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BRIEF REPORT

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Acute occupational inhalation injuries—United States, 2011–2022

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Abstract

Background: Inhalation injuries due to acute occupational exposures to chemicals are preventable. National surveillance of acute inhalation exposures is limited. This study identified the most common acute inhalation exposure-related incidents by industry sector among US workers.

Methods: To characterize inhalation-related injuries and their exposures during April 2011–March 2022, state and federal records from the Occupational Safety and Health Administration (OSHA) Occupational Safety and Health Information System (OIS) accident database were analyzed. Industry-specific injury, hospitalization, and fatality rates were calculated.

Results: The most frequent acute inhalation incidents investigated by OSHA were caused by inorganic gases (52.9%) such as carbon monoxide (CO) or acids, bases, and oxidizing chemical agents (12.9%) such as anhydrous ammonia. The largest number of fatal and nonfatal injuries were reported in the manufacturing (28.6%) and construction (17.2%) sectors.

Conclusions: Workers were affected by acute inhalation exposures in most industries. Using this surveillance, employers can recognize frequently-occurring preventable acute inhalation exposures by industry, such as inorganic gases in the manufacturing sector, and implement prevention measures. Training of workers on exposure characteristics and limits, adverse health effects, and use of protective equipment by exposure agent can prevent inhalation injuries.

KEYWORDS

acute inhalation exposures, ammonia, carbon monoxide, cleaning materials, fatality rate, hospitalization rate, industry sectors, injury rate, occupational exposures

1 | INTRODUCTION

Occupational inhalation injuries due to acute chemical exposures are preventable. Surveillance to characterize the burden of injuries caused by inhalation exposures has typically been conducted at the state level[1–3] or using emergency department data.[4,5] Publicly accessible data such as the Occupational Safety and Health Administration (OSHA) Severe Injury Reporting available from 2015[6] and Fatality Inspection Data available from 2009[7] provide limited investigation details. Census of Fatal Occupational Injuries[8] and Survey of Occupational Injuries and Illnesses[9] from the United States Bureau of Labor Statistics (US BLS) and the National Poison Data System[10] publish aggregated data. As such, detailed evaluations of recent industry-specific inhalation exposures and their injuries are lacking.

We provide the first national estimates of inhalation-related injuries among US workers during 2011–2022 using the OSHA Occupational Safety and Health Information System (OIS) accident database. OIS contains summaries of federal and state investigations of fatal and nonfatal incidents across industry sectors. Identifying the most common inhalation-related incidents and their causative exposures could help employers and safety professionals tailor prevention activities and safety protocols.

2 | METHODS

We analyzed deidentified OSHA OIS records from April 2011–March 2022. OSHA OIS was implemented in 2012 and investigation records available to date were included in this analysis. Investigations recorded during the transition of Integrated Management Information System (IMIS) to OIS in 2011 were also included. OSHA used IMIS to compile inspection and consultation visits before 2012. The records consisted of state and federal OSHA investigations of fatalities, catastrophes, and referrals of hazards from other federal, state, or local agencies, individuals, organizations, or the media. Investigations were not conducted where OSHA does not have jurisdiction. That included public sector employees if not covered by state OSHA plans, self-employed, volunteers, workers on family farms, and workers covered by other federal agencies, for example, mineral mining, interstate trucking, ships at sea, as well as parts of maritime, aviation, and railroad jurisdictions. Human research protections review was not required since this study involved deidentified data.

Acute occupational inhalation injuries from OIS-defined categories and free-text descriptive fields were identified as follows: (1) All investigations labeled by OSHA inspectors as "inhalation" were included; (2) potentially respiratory-associated keywords including asphyxia, breath/shortness of breath, chemical, fumes, gas, hypoxia, inhalation, lungs, odor, respiratory, respirator, toxic atmosphere, vapor, ventilation, and unspecified inhalation exposures were used to identify investigations with a potential inhalation exposure among incidents not labelled as an inhalational. These keywords were selected from the investigation records that were labelled as "inhalation" by OSHA inspectors; and (3) inhalation exposures were manually cross-validated and coded using the Association of Occupational and Environmental Clinic (AOEC) Exposure Code List.[11] Industries were grouped into 20 sectors using the North American Industry Classification System (NAICS).[12] Data for Mining, Quarrying, and Oil and Gas Extraction (NAICS Sector 21) include establishments not governed by the Mine Safety and Health Administration (MSHA) rules and reporting. Injury (i.e., sum of deceased, hospitalized, and nonhospitalized workers), hospitalization, and fatality rates were calculated using total employed workers for each year reported by US BLS.[13] Averages per year including 95% confidence intervals (CI) were calculated from 2011 to 2021 since this data set had investigations recorded only through March 10, 2022. Data were analyzed using SAS (version 9.4; SAS Institute).

3 | RESULTS

During 2011–2022, 810 (1.2%) of 65,704 OSHA OIS investigations involved inhalation-related injuries caused by acute exposure to chemicals. A total of 2518 workers were injured, resulting in 1301 outpatient visits, 880 hospitalizations, and 337 deaths. Most investigations involved one worker (58.8%); of these, most affected workers were men (85.5%). Demographic characteristics were not available for the 334 investigations involving multiple workers.

Among the 810 investigations, 26.9% were of only fatalities (218 investigations involving 240 workers), 37.9% reported only hospitalizations (307 investigations involving 517 workers), and 11.5% reported only outpatient visits (93 investigations involving 356 workers). The remaining 23.7% involved multiple workers with varying levels of injuries that required hospitalizations or outpatient visits or even resulted in fatalities (192 investigations that affected 1405 workers).

The average annual injury rate from 2011 to 2021 was 14.9 per 10 million workers (95% CI: 10.0–19.9). The average annual hospitalization and fatality rates for the same period were 5.2 (95% CI: 3.4–7.0) and 2.0 per 10 million workers (95% CI: 1.5–2.5), respectively. Investigations were most frequently reported for the following sectors: manufacturing (28.6%), construction (17.2%), and administrative and support and waste management and remediation services (8.0%) (Table 1). The average annual rates of injury, hospitalization, and fatality were highest for the mining, quarrying, and oil and gas extraction sector due to a lower number of workers employed in this sector compared to others.

Review of 810 investigation records identified 840 exposures (Table 2). Among 2518 workers, 2455 were exposed to one agent and 63 workers were exposed to two or three agents. Without stratification by industry sector, the most frequently reported agents were inorganic gases (52.9%) including carbon monoxide (CO) (26.5%) and acids, bases, and oxidizing chemical agents (12.9%) including anhydrous ammonia (7.3%). Bleach (1.8%) and mixtures of bleach and acid (1.8%) were among those reported for cleaning materials (7.0%).

Exposures to inorganic gases were most common in the manufacturing (25.2%) and construction (22.7%) sectors (Figure 1). Exposures to acids, bases, and oxidizing chemical agents were most frequently reported in the manufacturing industry (48.1%). Exposure to cleaning materials were reported in 16 of 20 industry sectors, with highest frequencies in manufacturing (25.4%) and accommodation and food services (20.3%).

4 | EXAMPLES OF NARRATIVES

1) A preventable CO poisoning in 2016 resulting in five employee hospitalizations:

> Employees were overcome by CO gas as a byproduct of combustion from the gas operated pressure washer

TABLE 1 Top five industry sectors with investigations from the Occupational Safety and Health Administration (OSHA) Occupational Safety and Health Information System (OIS) database—Acute occupational inhalation injuries, United States, 2011–2022.[a]

NAICS code[b]	Industry	No. of investigations	No. of workers[c]	Average annual no. of injuries per 10 million workers (95% CI)[d]	No. of hospitalizations	Average annual no. of hospitalizations per 10 million workers (95% CI)	No. of fatalities	Average annual no. of fatalities per 10 million workers (95% CI)
31–33	Manufacturing	232	784	46.0 (31.0–61.0)	271	15.5 (10.3–20.8)	78	4.7 (2.6–6.8)
23	Construction	139	395	34.0 (21.2–46.8)	166	14.3 (7.9–20.7)	72	6.3 (4.6–7.9)
56	Administrative and Support and Waste Management and Remediation Services	65	319	15.7 (−0.4 to 31.8)	54	2.6 (1.3–3.9)	33	1.6 (0.8–2.4)
48, 49	Transportation and Warehousing	47	71	7.7 (5.0–10.4)	23	2.5 (0.7–4.3)	27	3.0 (1.5–4.4)
21	Mining, Quarrying, and Oil and Gas Extraction	43	76	80.8 (58.7–102.9)	30	32.7 (19.6–45.7)	26	27.1 (13.3–40.9)

[a]The average annual rates and 95% confidence intervals (CI) for injuries, hospitalizations, and fatalities were calculated for 2011–2021 since investigations in 2022 were recorded only through March 10th, 2022.

[b]North American Industry Classification System (NAICS).

[c]Each investigation can have more than one worker involved.

[d]Injury rate was calculated by the sum of deceased, hospitalized, and nonhospitalized workers over the employed worker statistics reported by the US Bureau of Labor Statistics (BLS) for each year.

TABLE 2 Classification of inhalation exposures that led to acute occupational inhalation injuries—Occupational Safety and Health Administration, Occupational Safety and Health Information System database, United States, 2011–2022.

Exposure agent	No. of exposures	%[a]
Inorganic gases	**444**	**52.9**
Carbon monoxide	223	26.5
Hydrogen sulfide	60	7.1
Toxic gases or oxygen-deficient environments	52	6.2
Chlorine	41	4.9
Nitrogen	27	3.2
Carbon dioxide	17	2.0
Sulfur dioxide	9	1.1
Argon	6	0.7
Chlorine dioxide	6	0.7
Other[b]	3	0.4
Acids, bases, and oxidizing chemical agents	**108**	**12.9**
Anhydrous ammonia	61	7.3
Hydrochloric acid	14	1.7
Hydrofluoric acid	9	1.1
Nitric acid	5	0.6
Other[c]	19	2.3
Hydrocarbons	**92**	**11.0**
Hydrocarbons n.o.s.	15	1.8
Methylene chloride	11	1.3
Natural gas	10	1.2
Toluene	7	0.8
Freon n.o.s.	6	0.7
Propane	7	0.8
Gasoline	5	0.6
Crude oil	5	0.6
Other[d]	26	3.1
Cleaning materials	**59**	**7.0**
Bleach	15	1.8
Bleach plus acid (mixture)	15	1.8
Cleaning materials n.o.s.	9	1.1
Cleaning mixtures (excluding bleach plus acid or ammonia)	9	1.1
Other[e]	11	1.3
Solvents[f]	**14**	**1.7**
Metals and metalloid fumes[g]	**12**	**1.4**
Pesticides[h]	**11**	**1.3**
Alcohols[i]	**7**	**0.8**
Other exposures	**93**	**11.1**
Unidentified chemicals	47	5.6
Other[j]	46	5.5
Total	**840**	

Abbreviation: n.o.s., not otherwise specified.

[a]Total represents the total number of inhalation exposures ($n = 840$). An investigation can involve up to three exposures, therefore, the percentages are based on the total number of inhalation exposures and do not sum to 100% of the investigations ($n = 810$). Exposure categories with fewer than 5 counts were collapsed into a subcategory labeled "other."

[b]Among inorganic gases, "other" includes phosgene, sewer gas, and sulfur oxides n.o.s.

[c]Among acids, bases, and oxidizing chemical agents, "other" includes sodium hydroxide, sulfuric acid, calcium oxide, peracetic acid, phosphoric acids, glacial acetic acid, hydrogen peroxide, a mixture of hydrogen peroxide and peroxyacetic acid, and acids, bases, oxidizers n.o.s.

[d]Among hydrocarbons, "other" includes methane, diesel fuel, difluoroethane, oils n.o.s., styrene, acetylene, isobutane, jet fuel, mineral oil, naphtha, off gassing of hydraulic fracturing holding tanks, pentane, vinyl chloride monomer, xylene, and aromatic hydrocarbons n.o.s.

[e]Among cleaning materials, "other" includes bleach plus ammonia (mixture); cleaners: floor stripping; cleaners: household general purpose, ammonium hydroxide n.o.s., calcium hypochloride; cleaners: laundry soap/detergent, cleaners: oven, and cleaners: disinfectant n.o.s.

[f]Includes ethylene oxide, paint n.o.s., degreaser n.o.s., paint epoxy n.o.s., propylene glycol ethers, stripper, and solvents n.o.s.

[g]Includes welding fumes of aluminum, chromium, nickel, copper/nickel, galvanized metal, and fumes n.o.s.

[h]Includes methyl bromide and pesticides n.o.s.

[i]Includes isopropyl alcohol, methanol, allyl alcohol, ethanol, polypropylene glycol, and alcohols n.o.s.

[j]Includes hydrogen cyanide, fertilizers n.o.s., hazardous waste, glues and adhesives n.o.s., pepper spray, air freshener, formaldehyde, perfume n.o.s., rubber n.o.s., acrylonitrile, aniline, cresol, fentanyl, fire extinguisher discharge, isocyanates n.o.s., mace, manure, mercaptans n.o.s., mixture of a sanitizer and industrial water treatment kit, mixture of prepolymer of polymethylene polyphenylisocyanate (PPI) and 4,4′-methylenediphenyl diisocyanate (MDI), naphthalene diisocyanate, polybutadiene, polytetrafluoroethylene, potassium cyanide, sanitizing chemical, sewer smoke test, sewer water, tetrahydrocannabinol (THC), and toluene diisocyanate.

equipment, being used in a non-ventilated area of the establishment.

2) A preventable cleaning material exposure in 2019 resulting in an employee hospitalization:

The spray bottle contained a small amount of unknown liquid. The employee added bleach to the

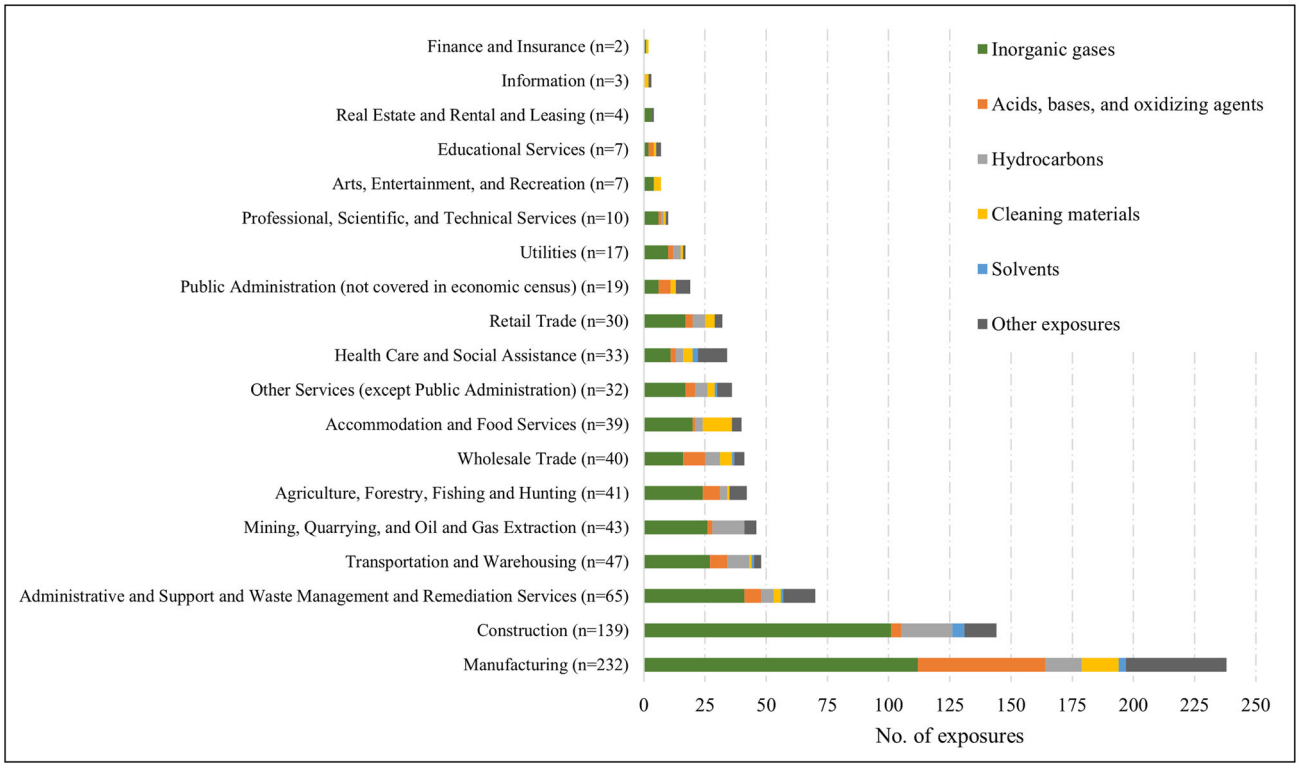

FIGURE 1 Occupational inhalation exposures[a] by industry sector[b] using the Occupational Safety and Health Administration (OSHA) Occupational Safety and Health Information System (OIS) database—United States, 2011–2022. [a]Number of investigations are noted in parentheses for each industry sector on the *y*-axis, totaling to 810 investigations with 840 inhalation exposures. The other category represented exposures to metals and metalloids fumes, pesticides, alcohols, cyanides and nitriles, isocyanates, polymers, plant and tree materials, aldehydes and acetals, aromatic nitro and amino compounds, glycol ethers, phenols and phenolic compounds, and unidentified chemicals and gases. [b]Data for mining, quarrying, and oil and gas extraction (Sector 21 in the North American Industry Classification System) include establishments not governed by the Mine Safety and Health Administration (MSHA) rules and reporting. No investigations were recorded for the Management of Companies and Enterprises (Sector 55 in the North American Industry Classification System).

> unknown liquid in the bottle. A chemical reaction occurred between the two liquids. The employee inhaled the chemical vapors and had difficulty breathing and vomited. The employee was hospitalized.

3) A preventable anhydrous ammonia exposure in 2020 resulting in an employee hospitalization:

> The employee had just finished filling a nurse tank with anhydrous ammonia. Due to lack of familiarity with [the] new valve, the employee did not realize how much pressure remained at the connection. When the valve was disconnected, gas and liquid ammonia struck him in the face.

4) A preventable hydrogen sulfide exposure in 2021 resulting in an employee fatality:

> Employee #1 was overcome by high levels of hydrogen sulfide at the base of the sewer manhole shortly after entry. Employee #1 had not conducted *monitoring for oxygen*, lower explosive limit (lel), and hydrogen sulfide monitoring before entering the sewer manhole. Employee #1 had not *donned his harness* attached to a rescue tripod before entering the sewer manhole. A four-gas monitor and rescue tripod with lanyard and harness were available for use in employee #1 work vehicle. The confined space attendant and a helper were *not trained or equipped for performing a confined space entry rescue.*

The underlined phrases highlight missed opportunities for preventing this fatality. OSHA issued a serious citation for the incident. Information on safety practices and trainings available to workers in this workplace were not included in the investigation summary.

5 | DISCUSSION

This study used OSHA investigation records to provide the first national and industry-specific estimates of acute occupational inhalation exposures leading to fatal and nonfatal injuries. Nonfatal incidents include hospitalizations and outpatient visits that have not been analyzed previously. Previous studies of several acute occupational inhalation exposures have examined nonfatal incidents using hospital discharge data in Michigan[2,3] and emergency department visits by industry[4,5]; fatal and nonfatal incidents by industry using workers' compensation claims in Washington state.[1] Other data sources from OSHA such as Severe Injury Reporting and Fatality Inspection Data provide limited information on the investigations. Census of Fatal Occupational Injuries and Survey of Occupational Injuries and Illnesses from US BLS and National Poison Data System are published only as aggregate information. After OSHA receives information on an incident, the initial reports are checked for validity and any duplicates are removed. Valid cases are inspected and receive an inspection number. However, investigations are conducted by OSHA inspectors for only a limited percentage of the inspected cases. From 2014 to 2021, OSHA inspected 68,978 incidents annually on average for all events (i.e., falls, trips, crushed by material, burns, inhalation, etc.) and approximately 11% of the inspected cases were investigated annually (internal correspondence, data not shown). Since our analysis only included inhalation-related investigations completed by OSHA, there were fewer incidents than the previous studies.

Our study shows that workers were affected by inhalation exposures in most industries. The annual injury, hospitalization and fatality rates varied by industry sector, with the highest average for the mining, quarrying, and oil and gas extraction sector. Rapid release of hydrocarbon gases and vapors can occur during tank gauging and sampling at oil and gas extraction sites. A safety standard was developed in 2016 to protect these workers from oxygen-deficient environments and high hydrocarbon exposures.[14]

The exposures identified in this report are consistent with previous reports.[1,4,15] CO, the most frequent cause of poisonings and fatalities in this study, is a well-documented occupational respiratory hazard.[16,17] Investigations related to CO poisonings often involved multiple workers; common sources included gasoline-powered generators and machines. OSHA recommendations published in 2012 to prevent CO poisoning include avoiding gasoline-powered engine and tool use in poorly ventilated areas and using personal CO monitors with audible alarms.[18] The hospitalizations described above could have been prevented by implementing these recommendations.

Acids, bases, and oxidizing agents were the second most frequently reported exposure category. Anhydrous ammonia, a well-characterized respiratory irritant,[19–21] was the most frequently involved chemical in this category. Workers were exposed due to leaks and spillage from ammonia refrigeration systems, drums, pipes, and vents. New Jersey Department of Health recommendations from 2007 (accessible through the OSHA website) include the use of well-fitting respirators and eye protection that could have prevented the incident described above.[22]

Exposures due to off-gassing of cleaning materials were frequently reported while cleaning and disinfecting locations such as restrooms, kitchens, and swimming pools. An epidemiological review identified associations between occupational cleaning and disinfecting and increased risk of respiratory diseases for cleaning workers and janitors.[23] A recent meta-analysis reported increased risk of asthma symptoms among healthcare workers.[24] OSHA 2012 recommendations for prevention include increasing worker familiarity to cleaners and training for proper use of protective equipment.[25]

6 | LIMITATIONS

The findings in this report are subject to at least five limitations. First, the OSHA OIS data set was not primarily intended for surveillance purposes and narratives did not always contain high levels of detail. It is also possible that exposure sources were missed during investigations. However, due to national coverage and the injury reporting requirement by OSHA, this data set has value as a surveillance resource. Second, it was likely that less severe incidents were not investigated or even reported to OSHA. Furthermore, investigations conducted in industries and establishments not covered by OSHA's jurisdiction were not included in this report. However, the employment statistics used to calculate the annual rates were not stratified by jurisdiction. Thus, the calculated rates may underestimate the true rate of inhalation injuries for this population. Third, demographics were not recorded for investigations with multiple workers. Fourth, as identifiers were not available, it was not possible to validate the causes of hospitalizations and deaths using hospital discharge data and coroner reports, respectively. Finally, information on potential long-term adverse health effects of nonfatal injuries was unavailable for analyses.

7 | CONCLUSIONS

Our analysis provides the first national and industry-specific estimates of acute occupational inhalation exposures leading to fatal and nonfatal injuries using OIS records. Workers were affected by inhalation exposures in most sectors, largely in manufacturing and construction. To prevent inhalation exposures, employers should use the hierarchy of control measures, including substituting less hazardous substances, developing and implementing engineering controls and respiratory protection programs, and educating workers to identify exposure characteristics and reduce potential respiratory hazards using standard operating procedures and trainings. Conducting surveys to identify and manage potential occupational exposures, marking containers legibly during transport and storage, and avoiding mixing of chemicals in unlabeled containers are a few examples of simple, effective steps to reduce or eliminate hazardous inhalation exposures. Continued surveillance of inhalation-related incidents can help employers and occupational safety and health professionals recognize current exposure patterns and update control measures.

AUTHOR CONTRIBUTIONS

Nirmala T. Myers designed the study, analyzed and interpreted the data, led writing of the article, and took responsibility for its content. Katelynn E. Dodd and A. Scott Laney assisted with interpreting data and writing the article. Janet M. Hale assisted with data acquisition and writing the article. David J. Blackley and Noemi B. Hall conceptualized and designed the study and helped with data interpretation and writing.

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CONFLICT OF INTEREST STATEMENT

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.

DATA AVAILABILITY STATEMENT

The data are not publicly available due to privacy restrictions.

ETHICS APPROVAL AND INFORMED CONSENT

Data were collected for compliance purposes by OSHA and are deidentified; certain sections such as fatalities and severe injury reporting are publicly available. NIOSH determined this study to be research involving deidentified data; human research protections review was not required.

DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

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