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RESEARCH ARTICLE

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Burden of occupational morbidity from selected causes in the United States overall and by NORA industry sector, 2012: A conservative estimate

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Abstract

Background: Timely and reliable national estimates of the occurrence of occupational injury and illness are needed to monitor the burden of occupational morbidity and mortality, establish research and intervention priorities, and evaluate the progress and effectiveness of prevention efforts.

Methods: We provide updated estimates of morbidity from occupational injuries and selected illnesses, using current general population incidence rates, the proportion of the general public with a particular workplace exposure, and the relative risk of illness from that exposure. We provide estimates for the total U.S. working population and for specific industry sectors.

Results: We estimate that, in 2012, between 5 712 362 and 5 961 620 total occupational cases, including 0.7 to 1.0 million incident illnesses and 5.0 million injuries, occurred in the United States.

Conclusion: The variety of disparate data sources and methods required to compile these estimates highlight the need for more comprehensive and compatible occupational health surveillance in the United States.

KEYWORDS
occupational exposure, occupational illness, occupational injury, surveillance

1 | INTRODUCTION

Occupational injuries and illnesses contribute substantially to overall morbidity and mortality globally and in the United States, imposing considerable burdens on affected workers, their families, employers, and society. Estimates of the burden of both fatal and nonfatal occupational injuries are available at the national level. The Census of Fatal Occupational Injuries (CFOI), conducted by the Department of Labor's Bureau of Labor Statistics (BLS), uses various state, federal, and independent data sources to provide a complete annual accounting of all fatal occupational injuries in the United States. The BLS's Survey of Occupational Injuries and Illnesses (SOII) uses self-reported data collected from a national probability sample of employers covered by the Occupational Safety and Health Act to produce annual estimates of the number (and rate) of nonfatal occupational injuries and certain acute occupational illnesses. The BLS estimated that private industry, and state and local government workers suffered approximately 3.5 million nonfatal injuries in 2014.[1] The SOII is subject to known issues of under-counting and underreporting but their effects can be estimated and mitigated through statistical adjustment.[2-4]

The burden of most occupational illnesses, especially chronic diseases, is harder to quantify. While the SOII captures the occurrence of certain acute occupational illnesses with reasonable reliability, most occupational illness is either not captured at all (eg, cancer) or is captured unreliably (eg, hearing loss). Therefore, different data sources are needed for estimating overall morbidity due to occupational illness.

In the United States, various attempts have been made to quantify the burden of occupational morbidity and mortality in both human and economic terms. For example, Steenland et al[5] applied attributable fractions (AFs) calculated using relative risk (RR) estimates from published epidemiologic studies to 1997 mortality data and estimated that there were approximately 49 000 deaths due to occupational illness in the United States. Leigh[6] used a similar approach but adjusted for underreporting to estimate that there were 53 000 deaths from chronic diseases due to occupational exposures in 2007. Leigh also used SOII data on acute occupational illness. After adjusting for underreporting, he estimated that here were 427 000 new, acute occupational illnesses in 2007. Neither study estimated new cases of chronic occupational diseases outside of the limited list of OSHA-recordable illnesses.

Timely and reliable national estimates of the occurrence of occupational injury and illness are needed to monitor the burden of occupational morbidity and mortality, establish research and intervention priorities, and evaluate the progress and effectiveness of prevention efforts. However, in the absence of a national surveillance system that completely and reliably captures cases of both occupational injury and illness, comprehensive estimates remain elusive. Because there is currently no single surveillance system that can provide such estimates directly, efforts must be periodically undertaken to calculate them using a variety of data sources. Now that the most recent estimates of occupational morbidity and mortality are out of date by a decade,[5,7] a need exists for revised estimates. In this paper, we provide updated estimates of occupational morbidity (eg, number of new cases and incidence rates) from occupational injuries and selected illnesses, using current general population incidence rates, the proportion of the general public with a particular workplace exposure, and the RR of illness from that exposure. We provide estimates for the total U.S. working population and for specific industry sectors.

2 | MATERIALS AND METHODS

2.1 | General approach

Our general approach for estimating the annual incidence of chronic illnesses that are well established to have occupational causes but are not well captured by national surveillance systems was to apply AF estimates to 2012 population incidence data. We used this approach to produce estimates of the burden of selected illnesses for the total U.S. working population and for each of the 10 major industry sectors defined by the National Institute for Occupational Safety and Health (NIOSH) for the National Occupational Research Agenda (NORA). These NORA sectors are intended to represent major areas of the U.S. economy and were created by aggregating 20 more detailed industry sectors defined according to the North American Industry Classification System (NAICS).[6]

For the total population, but not industry sectors, we also included estimates of the total number of fatal occupational injuries from the BLS CFOI and recordable* nonfatal injuries and acute illnesses (except hearing loss) from the BLS CFOI and SOII, after adjustment for underreporting. Occupational illnesses captured in the SOII technically include any illness recognized, diagnosed, and reported during the calendar year and caused or contributed to by an event or exposure in the work environment that meets recordability criteria set forth in the Occupational Safety and Health Administration's recordkeeping guidelines. However, the BLS acknowledges as that, "Overwhelmingly, reported illnesses are more often acute cases that are easier to directly relate to workplace activity (eg, contact dermatitis or carpal tunnel syndrome), as opposed to long-term latent illnesses, such as cancers." They are reported in the SOII grouped into five broad categories: skin diseases or disorders, such as contact dermatitis, eczema, and rashes caused by irritants; respiratory conditions, such as hypersensitivity pneumonitis or toxic inhalation injury (eg, metal fume fever); poisonings; hearing loss; and other occupational illnesses, which could include heatstroke, frostbite or decompression sickness. We excluded hearing loss cases from the SOII-based estimates of acute illnesses and replaced them with our AF-based estimates, which we considered to be more accurate, because we considered hearing loss to be a chronic illness. We also included direct estimates of the number of incident pneumoconiosis cases, all of which we assumed to be occupational. SOII and pneumoconiosis estimates were not available by NORA industry sector.

Population estimates for the United States were obtained from the CDC WONDER system, U.S. Cancer Statistics, and the 2012 Cancer Incidence Populations for age groups 20+ (asthma, hepatitis B virus [HBV], HCV, hearing loss), 20 to 69 (coronary heart disease [CHD]), and 30+ (chronic obstructive pulmonary disease [COPD], all cancers).[9] Worker population estimates for NORA industry sectors were obtained from the Current Population Survey (CPS) via the NIOSH Employed Labor Force Estimates tool.[10]

2.2 | Chronic conditions

For consistency and comparability, we chose to estimate total incident cases (fatal and nonfatal) of the same 16 chronic conditions with well-established occupational causes that Steenland et al included in their estimate of occupational mortality[5] plus hearing loss, which was not included in the Steenland et al mortality study

*An occupational injury or illness is defined as recordable if it results in death, unconsciousness, days away from work, restricted work, transfer to another job, or requires medical treatment beyond first aid. Occupational fractures of bones or teeth, punctured eardrums, cancers, and chronic irreversible diseases are also recordable, although cancers and chronic diseases are rarely recorded. In addition, special recording criteria apply to occupational cases involving needlestick and sharps injuries; medical removal; hearing loss; and tuberculosis (TB). Employers record injuries separate from illnesses and also identify for each whether a case involved any days away from work or days of restricted work activity, or both, beyond the day of injury or onset of illness. Occupational illnesses are new cases recognized, diagnosed, and reported during the calendar year.[8]

but is the most prevalent occupational illness in the United States.[11] Thus, the chronic conditions included nine cancers (lung, mesothelioma, urinary bladder, leukemia, laryngeal, melanoma of the skin, sinonasal, kidney, and liver) and seven noncancers (asthma, COPD, pulmonary TB, CHD, HBV and HCV infections, and hearing loss). We excluded nonmelanoma skin cancers because national incidence data are not available on basal and squamous skin cancers. These illnesses are all relatively common, at least among certain occupational groups. Many other illnesses known to have occupational causes that may be of great significance to individual workers or specific groups of workers, but for which either the exposure or the outcome are considered rare are not included in these burden estimates because they would not be expected to contribute substantially to burden at the population level.

For each included illness, we identified the most common occupational exposures known to be associated with it.

2.2.1 | Attributable fractions

We calculated the AF—the proportion of cases of a given condition that is caused by a particular exposure or risk factor—using the following formula[12]:

$$AF = P(E)(RR\text{-}1)/(1 + P(E)(RR\text{-}1)),$$

where P(E) is the proportion of the general population with a particular occupational exposure and RR is the RR of disease (ie, risk in the exposed/risk in the unexposed).

For each included condition, we calculated one or two AFs for each of its identified occupational causes. AF1 was calculated using the smallest of the range of RR estimates identified in a comprehensive review of the epidemiologic literature for each occupational exposure considered; AF2 was calculated using the largest estimate. If there was only one occupational exposure associated with a condition (eg, mesothelioma and exposure to asbestos), then AF1 and AF2 for that exposure were used directly to establish a range of AFs for the condition. However, for many of the conditions, there were multiple well-known occupational causes (eg, lung cancer and exposure to arsenic, asbestos, chromium, diesel engine exhaust [DEE]). For conditions caused by more than one occupational exposure, a combined AF for the lower range, $AF1_{combined}$, was calculated using the following formula[12]:

$$AF1_{combined} = 1 - (1 - AF1_1)(1 - AF1_2)(1 - AF1_3)\ldots(1 - AF1_n),$$

where $AF1_1 - AF1_n$ are the individual AF1s for each known cause in a condition with n known occupational causes. The AF for the upper range, $AF2_{combined}$, was calculated using the same formula as for $AF1_{combined}$ but used the largest AF value for each exposure, generally AF2 except when there was only an AF1 value for an exposure.

Applying the AF range for each of the included conditions to annual population incidence data allowed us to calculate minimum and maximum estimates of the number and incidence rate of occupational cases occurring in 2012.

2.2.2 | RR measures for identified occupational exposures

Occupational exposures having well-established associations with the included cancers (ie, acid mists, arsenic, asbestos, benzene, β-naphthylamine (BNA), 1,3-butadiene, chromium, DEE, environmental tobacco smoke (ETS), formaldehyde, ionizing radiation, leather dust, nickel and nickel compounds, *ortho*-toluidine (*o*-toluidine), polycyclic aromatic hydrocarbons (PAHs), radon, solar radiation, trichlorethylene (TCE), vinyl chloride, and wood dust) and noncancer illnesses (ie, asthmagens; contact with TB-infected person; ETS, needlestick injury, noise, shift work, silica; vapors, gas, dusts, and fumes [VGDF]; and work stress) were identified through a comprehensive literature review. To best approximate current risk, RR estimates used in the derivation of AFs for each exposure were taken from recent (past 10 years), well-designed epidemiologic studies and could include risk ratios, rate ratios or standardized mortality ratios (SMRs) from cohort studies; odds ratios from case control studies; or inverse-variance weighted averages of RR measures across multiple studies from meta-analyses. Detailed descriptions of our literature review methodology including our rationale for which occupational exposures to include and determination of the RR range are provided in Appendix A.

2.2.3 | Population exposure data

We used a variety of sources to produce estimates of the proportion of people within each of the identified occupational exposures for the overall employed population and for the worker populations within each of the 10 NORA industry sectors.

2.2.4 | Occupational exposure to carcinogens

For most of the carcinogens we considered, estimates of the proportion of workers exposed were taken from two main sources: CAREX (CARcinogen Exposure) Canada and CAREX (Europe). CAREX Canada is a multiinstitution research project that combines academic expertise and government resources to generate an evidence-based carcinogen surveillance program for Canada.[13] CAREX Canada developed estimates of occupational exposure for a number of known carcinogenic agents by industry and occupation. To generate the exposure prevalence estimates, they combined information gathered in a scientific literature review, data included in the Canadian Workplace Exposure Database (CWED), information from previous CAREX projects in Europe, Canadian-specific information on exposure from government and other sources, and CAREX occupational hygienists' expert assessment. CAREX Canada is modeled after CAREX. CAREX was established by the Finnish Institute for the European Union's "Europe Against Cancer" program.[14] The European CAREX project developed estimates of the burden of occupational cancer for 15 European Union (EU) countries from 1990 to 1993. Although they are not based on U.S. data and require the assumption that the proportions generated using these data are representative of current U.S. occupational exposures, we used these sources because they provide much more current occupational exposure estimates for carcinogens than are available from U.S. surveys or other data sources.

Because it was the more recent source of carcinogen exposure data, we used CAREX Canada-based estimates when available. To estimate the proportion of the employed population exposed, we divided the number of exposed workers obtained by using the CAREX Canada online tool e-WORK Online [15] by the total employed population obtained from 2006 Canadian census data.[16] These two sources were used to estimate the proportion of U.S. workers exposed to arsenic, asbestos, benzene, 1,3-butadiene, chromium (hexavalent), DEE, formaldehyde, nickel and nickel compounds, PAH/coal tar and coal tar pitches, silica,[†] solar radiation, TCE, and wood dust. CAREX Canada developed estimates of occupational exposure for carcinogenic agents by industry and occupation. To produce NORA industry sector-specific exposure estimates, NAICS 2002 codes from the 2006 Canadian Census were mapped to NORA industry sectors. A combination of Industry and Occupation Codes was used to separate out exposures related to the NORA Public Safety and Services sectors.

Estimates of the proportion of the employed population exposed to acid mists, BNA, ionizing radiation (low dose), radon, and vinyl chloride were obtained using 1990 to 1993 exposure estimates for 15 EU countries from the CAREX (Europe) database[17] and mean 1990 to 1993 EU labor force data from the Organization for Economic Co-operation and Development.[18] The number of exposures and exposed workers in CAREX were estimated mainly for industrial classes (CAREX industries) at the three-digit level of United Nations international standard industrial classification revision 2 (ISIC-2).[19] To produce NORA industry sector-specific exposure estimates, ISIC-2 codes from CAREX for each agent by industry and the numbers of employed workers in the EU by industry in 1990 to 1993[18] were mapped to the NORA industry sectors.

Exposure data for two carcinogens, leather dust and *o*-toluidine, were not available from CAREX Canada or CAREX (Europe). We obtained estimates of occupational exposure to leather dust from a Canadian study published by the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), the Exposure Profile of Quebec Workers.[20] The number of workers exposed to leather dust was reported in the profile by NAICS 2002 two-digit codes. To produce NORA industry sector-specific exposure estimates, numbers of exposed and total workers employed were estimated based on the 2006 Census of Canada and mapped to NORA sectors as for CAREX Canada-based estimates.

National Occupational Exposure Survey (NOES) data[21] and 1983 U.S. labor force data from the U.S. Census bureau[22] were used to estimate proportions of occupational exposure to *o*-toluidine. NIOSH conducted the NOES from 1980 to 1983, which collected data on potential occupational exposures to chemical, physical, and biological agents. The survey involved on-site visits to 4490 establishments in 522 industry types employing approximately 1 800 000 workers in 377 occupational categories. Nearly 13 000 different potential exposure agents and over 100 000 unique trade name products were observed during these on-site visits. To produce NORA industry sector-specific exposure estimates, the 1987 Standard Industrial Classification codes used in NOES were mapped to NORA industry sectors.

2.2.5 | Occupational exposure to noncarcinogens

All estimates for occupational exposure estimates for noncarcinogens were taken from U.S. data sources. Data from the 2010 National Health Interview Survey—Occupational Health Supplement (NHIS-OHS) were used to estimate the proportion of workers exposed to ETS, VGDF, asthmagens, and work stress. The NHIS is a cross-sectional household interview survey of the civilian noninstitutionalized population of the United States on a broad range of health topics. NIOSH sponsored an OHS to the 2010 NHIS to collect information on the prevalence and correlates of occupational health conditions and exposures to potential psychological and physical occupational hazards in the U.S. working population. The 2010 NHIS-OHS sample included 17 524 sample adults who had worked at least part of the 12 months preceding their interviews; most of the OHS questions focused on these respondents. The sample was designed and weighted to produce national estimates.[23]

Estimates of the proportion of all U.S. workers with occupational exposure to ETS and VGDF were obtained directly from NHIS-OHS profile made available online based on the weighted proportion of employed respondents with affirmative responses to the questions "During the past 12 months, were you regularly exposed to tobacco smoke from other people at work twice a week or more?" and "Were you regularly exposed to vapors, gas, dust, or fumes at work twice a week or more?" respectively.[24]

Because published estimates were not found for occupational exposure to "asthmagens" as a group, NHIS-OHS estimates of occupational exposure to VGDF were used as estimates of occupational exposure to asthmagens. The American Academy of Allergy, Asthma and Immunology notes that "Occupational asthma is caused by inhaling fumes, gases, dust or other potentially harmful substances while 'on the job.'"[25]

Four indicators were available in the NHIS-OHS to estimate job stress: long hours, job insecurity, work-family imbalance, and a hostile work environment. The 2010 NHIS-OHS defined Long hours as a response greater than 48 to the question "How many hours did you work last week?" A response of "Agree" or "Strongly Agree" to the statement "I am/was worried about becoming unemployed" was used to define job insecurity. Work-family imbalance was indicated as

[†]Although some sources have (eg, in the OSHA silica rule) have stated that occupational exposure to silica is a potential cause of lung cancer, it was not identified as a well-established cause in our systematic literature review. It was, however, identified as a well-established cause of TB and we did use silica exposure data in the calculation of TB AFs.

a response of “Disagree” or “Strongly Disagree” with “It is/was easy for me to combine work with family responsibilities.” A hostile work environment was defined as an affirmative response to the following question: “During the past 12 months, were you threatened, bullied, or harassed by anyone while you were on the job?” For each indicator, estimates of the proportion of all U.S. workers exposed were available online.[24] The highest of the four proportions was used as a proxy for a general “job stress” indicator.

Estimates of the proportion of workers with occupational exposure to ETS, VGDF, asthmagens, and the components of work stress were available from the NHIS-OHS profile for all U.S. workers and for each NORA industry sector separately, except for “Mining” and “Oil and Gas Extraction,” which were combined. The combined “Mining and Oil and Gas Extraction” sector comprised three subsectors: “Oil and Gas Extraction,” “Mining (except oil and gas extraction),” and “Support Activities for Mining.”[6] This information was used to generate separate exposure estimates for the “Mining” and “Oil and Gas Extraction” NORA sectors. A weighted estimate was calculated for the NORA “Mining” sector using the given (unweighted) exposure proportions for the “Mining (except oil and gas extraction)” and “Support Activities for Mining” subsectors. These estimates were applied to the estimated population represented by the sample to generate weighted exposure proportion estimates, which were then summed to produce an overall estimate of the proportion of exposed workers for the “Mining” NORA sector.

For some exposures, the exposure estimate for the “Oil and Gas Extraction” subsector did not meet NCHS reliability/precision standards and was not provided. Therefore, an estimate was calculated using subsector population estimates and weighted exposure proportions for the “Mining (except oil and gas extraction)” and “Support Activities for Mining” subsectors. These estimates were subtracted from the exposure estimate for the combined “Mining and Oil and Gas Extraction” sector, providing the weighted exposure estimate for the “Oil and Gas Extraction” subsector. The population data was then used to calculate the unweighted exposure estimate for in the “Oil and Gas Extraction” subsector that was used to estimate the proportion of exposed workers for the “Oil and Gas Extraction” NORA sector.

Estimates of the proportion of workers exposed to hazardous workplace noise, overall and by NORA industry sector, were taken from an analysis by Tak et al,[26] which utilized data from the 1999 to 2004 National Health and Nutrition Examination Survey (NHANES). Currently employed adults aged 16 years and older were included in the analysis. Each participant provided information on their place of work (industry) and kind of work (occupation), which was subsequently grouped into 28 NAICS categories.[27] Hazardous workplace noise exposure was defined as self-reported exposure to noise at their current job by an affirmative response to the question “At your current job, are you currently exposed to loud noise? [By loud noise I mean noise so loud that you have to speak in a raised voice to be heard?].” The weighted population size and prevalence of workplace noise exposure were estimated by industry and occupation categories.

The estimates of the proportion of workers exposed to hazardous workplace noise provided by Tak et al[26] were directly mapped to the following NORA industry sectors: Agriculture, Forestry and Fishing; Construction; Healthcare and Social Assistance; and Manufacturing. The estimate for hazardous noise exposure within the Mining industry sector was used for both Mining and Oil and Gas Extraction industry sectors, as noise exposure estimates were not available separately.

Proportions for multiple occupations were weighted and summed to generate hazardous occupational noise exposure estimates within the following industry sectors: Services (except Public Safety); Transportation, Warehousing and Utilities; and Wholesale and Retail Trade. Where applicable, occupational categories were subset within their respective industries, and the percentage that each occupation comprised of the overall industry was calculated. Weighted proportions were then calculated to determine the overall proportion exposed within each specific NORA industry sector.

Hazardous noise exposure prevalence was estimated for the Public Safety workers by calculating the prevalence that would be required to yield the known prevalence for the Public Administration subsector of the Services sector, of which Public Safety is a component. This calculation was based on the proportion of the Public Administration subsector comprised by Public Safety workers, which is known from BLS data,[10] and the assumption that the prevalence of hazardous noise exposure among non-Public Safety Public Administration workers was equivalent to the average of that of workers in the Finance, Insurance, and Real Estate and the Professional, Scientific, and Technical Services industry subsectors, for which estimates were available from the Tak et al analysis.

Based on a meta-analysis by Vyas et al,[28] shift work was considered any type of work schedule other than a regular daytime schedule. Data were obtained from a supplement to the May 2004 CPS.[29] The CPS is a monthly household survey that provides information on national employment and unemployment. In May 2004, the survey also collected information about flexible schedules, shift work, and other related topics. The data presented pertain to wage and salary workers who usually worked full time (35 or more hours per week) on their main job.

NORA industry sector-specific estimates of the proportion of workers exposed to shift work provided by the 2004 CPS were directly mapped to the following NORA industry sectors: Construction; Healthcare and Social Assistance; Manufacturing; Transportation, Warehousing and Utilities; and Wholesale and Retail Trade. The proportion of exposed workers in the Agriculture, Forestry and Fishing and Public Safety industry was estimated by using the percentage of workers employed in Farming, fishing and forestry occupations; and in Protective service occupations, respectively. The proportion of exposed workers in the Services sector was estimated by summing the number of workers in the Services subsectors (Information, Financial activities, Professional and business services, Educational services, Leisure and hospitality, and Other services) and the Public Administration sector (minus Protective service occupations). Separate exposure estimates were not provided for the Mining and Oil and Gas Extraction NORA sectors, thus the estimate for Mining was applied to both NORA sectors.

Data from the National Surveillance System for Health Care Workers and the Exposure Prevention Information Network were used to estimate the annual number of hospital-based healthcare workers (HCWs) who experience a needlestick injury.[30] After adjusting for underreporting, Panlilio et al estimated that 384 325 needlestick injuries occur each year among hospital-based HCWs. Applying this number to 1998 CPS data, an estimated 7.5% of hospital-based HCWs experience a needlestick injury each year. It was assumed that this proportion is the same among nonhospital HCWs.[31] The proportion of exposed U.S. workers (the number of exposed HCW/the total number of employed workers) was calculated based on CPS data. An industry sector-specific estimate was only generated for the Healthcare and Social Assistance NORA sector as estimates were unavailable for the other sectors. It was assumed that those sectors were either unexposed or that exposure was negligible at the industry sector population level.

NOES data from 1980 to 1983[21] were used to estimate the number of U.S. workers with occupational exposure to *Mycobacterium tuberculosis* (used as a surrogate for contact with TB-infected person). Data from the U.S. Census Bureau[22] were used to obtain estimates of the workforce in 1983. The initial estimate of the proportion exposed was calculated using these data. Then, to account for changes in overall TB incidence rates between 1983 (10.2/100 000)[32] and 2012 (3.1/100 000),[33] the initial proportions were divided by 3.3 to obtain the final proportion of U.S. workers exposed. As with needlestick injuries, an industry sector-specific estimate was only generated for the Healthcare and Social Assistance NORA sector as estimates were unavailable for the other sectors. It was assumed that those sectors were either unexposed or that exposure was negligible at the industry sector population level.

2.2.6 | Attributable cases

Minimum and maximum estimates of the number of occupational cases of the conditions we considered occurring in 2012 were calculated by applying the AF range for each condition to 2012 population incidence estimates for the United States overall and for each NORA industry sector. Multiplying the lower of the AF estimates by the estimated number of incident cases gave us the minimum estimate of occupational cases for each condition and multiplying the higher by the same incidence number gave us the maximum estimate.

To account for latency and—in the case of CHD—cessation of exposure, we used incidence data from a variety of sources to estimate the number of cases occurring in 2012 among all employed U.S. residents and among workers in the various NORA industry sectors in the following age groups: 20 to 69 years (CHD), greater than or equal to 20 years (asthma, HBV and HCV infection, and hearing loss), greater than or equal to 25 years (TB), and greater than or equal to 30 years (cancers and COPD).

2.2.7 | Cancer

Crude 2012 cancer incidence rates from the U.S. Cancer Statistics (USCS) produced by the CDC National Program of Cancer Registries (NPCR) and the National Cancer Institute Surveillance, Epidemiology and End Results (SEER) program were obtained using the CDC Wonder program[34] for ages greater than or equal to 30 years for all races and both sexes combined for the included cancers using the following ICD 10 codes: C34 (lung and bronchus); C45 (mesothelioma); C67 (urinary bladder); C91-95 (leukemia); C32 (larynx); C43 (melanoma of the skin); C30-31/C11 (nose, nasal cavity, middle ear/ nasopharynx); C64-65 (kidney and renal pelvis); and C22.0, C22.2-C22.4, C22.7 (liver).

Data on cancer incidence by industry were not available from NPCR or SEER. In addition, the number of participants in NHANES with cancer by industry was small. Thus, NORA industry sector-specific estimates were calculated from pooled 2006 to 2014 NHIS data or, when the estimated number of cancers using NHIS data was less than five, by applying National Occupational Mortality Surveillance (NOMS) proportionate mortality ratios (PMRs).

Annualized weighted cancer incidence rates were calculated using NHIS data for 2006 to 2014 for all races and both sexes combined for those age greater than or equal to 30 years by NORA industry sector for the following cancers: lung, bladder, leukemia, larynx, melanoma, kidney, and liver. For the incidence calculations, a pooled analysis file was created by appending the 2006 to 2014 sample adult files. Following recommended guidance for using adjacent years of NHIS data,[35] an adjusted weight was calculated by dividing the sample adult weight by the number of pooled years. To count only incident cases, incidence was coded as 1 if the respondent's age minus "the age first diagnosed with [type of cancer]" was 0 or 1, otherwise incidence was coded as 0.

Cancer incidence rates by NORA industry sector for mesothelioma and sinonasal/naso-pharynx cancers were not available in any national survey data (NHIS, NHANES) or in the literature. In addition, the sample number of larynx cancers by sector ranged from 0 to 3 and the industry sector-specific sample number of certain other cancers (eg, for Mining and Oil and Gas Extraction) were also small. In these cases, we used PMRs from the NOMS program as estimates of the standardized incidence ratio (SIR). The industry sector-specific incidence rate was calculated by multiplying the U.S incidence rate for each cancer by the sector-specific SIR.

The only known cause of mesothelioma is exposure to asbestos. Based on results provided by Rushton et al,[9] we assumed that 75%-98% of the cases of mesothelioma were due to either occupational or paraoccupational asbestos exposure (eg, exposure from handling clothes contaminated due to occupational exposure). Thus, we used 0.75-0.98 as our estimated proportion due to occupational exposure and did not calculate an AF estimate based on P(E) and RRs.

2.2.8 | Noncancer respiratory diseases and CHD

Weighted incidence rates for asthma, COPD, and CHD were calculated for 2011 to 2012 for all races and both sexes combined for ages greater than or equal to 20 years for asthma, ages greater than or equal to 30 years for COPD, and ages 20 to 69 for CHD using the 2011 to 2012 NHANES demographics and medical conditions data files. Incident cases of each illness were identified based on the respondent's self-report of having been told by a doctor or other health professional that they had the illness and the diagnosis having been made during the time period covered by the survey (ie, 2011-2012, identified where respondent age—age when first diagnosed with [condition] = 0 or 1).

To calculate the incidence of asthma, COPD, and CHD by NORA industry sector, a pooled analysis file was created using three NHANES cycles, 2005 to 2006, 2007 to 2008, and 2009 to 2010. Following recommended guidance[36] for using multiple cycles of NHANES data, an adjusted weight was calculated by dividing the interview weight by the number of cycles used. Incidence rates were calculated for each outcome by NORA sector using NHANES 2005 to 2010 as industry data were not available for NHANES 2011 to 2012 at the time of our analysis. In cases where the sample number of cases was greater than 5 (eg, for the Mining and Oil and Gas Extraction sectors for each outcome), industry sector-specific incidence rates were calculated using NOMS PMRs as proxies for SIRs as described above.

We assumed that 100% of the cases of each of the pneumoconioses—including silicosis, asbestosis, coal workers' pneumoconiosis, and those due to a variety of other mineral dusts, including talc, aluminum, bauxite, and graphite—were occupational. Thus, we did not calculate AF estimates for them. Because it is well known that pneumoconiosis and other long-latency illnesses are very poorly documented in the BLS-SOII, we took our estimates of the national number of pneumoconiosis cases from the Council of State and Territorial Epidemiologists (CSTE) Occupational Health Indicators for 2010.[37] CSTE uses the annual number of pneumoconiosis hospitalizations as its indicator and the national estimate has been calculated using data from the National Hospital Discharge Survey (NHDS). The NHDS was discontinued in 2010, thus, we based our estimate on the 2010 indicator. While recognizing that not all people with pneumoconiosis are hospitalized for that condition and that not all pneumoconiosis hospitalizations are incident cases, we felt that hospitalization data provided the best estimate of pneumoconiosis incidence. Using either mortality data[33] or estimates from the BLS-SOII, would have resulted in larger underestimates of incidence. Estimates of pneumoconiosis incidence were not available by NORA industry sector.

2.2.9 | Hearing loss

Weighted average annual hearing loss incidence for 2010 to 2014 for all races and both sexes combined for ages greater than or equal to 20 years was calculated using combined 2010 to 2014 NHIS data. Incident cases of hearing loss were identified based on the respondent's self-report of having at least some trouble hearing without the use of hearing aids or other listening devices and the duration of the hearing trouble being less than 1 year (ie, beginning in the year of the survey). For the incidence calculations, a pooled analysis file was created by appending the 2006 to 2014 sample adult files. Following recommended guidance for using adjacent years of NHIS data,[35] an adjusted weight was calculated by dividing the sample adult weight by the number of pooled years.

Data on hearing loss incidence by industry were available from NHIS or from the BLS. When the number of cases in NHIS was unavailable or less than four, data were used from BLS. Data derived from the BLS were used to calculate incidence of hearing loss for the Mining and Oil and Gas Extraction industry sectors. The "Occupational Injuries and Illnesses and Fatal Injuries Profiles" tool[38] was used to generate annual survey (SOII) numbers and rates within the private industry in the United States in 2013. U.S. population counts by occupation were derived from the 2013 CPS. Specific counts were combined to align with the NORA industries using 2012 NAICS codes. Incidence rates were then calculated to determine the overall incidence rate within each specific NORA industry sector.

2.2.10 | Infectious disease

Crude TB incidence rates from the Online Tuberculosis Information System (OTIS), which contains information on verified TB cases reported to CDC by state health departments, DC, and Puerto Rico from 1993 to 2013, were obtained for 2012, for ages greater than or equal to 25 years, for all races and both sexes combined using the CDC Wonder program.[33] To calculate TB incidence rates for each NORA industry sector, occupational data from OTIS were applied to Labor Force Statistics from the 2012 CPS.[35]

Crude noncancer incidence rates for 2013 were calculated for chronic HBV and HCV, for ages greater than or equal to 25 years and for acute HBV and HCV for ages greater than or equal to 20 years for all races and both sexes combined using 2013 U.S. viral hepatitis surveillance data and 2013 census data.[8,39] The estimated rates for total HBV and HCV for ages greater than or equal to 20 years were calculated by summing the acute and chronic rates. To calculate Viral Hepatitis incidence rates for each NORA industry sector, risk factor data from the 2013 CDC Hepatitis Surveillance Report were applied to Labor Force Statistics from the 2013 CPS.

2.3 | Acute illnesses

The number of acute occupational illnesses recognized, diagnosed and reported in 2012, less hearing loss cases, was taken from the 2012 BLS-SOII[40] but were inflated by 40% to account for known problems of underreporting.[2-4]

2.4 | Traumatic injuries

The number of fatal and nonfatal occupational injuries, including MSDs, in 2012 were captured using BLS statistics. The number of fatal occupational injuries were was taken directly from the 2012 BLS-CFOI (BLS, 2014). The number of all recordable (total recordable case rate) nonfatal occupational injuries were was taken from the 2012 BLS-SOII[40] but were inflated by 40% to account for known problems of underreporting.[2-4]

3 | RESULTS

3.1 | Chronic conditions

Tables 1 and 2 show the ranges of RR estimates for each of the occupational exposures identified in our systematic literature review as being well-established causes of our selected cancer and noncancer conditions respectively. The range may reflect the lowest and highest RR estimates reported from different studies identified in our literature review or it may reflect the lowest and highest reported RR estimates from a single study in which a range of estimates was reported. For some exposures, only one relevant study was identified with only one RR estimate reported, resulting in a point estimate, rather than a range, of RR.

Tables 3 and 4 show the estimated numbers of occupational cases of the selected cancer and noncancer conditions, respectively, that were calculated using AFs. For each condition, we present the estimated incidence rate and total number of cases in the United States in 2012 and the estimated range of the proportion due to occupational exposures (ie, the range of combined AFs derived from the individual AFs for each occupational exposure associated with the condition) as well as the resulting range of estimated occupational cases. Also included for each of the selected conditions are each of the occupational exposures identified in our systematic literature review as causes of the condition, the estimated proportions of the overall population exposed, the ranges of RR estimates associated with the exposure and the resulting range of AFs used to calculate the combined AF ranges for each condition.

Tables 5 and 6 are summary tables that show the estimated ranges of numbers and incidence rates, respectively, of occupational cases of 17 chronic conditions with occupational causes for each NORA industry sector. More detailed, supplemental tables (Tables S1-S20) that present the same information as in Tables 3 and 4 by NORA industry sector are available in Appendix B.

3.1.1 | Cancers

We estimated that in the United States in 2012, there were a total of between 16 764 and 30 444 new occupational cancer cases.

Lung cancer was responsible for most of the occupational cancers. Occupational exposure to arsenic, asbestos, chromium, DEE, ETS, nickel and nickel compounds, PAHs, and radon resulted in an estimated 11 371 to 20 236 new cases, representing 5.40%-9.61% of all U.S. lung and bronchus cancers among people aged greater than or equal to 30 years. Occupational exposure to asbestos continues to contribute to mesothelioma with an estimate 2383 to 3113 new cases representing 75% to 98% of all new US cases in 2012. While, a rare cancer (463-747 new cases), occupational exposures were responsible for a fairly high percentage of these nasal and nasopharynx cancer (12.0%-19.3%) due to exposure to formaldehyde, leather dust, nickel and nickel compounds and wood dust. We estimated that occupational exposure to solar radiation resulted in 1727 to 5267 new cases of melanoma in 2012, representing 2.64%-8.05% of all incident U.S. melanoma cases among people aged greater than or equal to 30 years.

TABLE 1 Ranges of RR estimates for selected occupational cancers by exposure

Exposure	Lowest RR estimate (source)	Highest RR estimate (source)
Selected cancers		
Lung cancer (and bronchus)		
Arsenic	1.58[41,42]	1.91[41,42]
Asbestos	1.70[43]	2.72[43]
Chromium	1.63[44]	1.79[45]
Diesel engine exhaust	1.03[46]	1.47[46]
Environmental tobacco smoke	1.24[47]	
Nickel and nickel compounds	1.33[48]	1.50[49]
Polycyclic aromatic hydrocarbon	1.31[50]	1.82[51]
Radon	1.55[52]	
Bladder cancer		
β-Naphthylamine	16.83[53]	
o-Toluidine	2.87[54]	
Leukemia		
Benzene	1.72[55]	
1,3 Butadine	1.40[56]	3.00[56]
Ionizing radiation	1.16[57]	1.30[57]
Laryngeal cancer		
Acid mists	1.97[58]	5.57[58]
Asbestos	1.55[59]	1.69[60]
Melanoma (skin cancer)		
Solar radiation	1.31[61]	2.00[62]
Sinonasal and nasopharynx cancer		
Formaldehyde	1.09[63]	1.68[63]
Leather dust	11.89[63]	
Nickel and nickel compounds	18.00[63]	
Wood dust	1.61[63]	5.91[63]
Kidney cancer (and renal pelvis)		
Trichlorethylene	1.26[64]	1.35[64]
Liver cancer		
Vinyl chloride	1.35[59]	2.96[59]

Abbreviations: RR, relative risk.

The construction; manufacturing; mining; oil and gas extraction; public safety; and transportation, warehousing and utilities industries had the highest occupational lung cancer rates. The agriculture, forestry and fishing; construction; mining; and public safety industries had the highest occupational melanoma risk.

3.1.2 | Noncancer respiratory diseases and CHD

We estimated that in the United States in 2012, there were a total of between 399 799 and 553 566 new cases of noncancer occupational respiratory diseases such as asthma, COPD, and pneumoconiosis.

TABLE 2 Ranges of RR estimates for selected noncancer occupational illnesses by exposure

Exposure	Lowest RR estimate (source)	Highest RR estimate (source)
Selected respiratory diseases		
Asthma		
Asthmagens	1.48[65]	2.40[66]
COPD		
Vapors, gas, dusts, and fumes	2.11[67]	
TB		
Contact with TB-infected person	1.93[68]	
Silica	3.39[69]	
Other conditions of interest		
CHD		
Environmental tobacco smoke	1.19[70]	1.22[70]
Noise	1.06[70]	1.51[71]
Shiftwork	1.12[28]	1.32[28]
Work stress	1.13[72]	1.34[72]
HBV		
Needlestick injury	1.21[73]	1.48[74]
HCV		
Needlestick injury	1.17[75]	
Hearing loss		
Noise	1.09[76]	1.74[77]

Abbreviations: CHD, coronary heart disease; COPD, chronic obstructive pulmonary disease; HBV, hepatitis B virus; RR, relative risk; TB, tuberculosis.

Occupational exposures were responsible for 10.71% to 25.93% of all incident U.S. asthma cases among people aged greater than or equal to 20 years resulting in an estimated 108 202 to 261 969 cases in 2012. An estimated 281 336 new cases of COPD occurred in 2012, representing approximately 21.72% of all incident U.S. cases among people aged greater than or equal to 30 years. We assigned a 100% AF percentage to pneumoconiosis. There were a total of 10 261 pneumoconiosis hospitalizations in 2010, including 8123 asbestosis cases, 670 CWP cases, 249 silicosis cases, and 1220 other or unspecified pneumoconiosis cases. Estimates of the occurrence of pneumoconiosis were not available for 2012.

The agriculture, forestry, and fishing; manufacturing; public safety; and transportation, warehousing and utilities industries had the highest asthma rates. The agriculture, forestry, and fishing; construction; mining; oil and gas extraction; and transportation, warehousing, and utilities industries had the highest COPD rates.

We estimated that, in the U.S. 2012, occupational exposure to ETS, noise, shift work, and work stress resulted in between 41 736 and 113 747 new cases of coronary heart disease, representing 7.83% to 21.34% of all incident U.S. cases among people aged 20 to 69 years.

3.1.3 | Hearing loss

We estimated that 1514 to 11 249 new cased of hearing loss were attributable to occupational exposure to noise in 2012, representing 1.52% to 11.29% of all incident U.S. cases.

3.1.4 | Infectious diseases

Infectious diseases had a low occupational AF. We estimated that occupational percutaneous needlestick injuries resulted in 53 to 118 new HBV and approximately 239 HCV infections in 2012, representing 0.14% to 0.31% and approximately 0.11% of all incident HBV and HCV infections among people aged greater than or equal to 20 years, respectively. Approximately 429 new cases of pulmonary TB occurred in 2012 as a result of occupational exposure to TB-infected persons and silica, representing approximately 5.13% of all incident U.S. TB cases among people aged greater than or equal to 25 years.

The construction; manufacturing; mining; oil and gas extraction; public safety; and transportation, warehousing, and utilities industries had the highest rates of CHD. The agriculture; construction; manufacturing; mining; and oil and gas extraction industries had the highest rates of hearing loss.

3.2 | Acute illnesses

The BLS estimated that there were 207 800 acute occupational illnesses diagnosed, recognized, and reported in 2012, including 21 200 hearing loss cases. Adjusting for an assumed 40% undercount of acute illnesses in the BLS-SOII, we estimated that there were 261 240 nonhearing loss acute occupational illnesses in 2012.

3.3 | Traumatic injuries

The BLS estimated that there were 4628 fatal and approximately 3 561 400 nonfatal occupational injuries in 2012. Adjusting for an assumed 40% undercount of nonfatal injuries in the BLS-SOII, we estimate that there were 4 990 588 total fatal and nonfatal occupational injuries in 2012, including approximately 546 350 musculoskeletal disorders resulting in one or more days away from work.

3.4 | Total number of occupational injuries and illnesses

Adding our estimates of the number of fatal and nonfatal traumatic injury, acute illness, and pneumoconiosis cases to the range of chronic occupational illness cases that we calculated using AF estimates, we estimated the total annual number of incident occupational injury and illness in the United States to be between 5 712 362 and 5 961 620 cases. (Table 7)

TABLE 3 Estimated number and proportion of selected cancers due to occupational exposure, United States, 2012

Exposures	U.S population 2012[a]	Incidence rate (per 100 000)	Estimated number of U.S. cases	Estimated % exposed	RR	Estimated proportion due to occupational exposures (%) (AF)	Incidence rate due to occupational exposures (per 100 000)	Estimated number of cases due to occupational exposures
Selected cancers								
Lung cancer (and bronchus) (age 30+)	185 775 911	113.35	210 577			5.40-9.61	6.12-10.89	11 371-20 236
Arsenic				0.146	1.58-1.91	0.08-0.13		
Asbestos				0.899	1.70-2.72	0.63-1.52		
Chromium				0.614	1.63-1.79	0.39-0.48		
Diesel engine exhaust				5.318	1.03-1.47	0.16-2.44		
Environmental tobacco smoke				10.00	1.24-1.24	2.34-2.34		
Nickel and nickel compounds				0.694	1.33-1.50	0.23-0.35		
Polycyclic aromatic hydrocarbon				2.123	1.31-1.82	0.65-1.71		
Radon				1.906	1.55-1.55	1.04-1.04		
Mesothelioma (age 30+)	185 775 911	1.71	3177			75.00-98.00	1.283-1.68	2383-3113
Asbestos				…	…	75.00-98.00		
Bladder cancer (age 30+)	185 775 911	37.57	69 796			0.08-0.08	0.03-0.03	56-56
β-Naphthylamine				0.0015	16.83-16.83	0.02-0.02		
o-Toluidine				0.0293	2.87-2.87	0.05-0.05		
Leukemia (age 30+)	185 775 911	21.35	39 663			1.60-1.65	0.34-0.35	635-654
Benzene				2.221	1.72-1.72	1.57-1.57		
1,3 Butadine				0.023	1.40-3.00	0.0092-0.046		
Ionizing radiation				0.103	1.16-1.30	0.02-0.03		
Laryngeal cancer (age 30+)	185 775 911	6.53	12 131			0.98-2.85	0.064-0.19	119-346
Acid mists				0.503	1.97-5.57	0.49-2.25		
Asbestos				0.899	1.55-1.69	0.49-0.62		
Melanoma (skin cancer) (age 30+)	185 775 911	35.22	65 430			2.64-8.05	0.93-2.84	1727-5267
Solar radiation				8.755	1.31-2.00	2.64-8.05		
Sinonasal and nasopharynx cancer (age 30+)	185 775 911	2.08	3864			11.99-19.33	0.25-0.40	463-747
Formaldehyde				0.898	1.09-1.68	0.081-0.61		
Leather dust				0.031	11.89-11.89	0.33-0.33		
Nickel and nickel compounds				0.694	18.00-18.00	10.55-10.55		
Wood dust				2.007	1.61-5.91	1.21-8.97		

(Continues)

TABLE 3 (Continued)

Exposures	U.S population 2012[a]	Incidence rate (per 100 000)	Estimated number of U.S. cases	Estimated % exposed	RR	Estimated proportion due to occupational exposures (%) (AF)	Incidence rate due to occupational exposures (per 100 000)	Estimated number of cases due to occupational exposures
Kidney cancer (and renal pelvis) (age 30+)	185 775 911	29.20	54 247			0.015-0.020	0.0044-0.0058	8-11
Trichlorethylene				0.058	1.26-1.35	0.015-0.020		
Liver cancer (age 30+)	185 775 911	13.11	24 355			0.010-0.056	0.0013-0.0073	2-14
Vinyl chloride				0.029	1.35-2.96	0.010-0.056		
Total occupationally related conditions			483 240					16 764-30 444

Abbreviation: AF, attributable fractions; RR, relative risk.

[a]Population estimate based on CDC Wonder, U.S. Cancer Statistics, 2012 Cancer Incidence Populations for age groups 20+ (asthma, HBV, HCV, hearing loss), 20-69 (CHD), and 30+ (COPD, all cancers).

4 | DISCUSSION

In this paper, we use incidence data to provide an estimate of the total annual occurrence of occupational injury and well-established occupational illness in the United States overall and by major industrial sectors. We modeled our approach after Steenland et al, 2003, who used mortality data to estimate 49 000 deaths from occupational disease and injuries in 1997. By using incident data, our estimate of between 5 712 362 and 5 961 620 total cases including 0.7 to 1.0 million occupational incident illnesses and 5.0 million injuries, reflects the broader impact of occupational illness and injury.

Comprehensive estimates of the occurrence of occupational injury and illness are difficult to produce and require the combination of data from numerous sources. While there are known problems of undercounting associated with national surveillance systems that primarily capture straightforward occupational injuries and acute illnesses, these can, at least in principle, be quantified and adjusted for.[2-4] The larger issue is that direct estimates of the national occurrence of most occupational chronic illnesses are not available. This is largely because the causes of most of these illnesses are not exclusively due to occupational exposures, making the determination of the occupational component complicated and often difficult. The routine inclusion of information on subjects' employment status, industry, and occupation of employment in all national surveillance and survey datasets as basic demographic descriptors would help to systematically identify potential occupational illnesses. These indications could then be investigated through research to explore the occupational component including the occurrence of unrecognized or less well-established occupational chronic illnesses. They can also be used in conjunction with economic data to produce cost estimates and estimates of years of potential life lost, quality-adjusted life years, or disability-adjusted life years that characterize the burden of occupational injury and illness in economic and human suffering terms to more fully assess the relative burden of different types of occupational illness on society.

Because there are few studies that attempt to provide comprehensive national estimates of the total annual incidence of occupational injuries and illnesses, it is challenging to place our findings in context. Perhaps the most comparable effort is that of Paul Leigh.[6] Using 2007 data, he estimated the occurrence of 8.6 million fatal and nonfatal occupational injuries and 480 000 fatal and nonfatal occupational illnesses. Our overall estimates are at least roughly consistent with Leigh's findings. We estimate fewer injuries, but this is broadly consistent with a steady annual decline in the incidence of fatal and nonfatal occupation injuries reported by BLS. We estimate more occupational illnesses, but Leigh did not include cases of chronic occupational diseases outside of the limited list of OSHA-recordable illnesses captured in the SOII. Although directly comparable estimates in terms of methodology and scope are hard to come by, we anticipate that our disease-specific findings may well differ from other published estimates.

TABLE 4 Estimated number and proportion of selected noncancer illnesses due to occupational exposure, United States, 2012

Exposures	U.S. population 2012[a]	Incidence rate (per 100 000)	Estimated number of U.S. cases	Estimated % exposed	RR	Estimated proportion due to occupational exposures (%) (AF)	Incidence rate due to occupational exposures (per 100 000)	Estimated number of cases due to occupational exposures
Selected respiratory diseases								
Asthma (age 20+)	229 362 079	440.48	1 010 294			10.71-25.93	47.18-114.22	108 202-261 969
Asthmagens				25.00	1.48-2.40	10.71-25.93		
COPD (age 30+)	185 775 911	697.23	1 295 285			21.72-21.72	151.44-151.44	281 336- 281 336
Vapors, gas, dusts, and fumes				25.00	2.11-2.11	21.72-21.72		
TB (age 25+)	206 971 087	4.04	8362			5.13-5.13	0.21-0.21	429-429
Contact with Tuberculosis-infected person				0.00028	1.93-1.93	0.00026-0.00026		
Silica				2.263	3.39-3.39	5.13-5.13		
Other conditions of interest								
Coronary heart disease (age 20-69)	200 436 822	265.93	533 022			7.83-21.34	20.82-56.75	41 736-113 747
Environmental tobacco smoke				10.00	1.19-1.22	1.86-2.15		
Noise				17.20	1.06-1.51	1.02-8.06		
Shiftwork				10.10	1.12-1.32	1.20-3.13		
Work stress				31.70	1.13-1.34	3.96-9.73		
HBV (age 20+)	229 362 079	16.60	38 074			0.14-0.31	0.023-0.051	53-118
Needlestick injury				0.654	1.21-1.48	0.14-0.31		
HCV (age 20+)	229 362 079	94.80	217 435			0.11-0.11	0.10-0.10	239-239
Needlestick injury				0.654	1.17-1.17	0.11-0.11		
Hearing loss (age 20+)	229 362 079	43.44	99 635			1.52-11.29	0.66-4.90	1514-11 249
Noise				17.20	1.09-1.74	1.52-11.29		
Total occupationally related conditions			3 202 107					433 509-669 087

Abbreviations: AF, attributable fractions; CHD, coronary heart disease; COPD, chronic obstructive pulmonary disease; HBV, hepatitis B virus; RR, relative risk; TB, tuberculosis.

[a]Population estimate based on CDC Wonder, U.S. Cancer Statistics, 2012 Cancer Incidence Populations for age groups 20+ (asthma, HBV, HCV, hearing loss), 20-69 (CHD), and 30+ (COPD, all cancers).

5 | LIMITATIONS

This study is subject to a number of limitations which may have affected our estimation of the number of cases due to occupational exposures. These include: (a) the selection of the illnesses to include; (b) problems estimating national incidence rates for noncancers and industry-specific incidence rates for all chronic illnesses; (c) reliance on RR estimates obtained from a variety of US and non-U.S. epidemiologic studies using different methodologies to calculate the AFs; and (d) use of exposure estimates for carcinogens based on data from non-U.S. sources and for noncarcinogens based on survey data to calculate the AFs. The relative contribution of each of these limitations will have been different for each of the occupational conditions considered, so it is not possible to say which is most important or had the largest effect.

The first limitation, selecting which illnesses to include has been well articulated by Steenland et al.[5] For example, underestimation may result from: (a) exclusion of illnesses without well-established occupational causes for which there is strong scientific evidence,[78] (eg, breast cancer, prostate cancer, brain cancer, non-Hodgkin lymphoma; and certain autoimmune, infectious, and neurodegenerative diseases (b) exclusion of newly recognized or emerging occupational illnesses or those caused by unrecognized work-place hazards (eg, mental health outcomes), and (c) the use of RRs derived from SMRs for certain cancers. In addition, by following the methodology of Steenland et al,[5] we may have underestimated the

TABLE 5 Estimated number of selected illnesses due to occupational exposure by NORA industry sector, United States, 2012

Outcome	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
Selected cancers										
Lung cancer (and bronchus) (age 30+)	55-144	954-1737	290-344	1767-2538	32-71	81-126	432-1039	1938-2920	925-3292	794-1237
Mesothelioma (age 30+)	16-20	234-305	163-213	260-339	1-2	13-17	34-45	630-823	101-131	174-227
Bladder cancer (age 30+)	1-1	0-0	8-8	13-13	0-0	0-0	0-0	30-30	3-3	0-0
Leukemia (age 30+)	1-1	35-35	8-9	122-128	1-1	11-13	135-135	102-102	88-90	99-99
Laryngeal cancer (age 30+)	0-0	70-103	3-14	18-72	0-0	2-7	0-0	5-15	3-14	3-13
Melanoma (skin cancer) (age 30+)	543-1271	870-2335	100-318	170-536	61-165	15-42	281-816	787-2467	204-590	103-325
Sinonasal and nasopharynx cancer (age 30+)	1-4	43-103	8-11	136-181	2-2	2-2	0-2	72-88	9-10	9-12
Kidney cancer (and renal pelvis) (age 30+)	0-0	0-0	0-0	7-9	0-0	0-0	0-0	2-2	0-0	0-0
Liver cancer (age 30+)	0-0	0-1	0-0	2-13	0- 0	0-0	0-0	0-1	0-2	0-0
Selected respiratory diseases										
Asthma (age 20+)	3605-7576	4520-9567	5663-14 768	15 436-33 944	101-200	185-400	5622-12 817	48 294-122 637	15 167-33 744	7405-18 315
COPD (age 30+)	7534-7534	41 845-41 845	11 878-11 878	18 370-18 370	956-956	1808-1808	5066-5066	89 566-89 566	25 435-25 435	24 029-24 029
TB (age 25+)	1-1	101-101	0-0	36-36	2-2	1-1	0-0	16-16	10-10	5-5
Other conditions of interest										
CHD (age 20-69)	559-1843	4817-12 743	2434-5663	6557-19 883	132-352	376-891	1042-2492	8704-22 187	2400-6693	4023-10 094
HBV (age 20+)	0-0	0-0	19-43	0-0	0-0	0-0	0-0	0-0	0-0	0-0
HCV (age 20+)	0-0	0-0	31-31	0-0	0-0	0-0	0-0	0-0	0-0	0-0
Hearing loss (age 20+)	26-167	157-1016	28-224	276-1838	8-45	8-44	14-100	145-1121	23-160	85-663
Total occupationally related conditions	12 342-18 562	53 646-69 891	20 633-33 524	43 170-77 900	1296-1796	2502-3351	12 626-22 512	150 291-241 975	44 368-70 174	36 729-55 019

Abbreviations: CHD, coronary heart disease; COPD, chronic obstructive pulmonary disease; HBV, hepatitis B virus; TB, tuberculosis.

TABLE 6 Estimated incidence rate per 100 000 population of selected illnesses due to occupational exposure by NORA industry sector, United States, 2012

Outcome	Agriculture (forestry and fishing)	Construc-tion	Healthcare and social assistance	Manufacturing	Mining	Oil and gas extraction	Public safety	Services	Transportation (warehousing and utilities)	Wholesale and retail trade
Selected cancers										
Lung cancer (and bronchus) (age 30+)	2.56-6.75	10.30-18.74	1.48-1.76	11.89-17.08	14.11-31.19	13.80-21.44	15.48-37.26	2.84-4.28	12.49-44.43	4.04-6.29
Mesothelioma (age 30+)	0.735-0.960	2.520-3.293	0.833-1.088	1.748-2.283	0.630-0.823	2.258-2.950	1.223-1.597	0.923-1.205	1.358-1.774	0.885-1.156
Bladder cancer (age 30+)	0.02-0.02	0.00-0.00	0.04-0.04	0.09-0.09	0.00-0.00	0.00-0.00	0.00-0.00	0.04-0.04	0.04-0.04	0.00-0.00
Leukemia (age 30+)	0.07-0.07	0.38-0.38	0.04-0.05	0.82-0.86	0.36-0.41	1.93-2.13	4.84-4.84	0.15-0.15	1.19-1.22	0.50-0.51
Laryngeal cancer (age 30+)	0.001-0.001	0.752-1.115	0.016-0.072	0.119-0.482	0.008-0.010	0.282-1.219	0.000-0.000	0.008-0.021	0.047-0.194	0.014-0.066
Melanoma (skin cancer) (age 30+)	25.52-59.72	9.39-25.19	0.51-1.63	1.14-3.61	27.05-73.02	2.50-7.08	10.09-29.24	1.15-3.61	2.75-7.96	0.52-1.65
Sinonasal and nasopharynx cancer (age 30+)	0.05-0.18	0.47-1.12	0.04-0.06	0.91-1.22	0.68-0.70	0.32-0.33	0.01-0.07	0.10-0.13	0.12-0.13	0.05-0.06
Kidney cancer (and renal pelvis) (age 30+)	0.000-0.000	0.000-0.000	0.000-0.000	0.044-0.058	0.000-0.000	0.000-0.000	0.000-0.000	0.003-0.003	0.000-0.000	0.000-0.000
Liver cancer (age 30+)	0.000-0.000	0.001-0.007	0.000-0.000	0.016-0.087	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.001	0.005-0.028	0.000-0.000
Selected respiratory diseases										
Asthma (age 20+)	169.43-356.02	48.76-103.21	28.96-75.53	103.89-228.44	44.79-88.53	31.58-68.11	201.60-459.58	70.76-179.68	204.69-455.39	37.65-93.12
COPD (age 30+)	354.03-354.03	451.43-451.43	60.75-60.75	123.63-123.63	422.27-422.27	308.05-308.05	181.66-181.66	131.23-131.23	343.26-343.26	122.17-122.17
TB (age 25+)	0.042-0.042	1.084-1.084	0.001-0.001	0.241-0.241	0.687-0.687	0.160-0.160	0.000-0.000	0.024-0.024	0.132-0.132	0.023-0.023
Other conditions of interest										
CHD (age 20-69)	26.29-86.62	51.97-137.47	12.45-28.96	44.13-133.81	58.46-155.48	64.03-151.76	37.36-89.35	12.75-32.51	32.39-90.32	20.45-51.32
HBV (age 20+)	0.00-0.00	0.00-0.00	0.10-0.22	0.00-0.00	0.00-0.00	0.00-0.00	0.00-0.00	0.00-0.00	0.00-0.00	0.00-0.00
HCV (age 20+)	0.00-0.00	0.00-0.00	0.16-0.16	0.00-0.00	0.00-0.00	0.00-0.00	0.00-0.00	0.00-0.00	0.00-0.00	0.00-0.00
Hearing loss (age 20+)	1.22-7.87	1.70-10.96	0.14-1.15	1.86-12.37	3.51-19.77	1.34-7.55	0.50-3.57	0.21-1.64	0.31-2.16	0.43-3.37

Abbreviations: CHD, coronary heart disease; COPD, chronic obstructive pulmonary disease; HBV, hepatitis B virus; TB, tuberculosis.

TABLE 7 Total estimated number of incident occupational injuries and illnesses, United States 2012

Outcome	Low estimate	High estimate
Chronic conditions	**460 534**	**709 792**
Cancer	16 764	30 444
Noncancer chronic illnesses	433 509	669 087
Pneumoconioses	10 261	10 261
Acute illnesses (less hearing loss)	**261 240**	**261 240**
Traumatic injuries	**4 990 588**	**4 990 588**
Fatal	4628	4628
Nonfatal	4 985 960	4 985 960
Musculoskeletal disorders[a]	546 350	546 350
Total	**5 712 362**	**5 961 620**

Abbreviations: DAFW, days away from work; MSD, musculoskeletal disorder; SOII, Survey of Occupational Injuries and Illnesses.
The bolded values represent the top line total for the 3 major categories of outcome (chronic conditions, acute illnesses and traumatic injuries) and the grand total.
[a]MSDs resulting in one or more DAFW. MSDs are shown here as a subset of nonfatal traumatic injuries. A small proportion of MSDs are actually classified as illnesses in the SOII.

occupational burden from cardiovascular disease by only including incident CHD cases occurring before the age of 70 years and by excluding other cardiovascular illnesses (eg, hypertension, stroke, peripheral atherosclerotic disease) because only CHD was considered to have a well-established occupational cause.

The second limitation relates to the validity and reliability of the national and industry specific incidence rates calculated for each of the occupational conditions considered. A number of global and source-specific sources of potential error could have affected both the numerators and denominators of these rates. For example, under ascertainment and underreporting affecting the numerators we used for incidence estimates (eg, due to misdiagnosis) could have led to underestimation. Small numbers in either the numerator (eg, for rare diseases) or the denominator (eg, for small industry sectors) may also have resulted in unstable and unreliable rates for some estimates. In some cases, operationalized rate denominators may not have been fully congruent with the relevant risk population.

The third limitation is related to the calculation of RRs based on the review of epidemiologic data. Although we attempted to find the most recent high-quality, comprehensive epidemiologic studies (eg, meta-analyses or pooled analyses), the actual risk estimates were derived from a wide variety of studies and included various types of estimates such as ORs, SMRs, and so forth, in addition to RRs. They also may have been derived from studies with methodological flaws such as: (a) exposure misclassification (eg, use of retrospective data that may not represent current exposures, exposure levels not relevant to U.S. workers, lack of personal exposure monitoring, inability to differentiate between exposure levels according to job tasks, no adjustment for use of respiratory protection, inaccurate knowledge of subject's workplace exposure history by next of kin, and overlapping exposures), (b) disease misclassification (eg, missing or inconsistent histologic confirmation of cancer, use of death certificate as the cause of death information, self-report of physician diagnosis), (c) inadequate control of confounding (eg, from cigarette smoking and other occupational and environmental exposures), (d) bias (eg, recall bias in case-control studies, healthy worker effect in cohort, and cross-sectional studies), and (e) small sample sizes, particularly for rare cancers.

The fourth limitation of our study relates to our estimates of the proportion of the population with each of the identified occupational exposures. We made every effort to use the most valid, reliable, and current exposure data available. However, because there has been no national survey of occupational exposures (especially of industrial/chemical exposures) in the United States since the NOES was conducted in the early 1980s, we had to rely on non-U.S. sources for more current population data on exposure to carcinogens. Where possible, we relied on North American data (ie, from Canada), but in some cases, we were forced to rely on European data. If the non-U.S. carcinogen exposure proportions are higher than the actual U.S. proportions, we will have overestimated the number of occupational cancers; conversely, if they are lower, we will have underestimated occupational cancers.

It is true that even the European CAREX data are somewhat dated, being only 10 years more current than the NOES data, which is why we used CAREX Canada data whenever possible. However, we also note that these data sources (CAREX and CAREX Canada) were only used for exposure estimates for carcinogens such as radon and vinyl chloride, the carcinogenic effects of which tend to have latency periods measured in decades. So estimates of the exposure prevalence in the 1990s may, in fact, be the appropriate statistic for these exposures. Nevertheless, the use of current or recent exposure estimates in combination with current labor force estimates may have resulted in an underestimation of diseases with long latencies.

A number of additional limitations, specific to the data sources used and related to the assumptions required to operationalize exposure estimates from them, also apply to noncarcinogen exposures. Another limitation related to the exposure estimates is that the number of workers exposed to specific substances changes over time as the numbers of workers in specific industries increase and decrease. Development of chronic diseases often comes years, or decades, after exposure; but, the timing of the various exposure estimates available did not necessarily correspond to the latency periods for the relevant diseases. Further, our methods do not take account of variations in the intensity or duration of exposures between individuals or industry sectors.

6 | CONCLUSIONS

Using a combination of surveillance, exposure, and epidemiologic data from various sources, we have produced updated estimates of the total annual number of new well-established occupational injury and illness cases occurring in 2012. We believe that, beyond being more current, our estimate of between 5 710 063 and 5 959 690 total occupational injury and illness cases, including 4 990 588 injuries and 719 475 to 969 102 illnesses, improves upon previous estimates in two important ways. First, our estimates include all incident injury and chronic illness cases, not just fatal ones. Second, we have included occupational chronic diseases that are not well captured by existing national surveillance systems and, therefore, have been underestimated in some previous estimates. Although there are some limitations to our calculation of AF estimates, we were able to apply our AFs estimates to 2012 incidence data to estimate the annual number of cases due to occupational exposures to inform future estimates of the impact of occupational injury and illness on total economic burden, human suffering, and quality of life.

We have provided these estimates in full recognition that, in certain instances, their precision and reliability may be lower than we would have hoped. The fact that, to estimate the total annual occurrence of occupational morbidity in the United States, one must draw upon numerous data sources with disparate measures and methodologies makes this inevitable. We have also tried, at the same time, to be both as comprehensive and as precise as we could be. But these aims were, at times, in tension with each other. It has been our goal to both provide an initial estimate that invites suggestions for refinement and to stake out a likely lower limit of occupational morbidity in the United States. It has also been our goal to demonstrate that, even when using the best and most comprehensive data currently available, significant gaps remain in the occupational morbidity surveillance tableau. It is our hope that attention to any shortcomings of our results may prove as informative as to their strengths, insofar as they illuminate those areas where more or better occupational health surveillance data are needed.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

John Meyer declares that he has no conflict of interest in the review and publication decision regarding this article.

AUTHOR CONTRIBUTIONS

MRG contributed to the design of the study, interpreted data, drafted and revised the manuscript, and is responsible for all aspects of the work. LB and ES contributed to the design of the study, interpreted data, performed statistical analysis, and helped revise the manuscript. MS, RPC, and TS contributed to the design of the study, interpreted the data and helped revise the manuscript. All authors approved of the final version of the manuscript.

ETHICS APPROVAL AND INFORMED CONSENT

This study was conducted at the Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health (NIOSH). The NIOSH Human Subjects Review Board determined that the activities in this project were did not meet the criteria of research according to 45 CFR 46.1101(b)(2) and CDC Guidelines for Defining Public Health Research and Public Health Non-Research.

DISCLAIMER

The findings and conclusions in this article have not been formally disseminated by the National Institute for Occupational Safety and Health and should not be construed to represent any agency determination or policy.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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