Surveillance of toxic inhalation for Washington workers, 2017 – 2020

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DEFINITIONS

ACGIH	American Conference of Governmental Hygienists
AOEC	Association of Occupational and Environmental Clinics
CAS	Chemical Abstract Number
CO	Carbon Monoxide
DOSH	Division of Occupational Safety & Health, Labor & Industries
ICD-10-CM	International Classification of Disease, 10^{th} Revision, Clinical Modification
Industry	The type of activity at a person's place of work
L&I	Washington State Department of Labor and Industries
NAICS	North American Industry Classification System
NOS	Not otherwise specified
Occupation	The kind of work a person does to earn a living
OIICS	Occupational Injury and Illness Coding System
OSHA	Occupational Safety and Health Administration
ROIID	Report of Industrial Injury or Occupational Disease (ROIID) form
SOC	Standard Occupation Classification

OBJECTIVE

The goal of Washington State's toxic inhalation surveillance system is to identify emerging patterns in hazardous workplace exposures. In this report, we discuss the methods underlying the surveillance system for the first time, summarize findings from cases established between 2017 and 2020, and present future directions for the surveillance system. Surveillance system methods and an evaluation of the system's case-capture criteria can be found in a companion report (Washington State Department Labor and Industries, 2021, link).

INTRODUCTION

Washington's toxic inhalation surveillance system was established in January 2017 to characterize toxic inhalation exposures that may result in either acute injury or chronic disease. The sole data source for the surveillance system is the Washington State Department of Labor and Industries (L&I) workers' compensation system. We describe toxic inhalation exposures as reported through workers' compensation claims, identify clusters of related exposures, and provide detailed data tables by industry and occupation. These results can be used by employers, trade associations, and public health entities interested in developing prevention activities. The goal of the surveillance system is to inform targeted prevention activities and reduce the burden of preventable toxic inhalation exposures.

At the onset, this surveillance system initially focused on eight exposures with high relevance to Washington industries and workers. **Carbon monoxide** is a well-known and common workplace hazard, particularly in the agriculture and construction industries (Lofgren 2002, Reeb-Whitaker 2010). **Chromium** and **beryllium** are highly toxic metals and are the subject of federal Occupational Safety and Health Administration (OSHA) standards with contemporary updates. L&I's Division of Occupational Safety and Health (DOSH) administers these standards in Washington. The Permissible Exposure Level (PEL) for hexavalent chromium was reduced in 2006 (Chapter 296-62 WAC, Part I-2) and L&I's rule for beryllium in all industries took effect in 2018 (Chapter 296-850 WAC). Both rules mandate that employers provide medical surveillance for exposed workers. **Methylene chloride**, also known as dichloromethane or DMC, was identified in 2012 as a lethal exposure in bathtub refinishers in multiple states (CDC

MMWR 2012). The Environmental Protection Agency's Final Risk Evaluation on methylene chloride determined 'unreasonable risks' to workers and others. Methylene chloride was banned from paint removers for consumer use in 2019. Additional strategies to address these risks are currently under discussion (EPA 2020). **Ammonia** exposure, in particular anhydrous ammonia, was included in our surveillance because our work-related asthma surveillance system indicates this is an emerging hazard, one that affects primarily food processing and warehouse workers. **Wildland smoke** exposure is a major health risk faced by emergency responders and all outdoor workers in Washington State. Exposure to wildland smoke is expected to increase in frequency and severity due to climate change. **Welding fume** exposure continues to be a major respiratory health concern among chronically exposed welders, often working in enclosed spaces. **Chlorine** exposure is readily reported by workers due to its low odor threshold, high irritation properties, and distinctive symptoms following exposure. Both welding fume and chlorine exposures affect a large number of workers across several industries.

As this system is new and evolving, we did not limit surveillance to these eight exposures. A broad array of toxic inhalation exposures were brought into the surveillance system simply as "other", without chemical-specific case capture criteria. The medical records of these potential inhalation cases were manually reviewed to identify the exposure substance. The vast majority of valid cases in the surveillance system are in this "other" category. The "other" category allows us to observe timely changes in hazardous exposures, such as an increase in disinfectant exposures during the COVID-19 pandemic, and explore new directions for the surveillance system.

Another exploratory component of this surveillance system is our cluster identification tool. A cluster is defined as two or more workers exposed to the same substance within two rolling dates of each other. Historically, carbon monoxide exposure is associated with large clusters of workers' compensation claim clusters, sometimes affecting dozens of workers in the same incident. One cluster can involve numerous occupations and more than one employer, such as exposures at construction sites where multiple trades are present, or in warehouses where agriculture inspectors are present alongside warehouse workers. As employers do not typically compare workplace injury data with each other, surveillance is the ideal way to characterize cluster incidents involving multiple employers and detect the reach of an exposure.

It is important to note that this surveillance system does not characterize the clinical diagnosis or medical outcome from the toxic inhalation, it characterizes only the exposure substance. We anticipated that the clinical diagnoses for the vast majority of inhalation claims would be non-specific (i.e. ‘exposure to toxic effect’) and have limited medical documentation, particularly for low-level exposures. The workers’ compensation system administered by L&I covers a worker’s initial medical encounter, such as a brief emergency room visit for shortness of breath, regardless of whether an injury or disease subsequently manifests. We have chosen to focus on exposure instead of medical outcome because our prevention activities are aimed at reducing exposures.

To identify high-risk exposures, we summarize the potential toxicological effects of the chemicals for which an occupational threshold limit value (TLV) exists. The toxicologic effect summary illustrates the *risk or possible outcome* from the exposure. It does not take into account the toxicity experienced by the worker, as defined by dose or exposure frequency, as these metrics are not known.

In this report, we give an overview of the data source, case capture methods, case definitions and case counts. We characterize cases by industry, occupation, inhalation exposure, and potential toxicological effects. Finally, we discuss recommendations and future steps for this surveillance system. For a review and evaluation of the surveillance system case-capture methods, please see the companion report (Washington State Department Labor and Industries, 2021, link).

METHODS

Data Source

The data source for this surveillance system are workers' compensation claims established with the Washington State Department of Labor and Industries (L&I) between Jan 1, 2017 and Dec 31, 2020. Both State Fund and Self-Insurance claims are included in this system. In Washington State, nonfederal employers are required to obtain workers' compensation insurance through L&I unless they meet specific requirements to self-insure or are covered under an alternative workers' compensation program. L&I's State Fund insurance program provides coverage for approximately 1.9 million (about two-thirds) of the workers in the state and 99.7% of all employers. Data from both the State Fund and Self-Insurance programs are entered into a centralized data warehouse.

Surveillance Procedures

L&I's workers' compensation data warehouse is queried monthly to capture potential toxic inhalation injury claims. Potential cases are captured using narrative keywords, International Classification of Disease (ICD-10-CM) codes, and Occupational Injury and Illness Classification System (OIICS) codes. A complete description and evaluation of the case capture criteria is presented in a supplemental report (WA State Department of Labor and Industries, 2021). Any captured cases that are found to be non-respiratory in nature are excluded. We review the claim initiation form, the medical records, and correspondence with L&I to identify the substance(s) to which the worker was exposed. Statements about the incident and exposure can come from the worker, their doctor, or their employer. In some cases, product Safety Data Sheets (SDS) listing the product's chemical ingredients are included in the medical record or are provided to L&I. Our case validation process is independent of L&I's decision to accept or deny the claim.

Case Definition

A valid case has a known or suspected inhalation exposure to one or more of the eight specified priority substances or to an "other" substance. The eight priority substances are ammonia, beryllium, carbon monoxide, chlorine, chromium, metal fume, methylene chloride, and wildland smoke. Other substances can be chemical, metal, organic, or inorganic in the form of vapor, gas, dust or fume.

Among the eight priority substances, variation in chemical form are allowed. Variations in the form of ammonia include ammonia hydroxide, anhydrous ammonia, and ammonium chloride. Beryllium forms include pure beryllium metal as well as beryllium-containing alloys. The predominant forms of chlorine include chlorine gas and sodium hypochlorite. Chromium exposure includes hexavalent chromium (predominant), chromium metal and chromium compounds. Metal fume includes welding fume (predominant) as well as metal fume from non-welding exposures. Carbon monoxide, methylene chloride, and wildland smoke have no variation in the stated chemical form.

Other routes of exposure, such as dermal or ingestion may occur simultaneous with inhalation exposure, especially with splashes to the face or whole-body exposure to a gas. Our case capture criteria do not intend to capture non-inhalation cases but these other routes do occur among the potential cases being evaluated. A potential case will meet our surveillance case definition provided there is some measure of inhalation associated with the exposure. Potential cases that do not meet the case definition may be deemed either not valid, duplicate, or unknown (data not shown).

Exposure Classification System

To classify the exposures described in a valid case, we use the Association of Occupational and Environmental Clinic's coding system for chemical and non-chemical agents (AOEC). This hierarchical system contains over 1,300 unique codes. Each case is assigned between one and five codes, as a worker is often exposed to more than one substance. We use the AOEC codes to specify the type of ammonia, chlorine, and chromium exposure (e.g. anhydrous ammonia, chlorine dioxide, and hexavalent chromium) among cases in the priority exposure set. The codes are central to our exploration and analysis of cases within the "other" category.

Industry and Occupation Codes

Data elements such as industry and occupation derive from the workers' compensation administrative data. Industry is coded using the 2007 North American Industry Classification Coding System (NAICS). Occupation is coded using the 2002 Standard Occupational Classification (SOC). If missing from the administrative data, industry and occupation are manually coded using employer information in the claim file. All valid claims have coded industry and occupation.

Potential Toxicologic Effects

Workers are at risk for numerous potential toxicologic effects following hazardous inhalation exposure. The toxicologic effects may be acute or chronic, and may arise from short- or long-term exposures. The American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLV) booklet lists the threshold limit values and the toxicologic effects of occupational chemical substances (ACGIH 2018). Chemical substances can be, and typically are, associated with more than one toxicologic effect. By joining an AOEC substance code with the toxicologic effects associated with that same substance, we can describe a workers' *potential* risk of injury or illness. The concentration, dose, and duration of the chemical exposure contribute to the severity of the toxicologic effect and these factors are not defined in our surveillance system. As discussed in the introduction, this surveillance system does not collect information on workers' medical outcomes, only on their exposures.

A significant limitation to the toxicologic effect estimate is that many substances in the AOEC coding system (i.e. dusts, cleaning chemicals, 'chemicals, not otherwise specified') are too ill-defined to have an associated TLV threshold limit. Therefore, cases with those AOEC substances are excluded from the discussion of potential toxicologic effects. For example, the acute or chronic effects from pesticide exposure among agriculture workers are not well represented because we typically do not know the pesticide formulation and therefore we could not derive the specific toxicologic effect(s).

RESULTS

A total of 4104 potential cases were captured during the four-year period 2017-2020. Of these, 2604 cases were inhalation injuries valid for exposure to at least one substance. Overall, 1630 (59%) of the valid claims were adjudicated as an accepted workers' compensation claim by L&I, 106 (4%) claims had at least 1 day of time-loss, 35 workers were hospitalized, and six workers who had a toxic inhalation also died.

A total of 388 different AOEC substance codes were associated with the 2604 valid cases (median 1 code per case, range 1-5). Of the 388 AOEC codes, 130 were present in the Threshold Limit Values (TLV) booklet from which toxicologic effects could be derived. These toxicologic effects are characterized for 1328 (55%) of valid cases.

Claim filing trends and claimant demographics

For the period 2017 - 2019 the number of annual toxic inhalation cases fluctuated between 680 to 751 cases (annually 26% to 29% of all cases). In 2020 case counts dropped to 472 (18% of all cases), possibly due to reduced employment during the COVID-19 pandemic. The majority of claimants were male (61%) and the median age was 43 (range 17 to 87, see Table 1).

Table 1. Valid Case Counts and Claimant Demographics per Year

Claim Established Year	Valid Cases	Claimant Sex (% Female)	Median Claimant Age (Years)
2017	701	42%	44
2018	680	38%	43
2019	751	39%	43
2020	472	38%	41
All Valid Cases	2604	39%	43

Geographic distribution of toxic inhalation exposures

L&I's Division of Occupational Safety and Health (DOSH) is organized in six regions with field offices where consultation and enforcement inspectors are based (Figure 1). The majority (92%) of valid cases were associated with a county based on the accident location's street address. Region 2 (King county) and Region 5 (eastern-central WA) had the largest proportions of toxic inhalation cases (25% and 22%, respectively) (Table 2). DOSH consultation and enforcement officers play an important role in preventing these types of workplace exposures.

Figure 1. L&I geographic regions and field office locations

Table 2. Valid case counts by L&I region, 2017-2020

L&I Region	Valid Cases (% of total)
Region 1	369 (14%)
Region 2	640 (25%)
Region 3	266 (10%)
Region 4	266 (10%)
Region 5	560 (22%)
Region 6	218 (8%)
Out-Of-State	71 (3%)
Unknown Or Not Specified	214 (8%)
All Valid Cases	2604

Specific priority surveillance exposures

Case counts for the eight priority exposures as well as the “other” toxic inhalations are shown in Table 3. Twenty-four cases were valid for more than one exposure. Carbon monoxide is an exposure historically known as an occupational health risk, and was the leading exposure of the priority substances (n=389 cases, see Table 3) with vehicles as the predominant source (Table 4) (Lofgren 2002, Reeb-Whitaker 2010). Chlorine was the second most frequent exposure (n=298, Table 3), most commonly associated with cleaning tasks and swimming pool/spa chlorination (data not shown). There were just 32 cases of exposure to wildland smoke, likely an underestimate of the total burden on Washington workers. Beryllium exposures had the oldest median age; this was due to five workers exposed over the course of their careers at the Hanford Nuclear Reservation. Exposure to methylene chloride was rare (n=2) possibly because workers may refer to the use of paint strippers or adhesives in the claim documentation, but not know or specify whether methylene chloride is in the formulation of the product they are using (Table 3). In the exploratory “other” exposure group, the top AOEC exposures were ‘chemicals, not otherwise specified’ (n=284), cleaning materials/disinfectants (n=295), dusts (n=137), paint (n=97), pesticides (n=80), and indoor air pollutants from building renovation (n=63).

Table 3. Valid case counts and claimant demographics by exposure, 2017-2020

Exposure	Valid Cases	Claimant Gender (% Female)	Median Claimant Age (Years)
Carbon monoxide	389	32%	41
Chlorine	298	44%	37
Ammonia	99	37%	43
Metal fume	80	8%	42
Wildland smoke	32	34%	40
Chromium	15	20%	37
Beryllium	9	11%	60
Methylene Chloride	2	0%	39
Other	1706	42%	41
All Valid Cases	2604	39%	43

Table 4. Valid carbon monoxide case count by source

Source	Valid Cases
Vehicle	171
Other	50
Heater/furnace	35
Forklift	31
Smoke/Fire inhalation	26
Saw	17
Pressure washer	14
Airplane	9
Generator	7
Boiler	1
Unknown	28
Total	389

Results by AOEC Group

To broadly summarize the exposures, we created 16 high-level categories (e.g. inorganic chemicals, organic chemicals, cleaners and disinfectants, etc.) that contain 4 to 96 AOEC codes each. Cases can be associated with more than one AOEC code and also more than one AOEC group. Inorganic chemicals were the leading AOEC group and were associated with 37% of valid cases; carbon monoxide (n=389), chlorine (n=298), and anhydrous ammonia (n=47) predominate in the inorganic chemical group. Groups such as cleaners and disinfectants; chemicals, not otherwise specified; and organic chemicals were associated with 11 to 17% of valid cases. Women were exposed to cleaners and disinfectants (54%) and indoor air quality hazards (80%) more frequently than men. Exposures that did not fall neatly into any group were classified into "other chemicals"; this group is predominant for solvents (n=47) and pharmaceuticals (n=38).

Table 5. Case counts and claimant demographics by AOEC substance group

Exposure	Valid Cases	Claimant Sex (% Female)	Median Claimant Age (Years)
Inorganic Chemicals	961 (37%)	36%	40
Cleaners & Disinfectants	453 (17%)	54%	39
Other Chemicals	396 (15%)	49%	43
Chemicals, not otherwise specified	305 (12%)	46%	41
Organic Chemicals	284 (11%)	43%	39
Metals	197 (8%)	13%	41
Inorganic Dusts	181 (7%)	23%	45
Pesticide, Insecticide, Fungicide, Herbicide, Etc.	143 (5%)	39%	40
Paint	116 (4%)	28%	42
Smoke And Exhaust	97 (4%)	39%	46
Indoor Air Quality	79 (3%)	80%	42
Polymers	63 (2%)	21%	38
Plant Material	56 (2%)	27%	43
Halogenated Hydrocarbons	55 (2%)	25%	37
Animal & Biological Agents	49 (2%)	45%	40
All Valid Cases	2604	39%	43

Results by Industry

Industry sectors of Manufacturing (n=353), Agriculture (n=252), Construction (n=252), and Health Care (n=252) had the leading number of toxic inhalation cases, shown in Table 6. Exposures in the Health Care, Educational Services, and 'Finance and Insurance' sectors were predominantly filed by women, whereas exposures in Manufacturing and Construction were predominantly filed by men (Table 6).

Table 6. Case counts and demographics by industry sector

Industry Sector	Valid Cases	Claimant Sex (% Female)	Median Claimant Age (Years)
Manufacturing	353	27%	42
Agriculture, Forestry, Fishing and Hunting	252	43%	39
Construction	252	8%	38
Health Care and Social Assistance	252	79%	43
Public Administration	243	31%	46
Admin., Support, Waste Mgmt and Remed. Serv	209	31%	38
Retail Trade	195	44%	35
Transportation and Warehousing	165	39%	49
Accommodation and Food Services	146	49%	35
Wholesale Trade	128	29%	40
Educational Services	112	68%	50
Other Services (except Public Admin.)	112	38%	44
Prof., Scientific, and Technical Services	70	47%	39
Real Estate and Rental and Leasing	50	48%	46
Arts, Entertainment, and Recreation	23	26%	32
Finance and Insurance	17	82%	40
Utilities	12	33%	37
Information	10	50%	29
Management of Companies and Enterprises	1	100%	69
Mining, Quarrying, and Oil and Gas Extract.	1	0%	40
Unknown Industry	1	0%	46
All Valid Cases	2604	39%	43

Figure 2 illustrates the extent and diversity of exposures within 2-digit NAICS industry sectors. Most industries have at least one exposure from each of thirteen specific exposure groups. The predominant exposure group within Manufacturing is inorganic chemicals, within Health Care is cleaners and disinfectants, and within Construction is inorganic dusts.

Figure 2: Distribution of exposures for the top exposure groups and the top industry sectors

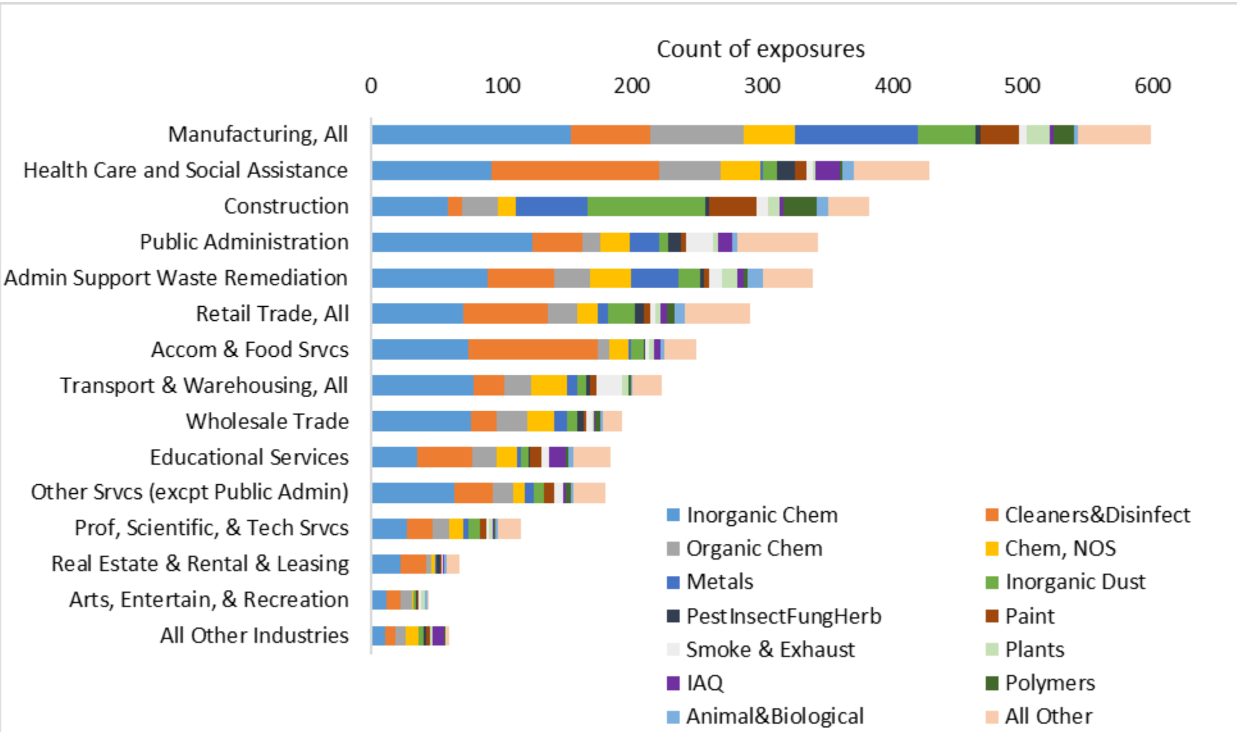

Table 7 shows the five most common AOEC groups within the five most common NAICS industry sectors. The most frequent type of substance workers were exposed to was inorganic chemicals, followed by cleaners and disinfectants (Table 7). For more information, we provide detailed tables of the occurrence of each AOEC exposure code (not grouped) within each industry sector in the appendix tables (Washington State Department Labor and Industries, 2021, link).

Table 7. Top five industry sectors within the top five AOEC exposure groups, 2017-2020

AOEC Group	Total # Cases	Industry Sector	Case Count
Inorganic Chemicals	961	Public Administration	121
		Manufacturing	118
		Health Care and Social Assistance	86
		Admin., Support, Waste Mgmt and Remed. Serv	79
		Agriculture, Forestry, Fishing and Hunting	77
Cleaners and Disinfectants	453	Health Care and Social Assistance	87
		Accommodation and Food Services	58
		Manufacturing	46
		Retail Trade	44
		Admin., Support, Waste Mgmt and Remed. Serv	37
Other Chemicals	396	Public Administration	51
		Health Care and Social Assistance	50
		Manufacturing	47
		Retail Trade	43
		Agriculture, Forestry, Fishing and Hunting	41
Chemicals, not otherwise specified	305	Manufacturing	39
		Agriculture, Forestry, Fishing and Hunting	38
		Admin., Support, Waste Mgmt and Remed. Serv	32
		Health Care and Social Assistance	31
		Transportation and Warehousing	27
Organic Chemicals	284	Manufacturing	50
		Health Care and Social Assistance	40
		Agriculture, Forestry, Fishing and Hunting	28
		Retail Trade	21
		Construction	20

Results by Occupation

Workers with an occupation of Production (n=385) and 'Transportation and Material Moving' (n=361) had the most toxic inhalation exposures, followed by Construction (n=244), 'Installation, Maintenance, and Repair' (n=214), and 'Farming, Fishing and Forestry' (n=212, see Table 8). Cases in the occupations of Healthcare, Personal Care, and 'Community and Social Services' were predominantly female, while exposures in the Construction and 'Installation, Maintenance and Repair' were mostly male. For occupations with more than 10 cases, the median age was youngest for occupations of 'Community and Social Service', Personal Care, and Food Preparation. The median age was oldest for 'Business and Financial' and

‘Transportation and Material Moving’ occupations. Occupations that had less than a 50% claim acceptance rate included Production and Construction (not shown). For more information, we provide detailed tables of the occurrence of each AOEC exposure code (not grouped) within each occupation in the appendix tables (Washington State Department Labor and Industries, 2021, link).

Table 8. Toxic inhalation exposures by occupation

Occupation	Valid Cases	Claimant Sex (% Female)	Median Claimant Age (Years)
Production	385	25%	39
Transportation and Material Moving	361	35%	47
Construction and Extraction	244	8%	38
Installation, Maintenance, and Repair	214	8%	42
Farming, Fishing, and Forestry	212	42%	39
Building and Grounds Cleaning and Maint.	171	54%	44
Protective Service	170	15%	39
Office and Administrative Support	122	76%	43
Food Preparation and Serving Related	109	50%	35
Healthcare Practitioners and Technical	97	81%	41
Sales and Related	85	62%	36
Healthcare Support	68	87%	41
Management	68	62%	44
Personal Care and Service	50	90%	35
Life, Physical, and Social Science	49	57%	42
Education, Training, and Library	22	95%	42
Architecture and Engineering	18	22%	40
Community and Social Service	16	94%	33
Business and Financial Operations	14	79%	48
Arts, Design, Entertain., Sports, and Media	4	50%	48
Computer and Mathematical	3	33%	61
Legal	3	100%	62
Non-classifiable	119	42%	46
Total	2604	39%	41

Results for Potential Toxicologic Effects

We could identify potential toxicologic effects using the ACGIH's 2018 TLV publication for 1328 claims (55% of all valid claims)(ACGIH 2018). The other 45% of valid claims could not be described because either the exposure substance was ill-defined or the specified substance did not have a threshold-value defined in the 2018 TLV publication. The following results are not meant to prioritize or draw absolute conclusions regarding health burden. It is helpful to state common toxicologic effects to remind the reader of the possible health outcomes experienced by workers included in this dataset.

To broadly summarize the toxicologic effects, we created 17 high-level categories for reporting purposes (e.g. irritant, pulmonary effects, nervous system effects). Table 9 illustrates the most common potential toxicologic effects per category and industry. Note that exposure events include more than one substance, and a given substance can have more than one toxicologic effect. The predominant toxicologic effect was irritation to the upper or lower respiratory tract, eyes or skin (720 cases total). The second most common were pulmonary effects, including pulmonary edema, function, and airway hyper-reactivity (473 cases total). Chlorine was an often-cited exposure and has both irritant and pulmonary toxicologic effects; exposure to chlorine drives the case counts (298 cases) in both of these toxicologic effect categories. Chlorine is used as a cleaning agent across many industries and in many formulations. The potential for asphyxiation is dominated by exposure to carbon monoxide (389 cases), such as the cases in the Public Administration industry from patrol cars discussed previously (Table 4). Lead and lead-based paint make up the majority of exposures with potential effects to the nervous system. The majority of lead exposures are reported by workers in the Construction and 'Administrative and Support and Waste Management and Remediation Services' industries. Table 9 lists non-respiratory effects such as eye damage or impairment, which can occur simultaneously with inhalation injuries in the case of vapor exposure or a splash to the face. Anhydrous ammonia and ammonium hydroxide can damage the eyes and is predominantly associated in this data with fertilizer production and use and with refrigeration leaks in agricultural wholesale warehouses. Certain exposures in our data are associated with potential cancer risk: silica with lung cancer, hexavalent chromium with sinonasal cancer, and formaldehyde with upper respiratory tract cancer.

Table 9. Examples of exposures by potential toxicologic effects

Toxicologic effect Example (Total Cases)	Exposure Examples (Total Cases)	Industry Examples (Total Cases)
Irritant (720)	Chlorine (298)	Health Care (44); Accom.. & Food Serv. (41)
	Anhydrous Ammonia (47)	Manufacturing (20); Wholesale Trade (13)
	Mace (35)	Retail Trade (9); Accommod. & Food Serv. (6)
	Fiberglass (31)	Manufacturing (9); Construction (8); Retail (5)
Pulmonary (473)	Chlorine (298)	Healthcare (44); Accommod. & Food Serv. (41)
	Silica, Crystalline (24)	Construction (10); Manufacturing (6); Retail (2)
	Sulfuric Acid (22)	Manufactur. (6); Wholesale Trade (4); Retail (3)
	Wood Dust (22)	Manufacturing (8); Construction (3)
Asphyxiation (466)	Carbon Monoxide (389)	Public Admin. (90); Transp. & Warehous. (65)
	Propane (32)	Agricult., Forestry, Fishing & Hunt. (10)
	Natural Gas (27)	Healthcare (13); Retail Trade (4)
	Methylene Chloride (2)	Manufacturing (1); Retail Trade (1)
Nervous System (157)	Lead-based Paint (30)	Construction (19)
	Acetone (17)	Manufacturing (6); Retail Trade (4)
	Gasoline (17)	Wholesale Trade (5); Retail Trade (3)
	Isopropyl Alcohol (16)	Manufacturing (4); Healthcare (3)
	Methyl Ethyl Ketone (12)	Manufacturing (5)
Eye Damage/Impair. (92)	Anhydrous Ammonia (47)	Manufacturing (20); Wholesale Trade (13)
	Ammonium Hydroxide (28)	Wholesale Trade (6); Manufacturing (5);
Cancer (62)	Silica, Crystalline (24)	Construction (10); Manufacturing (6); Retail (2)
	Hexavalent Chromium (11)	Manufacturing (5); Transp. & Warehous. (2)
	Asbestos (10)	Manufacturing (3); Prof., Sci., & Tech. Serv. (2)
	Formaldehyde (10)	Healthcare (4); Prof., Sci., & Tech. Serv. (3)
Circulatory (41)	Lead-based Paint (30)	Construction (19)
	Lead, Metal (9)	Construction (2); Public Admin. (2)
Whole Body (25)	Beryllium (8)	Admin., Supp., Waste Mgmt & Remed. Serv. (3)
Teeth (16)	Hydrofluoric Acid (13)	Admin., Supp., Waste Mgmt & Remed. Serv. (5)
	Nitric Acid (3)	Admin., Supp., Waste Mgmt & Remed. Serv. (1)
Kidney Damage/Impairment (15)	Cadmium (4)	Manufacturing (3); Retail Trade (1)
	N,N-Dimethylacetamide (2)	Manufacturing (2)
	Stoddard Solvent (2)	Accommodation & Food Serv. (1)
	Tetrahydrofuran (2)	Construction (1); Manufacturing (1)
	Trichloroethylene (2)	Construction (1); Manufacturing (1)
Reproductive Effects (12)	Toluene (8)	Admin., Supp., Waste Mgmt & Remed. Serv. (1)
	N,N-Dimethylacetamide (2)	Manufacturing (2)
All other effects* (20)	Various	Various

*Examples of 'all other effects' include liver, thyroid, ear nose and throat, cardiac, and hearing.

Clusters of exposed workers

Clusters were defined as two or more cases occurring at the same business location, within a maximum of two days between any of the cases' injury dates. Cases in a cluster can be from more than one employer, such as on a construction site with various subcontractors. For the years 2017-2020, there were 161 clusters identified, with a median of two cases per cluster (range 2 to 30). On average, 40 clusters were identified per year. Multiple employers were involved in 44 (27%) clusters.

Table 10. Top Ten Leading Exposures Associated with clusters, by total number of cases affected

Exposure	Total Clusters	Total Cases within Clusters	Median Number of Cases per Cluster
Carbon Monoxide	44	132	2.0 (2-13)
Chemicals, Not Otherwise Specified	12	35	2.0 (2-8)
Insecticides	2	33	16.5 (3-30)
Pesticides	8	23	2.0 (2-5)
Lead-based Paint	3	19	7.0 (4-8)
Cleaners, Disinfectant	5	18	3.0 (2-6)
Natural Gas	6	17	2.5 (2-5)
Chlorine	4	17	4.0 (2-7)
Freon	6	16	2.0 (2-5)
Anhydrous Ammonia	3	16	3.0 (2-11)
All Other Exposures	68	173	2.0 (2-7)
Total	161	499	2.0 (2-30)

DISCUSSION

Surveillance of the eight prioritized exposures

The toxic inhalation surveillance system was initially set up to track eight priority exposures known for their toxicity, high exposure frequency, and/or relevance to L&I's workplace rules. Two previous analyses of occupational **carbon monoxide (CO)** exposure in WA showed that propane-powered forklifts in agricultural cold storage warehouses were a predominant source of CO poisoning for the period 1994-2005 (Lofgren 2002, Reeb-Whitaker 2010). In contrast, the data reported here indicates that forklift exposure occurs less frequently (8%) compared to vehicle exhaust (44%) as a CO exposure source. The adoption of electric-powered lifts and the manufacture of cleaner burning propane forklift engines in accordance with EPA regulations (EPA 40 CFR part 1048) may have contributed to the reduction in CO cases caused by propane forklifts. Cases counts were high for **chlorine**, with most associated with cleaning. In 54 cases, workers were exposed to chlorine gas from the mixture of cleaning products containing bleach with those containing ammonia or acids. **Ammonia** was included as a priority based on suspicion that exposure from industrial refrigeration systems used in fruit processing were becoming more frequent. Indeed, anhydrous ammonia was the most common form of ammonia exposure (47 cases, 47% of valid ammonia cases). Anhydrous ammonia exposures were predominantly in fruit and vegetable preserving and specialty food manufacturing (19 cases) and the wholesale trade sector (13 cases). Other notable forms of ammonia exposure were ammonium hydroxide (28 cases) in wholesale trade and manufacturing where it is used as an industrial cleaner and sanitizer and in agriculture where it is found in fertilizer. Other forms included ammonia mixed with bleach when cleaning (10 cases) and ammonium chloride (8 cases). While **Methylene chloride** exposure in bathtub refinishers are known to be fatal,we identified no cases in this industry (MMWR 2012). Two cases of methylene chloride exposure were observed in the commercial screen-printing industry; both workers were exposed to solvents containing methylene chloride while cleaning print screens.

Except for two cases, all **metal fume** exposures resulted from welding processes. Exposed welders were predominantly in the manufacturing (38%) and construction (22%) industries, though welding did occur in a wide range of other industries. The two remaining cases were for exposure to metal fume from lead molding and metal cutting. **Chromium** cases were predominantly for hexavalent chromium (12); other forms include chromium hydroxide (1), chromium metal (1), and unspecified chromium compounds (1). The majority of chromium exposures occurred in aerospace industry: four in aircraft manufacturing, two aerospace repair technicians, one on-site test engineer, and one cluster of two security guards incidentally exposed. Non-aerospace chromium exposures included two welders working with rust-resistant stainless steel, a painter applying ceramic coatings to exhaust system parts, and a program control analyst exposed to a wide range of substances at the Hanford Nuclear Reservation.

Among the nine cases of **beryllium** exposure, five occurred in workers associated with Hanford Nuclear Reservation. A cluster of three beryllium cases occurred from the controlled sandblasting of copper alloy parts that contained less than 2% beryllium to be used in the aerospace industry. The remaining exposure was a worker debarring beryllium copper in an aircraft parts manufacturer.

Wildland smoke cases predominantly occurred among fire protection and related workers (39% of total) but also in construction, recreation, retail trade, and accommodation and food services. It is anticipated that agricultural workers are at high risk for wildland smoke exposure. We report here two cases, one in logging and one in non-citrus fruit farming. These are likely an underestimate of the true burden of wildland smoke exposure.

Cluster Surveillance

Exposures that impact a large number of workers at once are of interest for prioritizing prevention resources. Carbon monoxide is the leading exposure associated with clusters (Table 10). The sources of carbon monoxide in clusters follows the same pattern as the carbon monoxide claims overall, with vehicles being the most common source (Table 4). Large groups of workers may file claims for carbon monoxide exposure after building evacuations. While less common, evacuations due to ammonia leaks also result in large clusters. Unclear or unknown exposures resulted in 12 clusters particularly among airline crews, with possible but unverified exposure to strange odors, jet fuel, and carbon monoxide that occur inside the aircraft. Insecticides and pesticides resulted in the largest clusters overall. Several of these events involved large groups of agricultural workers incidentally exposed to spray from neighboring farms.

Clusters in our surveillance system often involve multiple employers and occupations sharing a work location. Forty-four clusters involved more than one employer. These often occurred at construction sites, government buildings, and medical complexes. For example, 12 workers from two employers were exposed to spray foam insulation fumes at a construction site, due to miscommunication with a third employer. Evacuations of government buildings often result in cases from multiple employers; for instance, a propane leak at a correctional facility resulted in seven cases from three employers. At a medical complex, a DLCO tank (contains CO, methane, oxygen and nitrogen) used for testing the lung diffusion capacity of patients leaked, affecting ten workers from six employers.

Severe exposures

Six workers identified by the surveillance system with a toxic inhalation also died. Three of the fatalities were from disease following chronic inhalation exposures over the course of the workers' career: two workers died of cancer caused by complex exposures at Hanford Nuclear Reservation and one pipefitter died of asbestosis. In addition to the toxic inhalation surveillance described here, the SHARP program also conducts surveillance for respiratory disease, including asbestosis, and the occurrence of asbestos-related deaths are described in full from that system (Washington State Dept. of Labor and Industries 2019). The fourth fatality from a toxic inhalation occurred in a firefighter at a chemical plant who had minimal inhalation exposure to tetramethylammonium hydroxide (TMAH) but primarily succumbed to extensive chemical burns from TMAH during the same incident. The fifth fatality was from causes unrelated to the occupational inhalation exposure noted in our surveillance system, and the final review of the sixth fatality is pending due to outstanding medical records at the time of this writing.

Inhalations that were associated with hospitalization arose from both acute and chronic exposure, with 13 of the 35 hospitalized workers having compensable claims. One severe acute injury occurred in a floor supervisor from a shipping business who was exposed to sodium metabisulphite upon opening and entering a shipping container for inspection. The injured worker was diagnosed with severe interstitial lung disease and reactive airways dysfunction syndrome (RADS) resulting in total and permanent disability. Sodium metabisulphite is an inorganic compound used as a disinfectant, antioxidant and preservative agent; it is unclear if the residual was from container disinfection or whether the chemical itself was being shipped. Similar exposures from international container and bulk cargo transport processes are described by Baur et al. (Baur 2015). A second severe injury occurred in a truck wash worker at an auto detail truck washing shop who inhaled hydrofluoric acid (HF). The incident occurred when the worker pumped undiluted HF from a stock 55-gallon barrel into 5-gallon lidded bucket for transport. The pump handle broke resulting in exposure to HF that caused acute shortness of breath and a subsequent three-day hospitalization. A case series of 48 workers' compensation cases with HF exposure have been described in Washington's car and truck wash workers predominantly for burn injury; in comparison the present case is noted for its inhalation health risk (Reeb-Whitaker 2015). Other hospitalizations included a worker exposed to chlorine gas while adjusting the chlorinator in a pool; a maintenance worker injured in a fall sustained after blacking out from indirect exposure to a floor finish product (formulation unknown); and an agricultural worker exposed to pesticide while spray-treating infested grain.

Surveillance strengths and limitations

Workers' compensation, the primary data source for this surveillance system, has factors that contribute to under-estimating the exposure burden: injured workers unaware of the workers' compensation system, failure by both workers and/or healthcare providers to recognize the work-relatedness of a condition, and barriers to filing a claim such as a perceived fear of retribution or job loss. The advantages of this system are a stable reporting source, standardized injury and illness codes, consistent and controllable case capture methods, and program longevity. The timeliness of the data source allows for the rapid referral of cases to compliance officers in L&I's Division of Occupational Health and Safety. Seven cases were referred between 2017 to 2020: three for carbon monoxide, two for ammonium, one for chromium, and one for beryllium.

Our toxic inhalation case definition does not specify clinical injury or disease sustained by workers. This is somewhat a limitation to our ability to describe health outcomes. However, we gather significant amounts of information on the type and source of the exposure. This information often cannot be found through any other means, such as ICD-10 codes or administrative injury codes. This specificity is a significant strength of our surveillance system.

Our working definition of clusters works well in identifying acute incidents, such as a group of construction workers with different employers exposed to fumes from spray foam installation at a shared worksite. Our definition would not capture an exposure that occurred intermittently across a longer period. For example, our algorithm identified a cluster of six healthcare workers exposed to fumes from a disinfection fogger on the same day, related to increased COVID-19 disinfection activities. A similar event occurred among five bus drivers exposed to hospital-grade disinfectants inappropriately applied in buses. However, because these employees were exposed to the chemical on dates more than two days apart, only three of the five cases met the definition of a cluster. Overall, our cluster algorithm does not capture intermittent or rare exposure events, though these could be case series of great interest.

Future Direction

Two areas of future work are surveillance system operation and injury prevention. Operationally, the toxic surveillance system is young with three years of consecutive data. In a separate technical report, we evaluated the case capture methods for this surveillance system and identified ways to improve case capture for the priority exposures (Washington State Dept. of Labor and Industries 2021). Frequent well-defined exposures from the "other" category that could be captured similar to the eight priority exposures include cleaning chemicals and disinfectants; pesticides, insecticides, and fungicides; and caustic acids. Moving forward, these exposures will be captured similar to the priority substances with specific keywords, ICD-10 codes, and OIICS codes. Data fields that describe the exposure source will be developed to facilitate systematic coding of such contextual information during case review. Many of the most common exposures in the "other" category were too ill-defined to be good targets of surveillance activities or prevention; these include dust, paint, and indoor air pollutants from building renovation. Regarding prevention activities, one of the benefits of having validated all toxic inhalations over a four-year period is the ability to respond to regional or national inquires on diverse exposures of emerging interest. Employers, industry groups and prevention specialists should review the appendix tables provided with this report for inhalation exposures by industry and occupation that may inform their specific area of interest. Two potential areas for immediate prevention work include the characterization of cleaning and disinfecting exposures related to the COVID-19 pandemic and the anhydrous ammonia exposures in fruit and vegetable processing.

CONCLUSION

The toxic inhalation surveillance system is able to identify workers and industries with high or emerging exposure and exposure risk. Priority exposures such as chromium, methylene chloride, and beryllium are relatively rare but remain important to characterize. In contrast, exposure to cleaning materials and pesticides are frequently occurring in the workers' compensation data and case capture for these exposures should be enhanced in our system. The surveillance system was able to identify areas in need of prevention, including but not limited to cleaning that mitigates SARS-CoV-2 and also exposure to anhydrous ammonia in food processing workers. Extensive data tables that characterize inhalation exposure by industry, occupation, and health effects are given to help workers, employers, and the public health community understand the frequency and type of inhalation exposures that workers face.

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SUPPLEMENTARY MATERIALS

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