and relevant core and specialty programs. Each goal fits within one cell of the NIOSH Program Grid as illustrated in Figure 2.

Cross-sectors:	Cancer, Reproductive, Cardiovascular and Other Chronic Disease Prev.	Hearing Loss Prevention	Immune, Infectious and Dermal Disease Prevention	Musculoskeletal Health	Respiratory Health	Traumatic Injury Prevention	Healthy Work Design and Well-Being
Agriculture, Forestry and Fishing							
Construction							
Healthcare and Social Assistance							
Manufacturing							
Mining							
Oil and Gas Extraction							
Public Safety							
Services							
Transportation, Warehousing and Utilities							
Wholesale and Retail Trade							

Figure 2. The NIOSH Program Grid

Within each cell, there are up to four intermediate goals. A table and short narrative describing burden and need accompany each intermediate goal. This information guides researchers to high priority areas, while allowing flexibility for new ideas. See Figure 3 for an illustration of the intermediate goal table. An explanation for each column follows.

Health Outcome	Research Focus	Worker Population	Research Type

Figure 3. Intermediate goal table

Health outcome **–** Health outcomes are reductions in illnesses, injuries and fatalities, as well as improvements to health and well-being. Intermediate goals sometimes encompass more than one health outcome, so this column provides greater specificity. For example, a goal to reduce a workplace hazardous exposure might contribute to reducing both cancer and adverse reproductive outcomes.

Research Focus – This column identifies the problems that programs want to solve. For example, a research focus can be a hazardous exposure that contributes to an illness or injury; an aspect of the organization of work; a risk factor for injuries, illnesses, or decreased well-being; or a type of injury.

Worker population – The worker populations with the greatest burden include either workers in a specific job or setting, or workers with a specific hazardous exposure. In some cases, additional worker populations experience a high burden because of the changing nature of work and employment arrangements.

NIOSH has developed the following taxonomy for work arrangements.[1]

- *Standard work arrangement* - An arrangement that is secure or permanent (career). These workers have employee status, stable and adequate pay, access to health insurance, paid leave and retirement benefits, a regular, full-time work schedule, and the ability to negotiate their schedule and take time off.
- *Non-standard work arrangement* - An arrangement that differs in some way from the standard arrangement.
- *Contingent workers* - Those with a job that they do not expect to last (see alternative definitions used by the Bureau of Labor Statistics (BLS) with the Contingent Work Survey[2]).
- *Precarious employment* - Employment with some degree of the following: insecurity, temporariness, vulnerability to unfair treatment, lack of ability to negotiate pay, benefits, and work schedule, lack of ability to take leave, and lack of social safety net including unemployment and workers' compensation insurance.

Work arrangement categories are not mutually exclusive. For example, some workers in standard arrangements may experience unfair treatment, a characteristic of precarious employment.

[1] Bushnell T, Scharf T, Alterman T, Cummings KJ, Luckhaupt SE, Ray TK, Rosa RR, Su CP [2017]. Developing a Taxonomy of Work Arrangements to Examine Relationships with Worker Safety, Health, and Well-Being. Poster presented at Work, Stress and Health 2017, Minneapolis, MN, June 8, http://www.apa.org/wsh/preliminary-program.pdf

[2] BLS [2005] Contingent and alternative employment arrangements. Washington DC: U.S. Department of Labor, Bureau of Labor Statistics, https://www.bls.gov/news.release/pdf/conemp.pdf

The intermediate goal tables refer to two other worker populations:

- *Vulnerable workers* - Different factors can make some workers more vulnerable than others to workplace illness or injury. These differences include factors, such as age, race/ethnicity, class, nativity, gender, English language skills, and disability status; economic trends, such as growth of the temporary workforce; and organizational factors, such as business size. Vulnerable workers have increased rates of work-related injuries and illnesses.
- *Small businesses* - For most occupational safety and health research purposes, NIOSH considers small businesses as having fewer than 50 employees. Smaller businesses often have fewer resources to devote to occupational safety and health because they face a riskier economic environment and have greater financial limitations than larger businesses.
- *Young worker* – NIOSH defines young workers as those between the ages of 15 and 24. Federal and state child labor laws, which regulate the employment of minors, are tied to the Fair Labor Standards Act (FLSA) of 1938 ("Fair Labor Standards Act," 1938). The FLSA limits the types of jobs youths aged 14 to 17 years are allowed to perform, the number of hours they may work, and the timing of these hours. However, national injury and fatality data usually do not include youth under age 15.
- *Older workers*- There is no consensus on the definition of "older worker." Generally, in the United States, research efforts tend to focus on the age group 55 years or older. But other age thresholds are sometimes used, such as 50 years or older (AARP) and 40 years or older (Age Discrimination Employment Act of 1967). However, it is important to acknowledge that chronological age, by itself, is not always a strong predictor of workplace outcomes, and that aging is a complex process influenced by many factors. As a result, there can be great individual variability in the work ability and occupational safety and health outcomes among older workers. Therefore, researchers should be aware that it might be of more value to think about a worker's lifespan and not an absolute chronological age at which all workers can be considered "older."

Research Type – NIOSH has adopted an organizing framework comprised of four types of research. The framework avoids duplicating existing knowledge and maximizes impact by moving research along a continuum from basic to applied research, to the translation of research into practice.

- *Basic/etiologic*: Builds a foundation of scientific knowledge to base future interventions. Most laboratory research falls into this category, as well as exposure assessment.
- *Intervention*: Engages in the development, testing, or evaluation of a solution to an occupational safety and health problem or the improvement of an existing intervention. Intervention is a broad term that includes engineering controls, personal protective equipment, training, and fact sheets, and other written materials intended to inform and change behavior, among other occupational safety and health solutions.
- *Translation*: Discovers strategies to translate research findings and theoretical knowledge to practices or technologies in the workplace. This type of research seeks to understand why available, effective, evidence-based interventions are not being adopted.
- *Surveillance*: Develops *new* surveillance methods, tools, and analytical techniques. NIOSH covers a broader type of surveillance, illness and injury surveillance, in the service goals of the NIOSH Strategic Plan.

Activity Goals

Activity goals describe which of the four types of research will move goals along the research to practice (r2p) continuum. Activity goals identify the type of research that will address strategic and intermediate goals. Each activity goal includes the types of research, the health outcome, and the sector in which the research will be undertaken.

Part II: Service Goals

Service activities contribute to the NIOSH mission by providing a service to individuals and organizations outside of NIOSH, support internally to NIOSH staff, or a combination of the two. Some services are mandated by law. Services can support a single sector or cross-sector (e.g. the Coal Worker's Health Surveillance Program benefits the mining sector), while others are crosscutting (e.g. FACE investigates fatalities in a wide range of industries with a variety of causes). NIOSH provides the following service work:

- Respirator approvals
- Health Hazard Evaluations
- Radiation dose reconstruction
- Emergency preparedness and response activities, except Disaster Science Responder Research (DSRR) activities
- Global collaborations
- Coal Worker's Health Surveillance Program activities
- B-Reader certification
- Spirometry
- MINER Act activities
- Fatality Assessment and Control Evaluation (FACE) activities
- Fire Fighter Fatality Investigation and Prevention (FFFIP) activities
- Injury and illness surveillance (but not surveillance research)
- Information and dissemination activities, including the NIOSH website and NIOSHTIC-2 publications database

Goal Hierarchy

Service goals are also hierarchical. Intermediate goals flow from strategic goals, and activity goals flow from intermediate goals. Unlike research goals, service goals are not mapped into the NIOSH Program Grid. Service goals are carried out through entirely different processes.

Goal Development Process

Service activities developed goals based on what they anticipate will be their most important activities over the next five years. Service goals emphasize improving the quality, timeliness and relevance of service work.

Strategic Goals

Service activities use the same strategic goals as research programs:

1. Reduce occupational cancer, cardiovascular disease, adverse reproductive outcomes, and other chronic diseases.
2. Reduce occupational hearing loss.
3. Reduce occupational immune, infectious, and dermal disease.

4. Reduce occupational musculoskeletal disorders.
5. Reduce occupational respiratory disease.
6. Improve workplace safety to reduce traumatic injuries.
7. Promote safe and healthy work design and well-being.

Intermediate Goals

Intermediate goals identify improvements and maintenance of service activities that allow organizations or individuals to take action more easily or quickly. In some cases, NIOSH's stakeholders are able to take direct action to improve occupational safety and health, such as the employers who receive HHE reports. In other instances, service is less direct. For example, the NIOSH web team might provide support to NIOSH staff, who are then able to post new information online that will help external stakeholders take action.

Intermediate goals can support more than one strategic goal. Focused service activities may flow from only one strategic goal, but others might support a broad range of occupational safety and health activities and flow from several strategic goals, or even all seven.

Activity Goals

Activity goals are statements of activities that improve or maintain the timeliness, relevance, and quality of services. If improvements are not possible, programs establish goals around maintaining high quality service functions.

Part I. Research

Strategic Goal 1: Reduce occupational cancer, cardiovascular disease, adverse reproductive outcomes and other chronic diseases.

Agriculture Forestry and Fishing/Cancer, Reproductive, Cardiovascular Disease and Other Chronic Disease Prevention (AFFxCRC)

Participating core and specialty programs: Authoritative Recommendations, Exposure Assessment, Occupational Health Equity, and Translation Research.

Intermediate goal 1.1 (Pesticide Exposure and Neurologic Disorders):

Government agencies, employers, non-governmental organizations, workers, and researchers use NIOSH information to prevent neurologic disorders related to pesticide exposure among agricultural workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker population*	Research Type
A	Neurologic disorders	Health effects of chronic pesticide exposure at varying levels	Agriculture and forestry subsectors; migrant workers, older workers and other vulnerable worker populations	Basic/etiologic Surveillance research
B	Neurologic disorders	Exposure assessment and new tools (esp. rapid assessment tools)	Agriculture and forestry subsectors	Basic/etiologic
C	Neurologic disorders	Interventions (e.g., training programs, product substitution testing)	Agriculture and forestry subsectors, vulnerable workers	Intervention
D	**Neurologic disorders**	**Effective implementation strategies**	**Agriculture and forestry subsectors, vulnerable workers**	**Translation**

*See definitions of worker populations

Activity Goal 1.1.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand the relationship between chronic pesticide exposure and neurologic disorders among agriculture and forestry workers.

Activity Goal 1.1.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to reduce neurologic disorders from pesticide exposure among agriculture and forestry workers.

Activity Goal 1.1.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective interventions to reduce neurologic disorders from pesticide exposure among agriculture and forestry workers.

Burden

Agricultural workers are one of the major occupational groups exposed to pesticides [MacFarlane et al. 2013]. Pesticides are used extensively throughout the U.S., where more than 18,000 products are licensed for use [EPA 2002]. About 1.1 billion pounds of pesticides are used annually in the U.S., and widespread use results in pervasive occupational exposure [EPA 2011]. Every year physicians diagnose 10,000-20,000 pesticide poisonings among the estimated 2 million U.S. agricultural workers [EPA 1992].

Many pesticides have been studied for occupational effects, including organophosphate insecticides, fungicides, fumigants, and organochlorine and carbamate insecticides. Neurologic toxicity is one of the most prominent adverse health effects associated with pesticide exposure [Keifer and Firestone 2007]. At least 23 neurologic symptoms are typically associated with pesticide intoxication [Kamel et al. 2005].

Need

Poisoning by acute high-level exposure to certain pesticides has well-known neurotoxic effects, but occupational health effects from chronic exposure to more moderate levels of pesticides is an area in need of study. Some other areas of need may include the role of genetic susceptibility, and more studies of pesticides other than organophosphates.

Current immediate research needs include basic research to evaluate and characterize potential health effects of chronic pesticide exposure at different levels, including low levels. Basic research is also needed to develop, test and apply better exposure assessment tools, including samplers, biomarkers and diagnostic tools to confirm cases of acute pesticide poisoning. Intervention research is needed to develop and test interventions, programs or strategies aimed at minimizing or preventing pesticide exposure among farmers. Finally, translation research to expand the high-quality implementation of evidence-based interventions, programs and strategies would be beneficial.

Intermediate goal 1.2 (Renal diseases):

Non-governmental organizations, international organizations, and employers use NIOSH information to reduce renal disease related to occupational exposures among agricultural workers.

	Health Outcome	Research Focus	Worker population	Research Type
A	Renal diseases	Exposure assessment for chronic kidney disease of unknown etiology	Agriculture subsector, Forestry subsector	Basic/etiologic
B	Renal diseases	Pesticide-related surveillance	Agriculture subsector, Forestry subsector	Surveillance research

Activity Goal 1.2.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand chronic kidney disease of unknown etiology among agriculture workers.

Activity Goal 1.2.2 (Surveillance Research): Conduct surveillance research to better understand the burden of chronic kidney disease among agricultural workers.

Burden

There is currently an epidemic of chronic kidney disease of unknown etiology (CKDu) around the world. Workers in industries with jobs that occur outdoors and with a high work load, such as agriculture, seem to be the most

affected [Valcke et al. 2017]. Among agricultural industries, workers in sugarcane cultivation appear to have garnered more attention. Currently it is unclear what causes CKDu, however heat stress and exposure to pesticides are thought to be possible contributors.

Potential sources of hazardous chemicals in agriculture include pesticides, fertilizers, organic solvents, metals, sterilization compounds, gasses from confined animal wastes and silos, and plant residues [Keifer et al. 2010]. Farmers and farm workers are exposed to high levels of pesticides during the preparation and application of pesticide spray solutions, and while cleaning the spraying equipment [Damalas and Koutroubas 2016]. Exposure to pesticides may lead to acute poisonings, as well as chronic adverse health effects from long term, low-level exposure [Damalas and Koutroubas 2016]. During 2007–2011, 2,606 total cases (0.9/100,000) and 833 cases in agriculture (18.6/100,000) of acute occupational pesticide-related illness and injury were identified in 12 states; most affected were those exposed to insecticides or herbicides [Damalas 2016]. Additional studies suggest that farmworkers and their families may face higher levels of agricultural pesticide exposure in their homes [Trunnelle et al. 2013, 2014; Sugeng 2016].

Herbicide application for utility line clearance and other vegetation control tasks is common in forestry [Green 1991]. However, there is limited literature on the magnitude and distribution of chemical exposures and associated adverse health effects among forestry workers. Low levels of certain pesticides have been found on seedlings and on the skin of Canadian tree planters, coupled with evidence of increased exposure potential due to poor hygiene conditions [Gorman et al. 2011].

Need

Most of the NIOSH-funded Agricultural Safety and Health Centers (Ag Centers) have been involved in research that address pesticide exposure. These centers have already established partners and facilities, and developed methods to approach research in this area. Prior research has led to additional research questions involving new technologies and procedures to develop and use pesticides/herbicides for agricultural use. NIOSH has also developed a network of partners through the SENSOR pesticide surveillance initiative to provide pesticide surveillance in cooperating states. This network can be tapped by researchers to continue work in this area. Additional surveillance needs include acute occupational pesticide-related illness and injury surveillance through SENSOR to determine the magnitude and underlying causes of over-exposure to pesticides in the workplace.

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Valcke M, Levasseur ME, da Silva AS, Wesseling C [2017]. Pesticide exposures and chronic kidney disease of unknown etiology: an epidemiologic review. Environ Health *16*(1), 49.

Healthcare and Social Assistance/Cancer, Reproductive, Cardiovascular Disease and Other Chronic Disease Prevention (HSAxCRC)

Participating core and specialty programs: Authoritative Recommendations, Engineering Controls, National Center for Productive Aging and Work, and Personal Protective Technology.

Intermediate Goal 1.3 (Adverse Reproductive Outcomes):

Employers, workers and manufacturers use NIOSH information to reduce hazardous exposures that contribute to cancer and adverse reproductive outcomes among healthcare and social assistance workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Issue	Target population	Research needed
A	Cancers, Adverse reproductive outcomes	Development of closed drug transfer systems	Management, medical workers who handle hazardous drugs (includes human and veterinary)	Intervention
B	Cancers, Adverse reproductive outcomes	Development of exposure controls, including local exhaust ventilation for hazardous drugs	Management and workers in inpatient and outpatient clinics where hazardous drugs are administered (includes human and veterinary)	Intervention
C	Cancers (also infectious diseases)	Development of exposure controls, including local exhaust for surgical smoke	Human surgical, human outpatient, veterinary work settings	Intervention
D	Adverse reproductive outcomes, Cancers	Development of exposure controls, including local exhaust for waste anesthetic gases	Management and workers administering anesthetic gases or caring for patients recovering from anesthetic gas administration, especially recovery room nurses (includes human and veterinary)	Intervention
E	**Cancers, Adverse reproductive outcomes**	**Adherence to Safe Handling of Hazardous Drug Guidance**	**Range of work settings, such as: pharmacy, outpatient clinics, veterinary medicine**	**Intervention Translation**
F	Cancers	Development of exposure assessment tools for assessing environments and for hazard surveillance	Nurses, others with potential carcinogenic exposures (includes human and veterinary)	Basic/etiologic Surveillance research

Activity Goal 1.3.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better assess relationships between level of exposure and risk for cancers and adverse reproductive outcomes in healthcare and social assistance.

Activity Goal 1.3.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent exposures to hazardous drugs and other chemicals linked to cancers and adverse reproductive outcomes among healthcare and social assistance workers.

Activity Goal 1.3.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing best practices for the safe handling of hazardous drugs and other chemicals linked to cancers and adverse reproductive outcomes among healthcare and social assistance workers.

Activity Goal 1.3.4 (Surveillance Research): Conduct surveillance research to develop new tools and methods for assessing the burden of work-related exposures to carcinogens among healthcare and social assistance workers.

Burden

Human and animal healthcare workers are routinely exposed to hazardous drugs and other chemicals. NIOSH estimates that about 8 million healthcare workers in a wide range of occupations (e.g., pharmacists, nurses, physicians, veterinarians, and workers in environmental, laundry or waste handling services) are potentially exposed to hazardous drugs [NIOSH 2016]. Exposure to antineoplastic or chemotherapy drugs have been linked to multiple health effects ranging from skin rashes and asthma to adverse reproductive outcomes, as well as leukemia and other cancers [Lawson et al. 2012; Skov et al. 1992]. Other chemicals commonly found in healthcare settings include cleaning and disinfecting (C&D) agents, high level disinfectants (HLDs), anesthetic gases, surgical smoke, aerosolized medications, and chemical sterilants including ethylene oxide [Casey et al. 2017; Saito et al. 2015; Steege et al. 2014]. Exposure to these substances have been linked to adverse reproductive effects and cancer and other health effects.

Need

Efforts to translate research into practice by identifying and disseminating best practices to reduce chemical exposures are needed where mature best practices already exist, such as for hazardous drugs. Research to develop interventions to reduce exposures to chemical hazards and to demonstrate the effectiveness of interventions are needed in areas where there are gaps, such as for controlling exposures to waste anesthetic gases. Surveillance and basic/etiologic research continues to be important in order to document the burden and magnitude of work-related exposures and assess relationships between exposures and other risk factors with adverse health outcomes. Unless new sources of information become available, repeat discrete studies over time will be needed to track progress in applying prevention measures and the success of those measures.

Intermediate Goal 1.4 (Work Organization and Cancer, CVD):

Employers and workers use NIOSH information to mitigate the effects of work organization to help prevent cancer and cardiovascular disease among healthcare and social assistance workers.

	Health Outcome	Issue	Worker population	Research needed
A	Cancers, Cardiovascular disease	Work-related stress, anxiety, depression, fatigue as a result of suboptimal work organization	Nurses, certain types of physicians, home health care workers, environmental services workers, veterinary/animal care workers	Basic/etiologic

Activity Goal 1.4.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand the relationship between work organization and cancers, and work organization and cardiovascular disease, in healthcare and social assistance.

Burden

Work in Healthcare (human and animal) and Social Assistance is often associated with high levels of stress resulting in multiple adverse health outcomes. The American Nurses Association surveyed its members in 2011 and found that 74% of respondents had concerns about the effects of stress and overwork. This survey also found that 53% of nurses worked some mandatory or unplanned overtime each month [ANA 2011]. In one survey of veterinary personnel, 35% consider their job dangerous, 34% reported adverse effects from workplace

stress, and 42% of veterinarians experienced or witnessed workplace abuse [Fowler et al. 2016]. Psychological stress is associated with adverse cardiovascular health outcomes [Lagraauw et al. 2015]. Risks of long shift work include reduced job performance on the job, obesity, injuries, and a wide range of chronic diseases [Caruso 2014]. Five or more years of rotating nightshift work is associated with an increased risk of coronary heart disease [Vetter et al. 2016]. The International Agency for Research on Cancer considers shift work with circadian rhythm disruption as a carcinogen [Straif 2007].

Need

Little is known about the biologic link between shift work and cancer or cardiovascular disease. Similarly, the link between work-related stress, anxiety, depression, fatigue and adverse health outcomes such as cardiovascular disease needs to be better understood. Research to quantify these risk factors, document exposure-response relationships, and better define mechanisms for causation of adverse health outcomes by these risk factors is needed.

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Manufacturing/Cancer, Reproductive, Cardiovascular Disease and Other Chronic Disease Prevention (MNFxCRC)

Participating core and specialty programs: Authoritative Recommendations, Center for Maritime Safety and Health Studies, Engineering Controls, Exposure Assessment, Nanotechnology Research Center, and Occupational Health Equity.

Intermediate goal 1.5 (Exposure to carcinogens):

Employers, workers and their representatives, researchers, safety and health professionals, and authoritative bodies use NIOSH information to prevent exposures to known or suspected carcinogens among manufacturing workers.

	Health Outcome	Research Focus	Worker population	Research Type
A	Cancers, Cardiovascular disease	Exposure to nanomaterials (e.g., carbon nanoparticles)	Workers in advanced manufacturing, manufacturers that use or make nanomaterials	Basic/etiologic Intervention
B	Cancers	Exposure to welding fumes	Those who perform welding tasks at work	Basic/etiologic Intervention
C	Cancers	Exposure to plasticizers and flame retardants	Those who make or apply plasticizers and flame retardants	Basic/etiologic Intervention

Activity Goal 1.5.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between exposures to high priority agents and cancers among manufacturing workers.

Activity Goal 1.5.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent exposures to high priority agents linked to cancers among manufacturing workers.

Burden

Cancer is a leading cause of death in the U.S. and the world [American Cancer Society 2016]. Based on well-documented associations between occupational exposures and cancer, researchers have estimated that

between 2-8% of all cancers worldwide are caused by exposures to carcinogens in the workplace [Driscoll et al. 2005; Rushton et al. 2012; Purdue et al. 2015, Steenland et al. 2003]. Using cancer incidence numbers in the U.S., this means that in 2013, there were between 31,180 and 124,720 new cancer cases that were caused by past exposure in the workplace [Rushton et al. 2010]. NIOSH burden data show that the following cancers are an important source of morbidity among workers in the manufacturing sector: lung and bronchus cancer (attributable fraction [AF] = 8-11 %); mesothelioma (AF = 1-19 %); leukemia (AF = ~4%); laryngeal cancer (AF = 2-7 %); and sinonasal and nasopharynx cancer (AF = 41-54%) [Groenewold et al. 2017].

Need

High priority agents for study within the manufacturing sector include nanomaterials (specifically, carbon nanoparticles) and welding fumes; emerging agents of concern related to occupational cancer among workers in this sector include plasticizers and flame retardants. Each of these categories of agents includes multiple specific agents of concern – the type of research needed for the different specific agents will vary depending on the amount of work that has been performed to this point. For example, among the many types of nanomaterials, etiologic epidemiologic research would be most appropriate currently only for carbon-based nanomaterials, while other types of etiologic research (toxicologic, basic exposure) and intervention research is needed for carbon-based nanomaterials but also for a number of other types of nanomaterials. Information is also needed on the occupational exposure levels to potentially carcinogenic chemicals that are in new or increased use, such as flame retardant chemicals and bisphenol A (BPA) and other plasticizers being proposed as substitutions for BPA. BPA was recently listed as "high priority" for review by the International Agency for Research on Cancer (IARC 2014), based on anticipated information from toxicology studies. Concomitant occupational exposure assessment would be very timely for such an assessment.

The need for etiologic and intervention research in the manufacturing sector is justified by: (1) the frequency with which studies conducted in this sector have contributed information about known human carcinogens (e.g., asbestos, benzene, beryllium, ortho-toluidine, vinyl chloride); (2) the fact that the population is relatively stable, can be documented, and exposures may be concentrated and measurable among this workforce; and (3) importantly, cancers that occur as a result of exposures in the workplace are preventable, if exposures to known or suspected carcinogens can be reduced.

Intermediate goal 1.6 (Adverse Reproductive Outcomes):

Employers, workers and their representatives, researchers, safety and health professionals, and authoritative bodies use NIOSH information to prevent adverse reproductive outcomes among manufacturing workers.

	Health Outcome	Research Focus	Worker population	Research Type
A	Adverse reproductive outcomes	Exposure to endocrine disrupters (e.g., BPA)	Exposed workers (men and women)	Basic/etiologic Intervention
B	Adverse reproductive outcomes	Exposure to solvents	Exposed workers (men and women)	Basic/etiologic
C	Adverse reproductive outcomes	Exposure to heavy metals	Exposed workers (men and women)	Basic/etiologic Intervention

Activity Goal 1.6.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between exposures to high priority agents and adverse reproductive outcomes among manufacturing workers.

Activity Goal 1.6.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent exposures to high priority agents linked to adverse reproductive outcomes among manufacturing workers.

Burden

Adverse reproductive outcomes can affect both men and women and can include infertility, menstrual cycle changes, pregnancy loss, pregnancy complications, and congenital malformations in offspring. Specifically concerning one type of adverse reproductive outcome, congenital malformations affect one in every 33 babies (about 3% of all babies) born in the U.S. each year. While most adverse reproductive outcomes are related to a number of different etiologic factors, occupational exposures likely play an important and perhaps under-recognized role. For example, it has been estimated that 3% of major malformations among live births are due to toxicant exposures, 28% can be attributed to genetic causes, and approximately 23% are attributable to multifactorial causes, which are complex interactions between genes and environmental factors [CDC 2008, 2017; Macdorman and Gregory 2015; Mathews et al. 2015; Thoma et al. 2013].

Need

Toxicants with reported reproductive and developmental effects are in regular commercial use and thus present potential exposure to workers. High priority agents to which workers in the manufacturing sector may be exposed include heavy metals, organic solvents, and the large class of agents characterized as endocrine disrupters. Bisphenol A (BPA) is an important endocrine disrupter for which basic/etiologic research (as well as intervention research) is needed. In more general terms, the need for research in the manufacturing sector is bolstered by the fact that progress has been limited in identifying new reproductive hazards, quantifying their potencies, and separating the contribution of these hazards from other etiologic factors. The pace of laboratory studies to identify hazards and to underpin the biologic plausibility of reproductive effects in humans has not matched the pace at which new chemicals are introduced into commerce.

Intermediate goal 1.7 (Exposure to welding fumes and neurologic disorders):

Employers, workers and their representatives, researchers, safety and health professionals, and authoritative bodies use NIOSH information to prevent neurologic disorders among manufacturing workers.

	Health Outcome	Research Focus	Worker population	Research Type
A	Neurologic disorders	Exposure to welding fumes	Those who perform welding tasks at work	Basic/etiologic Intervention

Activity Goal 1.7.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between exposures to welding fumes and neurologic disorders among manufacturing workers.

Activity Goal 1.7.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of welding fume interventions to prevent neurologic disorders among manufacturing workers.

Burden

Neurologic disorders, which may be associated with occupational exposures include neurodegenerative diseases (such as the motor neuron diseases (MND), Parkinson's disease (PD), dementias, and multiple sclerosis) and other conditions such as peripheral neuropathies and chronic toxic encephalopathies. Clinical syndromes associated with neurotoxicity comprise one of the 10 leading occupational disorders in the U.S., and neurotoxic effects are the basis for exposure limit criteria for about 40% of the agents considered hazardous by NIOSH [Pearce and Kromhout 2014]. Welding is a common activity occurring in many industrial sectors but is particularly common in the manufacturing sector. There is a concern about potential neurological effects associated with welding, and specifically concerning exposure to manganese in welding fumes [Al-Lozi et al. 2017].

Need

Current knowledge indicates that occupational and environmental exposures cause an uncertain proportion of most types of neurodegenerative disease. In addition, for some common neurodegenerative diseases (e.g., MND and PD) the incidence is higher in men than in women, which suggests occupational causes [Pearce and Kromhout 2014]. However, so far no occupational agent has been identified that is responsible for a significant number of cases, reflecting the "emerging" nature of the study of occupational neurologic diseases compared to some other health outcomes. Focused etiologic research could help to ascertain whether workplace exposures are contributing to this burden.

While it is recognized that prolonged exposure to high manganese concentrations in air may lead to a Parkinsonian syndrome known as "manganism," research is mixed concerning neurological and neurobehavioral deficits occurring when workers are exposed to low levels of manganese in welding fumes over time. Workers performing welding operations in the manufacturing sector may experience other exposures as well, such as to lead, iron, carbon monoxide, heat and stress, which can also contribute to neurological impairments. Research from NIOSH and other researchers can play an important role in furthering our understanding of the etiology and towards the development and evaluation of control interventions for the prevention of those occupational health effects.

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Mining/Cancer, Reproductive, Cardiovascular Disease and Other Chronic Disease Prevention (MINxCRC)

Participating core and specialty programs: Exposure Assessment and Personal Protective Technology.

Intermediate goal 1.8 (Hazardous airborne exposures and cancer):

Industry, academia, and other government agencies use NIOSH information to reduce exposure to hazardous airborne contaminants to reduce lung cancer and mesothelioma in mining workers.

	Health Outcome	Research Focus	Worker population	Research Type
A	Lung cancer, mesothelioma	Exposure to elongate mineral particles (especially taconite)	Metal/non-metal mines	Basic/etiologic
B	Lung cancer	Exposure to diesel exhaust	Metal/non-metal; coal; stone, sand and gravel mines	Intervention

	Health Outcome	Research Focus	Worker population	Research Type
C	Lung cancer	Develop more accurate and timely monitoring of crystalline silica	Metal/non-metal; coal; stone, sand and gravel mines	Basic/etiologic Intervention
D	Lung cancer	Exposure to crystalline silica	Metal/non-metal; coal; stone, sand and gravel mines	Basic/etiologic Intervention
E	Lung cancer	Exposure assessment for known or suspected carcinogens (e.g., radon)	Underground mines	Basic/etiologic

Activity Goal 1.8.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between exposures to hazardous airborne contaminants and lung cancer and mesothelioma among mining workers.

Activity Goal 1.8.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of crystalline silica and diesel exposure interventions to reduce exposures to prevent lung cancer among mining workers.

Burden

Extracting and processing mined materials can result in overexposures to several hazardous airborne contaminants, including mine dust such as elongate mineral particles (EMP) and crystalline silica dust and diesel exhaust. Mine Safety and Health Administration (MHSA) compliance data demonstrates overexposures to these airborne contaminants at rates as high as 24%. In addition, mining environments can be sources of high exposures to radon gas and its radioactive decay progeny [Daniels and Schubauer-Berigan 2017]. Radon levels are highest in uranium mines, but are also elevated in other hard-rock mines. The International Agency for Research on Cancer (IARC) [2017] classifies crystalline silica, diesel engine exhaust and radon as carcinogenic to humans. In addition, miners suffer from higher rates of lung cancer and mesothelioma than other workers which can be caused by these agents or asbestos and elongate mineral particles with asbestos-like effects. These diseases can have a severe impact on affected miners and be disabling or even fatal. A recent study estimates that 10-23% of lung cancers among miners are likely attributable to their work [Groenewald et al., 2017]. In 2007, a mesothelioma cluster of 58 cases was found in 72,000 former taconite miners who worked in a large iron range in Minnesota, while the expected occupational mesothelioma rate is much lower at 1 per 200,000 workers [Minnesota Department of Health 2007]. Asbestos has been found in many mines, even where the product mined was not asbestos; the National Occupational Health Survey of Mining recorded detectable asbestos in settled dust collected from at least one mine extracting 21 different non-asbestos commodities [NIOSH 1996]. MSHA sampling data collected (2000-2003) in 123 mines of various commodities showed that at 15% of sampled mines, 8% of personal samples had asbestos fiber concentrations in excess of the OSHA regulated concentration of 0.1 fibers/cc [OSHA 2005].

Need

There is need for a range of work to reduce the burden of dust, diesel, and radon-related respiratory malignancies in mining. Basic/etiologic research is needed to improve methods for exposure assessment for most lung carcinogens in the mining environment. Improvements might include real or near-real time silica exposure monitoring, improved detection thresholds for silica exposure assessment and better approaches to characterizing EMP exposures. Exposure assessment research is also needed for radon and other known or

suspected carcinogens in underground mines. In addition, work is needed to understand the relative toxicities of various EMP and to improve the ability to predict which EMP will have asbestos-like health effects (see NIOSH Roadmap 2011). Intervention research is needed to improve engineering controls and document the impact of interventions on dust exposure levels and associated cancer risk. For diesel-powered equipment, the need is to reduce hazardous emissions from older engines being used in mines. NIOSH has extensive laboratories for developing and testing diesel controls, and these facilities are served by a dedicated team with two decades of experience and worldwide recognition for their diesel expertise. NIOSH also has expertise, partnerships, and cohorts available to study the association between low-level radon exposure and lung cancer risk.

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Public Safety/Cancer, Reproductive, Cardiovascular Disease and Other Chronic Disease Prevention (PSSxCRC)

Participating core and specialty programs: Emergency Preparedness and Response, National Center for Productive Aging and Work, and Personal Protective Technology.

Intermediate goal 1.9 (Exposure to carcinogens):

Management groups, labor organizations, and consensus standard bodies use NIOSH information to prevent exposures to known or suspected carcinogens among public safety workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker population	Research Type
A	Cancers	Exposures during structural operations and overhaul operations	Fire service subsector	Basic/etiologic
B	Cancers	Respiratory protection during over-haul operations	Fire service subsector	Intervention
C	**Cancers**	**Respiratory protection during overhaul operations**	**Fire service subsector**	**Translation**
D	Cancers	Exposures from wearing contaminated gear	Fire service subsector	Intervention
E	Cancers	Exposure assessment, esp. direct reading	Fire Service subsector	Basic/etiologic
F	Cancers	Understanding linkages between shift work and cancers	Corrections and Law enforcement subsectors	Basic/etiologic Surveillance research

Activity Goal 1.9.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between exposures and cancers among fire service, corrections and law enforcement workers.

Activity Goal 1.9.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to reduce exposures to carcinogens among fire service workers.

Activity Goal 1.9.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective interventions, particularly related to PPE, to prevent exposures to carcinogens among fire service workers.

Activity Goal 1.9.4 (Surveillance Research): Conduct surveillance research to develop new tools and methods to identify cancer risks and understand the magnitude of those risks among corrections and law enforcement workers.

Burden

Cancer is a leading cause of death in the U.S. and the world. Cancers that occur as a result of exposures in the workplace are preventable, if exposures to known or suspected carcinogens can be reduced [NIOSH 2015]. Based on well-documented associations between occupational exposures and cancer, researchers have estimated that between 3-6 % of all cancers worldwide are caused by exposures to carcinogens in the workplace [Driscoll et al. 2005; Rushton et al. 2012]. NIOSH burden data show the following cancers are an important source of morbidity among workers in the public safety sector: lung and bronchus cancer (attributable fraction [AF] = 15-35 %); leukemia (AF = ~18%); melanoma (skin cancer) (AF = 5-15%); and sinonasal and nasopharynx cancer (AF = 0-2%) [Groenewold et al. 2017]. Among the limited research conducted with the public safety sector workforces, the occupational risks have been evaluated to the greatest extent among firefighters. A recent NIOSH cohort study of 30,000 career firefighters employed from 1950–2009 found an excess risk of

developing digestive, oral, pharyngeal, and laryngeal cancers, as well as mesothelioma when compared with the general U.S. population [Daniels et al. 2014, 2015; Pinkerton 2015]. Law enforcement and corrections officers may have several work factors, including shift work and work organization factors, which may be potential causative risk factors for cancer.

Need

The full range of occupational exposures to potential carcinogens among public safety workers is not well understood. For example, for firefighters it is not known how important factors related to occupational cancers among firefighters such as the different sizes of fires and attack methods (including personal protective equipment [PPE] use) have on firefighters' airborne, dermal, or systemic exposures to potential carcinogens. To date, there has been little to no research studying cancer incidence among the other public safety sub-sectors including law enforcement, emergency medical services, wildland firefighters, and corrections officers; however, there are several work factors, including workplace exposures, shift work, and work organization factors, which may be potential causative risk factors for cancer. To improve the ability to implement effective preventive measures, occupational cancer risks must be identified and the magnitude of those risks better understood. In addition, there is stakeholder interest and a demonstrated need to determine the applicability and performance of air-purifying respirators and powered air-purifying respirators as potential alternatives to self-contained breathing apparatus for fire fighter over-haul operations. Furthermore, current work is underway to evaluate turnout clothing contamination levels and cleaning agents, additional work is needed to develop sampling and testing procedures to assess contaminant levels in turnout clothing materials, characterize persistent contaminants in firefighter protective clothing, and develop validated cleaning procedures to determine efficacy of specific PPE cleaning equipment, cleaning agents, and procedures.

Intermediate goal 1.10 (Risk factors for CVD):

Consensus standard bodies, labor organizations, and management groups use NIOSH information to reduce risk factors to cardiovascular disease among public safety workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker population	Research Type
A	Cardiovascular disease	Hazardous exposures (e.g., particulate matter, heat)	Fire service and wildland fire subsectors	Basic/etiologic
B	Cardiovascular disease	Workplace stress, work organization factors, and non-occupational risk factors (e.g., hypertension, obesity, smoking)	Corrections, law enforcement, emergency medical service (EMS), and Fire service subsectors	Basic/etiologic Surveillance research
C	**Cardiovascular disease**	**Reduce known non-occupational risk factors**	**Corrections, law enforcement, EMS, and fire service subsectors**	**Intervention Translation**
D	**Cardiovascular disease**	**Respiratory and thermal protection, other interventions on fire ground**	**Fire service subsector**	**Intervention Translation**

Activity Goal 1.10.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between exposures and cardiovascular disease among public safety workers.

Activity Goal 1.10.2 (Intervention Research): Conduct intervention studies to develop and assess the effectiveness of interventions to mitigate risk factors for cardiovascular disease among fire service and wildland firefighters.

Activity Goal 1.10.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective cardiovascular health interventions among fire service and wildland firefighters.

Activity Goal 1.10.4 (Surveillance Research): Conduct surveillance research to develop new tools and methods to track occupational and non-occupational risk factors for cardiovascular disease among public safety workers.

Burden

Cardiovascular disease (CVD) is the leading cause of death in the U.S. and an occupational health concern among all public safety workers. While some behavior risk factors for CVD have been researched, occupational factors related to CVD among workers is an emerging area of research. Overall, NIOSH burden data show that the attributable fraction for coronary heart disease among workers in the public safety sector is 13-31% [Groenewold et al. 2017]. For structural firefighters, sudden cardiac events account for more than half of all on-duty deaths each year [USFA 2017]. In addition, it is also estimated that that for every one on-duty sudden cardiac death, 17 non-fatal cardiac events occur while on-duty [Karter and Molis 2011].

Data have also indicated that 7-22% of on-duty deaths among police officers, 17% among wildland firefighters, and 11% of emergency medical service workers are due to sudden cardiac events [Butler et al. 2017; Zimmerman 2012; Maguire et al. 2002; TriData Corporation 2002]. Workplace exposures, such as exposure to combustion by-products, physical, and psychological factors likely contribute to increased risk of cardiovascular disease among public safety workers. Rapidly accumulating evidence also suggests that stress at work plays an important role in high blood pressure, cholesterol levels, and other cardiovascular intermediate and end outcomes, and many types of occupational stressors are prevalent among workers in this sector [Fujishiro et al. 2015; Kaur 2014]. For example, among correction officers and law enforcement many stressors fall far outside the range of the ordinary work experience, e.g., habitual exposure to interpersonal violence, anticipation of inmate contact, actual negative or confrontational interactions, and a general sense of job danger. Other workplace factors of concern related to CVD include physical exertion and physical inactivity, excessive heat or cold, noise, and organizational factors such as shift work and long work hours [Stewart et al. 2017; Charles et al. 2016; Giada et al. 2008; Kales et al. 2007; Tomei et al. 2000].

Need

NIOSH investigators have the capability to assess occupational exposures potentially related to CVD among public safety workers, including such exposures such as combustion by-products (among firefighters) and occupational stress and work organization factors. Additional research is needed to better understand the mechanisms by which occupational factors increase risk; the proportion of CVD due to occupational factors; the interaction of workplace factors and known non-occupational CVD risk factors, and the effectiveness of various interventions to reduce CVD among workers. Translational research is needed across the sector to educate public safety workers on NIOSH and stakeholder research findings related to reducing CVD.

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Services/Cancer, Reproductive, Cardiovascular Disease and Other Chronic Disease Prevention (SRVxCRC)

Participating core and specialty programs: Exposure Assessment, National Center for Productive Aging and Work, Occupational Health Equity, Small Business Assistance, and Surveillance.

Intermediate goal 1.11 (Risk factors and burden of CVD):

Employers, workers, researchers, and non-governmental organizations use NIOSH information to modify work practices to reduce cardiovascular disease among services workers.

	Health Outcome	Research Focus	Worker population*	Research Type
A	Cardiovascular disease	Understanding workplace stress as a risk factor	Small businesses, teachers, immigrants and other vulnerable workers	Basic/etiologic Intervention
B	Cardiovascular disease	Understanding shift work as a risk factor	Small businesses, shift workers, immigrants and other vulnerable workers	Basic/etiologic Intervention
C	Cardiovascular disease	Burden characterization	All services workers (esp. those in the administrative and support and waste management and remediation services subsector, and accommodation and food service subsector)	Surveillance research

	Health Outcome	Research Focus	Worker population*	Research Type
D	Cardiovascular disease	Understanding heat stress as a risk factor	Landscaping, building services workers, waste management	Basic/etiologic

*See definitions of worker populations

Activity Goal 1.11.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between cardiovascular disease and risk factors among services workers.

Activity Goal 1.11.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to reduce cardiovascular disease risk factors among services workers.

Activity Goal 1.11.3 (Surveillance Research): Develop new surveillance methods to improve the characterization of the burden of cardiovascular disease and its risk factors among services workers.

Burden

According to data from the National Health Interview Survey (NHIS), the only two industry groups that had significantly higher adjusted prevalence ratios for cardiovascular disease (CVD)/stroke when compared to workers in all other industry groups were both in the services sector: administrative and support and waste management and remediation services, and accommodation and food service [CDC 2014]. These industry groups also have slightly elevated proportionate mortality ratios for circulatory diseases according to the National Occupational Mortality Surveillance (NOMS) system [NIOSH 2015]. However, our current understanding of the overall burden of CVD in the services sector is limited by the small subsamples of workers in any given subsector that participate in the NHIS each year, the small number of States currently participating in NOMS, and the paucity of other data sources for assessing CVD burden among workers.

Behaviors and other factors that increase the risk of cardiovascular ill health have been characterized, however occupational factors related to CVD among workers is an emerging area of research. Workplace factors of concern related to CVD among workers in the services sector include multiple types of workplace stressors (e.g., physical exertion and physical inactivity, excessive heat or cold, noise, and long work hours) and shift work [Kivimacki 2015]. Psychosocial factors, such as job strain, are also relevant workplace stressors; a recent comprehensive review found moderately strong evidence for a relationship between coronary heart disease and job strain and low decision latitude [Theorell et al. 2016]. Among services sector workers with exposure to these work-related factors are the approximately 4.4 million workers employed in jobs classified in the building and landscape services industries [BLS 2017a]. Many of these workers are immigrants whose exposures and health outcomes are exacerbated due to stressors including many types of occupational health disparities [Landsbergis et al 2014]. In addition, in the services sector, 89% of the 3 million firms have less than 20 employees, and these small businesses typically have limited access to health and safety specialists [U.S. Census Bureau 2011].

Need

Improved surveillance methods are needed to better characterize the burden of cardiovascular disease and its risk factors among Services workers. Exposure assessment studies are needed to understand these different factors and how they are interrelated with CVD causation and progression. Further research is needed in the services sector to better understand the mechanisms by which occupational factors increase CVD risk and the proportion of CVD due to occupational factors, as well as the effectiveness of various interventions to reduce CVD among workers. Guidelines and training materials are needed for effective interventions to prevent CVD

among building service workers and grounds keepers. These workplaces frequently lack access to health and safety professionals. Administrative controls and work organization improvements that may be routinely adopted at construction or manufacturing workplaces are not widely adopted for routine but intermittent tasks in building services.

Intermediate goal 1.12 (Adverse reproductive outcomes):

Employers, healthcare providers, and non-governmental organizations use NIOSH information to reduce adverse reproductive outcomes among services workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker population*	Research Type
A	Adverse reproductive outcomes	Chemical exposures	Immigrants and other vulnerable workers, young women, personal services workers, small businesses	Basic/etiologic Surveillance Research
B	**Adverse reproductive outcomes**	**Chemical exposures**	**Nail and hair salon workers, small businesses**	**Intervention Translation**

*See definitions of worker populations

Activity Goal 1.12.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between chemical exposures and adverse reproductive outcomes among personal care services sector workers.

Activity Goal 1.12.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to reduce chemical exposures associated with adverse reproductive outcomes among nail salon workers.

Activity Goal 1.12.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective interventions to reduce chemical exposures associated with adverse reproductive outcomes among nail salon workers.

Activity Goal 1.12.4 (Surveillance Research): Develop new surveillance methods to measure the burden of chemical exposures and adverse reproductive outcomes among services workers.

Burden

In the services sector, 89% of the 3 million firms have less than 20 employees, and these small businesses typically have limited access to health and safety specialists [U.S. Census Bureau 2011]. The personal care services component of the sector employs approximately 1.45 million workers [BLS 2017b]. Many of these workers are employed in hair and nail salons and are exposed to a wide variety of chemicals that potentially cause a number of health effects including reproductive toxicity [Pak et al 2013]. The hair and nail salon industry largely employs women of reproductive age and also employs a high proportion of minorities and immigrants [BLS 2017c; Maslin Nir 2015a,b].

Need

Etiologic studies are needed concerning reproductive hazards from exposure to many of the chemicals used in nail salons (e.g., phthalates, ethyl methacrylate, toluene, and formaldehyde) and among other workers in the personal care services industries (e.g., epidemiologic studies of low level solvent exposures and reproductive outcomes for the personal care industry). Businesses in the services sector (particularly the small businesses) need evidence-based data to support interventions to reduce chemical exposures among their workers. Studies on identifying effective outreach methods through trusted partners are needed for all workers in the services sector, particularly among workers in small businesses and among the immigrant populations.

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Transportation, Warehousing and Utilities/Cancer, Reproductive, Cardiovascular Disease and Other Chronic Disease Prevention (TWUxCRC)

Core and specialty programs: National Center for Productive Aging and Work

Intermediate goal 1.13 (CVD and obesity, work organization):

Federal agencies, trade associations, labor organizations, employers, owner/operators, and researchers use NIOSH information to reduce cardiovascular disease among transportation, warehousing and utilities workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker population*	Research Type
A	Cardiovascular disease	Best type of interventions to address the risk factor of obesity	Long-haul truck drivers, short-haul truck drivers, bus and transit, rail, maritime, couriers and messengers	Intervention
B	**Cardiovascular disease**	**Best communication methods to decrease risk factors, tailoring interventions from other sectors**	**Long-haul truck drivers**	**Intervention Translation**
C	Cardiovascular disease	Work organization best practices (e.g., sleep and fleet management)	Workers with non-standard work arrangements, long-haul truck drivers, short-haul truck drivers, bus and transit, rail, maritime, couriers and messengers	Basic/etiologic Intervention
D	Cardiovascular disease and other heat-related illnesses	Work organization best practices to prevent heat stress	Utilities and warehousing workers	Intervention

*See definitions of worker populations

Activity Goal 1.13.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between work organization factors and cardiovascular disease among TWU workers.

Activity Goal 1.13.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to decrease cardiovascular disease risk factors among TWU workers.

Activity Goal 1.13.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing cardiovascular risk factor interventions among TWU workers.

Burden

Obesity is a risk factor for chronic disease that manifests itself in health conditions such as metabolic syndrome, cardiovascular disease, obstructive sleep apnea, and diabetes; premature death and disability; increases in health care costs; lost productivity; and social stigmatization [NIH 1998; Thompson et al. 1999; Martin and

Church 2009]. It has also been noted that a higher prevalence of hyperlipidemia and hypertension is found in overweight and obese individuals. An estimated 34.2% of all TWU workers are obese [NIOSH 2013], 21.1% have hypertension [NIOSH 2013] and 6.1% have cardiovascular disease (CVD) [Helmkamp et al. 2013]. Obesity is related to multiple medical factors as well as increasing numbers of conditions which may, for example, limit a commercial motor vehicle driver's driving certification [Thiese et al. 2015]. Psychological stressors and the work demands of TWU workers create special challenges: tasks may be sedentary in nature, limited options may be available for where and when to eat while working or resting away from home, sleep periods may often be less than the 7-9 hours daily recommended, and work arrangements may be non-standard [Hirschkowitz et al. 2015]. Thirty-eight percent of TWU workers indicate less than 7 hours of sleep in a 24-hour period [CDC 2012], 66.7 percent of TWU workers did not meet CDC guidelines for physical activity [Helmkamp et al. 2013], and 31.1% report work-life interference [NIOSH 2015]. Twenty seven point eight percent of TWU workers work more than 48 hours per week compared to 18.7% of the U.S. work force and 35.7 percent work non-standard shift, compared to 26.6% of the U.S. workforce [NIOSH 2010]. Seventeen point four percent of TWU workers report frequent night work [NIOSH 2015]. Other psychological stressors occur because of the increasingly common nontraditional employer-employee relationships TWU workers with non-standard work arrangements account for 15.9% of employees [Violanti et al. 2009, Katz and Krueger 2016]. The cardiovascular system has an important role in thermoregulation, as warm blood is circulated from the core to the skin during heat transfer to the environment. However, heat stress and factors like dehydration, can lead to cardiovascular strain, resulting in heat-related illnesses [Wilson et al. 2014, NIOSH 2016]. Severe heat-related illness may cause permanent damage to the organs, including the heart. One study found that males with heat-related illness were at an increased risk of death from cardiovascular disease and ischemic heart disease [Wallace et al. 2007].

Need

Previous NIOSH obesity TWU surveillance research has focused on long- and short-haul truck drivers, and more efficient methods to monitor obesity among TWU workers are needed. Further NIOSH research on obesity should include intervention and evaluation studies focusing on obesity in commercial drivers as well as other high prevalence occupations. There is a need to evaluate both programmatic and technological approaches so that health guidelines for the TWU sector are supported by scientific evidence. Intervention research to assess the effectiveness of organizational interventions and translation research to understand barriers to drivers in adopting effective interventions is needed. Research should consider cost-effectiveness as well as features of work organization in the TWU sector such as self-employment, time pressures, and other work-related stressors. Because non-standard worker arrangements are understudied but increasingly prevalent, and their determinants and health and safety consequences are poorly understood, basic/etiologic research leading to intervention is needed. Research should also address work organization models for sleep as well as fleet management. Particularly needed are models on the determinants and effects of work arrangements and efforts to improve the taxonomy of work arrangements and their characteristics. Workers and managers show widespread lack of appreciation and knowledge about the importance of sleep health and risks associated with poor sleep and fatigue. The evidence for a link between short sleep and CVD risk factors is an active area of research [Knutson KL et al. 2007]. Translation and intervention research are needed to develop effective administrative controls for management and to understand how to implement them most effectively, as well as how to best communicate the health risks of obesity. Existing approaches are not always accepted among TWU workers. Intervention research is needed to develop better heat prevention work practices that fit into the unique indoor environments of warehouse workers and outdoor environments of utilities workers.

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Strategic Goal 2: Reduce occupational hearing loss

Construction/Hearing Loss Prevention (CONxHLP)

Participating core and specialty programs: Center for Direct Reading and Sensor Technologies, Engineering Controls, Occupational Health Equity, Safe•Skilled•Ready Workforce, Small Business Assistance, and Surveillance.

Intermediate goal 2.1 (Engineering controls to reduce noise exposure):

Manufacturers, equipment purchasers, and insurers (including workers' compensation) adopt engineering controls to reduce harmful noise exposure among construction workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker population*	Research Type
A	Hearing loss	Increase supply and demand for quieter equipment and vehicles (jackhammers, enclosed cabs, heavy equipment)	Iron workers, welding, masons, boilermakers, laborers, small businesses, vulnerable workers	Intervention
B	Hearing loss	Translate solutions from Mining and other sectors (fans, rotary drilling)	Highway construction, laborers, small businesses, vulnerable workers	Intervention
C	**Hearing loss**	**Develop supply of and demand for quieter hand tools**	**Laborers, carpenters, boilermakers, vulnerable workers, small businesses**	**Intervention Translation**

*See definitions of worker populations

Activity Goal 2.1.1 (Intervention Research): Conduct studies to develop and assess the effectiveness of noise engineering controls to reduce hearing loss among construction workers.

Activity Goal 2.1.2 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective noise engineering controls to reduce hearing loss among construction workers.

Burden

Within the construction sector, 44% of workers are exposed to hazardous noise and about 31% of these noise-exposed workers report not wearing hearing protection [Tak et al. 2009]. Thirteen percent of all construction workers have hearing difficulty and 7% have tinnitus [Masterson et al. 2016]. However, among noise-exposed construction workers, twenty-five percent have a material hearing impairment (average hearing threshold levels above 25 dB for 1, 2, 3, & 4 kHz) in at least one ear [Masterson et al. 2015] and 16% have hearing impairment in both ears [Masterson et al. 2016]. Hearing impairment is hearing loss that impacts day-to-day activities. Almost three-quarters (73%) of construction workers measured in a longitudinal study between (1999-2009) were exposed daily to full-shift, noise levels above the NIOSH recommended exposure level (REL) of 85 dB time-weighted average A-weighted [CPWR 2010]. Many construction workers are also exposed to impulse or impact noise. Noise exposures are caused by a wide range of sources, including hand tools, larger machinery, heavy equipment, and generators.

Construction trades with the highest prevalence of hearing loss include welders, iron workers, laborers, boilermakers, carpenters, sheet-metal workers, and brick masons [CPWR 2010]. Many vulnerable workers may have an elevated or disproportionate risk, including foreign-born workers and workers with limited English-language skills, workers in small businesses, contingent workers, and younger (teenage) and older (65 and over) workers [Themann et al. 2013a,b]. Hearing loss can have a profound impact on quality of life. It is associated with cognitive decline [Chien et al. 2012] and cardiovascular outcomes such as hypertension [Themann et al. 2013a]. It is also strongly associated with depression [Themann et al. 2013a; Hetu et al. 1995]. Tinnitus, which often co-occurs with hearing loss, can disrupt sleep and is associated with both depression and anxiety [Shargorodsky et al. 2010]. Construction workers lose 3.1 healthy years, each year, for every 1,000 noise-exposed workers, the second highest loss among industries [CDC 2016].

Need

Noise control engineering solutions are the most effective methods to reduce noise exposures and to assure the exposure levels stay below the NIOSH REL of 85 dB(A). Noise controls and related equipment need to be developed or improved upon and evaluated in the laboratory, followed by work with manufacturers to evaluate the feasibility of the noise control solutions through field studies. Noise hazards posed by power tools and heavy equipment in construction need to be controlled at the source. There is also a need to develop quieter powered hand tools. Researchers should continue to promote and develop "Buy Quiet" approaches that address supply and demand, in addition to development of databases of tools and the noise levels produced when operated. Noise labeling with the level of noise produced by equipment or use of Safety Data Sheets documenting the hazardous noise and the means to protect against it is also helpful. Areas in need of research include reducing impulsive noise generated by pneumatic tools and continued expansion of the ability to assess and control noise in construction. Collaboration with the mining industry could help to understand how miners' hearing is protected, and to determine if some of the mining technologies are suitable for similar applications and use in construction. Additional efforts are needed to transfer findings from this research into influential documents such as guidance and voluntary consensus standards. There is also a need to translate research findings into software products, applications and interactive webpages to make information easily accessible for construction stakeholders.

Intermediate goal 2.2 (Hearing loss prevention education for employers and workers):

Employers and supervisors use NIOSH education tools and resources to prevent harmful noise exposures among construction workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	**Hearing loss**	**Fit testing (voluntary consensus standards, increasing availability)**	**Noise exposed workers**	**Translation**
B	**Hearing loss**	**Training and awareness (Employers, supervisors and workers; apps)**	**Noise exposed workers, vulnerable workers**	**Intervention Translation**

*See definitions of worker populations

Activity Goal 2.2.1(Intervention Research): Conduct studies to develop and assess the effectiveness of noise education and awareness interventions to reduce hearing loss in the construction industry.

Activity Goal 2.2.2 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective noise education and awareness interventions to reduce hearing loss in the construction industry.

Burden

Within the construction sector, 44% of workers are exposed to hazardous noise and about 31% of these noise-exposed construction workers report not wearing hearing protection [Tak et al. 2009]. The use of hearing protection is influenced by many factors including perceived hearing loss, education, and work experience. Integration of hearing protection device (HPD) training into multi-faceted intervention programs can be effective, but there are gaps in our understanding related to HPD usage, design, and effective training materials [CPWR 2010]. As described above, construction trades with the highest prevalence of hearing loss include welders, iron workers, laborers, boilermakers, carpenters, sheet-metal workers, and brick masons [CPWR 2010]. Many vulnerable workers may have an elevated or disproportionate risk, including foreign-born workers and workers with limited English-language skills, workers in small businesses, contingent workers, and younger (teenage) and older (65 and over) workers [Themann et al. 2013a, b].

Need

A Cochrane systematic review has identified a lack of demonstrated effectiveness for hearing conservation programs with regards to reducing the incidence of noise induced hearing loss [Verbeek et al. 2012]. Interventions to prevent hearing loss are sometimes ineffective due to improper and inconsistent use of hearing protection coupled with inadequate training [Byrne et al. 2017; Voix et al. 2009]. Employers and workers need to be educated about noise, including: (1) the proper way to insert foam ear plugs; and (2) provide information to trainers and workers about (a) "Buy Quiet" programs; (b) ways to reduce vibration of equipment to possibly reduce noise; and (c) use of administrative controls to limit exposure to hazardous noise, as specified by Occupational Safety and Health Administration (OSHA) requirements that allow for various exposure time/noise intensity levels [OSHA 2011]. There is a need to better understand the best approaches to train and educate construction workers, employers, and safety professionals. Many of these groups include non-English speaking learners and low-literacy audiences, so it is important that the educational materials be available in English and Spanish and written in a manner that addresses the needs of vulnerable workers. Micro-learning, online training and use of augmented, virtual, and immersive reality should be considered. Many of these educational materials could be applicable across all sectors for noise-exposed workers.

Some hearing protection manufacturers now provide hearing protector fit-testing systems that can measure a Personal Attenuation Rating of hearing protectors which provide opportunities to aid in the proper selection of hearing protection. Translational research for fit testing methods is needed. In addition, hearing protection researchers and advocates should communicate with employers and employees about new smartphone-based noise metering apps [Roberts et al. 2016, Kardous et al. 2014]. Use of these tools will create an awareness of noise exposures, and following from that, take steps to limit or reduce exposure to noise hazards. Additional efforts are needed to transfer findings from this research into influential documents such as guidance and voluntary consensus standards. There is also a need to translate research findings into software products, applications and interactive webpages to make information easily accessible for construction stakeholders.

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Manufacturing/Hearing Loss Prevention (MNFxHLP)

Participating core and specialty programs: Center for Direct Reading and Sensor Technologies, Center for Maritime Safety and Health Studies, Engineering Controls, Occupational Health Equity, Prevention through Design, Small Business Assistance, and Surveillance.

Intermediate goal 2.3 (Exposure to hazardous noise and ototoxic chemicals):

Employers, safety professionals, workers, and consensus standard organizations use NIOSH information to reduce noise and ototoxic chemical exposures among manufacturing workers.

	Health Outcome	Research Focus	Worker Population	Research Type
A	Hearing loss	Develop updated damage/risk recommendations	Forge plant workers, as well as others in metal and furniture making subsectors	Basic/etiologic
B	Hearing loss	Develop hearing protection for impulse noise	Forge plant, as well as others in metal and furniture making subsectors	Intervention
C	Hearing loss	Understanding the burden of impulse noise	Forge plants, as well as others in metal and furniture making	Surveillance research
D	Hearing Loss	Understanding combination of impulse and continuous noise	Noise-exposed manufacturing workers	Surveillance research
E	Hearing Loss	Exposure to ototoxic chemicals	Manufacturing workers (esp. petroleum and coal products, leather, fiberglass)	Surveillance research

Activity Goal 2.3.1 (Basic/Etiologic Research): Conduct basic/etiologic research update damage/risk criteria for impulse noise to reduce hearing loss among manufacturing workers.

Activity Goal 2.3.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of hearing protection interventions for impulse noise to reduce hearing loss among manufacturing workers.

Activity Goal 2.3.3 (Surveillance Research): Conduct surveillance research to develop new tools and methods to better understand the burden of noise overexposure among manufacturing workers.

Burden

An estimated prevalence of noise exposed workers in the manufacturing sector is nearly 6 million workers (37%) based upon National Health and Nutrition Examination Survey (NHANES) data [Tak et al. 2009]. To further

understand the burden of hearing loss, NIOSH has partnered with hearing conservation providers to collect audiometric data from a broad spectrum of sectors. The burden for hearing loss among noise-exposed workers in the manufacturing sector was about 20% [Masterson et al. 2015]. Noise exposures are typically described as continuous, intermittent and impulsive. Occupational exposure limits have been developed assuming that the exposures are for continuous noise exposures over the course of a lifetime of exposure. Impulsive noise exposures or combinations of continuous noise and impulsive noise pose an increased risk of hearing loss [Davis et al. 2009; Zhao et al. 2010].

Exposures to noise in combination with solvents potentially poses an increased risk of hearing loss because the solvents can affect the auditory system through different mechanisms than the mechanical or metabolic destruction of the sensory hair cells [Johnson and Morata 2010]. The number of workers in the Manufacturing sector that experience mixed exposures is not well known and further surveillance research is needed to characterize the risk.

Need

While the general trend has been one of decline in the incidence of hearing loss in the manufacturing sector (a 2% reduction from 1986–2010), additional research and dissemination efforts are needed [Masterson et al. 2015]. Exposures to impulse noise represent a greater risk for early onset of hearing loss [Zhao et al. 2010; NIOSH 2016] and the interventions to prevent hearing loss from impulse noise have not been assessed for their effectiveness. A better understanding of risk factors (impulse noise, aging, and other agents) is needed. Specific needs include updated guidelines towards these risk factors and the incorporation of new technologies within hearing prevention loss programs, such as the integration of fit testing. A range of new hearing protector technologies has been brought to market in recent years and methods to evaluate their protection against impulse noise is necessary. Among these are devices with Bluetooth™, active noise cancellation, and near field communication capabilities. Research is needed to provide assessment and promotion of new technologies that can affect the field of hearing conservation.

Surveillance research is needed to better characterize noise exposures and hearing loss prevalence, especially among chemical, petroleum, and metal industries within the manufacturing sector. Surveillance research might include using new data sources for surveillance purposes, using existing methods to surveil a new population for which there is limited or no applicable surveillance data, or adding new questions to an existing survey like the National Health Interview Survey that target a population, exposure or outcome. Additionally, workplace noise exposures for targeted Manufacturing Sector tasks should be studied to characterize the noise dose, use/non-use of hearing protection and other personal protective equipment, and assessment of hearing conservation programs.

Intermediate goal 2.4 (Hearing loss prevention education for employers and workers):

Employers, workers, hearing conservation providers, health and safety vendors, and safety professionals use NIOSH education tools and resources to prevent harmful noise exposures among manufacturing workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	**Hearing loss**	**Integrating new technologies into education (e.g., noise app, fit testing)**	**Noise-exposed manufacturing workers (esp. small businesses)**	**Translation**
B	Hearing loss	Education intervention effectiveness	Noise-exposed manufacturing workers (esp. small businesses)	Intervention

*See definitions of worker populations

Activity Goal 2.4.1 (Intervention Research): Conduct studies to develop and assess the effectiveness of education interventions to prevent hearing loss among manufacturing workers.

Activity Goal 2.4.2 (Translation Research): Conduct translation research to understand barriers and aids to integrating new technologies into hearing loss prevention education in the manufacturing sector.

Burden

Within the manufacturing sector, 22%–55% of workers are exposed to hazardous noise (depending on sub-sector), and between 13% and 39% of these noise-exposed workers report not wearing hearing protection [Tak et al. 2009]. Noise-exposed manufacturing workers in electrical machinery, non-electrical machinery and textiles have the highest prevalence of not using hearing protection [Tak et al. 2009]. Many workers may have an elevated or disproportionate risk, including foreign-born workers and workers with limited English-language skills, workers in small businesses, contingent workers, and younger (teenage) and older (65 and over) workers [Themann et al. 2013].

Need

The 2017 Cochrane systematic review has identified a lack of demonstrated effectiveness for hearing conservation programs with regards to reducing the incidence of noise induced hearing loss [Tikka et al. 2017]. Interventions to prevent hearing loss are sometimes ineffective due to improper and inconsistent use of hearing protection coupled with inadequate training [Voix and Laville 2009; Byrne et al. 2017]. Employers and workers would benefit from education about noise, including the proper way to insert foam ear plugs, "Buy Quiet" programs, ways to reduce vibration of equipment to possibly reduce noise, and use of administrative controls to limit exposure to hazardous noise, as specified by OSHA requirements that allow for various exposure time/noise intensity levels [OSHA 2011].

Some hearing protection manufacturers now provide hearing protector fit-testing systems that can measure a Personal Attenuation Rating of hearing protectors which provide opportunities to aid in the proper selection of hearing protection. Translational research for fit testing methods is needed. In addition, hearing protection researchers and advocates should communicate with employers and employees about new smartphone-based noise metering apps [Kardous and Shaw 2015; Roberts et al. 2016]. Use of these tools will create an awareness of noise exposures, leading to steps to limit or reduce exposure to noise hazards.

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Mining/Hearing Loss Prevention (MINxHLP)

Participating core and specialty programs: Center for Direct Reading and Sensor Technologies, Engineering Controls, and Surveillance.

Intermediate goal 2.5 (Noise control engineering and hearing loss surveillance):

Industry, academia, and other government agencies use NIOSH information to reduce hearing loss among miners.

	Health Outcome	Research Focus	Worker Population	Research Type
A	Hearing loss	Noise controls for mining equipment	Metal/non-metal mines	Intervention
B	Hearing loss	Hearing conservation approach	Stone, sand and gravel mines	Intervention Surveillance research
C	Hearing loss	Quiet by design (manufacturing quieter equipment)	All mines (esp. coal, metal/non-metal)	Intervention
D	Hearing loss	Understanding cumulative noise exposure levels	Non-machine operators who work in mines	Surveillance research

Activity Goal 2.5.1 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent noise overexposures among mining workers.

Activity Goal 2.5.2 (Surveillance Research): Conduct surveillance research to develop new methods and tools to track noise exposures to reduce hearing loss among mining workers.

Burden

Noise-induced hearing loss is a pervasive concern in the mining industry. Large machinery performing crushing, cutting, and conveying processes in relatively tight-quarter conditions leads to a high level of noise exposure of the machinery operators and others working in the vicinity. The mining sector has the highest prevalence of hazardous workplace noise exposures (76%) among all industrial sectors [Tak et al. 2008]. Despite engineering and administrative controls implemented to reduce noise, miners continue to exhibit a high prevalence (24%) of hearing difficulty [Tak et al. 2009]. A recent NIOSH evaluation of over 1 million audiograms indicates that mining has the highest prevalence, 27%, of hearing loss among industries sampled, with the average industry prevalence at 18% [Masterson et al. 2015]. Mine Safety and Health Administration exposure data indicate average noise exposure exceeding the permissible exposure limit (PEL) across surface and underground coal and non-coal mining sectors. Exceedance values range from approximately 7% to 18% [Roberts et al. 2017], which is greater than the 4-16% of the general, low-noise-exposed population [Tak et al. 2009].

Need

Ongoing surveillance efforts regarding noise exposure and hearing loss in the industry are necessary to identify future research needs and to assess the effectiveness of past work. Although larger scale industry-wide surveillance initiatives are ongoing, there must be a specific focus on mining to gain a full, accurate understanding of the noise problem by working area and job type. No information exists on the actual use of hearing conservation programs in mining, beyond noting the presence or absence of audiometric testing and the use of hearing protection devices. Continued and expanded surveillance efforts are needed to fill these critical gaps in knowledge.

Currently, in the U.S., mining equipment manufacturers are not held to sound level limitations. Equipment operators are in turn exposed to high noise levels from operating original equipment and the only solutions is add-on noise controls, administrative controls or use of PPE. Focus must be placed on designed quieter equipment from the start, therefore reducing the noise for administrative and personal protective controls. Two of the only facilities in the country with the capability to conduct noise evaluations on large mining machines are located at NIOSH.

In addition, NIOSH researchers have developed relationships with the relatively small mining community that enhances their abilities to access mines to conduct field studies. This access to sites and mine workers enhances the relevance of the research by assuring that strategies, products, or concepts will be accepted by the end user, and can be effectively produced (if required) by a manufacturer. Reducing the noise at the source through a quieter original design or through use of engineering noise controls is the preferred method to reduce overall noise emission and in turn noise exposure of equipment operators.

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Oil and Gas Extraction/Hearing Loss Prevention (OGExHLP)

Participating core and specialty programs: Engineering Controls, Small Business Assistance, Surveillance, and Translation Research.

Intermediate goal 2.6 (Exposures to hazardous noise and ototoxic chemicals):

Employers, equipment manufacturers, professional associations, and workers use NIOSH information to prevent hazardous noise exposure among oil and gas extraction workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	Hearing loss	Identification of noise sources at worksites	Drilling contractors, well servicing contractors, small businesses	Surveillance research Basic/etiologic
B	Hearing loss	Exposure to noise and ototoxic chemicals from large equipment with diesel engines	Drilling contractors, well servicing contractors, small businesses	Intervention
C	**Hearing loss**	**Effective use of personal protective equipment (PPE)**	**Drilling contractors, well servicing contractors, small businesses**	**Translation**

*See definitions of worker populations

Activity Goal 2.6.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand sources of noise exposure in oil and gas extraction worksites.

Activity Goal 2.6.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent noise overexposure among oil and gas extraction workers.

Activity Goal 2.6.3 (Translation Research): Conduct translation research to understand barriers and aids to effective use of PPE to prevent hearing loss among oil and gas extraction workers.

Activity Goal 2.6.4 (Surveillance Research): Conduct surveillance research to better understand the burden of hearing loss and sources of noise in the oil and gas extraction sector.

Burden

Businesses in the oil and gas extraction sector (OGE) are exempt from complying with the federal requirements requiring a hearing conservation program, monitoring noise levels, and annual audiometric testing for workers (29 CFR 1910.95). While every year approximately 22 million workers are exposed to hazardous noise in the workplace [Tak et al. 2009], accurate data for workers in this industry are lacking. In 2002 the Occupational Safety and Health Administration (OSHA) modified the federal requirements to include hearing loss as a recordable injury on OSHA 300 logs (29 CFR 1904.10) in order to document this injury, but again OGE operations are exempt. Previous NIOSH work [NIOSH 1998] estimated that 23% (76,500) of all OGE workers were exposed to potentially damaging noise (>85dBA) at least once a week, for 90% of the weeks they worked in a year, and safety professionals within OGE have identified hearing loss as an important issue [McCrary 1994, Smith 1991]. According to an alert issued by the International Association of Drilling Contractors [IADC 1998], noise measured on a drilling rig was reported at 102 dBA beside an engine skid and 90-97 dBA on the rig floor (where many of the workers are located) while drilling. Statistics from the NIOSH Occupational Hearing Loss Surveillance project estimated that approximately 76% of all workers in mining, oil and gas extraction are exposed to hazardous noise levels [Tak et al. 2009]. About 13% of noise-exposed workers report not wearing hearing protection when working in noisy areas [Tak et al. 2009]. Among all workers in mining, oil and gas extraction, 12% have hearing difficulty and 11% have tinnitus [Masterson et al. 2016]. Among noise-exposed workers, 25% have a material hearing impairment [Masterson et al. 2015], meaning they have significant difficulty understanding speech.

Need

There exists a need for NIOSH to conduct noise exposure surveys in the oil and gas extraction sector. During the 20 years since NIOSH's last publication in this area [NIOSH 1998], new work practices and equipment have been introduced, but not independently evaluated. Further, much of the noise attenuation activities in the industry have focused on reducing noise emissions for residents of nearby communities rather than for workers. New research, including surveillance, to characterize noise hazards to workers in the modern OGE workplace is needed. Once the exposures have been characterized, work to eliminate sources of noise, develop and evaluate noise controls, improve work practices, or provide enhanced personal protection for workers in the OGE sector can begin. There is potential for workers to be exposed to volatile hydrocarbons that could potentially interact with noise to exacerbate the hearing loss that workers might experience, which should be considered during intervention research. Translational research is necessary to communicate the risk of noise induced hearing loss to workers in this sector. The efforts that have been undertaken in other sectors (e.g., mining, manufacturing, and construction) can be useful to help aid workers learn proper fitting techniques for hearing protection devices [Murphy et al. 2016]. The use of hearing protector fit testing systems can aid in training workers. However, the message needs to be tailored to the industry [Murphy et al. 2011]. With a lower price for oil and natural gas, the workforce is currently lower than previous high-activity periods which makes this a good time

for NIOSH to act as partnerships could be established giving our noise control engineers access to equipment not currently in high demand for use in the field.

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Services/Hearing Loss Prevention (SRVxHLP)

Participating core and specialty programs: Occupational Health Equity, Small Business Assistance, Safe•Skilled•Ready, and Surveillance

Intermediate goal 2.7 (Exposure to hazardous noise):

Employers, workers, equipment manufacturers, non-governmental organizations, and suppliers use NIOSH information to reduce hearing loss in building services workers and in services sector small business enterprises.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	**Hearing loss**	**Overexposure to noise (intermittent use of loud equipment)**	**Building services workers, arts and entertainment subsector, small businesses**	**Intervention Translation**
B	**Hearing loss**	**Lack of awareness of noise as a hazard and how to protect hearing**	**Building services workers, arts and entertainment subsector, small businesses**	**Translation**
C	Hearing loss	Characterizing noise exposures and prevalence of hearing loss	Building services workers, arts and entertainment subsector, small businesses	Basic/etiologic Surveillance research

*See definitions of worker populations

Activity Goal 2.7.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better characterize noise exposures among building services and arts and entertainment workers in the services sector.

Activity Goal 2.7.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to reduce noise exposure among building services and arts and entertainment workers in the services sector.

Activity Goal 2.7.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective hearing protection interventions among building services and arts and entertainment workers in the services sector.

Activity Goal 2.7.4 (Surveillance Research): Conduct surveillance research to better characterize hearing loss prevalence among building services and arts and entertainment workers in the services sector.

Burden

In the U.S., occupational hearing loss is one of the most common work-related illnesses. Twenty-four percent of the hearing difficulty among U.S. workers is attributable to occupational exposures [Tak and Calvert 2008; Themann et al. 2013]. Within the services sector, there are very large groups of workers with hazardous noise exposure. For instance, 45% are exposed in repair and maintenance (approximately 900,000 exposed workers); within arts, entertainment, and recreation 22% of workers are exposed (approximately 550,000 exposed workers); and approximately 13% are exposed within public administration (approximately 650,000 exposed workers) [Tak et al. 2009]. Twenty percent of noise-exposed services workers have a material hearing impairment in one or both ears (overall) [Masterson et al. 2015]. However, among some industry sub-sectors, 23-36% have impairment [Masterson et al. 2013]. Services workers lose 2.6 healthy years, each year, for every 1,000 noise-exposed workers [CDC 2016]. These lost healthy years are shared among the 13% of noise-exposed services workers with hearing impairment in both ears (about 130 workers out of each 1,000 workers). Over a 30-year working lifetime, about 78 healthy years are lost by 130 workers [CDC 2016].

Need

Effective interventions to prevent noise induced hearing loss in the services sector are multi-faceted. First, field studies are needed to evaluate feasibility and effectiveness of noise control solutions, as workplace noise is best controlled at the source. In particular, research is needed to promote and develop "Buy Quiet" approaches that address supply and demand for equipment often used in Services, in addition to developing databases of noise levels for tools and equipment [Beamer et al. 2016]. Second, best practices for hearing conservation programs in

Services are needed that include effective use of hearing protectors, hearing protector fit-testing, and effective worker training on the dangers of noise exposure and preventing hearing loss [Byrne et al. 2017; Murphy et al. 2011]. Services sector workers are often from vulnerable populations which puts them at higher risk to occupational hazards, noise exposure among them. Moreover, services sector employers are often small business employers which often have fewer resources to devote to issues like occupational noise exposure.

Educational materials and guidelines for workers and employers are needed to inform them about steps that can be taken to reduce noise exposures and to protect their hearing, such as the proper way to insert foam ear plugs, "Buy Quiet" programs, ways to reduce vibration of equipment to possibly reduce noise, and use of administrative controls. Furthermore, educational materials should be tailored to specific Services audiences, taking into account barriers to implementing best practices. Contingent workers and their employers are an especially important audience as these workers are particularly vulnerable to workplace hazards and that there is sometimes a lack of clarity about who is responsible for their hearing protection programs.

Basic/etiologic and surveillance research are needed to better characterize noise exposures and hearing loss prevalence, especially among building services and arts and entertainment workers in the service sector. Additionally workplace noise exposures for targeted services sector tasks should be studied to characterize the noise dose, use/non-use of hearing protection, and assessment of hearing conservation programs.

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Strategic Goal 3: Reduce occupational immune, infectious and dermal disease

Agriculture, Forestry, and Fishing/Immune, Infectious and Dermal Disease Prevention (AFFxIID)

Participating core and specialty programs: Authoritative Recommendations, and Emergency Preparedness and Response.

Intermediate goal 3.1 (Skin exposure to pesticides and total body burden):

Policy-makers, federal and state agencies, and researchers incorporate NIOSH data into risk assessment strategies to reduce dermal diseases and total body burden related to pesticide exposure among agricultural workers.

	Health Outcome	Research Focus	Worker Population*	Research Type
A	Local and systemic toxicity	Understanding dermal exposure and permeation of pesticides and herbicides	Agriculture and forestry subsectors; vulnerable workers	Basic/etiologic

*See definitions of worker populations

Activity Goal 3.1.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand dermal exposure and permeation of pesticides and herbicides among agriculture and forestry workers.

Burden

There were 761,700 agricultural workers in the U.S. in 2014, and 528,000 of them were employed as equipment operators, farmworkers and laborers, and crop, nursery and greenhouse workers [BLS 2017]. 82% were male, 42% were foreign born, 45% reported Hispanic ethnicity, and 64% were US citizens [USDA 2017]. Pesticides are used throughout the agricultural industry, and in 2007 a total of 684 million pounds of active ingredients were used in US agriculture [Fishel 2007]. Farm workers are exposed to pesticides during mixing, loading and application tasks and during reentry following application. Skin is the primary route of pesticide exposure, contributing between 81 to 97% of total systemic uptake from these operations [EFSA 2013]. Dermal exposures to pesticides lead to diseases of the skin including both irritant and allergic contact dermatitis. Both acute and chronic pesticide exposures carry health risks [Donham and Thelin 2016].

Acute pesticide exposure illnesses can include abdominal pain, dizziness, headaches, nausea, vomiting as well as skin and eye complications [Hoppin and LePrevost 2017]. Death is rare but still a known outcome. From 1998–2005, there were 3,271 cases of acute pesticide poisoning reported among 10 participating states for an incidence rate of 53.6 out of 100,000 full time agricultural workers [Calvert et al. 2008]. In another analysis, only 13% of applicators and 22% of their spouses with symptoms resulting from high pesticide exposure events sought medical care, suggesting that pesticide poisoning surveillance data may underreport the actual occurrence [Bell et al. 2006].

Need

Data is needed to improve dermal risk assessments of pesticide exposures. Basic research needs to be conducted to measure the dermal uptake rates of pesticides in concentrated and in-use commercial

formulations at exposure levels that are typical of agricultural applications. Quantitative pesticide exposure assessments among agricultural workers and their families will provide this additional data.

NIOSH and NIOSH-funded researchers are uniquely suited to carry on this work. Past and current laboratory and field work has been done on worker pesticide exposure. NIOSH is currently leading surveillance on pesticide exposure in the U.S. NIOSH-funded Agricultural Safety and Health Centers have completed multiple projects on various aspects of pesticide exposure to workers. Recently completed studies include neuromotor and work injury risk after pesticide exposure, discovering improved methods to assess pesticide exposure, reducing pyrethroid pesticide exposures in dairy workers, and pesticide safety in tree fruit growers.

Intermediate goal 3.2 (Infectious disease transmission):

Employers, workers, other government agencies, non-governmental organizations, and professional associations use NIOSH information to prevent zoonotic disease transmission from animals to agriculture workers.

	Health Outcome	Research Focus	Worker Population	Research Type
A	Infectious diseases	Understanding disease transmission to and from animals (e.g., bird and swine influenza, unknown and emerging infections)	Livestock agriculture workers	Basic/etiologic Surveillance research

Activity Goal 3.2.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand infectious disease transmission between agriculture workers and livestock.

Activity Goal 3.2.2 (Surveillance Research): Conduct surveillance research to develop new methods and tools to track infectious disease transmission between agricultural workers and livestock.

Burden

Diseases shared by humans and animals are likely to affect agricultural workers and their families. Examples of pathogens causing zoonotic diseases include *Escherichia coli* O157:H7, *Salmonella*, and *Cryptosporidium*. Daly and Hill [2016] found Cryptosporidiosis and *E. coli* infection as two especially harmful diseases from farm exposure in a rural setting, whose burden may be larger than previously considered. Little information is available describing specific risk factors on the farm for developing a zoonotic disease and how frequently agricultural workers and their families get sick from food animals. Surveillance of zoonotic disease is critiqued as being challenging and progressing slowly [GAO 2010]. Most new or emerging infectious diseases (3 out 4) are zoonotic, transmitted between animals and humans [CDC 2016]. Zoonotic avian viral strains, such as the highly pathogenic H5N1 or H7N7 virus strains, can cause an influenza pandemic should they become communicable between people [NIOSH 2008].

Need

Currently, information is lacking on how frequently these infections occur among agricultural workers, what the specific risk factors are for becoming ill from a zoonotic disease, and what preventive measures may be most effective. NIOSH is frequently called on to help develop guidance on protecting these workers during outbreaks. Information gained from this research is critical in aiding the development of guidance. Research on surveillance (i.e. Cryptosporidiosis and *Escherichia coli* listed above), transmission, risk assessment, infectious disease networks, prevention, and control measures for U.S. workers is lacking and should be addressed. While it's clear

that agricultural exposures are linked to infectious disease transmission, surveillance data is known to be meager [Klumb et al. 2013]. NIOSH is funding Agriculture Safety and Health Centers around the country, and many of them have experience and facilities to do work on zoonotic diseases. By understanding how to minimize the risk of zoonotic disease transmission, public health professionals can safeguard worker and community health.

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Healthcare and Social Assistance/Immune, Infectious and Dermal Disease Prevention (HSAxIID)

Participating core and specialty programs: Authoritative Recommendations, Emergency Preparedness and Response, Exposure Assessment, Personal Protective Technology, and Translation Research.

Intermediate goal 3.3 (Infectious disease transmission):

Employers, workers, professional associations, and manufacturers use NIOSH information to prevent the transmission of pathogens, including drug-resistant organisms, among workers in human and veterinary healthcare settings.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population	Research Type
A	**Bloodborne pathogen infection**	**Sharps injury prevention technology**	**Management, workers who use sharps medical devices**	**Intervention**
B	**Bloodborne pathogen infection**	**Sharps injury prevention (safety culture)**	**Management, workers (human or veterinary settings)**	**Translation**
C	Bloodborne pathogen infection	Sharps injury reporting	Management, workers who use sharps medical devices	Surveillance research
D	Influenza and emerging work-related pathogen infection	Understanding modes of transmission	Workers in pediatrics, acute care, daycare centers, others as needed to address outbreaks (human or veterinary)	Basic/etiologic
E	Influenza and other healthcare associated-infections	Ultraviolet germicidal irradiation utility, Surface disinfection	Workers in pediatrics, acute care, daycare centers, others as needed to address outbreaks (human or veterinary)	Intervention
F	**Influenza and other vaccine-preventable diseases**	**Vaccinations are underutilized**	**All healthcare workers (esp. long-term care, home care), veterinary and animal care (VM/AC) workers**	**Translation**
G	**Influenza and other diseases transmitted by contact/droplet sprays**	**Handwashing best practices underused**	**All healthcare and VM/AC workers**	**Translation**
H	**Influenza and other work-related infectious diseases**	**Personal protective equipment (PPE) (e.g., barrier PPE such as gowns, gloves, eye protection; and respiratory protection)**	**All healthcare and VM/AC workers**	**Intervention Translation**
I	Influenza	Lack of Industry/ occupation variables in surveillance systems	All healthcare and VM/AC workers	Surveillance research

	Health Outcome	Research Focus	Worker Population	Research Type
J	**Tuberculosis**	**Rapid identification and isolation of contagious individuals**	**Workers in hospitals, urgent care, homeless shelters, others as needed to address outbreaks (human or veterinary)**	**Basic/etiologic**
K	**Infection by drug-resistant organisms**	**Barriers to implementing existing recommendations**	**Workers in hospitals, urgent care, homeless shelters, others as needed to address outbreaks (human or veterinary)**	**Translation**
L	Tuberculosis	Improved surveillance for work-related transmission	All healthcare workers	Surveillance research
M	Zoonotic diseases	Improved surveillance	VM/AC	Surveillance research

Activity Goal 3.3.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand influenza aerobiology and transmission in healthcare settings and develop improved approaches to rapidly identify patients with active tuberculosis.

Activity Goal 3.3.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent transmission of work-related infectious disease among workers in human and veterinary healthcare settings.

Activity Goal 3.3.3 (Translation Research): Conduct translation research to understand barriers to implementation and aid in implementation of best practices for preventing the transmission of work-related infectious disease in human and veterinary healthcare settings.

Activity Goal 3.3.4 (Surveillance Research)**:** Conduct surveillance research to evaluate and track the burden of work-related infectious disease among workers in human and veterinary healthcare settings.

Burden

Occupational infectious diseases are an important hazard for Healthcare and Social Assistance (HCSA) workers caring for human patients. Examples include bloodborne pathogens such as Hepatitis B virus (HBV), Hepatitis C virus (HCV), and Human Immunodeficiency Virus (HIV); tuberculosis (TB); and seasonal influenza. Sharps injuries are important risk factors for transmission of bloodborne pathogens such as HIV, HBV, and HCV. In 2009, it was estimated that there were about 385,000 percutaneous injuries in U.S. hospital-based healthcare and social assistance (HCSA) workers alone each year [NIOSH 2009]. Several well-known emerging infectious diseases affecting healthcare workers in recent years have included 2009 H1N1 pandemic influenza, Ebola, and Middle Eastern Respiratory Syndrome (MERS). A 2015 report indicated that Ebola had killed about 8% of the healthcare workers in Liberia and about 7% in Sierra Leone [Evans et al. 2015]. A recent meta-analysis of the world literature on infection of healthcare personnel during the 2009 H1N1 influenza pandemic found an approximately two-fold increased risk relative to the general population [Lietz et al. 2016]. Multi-drug resistant organisms present a growing challenge for workers in the HCSA sector, with 88 cases of multidrug resistant TB and one case of extensively drug-resistant TB identified in the U.S. in 2015 [CDC 2017]. Occupational infectious diseases are also an important hazard for veterinary medicine/animal care (VM/AC) workers, who face the hazard of zoonotic (animal-to-human) transmission of infectious diseases such as brucellosis, rabies and other zoonotic diseases.

Need

Surveillance information on sharps injuries is an immediate research need for the HCSA sector. Research is also needed to develop surveillance methods to document the burden of infectious disease transmission in VM/AC workers. Currently, innovation and evaluation of sharps injury prevention technology and safety culture is lacking. This research could produce engineering and administrative controls along with other best practices to reduce sharps injuries. Research gaps regarding the pathways of transmission, environmental persistence, and vulnerability of pathogens to disinfection strategies need to be addressed, specifically for influenza and tuberculosis. Better intervention design to prevent workplace transmission of infectious diseases and documentation of effectiveness of strategies such as use of respiratory protection and air disinfection with ultraviolet germicidal irradiation to prevent influenza transmission would be a significant contribution to the protection of HCSA workers. Identification and elimination of barriers to intervention dissemination such as implementation of effective engineering controls (e.g., environmental controls and safe sharps devices), handwashing, vaccination, providing sick leave for contagious workers, and the appropriate availability and use of personal protective equipment (PPE) is needed.

Intermediate goal 3.4 (Exposures related to asthma and other immune diseases):

Employers, workers, professional associations, and others use NIOSH information to prevent chemical exposures that contribute to immune diseases among healthcare and social assistance workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	Dermatitis	Exposure characterization to novel agents	Home healthcare workers	Basic/etiologic
B	Asthma	Exposure to cleaning agents and disinfectants	Environmental workers, nursing assistants, nurses	Basic/etiologic
C	Effect of chronic low dose exposure	Exposure to cleaning agents and disinfectants	Environmental workers, nursing assistants, nurses	Basic/etiologic
D	**Asthma**	**Adherence to best practices re: cleaning agents**	**Environmental workers, nursing assistants, nurses**	**Translation**
E	Asthma	Exposure to surgical smoke	Workers in inpatient and outpatient surgical facilities	Basic/etiologic
F	Dermatitis	Use of latex gloves and disinfectants	Nurses	Basic/etiologic
G	Immune diseases	Exposure characterization aerosolized medication	Respiratory therapists	Basic/etiologic Intervention
H	Infections	Host susceptibility	Older workers and other vulnerable workers, workers with chronic disease	Basic/etiologic

*See definitions of worker populations

Activity Goal 3.4.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better characterize exposures to hazardous chemicals and understand the relationship between hazardous exposures and immune diseases among healthcare and social assistance workers.

Activity Goal 3.4.2 (Intervention research): Conduct studies to develop and assess the effectiveness of interventions to prevent exposures to aerosolized medications linked to immune diseases among healthcare and social assistance workers.

Activity Goal 3.4.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing best practices regarding cleaning agents and disinfectants linked to immune diseases in healthcare and social assistance workplaces.

Burden

Irritant contact dermatitis is very common in nurses, with prevalence documented by surveys ranging from 25-50% [WHO 2009]. Hand dermatitis resulting from frequent hand hygiene and use of occlusive gloves is especially common. Allergic contact dermatitis can also occur as a result of immune sensitization to agents contacting the skin [WHO 2009]. Healthcare workers have one of the highest prevalences of occupational asthma at 8.8%, compared to 7.2% among all workers [NIOSH 2013]. Healthcare workers account for about 16% of all occupational asthma cases and up to 24% of these cases are due to exposure to cleaning agents [NIOSH 2015]. Chemicals commonly found in healthcare settings that can potentially cause or exacerbate asthma include cleaning and disinfecting agents, high level disinfectants, anesthetic gases, surgical smoke, aerosolized medications, and chemical sterilants [Saito et al. 2015; Steege et al. 2014]. Exposure to antineoplastic or chemotherapy drugs have also been linked to skin rashes and asthma [Skov et al. 1992; Lawson et al. 2012]. Healthcare and social assistance (HCSA) workers are routinely exposed to infectious agents; thus, factors that potentially impair their resistance to infection such as aging or chronic disease may put them at increased risk.

Need

Characterization of the biological mechanisms between hazardous exposures and immune diseases (i.e. asthma and dermatitis) in the Healthcare and Social Assistance sector is needed. Of particular interest is identification of agents that are immune sensitizers and characterizing the immune responses that they induce. Little research has been focused on environmental services staff despite their high-frequency and long-duration exposures to cleaning and disinfecting agents. Recommended practices for cleaning and disinfecting in healthcare settings have been identified, however, infection control practices may not adhere to these guidelines [CDC 2008]. Similarly, respiratory therapists have not been specifically researched despite their exposure to aerosolized medications. Other targeted groups in the HCSA sector include older workers and workers with chronic diseases as little is known regarding their susceptibility to infections and whether this puts them at increased risk for acquisition of work-related infections.

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Manufacturing/ Immune, Infectious and Dermal Disease Prevention (MNFxIID)

Participating core and specialty programs: Center for Maritime Safety and Health Studies, Personal Protective Technology

Intermediate Goal 3.8 (Hazardous exposures and immune diseases):

Employers, policy-makers, trade associations, and manufacturers use NIOSH information to prevent immune and dermal diseases among manufacturing workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population	Research Type
A	Dermatitis	Exposures to manufacturing chemicals (e.g., metals, isocyanates, formaldehyde, metalworking fluids)	Manufacturing workers with exposures (e.g., automotive, furniture, plastics, painting, printing, metalworking)	Basic/etiologic
B	Work-related asthma	Mechanistic studies of exposures leading to allergic sensitization	Manufacturing workers with exposures (e.g., automotive, furniture, plastics, painting, printing, metalworking)	Basic/etiologic
C	Hypersensitivity pneumonitis (HP)	Mechanistic laboratory-based studies of exposures to organic and inorganic substances	Manufacturing workers with exposures (e.g., automotive, furniture, plastics, painting, printing, metalworking)	Basic/etiologic
D	**Immune suppressive disorders**	**Identification of substances and the mechanism by which they cause immune suppression**	**Manufacturing workers with exposures (e.g., automotive, furniture, plastics, painting, printing, metalworking)**	**Basic/etiologic**

Activity Goal 3.8.1 (Basic/etiologic research): Conduct basic/etiologic research to better characterize exposures related to immune and dermal disorders among manufacturing workers with an emphasis on studies to better understand basic immunological mechanisms.

Burden

Approximately 82,000 chemicals are currently used in industry with an estimated 700 new chemicals being introduced annually resulting in a high potential for occupational exposure [GAO 2005]. Occupational exposures to chemicals can result in numerous diseases which can adversely affect an individual's health and capacity to perform at work. The associated direct and indirect costs have been estimated to exceed $1 billion annually in the United States alone [Cashman et al. 2012, Mancini et al. 2008]. The two most common routes of occupational exposure to chemicals is through the skin and lungs. Hundreds of chemicals present in virtually every industry (metals, epoxy and acrylic resins, rubber additives, chemical intermediates) have been identified to cause immune mediated disorders such as contact dermatitis and asthma or other systemic effects [Anderson and Meade 2014]. The manufacturing sector includes a number of professions such as printing, petroleum and coal products manufacturing, chemical manufacturing, automotive manufacturing, plastic and rubber products manufacturing, metal manufacturing and furniture manufacturing in which a high potential for exposure to toxic chemicals exists. Contact dermatitis is the second most commonly reported occupational illness accounting for 10% to 15% of all occupational diseases and the Manufacturing sector has the highest number of cases (26,000) and the second highest reported incidence (139 per 100,000) of occupational skin diseases among major industries [Lushniak 2003]. Additionally, there are over 80 chemicals used in the manufacturing sector including amines, acrylates, acid anhydrides, and isocyanates that are associated with occupational asthma. Isocyanates (chemicals used in many products, including polyurethane foams and automotive paint) are considered to be some of the most common occupational asthmogens.

Need

Chemicals are used very commonly in workplaces for purposes such as cleaning and in manufacturing and production processes. At the same time, there is a responsibility to provide a safe and healthy environment for workers. While immunological mechanisms are thought to underlie certain occupational disorders due to chemical exposures, research in this area is still lacking. Overall, there is a need to better understand the adverse impact of chemicals on occupational immune health.

To minimize the hazards of dermal and respiratory occupational exposures and immune diseases, research is needed to understand the mechanisms driving the diseases in the context of exposure. Exposure monitoring is important to identify and quantify workplace occupational chemical exposures as well as help guide the development of control interventions. Further, these data can help to determine the chemical source and route(s) of exposure, the effectiveness of engineering controls, how to improve work practices, selection of appropriate personal protective equipment, and provide risk assessment guidance to risk managers. Workers should be aware not only of the hazards associated with the chemicals in their work environment but also the best ways to protect themselves from exposure and disease. Research involving matching the personal protective technology/equipment (PPE) appropriate to the hazard is needed in the manufacturing sector. Different glove materials differ in their ability to prevent dermal hazards and research is needed in this area regarding the protective factors of gloves and their ability to protect manufacturing workers from dermal exposures.

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Oil and Gas Extraction/Immune, Infectious and Dermal Disease Prevention (OGExIID)

Participating core and specialty programs: Authoritative Recommendations, Engineering Controls, Exposure Assessment, and Small Business Assistance.

Intermediate goal 3.5 (Hazardous dermal exposures):

Employers, policy-makers, trade associations, and manufacturers use NIOSH information to prevent hazardous dermal exposures among oil and gas extraction workers.

	Health Outcome	Research Focus	Worker Population*	Research Type
A	Unknown (possibly dermatitis, organ toxicity)	Hazardous dermal exposures (e.g., drilling fluid)	Drilling contractors, small businesses	Basic/etiologic Intervention

*See definitions of worker populations

Activity Goal 3.5.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better characterize dermal exposure to drilling fluids among oil and gas extraction workers.

Activity Goal 3.5.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent hazardous dermal exposures to drilling fluid among oil and gas extraction workers.

Burden

There were 540,000 workers employed in the U.S. oil and gas extraction (OGE) sector in 2015; nearly two-thirds were employed as contract workers [BLS 2016]. These estimates don't include thousands more contractors and self-employed workers from other industry sectors working at oil and gas worksites, completing tasks such as hauling equipment and water, constructing roads and new oil and gas well pads, and servicing existing ones. Oil and gas extraction workers face significant risks for a variety of acute and chronic exposures, including hydrogen sulfide, potentially lethal exposures to hydrocarbons [CDC 2016], respirable crystalline silica, acid gases, drilling muds, diesel particulate matter, naturally occurring radioactive material and lead. While field studies are ongoing, much more work remains to fully characterize dermal hazards to workers in the oil and gas extraction sector. In addition, dermal exposures to toxic chemicals used within the industry present a broadly recognized but difficult to quantify burden related to the ability of these chemicals to be dermally absorbed into the body and contribute to systemic toxicity.

Need

Few scientifically rigorous published studies exist for OGE activities. As a result, the magnitude of exposures for workers to the drilling fluids (i.e. muds), minerals, and formulation amendments used during drilling activities are unknown, demonstrating the need for systematic investigations of these exposure risks on worker safety and health. Because of the concerns of workers' exposures to these drilling compounds, some drilling contractors have implemented engineering controls such as operator control rooms, enclosures for drilling fluids and (drilling) mud pits, exhaust ventilation, automated samplers, remote handling of additives, and barriers to separate travel pathways from areas of increased exposure [Steinsvag et al. 2006; Murray et al. 2009]. To date, there are no scientifically rigorous studies that assess the extent of the use of such controls throughout the industry or the effectiveness of such interventions to control exposures during the U.S. onshore drilling process.

NIOSH has established credibility with this industry, including a track record of conducting useful, objective research, and a successful collaborative council with partners from industry, academia, and trade associations.

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Public Safety/Immune, Infectious and Dermal Disease Prevention (PSSxIID)

Participating core and specialty programs: Emergency Preparedness and Response, Personal Protective Technology

Intermediate goal 3.6 (Infectious disease transmission):

Employers, workers, professional associations, policy-makers, researchers, and consensus standard organizations use NIOSH information to prevent transmission of infectious disease among public safety workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population	Research Type
A	**Infectious disease (e.g., tuberculosis , hepatitis)**	**Adapt guidelines to prevent exposure to blood and bodily fluids**	**Corrections and law enforcement subsectors**	**Intervention**
B	Infectious disease (e.g., tuberculosis influenza)	Exposures to airborne and vector-borne infectious diseases	Corrections, law enforcement, fire service, and emergency medical service (EMS) subsectors	Basic/etiologic Surveillance research
C	**Infectious disease (e.g., tuberculosis, influenza)**	**Underutilization of personal protective equipment (PPE) to prevent infectious disease transmission**	**Corrections and law enforcement subsectors**	**Intervention Translation**
D	**Infectious disease (e.g., tuberculosis, influenza)**	**No reporting of infectious disease exposures; Industry/occupation variables not included in existing surveillance systems**	**Corrections, law enforcement, and EMS subsectors**	**Surveillance research**

Activity Goal 3.6.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between exposures to airborne and vector-borne infectious diseases among public safety workers.

Activity Goal 3.6.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent the transmission of infectious diseases among law enforcement and corrections workers.

Activity Goal 3.6.3 (Translation Research): Conduct translation research to understand barriers and aids to effective use of PPE to prevent infectious disease transmission among law enforcement and corrections workers.

Activity Goal 3.6.4 (Surveillance Research): Conduct surveillance research to develop new methods and tools to measure infectious disease exposures among public safety workers.

Burden

The public safety sector workforce includes emergency medical service (EMS), corrections, law enforcement and fire service. These public safety professionals can be exposed to airborne and vector-borne infectious diseases and blood and bodily fluid disease causing pathogens in performing their duties. These regularly include tuberculosis, human immunodeficiency virus (HIV), Hepatitis B and C, influenza, and methicillin-resistant Staphylococcus aureus (MRSA), with the additional potential to involve emerging or epidemic threats such as but not limited to Ebola.[Thomas et al. 2017; Roberts 2014; Amiry et al. 2013; Sayed et al.2011; Gershop et al. 2007; Speers 2014; IAFF 2000] EMS and fire service workers provide lifesaving, medical support and other functions in unpredictable and uncontrolled environments and under adverse conditions which can increase the risk of exposure. [Sayed 2011]. Corrections officers can be exposed to a variety of infectious agents when interacting with detainees and inmates [Bick 2007; Gershop et al. 2007]. Infectious agents vary in their routes of transmission and can occur via contact with the skin, mucous membranes such as the eyes and nose, or inhalation. Not wearing appropriate personal protective equipment (PPE) such as respiratory protection, eye/face protection, gloves and gowns can increase the risk of exposures.

Need

Public safety workers, especially law enforcement and corrections officers face volatile work situations and encounters with uncooperative individuals. The work environment often is an uncontrolled setting with the possibility of exposure to large amounts of blood and bodily fluids. Surveillance research needs to be conducted on the development and implementation of new methods and tools to gather data, measure and report the extent of infectious disease exposures among these workers. Basic research needs to be conducted to better define the exposure pathways to airborne and vector-borne diseases among public safety workers. Interventions to prevent exposures and transmissions of infectious diseases needs to be developed and studies conducted to demonstrate their effectiveness. Translational research is needed to understand the barriers to the adoption and use of PPE among law enforcement and corrections workers and to translate OSHA and NIOSH fact sheets and publications to other languages to increase their utility to the public safety workers.

Intermediate goal 3.7 (Hazardous exposures to illicit drugs):

Employers, workers, professional associations, policy-makers, researchers, and standard setting bodies use NIOSH information to prevent dermal exposure to illicit drugs among public safety workers.

	Health Outcome	Research Focus	Worker Population	Research Type
A	Fatality, systemic toxicity	Exposure to fentanyl and other illicit drugs	Law enforcement and emergency medical service (EMS) subsectors	Basic/etiologic Surveillance research
B	Fatality, systemic toxicity	How to respond to potential exposures to fentanyl and other illicit drugs	Law enforcement and EMS subsectors	Intervention

Activity Goal 3.7.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand the health effects of dermal exposures to illicit drugs among law enforcement and EMS workers.

Activity Goal 3.7.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to mitigate potential dermal exposures to illicit drugs among law enforcement and EMS workers.

Activity Goal 3.7.3 (Surveillance Research): Conduct surveillance research to develop new methods and tools to measuring dermal exposures to illicit drugs among law enforcement and EMS workers.

Burden

Between 2000 and 2014, the death rate from drug over dosage in the U.S. has more than doubled, and in 2014, 61% of drug overdose deaths involved some type of opioid, including heroin [CDC 2016]. The rate of drug overdose deaths involving synthetic opioids (e.g., fentanyl and tramadol) and non-pharmaceutical fentanyl manufactured in illegal laboratories (illicit fentanyl) nearly doubled between 2013 and 2014 [CDC 2016]. Reports from law enforcement agencies indicate that synthetic opioid overdoses may be due to illegally made fentanyl.

Fentanyl and its analogues pose a potential hazard to a variety of responders who could come into contact with these drugs in the course of their work. Possible exposure routes to fentanyl and its analogues can vary based on the source and form of the drug. Responders are most likely to encounter illicitly manufactured fentanyl and its analogues in powder, tablet, and liquid form. Potential exposure routes of greatest concern include inhalation, mucous membrane contact, ingestion, and percutaneous exposure (e.g., needlestick). Any of these exposure routes can potentially result in a variety of symptoms that can include the rapid onset of life-threatening respiratory depression. Skin contact is also a potential exposure route, but is not likely to lead to overdose unless large volumes of highly concentrated powder are encountered over an extended period of time. Brief skin contact with fentanyl or its analogues is not expected to lead to toxic effects if any visible contamination is promptly removed [NIOSH 2018].

Need

Surveillance research needs to be conducted to development new procedures, methods, and tools for gathering illicit drug exposure data for law enforcement and EMS workers. Basic research is needed to better understand the physical health effects of contacting opioids and the emotional effects including trauma, long term stress resulting from illicit drug exposures among law enforcement and EMS workers. Studies need to be completed to

assess the modes of exposure that are of greatest risk and the effectiveness of interventions to mitigate the potential exposures to illicit drugs among law enforcement and EMS workers.

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Services/Immune, Infectious and Dermal Disease Prevention (SRVxIID)

No participating core and specialty programs

Intermediate Goal 3.9 (Hazardous exposures and immune diseases):

Employers, policy-makers, trade associations, and manufacturers use NIOSH information to prevent immune and dermal diseases among services sector workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population	Research Type
A	Dermatitis	Exposures to chemicals (e.g., biocides, pesticides, solvents, acrylates)	Service workers with exposures (e.g., personal care, building maintenance, food handling and preparation, automotive)	Basic/etiologic
B	Work-related asthma	Mechanistic studies of exposures leading to allergic sensitization (e.g., high molecular weight, low molecular weight antigens, microbiological exposures)	Service workers with exposures (e.g., personal care, food handling and preparation, building maintenance, office workers, education)	Basic/etiologic
C	Hypersensitivity pneumonitis (HP)	Mechanistic laboratory-based studies of exposures to organic and inorganic substances	Service workers with exposures (e.g., building maintenance, office workers, education)	Basic/etiologic
D	**Immune suppressive disorders**	**Identification of substances and the mechanism by which they cause immune suppression**	**Service workers with exposures (e.g., personal care, food handling and preparation, building maintenance, office workers, education)**	**Basic/etiologic**

Activity Goal 3.9.1 (Basic/etiologic research): Conduct basic/etiologic research to better characterize exposures related to immune and dermal disorders among services sector workers with an emphasis on studies to better understand basic immunological mechanisms.

Burden

Services sector workers are routinely subjected to a wide array of exposures that can lead to chronic disease including immune-mediated diseases. The Personal Care Services component of the sector employs approximately 1.45 million [BLS 2017]. Many of these workers are employed in hair and nail salons and are exposed to a variety of chemicals that potentially cause a number of health effects, including allergic and irritant contact dermatitis [Lyons et al. 2013]. These skin disorders have been associated most commonly with chemical exposures from the detergents/surfactant/colors/fragrances present in shampoos, additives such as preservatives or biocides, permanent wave solutions, bleaching agents, fragrances or dyes present in other hair product formulations, acrylates used for nail art acrylic products, and nickel sulfate used in the cosmetology equipment [Hougaard et al. 2012, Krecisz et al. 2011, Landers et al. 2003, Uter et al. 1998, Warshaw et al. 2013].

There are approximately 2.5 million workers employed in building services. These individuals are exposed to pesticides and other chemicals, solvents, asbestos, lead, as well as microbial agents such as bacteria and fungi [OSHA 2017]. Allergic diseases such as dermatitis and asthma are common among workers that have cleaning related occupational tasks. Additionally, there are 1.8 million workers employed in the hotel industry. Hotel room cleaners are likewise exposed to chemicals and other sources of high molecular weight proteins that can result in allergic sensitization or the development and exacerbation of dermatitis and asthma.

Food preparation and handling can also be a source of worker exposure to high molecular weight allergens derived from a variety of botanical, animal, or seafood sources. Personal exposure to high molecular weight allergens during preparative stages can result in allergic sensitization and occupational asthma. Although broadly characterized in European studies, these scenarios are an emerging issue within the United States especially due to the rapid growth of the food preparation and meal delivery industries [Bauer et al. 2017, Cartier 2010, Desjardins et al. 1995, Lopata and Jeebhay 2013, Zuskin et al. 1992, Green et al. 2011].

Moisture damage within the built environment continues to be a public health burden in the United States and has resulted in community and worker concern regarding personal exposures to microorganisms including fungi and fungal associated byproducts. Dampness and fungal contamination are commonly identified within US schools [Sahakian 2008, GAO 1990]; however little is known about the effects of reduced indoor air quality on teachers' health. Recent studies have identified that the teachers work environment can be the source of a range of adverse respiratory health effects including self-reported sinus problems, headache, allergies/nasal congestion, and throat irritation.

Workers in repair and maintenance (such as automotive technicians) and personal services (such as hair dressers and nail technicians) are also exposed to an array of industrial chemicals including heavy metals contained in break fluids, degreasers, detergents, lubricants, metal cleaners, paints, fuel, solvents, etc. [International Labour Organization 2000]. In these fields, there is an increased prevalence of potential skin hazards of 52.4% and 51.5%, respectively, compared to 20.5% in all industries [NIOSH 2010].

Need

Hazards for Services workers include pesticides, cleaning compounds, microbial agents, high molecular weight allergens and other secondary metabolites, solvents, and degreasing agents. Studies evaluating the immunological hazards from exposure to many of these agents are needed. Indoor dust including bacteria and fungi as well as high molecular weight allergens (dust mite and pets) and chemical irritants have been associated with many symptoms but there continues to be a lack of understanding of the immunological mechanisms and the diversity of microorganisms and other chemical exposures that contribute to these health effects [Kielb et al. 2015]. Considering that the service sector employs over 70 million workers, research on work-related immune diseases is needed.

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Strategic Goal 4: Reduce occupational musculoskeletal disorders (MSDs)

Agriculture, Forestry and Fishing/Musculoskeletal Health (AFFxMUS)

Participating core and specialty programs: Center for Occupational Robotics Research, Center for Maritime Safety and Health Studies

Intermediate goal 4.1 (Exposure to vibration and repetitive motion):

Researchers, safety and health professionals, professional associations, foundations and employers use NIOSH information to prevent musculoskeletal disorders among agriculture, forestry and fishing workers, especially considering the aging workforce.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population	Research Type
A	Musculoskeletal disorders (MSDs)	Whole body vibration (e.g., sit on/ride in old equipment)	Agriculture subsector; aging workers and other vulnerable workers	Basic/etiologic
B	Back and upper extremity MSDs	Repetitive motion (e.g., bending over, long working hours, robotics)	Dairy workers; aging workers and other vulnerable workers	Intervention
C	MSDs	Manual harvesting	Agriculture subsector; aging workers and other vulnerable workers	Intervention
D	MSDs	Whole body vibration (e.g., mechanized harvesters)	Forestry subsector	Basic/etiologic
E	Hand and upper body MSDs	Hand and upper extremity vibration (e.g., work at tree stump, chainsaws use)	Forestry subsector	Intervention
F	Upper body MSDs	Repetitive motion	Commercial fishing workers	Basic/etiologic Intervention
G	**MSDs**	**Lifting (e.g., product)**	**Seafood processing workers**	**Intervention Translation**

Activity Goal 4.1.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between exposures to vibration and repetitive motion and musculoskeletal disorders among agriculture, forestry and fishing workers.

Activity Goal 4.1.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions and public health practice efforts to prevent musculoskeletal disorders among agriculture, forestry and fishing workers.

Burden

Work-related musculoskeletal disorders (MSDs) have been described as one of the foremost adverse work-related health conditions among farm workers [Taghavi et al. 2017]. Several studies have shown increased risk of developing MSDs among agricultural workers compared to other occupational groups [Holmberg et al. 2002; Maetzel et al. 1997; Manninen 1996; Morse et al. 2007; Stiernström et al. 1998]. Annual prevalence of

musculoskeletal symptoms has been estimated between 40% and 73% among U.S. agricultural workers [Alterman et al. 2008; Gomez et al. 2003; Rosecrance et al. 2006; Villarejo and McCurdy 2008]. Significant associations were observed between performing equipment repair and maintenance and low back pain; milking animals and neck/shoulder pain; and manual material handling and elbow/wrist/hand pain, among others [Fethke et al. 2015].

MSDs are common among workers in the fishing sub-sector as well [Bloswick and Dzugan 2014]. In a study conducted among commercial fishermen along the coast of North Carolina, 84% reported musculoskeletal symptoms for any region of the body in the previous 12 months. Of the U.S. fishermen that reported symptoms, 39% indicated that those symptoms were at a level sufficient to limit their work activity in the last year [Lipscomb et al. 2004]. In a recent study among lobstermen of the Northeast U.S., one half of the respondents reported low back pain [Fulmer et al. 2017].

There is limited information on the prevalence of MSDs among forestry workers in the U.S. Much of the research in this area has been conducted in Scandinavia and Europe. In a study among loggers in Poland, the prevalence of any self-reported MSD symptoms during the last twelve months was 94%. The highest occurrence of symptoms was for lower back (66%), hands/wrists (50%) and upper back (46%) [Grzywiński et al. 2016]. Additionally, a study among logging machine operators in the Southern U.S., 10.5% reported a MSD diagnosis, 74.3% reported at least mild back pain, and 71.7% reported at least mild neck pain over the past year [Lynch et al. 2014].

Need

Given that little is known about the background and cause of MSDs among agriculture, commercial fishing, and forestry workers in the U.S., future research efforts should further characterize hazards in all three of these extremely labor-intensive sub-sectors. Effective methods for addressing MSD risk factors include reducing the weight of the load lifted through engineering or administrative controls and using ergonomic guidelines to design work stations and work tasks. Studies have shown that the incidence of work-related MSDs can be decreased when workers reduce task repetition and adopt a less extreme working posture. Furthermore, these modifications may improve symptoms in already affected dairy workers, manual harvesting workers, and fisherman [NIOSH 1997]. Future research is needed to address reducing biomechanical risk factors (whole body vibration, static postures, repetitive movements, spine stability, and work duration) in forestry workers, and taking into consideration possible interactions between these risk factors [Jack and Oliver 2008]. To address MSD issues in agricultural workers, researchers could develop and target interventions to highly diverse farmer and farm worker populations, and better identify risk factors for vulnerable occupational groups [Davis and Kotowski 2007]. The effectiveness of interventions in dynamic workplace environments should also be assessed, particularly to ensure they fit within the business model of industries [Douphrate et al. 2013].

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Construction/Musculoskeletal Health (CONxMUS)

Participating core and specialty programs: Center for Workers' Compensation Studies, Center for Direct Reading and Sensor Technologies, Center for Occupational Robotics Research, Occupational Health Equity, and Small Business Assistance.

Intermediate goal 4.2 (MSD interventions :

Professional organizations, insurers, workers' compensation providers, government agencies, and trade unions use NIOSH information to reduce musculoskeletal disorders among construction workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	**Musculoskeletal disorders (MSDs) (esp. Back injuries, strains and sprains)**	**Underuse of existing interventions**	**Masonry, concrete, dry wall, roofing, and plumbing workers; laborers; small businesses; vulnerable workers**	**Translation**
B	Musculoskeletal disorders (MSDs) (esp. Back injuries, strains and sprains)	Emerging technology (e.g., automation, robotics, drones)	Communication tower, wind energy, masonry and concrete workers; laborers	Basic/etiologic Intervention
C	Musculoskeletal disorders (MSDs) (esp. Back injuries, strains and sprains)	Use of exoskeletons	Masonry, concrete, dry wall, roofing, and plumbing workers; laborers; small businesses; vulnerable workers	Intervention
D	Musculoskeletal disorders (MSDs) (esp. Back injuries, strains and sprains)	Prescription drug (incl. opioids), illicit drug, and substance use/misuse	Masonry, concrete, dry wall, roofing, and plumbing workers; laborers; small businesses; vulnerable workers	Intervention Surveillance research

*See definitions of worker populations

Activity Goal 4.2.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand the benefits and risks of emerging technologies (e.g., automation, robotics, drones) regarding musculoskeletal disorders among construction workers.

Activity Goal 4.2.2 (Intervention Research): Conduct studies to develop, enhance, and assess the effectiveness of interventions to prevent musculoskeletal disorders and use of opioids, illicit drugs, and other substances among construction workers.

Activity Goal 4.2.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective musculoskeletal injury interventions among construction workers.

Activity Goal 4.2.4 (Surveillance Research):Conduct surveillance research to develop new approaches to collecting data on use of opioids, illicit drugs, and other substances and assessing associations with musculoskeletal injuries among construction workers.

Burden

Musculoskeletal disorders (MSDs) are common among construction workers due to the nature of the work, which is physically demanding [Schneider et al. 1998]. In 2014, "sprains and strains" represented 27.3% of all construction injuries and illnesses [BLS 2016a,b] while another 17.3% of injuries and illnesses were from "soreness, pain," related to MSDs. Lifetime risk of "overexertion" injuries in construction is about 21%, so more than 1 in 5 construction workers might be expected to get an overexertion injury during their career [Dong, et al. 2014]. Some of the trades that have elevated rates of overexertion injuries include masonry, concrete, drywall, plumbing, and flooring among others [CPWR 2013]. Back injuries are another concern among construction workers. In 2010, the rate of back injuries among construction workers was 24.5 per 10,000 FTEs compared to 21.4 for all industries combined [CPWR 2013]. Construction trades with the highest rates of back injuries include masonry, roofing, drywall, plumbing, and glass and glazing. Many vulnerable workers have an elevated or disproportionate risk including Hispanic workers, foreign-born workers, workers in small businesses, workers, younger (teenage) workers and older (55 and over) workers [CPWR 2013]. These injuries have created a tremendous burden on workers, their families, companies and the health care system [OSHA, 2015].

The construction workforce is aging with a median age in 2015 of 42.7 years [BLS 2016c]. When older workers are injured, their injuries are more severe injuries and their compensation costs are higher [Dong et al. 2012]. MSDs not only cause days away from work, they also can shorten careers and impact retirement [Welch et al. 2010; LeMasters et al. 2006]. Many construction workers retire in their mid-50s due to MSDs.

MSDs are also a main contributor to the pain epidemic [Carnide et al. 2011], which has resulted in the overuse and misuse of prescription and illicit drugs including opioids, heroin, and fentanyl [DHHS 2016]. A recent analysis of workers' compensation data from 27 states found that workers in mining and construction industries were more likely than workers in other industries to receive opioids for pain [Thumula and Liu, 2018]. Drug overdose deaths, including those associated with opioids, have significantly increased in recent years and have disproportionally impacted construction workers [Hawkins et. Al., 2019; Tiesman et.al, 2019; Harduar Morano et. Al., 2018]. In Ohio, construction workers were seven times more likely than other workers to die from an opioid overdose (2010-2016) [CPWR 2018] In one study, over half of those who died from an overdose had suffered at least one job related injury [Cheng et al. 2013].

Need

Prevention of work-related MSDs has been a major focus of NIOSH research for many years, especially ergonomic interventions [NIOSH 2007, CPWR 2013]. Ergonomic interventions often pay for themselves by improving productivity as well as reducing injuries [Hendricks, 1996]. MSDs are a primary cause of occupational injuries and represent the largest portion of workers compensation costs. However, construction contractors may not understand the return on investment or improvements to productivity that often comes from making ergonomics changes. Surveillance and intervention research is needed to attain a better understanding of the connection between MSD injuries and opioids, illicit drugs, and substance use/misuse and the factors that influence it. There is also a need to develop and evaluate effective educational, administrative, and policy interventions to better protect construction workers from this epidemic.

Research is also needed to effectively develop, enhance, and transfer knowledge and interventions into new or improved construction equipment and practices. This includes developing and communicating evidence-based ergonomic prevention and protective measures and graphics-based guidelines. Additional efforts are needed to transfer findings from this research into influential documents such as guidance and voluntary consensus standards. There is also a need to translate research findings into software products, applications and interactive webpages to make information easily accessible for construction stakeholders.

With changes and advances in technology, novel approaches to risk reduction are being developed. For example, robotics, automation, and exoskeletons (or human augmentation devices) can be used to improve safety and productivity, and reduce MSD risk factors that can cause back injuries, strains, and sprains. These devices are rapidly appearing in the workplace despite limited research on their effectiveness in reducing MSDs. When new technologies enter the workplace, their impact needs to be studied. Research is needed to identify and document the costs and benefits of the intervention (including any productivity gain). For exoskeletons in particular, research should aim to include a broad range of body shapes and sizes that reflect the diversity of the Construction workforce (i.e. men and women; height and weight; race and ethnicity). Research needs to consider the range of potential interventions for a particular issue including engineering and administrative controls and their relative advantages. Translation research is also needed to identify and understand the aids and barriers to adoption and to promote effective solutions to construction decision makers. In many cases this data does not exist and needs to be collected. These new technologies have the potential to dramatically reduce the frequency and severity of MSDs in the workplace while also improving productivity. Regardless of the work system, interventions that are broadly used must be effective at reducing risk and make a strong business case for adoption.

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Healthcare and Social Assistance/Musculoskeletal Health (HSAxMUS)

Participating core and specialty programs: Center for Occupational Robotics Research, National Center for Productive Aging and Work, Occupational Health Equity, Safe Skilled Ready Workforce, Surveillance

Intermediate goal 4.8 (MSD interventions):

Employers, workers, professional organizations, researchers, and policy-makers use NIOSH information to reduce musculoskeletal disorders among healthcare and social assistance workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	Musculoskeletal disorders(MSDs)	Burden of hazardous exposures, ergonomic impacts and MSDs (with or without impairment)	All healthcare workers including veterinary and animal care (VM/AC) workers; vulnerable workers and hard to reach populations	Surveillance
B	**Musculoskeletal disorders (MSDs)**	**Identify and address barriers to implementation and dissemination of effective interventions and to identify key components of sustainability.**	**All healthcare workers including veterinary and animal care (VM/AC) workers**	**Translation**
C	**Musculoskeletal disorders (MSDs)**	**Evaluate the effectiveness of safe patient handling policies and regulations**	**All healthcare workers**	**Intervention**
D	Musculoskeletal disorders (MSDs)	Develop and evaluate interventions for vulnerable populations	Vulnerable workers	Intervention
E	**Musculoskeletal disorders (MSDs)**	**Evaluation of exoskeletons or other innovative approaches to reduce risk of MSDs during patient handling or performing healthcare procedures**	**All healthcare workers including veterinary and animal care (VM/AC) workers; vulnerable workers and previously injured workers**	**Intervention**

*See definitions of worker populations

Activity Goal 4.8.1 (Intervention research)**:** Conduct studies to evaluate the effectiveness (usefulness and unexpected results) of innovative approaches to reduce risk for MSDs and to reduce the return-to-work time among healthcare and social assistance workers with MSDs.

Activity Goal 4.8.2 (Translation Research): Conduct translation research to identify and address barriers to dissemination and implementation of effective interventions to prevent MSDs,identify key components of intervention sustainability, and disseminate best practices to prevent MSDs in healthcare and social assistance workplaces.

Activity Goal 4.8.3 (Surveillance Research): Conduct surveillance research to develop new approaches to understanding the burden of hazardous exposures, ergonomic impacts and chronic MSDs among healthcare and social assistance workers not well covered by currently-available surveillance data sources.

Burden

Working directly with patients, animal or human, poses substantial risk for injury. Physical stressors can result in a variety of musculoskeletal disorders (MSDs) [OSHA 2015]. Healthcare workers are at high risk of MSDs caused by overexertion from lifting and moving patients, i.e., patient handling. Among workers in nursing and residential care subsector, 68.5% report repeated lifting, pushing, pulling, or bending; 16% report frequent, severe, low back pain in the past 3 months; and 11.6% report low back pain attributed to work [NIOSH 2015]. A

survey conducted in Minnesota indicates that 31% and 45% of veterinary personnel reported musculoskeletal disorders working with small animals and large animals, respectively. This rose to 57% among veterinarians working with large animals [Fowler et al. 2016].

Patient movement and handling is not the only risk factor for MSDs among healthcare and social assistance workers. MSDs are also frequently found among gastrointestinal endoscopists, surgeons, dentists and other healthcare personnel who perform procedures in awkward or ergonomically compromised positions [Moodley et al. 2018, Stucky et al. 2018, Yung et al. 2017].

Need

Safe Patient Handling and Mobility [SPHM] interventions involving the use of ergonomic equipment and methods to lift and move patients have been demonstrated to result in statistically significant reduction in injuries [Teeple et al. 2017] and produce savings from injury cost reductions that surpass program costs within three years on average [Nelson et al., 2006]. Additionally, 11 states have implemented legislation regarding SPHM practices [ANA 2016, Weinmeyer 2016).] Nevertheless, comprehensive SPHM programs and interventions are not implemented in many U.S. healthcare settings [Lee et al. 2015]. These programs require support and implementation throughout the healthcare organization. While SPHM interventions at the worker-level are important, interventions that occur at the organization level or take a systems-based approach are much more likely to be sustainable over the long term [The Joint Commission 2012].

In addition, much of the work regarding MSDs has been done in acute healthcare settings. MSD risk factors are also prevalent in many other subsectors of the healthcare and social assistance workforce (e.g., home health care); however, these risks have not been fully characterized and assessed. MSDs among workers in the healthcare and social assistance workforce are often not acute injuries but often the result of continuous injury and damage that has occurred over a long period of time [Zwerdling 2015]. Injuries among healthcare personnel who perform repetitive procedures or perform procedures in ergonomically compromised positions are especially at risk for MSDs, yet a recent systematic review of musculoskeletal pain among surgeons performing minimally invasive surgery noted the limitations of current literature and the need for high quality exposure and intervention studies [Dalager et al. 2017]. Emerging engineering controls such as exoskeletons have been shown to reduce musculoskeletal stress during manual labor [deLooze, et al. 2015], but may have unanticipated consequences. Among painters and welders, exoskeletons have been found to reduce shoulder discomfort while increasing productivity and work quality [Butler 2016]. There is a need to explore the risks and benefits of these and other innovative preventive interventions in healthcare settings to reduce MSD hazards and to disseminate best practices for these innovative approaches if they are found to be effective.

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Manufacturing/Musculoskeletal Health (MNFxMUS)

Participating core and specialty programs: Center for Maritime Safety and Health Studies, Center for Occupational Robotics Research, and National Center for Productive Aging and Work.

Intermediate goal 4.3 (MSDs and emerging technologies [e.g., robots, exoskeletons]):

Employers, workers, researchers, insurance companies, and technology manufacturers use NIOSH information to utilize emerging technologies to reduce musculoskeletal disorders among manufacturing workers.

	Health Outcome	Research Focus	Worker Population*	Research Type
A	Low back, upper extremity musculoskeletal disorders (MSDs)	Increased use of robotics	Where robotics are used (esp. in food, wood product, foundries, and transportation equipment manufacturing), workers with non-standard work arrangements and other vulnerable workers	Basic/etiologic Intervention
B	Low back, upper extremity MSDs	Increased use of exoskeletons	Workers who do manual material handling tasks (esp. in food, wood product, foundries, and transportation equipment manufacturing), workers with non-standard work arrangements and other vulnerable workers	Intervention
C	Low back, upper extremity MSDs	Using sensors or sensor-less technologies to measure risk factors for MSDs	Workers who do forceful physical activities using torso or upper body (esp. in food, wood product, foundries, and transportation equipment manufacturing), workers with non-standard work arrangements, and other vulnerable workers	Basic/etiologic Intervention

*See definitions of worker populations

Activity Goal 4.3.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better measure risk factors for musculoskeletal disorders, as well as understand how emerging technologies might help prevent and/or increase risk of musculoskeletal disorders in the manufacturing sector.

Activity Goal 4.3.2 (Intervention Research): Conduct intervention studies to develop and assess the effectiveness of interventions to prevent musculoskeletal disorders among manufacturing workers.

Burden

Mechanization and automation has changed the nature of the work demands in the manufacturing industry and introduced new tasks to the shop floor that never existed previously. Interventions that may have addressed an issue several years ago may no longer be pertinent to how work is performed now. The incidence rate for musculoskeletal injuries resulting in days-away-from-work for the manufacturing sector was 33.4 per 10,000 equivalent full-time workers compared to an incidence rate of 29.8 for all private establishments in 2015 [BLS 2016]. This translates to approximately 41,000 severe musculoskeletal injuries in Manufacturing. Manual material handling tasks, while not entirely eliminated, have changed dramatically in the last 25 years. Work-

related musculoskeletal disorders (MSDs) or overexertion surveillance data from BLS [2016], Ohio Bureau of Workers' Compensation [Meyers et al. 2017], and Washington State Department of Labor and Industries [2017] offer evidence that the food, wood product, foundries, and transportation equipment manufacturing subsectors have the greatest burden. However, currently the available data for prioritizing industry burden by body region (e.g., low back, upper extremities) is limited. Rapid advances in robotics and other emerging manufacturing technologies are likely to present new risks or exacerbate existing risks due to lack of experience with robots in varied work settings, potential unforeseen hazards, and unanticipated consequences in the manufacturing industry.

Need

Overall, there is a need to coordinate current ergonomic guidelines, guidelines and tools to address the challenges found in current work environments and demands. Research efforts are especially needed to identify risk factors and prevent MSDs among worker populations who utilize or interact with machinery for material handling (e.g., conveyors) or processing (e.g., metal or woodworking machines), emerging industrial machines (e.g., robots, collaborative robots) and vulnerable workers or those with non-standard work arrangements. In particular there is a need to identify scenarios in which the use of robots and other emerging technologies can contribute to MSDs. Research must still be accomplished to identify the costs, benefits and effectiveness of the proposed interventions (including any productivity gains that can be documented). Research is needed to identify the range of potential interventions for a particular issue including both engineering and administrative controls and their relative advantages. The adoption and dissemination of effective interventions has the potential to dramatically reduce the frequency and severity of MSDs in the workplace.

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Mining/Musculoskeletal Health (MINxMUS)

No participating core and specialty programs

Intermediate goal 4.4 (MSD risk factors):

Industry, academia, and other government agencies adopt workplace solutions and recommended practices to reduce musculoskeletal disorders (MSDs) among mining workers

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker population	Research Type
A	**Musculoskeletal disorders**	**Improved identification and remediation of musculoskeletal disorder risk factors at mining facilities.**	**Metal/non-metal; stone, sand and gravel**	**Intervention Translation**
B	Musculoskeletal disorders	Develop and evaluate methods to monitor worker exposures to MSD risk factors.	Metal/non-metal; coal; stone, sand and gravel	Basic/etiologic
C	Musculoskeletal disorders	Conduct targeted research to ascertain biomechanical risks associated with high-risk mining tasks.	Metal/non-metal; coal; stone, sand and gravel	Basic/etiologic
D	Musculoskeletal disorders	Prescription drug (incl. opioids), illicit drug, and substance use/misuse	Metal/non-metal; coal; stone, sand and gravel	Surveillance research Intervention

Activity Goal 4.4.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand the relationship between exposures and musculoskeletal disorders among mining workers.

Activity Goal 4.4.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to reduce musculoskeletal disorders among mining workers.

Activity Goal 4.4.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective interventions to reduce the musculoskeletal disorders risk factors associated with common mining activities.

Activity Goal 4.4.4 (Surveillance Research): Conduct surveillance research to develop new approaches to collecting data on use of opioids, illicit drugs, and other substances and assessing associations with musculoskeletal injuries among mining workers.

Burden

Nearly a third (29%) of all nonfatal occupational injuries and illnesses reported to the Mine Safety and Health Administration in a recent 5-year span were MSDs [Weston et al., 2016]. The median number of days lost (sum of days lost from work and number of days with restricted work activity) was 21 for all reported MSD cases. Older workers, and those with more mining experience, showed more days lost from work as compared to their younger, or less experienced, counterparts who showed a higher frequency of injury. Further, having a past MSD places a worker at a higher risk for developing a future injury, and re-injury rates can be especially high in some jobs, leading to the loss of a worker from his or her specific occupation. In an analysis of annual costs, musculoskeletal disorders had a direct cost (medical costs plus indemnity) of $1.5 billion. The indirect costs (lost wages, fringe benefit losses, home production losses, and training, hiring, and disruption costs) amounted to an additional $1.1 billion [Bhattacharya, 2014]. In addition to financial costs to employers, MSDs affect the quality of life of workers; limiting their physical capabilities, vitality, and even negatively impacting their mental health.

Prescription opioids may be both a personal risk factor for work-related injury and a consequence of workplace exposures [Kowalski-McGraw et al., 2017]. A recent analysis of workers' compensation claims from 27 states reported that workers employed in mining and construction industries were more likely that workers in other industries to receive opioids for pain [Thumula and Liu 2018]. In a study of workplace opioid overdose deaths between 2011 and 2016, the fatality rate in the mining industry (2.6 per 1,000,000 FTEs) was second only to transportation and warehousing [Tiesman et al 2019].

Need

Intervention and Translational research is needed to ensure mine workers are equipped with the requisite knowledge to identify and appropriately remediate MSD risk factors. Although MSDs are one of the biggest contributors to incidents and lost days in mining, most mines do not have trained ergonomists or even safety professionals with ergonomics training. For this reason, it is important to develop tools and prevention approaches that can be used by persons with a range of backgrounds. Understanding the needs of the mining industry with respect to the types of tools or techniques that will be most effective for identifying and mitigating musculoskeletal disorder risk is critical to ensuring that research findings are appropriately transferred to practice. *Basic/etiologic* research is needed to develop and evaluate direct-reading equipment to provide detailed exposure information while workers perform their actual work tasks. Mining presents various challenges to direct measurement, including adverse environmental conditions, the need for rugged instrumentation, and permissibility limitations for underground use. Advancing our ability to directly measure exposure will provide a more accurate representation of mine worker exposures and provide mining companies with better metrics for injury risks. *Basic/etiologic* research is also needed to more quantitatively and comprehensively describe the biomechanics of high-risk mining tasks. Such studies will allow us to better understand the frequency, duration, and magnitude of these exposures. The exposure data can also be used to help identify jobs, tools, or tasks for intervention by focusing research on the specific issues posing highest risk. *Surveillance* research is needed to attain a more nuanced understanding of the connection between MSD injuries and prescription drug (incl. opioids), illicit drug, and substance use/misuse, as well as effective intervention strategies.

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Services/Musculoskeletal Health (SRVxMUS)

Participating core and specialty programs: Center for Direct Reading and Sensor Technologies, National Center for Productive Aging and Work, Occupational Health Equity, Safe•Skilled•Ready Workforce, Small Business Assistance, and Surveillance.

Intermediate goal 4.5 (Risk factors for back injuries):

Employers, workers, insurance companies, labor unions, and non-governmental organizations adopt interventions to reduce back injuries among services workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	**Musculoskeletal disorders (esp. back injuries)**	**Risk factors like manual labor, awkward posture, lifting, age**	**Building and dwelling, temporary employment services, auto repair and maintenance, lessors of real state, waste collectors, travel accommodations subsectors; vulnerable workers; small businesses**	**Intervention Translation**

*See definitions of worker populations

Activity Goal 4.5.1 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent musculoskeletal disorders in the services sector.

Activity Goal 4.5.2 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective interventions to prevent musculoskeletal disorders in the services sector.

Burden

Many services sector workers are required to complete repetitive tasks and often exert considerable force in sometimes awkward postures, which have been associated with musculoskeletal disorders (MSDs). The incidence rate for musculoskeletal injuries resulting in days-away-from-work for the services sector is 28.9 per 10,000 equivalent full-time workers compared to an incidence rate of 29.8 for all private establishments [BLS 2015]. Data from both the Ohio Bureau of Worker's Compensation and BLS indicated that building maintenance and repair, janitorial, cleaning, garbage collection, automotive repair workers, and hotels all have elevated rates of MSDs. [BLS 2015; Meyers et al 2017].

Smaller businesses, such as many found in services subsectors, are recognized as having fewer human and capital resources available to devote to the prevention of workplace illnesses, injuries, and fatalities. Managers in smaller businesses often work in isolation without sufficient access to peer opinion and industry best practices. These factors not only reduce prevention activities, but may also reduce the reporting of illnesses and injuries to government agencies, insurance companies, and other organizations.

Many of services industries employ workers that are vulnerable due to age, ethnic background, language, gender, education level or lack of long-term job stability. These workers may not report injuries or suggest job aids because of their vulnerabilities. They may be more likely to be required to do some of the most physically challenging jobs which could lead to back injuries.

Need

In the services sector, 89% of the 3 million firms have less than 20 employees, and these small businesses typically have limited access to health and safety specialists [U.S. Census Bureau 2011]. Therefore, these small businesses do not provide the same outreach, interventions, and proactive committees to reduce these exposures as, for example, manufacturing environments. Interventions that are targeted to specific populations within the services sector are needed to reduce the prevalence of MSDs in these subsectors. Intermediary organizations may be used for outreach and could include trade associations, worker groups, insurance companies, chambers of commerce, small business development centers, professional organizations, small-business-focused media, and public health and other government agencies. Some interventions for reducing back injuries are well known and utilized in other industries that could be adopted by Service sector industries. Intervention effectiveness studies using traditional and sensor related methods are needed. Translation work is needed to inform Service sector industries of these interventions and show how they could be adopted by these industries.

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Wholesale and Retail Trade/Musculoskeletal Health (WRTxMUS)

Participating core and specialty programs: Center for Occupational Robotics Research, Center for Workers' Compensation Studies, Exposure Assessment, National Center for Productive Aging and Work, Prevention through Design, Safe•Skilled•Ready Workforce, Small Business Assistance, and Surveillance.

Intermediate goal 4.6 (MSDs among older workers):

Employers, insurers, trade associations, healthcare providers, equipment manufacturers, and safety and health professionals use NIOSH information to prevent musculoskeletal disorders among older workers in wholesale and retail trade.

	Health Outcome	Research Focus	Worker Population*	Research Type
A	Musculoskeletal disorders	Aging workforce (e.g., physical capacity, return to work, economics)	Furniture workers, appliance stores, gardening, food and beverage	Surveillance research Translation

	Health Outcome	Research Focus	Worker Population*	Research Type
			subsectors; small businesses; vulnerable workers	

*See definitions of worker populations

Activity Goal 4.6.1 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective interventions for musculoskeletal disorders among aging workers in wholesale and retail trade.

Activity Goal 4.6.2 (Surveillance Research): Develop/enhance surveillance methods to better monitor trends in risk factors for musculoskeletal disorders and for preclinical musculoskeletal pain symptoms among aging wholesale and retail trade workers.

Burden

Injuries from overexertion continue to account for the majority of musculoskeletal disorders (MSDs) (36%) in the wholesale and retail trade sector [Bhattacharya 2017]. These injuries are typically associated with manual materials handling which involves lifting, bending, pushing, and carrying goods that often exceed the physical capacities of wholesale and retail workers. Although older workers are well trained and have learned how to avoid injuries, when they are injured their recovery times are typically longer and they are often subjected to restricted work routines that affects their salaries in many cases. According to BLS [2015], the average non-fatal injury rate for MSDs in both wholesale and retail have both declined over the past decade. The injury rate was 36.5 per 10,000 full-time workers in 2014 compared with 39.9 in 2004 in wholesale. For retail, the injury rate was 35.3 per 10,000 full-time workers in 2014, down from 43.9% in 2004. While the reductions are encouraging, there is still work to be done. The injury rates in WRT are still higher than the average for all industries (31.9 per 10,000 full-time workers in 2014). The retail sub-sectors with the highest rates of injury include building materials and gardening stores; general merchandise (department) stores; food and beverage stores; and furniture and home furnishing stores. In wholesale trade, merchants of nondurable goods have the highest MSD rates. MSD injuries are also costly, averaging $9,743 per case in 2014 [Bhattacharya 2014]. Using the BLS estimate of approximately 63,000 reported cases in (2014) of MSDs, the total cost would be $596 million. MSDs have a large economic impact on society that includes the cost of treatment and the related indirect costs of productivity losses. Workers, their families, employers, and tax payers share this burden.

Need

NIOSH is uniquely positioned to make a difference for the health and safety of workers in wholesale and retail trade due to the partnerships it has developed. NIOSH is the leading U.S. federal entity investigating the causes of MSDs and back injury, the primary reason for injury-related days away from work. Surveillance data are needed to provide information on the effectiveness of return-to-work (RTW) programs, especially for aging workers. While there are numerous RTW programs providing different strategies for returning workers to their jobs following a workplace injury, effective surveillance systems are needed to assess each of the different return-to-work programs. Second, the surveillance data needs to be analyzed to identify and prioritize the criterion used to determine if an injured employee is fit to return-to-work without increasing the risk for a subsequent injury. Third, characteristics of injured workers that influence the success of a RTW program need to be identified. Consideration of psychosocial risk factors in addition to physical risk factors for MSDs and the implementation of effective interventions to mitigate these factors is instrumental to the success of a RTW

program. Understanding why effective interventions are not widely used to prevent MSDs in the first place is an area in need of translational research.

Intermediate goal 4.7 (MSDs and emerging technologies [e.g, robots, exoskeletons]):

Employers, insurers, researchers, safety and health professionals, and equipment manufacturers use NIOSH information to implement cost-effective and risk mitigating interventions for MSDs in the wholesale and retail trade sector.

	Health Outcome	Research Focus	Worker Population*	Research Type
A	Musculoskeletal disorders (MSDs)	Emerging technologies (E.g., robotics/exoskeleton, economics, wearable sensing technology)	Non-store retailers, non-standard workers, small businesses, vulnerable workers	Basic/etiologic Intervention

*See definitions of worker populations

Activity Goal 4.7.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between emerging technologies and musculoskeletal disorders among wholesale and retail trade workers.

Activity Goal 4.7.2 (Intervention Research): Conduct intervention studies to develop and assess the effectiveness of interventions to utilize emerging technologies to reduce musculoskeletal disorders among wholesale and retail trade workers.

Burden

The wholesale and retail trade (WRT) sector is the second largest of the ten industry sectors comprising the National Occupational Research Agenda (NORA). Because of its size and range of establishments, WRT continues to burden the economy with an annual average (2004–2015) of 683,300 injuries/illnesses. About 30% of the reported injuries/illnesses were severe enough that those employees experienced combinations of lost work-time and restricted work, affecting their overall health and well-being [Bhattarcharya, 2017]. Robots, exoskeletons, and wearable sensor technologies present new challenges to employers and safety practitioners who must assess the role of new technology in injury/illness cases. Although there is little data available about the role of emerging technologies in WRT workplaces, it is clear that there are hundreds of injuries in labor intensive jobs such as manual material handling that are attributed to emerging technologies. As an example, robots are being used in fulfillment centers, a WRT sector growth area, and exoskeletons are being tested in building materials and gardening stores. The introduction of robotics and automation in general are considered as labor saving devices that will reduce the number of overexertion injuries or musculoskeletal disorders (MSDs) in the workplace. Unfortunately, there have been few studies conducted to test this hypothesis. This push to add more sophisticated robotic devices (exoskeletons and electromechanical devices) in the workplace has created situations where human operators and robots work side-by-side (i.e. cobots, working posture controller, the body extender, full-body, hybrid production systems) [Antonelli and Bruno 2017; Nguyen et al. 2017; de Looze et al 2016; Fontana et al 2014].

Need

Novel man-machine interactions bring into the workplace a unique set of potential health hazards: some dangerous tasks disappear, but new ones are generated. Many of the root causes (etiological causes) of the risks

inherent in hybrid production systems have not been clearly defined nor have the economic benefits achieved through the use of these systems been fully identified. Research is needed to study the causes of accident involving automation and workers who operate in adjacent work spaces. More information is also needed about the workers' responses to the presence of this technology. Workers that have physical limitations or speak another language (vulnerable populations) are likely to be at a greater risk in working adjacent to these automated or computerized systems. At present, there is not enough empirical evidence on the nature and causes of mishaps occurring in automated operations to effectively guide injury-prevention and loss control activities. In addition, research is needed to assess the effectiveness of automated systems or robots/exoskeletons as interventions designed to reduce the physical demands of jobs; and, thus MSDs. More extensive research is needed about the effectiveness of these robotic interventions in reducing musculoskeletal disorders, but at the same time, research must take into consideration the potential safety-related injuries due to the presence of these automated/robotic systems in the workplace.

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Strategic Goal 5: Reduce occupational respiratory disease

Agriculture, Forestry and Fishing/Respiratory Health (AFFxRHP)

Participating core and specialty programs: Authoritative Recommendations, Center for Maritime Safety and Health Studies, Occupational Health Equity, Surveillance, and Translation Research.

Intermediate goal 5.1 (Fixed airways diseases):

Researchers, safety and health professionals, professional associations, foundations, and employers will use NIOSH information to prevent fixed airways diseases among agriculture and forestry workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population	Research Type
A	Chronic obstructive pulmonary disease (COPD), Obliterative bronchiolitis (OB), Other diseases affecting airways such as hypersensitivity pneumonitis (HP)	Exposure to mineral and organic dusts (esp. animal feed), and related gases and fumes	Agriculture subsector (esp. concentrated animal feeding operations [CAFOs])	Basic/etiologic
B	**COPD, OB, Other diseases affecting airways such as HP**	**Engineering controls and PPE for organic dusts and related gases and fumes**	**Agriculture subsector(esp. CAFOs)**	**Intervention Translation**
C	COPD, OB, Other diseases affecting airways such as HP	Exposures to pesticides, herbicides, fertilizers and other chemicals	Agriculture subsector(esp. CAFOs)	Basic/etiologic
D	**COPD, OB, Other diseases affecting airways such as HP**	**Engineering controls and PPE for pesticides, herbicides, fertilizers, and chemicals (used in new areas as vectors move north)**	**Agriculture subsector (esp. CAFOs)**	**Translation**
E	COPD, OB, Other diseases affecting airways such as HP	Understanding risk factors for exposures and respiratory outcomes	Agriculture (including aquaculture) and forestry subsectors	Surveillance research

Activity Goal 5.1.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between exposures to dusts and chemicals, and fixed airways diseases among agriculture and forestry workers.

Activity Goal 5.1.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent airways diseases among agriculture and forestry workers.

Activity Goal 5.1.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective interventions to prevent airways diseases among agriculture and forestry workers.

Activity Goal 5.1.4 (Surveillance Research): Identify new approaches to tracking the burden of hazardous exposures and adverse respiratory health outcomes in agriculture (including aquaculture) and forestry.

Burden

Farmworkers are notably exposed to several work-related respiratory hazards, including organic and inorganic dusts, gases in concentrated animal feeding operations (CAFOs), bacteria and endotoxins, nitrogen dioxide from silo gases and agrochemicals (e.g., pesticides, fumigants, and antibiotics) [Holguin and Schenker 2017]. From 1988 –1998 crop and livestock farmworkers had significantly elevated mortality for several respiratory conditions, with mortality for hypersensitivity pneumonitis being 10 times higher than expected among crop workers and 50 times higher in livestock workers [Greskevitch et al. 2007]. Studies have demonstrated that exposure to pesticides may also increase asthma risk [Eduard et al. 2004, Nordgren and Bailey 2016]. Chronic asthma is an important risk factor for chronic obstructive pulmonary disease (COPD). Livestock farmers and farm workers have an increased risk of chronic bronchitis, COPD and reduced lung function [Eduard et al. 2009; May et al. 2012]. Higher prevalence of COPD has been reported among livestock workers, mostly in swine, poultry and cattle industries [Eduard et al. 2009; Guillien et al. 2016; Marescaux et al. 2016; Monsó et al. 2004]. Restrictive lung function among workers in swine [O'Shaughnessy et al. 2009] poultry [Viegas et al. 2013], dairy [Reynolds et al. 2013] and more recently in the thoroughbred horse industry, have been reported [Flunker et al. 2017].

Data from 1988 through 1998 forestry workers have shown statistically significant increased mortality from pulmonary tuberculosis, chronic airway obstruction, and pneumonia [Greskevitch et al. 2007]. Significantly elevated mortality due to chronic airway obstruction was also observed in landscape and horticultural workers, and fishery workers [Greskevitch et al. 2007]. Respiratory hazards with potential exposure in forestry include dust, tannins, insects, fungi and mycotoxins, pesticides, gases and fumes [Donham and Thelin 2006].

Need

Surveillance and research data have shown a wide variety of exposures leading to respiratory disease in agriculture and forestry workers. NIOSH and the NIOSH-funded Agricultural Safety and Health Centers are well fit, with experience and appropriate facilities, to continue research and public health activities in this area. In the last decade new chemical exposures, technologies, and procedures have introduced novel challenges concerning respiratory health in the workplace. Basic/etiologic research is needed to better characterize exposures to respiratory hazards in agriculture and forestry workers including dusts, related gases and fumes, and chemicals, and to better understand relationships between exposures and risk for fixed airways diseases. Intervention and translational research is needed to develop controls to reduce exposure to respiratory hazards, document effectiveness, and promote their use. It will be important to understand barriers and aids to implementing effective interventions. Finally improved surveillance methods are needed, specifically new sources of data for tracking hazardous exposures and adverse respiratory health outcomes in agriculture.

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Construction/Respiratory Health (CONxRHP)

Participating core and specialty programs: Engineering Controls, Emergency Preparedness and Response, Nanotechnology Research Center, Occupational Health Equity, Surveillance, and Translation Research

Intermediate goal 5.2 (Exposure to mineral dusts):

Policy-makers, manufacturers, trade associations, insurance companies (including workers' compensation) use NIOSH information to reduce diseases caused by mineral dusts among construction workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	**Mineral dust-induced diseases**	**Implementation of silica requirements (collection of objective data)**	**Small businesses, vulnerable workers**	**Translation**
B	Mineral dust-induced diseases	Excess burden of mineral dust-induced diseases and hazardous exposures	Construction involving excavation, highway construction	Surveillance research Intervention
C	Mineral dust-induced diseases	Exposure to commercial and non-commercial elongate mineral fibers	Construction involving excavation, renovation and demolition, highway construction	Basic/etiologic Intervention

*See definitions of worker populations

Activity Goal 5.2.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationships between exposures to commercial and non-commercial elongate mineral fibers and adverse respiratory health effects among construction workers.

Activity Goal 5.2.2 (Intervention Research): Conduct intervention studies to develop, enhance, and assess the effectiveness of interventions to reduce exposures to commercial and non-commercial elongate fibers linked to respiratory disease among construction workers.

Activity Goal 5.2.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing silica interventions to prevent diseases caused by mineral dusts among construction workers.

Activity Goal 5.2.4 (Surveillance Research): Conduct surveillance research to better understand the excess burden of mineral dust-induced diseases and hazardous exposures among construction workers.

Burden

Exposure to mineral dusts occurs during many different construction activities, notably abrasive blasting, jack hammering, rock or well drilling, concrete drilling, tuck-pointing, cement finishing, brick and concrete block cutting and sawing, excavating, and highway work. A 2010 study revealed that over 50% of construction workers reported occupational exposure to vapors, gas, dust, or fumes at least twice a week, which was twice as likely as workers from all industries [CPWR 2013]. These activities and subsequent exposures can result in respiratory diseases (e.g., silicosis, asbestosis, chronic obstructive pulmonary disease [COPD], and lung cancer), and reduce a worker's length and quality of life. In fact, older construction workers are about twice as likely to die of respiratory cancer or non-malignant respiratory disease as their white-collar counterparts, after adjusting for smoking and other confounders [Wang et al. 2016]. Based on the number of deaths among U.S. residents during 1990–1999, construction accounted for 13.4% of all deaths due to silicosis, which was the third largest percentage for any sector [NIOSH 2008a].

Mesothelioma deaths are a marker for previous asbestos exposure, and the construction sector had the highest PMR for mesothelioma deaths in 1999, the last year that industry and occupation was coded from death certificates from many states [NIOSH 2008b]. Construction workers continue to be exposed from previously-installed asbestos containing materials in old buildings that is disturbed by renovation or demolition. An emerging issue potentially affecting construction workers is exposure to noncommercial elongate mineral

particles (EMPs) with potential for asbestos-like health effects. These materials can be encountered by disturbing natural deposits during construction activities, or by using materials such as crushed stone products contaminated with EMPs [NIOSH 2011].

Need

There is a need for basic/etiologic research to identify potential health hazards of new and emerging agents such as commercial and non-commercial elongate mineral fibers; and improve understanding of dose-response relationships and use that information to better determine how much of a reduction in exposure is needed to prevent adverse health effects from these fibers. Surveillance research is needed to develop novel approaches for health and hazard surveillance that will improve the ability to track the burden of work-related illnesses associated with mineral dust and commercial and non-commercial elongate mineral fiber exposures.

Intervention research is needed to develop and enhance the performance of technologies such asengineering controls and personal protective equipment [PPE] to protect against adverse health effects of commercial and non-commercial elongate mineral fibers. There is also a need to evaluate the effectiveness of interventions and to encourage uptake of safer and healthier designs. Improving continuous personal dust monitors to be lighter and smaller is relevant and important, as well as developing technology to provide real-time assessment of respirable crystalline silica exposure. Development and demonstration of effectiveness of other improved interventions to control exposures (through the use of video exposure monitoring and other technologies) is also important. Finally, translation research is needed to assist construction stakeholders with implementing Occupational Safety and Health Administration requirements and to collect objective data. Additional efforts are needed to transfer findings from this research into influential documents such as guidance and voluntary consensus standards. There is also a need to translate research findings into software products, applications and interactive webpages to make information easily accessible for construction stakeholders.

Intermediate goal 5.3 (Mixed exposures):

Policy-makers, manufacturers, trade associations, insurance companies (including workers' comp) use NIOSH information to reduce mixed exposures among construction workers.

	Health Outcome	Research Focus	Worker Population	Research Type
A	Chronic obstructive pulmonary disease (COPD), lung cancer	Exposure to welding fumes and fumes generated by closed in-place pipe operations	Plumbers, sheet metal workers, boilermakers, and workers engaged in closed in-place pipe repairs	Basic/etiologic Intervention
B	Interstitial diseases, Asbestos-like diseases	Exposure to nanomaterials and other advanced materials (e.g., additive manufacturing)	Painters, laborers, plumbers, carpenters, masonry workers, welders	Basic/etiologic
C	Interstitial diseases, COPD	Hazardous exposures during abrasive blasting tasks	Laborers, painters and plasterers, highway construction workers	Basic/etiologic

Activity Goal 5.3.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationships between complex exposures and adverse respiratory health effects among construction workers.

Activity Goal 5.3.2 (Intervention Research): Conduct studies to develop, enhance, and assess the effectiveness of welding fume exposure interventions to prevent adverse respiratory health effects among construction workers.

Burden

Many construction tasks generate complex airborne hazards. Mixed exposures of particular current concern are welding fumes, those associated with abrasive blasting and those associated with the use of emerging advanced materials such as nanomaterials. Abrasive blasting can generate high levels of respirable particles, and their content can vary with abrasive being use and the surface being blasted. Crystalline silica exposure from sandblasting is the best known risk, and lead exposure is also possible when blasting leaded paint from steel bridges. The use of other blasting materials composed of coal or copper slag raises unanswered questions about the content of the resulting dust and its impact on the respiratory health of construction workers.

The potential for certain nanomaterials to cause asbestos-like effects such as mesothelioma is an emerging concern. Nanomaterial exposures have been measured during routine construction tasks, including: weighing, mixing and applying mortar [Dylla and Hassan 2012]; drilling, cutting, and nailing roofing tiles [West et al. 2016]; and spray applying and sanding wood sealant [Cooper et al. 2017]. The NIOSH-funded Center for Construction Research and Training maintains an eLCOSH Nano inventory that has shown numerous applications for engineered nanomaterials in construction, particularly for coatings and paints [CPWR 2014].

Welding is a common construction activity and welding fume exposure is another concern. Exposures often exceed NIOSH Recommended Exposure Limits (RELs) [CPWR 2013]. Welding fume toxicity is of particular concern in confined environments associated with activities like maintenance/repair, construction, and/or mobilization/demobilization of equipment, facilities, and infrastructure. Welders can experience occupational asthma, lung cancer, metal fume fever, and increased susceptibility to pneumonia [HSE 2017].

Need

Workers and contractors need to recognize the hazards posed by these complex exposures, understand the risk factors, and take appropriate precautions. What research is needed varies by agent and exposure. Basic/etiologic research is needed to identify potential health hazards of new and emerging agents such as nanomaterials, advanced manufacturing materials, and abrasive blasting agents. Many of the nanomaterials can be identified through the eLCOSH Nano inventory. There is a need to improve our understanding of dose-response relationships and use that information to determine how much of an exposure reduction is needed to prevent adverse health effects. Better documentation of exposures and health effects in workers exposed to beryllium-containing coal ash or abrasive blasting materials made from coal or copper slag is also needed. Etiologic research (epidemiology and toxicology studies) on the health effects of some types of welding exposures is needed. The relative potency of fumes generated by different welding processes and types of electrodes and base materials is also of interest. Intervention research is needed to improve the existence, performance, and adoption of control technologies, prevention approaches, and interventions for worker exposures to welding fumes (engineering controls, personal protective equipment, etc). An important need for secondary prevention is to develop evidence-based guidelines for construction workers. Research concerning beryllium sensitization and disease in these working populations would be timely and likely to have relevance and impact.

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Healthcare and Social Assistance/Respiratory Health (HSAxRHP)

Participating core and specialty programs: Authoritative Recommendations, Engineering Controls, Emergency Preparedness and Response, Exposure Assessment, Health Hazard Evaluations, Personal Protective Technology, Surveillance, and Translation Research.

Intermediate Goal 5.4 (Work-related asthma):

Employers, workers, professional organizations, medical educators, researchers, and policy-makers use NIOSH information to reduce work-related asthma among healthcare and social assistance workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population	Research Type
A	Work-related asthma	Cleaning and disinfection agents, stress	Healthcare workers	Basic/etiologic Intervention
B	Work-related asthma	Animal allergens (e.g., volatiles)	Veterinary medicine/animal care workers	Basic/etiologic Intervention
C	**Work-related asthma**	**Specialized exposures (i.e. Surgical smoke, aerosolized medication)**	**Respiratory therapists, nurses, surgeons**	**Intervention Translation**
D	Work-related asthma	Asthma-friendly workplaces	All healthcare workers	Intervention
E	Work-related asthma	Explore utilizing existing data sources to better understand exposures and asthma morbidity/mortality	All healthcare workers	Surveillance research

Activity Goal 5.4.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between occupational exposures and work-related asthma among healthcare and veterinary medicine/animal care workers.

Activity Goal 5.4.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of allergen and irritant exposure interventions to reduce work-related asthma among healthcare and veterinary medicine/animal care workers and foster asthma-friendly workplaces in healthcare.

Activity Goal 5.4.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective engineering controls for surgical smoke to reduce work-related asthma in healthcare worksites.

Activity Goal 5.4.4 (Surveillance Research): Conduct surveillance research to explore utilizing existing data sources to better understand exposures and asthma morbidity/mortality among healthcare workers.

Burden

Work-related asthma encompasses occupational asthma (caused by work) and work-exacerbated asthma (existing asthma is made worse by work exposures). The healthcare and social assistance (HCSA) workforce in the U.S. is large with 19.4 million workers, and includes a disproportionate number with asthma at 10.7% [CDC 2016], for a total of about 2.1 million workers. Conservatively, about 15% of these have asthma caused by work [Torén and Blanc 2009], about 315,000 workers. In addition, about 21.5% have work-exacerbated asthma [Henneberger et al. 2011], about 452,000 workers. WRA occurs more frequently in HCSA workers as compared to other industries; the most common responsible work exposures reported in one study were cleaning products, latex, and poor air quality [Pechter et al. 2005].

Exposures in this industry that contribute to the risk of asthma include various chemicals, such as ammonia, bleaching agents, disinfectants, and certain aerosolized medications [CDC 2016]. The past 10 years have seen an increased emphasis on the contribution of cleaning and disinfecting to the onset and exacerbation of asthma. This topic was highlighted in a report published by the National Occupational Research Agenda (NORA) Cleaning and Disinfecting in Healthcare Working Group [Quinn et al. 2015]. Mixing of bleach with animal urine to create chlorine gas can be an issue in veterinary/animal care settings. In addition to these chemical exposures, high-molecular weight sensitizers such as animal allergens in veterinary settings and latex allergen are important exposures.

Need

There is a need for further studies of healthcare workers to identify which tasks, products, and constituent chemicals contribute to WRA in the healthcare industry, and to develop strategies for interventions that protect workers from asthma and patients from healthcare-acquired infections. While not as common as cleaning and disinfecting products, other specialized exposures such as surgical smoke and aerosolized medications provide risks for WRA, notably among respiratory therapists, nurses, and surgeons, and deserve more attention with respect to intervention and translational research.

Intervention research to develop asthma-friendly healthcare workplaces is needed to reduce asthma morbidity and impact on the quality of life of workers with asthma. Also, surveillance research is needed to investigate effective strategies for occupational health surveillance for secondary prevention of asthma in healthcare settings. In addition, population surveillance is needed that exploits existing sources of data to monitor exposures as well as asthma morbidity and mortality in healthcare.

A frequently overlooked aspect of the healthcare industry is the work done in veterinary medicine and animal care. Workers in these areas are exposed to a variety of animal allergens and chemicals associated with asthma onset and exacerbation, and both basic/etiologic research and intervention research are needed.

Intermediate Goal 5.12 (interstitial/fibrotic lung disease):

Employers, workers, professional organizations, medical educators, researchers, and policy-makers use NIOSH information to reduce interstitial and fibrotic lung disease among dental personnel.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population	Research Type
A	**Interstitial/fibrotic lung disease**	**Relationship between airborne occupational exposures and the risk for developing interstitial/fibrotic lung disease**	**Dental personnel**	**Basic/etiologic Intervention**
B	Interstitial/fibrotic lung disease	Identify interstitial/fibrotic disease risks and their magnitude	Dental personnel	Surveillance research

Activity Goal 5.12.1 (Basic/etiologic Research): Conduct basic/etiologic research to better understand the relationships between occupational exposures and risk for interstitial and fibrotic lung disease among dental personnel.

Activity Goal 5.12.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to reduce the risk for interstitial and fibrotic lung disease among dental personnel.

Activity Goal 5.12.3 (Surveillance Research): Conduct surveillance research to develop new tools and methods to identify interstitial and fibrotic lung disease risks and understand the magnitude of those risks among dental personnel.

Burden

During 2016, approximately 674,000 dental personnel were estimated to be working in the United States, including over 122,000 dentists [BLS 2017]. Dental personnel are exposed to infectious agents, chemicals, heavy metals, airborne particulates, ionizing radiation, non-ionizing radiation, and other potential hazards [Leggat 2007]. Inhalational exposures experienced by dental personnel likely increase their risk for certain work-related respiratory diseases. Case reports of work-related lung diseases experienced by dental personnel have included silicosis, asbestosis, occupational asthma, and pulmonary granulomatosis [Chung et al. 2015; Kahraman et al. 2014; Jungmann et al. 2013; Sichletidis et al. 2009; De Vuyst et al. 2007; CDC 2004; Piirila at al. 2002; Selden et al. 1995; Reid et al. 1991; Loewen et al. 1988]. During 1996–September 2017, physicians at a tertiary care center specializing in treatment of idiopathic pulmonary fibrosis (IPF) identified 11 cases of IPF among dental personnel out of 899 patients undergoing treatment for IPF [CDC 2018; Nett et al. 2018]. Ten of the 11 identified cases occurred among dentists. The number of dentists identified in this patient population was 29-times higher than expected in the United States, as there is approximately one practicing dentist per 1,600 persons [Munson and Vujicic 2014]. An analysis of IPF mortality in the United States identified that 188 cases of IPF had occurred in 1999 among persons in the health services industry [Pinheiro et al. 2008]. A query of the National Occupational Respiratory Mortality System (NORMS) over four separate years (1999, 2003, 2004, and 2007) for the underlying or contributing cause of death as 'other interstitial pulmonary diseases with fibrosis', revealed 35 decedents categorized as having worked in the 'office of dentists' and 19 decedents categorized as having the occupation 'dentist', which results in proportionate mortality ratios (PMR) = 1.52 (95% confidence interval [CI] = 1.05–2.11) and PMR = 1.67 (95% CI = 1.01–2.61), respectively [CDC 2018].

Need

The burden estimates summarized above indicate that surveillance research is required to better define the burden of work-related interstitial and fibrotic lung diseases among all dental personnel. Likewise, additional research is needed currently to better understand the scope of inhalational exposures across a range of dental practice settings, including the activities and conditions that create those exposures. From this research, contributions these exposures have in the development of work-related interstitial and fibrotic lung diseases can be determined. Even in the absence of a complete understanding of these exposure-disease relationships, an improved characterization of inhalational exposures and how they are generated can help in identifying practical measures to control exposures across the broader hierarchy of available controls. Intervention studies, which might optimally take place in different workplace settings where exposures are occurring, can help to assess the effectiveness of such control measures. Both basic/etiologic research and intervention research will be critical in (1) improving our understanding of the relationship between inhalational exposures experienced by dental personnel and the risk for interstitial and fibrotic lung disease among dental personnel; and (2) informing

evidence-based recommendations for appropriate controls, which might include a range of engineering and administrative controls, and the use of personal protective equipment.

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Manufacturing/Respiratory Health (MNFxRHP)

Participating core and specialty programs: Authoritative Recommendations, Center for Maritime Safety and Health Studies, Engineering Controls, Exposure Assessment, Nanotechnology Research Center, Occupational Health Equity, Small Business Assistance, and Surveillance.

Intermediate goal MNFxRHP 5.5 (Dust-induced respiratory diseases):

Employers, workers, researchers, and policy-makers use NIOSH information to reduce dust-induced respiratory diseases among manufacturing workers.

	Health Outcome	Research Focus	Worker Population*	Research Type
A	Interstitial diseases, Lung cancer, Pleural disease	Exposures to dust related to nanomaterials	Advanced manufacturing (manufacture of materials and users/formulators) workers, small businesses, vulnerable workers	Basic/etiologic Intervention
B	Hypersensitivity pneumonitis, Chronic obstructive pulmonary disease (COPD), Asthma	Exposures to aerosols from metalworking fluids	Workers who use metalworking fluids for grinding, cutting, etc.	Basic/etiologic
C	Interstitial diseases, Beryllium sensitization	Exposure to beryllium and other metals such as indium	Shipyard workers, workers who do coal or copper slag abrasive blasting, workers involved in electronics	Basic/etiologic Intervention

	Health Outcome	Research Focus	Worker Population*	Research Type
			manufacturing using indium, vulnerable workers	
D	Silicosis, COPD, Lung cancer	Exposure to respirable crystalline silica	Cut stone and stone product manufacturing businesses, vulnerable workers	Surveillance research Intervention
E	Interstitial disease (asbestosis), Pleural disease, Lung cancer, Mesothelioma	Exposure to elongate mineral particles (EMPs) and asbestos	Crushed stone and stone product manufacturing workers, manufacturers and users of products containing natural or manmade EMPs; vulnerable workers	Basic/etiologic

*See definitions of worker populations

Activity Goal 5.5.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationships between exposures and dust-induced respiratory diseases among manufacturing workers.

Activity Goal 5.5.2 (Intervention Research): Conduct intervention studies to develop and assess the effectiveness of interventions to reduce dust exposures and dust-induced respiratory diseases among manufacturing workers.

Activity Goal 5.5.3 (Surveillance Research): Conduct surveillance research to better detect sentinel outbreaks of silicosis.

Burden

Respiratory diseases caused by mineral dusts and related exposures are a substantial problem in the manufacturing sector. For example, during 1990–1999, manufacturing accounted for 43.8% of all deaths due to silicosis, which was the largest percentage for any one industrial sector, and nearly twice as much as the next highest sector [NIOSH 2008a]. Silica is a recognized hazard in many manufacturing processes, but new sources of exposure continue to emerge. For example, production of engineered stone countertops was recently recognized as a cause of silicosis [CDC 2015a]. Abrasive blasting with copper or coal slag, such as in the shipbuilding industry, is currently controversial because of disagreement about whether the Occupational Safety and Health (OSHA) Beryllium Rule should address beryllium exposures associated with such blasting activities [OSHA 2017, Pearson 2017]. Mesothelioma deaths are an important marker of previous exposure to asbestos and elongate mineral particles (EMP) with asbestos-like health effects [NIOSH 2011]. The manufacturing sector accounted for a high proportion (24.8%) of mesothelioma deaths in 1999, the last year in which usual industry and occupation was coded from death certificates of a large proportion of states [NIOSH 2008b]. An important emerging source of elongate mineral exposure is manufacturing manmade elongate particles (such as engineered elongate nanomaterials) and using those materials in downstream manufacturing processes [NIOSH 2013]. Another potential source of EMP exposure in manufacturing are crushed stone operations when source materials contain EMP [Kullman et al. 1995, Ryan et al. 2011]. Hypersensitivity pneumonitis caused by used metalworking fluids, which contain metals and other contaminants such as microorganisms, remains an important problem. Approximately 1.2 million workers in the U.S. are exposed to metalworking fluids. Outbreaks of hypersensitivity pneumonitis, a potentially severe disease, continue to occur in these workers yet

the specific etiologic agent(s) in used metalworking fluids remain unknown, complicating preventive efforts [Rosenman 2009].

Need

There is a need for basic/etiologic research to characterize the hazards associated with emerging advanced materials such as nanoparticles, EMPs other than asbestos, metalworking fluids, and to assess the risk for beryllium sensitization and chronic beryllium disease posed by abrasive blasting with coal and copper slags containing small amounts of beryllium. If hazards are documented, clarification of exposure-response relationships will also be important. There is a need for surveillance research to develop novel approaches for health and hazard surveillance that will improve the ability to track the burden of hazardous exposures and work-related illnesses associated in particular with respirable crystalline silica, but also with other exposures. Intervention research is needed to improve certain types of exposure assessment, such as developing real-time or near real-time assessment of respirable crystalline silica exposure and developing methods to better assess exposures associated with abrasive blasting. Work could also seek to develop improved, better-performing control technologies (engineering controls, personal protective equipment, etc.) for a variety of manufacturing settings. There is a need to evaluate the effectiveness of primary and secondary preventive interventions, especially for novel exposures and in novel manufacturing settings. Additional research could also help to improve the evidence base for preventive recommendations related to beryllium exposure from materials containing small amounts of beryllium, such as abrasive blasting media made from coal or copper slag and ash generated in coal-fired power plants. Special efforts must be made to address the unique needs of vulnerable workers and small businesses.

Intermediate goal 5.6 (Fixed airways diseases):

Employers, workers, researchers and policy-makers use NIOSH information to reduce fixed airways diseases among manufacturing workers.

	Health Outcome	Research Focus	Worker Population*	Research Type
A	Obliterative bronchiolitis	Exposure to flavoring chemicals (diacetyl and related flavoring chemicals)	Coffee, food, and artificial flavors manufacturing workers, Small businesses	Basic/etiologic Intervention
B	Chronic obstructive pulmonary disease (COPD)	Improve strength of evidence for potential causes of COPD, especially organic dusts (rubber, cotton, wood, food-related, etc.) and various chemical exposures	Food products including seafood, textiles, rubber, and plastics & leather subsectors, others with exposures of concern	Basic/etiologic

*See definitions of worker populations

Activity Goal 5.6.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between exposures to flavorings and organic dusts, and fixed airways disease among manufacturing workers.

Activity Goal 5.6.2 (Intervention Research): Conduct intervention studies to develop and assess the effectiveness of interventions to prevent fixed airways diseases among manufacturing workers.

Burden

Using data from 2004–-2011, an estimated 3.2% of the average annual number of workers in the manufacturing sector (14.7 million) have chronic obstructive pulmonary disease (COPD), totaling about 470,000 people [NIOSH 2014a]. Evidence documents that workers in certain manufacturing subsectors are at increased risk for COPD. Based on objective spirometry data, odds ratio (OR) for COPD was significantly increased for rubber, plastics, and leather manufacturing (OR 2.5); textile mill products manufacturing (OR 2.2), and food products manufacturing (OR 2.1) [Hnizdo et al. 2002]. A systematic review identified various occupational agents reported to cause COPD. Those exposures relevant to manufacturing, identified with varying degrees of evidence, include silica, asbestos, refractory ceramic fibers, flour, endotoxin, cadmium, carbon black, agricultural dusts (animal and plant), dusts from rubber, cotton, wood, iron/steel and smelting, welding fumes, isocyanates and other chemicals [Fishwick et al. 2015]. Another emerging type of fixed airways disease, obliterative bronchiolitis, can cause very severe disease and is often misdiagnosed as COPD [Cullinan et al. 2017]. Exposure to the food flavoring chemical diacetyl continues to be an important emerging cause of obliterative bronchiolitis in food products manufacturing settings, such as popcorn, flavorings and coffee manufacturing [Kreiss 2013; Duling et al. 2016].

Need

Although much progress has been made in preventing flavorings-related lung disease, much remains to be done. Basic/etiologic research is needed to better define the mechanisms by which diacetyl and related flavoring chemicals damage the airway, since this information can help to better predict what other chemicals could cause similar toxicity and help to better refine our approaches to prevention. There is great need for prevention research to evaluate exposures in a broader range of food products manufacturing settings where diacetyl and related chemicals are present and, for purposes of primary prevention, to develop practical, cost-effective approaches to controlling exposures. Because usual medical testing is insufficiently sensitive to detect many cases of obliterative bronchiolitis, there is need to develop better approaches to early detection for use in secondary prevention efforts. Also, there is need for research to assess the effectiveness of primary and secondary preventive interventions. In addition, basic/etiologic research is needed to improve the strength of evidence for causation of COPD by various occupational exposures and to assess exposure-response relationships. In particular, more information is needed about the impact of organic dust exposures (rubber, cotton, wood, food & seafood-related, endotoxin, etc.) and the ability of various chemical exposures to cause COPD (examples include welding fumes and styrene).

Intermediate goal 5.7 (Work-related asthma):

Employers, workers, researchers, and policy-makers will use NIOSH information to prevent work-related asthma among manufacturing workers.

	Health Outcome	Research Focus	Worker Population*	Research Type
A	Work-related asthma	Exposure to irritants (e.g., chlorine gas, peracetic acid)	Exposed workers, esp. poultry processing, food & seafood processing workers; vulnerable workers; advanced manufacturing workers; small businesses	Basic/etiologic Intervention

	Health Outcome	Research Focus	Worker Population*	Research Type
B	Work-related asthma	Exposure to sensitizers (low molecular weight agents and high molecular weight agents such as food / seafood allergens)	Workers who manufacture and use paint, workers who use reactive chemicals such as in polyurethane foam, food and & seafood processing workers, vulnerable workers, small businesses	Basic/etiologic Intervention

*See definitions of worker populations

Activity Goal 5.7.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between exposures to irritants and low molecular weight sensitizers and work-related asthma among manufacturing workers, and to identify and validate biomarkers of sensitization to low molecular weight agents.

Activity Goal 5.7.2 (Intervention Research): Conduct intervention studies to develop and assess the effectiveness of primary and secondary preventive interventions to prevent or mitigate work-related asthma among manufacturing workers.

Burden

Work-related asthma (WRA) encompasses occupational asthma (caused by work) and work-exacerbated asthma (existing asthma is made worse by work exposures). The manufacturing workforce in the U.S. is large with 12.3 million workers. While the 6.1% prevalence of asthma for manufacturing workers is not excessive [CDC 2016], this represents a very large number of workers with asthma. Conservatively, about 15% of the 750,000 manufacturing workers have asthma caused by work [Torén and Blanc 2009], totaling about 113,000 workers. In addition, about 21.5% have work-exacerbated asthma (Henneberger, Redlich et al. 2011), totaling about 163,000 workers.

Manufacturing workers are exposed to numerous irritant and sensitizing agents that are risk factors for asthma. In NIOSH state-based surveillance, “miscellaneous chemicals and materials” were the most frequently identified cause of WRA [NIOSH 2015]. Chemicals can frequently be irritants (e.g., chlorine gas, peracetic acid, cleaning agents, etc.) and can also be immune sensitizers, such as widely-used reactive low molecular weight chemicals like isocyanates that are used in paints, plastics, and other materials [NIOSH 2014b]. High molecular weight agents such as proteins encountered in processing foods, whether of plant or animal origin, are also important sensitizers. New asthmagens and settings for WRA continue to be identified by the NIOSH Health Hazard Evaluation Program [NIOSH 2009, CDC 2015b].

Need

Basic/etiologic research is needed to better understand relationships between exposures to irritants and low molecular weight agents and WRA among manufacturing workers and to develop better biomarkers for immune sensitization to low-molecular weight agents. Better understanding of mechanisms of irritant-induced WRA is needed to provide a conceptual basis for better preventive interventions. There are needs to clarify the potential health hazards of new and emerging asthmagens in manufacturing such as chemicals released during additive manufacturing (three dimensional printing). Intervention research is also needed. For example, studies are needed to assess effectiveness of primary and secondary preventive interventions to prevent or mitigate

work-related asthma among manufacturing workers. Improving the existence and validated performance of control technologies (engineering controls and PPE) related to WRA is needed in a variety of settings. Better approaches to secondary prevention through identifying workers with WRA and preventing their progression to irreversible disease is needed. Further research is needed to determine how much of a reduction in exposure is needed to prevent WRA for a range of asthmagenic agents. For all types of research special efforts should be made to address the unique needs of vulnerable workers and small businesses.

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Mining/Respiratory Health (MINxRHP)

Participating core and specialty programs: Exposure Assessment, Personal Protective Technology, and Surveillance.

Intermediate goal 5.8 (Exposures to mineral dusts):

Industry, labor, other government agencies, professional organizations, equipment manufacturers, and academics use NIOSH information to reduce respiratory diseases caused by mineral dusts among mining workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population	Research Type
A	Asbestos-related disease	Early screening for diagnosis related to exposure to elongate mineral fibers	Metal/non-metal; stone, sand and gravel mine workers	Intervention Surveillance research
B	Asbestos-related disease	Identify toxicity of commercial elongate mineral particles	Metal/non-metal; stone, sand and gravel mine workers	Basic/etiologic
C	Asbestos-related disease	Improved exposure assessment for elongate mineral fibers and controls	Metal/non-metal; stone, sand and gravel mine workers	Basic/etiologic Intervention
D	**Coal workers' pneumoconiosis (CWP), Chronic Obstructive Pulmonary Disease (COPD), Diffuse fibrosis**	**Coal dust engineering controls**	**Coal mine workers**	**Intervention Translation**
E	CWP, COPD, Diffuse fibrosis, silicosis	Improved screening and surveillance for respiratory health (esp. in Appalachia)	Metal/non-metal; coal; stone, sand and gravel mine workers	Surveillance research
F	Silica-related diseases	More accurate and timely monitoring of crystalline silica and controlling exposures	Metal/non-metal; coal; stone, sand and gravel mine workers	Basic/etiologic Intervention
G	**Silica-related diseases**	**Increase usage of crystalline silica interventions**	**Metal/non-metal; coal; stone, sand and gravel mine workers**	**Translation**

Activity Goal 5.8.1 (Basic/Etiologic Research): Conduct basic/etiologic research to improve measurement of exposures and to better understand relationships between exposures to mining-related dusts and risks for respiratory diseases among mining workers.

Activity Goal 5.8.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent exposure to elongate mineral fibers, coal mine dust, and crystalline silica and reduce respiratory diseases among mining workers.

Activity Goal 5.8.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing interventions for coal mine dust and crystalline silica among mining workers.

Activity Goal 5.8.4 (Surveillance Research): Conduct surveillance research to improve screening and surveillance for respiratory health among mining workers.

Burden

Mineral dusts and the respiratory diseases that they cause continue to be important problems. Each type of dust exposure can cause a spectrum of respiratory diseases. For example, respirable coal mine dust can cause coal workers' pneumoconiosis (CWP; a fibrotic lung disease), chronic obstructive pulmonary disease (COPD; includes chronic bronchitis and emphysema); dust-related diffuse fibrosis, and other conditions [Petsonk et al. 2013]. Respirable crystalline silica can cause silicosis (a fibrotic lung disease), COPD, lung cancer, and other conditions [NIOSH 2002]. Asbestos and elongate mineral particles (EMP) with asbestos-like effects can cause nonmalignant pleural disease, asbestosis (a fibrotic lung disease), lung cancer, and mesothelioma [NIOSH 2011]. These diseases can have a severe impact on affected miners and be disabling or even fatal. In addition to being potentially severe, dust-related respiratory diseases are a substantial risk to miners. For example, risks for CWP in coal miners are well-documented, with recent data suggesting that about 5% of coal miners in Kentucky, Virginia and West Virginia with more than 25 years' tenure have progressive massive fibrosis, the worst type of CWP [CDC 2016]. Miners accounted for 23% of silicosis deaths in the U.S. from 1990-1999 [NIOSH 2008a]. COPD is the third-leading cause of death in the U.S., and workers in the mining industry sector have the greatest risk of dying from COPD of any industry, with a rate about 70% higher than industry in general [NIOSH 2008b].

Need

There is need for a range of work to reduce the burden of dust-related respiratory diseases in mining. Basic/Etiologic research is needed to improve methods for exposure assessment, including real or near-real time silica exposure monitoring, improved detection thresholds for silica exposure assessment, and better approaches to characterizing EMP exposures. In addition, work is needed to understand the relative toxicities of various EMP and to improve the ability to predict which EMP will have asbestos-like health effects (see *NIOSH Roadmap* [NIOSH 2011]). Intervention research is needed to improve engineering controls and document the impact of interventions on dust levels and associated disease risk. A specific need is to evaluate the effectiveness of interventions implemented through the Mine Safety and Health Administration 2014 Coal Mine Dust Rule [MSHA 2014]. Translation research is needed to identify barriers and improve uptake of known effective interventions for primary and secondary prevention of disease associated with respirable coal mine dust and respirable crystalline silica exposures. Surveillance research is needed to develop new data sources to track the burden of hazardous exposures and respiratory disease in the metal and nonmetal and sand, stone, and gravel segments of the mining industry, where relatively little surveillance information is currently available. Even in coal mining, improved surveillance to track the burden of disease in former miners not eligible for NIOSH respiratory health surveillance is needed. Improved approaches to medical screening and surveillance are also needed, including improved understanding of the role of low and ultra-low dose CT scanning of the chest and improved approaches to assessment of lung function for purposes of secondary prevention.

Intermediate goal 5.9 (Mixed exposures):

Industry, labor, other government agencies, professional organizations, equipment manufacturers, and academics use NIOSH information to reduce respiratory diseases caused by mixed exposures among mining workers.

	Health Outcome	Research Focus	Worker Population	Research Type
A	Chronic obstructive pulmonary disease (COPD), Asthma, Lung cancer	Exposure to gas and particle phase diesel and dust mixtures	All mining workers (esp. underground)	Basic/etiologic Intervention
B	Coal workers' pneumoconiosis (CWP), COPD, Diffuse fibrosis	Toxicity of contemporary coal dust (silica, coal and other mineral mixture)	Coal mining workers	Basic etiologic Intervention
C	Respiratory diseases	Interaction of work and personal risk factors on respiratory health outcomes	All mining workers	Basic/etiologic Intervention

Activity Goal 5.9.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between mixed respiratory exposures and respiratory diseases among mining workers.

Activity Goal 5.9.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent mixed exposures linked to respiratory disease among mining workers.

Burden

Most hazardous exposures in mining are not simple exposures to single agents. Instead, they are exposures to complex mixtures in the work environment. In addition, risks for adverse respiratory health outcomes from work exposures can be modified by non-work personal risk factors. It is important to understand the interactions between these exposures. For example, there has been a well-documented surge in coal workers' pneumoconiosis (CWP), including very severe CWP, in Appalachian coal miners [Blackley et al. 2016]. Pathology studies have shown a mixture of particles in the lungs of these workers, including coal, crystalline silica, and other silicate minerals [Cohen et al. 2016]. In another example, workers in the mining industry are at the highest risk for dying of COPD of any industry [NIOSH 2008b]. These workers can have multiple work exposures with the potential to cause COPD (and other respiratory diseases such as lung cancer), such as respirable coal mine dust, respirable crystalline silica dust, and diesel exhaust. This can be further complicated by exposures from outside work, such as from tobacco smoke, since the mining industry has one of the highest prevalence rates for smoking [NIOSH 2013].

Need

Basic/Intervention research is needed to assess modification of risk for respiratory health outcomes by co-exposures to individual components of complex mixtures. Are effects additive, supra-additive, multiplicative, or is there some other effect? The interactions between dust exposure, diesel exposure, and tobacco smoke are an important issue. Results from past NIOSH research evaluating coal miners and metal and nonmetal miners have suggested that coal mine dust and diesel exhaust interact with tobacco smoke in complex ways; further validation in human or mechanistic experimental studies is needed. Similarly, the relative contributions and interactions between respirable coal, crystalline silica, and other silicate mineral dust in causing the severe

emerging outbreak of CWP in Appalachian coal miners needs to be further evaluated in experimental studies. Intervention studies are also needed to demonstrate effectiveness of addressing these complex exposures, whether they occur at work or as a result of personal risk factors.

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Oil and Gas Extraction/Respiratory Health (OGExRHP)

Participating core and specialty programs: Center for Direct Reading and Sensors, Engineering Controls, Prevention through Design, Small Business Assistance, Surveillance and Translation Research

Intermediate goal 5.10 (Silica-induced respiratory diseases):

Employers, professional associations, manufacturers, and workers use NIOSH information to reduce silica-induced respiratory diseases among oil and gas extraction workers.

	Health Outcome	Research Focus	Worker Population	Research Type
A	Silica-related respiratory diseases	Silica exposure during hydraulic fracturing	Well servicing contractors	Intervention
B	Silica-related respiratory diseases	Silica exposures other than hydraulic fracturing	Drilling and servicing contractors	Basic/etiologic Intervention
C	Silica-related respiratory diseases	Potential data sources for burden of lung disease and early indicators of lung disease (e.g., lung function decline)	All oil and gas extraction workers	Surveillance Research Basic/etiologic

Activity Goal 5.10.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand exposures to silica other than hydraulic fracturing and their link to respiratory disease among oil and gas extraction workers.

Activity Goal 5.10.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent silica exposure and related respiratory diseases among oil and gas extraction workers.

Activity Goal 5.10.3 (Surveillance Research): Conduct surveillance research to explore potential data sources to assess burden of lung disease and early indicators of lung disease among oil and gas extraction workers.

Burden

NIOSH scientists identified respirable crystalline silica during hydraulic fracturing as a significant exposure hazard [NIOSH 2012]. NIOSH has reported that almost 80% of oil and gas extraction (OGE) workers sampled were exposed to greater than the NIOSH Recommended Exposure Limit (REL) of 0.05 mg/m^3 respirable crystalline silica [NIOSH 2012]. Respirable crystalline silica can cause silicosis (a fibrotic lung disease), COPD, lung cancer, increased susceptibility to tuberculosis and other conditions [NIOSH 2002]. Of these, statistically significant increases in proportional mortality ratio (PMR) in OGE workers (years 1999, 2003–2004, and 2007–2010) have been documented for COPD (PMR 112), malignancy of the respiratory system (PMR 109), and malignancy of the trachea, bronchus, and lung (PMR 107) [NIOSH 2015]. Although the PMR for silicosis was not increased based on all OGE workers, it was significantly increased for extractive occupations (PMR 2161) and first line supervisors of construction and extraction occupations (PMR 714) [NIOSH 2015].

Need

While field studies are ongoing, much more work remains to fully characterize respiratory hazards to workers in the phases of OGE operations outside of hydraulic fracturing. Determining worker exposure levels is important for selecting the right type of control measures, including engineering controls and respiratory protection, and

feedback received from stakeholders indicates that continued exposure assessment and intervention effectiveness studies are the most important research to conduct in order to reduce exposures to respirable hazards on OGE worksites. Improving our ability to assess and track the burden of respiratory disease in OGE workers is also important for setting priorities and evaluating progress. NIOSH holds several key advantages for performing this work or undertaking projects in partnership with extramural partners (1) NIOSH has access to companies, workers and worksites through formal partnerships with oil and gas companies; (2) NIOSH has established effective collaboration with stakeholders via the NORA Oil and Gas Sector Council and through an OSHA Alliance; and (3) NIOSH has the equipment, experienced researchers, protocols, and scientific integrity to complete this work.

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Public Safety/Respiratory Health (PSSxRHP)

Participating core and specialty programs: Authoritative Recommendations, Emergency Preparedness and Response, Personal Protective Equipment, and Surveillance.

Intermediate goal 5.11 (Fixed airways diseases):

Consensus standard organizations, professional associations, policy-makers, researchers, employers and workers use NIOSH information to prevent fixed airways diseases among public safety workers.

	Health Outcome	Research Focus	Worker Population	Research Type
A	Chronic obstructive pulmonary disease (COPD)	Dust inhalation, smoke inhalation during overhaul operations	Fire service subsector	Basic/etiologic Intervention
B	COPD	Dust inhalation, smoke inhalation	Wildland fire subsector	Basic/etiologic Intervention
C	COPD	Respiratory exposures during response and recovery work	Response workers	Basic/etiologic Intervention

Activity Goal 5.11.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between respiratory exposures and fixed airways diseases among structural firefighters, wildland firefighters, and response workers.

Activity Goal 5.11.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent fixed airways diseases among structural firefighters, wildland firefighters, and response workers.

Burden

There were about 1.16 million local firefighters in the U.S. in 2015. Of these, about 815,000 were volunteer firefighters and 346,000 were career firefighters [NFPA 2017]. Firefighters are routinely exposed to a range of hazardous particulate and gaseous toxins, which vary depending on the materials burning in different fires [Duffy et al. 2010]. For example, structural fires often involve the combustion of by-products of organic and synthetic material, solvents, pesticides, and industrial chemicals. Wildland firefighters are exposed to a complex mixture of organic material pyrolysis and decomposition products [Youakim 2013]. The respiratory effect of these toxic mixes has often been missed when firefighters, who are selected and retained for better-than-average healthiness, are compared to the general population. When mortality studies have addressed this "healthy worker effect" by comparing firefighters to police officers, firefighters had an increased mortality from non-cancer respiratory disease [Feuer and Rosenman 1986; Rosenstock et al. 1990]. Thus, the respiratory hazard posed by firefighting is well-recognized, with 32 states having presumptive disability laws recognizing lung disease in firefighters as occupational [Duffy et al. 2010]. Investigations of first responders at the World Trade Center site have demonstrated that non-routine events can have a devastating impact on the respiratory health of firefighters and other first responders. For example, NIOSH has officially recognized the exposures encountered by World Trade Center responders as a cause of COPD [CDC 2016]. Bronchiolar disorders have also been associated with World Trade Center exposures [Cummings and Kreiss 2015].

Need

Basic/etiologic research is still needed to improve our understanding of the association of fixed airways disease with the dust, smoke, and other airborne exposures experienced by structural firefighters, wildland firefighters, and response workers. Additional research is needed to clarify how repeated exposure to smoke, which commonly occurs in both the structural and wildland fire environment, may be linked with chronic pulmonary disease.

Given the ever-present threat of excessive exposure of structural and wildland firefighters and response workers to respiratory irritants and toxicants, it is essential that they have access to practical, effective interventions. Demonstration of the effectiveness of comprehensive prevention programs addressing primary and secondary preventive interventions is needed. Within the hierarchy of controls, there is stakeholder interest and a demonstrated need to determine the applicability and performance of air-purifying and powered air-purifying (APR/PAPR) respirators as an alternative to self-contained breathing apparatus (SCBA) for over-haul operations and to determine if a respirator is a practical option to prevent exposures in the wildland fire setting. There is also a need to address gaps in personal protective equipment (PPE) availability and training [Haynes and Stein 2016].

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Services/Respiratory Health

Participating core and specialty programs: Personal Protective Technology

Intermediate goal 5.13 (Mixed exposures):

Employers, workers, researchers, unions, professional associations, and policy-makers will use NIOSH information to prevent hazardous exposures and lower and upper airways diseases among services workers.

	Health Outcome	Research Focus	Worker population	Research Type
A	Upper and lower respiratory disease	Exposure assessment and Epidemiologic studies on mixed exposures in indoor environments	Service workers with exposures (e.g., education, hotel industry, building maintenance, office workers)	Basic/etiologic
B	Upper and lower respiratory disease	New methods to identify disease related to mixed exposures	Service workers with exposures (e.g., education, hotel industry, building maintenance, office workers)	Surveillance research
C	Upper and lower respiratory disease	Identifying effective strategies to translate research findings to practices in the workplace (e.g., the NIOSH Dampness and Mold Assessment Tool)	Service workers with exposures (e.g., education, hotel industry, building maintenance, office workers)	Translation

	Health Outcome	Research Focus	Worker population	Research Type
D	Upper and lower respiratory disease	Evaluate methods of PPE used to address mixed exposures	Building services and maintenance	Intervention

Activity Goal 5.13.1 (Basic/etiologic research): Conduct basic/etiologic research to better characterize mixed exposures and their associations with upper and lower respiratory disease among services sector workers.

Activity Goal 5.13.2 (Intervention research): Conduct studies to develop and assess the effectiveness of interventions to address mixed exposures related to upper and lower respiratory disease among services sector workers.

Activity Goal 5.13.3 (Translation research): Develop strategies to translate research findings and theoretical knowledge to practices in the workplace to prevent mixed exposures related to upper and lower respiratory disease among services sector workers

Activity Goal 5.13.4 (Surveillance Research): Conduct surveillance research to explore potential data sources to assess upper and lower respiratory disease among services sector workers.

Burden

The prevalence of asthma among services sector workers is 7.5% compared to 7.2% for all workers [NIOSH 2010]. Considering that the services sector employs over 70 million workers, research on work-related asthma is warranted. One industry of particular concern is educational services. It is the second largest industry in the United States (U.S.) with about 13.3 million workers, including 7.7 million teachers. The educational services industry has a high prevalence of current asthma with 9.1%, or about 1.2 million workers [Dodd and Mazurek 2016). The National Education Association has brought attention to the poor state of schools in the U.S., specifically that two-thirds of the nation's 80,000 public schools have unhealthy environmental conditions [NEA 2011]. For example, research conducted in New York State indicated that current asthma among teachers was associated with moldy odors, visible mold, moisture damage, dust, and odors from perfumes/air fresheners [Kielb et al. 2015]. Additionally, the services sector includes 1.8 million workers employed in the hotel industry. Hotel room cleaners are exposed to chemicals and other sources of high molecular weight proteins as well as to microbial exposures related to poor indoor environmental quality that can result in allergic sensitization or the development and exacerbation of upper respiratory disease and asthma. Also, there are approximately 2.5 million workers employed in building services. These individuals are exposed to chemicals, microbial agents, and particulates.

Need

Hazards for Services workers include a variety of compounds, such as, microbial agents, high molecular weight allergens, secondary metabolites, volatile organic compounds, low molecular weight agents, and particulates. Studies evaluating hazards from exposure to these agents which often occur together in indoor environments are needed. The National Academies of Sciences 2017 consensus document entitled "Microbiomes of the Built Environment: A Research Agenda for Indoor Microbiology, Human Health, and Buildings" [NAS, 2017], emphasized the need to better understand mixed exposures in damp buildings and the associations of these exposures with respiratory and allergic health outcomes. Stress is an emerging issue related to asthma and

should be considered as a possible effect modifier of other exposures in the work environment of Service sector workers. Workers in the Services sector who rely on PPE to reduce exposures need to understand the impact of mixed exposures on respirator change-out schedules and the physiological and psychological impact of wearing the PPE. Basic/etiologic, intervention, translation, and surveillance research are needed to better understand and prevent work-related lower and upper airways diseases associated with mixed exposures in the Services Sector.

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Strategic Goal 6: Improve workplace safety to reduce traumatic injuries

Agriculture, Forestry and Fishing/Traumatic Injury Prevention (AFFxTIP)

Participating core and specialty programs: Center for Direct Reading and Sensor Technologies, Center for Maritime Safety and Health Studies, Center for Occupational Robotics Research, National Center for Productive Aging and Work, Occupational Health Equity, Prevention through Design, Surveillance, and Translation Research.

Intermediate goal 6.1 (Traumatic injury among high risk populations):

Policy-makers, non-governmental organizations, employers, manufacturers, and industry associations use NIOSH information to prevent injuries among high risk workers in the agriculture, forestry, and fishing sector.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population	Research Type
A	Fatal and non-fatal injuries	Characterize safety hazards (e.g., struck-by, falls)	Forestry subsector	Basic/etiologic Intervention
B	Non-fatal injuries	Explore sources for non-fatal work-related injuries	Forestry subsector	Surveillance research
C	Fatal and non-fatal injuries	Direct reading and sensors to prevent machine-related injuries	Forestry subsector	Basic/etiologic
D	**Fatal and non-fatal injuries**	**Machine-related incidents (e.g., tractor, PTO, and grain engulfment)**	**Agriculture subsector; commercial fishing and seafood processing workers**	**Intervention Translation**
E	Fatal and non-fatal injuries	Use of robotics	Agriculture subsector	Basic/etiologic
F	Fatal and non-fatal injuries	Codes and other methods needed to identify robot-related injuries	Agriculture workers who interact with new technologies	Surveillance research
G	Non-fatal injuries	Explore sources for non-fatal work-related injuries	Agriculture subsector; commercial fishing and seafood processing workers	Surveillance research
H	**Fatal and non-fatal injuries**	**Falls overboard and vessel disasters**	**Commercial fishing workers**	**Intervention Translation**
I	**Non-fatal injuries**	**Falls (stairs & wet floors)**	**Seafood processing workers**	**Intervention Translation**

Activity Goal 6.1.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand safety hazards and emerging hazard control technologies to reduce traumatic injuries among agriculture and forestry workers.

Activity Goal 6.1.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent fatal and non-fatal injuries among agriculture, fishing, and seafood processing workers.

Activity Goal 6.1.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective safety interventions among agriculture, forestry, fishing, and seafood processing workers.

Activity Goal 6.1.4 (Surveillance Research): Conduct surveillance research to explore data sources and identification methods for non-fatal work-related injuries among agriculture, forestry, fishing, and seafood processing workers.

Burden

According to several studies, farm machinery is a leading source of fatalities and injuries in agriculture accounting for 23–50% of fatalities and approximately 50% of hospitalizations from non-fatal injuries [Jawa et al. 2013]. Farm machinery (particularly tractors) and livestock handling are the leading causes of injuries [NIOSH 2014; Swanton et al. 2015; Browning et al. 2013; Erkal et al. 2008; Dogan and Demirci 2012]. In a study that used death certificate data from 1995–2000, the leading sources of farm-related youth deaths were machinery (25%), followed by motor vehicles, including all-terrain vehicles, (17%) and drownings (16%) [Goldcamp et al. 2004].

Commercial fishing is consistently one of the most dangerous industries in the U.S. During 2000–2015, an annual average of 42 deaths occurred (117 deaths per 100,000 workers in total) [BLS 2016]. Data from the NIOSH Commercial Fishing Incident Database reveals that from 2000–2015, the majority of the deaths (354) occurred after a vessel disaster (defined as a sinking, capsizing, or other event in which the crew was forced to abandon ship) or a fall overboard (221). The Gulf of Mexico fishing region, however, had more fatalities caused by falls overboard than by vessel disasters [Lincoln and Lucas 2010].

During 2011–2014, seafood processing workers experienced the highest injury/illness rate of any maritime workers, with 6,286 injuries/illnesses per 100,000 workers [BLS 2016]. The few occupational safety and health studies conducted in U.S. have identified traumatic injuries as an area of concern [Anderson et al. 2013; Garcia and De Castro 2017; Lucas et al. 2014; Syron et al. 2017]. A study of occupational safety onboard vessels operating in Alaskan waters during 2001–2012 found that the two most frequent causes of injuries were workers being caught in running equipment and cut by slipping knives [Lucas et al. 2014].

In 2015, logging workers had the highest fatal work injury rate with 132.7 fatalities per 100,000 workers [BLS 2015]. In mechanized logging, the highest accident rate results from equipment maintenance and repairs and manual logging of inaccessible areas. In semi-mechanized logging operations, the majority of accidents are usually caused by chainsaws [Albizu- Urionabarrenetxea et al. 2013; Shaffer and Milburn 1999]. The main causes of injury in the logging process are falls and being struck by or against an object [Albizu- Urionabarrenetxea et al. 2013; Quandt et al. 2013]. Falls can occur when body parts are pinned between logs or equipment whereas struck by injuries can occur from falling trees branches, rolling logs, or kickback from power saws [Quandt et al. 2013].

Need

Rapid growth in the use of robotics and other emerging farming technologies are likely to present new risks or exacerbate existing risks due to lack of experience with emerging technologies in varied work settings in the agriculture, forestry and fishing sector. There is an urgent need to expand U.S. occupational injury surveillance capabilities to better identify, monitor, and quantify the burden of fatal and non-fatal incidents involving robots and other emerging technologies (e.g., development of new source or event codes). Systematic studies are needed on the impacts of personal, environmental, and task-related risk factors on worker injuries, and

evidence-based interventions to address gap in research. There is currently a gap in safety and health research for forestry workers. Immediate research needs include basic research to characterize safety hazards among forestry workers and develop direct reading methods and sensors to prevent machine-related injuries. NIOSH has strong ties with stakeholders in agriculture, including a history of developing surveillance data, funding Agriculture Safety and Health Centers and implementing multiple public health programs since 1991, making it well suited to carry out research in this area.

For the injuries caused by machinery in agriculture, there have been emerging technologies that have introduced potential hazards. Research should be focused on these new technologies including robotics which are becoming common in milking parlors and in the field. For forestry, research should also include emerging technologies and safety issues of working with mechanized harvesting techniques (struck by and falls) and sensors for monitoring and preventing injuries by human machine interaction. Machinery and slips and falls are important areas for safety research in the fishing and seafood processing industries. Further research on causes and injury prevention should be done in this area. It is important that research continues on systems and procedures to increase worker survival after vessel loss disasters. Between NIOSH Commercial Fishing Safety Research and Design Program and NIOSH Center for Maritime Safety and Health Studies, NIOSH is well positioned to conduct research in the commercial fishing and seafood processing industries. Intervention research is needed to determine if and how lessons learned from other high-risk food manufacturing industries – such as poultry processing – could be applied to seafood processing in onshore and offshore factory settings.

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Construction/Traumatic Injury Prevention (CONxTIP)

Participating core and specialty programs: Center for Occupational Robotics Research, Emergency Preparedness and Response, Health Hazard Evaluation, National Center for Productive Aging and Work, Occupational Health Equity, Prevention through Design, Safe•Skilled•Ready Workforce, Small Business Assistance, Surveillance, and Translation Research.

Intermediate goal 6.2 (Falls):

Insurance companies (including workers' compensation), businesses, policy-makers, professional associations, and unions adopt interventions to prevent and protect from falls among construction workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	**Fatal and non-fatal injuries**	**Falls from elevation**	**Iron workers, sheet metal workers, roofers, power line installers,**	**Intervention Translation**

	Health Outcome	Research Focus	Worker Population*	Research Type
			telecommunications workers, laborers, small businesses, vulnerable workers	
B	**Non-fatal injuries**	**Falls on the same level**	**All construction workers (especially laborers, small businesses, vulnerable workers)**	**Intervention Translation**

*See definitions of worker populations

Activity Goal 6.2.1 (Intervention Research): Conduct intervention studies to develop and assess the effectiveness of falls prevention and protection interventions among construction workers.

Activity Goal 6.2.2 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective falls prevention and protection interventions in the construction sector.

Burden

In 2016, there were over ten million workers in the U.S. construction industry, a number that has been rising since bottoming out in 2012 [CPWR 2017]. Between 2003 and 2016, there were between 267 and 448 fatal falls annually in construction. In 2015, almost six times as many fatal falls occurred in construction compared to manufacturing, the industry with the second highest number [CPWR 2017]. Examining 1,533 fatal falls in construction between 2011 and 2015, approximately 33% were falls from roofs, 24% were falls from ladders, and 15% were falls from scaffolding [CPWR 2017]. Occupations at higher risk include laborers, roofers, ironworkers, sheet metal workers, welders, and power-line installers [CPWR 2013, 2017]. Vulnerable workers at an elevated or disproportionate risk include Hispanic workers, foreign-born workers, workers in small businesses, workers with non-standard work arrangements, and older (55 and over) workers [CPWR 2013, 2017].

The burden of injuries from falls on the same level in construction is sometimes overlooked. In 2010, there were approximately 18,130 non-fatal injuries to construction workers as a result of falls. Approximately 40% of those injuries were the result of falls that occurred on the same level [CPWR 2013]. Fatal and non-fatal falls in construction result in heavy economic burdens on workers, families, employers, and society. Even when workers survive, many have traumatic brain or other injuries requiring lengthy rehabilitation, placing substantial emotional, medical, and financial burdens on their families. Falls also result in significant costs to employers, including lost productivity, loss of skilled workers, and increased workers' compensation costs [OSHA 2012].

Need

Intervention and translation research addressing engineering and design, education and training, communication, and administrative issues is needed to address this problem and achieve meaningful results. Future research to prevent and protect from falls should consider the effects and interactions of environmental, task-related, and personal factors that can affect workers' balance. Improvements in the work environment, in construction materials and methods, and in work procedures and practices should reduce falls. Research to reduce falls among higher risk groups is especially needed, along with research to develop, evaluate, and understand the safety, productivity, and latent hazards of emerging work methods and technologies (e.g., advanced fall prevention and protection technologies, height access devices, drones, automation, and robots).

There is a need to better understand the best approaches to train and educate construction workers, employers, and safety professionals on fall protection. Many of these groups include non-English speaking learners and low-literacy audiences. Additional efforts are needed to transfer findings from this research into influential documents such as guidance and voluntary consensus standards. There is also a need to translate research findings into software products, applications and interactive webpages to make information easily accessible for construction stakeholders.

Falls on the same level or slips, trips, and falls (STFs) are common in construction (representing approximately 19% of all construction falls requiring emergency room visits from 1998–2005) and a leading cause of workers' compensation claims [Shislov et al. 2011]. Many causes of STFs are unique to construction, easily observable, and should be addressed through research; for example, housekeeping and maintenance are often major contributing factors to falls on the same level [Lipscomb et al. 2006]. A better understanding of causal factors will address the need to develop and enhance effective interventions and technologies that can be translated into the construction work environment.

Intermediate Goal 6.3 (Injuries related to emerging technologies [e.g., robots, exoskeletons]):

Safety and health professionals, employers, labor organizations, consensus standard organizations, and robotics manufacturers use NIOSH information to prevent injuries related to automation technologies and robots and to improve safety among construction workers.

	Health Outcome	Issue	Worker population*	Research needed
A	Fatal and non-fatal injuries	Emerging ground robotics and automation technologies (e.g., collaborative robots, mobile robots)	Workers who interact with ground robots, vulnerable workers	Basic/etiologic Intervention
B	Fatal and non-fatal injuries	Emerging aerial robotics and automation technologies (e.g., unmanned aerial vehicles [UAV])	Workers who work in close proximity to an aerial robot at a construction site, vulnerable workers	Basic/etiologic Intervention
C	Fatal and non-fatal injuries	Codes and other methods needed to identify robot-related injuries	Workers who interact with construction robots, vulnerable workers	Surveillance

*See definitions of worker populations

Activity Goal 6.3.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand the benefits and risks of emerging ground/aerial robotics and automation technologies regarding injuries (or injury reduction) among construction workers.

Activity Goal 6.3.2 (Intervention Research): Conduct studies to evaluate robotics technologies as sources of, and interventions for, workplace injuries among construction workers.

Activity Goal 6.3.3 (Surveillance Research): Conduct surveillance research to develop new methods to identify robot-related injuries among construction workers.

Burden

More than ten million U.S. construction workers are at high risk of traumatic injuries because of inherently hazardous tasks and dynamic conditions of construction sites. With recent advances in automation and robotics, novel construction approaches are being developed with the potential to reduce occupational injury risks. New and emerging types of robots (e.g., collaborative robots, aerial robots) are becoming more available, and beginning to be more widely used in the construction industry to assist workers in handling hazardous tasks that have been performed traditionally by human workers. Ground robots can take on heavy loads; perform dirty, dangerous, or repetitive work; work at elevation, in hard to reach places, and perform tasks requiring awkward postures at a construction site. Unmanned Aerial Vehicles (UAVs) also can be used in the construction industry for various tasks including mapping of construction sites for project planning, monitoring workflow and logistics, inspecting and assessing structures and damages, and handling and transporting materials. In particular, UAVs can prevent construction worker injuries involving falls from heights by taking on tasks at higher elevations.

Market data show that average industrial robot sales worldwide increased 16% per year from 2010–2015, and continuing increases in adoption of industrial robots are predicted [IFR 2016]. It is estimated that more than 1.4 million new industrial robots will be installed in workplaces worldwide from 2016–2019 [IFR 2016]. Rapid advances and growth of applications of UAVs are particularly significant in the construction industry. It is estimated that the UAV market will increase to $100 billion by 2020 and the construction industry is expected to be the biggest market for commercial uses that are expected to account for over $11 billion [Goldman Sacks 2016]. Predicted growth of robotics in the construction industry can create new hazards to human workers who work in close proximity to or interact with these emerging technologies. This challenge can be particularly significant because of the characteristics of most construction projects: ever-changing work environments, the need for multiple skilled craftsmen, multiple employers sharing a common worksite, and the interactions of multiple pieces of automated equipment.

Need

Basic and etiologic research are needed to expand our understanding of applications of robotics and automation technologies in the construction industry and associated injury risks. Due to the rapid growth in these technologies, safety research is needed to address the efficacy, safety, and productivity improvements related to use of collaborative robots, mobile robots, and aerial robots in construction environments. Studies are needed on the impact of personal, environmental, and task-related risk factors in reducing worker injuries associated with robotics. In addition, developing engineering and administrative controls to enhance uptake of automation and robotic solutions and minimize robot-related incidents used in construction are topics warranting further study. There is a need to better understand the best approaches to train and educate construction workers, employers, and safety professionals on construction hazards. Many of these groups include non-English speaking learners and low-literacy audiences Additional efforts are needed to transfer findings from this research into influential documents such as guidance and voluntary consensus standards. There is also a need to translate research findings into software products, applications and interactive webpages to make information easily accessible for construction stakeholders.

There is also an urgent need to expand occupational injury surveillance capabilities to better identify, monitor, and quantify the burden of fatal and nonfatal injury incidents involving the robotics and automation

technologies in the construction industry. For instance, new source or event codes for automation- and robot-related incidents need to be developed for effective surveillance.

Intermediate goal 6.19 (Substance use/misuse):

Insurance companies (including workers' compensation), businesses, policy-makers, professional associations, government agencies, and unions adopt interventions to reduce injuries and risk factors for opioid use, illicit drugs, and substance use/misuse.

	Health Outcome	Research Focus	Worker Population*	Research Type
A	Fatal and non-fatal injuries	Patterns and risk factors for prescription drug (incl. opioids), illicit drug, and substance use/misuse	Iron workers, sheet metal workers, roofers, power line installers, telecommunications workers, laborers, small businesses, vulnerable workers	Basic/Etiologic Surveillance Research
B	Fatal and non-fatal injuries	Effectiveness of employer-based interventions for prescription drug (incl. opioids), illicit drug, and substance use/misuse	Iron workers, sheet metal workers, roofers, power line installers, telecommunications workers, laborers, small businesses, vulnerable workers	Intervention Translation

*See definitions of worker populations

Goal 6.19.1 (Basic/Etiologic Research)**:** Conduct basic/etiologic research to better understand risk factors for prescription drug (incl. opioids), illicit drug, and substance use/misuse among construction workers.

Activity Goal 6.19.2 (Intervention Research)**:** Conduct studies to develop and assess the effectiveness of interventions for prescription drug (incl. opioids), illicit drug, and substance use/misuse among construction workers.

Activity Goal 6.19.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective interventions for prescription drug (incl. opioids), illicit drug, and substance use/misuse among construction workers.

Activity Goal 6.19.4 (Surveillance Research)**:** Conduct surveillance research to develop new methods and tools to understand patterns of prescription drug (incl. opioids), illicit drug, and substance use/misuse among construction workers.

Burden

Construction comprises residential and commercial building and heavy and civil engineering (e.g., water and sewer lines, highways, and bridges), and includes specialty trades such as roofing, plumbing, electrical, and drywall. Over 10 million workers are employed in construction in the U.S. [BLS 2017], and these workers face risks of fatal and non-fatal injuries resulting from falls from elevated surfaces, struck-by incidents, and musculoskeletal disorders (MSDs), as well as adverse health effects from noise, silica, and other exposures.

Construction work is demanding and labor-intensive, involving significant manual material handling and awkward postures in challenging environments on dynamic work sites. Many of the building trades require skilled workers who are sometimes in short supply [CPWR 2018b].

Recent research demonstrates that workers and workplaces are impacted by the opioid crisis. According to the National Survey of Drug Use and Health, an estimated 4% of respondents age 18 years or older reported illicit opioid use in 2017, and an estimated 67% of these self-reported users were employed [SAMHSA 2018]. Prescription opioids may be both a personal risk factor for and a consequence of work-related injury. [Kowalski-McGraw et al. 2017].

The opioid crisis impacts construction workers more than other occupational groups. Construction workers have been commonly prescribed opioids to treat pain associated with MSDs and injuries [Thumula and Liu 2018], contributing to the opioid overdose epidemic. In 2007–2012, the percentage of opioid-related overdose deaths was higher in construction than the percentage of opioid-related overdose deaths in all occupation groups combined [Harduar Morano et al. 2018]. A recent analysis of data from the Bureau of Labor Statistics' Census of Fatal Occupational Injuries similarly found that the construction industry had high numbers and rates of drug overdose deaths at work compared to other industries [Tiesman et al. 2019]. Studies in Massachusetts and Ohio reported opioid overdose deaths among constructions workers that were 6 and 7 times higher than for other workers [Massachusetts Department of Public Health 2018; CPWR 2018a]. In another study, over half of those who died from an overdose had suffered at least one job-related injury [Cheng et al. 2013].

Misuse of illicit drugs and other substances is a public health problem that also affects the workplace. Numerous studies have documented the adverse impact of illicit drug and alcohol use (including heavy drinking) on workers [Wiebe 1995]. These negative outcomes can include absenteeism, turnover, accidents, reduced performance and productivity. This problem has had a greater impact on the construction industry and its workers than many other industry sectors. Studies of this issue have looked at prevalence of use and high-risk industries, demographic variables, the impact (including links to workplace accidents), and how employers have responded [Wickizer et al. 2004; Pidd et al. 2011; Cook et al. 2004].

Need

Surveillance is a significant part of the national response to the opioid crisis. Data collection and analyses related to prescription drug (incl. opioids), illicit drug, and substance use/misuse in construction are needed. A better understanding of the work-related factors and exposures that occur in construction and may increase the use of these substances would be helpful. There are many questions about the impact of substance use and misuse on construction workers and the work they do, the role of the work environment on use and misuse, and the effectiveness of employer-based interventions. Epidemiologic analyses of federal, state, and local data are needed to identify work-related factors, trends, and to evaluate prevention efforts. The following databases and data sources are promising: workers' compensation systems, prescription drug monitoring programs, emergency medical services runs, emergency department data, medical examiner data, data from ESOOS (Enhanced State Opioid Overdose Surveillance) and SUDORS (State Unintentional Drug Overdose Report System), and employer data. Methodologic challenges include: absence of validated survey instruments and questions about occupational exposures; absence of data on work-relatedness and work context in many systems; unstructured narrative data; improving data timeliness; database linkages to maximize the quality and utility of data on work and opioids; identifying type(s) of opioids, and whether use was licit or illicit; and assessing a range of outcomes for workers and employers (e.g. injuries, absenteeism, economic costs, mental health impacts). Potential areas

of research include: teasing out temporal associations between construction work factors and substance use/misuse; and assessing the effectiveness of efforts by construction employers, unions, and communities to reduce the impacts of substances on construction workers and workplaces.

Intervention research is needed to evaluate the determinants and consequences of existing and new employer-based interventions to reduce use/misuse of prescription drugs (incl. opioids), illicit drugs, and substances. Evaluation of these interventions should consider their effectiveness in reducing use of these substances and ultimately the impact on workplace safety and health including potential links to traumatic injuries. Such efforts might consider the business case for safety, owner and management commitment to safety, and novel work arrangements and their impact on leading and lagging indicators of safety and health. Translation research is needed to disseminate barriers and aids to implementation of proven effective interventions to reduce use/misuse of prescription drugs (incl. opioids), illicit drugs, and other substances and the impact on traumatic injuries. Findings from this research need to be incorporated into standards, guidance and other influential documents. There is also a need to translate research findings into software products, applications and interactive webpages, short videos, and other communication products to maximize its impact on construction stakeholders.

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Healthcare and Social Assistance/Traumatic Injury Prevention (HSAxTIP)

Participating core and specialty programs: Center for Direct Reading and Sensor Technologies, Safe•Skilled•Ready Workforce, and Surveillance

Intermediate Goal 6.4 (Injuries caused by patients [human and animal]):

Employers, workers, and professional associations use NIOSH information to prevent injuries among high-risk healthcare and social assistance workers.

	Health Outcome	Issue	Worker population*	Research needed
A	Non-fatal injuries	Injury risk factors (broadly)	Home healthcare workers (esp. those in non-standard work arrangements and other vulnerable workers)	Basic/etiologic Surveillance Research
B	Fatal and non-fatal injuries	Violence prevention	Nursing homes (esp. those in non-standard work arrangements and other vulnerable workers)	Intervention
C	Fatal and non-fatal injuries	Violence prevention	Home healthcare (esp. those in non-standard work arrangements and other vulnerable workers)	Basic/etiologic Surveillance research
D	Non-fatal injuries	Injuries caused by animals	Veterinary and animal care workers	Basic/etiologic

*See definitions of worker populations

Activity Goal (Basic/Etiologic Research) 6.4.1: Conduct basic/etiologic research to better understand the burden of non-fatal injuries in healthcare and social assistance and associated risk factors, particularly in home healthcare and veterinary/animal care.

Activity Goal (Intervention) 6.4.2: Evaluate the effectiveness and cost-effectiveness of interventions designed to prevent injuries due to violence among nursing home workers.

Activity Goal (Surveillance Research) 6.4.3: Identify new or improved surveillance methods, sources or tools to determine the burden of injuries (including violence) to home healthcare workers.

Burden

Interactions between healthcare and social assistance (HCSA) workers and their patients (human or animal) can result in injury due to acts of violence (in human healthcare) or due to kicks, bites, or scratches (in veterinary medicine/animal care). From 2002–2013, incidents of serious workplace violence (those requiring days away from work) were four times more common in human healthcare than in private industry on average. In 2013, the HCSA sector had 7.8 cases of workplace violence resulting in days away from work per 10,000 full-time employees. Eighty percent of these injuries were caused by patients. These figures likely underestimate the problem, since many violent incidents go unreported [OSHA 2015]. In the last 10 years, the number of workers employed in temporary or non-standard work arrangements has increased [BLS 2017; Nicholson 2015]. Industries with higher risk of fatal and non-fatal injuries are where many of these types of work arrangements exist (i.e. home healthcare, nursing homes). Veterinary medicine and animal care workers can also be injured by their patients. A survey of certified veterinary technicians found that 53% were injured in the past 12 months.

Among the most severe injury events reported were bites, cuts, lacerations and scratches that were a result of animal restraint and treatment. Six hundred bite injuries were reported among 873 certified veterinary technicians in the past 12 months with 353 (40%) reporting at least one bite injury event [Nordgren et al. 2014].

Need

Research to improve surveillance to address underreporting and misclassification of injuries (including injuries related to violence) is needed to better identify trends and modifiable risk factors across socio-demographic groups and within subsectors of HCSA. Specific populations of interest include workers in veterinary and animal care, home health care, nursing homes and vulnerable groups in these settings. As many workers in the HCSA sector work in non-standard work arrangements, research is needed to understand the occupational health risks involved in working in such arrangements. New or improved surveillance methods may be necessary to evaluate these groups. Research developing interventions in these settings and for these populations and evaluating their effectiveness and cost-effectiveness in reducing worker risk, including risk related to violence, is crucial.

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Manufacturing/Traumatic Injury Prevention (MNFxTIP)

Participating core and specialty programs: Center for Maritime Safety and Health Studies, Center for Occupational Robotics Research, National Center for Productive Aging and Work, and Safe•Skilled•Ready Workforce.

Intermediate goal 6.5 (Machine-related injuries):

Safety and health professionals, employers, labor organizations, standard setting bodies, and robotics manufacturers use NIOSH information to prevent injuries related to human-machine interaction among manufacturing workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	**Fatal and non-fatal injuries**	**Contacts with traditional machines**	**Many manufacturing workers (especially those using assembly lines and conveyor belts), vulnerable workers, workers with non-standard work arrangements**	**Intervention Translation**
B	Fatal and non-fatal injuries	Emerging technologies (e.g., robotics, advanced manufacturing)	Workers who interact with emerging manufacturing technologies	Basic/etiologic Intervention
C	Fatal and non-fatal injuries	Codes and other methods needed to identify robot-related injuries	Workers who interact with emerging manufacturing technologies	Surveillance research

*See definitions of worker populations

Activity Goal 6.5.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand the relationship between emerging automation technologies (such as collaborative robots) and injuries (or injury reduction) among manufacturing workers.

Activity Goal 6.5.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent machine-related injuries among manufacturing workers.

Activity Goal 6.5.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective interventions to prevent injuries from contact with traditional machines among manufacturing workers.

Activity Goal 6.5.4 (Surveillance Research): Conduct surveillance research to develop new methods to identify robot-related injuries among manufacturing workers.

Burden

In 2015, among over 15 million U.S. manufacturing workers, traumatic injury incidents led to 353 fatalities and approximately 425,700 non-fatal injuries, of which 122,610 involved missed work days [BLS 2016a,b,c]. One of the leading causes of fatal and non-fatal injuries was interaction with machines. The highest risk machines were: material and personnel handling machinery (e.g., conveyors and cranes); and metal, woodworking, and special material machinery. In addition to traditional machinery-related injuries, rapid advances in automation technologies (e.g., fixed robots, collaborative and mobile robots, and exoskeletons) have introduced additional, less understood sources of workplace hazards in manufacturing workplaces. Despite limited occupational surveillance data, 61 robot-related workplace fatalities were reported between 1992 and 2015 [Division of Safety Research 2017]. The robotics industry has predicted a worldwide increase in adoption of industrial robots and they estimated 1.4 million new robot installations in factories worldwide [IFR 2016]. Manufacturing workplaces adopting emerging technologies may expose workers, particularly vulnerable workers or those with non-standard work arrangements, to higher risks of injury or death associated with unfamiliarity of emerging technologies or safety practices. For instance, in 2016, both an auto parts supplier and a staffing agency were fined for failing to follow established safety practices in the death of a 20-year-old temporary worker involving a robot-related incident [OSHA 2016].

Need

To reduce the national burden related to incidents involving traditional machines in the manufacturing industry, continued research is needed on intervention and dissemination strategies to promote safe machine control and maintenance procedures, and on translating effective evidence-based interventions into workplace practice. Research efforts also are needed on tracking and preventing injuries and fatalities among 1) vulnerable workers or workers in non-standard work arrangements; and 2) worker populations who utilize or interact with machinery for material handling (e.g., conveyors) and processing (e.g., metal or woodworking machines). Rapid growth in the use of robotics and other emerging manufacturing technologies are likely to introduce new risks or exacerbate existing risks to workers due to potential unforeseen hazards, unanticipated human-robot interaction consequences, and lack of experience with new automation machines in varied work settings. There is a need to expand U.S. occupational injury surveillance capabilities to better identify, monitor, and quantify the burden of fatal and non-fatal incidents involving robots (e.g., development of new source or event codes). Scarce robotics safety research exists and has not specifically addressed the safety of new types of robots (such as collaborative and mobile robots) in work environments. Systematic studies are needed on the impacts of personal, environmental, and task-related risk factors on worker injuries associated with robots as well as evidence-based interventions for robotics safety.

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Mining/Traumatic Injury Prevention (MINxTIP)

Participating core and specialty programs: Center for Direct Reading and Sensor Technologies, Center for Occupational Robotics Research, Prevention through Design, and Translation Research.

Intermediate goal 6.6 (Machine-related injuries):

Industry, academia, other government agencies, and standard setting bodies adopt workplace solutions to reduce machine-related injuries among mining workers.

	Health Outcome	Research Focus	Worker Population	Research Type
A	Fatal and non-fatal injuries	Striking incidents in confined spaces	Underground mines (esp. coal)	Intervention
B	Fatal and non-fatal injuries	Collision avoidance, human interaction, automation	Surface mines (esp. metal/non-metal)	Intervention
C	Fatal and non-fatal injuries	Conveyance system maintenance	Stone, sand and gravel mines	Intervention
D	Fatal and non-fatal injuries	Use of automation, robotics and emerging technologies	Surface and underground mines	Basic/etiologic Surveillance research

Activity Goal 6.6.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand the relationship between automation, robotics and other emerging technologies and injuries among mining workers.

Activity Goal 6.6.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to reduce machine-related injuries among mining workers.

Activity Goal 6.6.3 (Surveillance Research): Conduct surveillance research to develop new methods to identify automation and robot-related injuries among mining workers.

Burden

According to the Mine Safety and Health Administration Accident/Injury/Illness database, a total of 871 fatalities occurred in mining from 2000–2015 [MSHA 2017a]. Of this total, 48% (419) were related to machinery or powered haulage, with striking and pinning the most common cause of death. Other causes of fatalities included entanglements with conveyor systems (especially for tasks associated with machine maintenance, repair, or cleanup), as well as entanglements and falls from heights during equipment maintenance.

The mining sector is undergoing a major change as mining companies are looking to gain a competitive advantage using automation, robotics, and other “smart mine” technologies. The resulting complex software-based mining systems can eliminate or reduce some risks associated with traditional mining systems, but potentially introduce new risks and increase some existing risks. Accidents involving mobile autonomous and semi-autonomous vehicles have occurred that include an autonomous haul truck colliding with a water truck and a grader, and a blast hole autonomous drill rig reversing direction and colliding with a stationary blast hold drill rig while in remote control. These safety issues will increase because the smart mining market is anticipated to increase at a compound annual growth rate of 14.5%, and create $13 billion in revenues [Future Market Insights 2017].

Need

There is need to conduct research on machinery and powered haulage safety. There exist opportunities to advance development of technologies and sensors to further reduce mine worker exposure to hazardous conditions using robotics and automation of processes and equipment in mining. Research into how sensor technologies could be used to eliminate fatal injuries resulting from unwanted events between machines/equipment and personnel as well as eliminate exposure-related health issues. Investigating the human system integration elements of capabilities/limitations and administrative/behavioral considerations associated with their implementation for automation remains a critical need of the mining industry.

Intermediate goal 6.7 (Ground control-related injuries)

Industry, academia, and other government agencies adopt design procedures and workplace solutions to reduce ground control-related injuries among mining workers.

	Health Outcome	Research Focus	Worker Population	Research Type
A	Fatal and non-fatal injuries	Striking injuries from roof/back and rib failures	Underground (metal/non-metal, coal, stone)	Intervention
B	Fatal and non-fatal injuries	Entrapment/massive support failure	Underground (metal/non-metal, coal, stone)	Intervention
C	Fatal and non-fatal injuries	Failure of gas well casing	Underground coal mines, rig workers at oil and gas wells	Intervention
D	Fatal and non-fatal injuries	Striking injuries from high wall failures	Surface (metal non-metal, coal, stone)	Intervention

Activity Goal 6.7.1 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to reduce ground control-related injuries among mining workers.

Burden

From 2000–2015 there were 125 ground control related fatalities. Of those 125 fatalities, there were 89 underground and 11 surface coal fatalities, and 20 underground and 5 surface metal/non-metal fatalities, respectively [MSHA 2017b]. Although the total number of mines, miners, fatalities, and injuries has been on a downward trend in the recent past, the near misses, injuries, and fatalities associated with and attributable to ground control failures are distributed amongst the following failure types: rib falls, roof falls, massive collapses, burst, bumps, back failures, dynamic failures, skin failures, highwall failures, slope failures, pillar failures, rock outbursts, insufficient barrier pillars, insufficient standing support, and intrinsic support.

Need

To address the ground control related fatalities and injuries, intervention research is needed. There are several areas where an enhanced understanding of the physics, causal factors, and effects of various activities, underground designs, and conditions utilizing “state of art” assessment techniques are needed. One of the largest knowledge gaps is the physical properties of the strata surrounding the mine opening that contributes significantly to the stability of the openings and need for additional support. Although significant advancements in the understanding of bursts have been made, investigations of underlying factors and trigger events leading to bursts have yet to be conducted. The most current techniques of laboratory testing, field instrumentation, and field observations provide improved input parameters and develop improved expected outcomes. Enhanced

numerical modeling and statistical analysis techniques provide for expanding the empirical dataset and improving methods, best practices, and risk levels. Previous projects conducted by NIOSH have investigated these problems/gaps through past research methods, and future projects will continue to improve miner safety through refined models and more comprehensive risk assessments. The new information combined with the historical research conducted by NIOSH and the U.S. Bureau of Mines provide the best opportunity to eliminate mining injuries and fatalities related to ground control failures.

Intermediate goal 6.8 (Traumatic injuries associated with fires and explosions):

Industry, academia, and other government agencies adopt design procedures and workplace solutions to reduce traumatic injuries associated with fires and explosions among mining workers.

	Health Outcome	Research Focus	Worker population	Research Type
A	Fatal and non-fatal injuries	Technology to improve successful mine worker self-escape	Underground coal and metal/non-metal	Intervention
B	Fatal and non-fatal injuries	Refuge alternatives and sensor systems	Underground coal and metal/non-metal mines	Intervention
C	Fatal and non-fatal injuries	Ventilation to limit/control methane levels	Underground coal and gassy non-coal mines	Intervention
D	Fatal and non-fatal injuries	Explosion propagation	Underground coal mines	Intervention

Activity Goal 6.8.1 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to reduce traumatic injuries associated with fires and explosions among mining workers.

Burden

Since 2000, 64 U.S. mine workers have been killed and 10 injured as a result of fires or explosions in underground workings [MSHA 2017c]. A rise in the number of injuries and fatalities since 2000 has prompted concerns into the causes and preventability of these accidents. These events may affect every underground worker in the mine, necessitating their rapid self-escape. In direct response to deficiencies in coal miner readiness to self-escape revealed during the 2006 mine disasters, Congress passed the Mine Improvement and New Emergency Response Act of 2006 (MINER Act), which strengthened already existing safety and health training requirements (30 CFR, Parts 46 and 48) and introduced new measures aimed at improving emergency preparedness and response in underground coal mines. This legislation resulted in a strong and steady demand for improved self-escape training methods and materials. The National Academy of Sciences compiled a comprehensive report that identifies a compelling set of recommendations for improving the effectiveness of self-escape from underground coal mines [NAS 2013]. When miners are unable to escape a mine following a disaster, refuge alternatives (RAs) become a critical survival tool by providing breathable air, water, food, and supplies. Although RAs have been required in underground coal mines for nearly 10 years, knowledge gaps exist in integrating RAs into mining environments.

Need

Major contributors to the scale of fires and explosions are coal dust and methane. All underground coal mine surfaces are required to be rock dusted, but no standard protocol exists by which inerting performance of a rock dust can be systematically evaluated. Effective ventilation is critical to controlling the large amounts of methane gas liberated during mining, where specific areas of concern include the bleeders and the longwall tailgate corner. Mine monitoring remains one of the most important means to safeguard the health and safety of the mineworker; yet sensors must be properly deployed to maintain the effectiveness of a monitoring system and the utility of the information it provides. Sensor deployment strategies must be developed and evaluated using performance-based metrics to afford the greatest effectiveness in early detection of a combustion incident.

While some significant progress has been made for self-escape, the industry is still lacking evidence-based data relating to the effectiveness of emergency response and self-escape training strategies. Field activities are needed to characterize the mine emergency escape system and determine the current state of self-escape competency training and assessment. Based on the results of this work, interventions to increase mine escape competencies can be improved and/or developed and assessed.

Knowledge gaps exist related to understanding heat and humidity accumulations inside an occupied RA. One such gap is the application of air delivery/conditioning systems to maintain life sustaining environments especially in deep and hot mines. Another is the use of purging mechanisms to eliminate contaminants. Communications between surface personnel and underground miners is especially important at strategic locations such as RAs due to their role in mine rescue efforts. Hence, research is needed on signal propagation in and out of various types of RAs to determine best practices for integration of communications and electronic tracking systems to provide coverage at the RA.

Intermediate Goal 6.9 (Excessive heat exposure):

Industry, academia, other government agencies, and standard setting bodies adopt workplace solutions to reduce illness and traumatic injuries associated with excessive heat exposure.

	Health Outcome	Research Focus	Worker population	Research Type
A	Fatal and non-fatal illness	Effects of heat strain (e.g., syncope, exhaustion, stroke)	All mining (esp. underground)	Basic/etiologic Intervention
B	Fatal and non-fatal injuries	Injuries as a result of diminished attention, awareness, etc.	Surface and underground mines	Basic/etiologic Intervention

Activity Goal MINxTIP 6.9.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand the current prevalence of heat stress/strain and contributing factors for injury among mining workers.

Activity Goal MINxTIP 6.9.2 (Intervention Research): Conduct studies to assess factors affecting cognitive functions as an indicator of excessive heat exposure; develop and assess the effectiveness of interventions to reduce the effects of heat stress and related injuries among mining workers.

Burden

Heat stress is likely a contributing factor to fatal and nonfatal injuries in the mining industry. Heat stress refers to the total heat load placed on the body from external environmental sources and from physical exertion. Miners exposed to excessive heat may be at higher risk of work-related injury. Studies have demonstrated increasing injury rates and unsafe work behaviors with increasing heat exposure [Fogleman et al. 2005; Knapik et al. 2002; Ramsey et al. 1983; Xiang et al. 2014]. Heat strain can also lead to adverse heat-related conditions of varying severity (e.g., heat syncope, heat rash, heat exhaustion, heat stroke). The burden of heat stress and heat illness in U.S. mining is unknown given underreporting, lack of formal surveillance systems for health and injuries among miners, and few U.S.-based studies of heat stress in mining. An analysis of Mine Safety and Health Administration data calculated the crude incidence of reported heat illness by mine sector and type during 1983−2001 and found 538 reported cases of heat illness associated with a total of 1,294 lost work days, averaging 2.4 lost work days per case. Further supporting the notion of underreporting in U.S. mines, a cross-sectional study estimated that 87 and 79% of Australian surface and underground miners, respectively, reported having experienced at least one heat illness symptom in the prior year, and over 80% of symptoms occurred on more than one occasion [Hunt et al. 2013].

Need

Although mines recognize the need to study heat strain among miners, most mines do not have the resources to perform comprehensive studies of heat strain that include cognitive changes, physiologic and environmental measurements, and personal risk factors. Three mines and one mine rescue team approached NIOSH for assistance with heat stress in 2016. Requests included heat stress education for miners and health and safety managers, underground heat surveys to evaluate areas with the highest heat exposure, and assistance with development of methods to predict heat strain among miners.

Many workplaces have designated the use of specific heat indices to determine thermal conditions (i.e. air temperature, radiant temperature, humidity, and air speed) that are unsafe for workers. Each heat index currently used in mining has limitations and its own ideal environmental application, and it is not clear which heat indices (if any) are appropriate for use in mining, and if they need to be task- and location-specific. Current heat indexes also do not account for the considerable variability between individuals in their tolerance to heat or include enough personal risk factors [Donoghue and Bates 2000; Donoghue et al. 2000; Kampmann and Bresser 1999; Lutz et al. 2014; NIOSH 2016].

Several facets of heat stress research have been identified by NIOSH as requiring further understanding in order to provide proper and effective guidance. These include: (1) heat exposure duration and patterns (e.g., intermittent vs constant exposure), (2) relationship of core body temperature and heat illness as a function of exposure time, (3) validation of personal monitoring methods, and (4) epidemiology studies to evaluate heat-related outcomes such as heat illness, productivity, and injuries [NIOSH 2016]. Studies under both controlled conditions and real-world mining conditions are needed to evaluate the effects of heat exposure on miners' performance, assess which mining jobs are at highest risk of impact from heat exposure, determine the most appropriate cognitive tests for the mining environment, and investigate the effectiveness of designed solutions.

Intermediate Goal 6.18 (Slips, trips, and falls):

Industry, academia, and other government agencies adopt workplace solutions that enable mines to remediate risk factors for slips, trips, and falls.

	Health Outcome	Research Focus	Worker population	Research Type
A	Non-fatal injuries	Environmental slip, trip, and fall hazard identification and recognition	Underground mining; surface stone, sand, and gravel; mineral processing plants; coal preparation plants	Basic/Etiologic Intervention
B	Non-fatal injures	Develop and evaluate tools to identify, recognize and remediate slip, trip, and fall hazards	Surface stone, sand, and gravel; mineral processing plants; coal preparation plants	Intervention

Activity Goal MINxTIP 6.18.1 (Basic/Etiologic Research): Conduct basic/etiologic studies to determine environmental factors associated with slips, trips, and falls in the mining industry.

Activity Goal MINxTIP 6.18.2 (Intervention Research): Conduct intervention studies to develop and assess the effectiveness of tools and interventions to allow mine workers to identify and remediate slip, trip, and fall hazards.

Burden

Slips, trips, and falls (STFs) of a person are the second largest contributor to nonfatal injuries in the U.S. mining industry. Slips, trips, and falls accounted for 20.6% of nonfatal injuries and led to 2,442,404 days lost from work during the period from 2006 to 2015. Slips, trips, and falls also lead to fatalities, and accounted for the deaths of 55 miners at surface coal and surface metal/nonmetal facilities between 2006 and 2015 [Weston et al. 2016]. Publicly available MSHA reports describing fatalities at surface mining facilities [MSHA 2018] reveal that laborer, equipment operator, mechanic/maintenance man, and truck driver were the job categories associated with a large proportion of fatalities. Maintenance and repair, installation, construction, and dismantling have been shown to be hazardous tasks, and were also found to result in STF fatalities. The most common contributing factor was the lack of adequate fall protection or inappropriate use of a personal fall arrest system. Inadequate barriers, equipment-related factors, and a lack of adequate operating procedure were also identified as contributing factors.

Need

Although well established as a major source of injury, STF hazards are still widespread in the mining industry. Several factors contribute to workplace STFs, including environmental factors such as inadequate lighting and poor housekeeping, personal factors such as not maintaining three points of contact when climbing ladders or wearing fall protection, and equipment-related factors such as limited equipment access and damaged or poorly designed ingress/egress systems. There are few mining-specific resources available that can be readily used to prevent STFs at mine sites. Hence, there is a need to investigate and provide recommendations and tools to identify and remediate the environmental, personal, and equipment-related factors that contribute to STF injuries and fatalities in mining.

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Oil and Gas Extraction/Traumatic Injury Prevention (OGExTIP)

Participating core and specialty programs: Center for Motor Vehicle Safety, Center for Direct Reading and Sensor Technologies, Safe•Skilled•Ready Workforce, Small Business Assistance, Surveillance, and Translation Research.

Intermediate goal 6.10 (Motor vehicle crashes):

Professional associations, insurers, employers, workers, and other government agencies use NIOSH information to prevent motor vehicle crashes among oil and gas extraction workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	Fatal and non-fatal injuries	Refine understanding of MV risk factors (e.g., commuting, risk tolerance, road type and rural worksites, driver distraction, work organization)	Well servicing contractors, drilling contractors, small businesses	Basic/etiologic
B	Fatal and non-fatal injuries	Exploring new data sources and data linkage	All oil and gas extraction workers	Surveillance research
C	Fatal and non-fatal injuries	Interventions (e.g., technologies like IVMS, safety management)	Well servicing contractors, small businesses	Intervention
D	**Fatal and non-fatal injuries**	**Seatbelts, fatigue prevention**	**Well servicing contractors, small businesses**	**Translation**

*See definitions of worker populations

Activity Goal 6.10.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand motor vehicle crash risk factors for oil and gas extraction workers.

Activity Goal 6.10.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent motor vehicle crashes and resulting injuries among oil and gas extraction workers.

Activity Goal 6.10.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective interventions to prevent motor vehicle crashes and resulting injuries among oil and gas extraction workers.

Activity Goal 6.10.4 (Surveillance Research): Conduct surveillance research to explore new sources for motor vehicle crash data for oil and gas extraction workers.

Burden

The oil and gas extraction industry employs approximately 541,000 workers (2015) and suffers from a high rate of occupational fatalities from all causes. According to the Bureau of Labor Statistics, 1,422 workers were killed on the job during 2003−2015, resulting in a fatality rate of 24.1 per 100,000 workers. Transportation incidents were the leading cause of death to oil and gas extraction workers, resulting in nearly 600 deaths (42%) over the same time period. The majority (80%) of these incidents were motor vehicle crashes [BLS 2017]. Half of the oil and gas extraction workers who died in motor vehicle crashes were not wearing a seat belt and were occupants

of light-duty vehicles (primarily pickup trucks). Risk is highest among workers of well-servicing companies and establishments with fewer than 20 employees [Retzer et al. 2013]. Nearly every worker in the oil and gas extraction sector drives as part of their job. Well sites are often located in remote locations, requiring workers to drive on rural roads which may lack safety features such as lighting, guard rails, and adequate road grading. Workers also often travel long distances from their homes to work sites and between work sites, putting them at increased risk of fatigue and at increased risk of crash involvement and injury [CDC 2015]. Long hours and shift work are typical; 12-hour shifts for two or more consecutive weeks are common.

Need

Available data, previous NIOSH research, and information collected from stakeholders have all identified the need for focused research and prevention activities to prevent motor vehicle crashes in this high-risk industry. Management of motor vehicle safety risks in this industry depends largely on the development, implementation, and enforcement of strong employer policies that cover light-duty vehicles (pickup trucks) because the coverage of these vehicles by state or federal safety requirements specific to driving for work is very limited. Research is needed to build an evidence base for effective road safety interventions. Interventions should address known risk factors for motor vehicle crashes, such as driver fatigue and distraction, seat belt non-compliance, shift work, long hours of driving for work, and long commutes. Interventions may take the form of administrative or management controls such as journey management programs, fatigue management programs, and driver training; or technology-based interventions such as in-vehicle monitoring systems (IVMS) and fatigue detection systems. In this industry, intervention and translational research are the most critical for reducing crashes, injuries, and fatalities. There is also a need for basic/etiologic research to better understand risk factors for crashes and surveillance research to identify novel methods for identifying and linking crash data for this worker population.

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Public Safety/Traumatic Injury Prevention (PSSxTIP)

Participating core and specialty programs: Center for Occupational Robotics Research, Center for Workers' Compensation Studies, Center for Motor Vehicle Safety, Center for Direct Reading and Sensor Technologies, Health Hazard Evaluations, National Center for Productive Aging and Work, Surveillance, and Translation Research

Intermediate goal 6.11 (Motor vehicle crashes):

Public safety department management, labor organizations, workers, and consensus standard organizations adopt interventions based on NIOSH research to prevent motor vehicle incidents and resulting injuries among public safety workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population	Research Type
A	**Fatal and non-fatal injuries**	**Collision as vehicle occupant (including fatigue as a risk factor)**	**Law enforcement, fire service and emergency medical service (EMS) subsectors**	**Intervention Translation**
B	**Fatal and non-fatal injuries**	**Struck-by on the side of the road**	**Fire service and EMS subsectors**	**Intervention Translation**
C	**Fatal and non-fatal injuries**	**Struck-by on the side of the road**	**Law enforcement subsector**	**Intervention Translation**

Activity Goal 6.11.1 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent motor vehicle collisions, roadside struck-by incidents, and resulting injuries among law enforcement, fire service, and EMS workers.

Activity Goal 6.11.2 (Translation Research): Conduct translation research to understand barriers and aids to disseminating and implementing effective interventions to prevent motor vehicle collisions, roadside struck-by incidents, and resulting injuries among law enforcement, fire service, and EMS workers.

Burden

Over 3.2 million people are employed in occupations in the public safety sector in the U.S. Public safety employees, particularly those engaged in law enforcement, firefighting, and emergency medical service (EMS), have substantial workplace exposure to road traffic hazards, often in emergency situations. Motor vehicle crashes (MVCs) are the leading cause of fatal occupational injuries in the U.S., accounting for 37% of all fatalities in 2015 [BLS 2016a] and among public safety workers, MVCs account for 44% of all fatalities [BLS 2016b]. Law enforcement officers were involved in the highest number of fatal MVCs (n=48), followed by firefighters (n=8) and EMS workers (n=8) [BLS 2016b]. Most of the incidents were due to collisions with other vehicles while the decedent was a vehicle occupant, but 25% occurred when a public safety worker was struck by another vehicle while working outside their vehicle [BLS 2016b]. Risk factors for MVCs involving public safety workers include non-use of occupant restraints, unsafe driving practices, non-use of high visibility clothing, inappropriate incident management, fatigue, and distractions from in-vehicle technology.

Need

In general, MVC risk factors for public safety employees are well-understood. For this worker population, intervention and translation research are the most critical for reducing crashes, injuries, and fatalities. Intervention research is needed because there is limited research to date that has assessed the effectiveness of road safety interventions within the unique operating environments of public safety organizations. Translational research is also important to ensure that information about effective interventions will be accepted and adopted, given the unique cultures of public safety organizations where workers routinely accept risk to help others. Research on implementation of connected vehicle technology may also lead to reduction of MVCs involving public safety workers. NIOSH research that follows the public health model from surveillance through to implementation of effective interventions complements the efforts of other agencies to prevent MVCs and injuries. In addition, NIOSH has built strong working relationships with professional and labor organizations and academic researchers with interest in public safety, increasing the likelihood that NIOSH research results will be adopted.

Intermediate goal 6.12 (Workplace violence):

Public safety and health department management, labor organizations, and consensus standard organizations will adopt interventions based on NIOSH research to prevent injuries among high-risk populations in public safety workplaces.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population	Research Type
A	**Fatal and non-fatal injuries**	**Assault and violent encounters, civil disturbances**	**Law enforcement subsector**	**Intervention Translation**
B	**Fatal and non-fatal injuries**	**Patient assault, bystander violence**	**Emergency medical service (EMS) and fire service subsectors**	**Intervention Translation**
C	**Fatal and non-fatal injuries**	**Violent encounters and daily interactions, bystander violence**	**Corrections subsector**	**Intervention Translation**
D	Fatal and non-fatal injures	Violent encounters related to prescription drug (incl. opioids), illicit drug, and substance use/misuse	Law enforcement, EMS, fire service, and corrections subsectors	Intervention

Activity Goal 6.12.1 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent violence in public safety worksites.

Activity Goal 6.12.2 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective violence-prevention strategies among public safety workers.

Burden

Violence is a leading cause of injury and death for public safety sector workers. Among correctional officers, assaults account for 40% of fatal injuries and 38% of non-fatal injuries occurring in the workplace from 1999-2008 [Konda et al. 2013]. Correctional officers are in close contact with inmates, often work alone and late at night and may experience institutional and organizational factors that may contribute to increased risk for correctional officer violence such as inmate overcrowding, inadequate officer training, and staffing shortages all of which may increase corrections officers' risk of workplace violence [Konda et al. 2012]. Correction officers may also encounter violence when conducting person or cell searches for illicit drugs including opioids. They may also be exposed to violence when responding to inmates under treatment for Opioid Use Disorder (OUD) who may be experiencing withdrawal symptom or when responding to inmate overdose situations where the officer may administer naloxone to reverse the overdose.

While just 8% of emergency medical service (EMS) provider fatalities have been attributed to assaults and violent acts [Maguire and Smith 2013], 67% of nationally registered EMS providers reported experiencing verbal violence and 44% reported experiencing physical violence within a one-year period [Gormley et al. 2016]. Recent research has indicated that many EMS workers are required to respond to calls that involve patients under the influence of alcohol or drugs (such as opioids), violent patients, or patients with weapons [Oliver and Levine 2015; Taylor et al. 2015]. They may also experience violence from patients whose overdose is reversed through naloxone. A substantial proportion of emergency medical services are also provided by the many fire departments within the U.S. [NFPA 2016]. Nationwide, 46% of fire departments report providing basic life

support and 16% providing advanced life support between 2015-2017 [NFPA 2019]. Firefighters are increasingly encountering violence in the varied first responder responsibilities, particularly EMS calls [Dean 2016; Taylor et al. 2016]. The latest NFPA Fireground injuries report shows 7% of injuries were due to assault by a person, animal, or object [Campbell 2016]. While NFPA does not have data on injuries or trends in attacks on firefighters, there were nine murders of firefighters while on duty over the past ten years and 19 over the past 20 years [Fahy 2019].

Among law enforcement officers, assaults accounted for 40% of duty-related fatalities in the last decade according to the National Law Enforcement Officers Memorial Fund [2017]. Regarding non-fatal injuries, 35% of law enforcement officers sought treatment at an emergency department for on-duty injuries due an assault or violent encounter [Tiesman et al. 2018]. Multiple factors impact the risk of assaults for law enforcement officers, including region of the country, type of force used on the suspect, type of call, number of officers on scene, and time of day.

Need

The public safety and emergency response community recognizes that violence-related injuries and fatalities are an important and preventable cause of injury. Risk factors for workplace violence in the public safety sector, however, vary widely based on occupation. Accordingly, preventive strategies are also occupation-dependent**.** Research is limited on effective and realistic strategies to reduce the risk of workplace violence in corrections facilities that take into account the unique work organization factors in this setting. For EMS and firefighters, research is needed to better understand how to protect these workers as they are required to respond to emergency situations. The inherent nature of police work puts law enforcement officers at an elevated risk for physical assault, and evidence-based interventions are needed to reduce risk factors.

Training, protocols, and protective gear all may impact the risk for workplace violence, however, studies on evidence-based strategies to decrease workplace violence incidents in public safety sector employees are rare. Effective safety management systems can play a part in this from the perspective of encouraging workers to report incidents of violence, monitoring those reports, and implementing interventions as appropriate.

Intermediate goal 6.20 (Substance use/misuse):

Employers, workers, professional associations, policy-makers, researchers, and standard setting bodies use NIOSH information to prevent adverse health effects from unintentional occupational exposure to illicit drugs among public safety workers.

	Health Outcome	Research Focus	Worker Population	Research Type
A	Non-fatal injuries	Unintentional occupational exposure to illicit drugs	Law enforcement, fire service, corrections, and emergency medical service (EMS) subsectors	Basic/etiologic Surveillance research
B	Non-fatal injuries	How to respond to potential unintentional occupational exposures to illicit drugs	Law enforcement, fire service, corrections, and EMS subsectors	Intervention

Activity Goal 6.20.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand unintentional occupational exposure to and adverse health effects from inhalation and mucus membrane exposure to illicit drugs among public safety workers.

Activity Goal 6.20.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent adverse health effects from unintentional occupational exposure to illicit drugs among public safety workers.

Activity Goal 6.20.3 (Surveillance Research): Conduct surveillance research to develop new methods and tools to track unintentional occupational exposures to illicit drugs and associated health effects among public safety workers.

Burden

In this context, illicit drugs are defined as drugs that are either (1) illegal to process, sell, and consume, or (2) are legally prescribed by a physician but have either been misused by a patient with a prescription or illegally obtained by or for a person for whom the drug was not prescribed. These include opioids, stimulants, and other drugs. Synthetic opioids, like fentanyl and tramadol are designed to provide pain relief by mimicking naturally occurring opioids such as codeine and morphine. They tend to be highly potent, which means only a small amount of the drug is required to produce a given effect. For example, fentanyl is 100 times more powerful than morphine [CDC 2019a].

The U.S. is in the midst of an opioid crisis. Opioids (including prescription opioids, heroin, and fentanyl) killed more than 47,600 people in 2017, more than any year on record. Thirty-seven percent of all opioid overdose deaths involved a prescription opioid [Hedegaard et al. 2018]. From 2016 to 2017, synthetic opioid-involved overdose death rates increased 45.2% [CDC 2019b]. Reports from law enforcement agencies indicate that synthetic opioid overdoses may be due to illegally made fentanyl. The opioid crisis has grown increasingly complex by co-involvement of prescription and illicit drugs [CDC 2019b]. NIOSH has completed several Health Hazard Evaluations at the request of public safety employers and workers concerned about occupational exposures to opioids and illicit drugs, and mental health impacts associated with responding to the opioid crisis [NIOSH 2019].

Fentanyl and its analogues pose a potential hazard to a variety of responders who could come into contact with these drugs in the course of their work. Possible exposure routes to fentanyl and its analogues can vary based on the source and form of the drug. Responders are most likely to encounter illicitly manufactured fentanyl and its analogues in powder and tablet form. Inhalation and mucous membrane contact are of particular concern. Contaminated personal protective equipment (PPE) can also serve as a source of exposure via contact and aerosol routes.

Exposures could result in lightheadedness, drowsiness, nausea and vomiting, dizziness, often creating the need for medical attention and preventing emergency responders from performing their duties as needed. Effects of opioid intoxication, including the rapid onset of life-threatening respiratory depression, would be the most severe adverse health effects that could be possible after excessive exposure to illicit opioids. There are no established federal or consensus occupational exposure limits for fentanyl or its analogues.

Need

There is a virtual absence of data to describe exposures and risks to workers who may be exposed to illicit drugs by the nature of the work they do, or the environments where they work. This includes law enforcement who respond to crime scenes and emergency response workers, including firefighters, who respond to overdoses. Data are needed to characterize and describe physical risks like potential inhalation, and absorption of opioids through mucous membranes. There is a critical knowledge gap regarding PPE decontamination and cleaning procedures for reusable PPE used in the presence of illicit drugs.

Surveillance research needs to be conducted to develop new procedures, methods, data sources and tools for gathering illicit drug exposure data for public safety workers. Currently, surveillance research is focused primarily on intentional use/misuse of opioids. More work is needed on low-dose exposure assessment and surveillance to fill these research gaps.

Basic and etiological research is needed to better understand the physical health effects of unintentional occupational exposures to illicit drugs. Studies are needed to assess the modes of exposure that are of greatest risk and the effectiveness of interventions to mitigate the potential exposures to illicit drugs among public safety workers.

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Services/Traumatic Injury Prevention (SRVxTIP)

Participating core and specialty programs: Center for Occupational Robotics Research, Center for Workers' Compensation Studies, National Center for Productive Aging and Work, Occupational Health Equity, Safe•Skilled•Ready Workforce, Small Business Assistance, and Surveillance.

Intermediate goal 6.13 (Falls):

Employers, workers, labor unions, insurance companies, and non-governmental organizations adopt interventions to reduce falls among services workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	**Non-fatal injuries**	**Falls on the same level**	**Building services, food services, waste management workers, and travel accommodations subsectors; small businesses; contingent workers and other vulnerable workers**	**Intervention Translation**
B	**Fatal and non-fatal injuries**	**Falls to a lower level**	**Buildings services; small businesses, contingent workers and other vulnerable workers**	**Intervention Translation**

*See definitions of worker populations

Activity Goal 6.13.1. (Intervention Research): Conduct intervention studies to develop and assess the effectiveness of interventions to prevent falls among services workers.

Activity Goal 6.13.2 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective fall prevention interventions among services workers.

Burden

In the services sector, slips, trips, and falls took the lives of 163 workers in the U.S. in 2015 and accounted for about 9% of all occupational fatalities within the service sector [BLS 2017a]. Building and dwellings service (i.e. maintenance and landscape workers), food services and waste management and remediation services, accommodations, and real estate sub-sectors had the highest number of fatalities and/or rates of injuries with days away from work [BLS 2015, 2017b]. Moreover, among these sub-sectors, services to buildings and dwellings recorded a particularly high incidence rate of injuries associated with falls to a lower level (14 per 10,000 full time works).

Work-related injuries and fatalities are known to differ greatly depending on the industry or occupation in which a worker is employed [BLS 2017a, b]. These problems are often exacerbated by the fact that in the services sector, 89% of the 3 million related firms have less than 20 employees and have limited access to safety and health professionals [U.S. Census Bureau, 2011]. In addition, many of these small businesses tend to employ vulnerable workers, such as immigrant or Hispanic workers and contingent workers (i.e. those who do not expect their job to last, such as those employed by temporary staffing companies and contract workers), whose status may be associated with higher occupational injury and illness [Johnson & Ostendorf, 2010; Headd, 2000; Wiatrowski, 1994]. Small businesses have fewer resources to develop safety plans for fall prevention. They are not as likely to have conducted training or purchased appropriate fall protection equipment. Additionally, training for temporary and contract workers on fall protection is often overlooked.

Need

Intervention research is needed to understand, evaluate, and communicate safety, productivity, and latent hazards of emerging work methods (e.g., advanced fall protection technologies, height access devices, drones, and robots) in adopting them in the workplace to reduce slip, trip and fall incidents among building service

(maintenance and landscape workers), food services, waste management, accommodations, and real estate workers. For instance, successful interventions that are used in construction for fall control could be evaluated and redesigned, as needed, for adoption by the building service subsectors.

Research to practice efforts are also needed to develop and communicate evidence-based fall prevention and protective measures and graphics-based guidelines for incorporation into industry practice and safety standards for building service (maintenance and landscape workers), food services, waste management, accommodations and real estate workers. Outreach in creative ways to small businesses, immigrant, and working populations with non-standard arrangements is needed to reduce falls.

Translational research focusing on expanding the use of proven interventions across diverse high-risk groups is required. This includes assessing barriers to implementing interventions that could include cultural issues as well as small or limited resource companies. Smaller businesses engage in fewer occupational safety and health activities than larger businesses, thus, there is clearly a need for delivering appropriate occupational safety and health assistance to smaller businesses [Sinclair, Cunningham, & Schulte, 2013]. Research is needed to understand risks associated with immigrant workers and workers with non-standard work arrangements. The risks may be a result of lack of knowledge by the worker or non-traditional employer (e.g., homeowner), or perhaps a worker's concern of losing a temporary position.

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Transportation, Warehousing, and Utilities/Traumatic Injury Prevention (TWUxTIP)

Participating core and specialty programs: Center for Maritime Safety and Health Studies, Center for Motor Vehicle Safety, Center for Occupational Robotics Research, Emergency Preparedness and Response, Exposure Assessment, Occupational Health Equity, Prevention through Design, Safe•Skilled•Ready Workforce, and Surveillance.

Intermediate goal 6.14 (Transportation incidents):

Employers, insurers (including workers' compensation), standard setting bodies, other government agencies, manufacturers, professional associations, and labor organizations use NIOSH information to reduce transportation incidents and related injuries among transportation, warehousing, and utilities workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population	Research Type
A	Fatal and non-fatal injuries	Role of work organization (e.g., fatigue, sleep, stress, hours of service, commuting, non-standard work arrangements, distraction)	Truck drivers, bus and transit (e.g., taxi) drivers, maritime workers, couriers and messengers, utilities workers, aviation workers	Basic/etiologic
B	**Fatal and non-fatal injuries**	**Develop evidence-based interventions (e.g., fleet management, administrative controls)**	**Truck drivers, bus and transit (e.g., taxi) drivers, aviation workers, maritime workers**	**Intervention Translation**
C	Fatal and non-fatal injuries	Vehicle design and technology (e.g., highly automated vehicles, connected vehicles, advanced driver assistance systems)	Truck drivers, bus and transit (e.g., taxi) drivers	Basic/etiologic Intervention
D	Fatal and non-fatal injuries	Prescription drug (incl. opioids), illicit drug, and substance use/misuse	Truck drivers, bus and transit (e.g., taxi) drivers, warehouse and utilities workers, maritime workers	Surveillance research Intervention

Activity Goal 6.14.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand the relationships between work organization factors and vehicle design and technology and transportation incidents and related injuries involving transportation workers.

Activity Goal 6.14.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent transportation incidents and related injuries involving transportation workers.

Activity Goal 6.14.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective interventions to prevent fatal and non-fatal injuries due to transportation incidents and related injuries involving transportation workers.

Activity Goal 6.14.4 (Surveillance Research): Conduct surveillance research to develop new tools and methods for collecting data on prescription drug (incl. opioids), illicit drug, and substance use/misuse

and assessing associations with transportation incidents and related injuries among transportation workers.

Burden

In 2015, 29% (615) of all transportation incidents occurred in the transportation, warehousing and utility (TWU) sector, which was the highest percentage among any industry sector. Transportation related incidents represent a high proportion of fatalities in all TWU industry sub-sectors, with the greatest burden in the truck transportation sub-sector at 83% (454 of 546) [BLS 2017a]. The rate of non-fatal days away from work transportation incidents in Transportation and Warehousing was 26.5 per 10,000 workers, 5.5 times the rate for all private industry sectors [BLS 2017b].

Recent research demonstrates that workers and workplaces are impacted by the opioid crisis. Prescription opioids may be both a personal risk factor for work-related injury and a consequence of workplace exposures [Kowalski-McGraw et al., 2017]. A study of workplace overdose fatalities between 2011 and 2016, showed that the transportation and warehousing industries accounted for the highest number (n=116) and rate of death (3.0 deaths per 1,000,000 FTEs) [Tiesman et al 2019]. The use of these drugs may negatively affect the performance of safety-sensitive work tasks such as driving or operating machinery [Manchikant et al. 2012; Hegmann et al. 2014a; Hegmann et al. 2014b]. In addition, several classes of medications have been found to increase the risk of impaired driving: barbiturates, benzodiazepines, certain non-benzodiazepine hypnotics, various antidepressants, opioid and non-steroidal analgesics, anticonvulsants, antipsychotics, antiparkinsonian agents, skeletal muscle relaxants, antihistamines, anticholinergic medications, and hypoglycemic agents [Hetland and Carr 2014].

The organizational structure of work in the TWU sector (e.g., long hours of work, irregular work schedules, non-standard work arrangements, time pressures, long periods away from home, commuting distances, and pay-by-the-mile compensation) can increase work stress and exacerbate risk factors associated with work-related transportation incidents (e.g., fatigue and distraction) [Härmä et al. 2008; NIOSH 2013]. Fatigue is associated with vehicle crashes and disturbances to cognition [Åkerstedt 2000; Marcus and Rosekind 2016; FMCSA 2007]. Highly-automated vehicles hold great promise for reducing these transportation incidents, but fully-automated vehicles will not become commonplace for 20 to 30 years [IIHS 2016], and the next decade is likely to involve a mix of vehicles with varying levels of automation and advanced driver assistance systems. There are questions about the safety of drivers of motor vehicles and operators of planes and ships in this rapidly-changing transportation environment.

Need

For TWU workers, research is needed to better characterize individual-level crash risk factors and adverse incident factors such as fatigued and distracted driving or navigating and impairment caused by both prescribed and illicit drugs. Organizational-level factors such as fleet management, journey management, shift work, training, safety climate, job demands and design, employment arrangements, pay structures, and safety management systems should be considered. Research is needed to characterize the effects of off-the-job factors such as sleep hygiene and health status on work-related driving and navigational safety, and to understand the interrelationship between off-the-job driving (e.g., “mega commutes”) and on-the-job factors (e.g., company driving and crew transportation policies) and motor vehicle safety. Surveillance research is needed to more broadly characterize the burden of prescription and illicit drug use and misuse on workers and workplaces and the role of work organization and employer policies. Intervention research is needed to evaluate the

effectiveness of employer-based interventions to reduce the impacts of substance use and misuse on workers and workplaces. For automated vehicles, research is needed to assess the effectiveness of currently available advanced driver assistance systems in vehicles used by TWU workers and to determine the safety consequences of operating TWU vehicles in an increasingly automated road environment. Evaluations of interventions, including vehicle design, technology, company practices, and laws are needed to focus implementation efforts on those which are most effective.

Intermediate goal 6.15 (Machine-related injuries):

Manufacturers, employers, standard setting bodies, other government agencies, professional associations, and labor organizations use NIOSH information to reduce machine-related injuries among transportation, warehousing, and utilities workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population	Research Type
A	Fatal and non-fatal injuries	Machine-related injuries (e.g., caught-in, struck-by)	Aviation, warehousing, and maritime workers	Intervention
B	**Fatal and non-fatal injuries**	**Machine-related injuries (e.g., caught-between, struck-by)**	**Aviation workers**	**Translation**
C	Fatal and non-fatal injuries	Use of collaborative and mobile robotics	Warehousing, utilities, maritime, and transit (e.g., taxi drivers) workers	Surveillance research Basic/etiologic
D	**Fatal and non-fatal injuries**	**Use of stationary robots**	**Warehousing, utilities, and maritime workers**	**Surveillance research Translation**

Activity Goal 6.15.1 (Basic/Etiologic Research): Conduct basic/etiologic research to better understand relationship between collaborative and mobile robots and fatal and non-fatal injuries among transportation, warehousing, and utilities workers.

Activity Goal 6.15.2 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions for machine-related injuries among transportation and warehousing workers.

Activity Goal 6.15.3 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective interventions to prevent machine related injuries among aviation workers and injuries related to traditional robots among transportation, warehousing, and utilities workers.

Activity Goal 6.15.4 (Surveillance Research): Conduct surveillance research to develop new tools and methods for collecting data on injuries related to robots in the transportation, warehousing, and utilities sector.

Burden

Interactions between workers and machines in transportation, warehousing and utilities (TWU) have been beneficial to the employer and worker by reducing work load and increasing production capabilities. But with these efficiencies have come worker injuries and fatalities. In 2015 in the TWU sector there were 654 vehicle and machine-related fatalities [BLS 2017c]. Heavy and tractor-trailer truck drivers and material moving workers are the groups with leading counts of vehicle and machine-related fatalities [BLS 2017d].

The International Federation of Robotics reports sharp increases in sales, and is projecting that a new type of robot, collaborative robots that work alongside and in conjunction with human workers, will have a market breakthrough in the next several years [IFR 2016]. As robotics and automation integrate into the TWU sector, workers are being tasked with working with these complex systems, such as, ship control systems, automated forklifts and picking machines, and use of drones in warehousing and utilities [Volpe 2012; Banker 2016; Schneider & Deml 2017]. Introduction of these highly automated systems has the potential to improve safety in many areas, but there are increased risks. These systems are highly complicated and more emphasis needs to be placed on operator training and maintenance [Moniz and Krings 2016]. Changes in the roles and responsibilities of the operator introduce increased risk of operator errors especially in the context of unforeseen or atypical events. The current faster pace of technology introduction increases the potential for unforeseen hazards being introduced in the workplace.

Need

Current injury statistics illustrate the need for continued research on the human/machine interface for machines used in today's workplace, and this research will need to be expanded to address future machines and vehicles. Researchers can provide tools to mitigate these hazards, and reduce injuries and fatalities, through hazard identification strategies and hazard mitigation methods, human factors analysis, educational programs on human factors engineering elements for system design for engineers, and integration of human factors engineering principles in technical engineering and design standards [Leva et. al. 2016; Murashov et. al. 2016]. Because robotics and automation are relatively new to the TWU sector, current surveillance systems do not provide readily available data or a real mechanism to tease out the injury and fatality events associated with robotics and automation. Research is needed to identify data for emerging machines including robots and automation, develop and evaluate surveillance tools, and identify emerging safety problems and risk factors. Research is also needed to develop and improve safety engineering features for new types of human-machine interfaces including robots and automated machines. Research should aim to identify safe and effective human-machine interface designs, develop and improve training for human workers, and evaluate and improve standards and policy.

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Wholesale and Retail Trade/Traumatic Injury Prevention (WRTxTIP)

Participating core and specialty programs: Center for Motor Vehicle Safety, Exposure Assessment, Productive Aging and Work, Small Business Assistance, and Translation Research

Intermediate goal 6.16 (Falls):

Employers, insurers, and workers in the wholesale and retail trades adopt effective interventions to prevent injuries due to falls.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	**Non-fatal injuries**	**Falls on the same level (e.g., caused by floor debris, spills, or slipperiness; organization of work)**	**Food and beverage, furniture and home furnishing, lumber, health and personal care, and general merchandise subsectors; aging workers and other vulnerable workers**	**Intervention Translation**
B	**Fatal and non-fatal injures**	**Falls to a lower level (e.g., associated with ladders; organization of work)**	**Merchant wholesalers of durable goods, motor vehicle and parts retailers, and health and personal care stores subsectors; vulnerable workers**	**Intervention Translation**

*See definitions of worker populations

Activity Goal 6.16.1 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions designed to reduce falls among wholesale and retail trade workers.

Activity Goal 6.16.2 (Translation Research): Conduct translation research to understand barriers and aids to disseminating and implementing effective fall prevention strategies among wholesale and retail trade workers.

Burden

The wholesale and retail trade (WRT) sector employs more than 20 million workers [BLS 2017a,b]; this includes not only those who work in sales and material handling, but also those who work in office environments where conditions exist that can cause slips, trips, and falls (STFs). STFs are the second most common cause of lost-workday injuries in general industry [BLS 2016a,b], resulting in injuries of varying severity, including back injuries, sprains, strains, contusions, fractures, severe head injuries, paralysis, and even fatalities. Non-fatal STFs can be severe and disabling, and can result in considerable financial burden and adversely affect quality of life. STFs collectively lead in costs to businesses with over $15 billion dollars in direct costs [Liberty Mutual 2017]. In the WRT sector, STFs are the third most common cause for lost-workday injuries [BLS 2017a]. Two-thirds of the total fall injuries in WRT occur from falls on the same level [BLS 2017a]. STFs are also responsible for 15% of all work-related fatal injuries, the second leading cause of fatalities behind motor vehicles [BLS 2017b] and the third leading cause for this industry [BLS 2017c]. STFs disproportionately affect certain demographic groups. Generally, STFs are the second leading cause of death among Hispanic workers and the third leading cause for Asian workers [BLS 2017d]. In addition, 47% of fatal occupational fall victims are age 55 and above [BLS 2017d].

Need

Several industrial and government entities have called for fall prevention and protection research and practice to control the national STF burden: the Center for Construction Research and Training (CPWR), the Occupational Safety and Health Administration (OSHA), the American Society of Safety Engineers (ASSE), and the National Safety Council (NSC), among others. Over the last 20 years or so, NIOSH research has shown that most STF incidents can be prevented with proper attention to three categories of risk factors: workplace, work organization, and individual or personal factors [NIOSH 2012]. However, very few STF intervention effectiveness studies have been conducted in WRT businesses. The WRT sector is also unique because the retail workers are sharing their work space with the customers, which adds to the spills and clutter often found in food and beverage stores. Future research should include collaborations with insurers, employers, and labor organizations to assess the effectiveness of fall-related prevention strategies. Cost-benefit studies are also needed to demonstrate the economic incentive for equitable adoption of various prevention strategies. The majority of the STF literature often ignores wider systems issues in workplace STF etiology. Future evaluations of interventions should investigate work organization factors that can shape worker behavior patterns related to STFs. Communicating evidence-based STFs prevention and protective measures and graphics-based guidelines for field implementation to be incorporated into industry practice and safety standards is needed to reach all populations, including older and younger workers, workers in non-standard work arrangements, Hispanic workers and workers born outside the U.S.

Intermediate goal 6.17 (Motor vehicle crashes):

Employers, insurers, and workers in the wholesale and retail trades adopt effective interventions to prevent injuries due to motor vehicle crashes.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	**Fatal and non-fatal injuries**	**Motor vehicle crashes**	**Wholesale workers (long distance and local), small businesses**	**Intervention Translation**

*See definitions of worker populations

Activity Goal 6.17.1 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions designed to reduce motor vehicle crashes and resulting injuries among wholesale trade workers.

Activity Goal 6.17.2 (Translation Research): Conduct translation research to understand barriers and aids to disseminating and implementing effective motor vehicle crash prevention strategies among wholesale trade workers.

Burden

Risk of death or injury in a motor vehicle crash (MVC) affects workers in all industries and occupations, whether they drive tractor-trailers, cars, pickup trucks, or emergency vehicles, and whether driving is a primary or occasional part of the job. Although there are no reliable estimates for levels of exposure to motor vehicle-related hazards, it is likely that workers in the Wholesale and Retail Trade sector spend substantial work time driving. For example, retail workers use passenger vehicles for local deliveries. However, the Wholesale Trade sub-sector, where the work involves the regular use of motor vehicles to distribute products, has the greater fatality burden, with MVCs accounting for 45.7% of all fatalities in 2015 compared to 37.3% for all sectors [BLS 2016c]. In 2015, an estimated 31,130 private-industry workers across all industries sustained non-fatal days-away-from-work injuries in work-related roadway incidents, 33.4% of which resulted in 31 or more days away from work [BLS 2016d]. Another source reported that MVCs made up 6.2% of serious non-fatal injuries at work in 2014 and an estimated $3.7 billion in workers' compensation costs [Liberty Mutual 2017].

Need

Although the burden of large-truck (i.e. weighing more than 10,000 pounds) crashes is high, there is a strong infrastructure in the U.S. Department of Transportation (DOT) and university research centers to support trucking safety and regulatory initiatives. Other workers who do a great deal of on-the-job driving (e.g., drivers for motor vehicle and parts wholesalers and dealers) are covered by few federal driver safety regulations. Consequently, research on these populations is limited. NIOSH can make a critical contribution by balancing research on trucking safety that is unlikely to be sponsored by DOT with research focusing on these less-studied populations.

Research is needed to demonstrate effectiveness and cost-effectiveness of a range of interventions to prevent work-related MVCs, from safety management strategies to new technologies. Of particular interest are evaluations of technology and administrative interventions to mitigate known risk factors such as fatigued and distracted driving. These include the evaluation of the effectiveness of highly-automated vehicles (not yet in wide use) and currently-available active safety systems in reducing and preventing crashes. Dissemination research is needed to identify optimum methods for moving evidence-based interventions into workplace practice, in particular where small business establishments are concerned. Those who communicate safety information should consider audience needs based on health and safety literacy, socio-demographic characteristics, and preferred communication channels.

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Strategic Goal 7: Promote safe and healthy work design and well-being

Construction/Healthy Work Design and Well-Being (CONxHWD)

Participating core and specialty program: Safe•Skilled•Ready Workforce, Personal Protective Technology

Intermediate goal 7.1 (Non-standard work arrangements):

Researchers, insurance companies, government agencies, labor groups, and employers utilize NIOSH information in decision-making about designing, structuring, and managing work to reduce illnesses and injuries among construction workers in non-standard work arrangements.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	Respiratory diseases, Musculoskeletal disorders (MSDs), Fatal and non-fatal injuries from falls, Opioid and other substance use disorders, Hearing loss	Better characterize risk factors for workers in non-standard work arrangements	Vulnerable workers, small businesses	Surveillance research
B	**Respiratory diseases, MSDs, Fatal and non-fatal injuries from falls, Opioid and other substance use disorders, Hearing loss, Heat-related illnesses**	**Increase use of safety and health programs and interventions among workers in non-standard work arrangements**	**Vulnerable workers, small businesses**	**Translation**
C	Respiratory diseases, MSDs, Fatal and non-fatal injuries from falls, Opioid and other substance use disorders, Hearing loss, Heat-related illnesses	Develop new cost-effective safety and health programs and interventions for workers in non-standard work arrangements	Vulnerable workers, small businesses	Intervention

*See definitions of worker populations

Activity Goal 7.1.1 (Intervention Research): Conduct intervention studies to develop and assess the cost-effectiveness of new safety and health programs and interventions to reduce illness and injury among construction workers in non-standard work arrangements.

Activity Goal 7.1.2 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective safety and health programs and interventions among construction workers in non-standard work arrangements.

Activity Goal 7.1.3 (Surveillance Research): Conduct surveillance research to better characterize risk factors for construction workers in non-standard work arrangements.

Burden

During the last recession, the construction sector saw a 23% decrease in the number of construction workers [CPWR 2013]. Many workers displaced during the recession are not returning to construction, and an influx of new workers is entering the sector. In 2013, about 1.3 million temporary workers were employed in construction, accounting for nearly 14% of the construction workforce [CPWR 2015]. A growing number of these new entrants have non-standard work arrangements and are new immigrants, or contingent workers. This means that they may belong to one or more vulnerable groups of workers at disproportionate risk for occupational injury or illness. The construction sector has one of the highest shares of workers in non-standard arrangements [Katz and Kruger 2016].

Workers employed through temporary agencies in 2005 were more likely to be African-American and Hispanic [BLS 2005]. Temporary workers, accounted for roughly 13.3% of the construction workforce from 2011−2013, were more likely to be younger than in the overall construction work force during that period [CPWR 2015]. Employment in the construction industry involves relatively short-term contracts. According to CPWR, approximately 30% of construction workers were employed in nonstandard work arrangements; 22% were independent contractors and 8% were in alternative arrangements, including temporary workers, day laborers, on-call workers, and workers provided by contract firms. [CPWR 2015; CPWR 2019]. About 35% of temporary workers were under age 35 years, compared to less than 30% of permanent construction workers in 2011−2013 [CPWR 2015]. Many temporary workers hold multiple jobs, and in 2012 approximately 16% of temporary construction workers were considered poor [CPWR 2015]. Temporary workers are more likely to experience more occupational hazards than permanent workers, including hazards associated with outdoor work, exposure to vapors/gas/dust/fumes, and skin contact with chemical substances [CPWR 2015]. Misclassification as independent contractors can leave temporary workers without access to needed safety and health precautions as well as workers' compensation.

Respiratory disease, musculoskeletal disorders, fatal and non-fatal injuries from falls, hearing loss , and drug overdose deaths are particularly high among construction workers and are priorities for construction sector leadership [CPWR 2013, Tiesman et al 2019]. Construction workers have been commonly prescribed opioids to treat pain associated with MSDs and injuries,[Thumala and Liu 2018] , contributing to the opioid crisis In Ohio, construction workers were seven times more likely than other workers to die from an opioid overdose (2010-2016) [CPWR 2018c] In one study, over half of those who died from an overdose had suffered at least one job related injury [Cheng et al. 2013].

Heat stress is also a problem for the construction sector, with 650 known cases of nonfatal heat-related illnesses and injuries occurring within the sector in 2017 [Acharya et al. 2018, BLS 2018]. Many of these hazardous exposures are more common for temporary construction workers compared to their full-time counterparts [CPWR 2015].

Need

Non-standard work arrangements are understudied but increasingly prevalent, and their determinants and health and safety consequences are poorly understood. NIOSH has been assessing quality of work life for a long time and is well-positioned to examine the determinants and effects of work arrangements. Surveillance research is needed to better characterize and track the complex risk factors and overlapping vulnerabilities for construction workers in non-standard work arrangements, as well as the burden suffered by the workers and their families, employers, and society. Translation research is needed to identify and disseminate barriers and aids to implementation of proven effective safety and health programs and interventions to reduce illness and injury for workers in non-standard work arrangements. Intervention research is needed to evaluate the determinants and consequences of existing and new work arrangements. The focus of such research could include studying the relationship between product and service quality and safety, the business case for safety, procurement practices, owner and management commitment to safety, selection of contractors and subcontractors, the use of temporary employees and independent contractors, and novel work arrangements in construction and their impact on leading and lagging indicators of safety and health. Newly identified risk factors will provide opportunities for innovative intervention research. Findings from this research needs to be incorporated into mandatory and consensus standards, guidance and other influential documents. There is also a need to translate research findings into software products, applications and interactive webpages to maximize its impact on construction stakeholders.

Intermediate Goal 7.11 (*Total Worker Health*®):

Researchers, insurance companies, employers, owners and labor unions effectively integrate protection from work-related safety and health hazards with promotion of injury and illness prevention efforts to advance worker well-being (i.e. *Total Worker Health* [TWH] approach) in the Construction sector.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	**Fatal and non-fatal injuries; illnesses**	**Work and non-work factors that contribute to worker safety, health, and well-being (i.e. *Total Worker Health* [TWH] approach) (e.g., substance misuse, tobacco use, shift work, fatigue, musculoskeletal health, heat stress)**	**All construction workers, especially vulnerable workers**	**Intervention**
B	**Fatal and non-fatal injuries; illnesses**	**Improve data around risks to worker safety, health, and well-being**	**All construction workers, especially vulnerable workers**	**Surveillance research**
C	**Fatal and non-fatal injuries; illnesses**	**Barriers and facilitators to implementing TWH research findings**	**All construction workers, especially vulnerable workers**	**Translation**
D	**Fatal and non-fatal injuries; illnesses**	**Evaluate effectiveness and adoption of TWH polices, practices and programs**	**All construction workers, especially vulnerable workers**	**Intervention Translation**

*See definitions of worker populations

Activity Goal 7.11.1 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions that integrate protection from work-related safety and health hazards with promotion of injury and illness prevention efforts to advance worker well-being in Construction.

Activity Goal 7.11.2 (Translation Research): Conduct translation research to understand barriers and aids to implementing policies, programs, and practices that integrate protection from work-related safety and health hazards with promotion of injury and illness prevention efforts in Construction.

Activity Goal 7.11.3 (Surveillance Research): Conduct surveillance research to better track risks to worker safety, health and well-being in Construction.

Burden

Construction comprises residential and commercial building and heavy and civil engineering (e.g., water and sewer lines, highways, and bridges), and includes specialty trades such as roofing, plumbing, electrical, and drywall. Over 10 million workers are employed in construction in the U.S., and these workers face risks of fatal and non-fatal injuries resulting from falls from elevated surfaces, struck-by incidents, and musculoskeletal disorders, as well as illnesses from noise, silica, and other exposures. Many different adverse health outcomes are particularly high among construction workers and are a continuing and difficult problem [CPWR 2018a].

Construction work is demanding and labor-intensive, involving significant manual material handling and awkward postures. Many of the building trades require skilled workers who are sometimes in short supply [CPWR 2018]. U.S. construction workers are at high risk of traumatic injuries and other adverse health consequences because of inherently dangerous tasks and dynamic conditions that are present on many of construction sites. A growing number of construction workers have non-standard work arrangements (approximately 30% of the industry) and are new immigrants, or contingent workers. Many of them belong to one or more vulnerable groups of workers (small businesses, Hispanic immigrants, young or older workers) at disproportionate risk for occupational injury or illness [Katz and Kruger 2016].

Systemic changes to our economy and socio-demographic workforce factors are rendering some past approaches to protecting workers ineffective. Increasingly, employers in the construction industry face tighter profit margins, demanding timelines and global completion. Workers and employers must navigate new types of work arrangements, the aging of the workforce, high levels of work-related stress, and the growing challenges of both work and home life. Many construction firms continue to confront the legacy hazards of the traditional workplace, such as traumatic injury, chemical exposures, and shift work. Approximately 90% of construction firms are small businesses with fewer than 20 employees. These small businesses often lack adequate time and resources to properly address safety and health. According to CPWR, (from 2003-2016) the rate of fatal injuries for small employers (<20 employees) was significantly higher than for large employers (> 20 employees). Additionally for the same period, the fatality rates have risen for small businesses at the same time they have fallen for large businesses [CPWR 2018b]. Scientific evidence now supports what many safety and health professionals, as well as workers themselves, have long suspected—that risk factors in the workplace can contribute to common health problems previously considered unrelated to work.

Need

Total Worker Health promotes the integration of occupational safety and health (OSH) protection with workplace policies, programs, and practices to prevent injury and illness and advance overall health and well-being through research, interventions, partnerships, and capacity-building to meet the needs of the 21st century

workforce. Evidence suggests that integrating occupational safety and health protection program activities with health promotion program activities may be more effective for safeguarding worker safety, health, and well-being than either of these programmatic activities on their own [Sorensen et al. 2013, NIOSH 2012, DeJoy and Southern 1993, Sauter 2013]. Despite these developments, there is need for continued research to better understand the benefits of integrated approaches to prevention and to promote more comprehensive intervention, especially among certain occupations and industries including construction.

There is a need within the construction industry to better understand the risks to construction worker safety, health, and well-being. This is particularly true for small construction businesses. These risks need to be examined holistically to examine both occupational and non-occupational factors and the interaction between them. Intervention research is needed to improve our understanding of the value of TWH programs, policies, and practices for the construction worker and their ability to improve workplace safety and health outcomes. There is also a need to better understand the barriers and potential aids within the construction industry and organized labor that can adversely impact adoption of TWH approaches that may be beneficial.

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Healthcare and Social Assistance/Healthy Work Design and Well-Being (HSA/HWD)

Participating core and specialty programs: Center for Motor Vehicle Safety, National Center for Productive Aging and Work, Prevention through Design, Surveillance and Translation Research.

Intermediate goal 7.2 (Work organization):

Employers, workers, professional and labor organizations, medical educators and accrediting bodies use NIOSH information to improve occupational safety and health through work design in the healthcare and social assistance sector.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	**Depression, Anxiety, Cognitive impairment, Suicide**	**Fatigue and stress due to suboptimal work organization**	**Healthcare workers, veterinary medicine/animal care (VM/AC) workers; vulnerable workers**	**Intervention Translation**

	Health Outcome	Research Focus	Worker Population*	Research Type
B	Depression, Anxiety, Cognitive impairment, Suicide	Improved surveillance on work practices, work factors (e.g., psychosocial and safety climate), and health outcomes	Healthcare and VM/AC workers	Surveillance research
C	**Fatal and non-fatal injuries**	**Fatigue, stress, work organization as risk factors for motor vehicle crashes during commutes and shifts**	**Residents, interns, and home healthcare workers; others with long hours / irregular schedules**	**Intervention Translation**
D	Depression, Anxiety, Cognitive impairment, Suicide	Stressful social, interpersonal, and situational aspects of work environment (esp. bullying, violence, interpersonal interactions, dealing with traumatic situations such as those involving death and dying, injury, illness, anger, grief, loss)	Healthcare and social assistance workers who directly interact with patients/families, VM/AC workers, small businesses	Intervention
E	**Infectious diseases, Blood borne pathogen infection**	**Safety culture/safety climate/safety leadership**	**Mid-to-small healthcare settings, nursing aides, home healthcare workers, management, VM/AC, other settings where poor adherence to safe practice has been documented**	**Intervention Translation**
F	Depression, Anxiety, Cognitive impairment	Non-standard work arrangements	Healthcare workers	Intervention Surveillance

*See definitions of worker populations

Activity Goal 7.2.1 (Intervention Research): Conduct intervention studies to develop and assess the effectiveness of work design and well-being interventions to reduce injuries and illness among healthcare workers.

Activity Goal 7.2.2 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective work design and well-being interventions among healthcare workers.

Activity Goal 7.2.3 (Surveillance Research): Conduct surveillance research to better track work practices, work factors (psychosocial and safety climate), and health and safety outcomes among healthcare workers, including those in contingent work arrangements and VM/AC workers.

Burden

Work in healthcare (human and animal) and social assistance is often associated with high levels of stress resulting in multiple adverse health and safety outcomes and burnout. The American Nurses Association surveyed 4,614 nurses in 2011 and found that 74% had concerns about the effects of stress and overwork, 24% cited the risk of a fatigue-related crash after a shift as one of their top 3 safety and health concerns, and 53%

worked some mandatory or unplanned overtime each month [ANA 2011]. In one survey of veterinary personnel, 35% consider their job dangerous, 34% reported adverse effects from workplace stress, and 42% of veterinarians experienced or witnessed workplace abuse [Fowler 2016]. Veterinarians are estimated to be at higher risk for suicide, compared with the suicide risk for the general population [Bartram and Baldwin 2010; Platt B 2012]. Suboptimal work organization issues have been associated with increased exposure to blood and body fluids and increased risk of needlestick injuries among healthcare workers [Clarke 2007; Hessels 2016]. Temporary, contract, as-needed (pro re nata or PRN), on-call and other non-standard job arrangements are common in healthcare. These work arrangements have been associated with adverse psychological outcomes and performance [Ferrie 2008; Martens 1999; Virtanen 2005].

Need

The relationship between suboptimal organization of work and resulting work-related fatigue and stress with depression, anxiety, cognitive impairment, suicide and other related health and safety outcomes among workers in the healthcare and social assistance sector is not fully understood. Research to better characterize how these organizational factors impact health, and interventions to address these organizational factors, is necessary. This may include surveillance on work practices, work factors (psychosocial and safety climate), and health outcomes among healthcare workers. Innovative surveillance approaches are especially needed for certain groups such as those in non-standard work arrangements. Work organization interventions from other healthcare settings such as hospitals and clinics could be translated to workers in nursing homes, homes, veterinary/animal care environments and non-standard work arrangements.

Intermediate Goal 7.12 (*Total Worker Health*®):

Employers, workers, professional and labor organizations, medical educators, accrediting bodies, and researchers effectively integrating protection from work-related safety and health hazards with promotion of injury and illness prevention efforts to advance worker well-being (i.e. *Total Worker Health* [TWH] approach) in the Healthcare and Social Assistance sector.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population	Research Type
A	**Illnesses, non-fatal injuries and suicide"**	**Work and non-work factors that contribute to worker safety, health, and well-being (i.e. *Total Worker Health* [TWH] approach) (e.g., musculoskeletal health, shift scheduling and control, well-being)**	**Healthcare workers, especially low-wage healthcare support occupations (e.g., home health aides, dental assistants, pharmacy aides, veterinary assistants and laboratory animal caretakers).**	**Intervention**
B	**Illnesses, non-fatal injuries and suicide"**	**Indicators for use of TWH approaches and adverse outcomes that might be improved by TWH**	**Healthcare workers, especially low-wage healthcare support occupations (e.g., home health aides, dental assistants, pharmacy aides, veterinary assistants and**	**Surveillance research**

	Health Outcome	Research Focus	Worker Population	Research Type
			laboratory animal caretakers).	
C	**Illnesses, non-fatal injuries and suicide"**	**Barriers and facilitators to implementing TWH research findings**	**Healthcare workers, especially low-wage healthcare support occupations (e.g., home health aides, dental assistants, pharmacy aides, veterinary assistants and laboratory animal caretakers).**	**Translation**
D	**Illnesses, non-fatal injuries and suicide"**	**Evaluate effectiveness and adoption TWH polices, practices and programs**	**Healthcare workers, especially low-wage healthcare support occupations (e.g., home health aides, dental assistants, pharmacy aides, veterinary assistants and laboratory animal caretakers).**	**Intervention Translation**

Activity Goal 7.12.1 (Intervention Research): Conduct intervention studies to develop and assess the effectiveness of work design and well-being interventions that integrate protection from work-related safety and health hazards with promotion of injury and illness prevention efforts to advance worker well-being in Healthcare and Social Assistance.

Activity Goal 7.12.2 (Translation Research): Conduct translation research to understand barriers and aids to implementing policies, programs, and practices that integrate protection from work-related safety and health hazards with promotion of injury and illness prevention efforts in Healthcare and Social Assistance.

Activity Goal 7.12.3 (Surveillance Research): Conduct surveillance research to better track risks to worker safety, health and well-being in Healthcare and Social Assistance.

Burden

In 2017, the healthcare and social assistance sector experienced the highest number of nonfatal occupational injuries and illnesses (583,000 cases) and the fourth highest incidence rate (4.1 per 100 full-time equivalent workers) of any private industry sector [BLS 2018a]. The highest incidence rate of nonfatal injuries and illnesses was in state-operated nursing and residential care facilities (10.9 per 100 FTE workers). Other industries covered by the HCSA program with high incidence rates include veterinary services (9.8), psychiatric and substance abuse hospitals (7.8) and state-operated hospitals (7.7) [BLS 2019]. In 2017, healthcare support occupations accounted for over 4.1 million jobs in the HCSA sector [BLS 2018b]. Of these, home health aides and personal care aides accounted for nearly 6 of every 10 jobs [BLS 2018b]. Low wage healthcare support occupations are at risk of injury due to overexertion, falls, suboptimal work organization and violence. Over a fifth of home care aides reported at least one incident of verbal abuse by clients and client's family members in the past 12 months [Karlsson et al 2019]. For veterinarians, suicide is of particular concern. Male veterinarians are 1.6 times more

likely and female veterinarians are 2.4 times more likely to commit suicide than the general population [Witte et al. 2019].

Systemic changes to our economy and socio-demographic workforce factors are rendering some past approaches to protecting workers ineffective. Increasingly, employers face tighter profit margins, demanding timelines and global completion. Workers and employers must navigate new types of work arrangements, the aging of the workforce, high levels of work-related stress, and the growing challenges of both work and home life. Many enterprises continue to confront the legacy hazards of the traditional workplace, such as traumatic injury associated with manual lifting and falls, chemical exposures, and shift work. At the same time, scientific evidence now supports what many safety and health professionals, as well as workers themselves, have long suspected—that risk factors in the workplace can contribute to common health problems previously considered unrelated to work.

Need

Total Worker Health promotes the integration of occupational safety and health (OSH) protection with workplace policies, programs, and practices to prevent injury and illness and advance overall health and well-being through research, interventions, partnerships, and capacity-building to meet the needs of the 21st century workforce. The healthcare and social assistance industry sector faces unique challenges and opportunities in promoting worker health as it relates to patient safety. For healthcare workers, patient-care issues often take precedence over personal safety [DeJoy, Murphy, & Gershon, 1995]. However, many opportunities exist where both worker safety and patient safety can be improved.[The Joint Commission, 2012]Evidence suggests that integrating occupational safety and health protection program activities with health promotion program activities may be more effective for safeguarding worker safety, health, and well-being than either of these programmatic activities on their own (Sorensen et al. 2013; NIOSH 2012; DeJoy 1993; Sauter 2013). Despite these developments, there is need for continued research to better understand the benefits of integrated approaches to prevention and to promote more comprehensive intervention, especially among certain occupations and industries.

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Mining/Healthy Work Design and Well-Being (MINxHWD)

No participating core and specialty programs

Intermediate Goal 7.3 (Work organization and fatigue-related injuries):

Industry, academia, other government agencies, and standard setting bodies adopt workplace solutions to reduce fatigue-associated events among mining workers.

	Health Outcome	Issue	Worker population	Research needed
A	Fatal and non-fatal injuries	Fatigue from long shifts over consecutive days	Underground mines	Intervention
B	Fatal and non-fatal injuries	Task-oriented fatigue	Surface mines (esp. metal/non-metal)	Intervention
C	Fatal and non-fatal injuries	Unique challenges in managing workload (seasonal, day/night)	Stone, sand and gravel	Intervention
D	Fatal and non-fatal injuries	More systematic measurement and reporting of fatigue	Underground; surface; and stone, sand, and gravel	Surveillance research

Activity Goal 7.3.1 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to reduce worker fatigue.

Activity Goal 7.3.2 (Surveillance Research): Conduct surveillance research to develop new methods to systematically measure and report fatigue issues among mining workers

Burden

Fatigue has been estimated to put roughly 130 million U.S. workers annually at risk for a fatigue-related occupational injury [Lombardi et al. 2010] and also is estimated to cost the U.S. economy upwards of $411 billion annually due to insufficient sleep [Hafner et al. 2016]. Although no explicit resources exist to evaluate the precise burden of fatigue in the mining industry, indirect indicators provide some evidence for potential burden. According to the Bureau of Labor Statistics (BLS) [2017], the mining sector continues to lead in average weekly hours worked, specifically working an average of 45.8 hours per week in 2015 [BLS 2016]. This is at least 4-5 hours on average per week more than the construction, logging, and oil and gas industries. Workers in the mining sector also have, on average, the longest commutes of nearly any other industry [Kopf 2016; U.S. Census Bureau 2014]. According to 2016 Mine Safety and Health Administration data, for all active mines with >20 employees (n=1583), approximately 50.2% operations use shifts longer than 8 hours (81,534 employees), and 18.2% longer than 10 hours (47,580 employees). Working 12+ hours a day has been associated with a 37% increase in injury hazard rates, and a 23% increase when working 60+ hours a week [Dembe et al. 2005]. Compared to workers who sleep between 7 and 8 hours a night, workers who sleep less than 6 hours are between 1.79 and 2.65 times greater risk for occupational injuries [Lombardi et al. 2010]. Finally, the Canadian Centre for Occupational Health and Safety [2012] explains how workplace fatigue is increased by dim lighting, limited visual acuity, high temperatures, high noise, and highly repetitive, sustained, and monotonous tasks: conditions which can frequently be met in surface as well as underground mining.

Need

Fatigue management remains a popular concern in industry circles. Many commercial suppliers and consultancy groups are moving into development of fatigue monitoring systems [McMillian 2013], which can monitor vehicle

operators for indicators of 'wakefulness' such as eye movement and head orientation. While such systems could offer some utility in addressing fatigue, a more comprehensive systems-level approach is needed that investigates root causes and outcomes of workplace fatigue. Such work, however, is cost-prohibitive for the private sector as such solutions require a substantive degree of time and experience to develop in an empirically sound manner, especially because fatigue is perceptual (i.e. non-objective) and therefore its prevalence can be difficult to specifically quantify. As a respected neutral scientific authority with a wealth of interdisciplinary expertise, NIOSH could be poised to provide prevention information for the mining industry. However, some practical guidance is needed beyond case-study reports and worker education to improve health and safety regarding the specific risk in mining, such as using a robust data-driven approach to determine which interventions are best suited for specific causes of workplace fatigue. In addition, there is a need to develop and supply mines with the tools to assess, evaluate, and solve health and safety problems in mines caused by worker fatigue. Research is needed to describe the potential frameworks for filling these critical gaps for the mining sector as well as other industries that rely on shiftwork or long working hours to accomplish business missions and goals.

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Oil and Gas Extraction/Healthy Work Design and Well-Being (OGExHWD)

Participating core and specialty programs: Center for Motor Vehicle Safety, Surveillance

Intermediate Goal 7.13 (Fatigue, Work organization, substance use/misuse):

Employers, workers, professional organizations, and accrediting bodies use NIOSH information to prevent injuries associated with work organization factors that contribute to fatigue, prescription drugs (including opioids), illicit drugs, and substance use/misuse in the oil and gas extraction sector

	Health Outcome	Issue	Worker population	Research needed
A	Fatal and non-fatal injuries	Fatigue from long shifts over consecutive days	Oil and gas operators, drilling contractors, and well servicing companies	Intervention Translation
B	Fatal and non-fatal injuries	Work organization	Vulnerable workers, non-standard work arrangements	Basic/etiologic
C	Fatal and non-fatal injuries	Prescription drug (incl. opioids), illicit drug, and substance use/misuse	Oil and gas operators, drilling contractors, and well servicing companies	Surveillance Intervention

Activity Goal 7.13.1. (Basic/Etiologic): Conduct basic/etiologic research to examine the impact of work organization factors on the safety and health of oil and gas extraction workers.

Activity Goal 7.13.2. (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to reduce injuries related to fatigue and prescription drug (incl. opioids), illicit drug, and substance use/misuse among oil and gas extraction workers.

Activity Goal 7.13.3 (Surveillance Research): Conduct surveillance research on risk factors for prescription drug (incl. opioids), illicit drug, and substance use/misuse among oil and gas extraction workers and its effects on worker well-being.

Burden

The overall fatality rate from workers in the oil and gas extraction (OGE) workers is over six times that of U.S. private sector workers [NIOSH 2019]. Insufficient sleep and long working hours are linked to fatigue and increased risk of injury at work [Uehli et al. 2014]. Many OGE workers work long hours, and in some cases, work for 14 consecutive days or more at a time. While the average U.S. worker works 34.3 hours per week, OGE company employees work on average 43.9 hours per week and employees of OGE support activities work on average 48.8 hours per week [BLS 2019]. Additionally, insufficient sleep (<7 hours per night) has been reported by 45% of workers in extraction occupations, which include OGE workers [Shockey & Wheaton 2017]. Economy-driven cycles of boom and bust in OGE lead to unpredictable work in the downturn and extended working hours and time pressures during upturns.

OGE workers face numerous hazards, including working with heavy equipment, working at heights, exposure to hazardous and flammable gases and vapors, and traveling long distances to well sites on rural roads. Falling

asleep at the wheel was a common contributing factor mentioned in an analysis of OGE transportation fatality narratives [Retzer et al. 2013].

Prescription opioids may be both a personal risk factor for work-related injury and a consequence of workplace exposures [Kowalski-McGraw et al. 2017]. The rate of workplace overdose fatalities for the mining, quarrying and OGE sector during 2011-2016 was 2.8 per 1,000,000 FTE, the third highest rate of all industry sectors [Tiesman et al., 2019]. Another recent analysis examining adult overdose deaths in 21 states by occupation (not just overdose deaths in the workplace) found a greater than expected proportion of deaths from natural and semisynthetic opioids within the extraction occupation group (including OGE workers), second only to construction [Morano et al., 2018]. OSHA data indicate that during 2015, support activities for mining (which consists of oil and gas well servicing and drilling operations) had the third highest number of severe injury reports [OSHA 2016]. It is likely that opioid prescriptions were a part of the pain management plan for at least some of these workers. A recent analysis of workers' compensation claims from 27 states reported that workers employed in mining, including oil and gas, were more likely that workers in other industries to receive opioids for pain [Thumula and Liu 2018].

Need

There is a need to develop and evaluate work organization interventions in the OGE industry to minimize fatigue and fatigue-related injuries. Of particular importance are evaluations of the effectiveness of fatigue risk management systems (FRMS) in OGE and barriers to their adoption.

Basic/etiologic research on the role that work organization plays in the occurrence of job stress, substance misuse, and work-related injuries among OGE workers is needed. Factors that are common in the industry that may be examined include remote and temporary work sites, extended work rotations away from home, contracted and subcontracted work tasks, and multi-employer worksites.

Surveillance research is needed to examine OGE work-related factors and exposures that may contribute to opioid misuse, and to identify potential data sources for tracking the effects of opioid misuse on worker health outcomes. Research to evaluate the effectiveness of employer-based interventions to reduce opioid misuse in the OGE workforce is also a priority.

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Public Safety/Healthy Work Design and Well-Being (PSSxHWD)

Participating core and specialty program: Center for Motor Vehicle Safety, Emergency Preparedness and Response, Personal Protective Technology

Intermediate Goal 7.4 (Work organization and mental health):

Public safety managers, labor organizations, and consensus standards organizations adopt interventions based on NIOSH research to prevent negative mental health outcomes among public safety workers. .

	Health Outcome	Research Focus	Worker Population	Research Type
A	Post-traumatic stress disorder (PTSD), substance misuse, depression	Identify problems before they evolve to PTSD, substance abuse, and depression	Law enforcement, fire service, emergency medical service (EMS), and Corrections	Surveillance research Intervention
B	Stress, anxiety, depression, compassion fatigue	Psychosocial impact of responding to opioid misuse and illicit drugs	Law enforcement, fire fighters, EMS, corrections	Surveillance research Intervention

Activity Goal 7.4.1 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to prevent negative mental health outcomes among public safety workers.

Activity Goal 7.4.2 (Surveillance Research): Conduct surveillance research to characterize and describe physical and psychosocial risks to public safety workers that includes unintentional exposures to drugs and the psychosocial toll of frequent exposure to traumatic incidents.

Burden

Public safety workers have stressful jobs and regular exposures to potentially traumatic and unpredictable events such as exposure to threatened or actual assaults, fires, explosions, and natural disasters. NIOSH has completed several Health Hazard Evaluations at the request of public safety employers and workers concerned

about occupational exposures to opioids and illicit drugs, and mental health impacts associated with responding to the opioid crisis [NIOSH 2019].

Exposure to these events one time, or multiple times over a career has been associated with the development of mental disorders, such as PTSD and depression, as well as a vulnerability for alcohol and substance misuse [Bucerius, et al 2019; Lerman 2017; James et al 2017; Boffa et al 2016; Faust & Ven 2014; Haugen et al, 2012; Haddock et al 2012; Neria et al 2011; Carey et al 2011; Carlier et al 1997]. In some cases, these disorders and other influences may increase public safety workers risk for suicide [Lerman, 2017; Martin et al 2016; Violanti 2013; Violanti 2010; Violanti et al 2009]. Public Safety workers often ignore their own emotional wellbeing during emergency responses and may not receive the training to engage in appropriate self-care before, during, and after a disaster, waiting instead to seek care only once symptoms appear, significantly interfere with work, or become severe.

Need

Despite early, emerging research on this topic, additional insights into the scope and nature of these risks and the appropriate, population-specific mitigations and interventions are lacking. In response to these limitations, accurate surveillance data is needed and more comprehensive approaches need to be developed and tested to evaluate risk and resiliency among various response and recovery worker populations and disaster scenarios, including traumatic incidents. Training is needed pre-event to enable responder populations (e.g., EMS, law enforcement, fire fighters) to enhance their own coping and resiliency skills based on scenario types (e.g., mass casualty, infectious disease outbreaks, responding to the opioid crisis). Additionally, field-friendly tools, such as mobile applications, are needed to rapidly identify those incidents and exposures requiring immediate follow-on medical care. Other needs include training for managers and team leads in this scenario to be aware of preventive efforts they can put in place in real-time to mitigate the hazards workers face, and training on early detection and intervention for workers at risk.

There is a virtual absence of data to describe exposures and risks to workers who may be exposed to opioids by the nature of the work they do, or the environments where they work. This includes law enforcement who respond to crime scenes, emergency response workers who respond to overdoses, and corrections officers who conduct inmate or cell searches for illicit drugs including opioids or respond to inmate overdoses. Data are needed to characterize and describe physical and psychosocial risks, like the trauma, and long-term stress resulting from responding to overdose victims.

Intermediate Goal 7.14 (*Total Worker Health*®):

Public safety and health department managers, labor organizations, professional associations and consensus standard organizations effectively integrating protection from work-related safety and health hazards with promotion of injury and illness prevention efforts to advance worker well-being (i.e. *Total Worker Health* [TWH] approach) in the Public Safety sector.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population	Research Type
A	**Fatal and non-fatal injuries; illnesses**	**Work and non-work factors that contribute to worker safety, health, and well-being (i.e. *Total Worker Health* [TWH] approach) (e.g., fatigue, shift work, obesity, violence, stress)**	**Law enforcement, fire service, Emergency Medical Service (EMS), corrections and wildland fire subsectors**	**Intervention**
B	**Fatal and non-fatal injuries; illnesses**	**Improve data around risks to worker safety, health, and well-being**	**Law enforcement, fire service, Emergency Medical Service (EMS), corrections and wildland fire subsectors**	**Surveillance research**
C	**Fatal and non-fatal injuries; illnesses**	**Barriers and facilitators to implementing TWH research findings**	**Law enforcement, fire service, Emergency Medical Service (EMS), corrections and wildland fire subsectors**	**Translation**
D	**Fatal and non-fatal injuries; illnesses**	**Evaluate effectiveness and adoption of TWH polices, practices and programs**	**Law enforcement, fire service, Emergency Medical Service (EMS), corrections and wildland fire subsectors**	**Intervention Translation**

Activity Goal 7.14.1 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions that integrate protection from work-related safety and health hazards with promotion of injury and illness prevention efforts to advance worker well-being in Public Safety.

Activity Goal 7.14.2 (Translation Research)**:** Conduct translation research to understand barriers and aids to implementing policies, programs, and practices that integrate protection from work-related safety and health hazards with promotion of injury and illness prevention efforts in Public Safety.

Activity Goal 7.14.3 (Surveillance Research)**:** Conduct surveillance research to better track risks to worker safety, health and well-being in Public Safety.

Burden

There are over 2.7 million people in the United States employed in occupations in the public safety sector [NIOSH 2018]. This estimate does not account for volunteers as they make up a large proportion of firefighters, wildland firefighters, and EMS personnel. A variety of occupational hazards potentially affect the health of public safety workers. Due to a variety of risks and stressors, emergency response activities expose public safety workers to the possibility of serious injuries from traumatic injuries, exposure to hazardous substances (including drugs), and acute and chronic diseases. The nature of occupations within the Public Safety sector requires workers to be in close contact with various hazards that may expose them to workplace violence. For example, research has indicated that many EMS workers are required to respond to calls that involve patients under the influence of alcohol or drugs (such as opioids), violent patients, or patients with weapons [Oliver and Levine 2015, Taylor et a. 2015]

Chronic diseases, such as cardiovascular disease (CVD) and cancer, are some of the greatest threats to public safety workers' health. Occupational stress can lead to high blood pressure and cholesterol levels, which increases the risk of heart disease, hypertension, diabetes, stroke, and a host of other physical ailments [APA 2016, Fujishiro et al. 2015]. Sudden cardiac deaths are one of the leading causes of death for law enforcement officers, wildland firefighters, and correctional officers; and are the main cause of death for firefighters [NFPA 2015].

Systemic changes to our economy and socio-demographic workforce factors are rendering some past approaches to protecting workers ineffective. Increasingly, employers face tighter profit margins, demanding timelines and global completion. Workers and employers must navigate new types of work arrangements, the aging of the workforce, high levels of work-related stress, and the growing challenges of both work and home life. Many public safety employers continue to confront the legacy hazards of the traditional workplace, such as traumatic injury, chemical exposures, and shift work. At the same time, scientific evidence now supports what many safety and health professionals, as well as workers themselves, have long suspected—that risk factors in the workplace can contribute to common health problems previously considered unrelated to work.

Need

Total Worker Health promotes the integration of occupational safety and health (OSH) protection with workplace policies, programs, and practices to prevent injury and illness and advance overall health and well-being through research, interventions, partnerships, and capacity-building to meet the needs of the 21st century workforce. Evidence suggests that integrating occupational safety and health protection program activities with health promotion program activities may be more effective for safeguarding worker safety, health, and well-being than either of these programmatic activities on their own (Sorensen et al, 2013; NIOSH, 2012; DeJoy, 1993; Sauter, 2013). Despite these developments, there is need for continued research to better understand the benefits of integrated approaches to prevention and to promote more comprehensive intervention, especially among certain occupations and industries.

According to the NFPA, 73% of fire departments do not have a program to maintain basic fire fighter fitness and health, such as is encouraged by NFPA 1500, Standard on Fire Department Occupational Safety and Health Program [NFPA, 2016]. Although the number of *Total Worker Health®* programs in other Public Safety sub-sectors (law enforcement, corrections, and emergency medical services) is not known, it is anticipated there are few agencies with active and effective programs that emphasize *Total Worker Health®* and it is likely that participation in many of these programs is voluntary. Studies have shown positive correlations between programs on health-related behavior and medical cost outcomes, evidence for positive effects on diet, exercise, smoking, alcohol use, physiologic markers and healthcare costs and various studies with Public Safety departments and agencies have shown similar findings as well [Bower 2013; Kuehl et al. 2013, 2016; Mabry et al. 2013].

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Services/Healthy Work Design and Well-Being (SRVxHWD)

Participating core and specialty programs: Center for Workers' Compensation Studies, Occupational Health Equity, Small Business Assistance, Safe•Skilled•Ready Workforce, and Translation Research.

Intermediate goal 7.5 (Non-standard work arrangements):

Employers, researchers, nongovernmental organizations, workers, and policy makers will use NIOSH information to improve safety, and health among contingent workers and workers in non-standard work arrangements in the service sector.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	Acute and chronic disease, Fatal and non-fatal injuries	Characterizing contingent workers and risk factors	Contingent workers; young workers and other vulnerable populations	Surveillance research
B	**Fatal and non-fatal injuries, Musculoskeletal disorders (MSDs)**	**Employer ambiguity, inadequate occupational safety and health training, and lack of programs**	**Contingent workers; young workers and other vulnerable populations**	**Intervention Translation**
C	Heat-related illnesses	Employer ambiguity, inadequate OSH training, and lack of programs	Non-standard work arrangements (including seasonal outdoor workers)	Intervention Translation

*See definitions of worker populations

Activity Goal 7.5.1 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to improve safety and health vulnerable workers and workers in non-standard work arrangements in the services sector.

Activity Goal 7.5.2 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective safety and health interventions for vulnerable workers and workers in non-standard work arrangements in the services sector.

Activity Goal 7.5.3 (Surveillance Research): Conduct surveillance research to better characterize the risk factors for vulnerable workers and workers in non-standard work arrangements in the services sector.

Burden

Contingent work is prevalent in the Services sector. Occupational hazards for these workers are the same or greater compared with those for workers in standard work arrangements in the same industry. Among all workers, there were 829 fatalities among contract employees in 2015 (17% of all workplace deaths). In the Service Sector, there were 139 fatalities among contract employees (29% of Service sector fatalities) [BLS 2016].

Occupational hazards can be greater for temporary agency workers because of a lack of clarity about which employer is responsible for their safety and the fact that they are more often likely to be performing a job for the first time. A hazard of temporary work is psychological morbidity possibly being related to job insecurity [Virtanen et al. 2005]. Other hazards are dependent on the work environment at the host establishment, which can be influenced by lack of training, protective measures, and adequate supervision.

Temporary employment services is within the top 20 industries with the largest wage and salary employment growth. Temporary agency workers report much higher levels of job stress, and experience about twice the number of poor physical and mental health days due to stress, than other service workers. Temporary agency workers are often employed in Construction and Manufacturing but a recent article about workers in Washington State, found that temporary agency workers working in the Construction and Manufacturing industries had more than a two- to four-fold higher rate-ratio than construction or manufacturing workers in standard work arrangements. For all major injury types suffered by construction and manufacturing temporary agency workers, medical only claims were 88 to 300% higher than those for workers in standard arrangements [Smith et al. 2010].

Need

Little surveillance information on contingent workers is available. Key data sources on work arrangements categorize workers different ways, and sometimes the categorization is very broad to combine temporary workers with long term contract workers. This lack of knowledge is a research gap that needs to be filled. Consistent and tested questions need to be added to the major sources of labor statistics and work-related health data so that this worker population can be better understood. Tracking of contingent worker's safety is lacking (GAO, 2015). Surveillance methods are not only needed to determine job types but also to count and record job risks and injuries and illnesses.

Temporary agency workers do not have clearly defined supervisory support for training and for expressing job concerns. Economic analysis, small business research, and other types of intervention research are needed to assist both host and client employers in creating a safe and healthy workplace, and improving well-being for temporary agency workers.

There is inadequate occupational safety and health training among temporary agency workers where socioeconomic and racial/ethnic disparities exist. This training should inform them of what is expected of their employer and host company. There are proven effective interventions to reduce the risk of health and safety hazards. These known interventions and employer and host company responsibilities need to be conveyed to temporary agencies and workers to improve health and safety in the workplace. Intervention and translation research is especially needed for young workers, seasonal outdoor workers, and other vulnerable worker populations.

Intermediate Goal 7.15 (*Total Worker Health*®):

Employers, unions, insurers, health and safety professionals, government agencies, and academicians effectively integrate protection from work-related safety and health hazards with promotion of injury and illness prevention efforts to advance worker well-being (i.e. *Total Worker Health* [TWH] approach) in the Services sector.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Research Focus	Worker Population*	Research Type
A	**Fatal and non-fatal injuries; illnesses**	**Work and non-work factors that contribute to worker safety, health, and well-being (i.e. *Total Worker Health* [TWH] approach)**	**Services workers, especially vulnerable workers and small businesses**	**Intervention**
B	**Fatal and non-fatal injuries; illnesses**	**Improve data around risks to worker safety, health, and well-being**	**Services workers, especially vulnerable workers and small businesses**	**Surveillance research**
C	**Fatal and non-fatal injuries; illnesses**	**Barriers and facilitators to implementing TWH research findings**	**Services workers, especially vulnerable workers and small businesses**	**Translation**
D	**Fatal and non-fatal injuries; illnesses**	**Evaluate the effectiveness, adoption, successful implementation, and sustainment of TWH polices, practices and programs**	**Services workers, especially vulnerable workers and small businesses**	**Intervention Translation**

*See definitions of worker populations

Activity Goal 7.15.1 (Intervention Research): Conduct studies to develop and assess the effectiveness of Interventions that integrate protection from work-related safety and health hazards with promotion of injury and illness prevention efforts to advance worker well-being in Services.

Activity Goal 7.15.2 (Translation Research): Conduct translation research to understand barriers and aids to implementing policies, programs, and practices that integrate protection from work-related safety and health hazards with promotion of injury and illness prevention efforts in Services.

Activity Goal 7.15.3 (Surveillance Research): Conduct surveillance research to better track risks to worker safety, health and well-being in Services.

Burden

In 2017, the Bureau of Labor Statistics (BLS) estimated that there were nearly 73 million workers in the services sector [BLS 2018]. Several subsectors within the services sector experience particularly elevated rates of injuries, fatalities, and chronic health conditions. More specifically, building and dwellings service (i.e. maintenance and landscape workers), food services, waste management and remediation services, and accommodations (hotel workers) had the highest number of fatalities and/or rates of injuries with days away from work [BLS 2015a,b, 2017]. For instance, data from both the Ohio Bureau of Worker's Compensation and BLS indicated that building maintenance and repair, janitorial, cleaning, garbage collection, and hotel workers all have elevated rates of MSDs. [BLS 2015b; Meyers et al 2017]. Further, workers in accommodation, food, and waste remediation services have also been found to have higher rates of cardiovascular disease/stroke [CDC 2014]. Workplace factors of concern among workers in the services sector include multiple types of workplace stressors (e.g., physical exertion and physical inactivity, excessive heat or cold, noise, long work hours, shift work, job strain, low-decision latitude, and other psychosocial factors) [Kivimacki 2015; Theorell et al. 2016].

In the services sector, 89% of the 3 million firms have fewer than than 20 employees, and these small businesses typically have limited access to health and safety specialists [U.S. Census Bureau 2011]. Managers in smaller businesses often work in isolation without sufficient access to peer opinion and industry best practices. These factors not only reduce prevention activities but may also reduce the reporting of illnesses and injuries to government agencies, insurance companies, and other organizations [Morse et al. 2004].

Many businesses in services industries employ workers that are vulnerable to higher rates of morbidity and mortality due to their age, ethnic background, language, gender, education level or lack of long-term job stability. Many of these workers are immigrants whose exposures and health outcomes are exacerbated due to stressors, including many types of occupational health disparities [Landsbergis et al 2014]. These workers may not report injuries or suggest job aids because of their vulnerabilities. They may be more likely to be required to do some of the most physically challenging jobs, and may face additional challenges associated with job insecurity and low wages.

Systemic changes to our economy and socio-demographic workforce factors are rendering some past approaches to protecting workers ineffective. Increasingly, employers face tighter profit margins, demanding timelines and global completion. Workers and employers must navigate new types of work arrangements, the aging of the workforce, high levels of work-related stress, and the growing challenges of both work and home life. Many enterprises continue to confront the legacy hazards of the traditional workplace, such as traumatic injury, chemical exposures, and shift work. At the same time, scientific evidence now supports what many safety and health professionals, as well as workers themselves, have long suspected—that risk factors in the workplace can contribute to common health problems previously considered unrelated to work.

Need

Total Worker Health promotes the integration of occupational safety and health (OSH) protection with workplace policies, programs, and practices to prevent injury and illness and advance overall health and well-being through research, interventions, partnerships, and capacity-building to meet the needs of the 21st century workforce. Evidence suggests that integrating occupational safety and health protection program activities with health promotion program activities may be more effective for safeguarding worker safety, health, and well-being than either of these programmatic activities on their own [Sorensen et al. 2013; NIOSH 2012; DeJoy 1993; Sauter 2013]. Despite these developments, there is need for continued research to better understand the benefits of integrated approaches to prevention and to promote more comprehensive intervention, especially among certain occupations and vulnerable worker groups, such as immigrants and young workers. Given that the majority of employers in the Services sector have fewer than 20 employees, studies to identify effective outreach methods through trusted partners are needed for all workers in the services sector, particularly among workers in small businesses and among immigrant populations.

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Transportation, Warehousing and Utilities/Healthy Work Design and Well-Being (TWU)

Participating core and specialty programs: Center for Occupational Robotics Research, National Center for Productive Aging and Work, Safe•Skilled•Ready Workforce, Surveillance and Translation Research.

Intermediate Goal 7.6 (Work organization and obesity/chronic disease):

Other federal agencies, trade associations, labor organizations, employers, owner/operators, and researchers use NIOSH information to reduce obesity and chronic disease among transportation, warehousing and utilities workers.

	Health Outcome	Research Focus	Worker Population	Research Type
A	Metabolic disorders, sleep disorders	Risk factors (obesity, sedentary work, lack of healthy eating options, stress, boredom)	Long-haul truck drivers, short-haul truck drivers, bus and transit drivers, rail workers	Intervention
B	Metabolic disorders, Sleep disorders	Understanding link between obesity and fatigue	Long-haul truck drivers, short-haul truck drivers, bus and transit drivers, rail workers	Intervention
C	Cardiovascular disease (CVD), Metabolic disorders, Sleep disorders Depression, Anxiety	Explore existing data and ways to efficiently monitor contribution of fatigue and stress	Long-haul truck drivers, short-haul truck drivers, bus and transit drivers, rail workers, aviation, utility workers, maritime, couriers	Surveillance Research
D	CVD, Metabolic disorders, Sleep disorders, Depression, Anxiety	Address socioeconomic risk factors (access to healthcare, non-standard work arrangements)	Long-haul truck drivers, short-haul truck drivers, couriers, rail transit and bus, warehousing workers, utilities workers	Intervention

Activity Goal 7.6.1 (Intervention Research): Conduct studies to assess effectiveness of interventions to address work organization and socioeconomic factors that contribute to obesity and chronic disease among transportation, warehousing and utility workers.

Activity Goa 7.6.2 (Surveillance Research): Conduct surveillance research on risk factors for chronic disease among transportation workers.

Burden

Obesity is a national problem and is prevalent in the transportation, warehousing and utilities (TWU) sector. Health conditions associated with obesity include metabolic disorders such as hypertension and diabetes, cardiovascular disease (CVD), and stroke [Thompson et al. 1999]. An estimated 34.2% of all TWU workers are obese [NIOSH 2013] and 6.1% have had a diagnosis of heart disease [Helmkamp et al. 2013]. 6.1 percent of TWU workers have been told they have diabetes and 21.1% have been told they have hypertension [NIOSH 2013]. The work demands and other psychological stressors of TWU workers create special challenges: tasks may be sedentary in nature, limited options may be available for where and when to eat while working or resting away from home, and sleep periods may often be less than the recommended 7-9 hours daily [Hirschkowitz et al.

2015]. Sixty-seven percent of TWU workers did not meet CDC guidelines for physical activity [Helmkamp et al. 2013], while 38.0% of TWU workers indicate less than 7 hours of sleep in a 24-hour period [CDC 2012]. Twenty-eight percent of TWU workers work more than 48 hours per week compared to 18.7% of the U.S. workforce [NIOSH 2010]. Thirty-six percent work non-standard shifts, compared to 26.6% of the U.S. workforce [NIOSH 2015]. Job insecurity may increase the odds of reporting poor health by 50%; high job demands raise the odds of having a physician-diagnosed illness by 35%, and long work hours increase mortality by almost 20% [Goh et al. 2015].

Obesity and related disorders manifest themselves in premature death and disability, increases in health care costs, lost productivity, social stigmatization, and increases risk of involvement in transportation incidents. [NIH 1998; Thompson et al. 1999; Martin et al. 2009; Anderson et al. 2012]. Obesity's related medical factors may limit a commercial motor vehicle driver's driving certification [Thiese et al. 2015]. Job stress is associated, in the short term, with affective reactions (e.g., irritability, anger), and, in the long term, with anxiety and depressive symptoms [Griffin et al. 2007]. Job stress also has cognitive and behavioral effects. High levels of stress can cause narrowing of attention and reduce working memory capacity, which can reduce performance accuracy. Work stressors are related to unsafe behaviors, accidents and injuries [Nahrgang et al. 2011].

Need

Research is needed to better understand the link between metabolic disorders, CVD, obesity, sleep disorders, depression, anxiety, fatigue, and stress and create interventions to mitigate negative effects. These conditions not only affect quality of life, but may also interfere with the ability to operate a vehicle safely. Previous NIOSH obesity TWU surveillance research has focused on long and short haul truck drivers, and more efficient methods to monitor obesity among other TWU workers are needed. The importance of obesity and heart disease to TWU is highlighted by the fact that individual trucking companies and insurance companies have initiated health and fitness programs based on NIOSH research findings [Baleka 2017]. High body mass index (obesity) is also a key investigatory variable called for in a recent report from the National Academy of Sciences on research needs for commercial motor driver fatigue, long-term health, and highway safety [National Academy of Sciences 2016]. Because non-standard work arrangements are understudied but increasingly prevalent, and their determinants and health and safety consequences are poorly understood, surveillance is needed. Particularly needed are models on the determinants and effects of work arrangements and efforts to improve the taxonomy of work arrangements and their characteristics. Shift work and long work hours represent complex workplace hazards. This complex hazard further requires research on many types of interventions to reduce risks. Similarly, job stress is a widespread problem in the working population and is one of the costliest risk factors to industry due to its effects on such a broad range of health, safety, productivity, social, and non-work factors.

Intermediate Goal 7.7 (Work organization and fatigue-related injuries):

Other federal agencies, trade associations, labor organizations, employers, owner/operators, and researchers use NIOSH information to reduce injuries and fatalities related to fatigue and stress among transportation and utility workers.

	Health Outcome	Research Focus	Worker Population	Research Type
A	Fatal and non-fatal injuries	Develop fatigue and stress interventions	Truck drivers, bus and transit drivers, aviation, marine, rail, and utility	Intervention

	Health Outcome	Research Focus	Worker Population	Research Type
B	Fatal and non-fatal injuries	Develop medication and substance use (stress or fatigue-induced) interventions	Truck drivers, bus and transit drivers, aviation, marine, rail, and utility	Intervention

Activity Goal 7.7.1 (Intervention Research): Conduct intervention studies to develop and assess the effectiveness of interventions to reduce fatigue and stress (and related medication and substance use) to prevent injuries and fatalities among transportation and utility workers.

Burden

In 2015, workers in the transportation and warehousing industry had a fatal work injuries rate of 13.8 per 100,000 workers, the second highest rate for all workers [BLS 2017]. The organization of work in the transportation, warehousing and utilities (TWU) sector exacerbates risk of work-related injuries and fatalities. The long hours of work and irregular work schedules typical of the sector often lead to chronic sleep deprivation, disruption of circadian rhythms, and poor sleep quality. Insufficient sleep is associated with a broad range of health and safety risks including, vehicle crashes and disturbances to cognition [AAA Foundation for Traffic Safety 2016; DOT 2015; FMCSA 2007]. For TWU sector workers, delivery deadlines, time pressures, long periods away from home, and pay-by-the-mile compensation can contribute to work stress and incentivize non-compliance with the U.S. Department of Transportation safety regulations that limit driving and duty hours.

Previous research suggests that stimulant use is an important problem for U.S. truck drivers. Couper et al. [2002] reported that 9.5% of truck drivers in Oregon and Washington State tested positive for central nervous system stimulants such as amphetamine, cocaine, and pseudoephedrine. Use during driving has been shown to multiply the risk of a fatal crash by 3 to 4.5 [Elvik 2013]. Results for a cross-sectional intercept study showed the prevalence of at-risk drinking (five or more drinks in one day) was significantly higher for male long-haul drivers, during break periods from work [Birdsey et al. 2015]. It has been reported that engaging in even one or two days of at-risk drinking per year increases the prevalence of alcohol abuse and alcohol dependence [Dawson et. al. 2005] causing problems such as failure to fulfill expectations at work or home, increased physical hazards, legal problems, social/interpersonal problems, or an inability to control drinking behavior [Maisto et. al. 2003].

Need

The Institute of Medicine [IOM 2006] calls poor sleep health, shift work, and long work hours a critical unmet public health problem, because of the societal requirements of a 24/7 clock. Scientific evidence on the topic of sleep health, shift work, and long work hours has mounted in recent decades, but information has not been adequately disseminated or implemented in the TWU sector. Despite the quite extensive body of research showing the links between stress and health and safety outcomes, there have been few studies to identify workplace psychosocial and work organization risk factors by sector and fewer studies of interventions to address these risk factors. There is a critical need to develop effective tools that organizations can use to assess sources of job stress and develop interventions to address these risk factors. Research is needed to develop effective administrative controls for managers and workers to improve sleep and reduce workplace stress. In addition, research is needed to determine effective interventions that reduce workplace injuries and fatalities correlated to fatigue, stress, and stimulants used by workers to personally mitigate these effects. This complex hazard requires research on many types of interventions to reduce risks: testing various work scheduling patterns; manipulating light exposure, pharmacology agents, and diet regimes; work organization strategies and

efforts to change workplace cultures; workplace interventions including policies, fatigue risk management systems, and education programs; mathematical models to predict risks; and studies of the impact of broader public policy measures (for example, impact of hours of service rules).

Intermediate goal 7.8 (Stress/fatigue and human-machine interaction):

Other federal agencies, trade associations, labor organizations, employers, owner/operators, and researchers use NIOSH information to reduce injuries associated with human-machine interaction among TWU workers.

	Health Outcome	Issue	Worker population	Research needed
A	Fatal and non-fatal injuries	Repetitive tasks, mental exhaustion	Warehousing workers; couriers and messengers; marine, rail, and aviation workers; truck drivers; transit workers	Intervention
B	Fatal and non-fatal injuries	Displacement by autonomous vehicles	Truck drivers; aviation, marine and rail workers	Intervention
C	Fatal and non-fatal injuries	Robotics and exoskeletons and interplay with fatigue and stress (displacement, psychosocial)	Warehousing workers, couriers, messengers, utilities workers, baggage handlers	Surveillance Research

Activity Goal 7.8.1 (Intervention Research): Conduct studies to develop and assess the effectiveness of interventions to reduce injuries associated with monotonous tasks and autonomous vehicles among transportation and warehousing workers.

Activity Goal 7.8.2 (Surveillance Research): Conduct surveillance research to better understand relationship between injuries, stress and robotics and exoskeletons and interplay with fatigue and the psychosocial stress of displacement among TWU workers.

Burden

Interactions between vehicles and machines have been beneficial to the employer and worker by reducing work load, repetitive tasks, and increasing production capabilities. The International Federation of Robotics reports sharp increases in sales and is projecting that a new type of robot, collaborative robots that work alongside and in conjunction with human workers, will have a market breakthrough in the next several years [IFR 2016]. Wearable robotics, such as exoskeletons to reduce physical loads on workers, are being marketed [Lowe et al. 2016]. Vehicles increasingly have automated safety features, and fully autonomous vehicles, including commercial trucks and transit vehicles, are currently being piloted on U.S. roadways. Projections on when autonomous vehicles will be commonplace vary, but some project this could be within the next decade [Kessler 2017]). As robotics and automation integrate into the transportation, warehousing and utilities (TWU) sector, workers are being tasked with working with these complex systems. Examples of these systems in TWU include: air traffic management, unmanned aviation systems, positive train control systems, motor vehicle dashboards, autonomous vehicles, ship control systems, automated warehousing, wearable robotic exoskeletons, and use of drones in warehousing and utilities [Volpe 2012; Banker 2016; Schneider and Demi 2017]. Introduction of these highly automated systems has the potential to improve safety in many areas including reducing vehicle crashes, but there are increased risks with highly automated systems. These systems are highly complicated and more

emphasis needs to be placed on operator training and maintenance [Moniz and Krings 2016] Changes in the roles and responsibilities of the operator introduce increased risk of operator errors especially in the context of unforeseen or atypical events. In the past introductions of new technologies occurred at a slow pace; the current faster pace of technology introduction increases the potential for unforeseen hazards being introduced in the workplace.

Need

Current Injury statistics illustrate the need for continued research on the human/machine interface for machines used in today's workplace, and this research will need to be expanded to address future machines and vehicles. Researchers can begin to mitigate these hazards, and reduce injuries and fatalities, through hazard identification strategies and hazard mitigation methods, human factors analysis, educational programs on human factors engineering elements for system design for engineers, and integration of human factors engineering principles in technical engineering and design standards [Leva et al. 2016; Murashov et al. 2016]. Surveillance research is needed to better understand the relationship between injuries and stress, robotics and exoskeletons among TWU workers and the interplay with fatigue and psychosocial stress of displacement robotics, exoskeletons, and autonomous vehicles. Intervention studies are needed to assess effectiveness of autonomous vehicle interventions to reduce injuries associated with monotonous and repetitive tasks.

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Wholesale and Retail Trade/Healthy Work Design and Well-Being (WRTxHWD)

Participating core and specialty programs: Exposure Assessment, Occupational Health Equity, National Center for Productive Aging and Work, Small Business Assistance, Surveillance and Translation Research.

Intermediate goal 7.9 (Work organization and MSDs)

Employers utilize NIOSH information in decision-making about managing and structuring work to reduce musculoskeletal disorders among wholesale and retail trade workers.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Issue	Worker population*	Research needed
A	Musculoskeletal disorders (MSDs)	Work organization	Food and beverage, building and gardening materials, and general merchandise subsectors; workers with non-standard work arrangements; vulnerable workers	Intervention
B	**MSDs**	**Develop communication and training products**	**Food and beverage, and general merchandise subsectors**	**Translation**
C	MSDs	Employer behavioral economics and organizational culture	Small businesses, workers with non-standard work arrangements, vulnerable workers	Surveillance research

*See definitions of worker populations

Activity Goal WRTxHWD 7.9.1 (Intervention Research): Conduct intervention studies to develop and assess best practices for managing and structuring work to reduce musculoskeletal disorders among wholesale and retail trade workers.

Activity Goal WRTxHWD 7.9.2 (Translation Research): Conduct studies on the barriers and facilitators to implementing effective musculoskeletal disorders interventions in wholesale and retail trade.

Activity Goal WRTxHWD 7.9.3 (Surveillance Research): Develop/enhance surveillance methods to better characterize employer behavioral economics and organizational culture characteristics that are risk factors for musculoskeletal disorders and for preclinical musculoskeletal pain symptoms among wholesale and retail trade workers.

Burden

Work-related musculoskeletal disorders (MSDs) are all too common in the wholesale and retail trade (WRT) sector and have significant costs. The Institute of Medicine estimates the economic burden of work-related

MSDs as measured by compensation costs, lost wages, and lost productivity, to be between $45 and $54 billion annually. The economic burden to employers is $13.4 billion annually [IOM 2001]. BLS [2015] estimates approximately 10 million WRT employees are at risk, especially those who work in building materials and gardening stores; general merchandise (department) stores; and food and beverage stores. In addition to the workplace hazards that lead to MSDs, multiple organizational and cultural (social) factors are known to affect employee health and well-being, including: high job demands, hostile work environment, low job control, low supervisory support, poor safety climate, work-life interference, a workplace that is perceived as unsafe, and worry about losing one's job [Luckhaupt et al. 2017]. Of all of the musculoskeletal problems, low back pain is the most common and accounts for the greatest number of lost work days in the WRT high risk subsectors. The adjusted prevalence of low back pain among WRT workers, 2004-2012 was 25.6 [NIOSH 2015].

Need

NIOSH has the expertise and experience to develop messages, recognizing the factors that influence decision makers, to take action in reducing MSDs. Research is needed to examine and consider how workplace organization of work influences the onset and reports of low back pain. Multidimensional programs that address the personal (demographics) and organizational factors as well as ergonomic factors are most successful for reducing the burden of low back pain in WRT small businesses. Interventions designed to reduce the burden of workplace MSDs, will require new surveillance methods (surveys) that can account for the changing workplace environment, which frequently confounds research designs aimed at evaluating the effectiveness of workplace interventions.

Finally, translation research is needed to develop messages based on behavioral and economics concepts that will move employers/owners to make decisions that demonstrate social responsibility in safety matters that will protect their employees. This intermediate goal calls for a revitalized effort on the part of NIOSH to develop and deliver informational products that will be more effective in demonstrating to employers the value added by ensuring a healthy and safe workforce.

Intermediate goal 7.10 (Non-standard work arrangements and vulnerable workers):

Employers, researchers, nongovernmental organizations, workers, and policy makers will use NIOSH information to improve safety, and health among workers in non-standard work arrangements; young workers and other vulnerable workers in the Wholesale and Retail Trade sector.

NOTE: Goals in bold in the table below are priorities for extramural research

	Health Outcome	Issue	Worker population*	Research needed
A	**Acute and chronic disease, Fatal and non-fatal injuries**	**Inadequate occupational safety and health training, and lack of OSH programs**	**Workers in non-standard work arrangements; young workers and other vulnerable workers**	**Intervention Translation**
B	**Acute and chronic disease, Fatal and non-fatal injuries**	**Characterizing workers in non-standard work arrangements, young workers and other vulnerable worker populations, as well as risk factors**	**Workers in non-standard work arrangements; young workers and other vulnerable workers**	**Surveillance research**

*See definitions of worker populations

Activity Goal 7.10.1 (Intervention Research): Conduct studies to develop and assess the effectiveness of training and other OSH interventions for workers in non-standard arrangements; young workers and other vulnerable workers in the WRT sector.

Activity Goal 7.10.2 (Translation Research): Conduct translation research to understand barriers and aids to implementing effective safety and health interventions for workers in non-standard arrangements and other vulnerable workers in the WRT sector.

Activity Goal 7.10.3 (Surveillance Research): Conduct surveillance research to better characterize the risk factors for workers in non-standard arrangements; young workers and other vulnerable workers in the WRT sector.

Burden

Younger workers (ages 15-24) and contingent workers, meaning those with a job they do not expect to last, are at elevated risk for workplace injuries [CDC 2010, Katz and Krueger 2016]. In 2011, 23% of working youth aged 16–17 worked in WRT, making it the 2nd largest group [Castillo and Lewko 2013]. Retail is consistently ranked in the top three most dangerous industries for young workers [Rauscher and Runyan 2013]. Between the years 2003 and 2007, 10% of all fatal injuries among younger wokers occurred in the WRT sector [CDC 2010]. The proportions of workers 18 and younger injured both fatally and nonfatally in a retail trade job are greater than those for adults [Castillo and Lewko 2013].Young workers face a number of stressors in the WRT sector—including having to interact with customers, handle cash, and work at night and without proper supervision—that elevate their risk of being injured or even killed on the job [Rauscher and Runyan 2013].Similarly, temporary workers of any age are at increased risk for occupational injury. Research demonstrates that temporary workers bear a higher burden (than permanent employees) of work-related injuries and illnesses [Benavides et al. 2006, Cummings and Kreiss 2008].

Need

Given the disproportionate number of workplace injuries suffered by young workers and new hires, occupational safety and health (OSH) education for these vulnerable populations is imperative. NIOSH developed 8 core competencies using widely-used health behavior models that are general, transferable, and portable across all jobs and industries. The competencies complement job-specific knowledge and skill curricula already taught through apprenticeship and other vocational and career technical training programs in WRT and other sectors. The *Youth@Work-Talking Safety* curriculum is the primary means through which NIOSH promotes the competencies in workplace safety and health. The pathway that potentially has the largest reach is the integration of OSH into middle school and high school programs (including in career technical education programs that focus on trades, including in the WRT sector).

Research is needed to understand how the competencies could be applied to other school and training settings (such as in career technical education pathways and in community colleges), and what barriers and incentives increase buy-in, adoption, and implementation with fidelity. Research is also needed to understand how other vulnerable workers can be reached with the foundational OSH knowledge and skills. There is also a need to explore the use/integration of the NIOSH 8 Core Competencies internationally to assess their utility for

promoting workplace safety and health knowledge and skills in a broad range of school, community, and work-based settings.

Surveillance research is needed to develop survey questions and other methods to better characterize workers in non-standard work arrangements, young workers and other vulnerable worker populations. This includes collection of updated and refined burden data on the prevalence of potentially harmful work arrangements (e.g. precarious work), work schedules, workload, and workplace psychosocial characteristics among these worker populations.

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Part II: Service

Service Goals

Surveillance Program

Supports Strategic Goals 1-7

Intermediate Goal [SS] 1.1 NIOSH sector and cross-sector programs and external stakeholders use NIOSH surveillance data and information products to identify, monitor, and evaluate occupational safety and health hazards and work-related health outcomes, reduce occupational illnesses and injuries and control hazards, and promote well-being among workers.

Activity Goal [SS] 1.1.1 The surveillance program will maintain and enhance the quality and timeliness of ongoing NIOSH-based or NIOSH-enhanced surveillance systems that provide data on the burden of hazards, illness, and injuries among workers and the impact of interventions. These include, but are not limited to:

- Adult Blood Lead Epidemiology and Surveillance (ABLES)
- State-Based Surveillance of Work-Related Asthma (WRA)
- Occupational Hearing Loss (OHL) Surveillance
- Behavioral Risk Factor Surveillance System (Industry and Occupation module)
- Commercial Fishing Incident Database
- Coal Workers' Health Surveillance Program
- Fatality Assessment and Control Evaluation
- Firefighter Fatality Investigation and Prevention Program
- Fatalities in Oil and Gas Extraction (FOG)
- NEISS-Work: National Electronic Injury Surveillance System—Occupational Supplement
- National Occupational Mortality Surveillance (NOMS)/ National Occupational Respiratory Mortality System (NORMS)
- Occupational Health Safety Network
- Sensor-Pesticides: Pesticides Illness and Injury Surveillance
- State-based Surveillance Silicosis Program
- NIOSH Center for Workers' Compensation Studies (CWCS)

Activity Goal [SS] 1.1.2 The Surveillance Program will develop technology to support and enhance ongoing and new NIOSH-based surveillance systems

Activity Goal [SS] 1.1.3 The Surveillance Program will use traditional, web-based, social media and newly emerging tools and resources to disseminate occupational safety and health (OSH) surveillance data and make it easier to access and use.

Activity Goal [SS] 1.1.4 The Surveillance Program will encourage the inclusion in information systems of standardized codes and narrative information related to work to increase the understanding of relationships between work and health.

Activity Goal [SS] 1.1.5 The Surveillance Program will identify and analyze new data sources to fill gaps in diseases, injuries, and exposures in worker populations.

MINER Act

Strategic Goal 6: Improve workplace safety to reduce traumatic injuries.

Intermediate goal [SS] 2.1: Industry (producers, workers, manufacturers, suppliers), academia and other governmental agencies use NIOSH research initiated under the MINER Act program to develop and implement workplace solutions to reduce risk of mine disasters and improve the survivability of mine workers.

Activity Goal [SS] 2.1.1: Identify critical health and safety technology gaps in mining and solicit (through a BAA or RFP process), award and monitor technology development and commercialization contracts to address these gaps.

Activity Goal [SS] 2.1.2: Solicit, award and monitor capacity-building contracts to support tenure-track academic positions and graduate students pursuing advanced degrees in the fields of underground mine ventilation and ground control, with research specifically directed toward major workplace health and safety challenges.

Activity Goal [SS] 2.1.3: Develop interagency relationships through working groups and agreements to identify and utilize existing federal capabilities and research that could be further developed to address health and safety technology gaps in mining.

Strategic Goal 2: Reduce occupational hearing loss.
Strategic Goal 4: Reduce occupational musculoskeletal disorders.
Strategic Goal 5: Reduce occupational respiratory disease.

Intermediate goal [SS] 2.2: Industry (producers, workers, manufacturers, suppliers), academia and other governmental agencies use NIOSH research initiated under the MINER Act program to develop, adapt and implement new mine safety technology and expedite its commercial availability.

Activity Goal [SS] 2.2.1: Identify critical health and safety technology gaps in mining and solicit (through a BAA or RFP process), award and monitor technology development and commercialization contracts to address these gaps.

Activity Goal [SS] 2.2.2: Solicit, award and monitor capacity-building contracts to support tenure-track academic positions and graduate students pursuing advanced degrees in the fields of underground mine ventilation and ground control, with research specifically directed toward major workplace health and safety challenges.

Activity Goal [SS] 2.2.3: Develop interagency relationships through working groups and agreements to identify and utilize existing federal capabilities and research that could be further developed to address health and safety technology gaps in mining.

Respirator Approval Program

Strategic Goal 1: Reduce occupational cancer, cardiovascular disease, adverse reproductive outcomes and other chronic diseases.
Strategic Goal 3: Reduce occupational immune, infectious and dermal disease
Strategic Goal 5: Reduce occupational respiratory disease

Intermediate Goal [SS] 3.1 Users are able to select and use a variety of respirators that meet NIOSH performance requirements.

Activity Goal [SS] 3.1.1 NIOSH will help ensure the integrity of the national supply of respirators by implementing an efficient, high quality respirator approval process.

Activity Goal [SS] 3.1.2 NIOSH will perform post market surveillance activities (e.g., conduct audits and field investigations) to establish corrective measures and inform user decisions on respirator selection (e.g., routine use, grant and stockpile decisions).

Activity Goal [SS] 3.1.3 NIOSH will develop new or improved test systems and methods to facilitate advancing respiratory protection.

Activity Goal [SS] 3.1.4 NIOSH will work with partners to develop and disseminate guidance, recommendations, outreach products and methods regarding selection, use and maintenance of respirators.

Radiation Dose Evaluations

Strategic Goal 1: Reduce occupational cancer, cardiovascular disease, adverse reproductive outcomes and other chronic diseases.

Intermediate Goal [SS] 4.1 The Department of Labor and Secretary of HHS use NIOSH dose reconstruction findings to fulfill claims and add new classes to the Special Exposure Cohort, respectively.

Activity Goal [SS] 4.1.1 Conduct timely, high quality radiation dose reconstructions for Energy Employees Occupational Illness Compensation Program Act (EEOCIPA) claimants or their survivors.

Activity Goal [SS] 4.1.2 Conduct timely, high quality Special Exposure Cohort (SEC) evaluations for EEOCIPA claimants or their survivors.

Activity Goal [SS] 4.1.3 Respond to Advisory Board Review of site profiles, procedure documents, and dose reconstructions to improve the scientific quality of the program.

Coal Workers' Health Surveillance Program (CWHSP)

Strategic Goal 5: Reduce occupational respiratory disease

Intermediate Goal [SS] 5.1 Coal miners learn about their respiratory health status and are able to make informed choices to improve their personal health outcomes. Industry, labor, policy makers, MSHA, academics, and others with the ability to improve prevention use population level data from the NIOSH

Coal Workers' Health Surveillance Program to take actions with the potential to reduce the burden of respiratory disease in coal miners.

Activity Goal [SS] 5.1.1: CWHSP will work with mine operators and medical facilities to assure accessibility and high quality of surveillance services.

Activity Goal [SS] 5.1.2: CWHSP will conduct mobile outreach to enhance participation in surveillance.

Activity Goal [SS] 5.1.3: CWHSP will provide timely and useful individual-level information to coal miners about their test results and population-level information describing the burden of respiratory disease to the range of stakeholders interested in prevention.

B-Reader Certification Program

Strategic Goal 5: Reduce occupational respiratory disease

Intermediate Goal [SS] 5.2 Workers, employers, and other stakeholders have access to medical providers able to competently classify chest radiographs for changes of pneumoconiosis using the International Labour Office (ILO) system.

Activity Goal [SS] 5.2.1: The B-Reader Certification Program will provide physicians with opportunities to learn about ILO classification of chest radiographs.

Activity Goal [SS] 5.2.2: The B-Reader Certification Program will provide physicians with opportunities to document their ability to use ILO classification through a certification examination.

Activity Goal [SS] 5.2.3: The B-Reader Certification Program will improve training and certification testing in ILO classification of chest radiographs through updates using current imaging technology and other efforts.

Spirometry Course Certification Program

Strategic Goal 5: Reduce occupational respiratory disease

Intermediate Goal [SS] 5.3 Workers, employers, and other stakeholders have access to spirometry technicians able to competently perform high quality spirometry.

Activity Goal [SS] 5.3.1: The Spirometry Course Certification Program will assist those seeking to provide NIOSH-approved spirometry training courses in establishing and maintaining them.

Activity Goal [SS] 5.3.2: The Spirometry Course Certification Program will periodically audit NIOSH-certified spirometry training courses to assure that the training they provide is of high quality.

Activity Goal [SS] 5.3.3: The Spirometry Course Certification Program will carry out a range of activities to promote high quality spirometry, for example by providing current, evidence-based, informational materials regarding current best-practice spirometry guidelines.

Health Hazard Evaluations (HHE)

Supports Strategic Goals 1-7

Intermediate Goal [SS] 6.1 Stakeholders submit Health Hazard Evaluation requests that meet the needs of vulnerable populations, address emerging occupational health problems, and can have broad preventive impact.

Activity Goal [SS] 6.1.1 The Health Hazard Evaluation Program will reach out to health departments to increase awareness and use of its services.

Activity Goal [SS] 6.1.2 The Health Hazard Evaluation Program will reach out to employers, employees, and unions in selected industries to increase awareness and use of its services.

Intermediate Goal [SS] 6.2 Stakeholders implement recommendations at workplaces evaluated through the Health Hazard Evaluation Program.

Activity Goal [SS] 6.2.1 The Health Hazard Evaluation Program will maintain its ability to ensure completion of timely, high quality evaluations.

Activity Goal [SS] 6.2.2 The Health Hazard Evaluation Program will evaluate and enhance its communication products to increase adoption of its preventive recommendations.

Activity Goal [SS] 6.2.3 The Health Hazard Evaluation Program will continue to assess effectiveness and obtain feedback from employers, employees, and unions at workplaces it evaluates through an ongoing, systematic followback program.

Intermediate Goal [SS] 6.3 Stakeholders at workplaces not evaluated by the Health Hazard Evaluation Program, and in agencies and organizations, are aware of hazards found and actions recommended during Health Hazard Evaluation Program activities.

Activity Goal [SS] 6.3.1 The Health Hazard Evaluation Program will maintain an up-to-date and user-friendly web page to share the outputs of its activities.

Activity Goal [SS] 6.3.2 The Health Hazard Evaluation Program will use social media to reach a diverse set of stakeholders.

Activity Goal [SS] 6.3.3 The Health Hazard Evaluation Program will share information directly with agencies and organizations that develop standards and guidelines.

Intermediate Goal [SS] 6.4 Physicians, nurses, industrial hygienists, and other professionals use HHE training and education to address workplace health hazards from a public health perspective.

Activity Goal [SS] 6.4.1 The Health Hazard Evaluation Program will offer in-house and field training opportunities for occupational safety and health professionals.

Activity Goal [SS] 6.4.2 The Health Hazard Evaluation Program will provide in-person and online instructional lectures developed from its workplace evaluations.

Emergency Preparedness and Response Office

Supports Strategic Goals 1-7

Intermediate Goal [SS] 7.1 Employers and federal, state and local governments integrate occupational safety and health into planning and preparedness activities for chemical, biological, radiological, and natural events to protect workers.

Activity Goal [SS] 7.1.1 EPRO will translate NIOSH knowledge into federal response and recovery plans to protect workers.

Activity Goa [SS] 7.1.2 EPRO will identify gaps in response knowledge and facilitate opportunities to foster research to generate new knowledge to improve health and safety.

Activity Goal [SS] 7.1.3 EPRO will work to ensure NIOSH is prepared to support responses through personnel and equipment readiness capabilities to respond to events.

Activity Goal [SS] 7.1.4 EPRO will conduct outreach to stakeholders to increase awareness and use of Emergency Responder Health Monitoring and Surveillance (ERHMS) system.

Intermediate Goal [SS] 7.2 Employers and federal, state and local governments integrate occupational safety and health into response and recovery to chemical, biological, radiological, and natural events to protect workers.

Activity Goal [SS] 7.2.1 EPRO will translate NIOSH knowledge into event specific guidance and other products to ensure health and safety of workers.

Activity Goal [SS] 7.2.2 EPRO will provide timely response to stakeholders requests for information during an event.

Global Collaborations

Supports Strategic Goals 1-7

Intermediate Goal [SS] 8.1 Global partners have the capacity and expertise needed to reduce occupational diseases, injuries and deaths in the U.S. and globally.

Activity Goal [SS] 8.1.1 The Global Collaborations Program will participate in World Health Organization (WHO) efforts to improve capacity for the global surveillance of occupational illness and injury.

Activity Goal [SS] 8.1.2 NIOSH experts participate in Technical Committees that produce international standards addressing a wide spectrum of workplace issues, ranging from respirators to workplace air to silica exposure to laboratory methods, to road safety.

Activity Goal [SS] 8.1.3 The Global Collaborations Program acts as a WHO occupational health collaborating center to enhance global occupational safety and health.

Activity Goal [SS] 8.1.4 NIOSH collaborates with WHO, Pan-American Health Organization (PAHO) and other international entities to build capacity building of primary care providers and training programs for healthcare workers.

Fatality Assessment and Control Evaluation (FACE)

Strategic Goal 6: Improve workplace safety to reduce traumatic injuries

Intermediate Goal [SS] 9.1 Employers implement recommendations in NIOSH FACE reports to prevent similar deaths.

Activity Goal [SS] 9.1.1 NIOSH FACE will provide law enforcement agencies with recommendations to prevent motor vehicle related death to law enforcement officers.

Activity Goal [SS] 9.1.2 NIOSH FACE will provide employers recommendations to prevent deaths caused by robots.

Activity Goal [SS] 9.1.3 NIOSH FACE will provide employers recommendations to prevent deaths identified through State FACE investigations.

Fire Fighter Fatality Investigation and Prevention Program (FFFIPP)

Strategic Goal 6: Improve workplace safety to reduce traumatic injuries

Intermediate Goal [SS] 9.2 Fire Fighter stakeholders implement recommendations in NIOSH FFFIPP reports to prevent fatalities.

Activity Goal [SS] 9.2.1 NIOSH FFFIPP will provide recommendations to prevent motor vehicle related death to firefighters.

Activity Goal [SS] 9.2.2 NIOSH FFFIPP will provide the fire service with recommendations to prevent deaths related to structural fires.

Activity Goal [SS] 9.2.3 NIOSH FFFIPP will provide findings from fire fighter fatality investigations to standard setting bodies to improve existing fire service standards.

Education and Information Division

Supports Strategic Goals 1-7

Intermediate Goal [SS] 10.1 A broad range of stakeholders are aware of and utilize quality information generated by NIOSH.

Activity Goal [SS] 10.1.1 EID document development, docket, writer-editor, visual communication/design, and web teams will translate NIOSH research creatively and effectively into quality educational and technical scientific products for employers, workers, and others.

Activity Goal [SS] 10.1.2 EID writer-editor, visual communication/design, document development, and web teams will maintain and improve the dissemination of NIOSH information through timely, relevant, quality postings to the NIOSH website.

Activity Goal [SS] 10.1.3 EID exhibit, visual communication/design, writer-editor, and document development teams will maintain and improve the dissemination of NIOSH information through exhibits at scientific meetings and conferences.

Activity Goal [SS] 10.1.4 EID NIOSHTIC-2 and web teams will maintain and improve the documentation and accessibility of NIOSH research and information products in a bibliographic research database.

Activity Goal [SS] 10.1.5 EID document development, visual communication/design, writer-editor, and web teams will maintain and improve the dissemination of NIOSH information through the targeted use of social media and communication products.

Activity Goal [SS] 10.1.6 EID NIOSH-Info team will conduct focused dissemination of NIOSH information directly to the public through the response to public inquiries.

Activity Goal [SS] 10.1.7 EID document development and web teams will maintain and improve the evaluation of NIOSH educational and technical scientific products to more effectively address the needs of internal and external stakeholders.

Workforce Development

NIOSH is mandated to provide an adequate supply of qualified personnel to carry out the purposes of the Occupational Safety and Health Act. The NIOSH funded Education and Research Centers (ERCs) and Training Project Grants (TPGs) are the principal means for meeting this mandate through occupational safety and health (OSH) workforce training, continuing education, regional outreach.

Supports Strategic Goals 1-7

Intermediate Goal [SS] 11.1 NIOSH-trained OSH personnel work in industry, labor, academia and government to improve occupational health and safety for the U.S. workforce.

Activity Goal [SS] 11.1.1 NIOSH-supported ERCs and TPGs provide academic training in accredited undergraduate and graduate degree programs, post-doctoral and academic certificate training of personnel to advance the field of OSH with new and dynamic approaches to reducing work-related injuries, illnesses and fatalities.

Activity Goal [SS] 11.1.2 NIOSH-supported ERCs and TPGs conduct regular needs assessments to identify the OSH curriculum for core and closely related disciplines that supports the competency needs of these professions.

Activity Goal [SS] 11.1.3 NIOSH-supported ERCs and TPGs provide annual report on their trainees' progress and career placement.

Intermediate Goal [SS] 11.2 OSH professionals, practitioners, researchers and workers improve workplace health and safety by applying knowledge gained through NIOSH-funded continuing education programs for professionals, practitioners, researchers and workers.

Activity Goal [SS] 11.2.1 NIOSH-supported ERCs and TPGs develop and offer needs-based continuing education programs using a variety of modalities, including workshops, classroom instruction, online and other virtual teaching methods to reach their targeted audience.

Activity Goal [SS] 11.2.2 NIOSH-supported ERCs and TPGs conduct regular needs assessments to identify topics, subject matter, course content, length of training and teaching methods most appropriate for the continuing education in the OSH professionals.

Activity goal [SS] 11.2.3 NIOSH-supported ERCs and TPGs provide annual reports on their continuing education program progress.

Intermediate Goal [SS] 11.3 OSH professionals, workers and others apply knowledge gained through NIOSH-funded ERC and TPG outreach programs to reduce work-related injuries, illnesses and fatalities.

Activity Goal [SS] 11.3.1 NIOSH-supported ERCs and TPGs offer outreach programs that promote worker safety and health; reach vulnerable, underserved, and underrepresented worker groups; and meet local, regional or national workplace OSH needs.

Activity Goal [SS] 11.3.2 NIOSH-supported ERCs and TPGs conduct regular needs assessments to identify OSH outreach program needs among businesses, community groups, agencies, or other institutions within the region.

Activity Goal [SS] 11.3.3 NIOSH-supported ERCs and TPGs provide annual reports on their OSH outreach program progress.

Appendix A. BNI Criteria

Both research and service/support are grounded in BNI and can be defined by the same general BNI criteria categories. The definitions under each category are different and have been modified to reflect the unique nature of research and service/support.

BNI Criteria for Research and Service Activities in NIOSH	
BURDEN	
Burden describes the magnitude, or potential magnitude, of the problem to be addressed. The most pressing occupational safety and health needs are determined by the evidence of the health and exposure burden on individuals, employers and society. Burden includes evidence of the economic burden, or potential burden, on individuals, employers and society. Burden may also include assessment of the potential burden from emerging issues or understudied hazards or risks.	
RESEARCH	**SERVICE**
B.1. Exposure/Hazard	**B.1. Exposure/Hazard**
Burden can be defined by risks from exposure to hazards. The extent of exposure can be viewed in terms of the number of workers exposed, the magnitude of the exposure, or both. For emerging issues the burden is anticipatory and can be described by increasing trends that are described as potential burden using the same traditional burden parameters.	Burden can be defined by risks from exposure to hazards. The extent of exposure can be viewed in terms of the number of workers exposed, the magnitude of the exposure, or both. For emerging issues the burden is anticipatory and can be described by increasing trends that are described as potential burden using the same traditional burden parameters.
B.2. Injury/Illness	**B.2. Injury/Illness**
Burden can defined by the occurrence of injuries, illnesses, and deaths due to work-related factors that would tell us how many fatalities or illnesses have occurred. Injury and illness criteria also describe the incidence or prevalence of the injury or illness, and if there are there disparities among worker populations.	Burden can defined by the occurrence of injuries, illnesses, and deaths due to work-related factors that would tell us how many fatalities or illnesses have occurred. Injury and illness criteria also describe the incidence or prevalence of the injury or illness, and if there are there disparities among worker populations.
B.3. Disability/Severity	**B.3. Disability/Severity**
Burden can be defined by the degree or severity of disability that results from the injury or illness being addressed. Disability criteria tell us how serious the health outcome is and if there is evidence of disability, years of life lost or disabled, reduction in quality of life, or days away from work.	Burden can be defined by the degree or severity of disability that results from the injury or illness being addressed. Disability criteria tell us how serious the health outcome is and if there is evidence of disability, years of life lost or disabled, reduction in quality of life, or days away from work.
B.4. Cost	**B.4.Cost**
Burden can be defined as the economic impact of the injury or illness and the effect on the worker, employer and society. Cost criteria tell us that the estimated cost of the injury or illness is, such as medical expenses, as well as the productivity losses, lost wages, or disability payments.	Burden can be defined as the economic impact of the injury or illness and the effect on the worker, employer and society. Cost criteria tell us that the estimated cost of the injury or illness is, such as medical expenses, as well as the productivity losses, lost wages, or disability payments.

NEED	
The concept of need is a critical factor intrinsic to identifying the most important activities NIOSH should conduct to address burden. NIOSH should not only invest in an important burden area but also focus on the most relevant and impactful issues pertaining to the burden. Need provides the rationale for conducting the proposed research at this point in time and includes assessment of stakeholder need.	
RESEARCH	**SERVICE**
N.1. Evidence of knowledge gap	**N.1. Evidence service gap**
Knowledge gap is related to what is known about burden and what gaps exist in reducing it. To evaluate the need to conduct proposed research we should establish whether there is evidence that this activity will address a knowledge gap.	Service gap is related to what is currently being done to address the need or request for service. To evaluate the need to conduct proposed service activity we should establish whether there is evidence that this activity will address a gap.
N.2. Methodological approach	**N.2. Service Approach**
Assessment of methodological approach includes understanding whether the proposed research method is well defined and appropriate to the proposed aims of the project, and how it compares with other approaches that could be considered to fill the knowledge gap.	Assessment of service approach includes understanding whether the proposed approach or type of response (e.g., interviews, field studies, investigation, referral to other agencies) is well defined and appropriate to address the burden the request for service seeks to address and how this approach compares with other approaches that could be considered to fill the service gap.
N.3. Time fit	**N.3. Time fit**
Need considers whether this is the best point in time to conduct the proposed research. Evidence of the best time fit includes assessing whether there is a necessary sequence to the proposed line of study that makes a strong case for conducting the research now.	Need considers whether this is the best point in time to conduct the proposed service activity. Evidence of the best time fit includes assessing whether there is a necessary sequence to the proposed activity that makes a strong case for conducting the service now.
N.4. NIOSH advantage	**N.4. NIOSH advantage**
The NIOSH advantage describes whether NIOSH is the most appropriate organization to conduct the proposed research. This criteria helps us understand whether NIOSH is ideally suited for this activity or whether the proposed work uses NIOSH expertise, facilities or partnerships. Perhaps the proposed work requires neutrality or the NIOSH convening authority. The NIOSH advantage provides evidence of the strengths or unique advantages NIOSH has in comparison with other agencies that could undertake this activity.	The NIOSH advantage describes whether NIOSH is the most appropriate organization to conduct the proposed service activity. This criteria helps us understand whether NIOSH is ideally suited for this activity or whether the proposed service uses NIOSH expertise, facilities or partnerships. Perhaps the proposed work requires neutrality or the NIOSH convening authority. The NIOSH advantage provides evidence of the strengths or unique advantages NIOSH has in comparison with other agencies that could undertake this activity.
N.5. Stakeholder need	**N.5. Stakeholder need**
Need also provides evidence of an explicit stakeholder need in the broad context of research, policy or practice to conduct the proposed research.	Need also provides evidence of an explicit stakeholder need in the broad context of the NIOSH mission to conduct the proposed service activity.

IMPACT	
Impact is a measure of the potential reduction in burden that is likely to result from the project based on evident or anticipated end outcomes or well-accepted intermediate outcomes. Potential impact is expressed as potential reduction in burden or increase in effectiveness. The assessment of potential impact is based on the expected result in knowledge, policy, interventions, technologies, or solutions to occupational health problems, project cost and time, and probability of success.	
RESEARCH	**SERVICE**
I1. Likelihood of success	**I1. Likelihood of success**
Likelihood of success describes the probability the proposed research is feasible and will likely address the stated need. Impact considers the potential for the proposed research to be used in setting standards, guidance, policy, or recommendations, adopted by manufacturers, trade associations, or others, and whether there is potential for dissemination of research results by external organizations.	Likelihood of success describes the probability the proposed activity is feasible and will likely address the stated need. Impact considers the potential for the proposed activity to be used in setting standards, guidance, policy, or recommendations, adopted by manufacturers, trade associations, or others, and whether there is potential for dissemination of research results by external organizations.
I2. Use or dissemination of research results by others	**I2. Use or dissemination of service activity results by others**
Use of research results by others describes the potential for the proposed research to be used in setting standards, guidance, policy, or recommendations; or adopted by manufacturers, trade associations, or others. The potential for relevant groups to adopt technology, training programs/materials, intervention strategies, or new surveillance methods used in or resulting from the proposed research is also considered, as well as the potential for technology to be transferred into the marketplace, or for partners to assist in tracking progress of research translation efforts.	Use of service activity results by others describes the potential for others to use the results in setting standards, guidance, policy, or recommendations; or adopted by manufacturers, trade associations, or others. The potential for relevant groups to adopt technology, training programs/materials, intervention strategies, or new surveillance methods used in or resulting from the proposed service activity is also considered, as well as the potential for technology to be transferred into the marketplace, or for partners to assist in tracking progress of research translation efforts.
I3. Follow-on research	**I3. Follow-on service**
Assessment of the potential for follow-on research is a measure of how likely the proposed research is to generate information that leads to future research that builds on the findings from this project.	Assessment of the potential for follow-on service is a measure of how likely the proposed activity is to generate information that leads to future research or service that builds on the results from this project.