Burden of Occupational Cancer in Ontario

Major Workplace Carcinogens and Prevention of Exposure

Occupational Cancer Research Centre

Ontario
Cancer Care Ontario

Published by Cancer Care Ontario and the Occupational Cancer Research Centre

Cancer Care Ontario
620 University Avenue
Toronto, Ontario M5G 2L7
Telephone: 416 971 9800
cancercare.on.ca

Occupational Cancer Research Centre
525 University Avenue, 3rd Floor
Toronto, Ontario M5G 2L3
Telephone: 416 217 1849
occupationalcancer.ca

ISBN 978-1-4868-0414-6 Print
ISBN 978-1-4868-0415-3 PDF

Permission to reproduce

How to cite this publication

Cancer Care Ontario, Occupational Cancer Research Centre. *Burden of occupational cancer in Ontario: Major workplace carcinogens and prevention of exposure.*
Toronto: Queen's Printer for Ontario; 2017.

This report and supplemental materials are available at www.cancercare.on.ca/occupationreport. The report is also available at www.occupationalcancer.ca/2017/occupational-burden-ontario-report.

Need this information in an accessible format?

1-855-460-2647 / TTY (416) 217-1815
publicaffairs@cancercare.on.ca

Acknowledgements

The burden of occupational cancer research presented in this report was funded by the Canadian Cancer Society Multi-Sector Team Grant in Prevention Research (#701285). Occupational carcinogen exposure estimates were provided by CAREX Canada, which is funded by the Canadian Partnership Against Cancer.

Canadian Cancer Society

CAREX CANADA

This report was prepared by:

Occupational Cancer Research Centre, Cancer Care Ontario:

Manisha Pahwa, MPH
Research Associate

Ela Rydz, MPH
Research Associate

Chaojie (Daniel) Song, MPH
Research Associate

Paul A. Demers, PhD
Director

Population Health and Prevention, Cancer Care Ontario:

Shelley A. Harris, PhD
Scientist

Stephanie Young, MPH
Senior Research Associate

Elisa Candido, MPH
Team Lead

Alice Peter, MA, MBA
Director

Contributors

Policy Advisory Committee members

Ray Copes, MD, Chief, Environmental and Occupational Health, Public Health Ontario

Fe de Leon, MPH, Researcher, Canadian Environmental Law Association

D. Linn Holness, MD, FRCPC, Director, Centre for Research Expertise in Occupational Disease, University of Toronto and St. Michael's Hospital

Andrew King, LLM, Department Leader (Ret.), Health, Safety and Environment Department, United Steelworkers Union and Researcher in Residence, School of Labour, McMaster University

Katherine Lippel, LLM, Canada Research Chair in Occupational Health and Safety Law, University of Ottawa

Rowena Pinto, BA, MPPPA, Vice-President, Public Affairs and Strategic Initiatives, Canadian Cancer Society—Ontario Division

Ellen Simmons, BA, Communications Officer, Workers Health and Safety Centre

William Swanson, CIH, Occupational Hygienist, Occupational Hygiene and Environment Section, Safety Department, Toronto Transit Commission

Valerie Wolfe, BASc, DOHS, CRM, Executive Director, Occupational Health Clinics for Ontario Workers – South Central Region, Ontario

Reviewers

Jeremy Beach, MBBS, MD, Assistant Registrar, College of Physicians & Surgeons of Alberta and Professor Emeritus, Department of Medicine University of Alberta

Paul Bozek, BASc, MEng, MBA, PEng, CIH, ROH, Assistant Professor, Dalla Lana School of Public Health, University of Toronto

Hugh Davies, PhD, CIH, Co-Investigator, CAREX Canada, Simon Fraser University and Lead, Canadian Workplace Exposures Database and Associate Professor, School of Population and Public Health, University of British Columbia

Leon Genesove (ex-officio expert), MD, CCFP, DIH, FCBOM, FRCPC, Chief Physician and (A) Director, Occupational Health and Safety Branch, Ontario Ministry of Labour

Tracy Kirkham, PhD, Assistant Professor, Dalla Lana School of Public Health, University of Toronto

Cheryl Peters, PhD, Postdoctoral Fellow, Carleton University & Institut national de la recherche scientifique and Co-Principal Investigator & Occupational Exposures Lead, CAREX Canada, Simon Fraser University

CAREX Canada

Hugh Davies, PhD, CIH, Co-Investigator, CAREX Canada, Simon Fraser University and Lead, Canadian Workplace Exposures Database and Associate Professor, School of Population and Public Health, University of British Columbia

Calvin Ge, MSc, PhD Student, Utrecht University, the Netherlands

Amy Hall, MSc, PhD Candidate, School of Population and Public Health, University of British Columbia and Associate, CAREX Canada, Simon Fraser University

Anne-Marie Nicol, PhD, Co-Principal Investigator, CAREX Canada, Simon Fraser University and Assistant Professor, Faculty of Health Sciences, Simon Fraser University

Alison Palmer, MSc, Managing Director, CAREX Canada, Simon Fraser University

Cheryl Peters, PhD, Postdoctoral Fellow, Carleton University and Institut national de la recherche scientifique and Co-Principal Investigator & Occupational Exposures Lead, CAREX Canada, Simon Fraser University

Joanne Telfer, MPH, Knowledge Translation Specialist, CAREX Canada, Simon Fraser University

Scientific team for the Burden of Occupational Cancer in Canada Study

The Burden of Occupational Cancer in Canada Study was led by Dr. Paul Demers (OCRC, CCO) and funded with a $1,000,000 team grant from the Canadian Cancer Society Research Institute. Scientists from across the country collaborated to form the study team. The lead scientists involved in the United Kingdom burden study, Dr. Lesley Rushton and Sally Hutchings, served as advisors over the four years of the Canadian study.

Victoria Arrandale, PhD, Senior Research Associate, Occupational Cancer Research Centre, Cancer Care Ontario and Assistant Professor, Dalla Lana School of Public Health, University of Toronto

Hugh Davies, PhD, CIH, Co-Investigator, CAREX Canada, Simon Fraser University and Lead, Canadian Workplace Exposures Database and Associate Professor, School of Population and Public Health, University of British Columbia

Paul A. Demers (Principal Investigator), PhD, Director, Occupational Cancer Research Centre, Cancer Care Ontario and Professor, Dalla Lana School of Public Health, University of Toronto and Scientific Director, CAREX Canada, Simon Fraser University

Calvin Ge, MSc, PhD Student, Utrecht University, the Netherlands

Sally Hutchings (Advisor), BSc, Research Fellow in Statistics, School of Public Health, Imperial College London (U.K.)

Joanne Kim, MPH, PhD Student, Department of Epidemiology, Biostatistics and Occupational Health, McGill University and Research Associate, Occupational Cancer Research Centre, Cancer Care Ontario

Desre Kramer, PhD, Associate Director and Scientist, Occupational Cancer Research Centre and Adjunct Professor, School of Public and Occupational Health, Ryerson University

France Labrèche, PhD, Researcher, Chemical and Biological Hazard Prevention, Institut de recherche Robert-Sauvé en santé et en sécurité du travail and Clinical Adjunct Professor, School of Public Health, Université de Montréal

Christopher B. McLeod, PhD, Assistant Professor, School of Population and Public Health, University of British Columbia and Associate Scientist, Institute for Work and Health and Co-Director, Partnership for Work, Health, and Safety, University of British Columbia

Anne-Marie Nicol, PhD, Co-Principal Investigator, CAREX Canada, Simon Fraser University and Assistant Professor, Faculty of Health Sciences, Simon Fraser University

Manisha Pahwa, MPH, Research Associate, Occupational Cancer Research Centre, Cancer Care Ontario

Cheryl Peters, PhD, Postdoctoral Fellow, Carleton University and Institut national de la recherche scientifique, Co-Principal Investigator and Occupational Exposures Lead, CAREX Canada, Simon Fraser University

Lesley Rushton (Advisor), PhD, Reader in Occupational Epidemiology, School of Public Health, Imperial College London (U.K.)

Chaojie (Daniel) Song, MPH, Research Associate, Occupational Cancer Research Centre, Cancer Care Ontario

Emile Tompa, PhD, Senior Scientist, Institute for Work and Health and Associate Professor, Department of Economics, McMaster University and Assistant Professor, Dalla Lana School of Public Health, University of Toronto

Internal support

The authors thank Jenny Lass of Prevention and Cancer Control, Cancer Care Ontario for copy editing this report. Additional thanks to Penney Kirby of Prevention and Cancer Control, Cancer Care Ontario for leading the knowledge transfer and exchange for this report.

Foreword

Since 2013, Cancer Care Ontario's *Cancer Risk Factors in Ontario* series has provided in-depth assessments of the multiple causes of cancer in Ontario.

Previous reports in the series have shown that tobacco, alcohol consumption, unhealthy diet, lack of physical activity, excess body weight and exposure to certain environmental pollutants increase the risk of some of the most common cancers in Ontario. Each of these distinct cancer risk factors can be prevented through modifying individual behaviours and policies designed to improve population health.

This sixth report in the series focuses on occupational risk factors for cancer. Occupational exposures are associated with a substantial and often overlooked burden of cancer (i.e., cancer cases that could be prevented by reducing exposure to occupational carcinogens) that is almost entirely preventable. This report includes the most common known or suspected carcinogens found in Ontario workplaces, particularly those that make the greatest contribution to the burden of occupational cancer. Policy recommendations that can reduce or prevent workplace exposures to carcinogens are a core component of this report. Many of these recommendations are directed to the Ontario Ministries of Labour, Health and Long-Term Care, and Environment and Climate Change, which reflects the need for multiple strategies around a shared purpose of prevention.

This report was jointly produced by the Occupational Cancer Research Centre (OCRC) and Cancer Care Ontario's Population Health and Prevention team, with input from experts across the province on scientific content and policy recommendations. The scientific information presented in this report is based on years of occupational cancer research in Canada, much of it led and produced by the OCRC. The OCRC, established in 2009 and located at Cancer Care Ontario, is one of the few centres in the world dedicated to understanding the causes, surveillance, prevention and burden of occupational cancer. The OCRC maintains a close collaboration with CAREX Canada, which conducts a national surveillance project for occupational and environmental carcinogens and provided nearly all of the exposure data in this report.

We hope that you find this report a compelling call to take action on preventing occupational cancer in Ontario.

Sincerely,

Linda Rabeneck, MD MPH FRCPC
Vice-President, Prevention and Cancer Control
Cancer Care Ontario

Paul A. Demers, PhD
Director, Occupational Cancer Research Centre
Cancer Care Ontario

Alice Peter, MA MBA
Director, Population Health and Prevention
Cancer Care Ontario

Key messages

What was done

Exposure estimates and occupational cancer burden estimates (i.e., cancer cases that could be prevented by reducing exposure to occupational carcinogens) were summarized by industry or occupation for the most common occupational carcinogens in Ontario. Exposure prevention recommendations for policy and workplaces were proposed.

What was found

The occupational carcinogens with the highest number of Ontario workers exposed and largest impact on cancer burden were solar radiation, asbestos, diesel engine exhaust and crystalline silica. Approximately 450,000 workers are exposed to solar radiation, which causes an estimated 1,400 non-melanoma skin cancer cases annually. Although fewer than 55,000 workers are occupationally exposed to asbestos, it is the cause of 630 lung cancers, 140 mesotheliomas, 15 laryngeal cancers and less than five ovarian cancers annually in Ontario. Diesel engine exhaust exposure, affecting about 301,000 workers, accounts for 170 lung and a suspected 45 bladder cancer cases each year. There are an estimated 142,000 Ontario workers exposed to crystalline silica, which causes almost 200 lung cancer cases each year. A number of other occupational carcinogens were found to have associated cancer burdens that were lower. Several other known and suspected carcinogens were identified as emerging issues.

Why this is important

Occupational exposure to carcinogens contributes substantially to the cancer burden in Ontario. The burden of occupational cancer can be reduced through workplace-based controls and improved policies that prevent carcinogenic exposures at work. This report has drawn upon the expertise of policy makers to present areas where occupational exposure reduction can be strengthened in Ontario at a systemic level.

What can be done

Overarching policy recommendations include strengthening occupational exposure limits so they are up to date, rigorous and evidence-based; enforcing existing occupational health and safety regulations; reducing the use of toxic substances; creating registries of workers exposed to occupational carcinogens to facilitate exposure surveillance; and broadening current occupational health and safety legislation to better protect workers in the construction industry.

Next steps

The evidence-based policy recommendations in this report have been developed with all levels of government in mind, as well as members of Ontario's occupational health and safety system, employers and non-governmental organizations. It is hoped that this report will stimulate these organizations to take further action to reduce exposure to occupational carcinogens. Future research on emerging exposures, including assessments of occupational exposure and evaluations of carcinogenic potential, will help generate a more complete picture of cancer burden in Ontario.

Executive summary

Occupational exposures are responsible for approximately two to 10 percent of all newly diagnosed cancer cases, based on studies conducted in the United Kingdom, Finland, Australia, United States and globally.

These exposures are wide ranging and over 80 have been classified as definitely or probably carcinogenic to humans according to the International Agency for Research on Cancer (IARC). Many are found in Ontario workplaces. Until recently, little research had been done to quantify the extent of exposure to known and probable occupational carcinogens in Ontario and the impact that these exposures have on cancer incidence (i.e., newly diagnosed cases). This knowledge is essential for making policy recommendations that aim to prevent exposure to these carcinogens and, ultimately, reduce the burden of occupational cancer (i.e., cancer cases that could be prevented by reducing exposure to occupational carcinogens).

This report provides evidence about the most important occupational risk factors for cancer in Ontario and recommendations for prevention. It profiles 11 major carcinogens that are well-established causes of cancer, that a large number of Ontario workers are exposed to and that contribute most to the burden of occupational cancer. Four additional carcinogens to which a large number of workers are exposed—but that contribute less to cancer burden—are also included. Because the body of knowledge about occupational cancer risk factors is constantly evolving, five carcinogens of special interest are also discussed.

This report provides evidence about the most important occupational risk factors for cancer in Ontario and recommendations for prevention.

The largest number of cancers (1,400 non-melanoma skin cancers) is from occupational solar ultraviolet radiation, which is a common occupational carcinogen exposure in Ontario. Workplace asbestos exposure, which has decreased over time, is nevertheless responsible for approximately 790 cancers each year, including mesothelioma, lung, laryngeal and ovarian cancer. Diesel engine exhaust accounts for over 200 lung and bladder cancers annually, and is an exposure that occurs in nearly 300,000 workers. Approximately 142,000 workers are exposed to crystalline silica, which causes an estimated 200 lung cancer cases each year.

The policy recommendations that are presented in this report were developed for occupational carcinogens overall and for some individual exposures that make the greatest contribution to occupational cancer burden in Ontario. The four overarching policy recommendations are to strengthen occupational exposure limits so they are up to date, rigorous and based on evidence of health effects; reduce or eliminate the use of toxic substances; create registries of worker exposure to occupational carcinogens to facilitate the tracking of exposures; and broadening current occupational health and safety legislation to better protect workers in the construction industry. All policy recommendations are intended for one or more Ontario government ministries, primarily Labour, but also Health and Long-Term Care, Environment and Climate Change, Transportation, and Infrastructure. The involvement of federal and local governments may also be necessary. This report demonstrates the tremendous opportunity for Ontario to take concerted and deliberate action to reduce the burden of occupational cancer and create healthy workplaces and environments for all.

Table of contents

List of figures

List of tables

Introduction

What are the objectives of this report?

The primary objective of this report is to describe and quantify important occupational risk factors for cancer in Ontario and present policy recommendations for reducing occupational carcinogen exposure. The secondary objectives are to propose workplace-based opportunities for reducing exposure to priority occupational carcinogens, as well as to discuss emerging issues in occupational cancer research that are relevant to Ontario workers.

Why focus on occupation for cancer prevention?

Cancer is the foremost cause of mortality in Ontarians, accounting for over 27,600 deaths in 2013.[1] The causes and risk factors for cancer are complex and multifactorial. Some are known, while evidence for others is limited or inconsistent. By focusing on established modifiable cancer causes and risk factors, we can take some control of our cancer risk.

One area that is within our grasp to change is occupational exposures. Asbestos, diesel engine exhaust, radon and solar ultraviolet radiation are a few examples of well-established occupational carcinogens with modifiable or preventable exposures. The significance of occupation as a contributor to cancer is underscored by the fact that Ontarians spend an average of one-third of their waking time at work.[2] Exposure to occupational carcinogens is disproportionate, with some workers being at much higher risk of exposure than others. These factors make the workplace an important focus in preventing disease and protecting health. This report provides evidence to support the ongoing work of the Ontario Ministry of Labour on its occupational disease strategy and to advance its goals in preventing occupational cancer.

What is currently known about the burden of occupational cancer?

In this report, the term "burden" refers to the estimated number and percentage of cancer cases that could be prevented by reducing occupational exposure to known and suspected carcinogens. In Ontario and all of Canada, there are no reliable, routinely collected data on the number of cancer cases caused by exposure to occupational carcinogens. There is also a lack of information on the economic impact of these cancers.

What formed the basis of this report?

Modelling approaches are commonly used to generate estimates of occupational cancer burden. A widely accepted approach used worldwide is the attributable fraction method, which approximates the proportion of total cancer cases that are due to occupational exposures. In 2012, scientists in the United Kingdom (U.K.) applied the attributable fraction method and estimated that 5.3 percent of all current cancers are a result of occupational carcinogen exposures in Great Britain.[3]

In studies conducted in the U.K. and other jurisdictions, estimates of the burden of occupational cancer ranged from two to 10 percent.[3-8] However, in Canadian workers, the impact of occupational exposure to cancer-causing substances was unknown. To address this knowledge gap, in 2012 the Occupational Cancer Research Centre (OCRC) initiated a four-year study to estimate the burden of occupational cancer in Canada in collaboration with a national team of experts. This was the first-ever study of occupational cancer burden for all of Canada, and burden estimates were produced by province, sex, industry and occupation.

What does this report include?

This report includes exposure and burden estimates for Ontario, and presents findings by major industry. The occupational carcinogens in this report (Table 1) were selected based on the following criteria:

- Number of Ontario workers exposed: 5,000 or more Ontario workers must be occupationally exposed to the carcinogen
- Strength of evidence of carcinogenicity: carcinogens classified as definite human carcinogens by the International Agency for Research on Cancer Monographs Program were prioritized
- Potential for prevention: Carcinogens associated with an estimated 10 or more newly diagnosed cancer cases per year were prioritized, whereas those associated with one to nine newly diagnosed cancers annually were considered to be of secondary interest

The special topics section of this report includes exposures that are of longstanding or emerging interest in occupational cancer and relevant in Canada. However, these exposures require additional research to determine their carcinogenic hazard, their exposure prevalence, and/or cancer burden in Ontario and Canada.

This report also includes carcinogen-specific and overarching policy recommendations designed to reduce the burden of occupational cancer in Ontario. Policy recommendations have the potential for a population-wide impact and producing greater equity in occupational health. Many of these recommendations are geared towards provincial ministries of Labour, and Health and Long Term Care, but some may involve additional or alternate Ontario ministries, such as Environment and Climate Change, Transportation, and Infrastructure, as well as cooperation from federal and local governments. Given that employers and organized labour play a central role in controlling exposure at worksites, workplace-based recommendations are included along with the systemic changes that the recommended policies can achieve.

How can this report be used?

Occupational cancer can be prevented through the evidence-based, concerted and deliberate actions of government, employers and other organizations responsible for the health and safety of Ontario's workers. By highlighting opportunities to reduce and prevent carcinogenic exposures that are responsible for the greatest number of occupational cancers, this report can serve as an evidence-based source of information that can be used to raise awareness, encourage discussion, create change and most importantly, to drive the prevention of future occupational cancers.

> Occupational cancer can be prevented through the evidence-based, concerted and deliberate actions of government, employers and other organizations responsible for the health and safety of Ontario's workers.

TABLE 1 Carcinogens selected for inclusion in this report

CARCINOGEN	IARC EVALUATION[a]	NUMBER OF ONTARIO WORKERS EXPOSED[b]	ANNUAL BURDEN OF OCCUPATIONAL CANCER IN ONTARIO[c]
Priority carcinogens (N=11)[d]			
Solar ultraviolet radiation	Definite	449,000	1,400 non-melanoma skin
Asbestos	Definite	52,000	630 lung, 140 mesothelioma, 15 laryngeal, <5 ovarian
Diesel engine exhaust	Definite	301,000	170 lung, 45 bladder
Silica (crystalline)	Definite	142,000	200 lung
Welding fumes	Definite	169,000	100 lung
Nickel compounds	Definite, possible	48,000	80 lung
Environmental tobacco smoke at work	Definite	2,368,000	50 lung, 10 pharynx, 5 larynx
Radon	Definite	34,000	60 lung
Chromium (VI)	Definite	39,000	25 lung
Arsenic	Definite	8,000	20 lung
Benzene	Definite	147,000	10 leukemia, <5 multiple myeloma
Secondary carcinogens (N=4)[e]			
Polycyclic aromatic hydrocarbons (PAHs)[f]	Definite, probable, possible, unclassifiable	134,000	60 lung, 15 skin, 30 bladder
Artificial ultraviolet radiation	Definite	48,000	5 ocular melanoma
Wood dust	Definite	92,000	<5 sinonasal, <5 nasopharynx
Formaldehyde	Definite	63,000	<5 leukemia, <5 nasopharynx, <5 sinonasal
Special interest (N=5)[g]			
Shift work involving circadian disruption	Probable	833,000	180–460 breast[h]
Antineoplastic agents	Definite, probable	NA	NA
Nanoparticles	Not evaluated	NA	NA
Pesticides	Definite, probable, possible	NA	NA (non-Hodgkin lymphoma, prostate, leukemia, lung, liver, testis, multiple myeloma, breast, other)
Sedentary work	Not evaluated	NA	NA

NOTES:

[a]The IARC Monographs program routinely evaluates carcinogenic risks to humans and categorizes agents as one of the following: (1) Group 1: definite human carcinogen; (2A) Group 2A: probable human carcinogen; (2B) Group 2B: possible human carcinogen; (3) Group 3: not classifiable; (4) Group 4: not carcinogenic to humans.

[b]All exposure estimates except for welding fumes and ETS were provided by CAREX Canada.

[c]Burden of occupational cancer in Ontario based on results from the national (Canadian) study, reported as the estimated number of cancer cases attributable to occupational exposure to the respective carcinogen. The range in estimated annual number of occupational cancer cases can be found at: www.cancercare.on.ca/occupationreport.

[d]Priority carcinogens selected based on accounting for 10 or more occupational cancer cases in Ontario.

[e]Secondary carcinogens selected based on accounting for fewer than 10 estimated occupational cancer cases in Ontario.

[f]Polycyclic aromatic hydrocarbons (PAHs) included as secondary carcinogens because they are a heterogeneous group of compounds with different carcinogenic classifications.

[g]Special interest carcinogens selected based on scientific and policy importance, emerging issue, high known or possible prevalence of exposure in Ontario workers, and/or incalculable burden estimate in Canada/Ontario.

[h]A range was generated because shift work is a probable carcinogen.

Carcinogens with "NA" indicate that CAREX Canada exposure estimates or occupational burden of cancer results are not available.

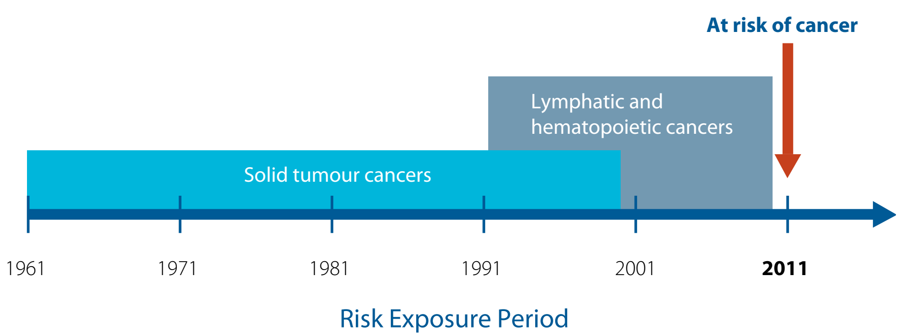
Approach

The methods that were used for estimating the burden of occupational cancer in Canada were adapted from the approach previously used in the United Kingdom (U.K.).

The Canadian study advanced the U.K. methods by incorporating more detailed estimates of occupational carcinogen exposure than were available in the U.K. In total, 44 different known and suspected occupational carcinogens and 27 associated cancer sites were included in the study, based on evaluations conducted by the International Agency for Research on Cancer (IARC) Monographs program. In this section, we describe the general methods used to estimate occupational cancer burden in Canada.

The year 2011 was selected as the target year to estimate burden. The time between exposure to occupational carcinogens and the occurrence of cancer can be up to several decades. For this reason, we assumed that exposure to occupational carcinogens between 1961 and 2000 could contribute to newly diagnosed solid tumour cancers in 2011. This 40-year period was called the risk exposure period (REP). For lymphatic and hematopoietic tumours (e.g., leukemia), which can develop more quickly than solid tumours (e.g., breast cancer), we used a 20-year REP from 1991 to 2010 (Figure 1).

FIGURE 1 The risk exposure period



The burden of occupational cancer was defined in this study as the attributable fraction (AF), which is the proportion of total cancers that could be prevented if occupational carcinogen exposures were eliminated. Calculating the AF for each cancer and its associated occupational carcinogens involved three major components. The first was to select an appropriate relative risk that best represented each association from a high-quality, population-based study suitable for the Canadian context.

The second component was to assess the prevalence of exposure to each occupational carcinogen in the Canadian working population.
The prevalence was mostly based on exposure estimates previously developed by CAREX Canada (carexcanada.ca/en/). CAREX Canada, funded by the Canadian Partnership Against Cancer, is a multi-institution research project that combines academic expertise and government resources to generate an evidence-based national carcinogen exposure surveillance program. As an enhanced model for the surveillance of population exposure to occupational (and environmental) carcinogens, CAREX Canada estimated the prevalence of Canadians' workplace exposure to 45 carcinogens in 2006 by incorporating national workforce information with evidence about the proportion of workers exposed to individual carcinogens. A detailed description of CAREX Canada's methods can be found in Peters et al., 2015.[9] It was possible for CAREX Canada to estimate the level of exposure to some carcinogens based on the availability of exposure measurement data. Workers were, for the most part, assigned to different exposure levels based on exposure measurement data from the Canadian Workplace Exposure Database, a database that consolidates regulatory exposure measurement data from six provincial and territorial jurisdictions.[10] Data from the Canadian job-exposure matrix (CANJEM) were used for a number of carcinogens that did not have CAREX exposure prevalence estimates.[11]

Since CAREX Canada assessed occupational carcinogen exposures for the year 2006, historical trends estimated as part of CANJEM were combined with CAREX Canada data to account for changes in the prevalence of exposure over the REP for certain carcinogens. There were a few carcinogens that warranted a separate and unique exposure assessment approach from the CAREX method, such as asbestos and environmental tobacco smoke.

The final component of the AF model was population modelling. Methods were used to model the working population in total and the working population exposed to specific carcinogens included in the study. The number of workers ever exposed during the REP was calculated by counting the number of all exposed workers in the first year of the REP (i.e., 1961 or 1991, depending on cancer type) and the number of exposed new hires in each subsequent year (i.e., 1962–2000 or 1992–2010); the survival of all of these workers was then followed to the target year (i.e., 2011). The population model was built using data from multiple Canadian censuses, labour force surveys and life tables.

> **The burden of cancer was defined in this study as the attributable fraction (AF), which is the proportion of total cancers that could be prevented if occupational carcinogen exposures were eliminated.**

Canadian Cancer Statistics for the year 2011 were used to determine the number of newly diagnosed cancers from exposure to each occupational carcinogen. This number was determined by multiplying the AF with the total number of incident cancers, by cancer type. Ranges in the estimated annual number of occupational cancer cases were estimated for all burden estimates. These ranges can be found at: cancercare.on.ca/occupationreport.

More information about the burden study can be found at:

- Occupational Cancer Research Centre: occupationalcancer.ca/2011/burden-of-occupational-cancer/ and occupationalcancer.ca/2015/burden-prevention-symposium/; and
- CAREX Canada: carexcanada.ca/en/announcements/CAREX_hosts_burden_of_occupational_cancer_symposium_in_BC/.

Policy recommendations were developed using two general sources of information. First, searches were conducted for published regulations and policies that have been used, proposed or developed by governments in Ontario, Canada and other jurisdictions. Second, a Policy Advisory Committee was assembled early in the development of this report to provide input on recommendations that would be appropriate for the Ontario context. The membership of this Ontario-based Committee reflected diverse areas of expertise in occupational health and safety, policy, and cancer and disease prevention. These evidence-based, expert-informed recommendations are directed to relevant Ontario ministries.

Guidance for understanding the results

How to interpret occupational carcinogen exposure estimates

CAREX Canada provided estimates of the number of workers in Ontario who are occupationally exposed to carcinogens. These exposure numbers do not include exposure from non-work sources. For instance, the number of workers who are occupationally exposed to diesel engine exhaust does not account for workers' exposure to diesel exhaust from air pollution in their community or potential residential exposure. Similarly, it is possible that workers who are not exposed to diesel engine exhaust at work may be exposed from other sources. The previous report in this series, *Environmental Burden of Cancer in Ontario*, focuses on cancer burden due to environmental exposure.

In this report, occupational estimates of the number of workers exposed are presented by major industry, such as construction, manufacturing, government services and mining. However, these industries are broad groupings, and each grouping encompasses multiple sub-industries that may be exposed to different carcinogen levels. For some carcinogens in this report, information about the estimated level of exposure (i.e., low, moderate, high, very high) is available. These estimates incorporate historical exposure measurement data (housed in the Canadian Workplace Exposure Database) due to the relative lack of currently collected exposure data. This use of historical data introduces some uncertainty in the exposure level estimates.

CAREX Canada has assessed exposure to 45 known and suspected occupational carcinogens in Canada. These exposures were selected as priorities based on assessments conducted by the International Agency for Research on Cancer (IARC) and evidence of occupational exposure in the Canadian context. There are many more carcinogens that Ontario (and Canadian) workers are exposed to, and evaluations by IARC are an ongoing process. This report is limited to carcinogens with large numbers of workers exposed and that contribute the most to occupational cancer burden in Ontario.

How to interpret occupational cancer burden estimates

The burden estimates in this report represent the number of newly diagnosed cancers each year in Ontario that are due to occupational exposure to carcinogens. In other words, how many cancers can be prevented by eliminating occupational exposure to carcinogens? Because these are estimates, ranges in the burden of occupational cancer cases were calculated. Refer to the supplementary table for more information. The attributable fraction for each exposure and cancer pair is also presented. The attributable fraction represents the percent of total cancer cases that is due to occupational exposure to a specific carcinogen. For example, an attributable fraction of 5.1% for non-melanoma skin cancer for solar ultraviolet radiation means that of all non-melanoma skin cancers that are diagnosed in a year, 5.1% are due to occupational exposure to solar ultraviolet radiation. This report provides quantitative estimates using an established method for calculating occupational cancer burden, based on detailed Canadian exposure information and relevant information on cancer risk.

Calculations of cancer burden were based on historical occupational exposure, taking into account changes in exposure over time. Cancer burden estimates may be underestimated in instances where cancer risk exists below the level chosen for considering a worker exposed. Because further reductions in exposure may occur, the number of associated cancers would decrease in the future. There is a need to assess the occupational cancer burden from new and emerging carcinogens, but this type of assessment falls outside of the scope of this report.

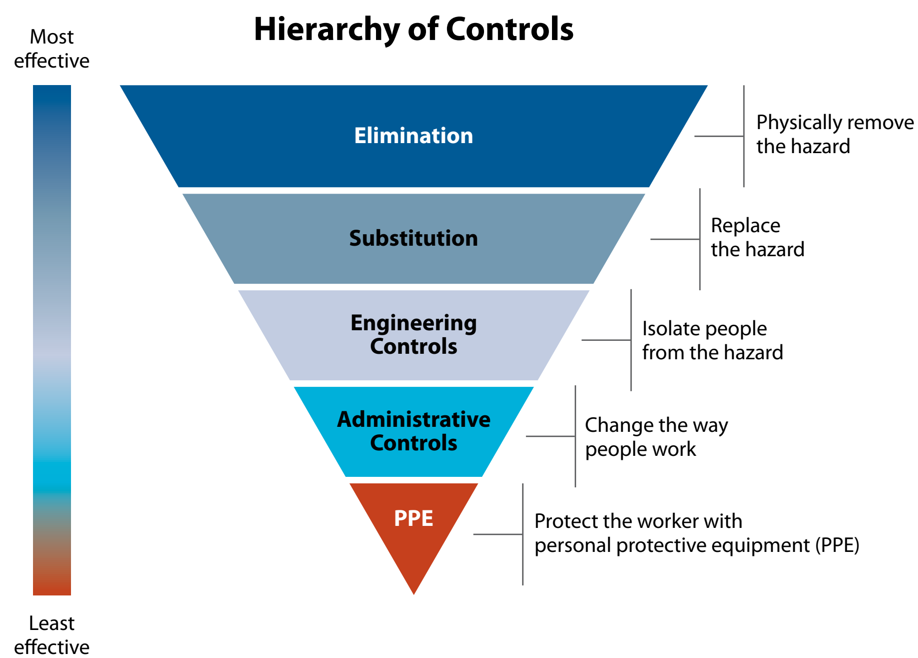
For a few carcinogens in this report, there is information about the level of occupational exposure. The level of exposure and the number of exposed workers are both reflected in the associated cancer burden. It is possible that there are low numbers of workers who are exposed to high levels of some carcinogens, but these workers have the greatest risk and bear the greatest burden of occupational cancer. The opposite may also occur; a large group of workers exposed to the lowest levels of certain carcinogens may account for the greatest burden of cancer.

> The burden estimates in this report represent the number of newly diagnosed cancers each year in Ontario that are due to occupational exposure to carcinogens.

Framework for workplace-based exposure reduction measures

The hierarchy of hazard controls (Figure 2) provided the framework for the workplace-based exposure reduction measures recommended for each carcinogen in this report. The hierarchy orders controls from most to least effective. Ultimately, the best exposure reduction strategies use elimination or substitution. If these strategies are not possible, other control measures within the hierarchy of controls may be considered. This report accounts for the strengths and limitations of each type of control, offering feasible directions for workplaces to consider. More effective controls were prioritized over less effective controls. For this reason, details on personal protective equipment were generally not included in this report, except for a few instances where its use was essential.

FIGURE 2 Hierarchy of hazard controls



Source: U.S. National Institute of Occupational Safety and Health[12]

Elimination involves physically removing the hazard (i.e., the substance, task or process that leads to exposure) from the workspace and substitution involves replacing the hazard with a safer alternative. These controls are the most effective at protecting workers and most easily and cheaply implemented at the design phase.

The next level of the hierarchy is engineering controls, which isolate people from the hazard. These may be less expensive than elimination and substitution, and are preferred over administrative controls and the use of personal protective equipment. Engineering controls must be designed so they do not interfere with work processes or interactions between workers, and must be adequately specified and maintained for efficacy.

Administrative controls, which reduce exposure potential through behaviour change, and personal protective equipment, are the least effective methods of preventing occupational exposure to hazards. They are often used when hazards are not well controlled and require large efforts on the part of workers. Common administrative controls that can be applied to many of the carcinogens included in this report are prohibiting eating, drinking or smoking in areas where carcinogens are present and providing showers, lockers, change rooms and laundering facilities at the worksite. Personal protective equipment is typically used as a last resort or as a temporary approach to reducing exposure. Examples of personal protective equipment include gloves, masks, respirators and clothing. The effectiveness of administrative controls and personal protective equipment use is variable. For example, personal protective equipment depends on workers' compliance, and proper maintenance and use. Even though these controls usually have lower up-front financial costs, in the long run, they can be costly to sustain.

For this report, workplace-based approaches to reducing occupational exposure to carcinogens were identified through searches for published literature in Ontario, Canada and other jurisdictions worldwide. The amount, type and quality of available published information was variable. This information likely underrepresents the actual number and type of reduction approaches that have been implemented in workplaces because these approaches are often unpublished. Nevertheless, the hierarchy of hazard controls is a suitable and widely-accepted way to classify and organize exposure reduction and prevention methods in workplaces.

Policy recommendations

This report presents policy recommendations that were the result of a search of published prevention literature and consultations with the report's Policy Advisory Committee. The general policy recommendations are meant to be applied to all carcinogens in this report. Specific recommendations were made for exposures with the highest impact on the burden of occupational cancer. Other feasible policy avenues may exist and should continue to be discussed with policy-makers.

Drawing conclusions

The estimates for occupational exposure and burden of occupational cancer can be used to inform cancer prevention initiatives in Ontario. Prevention recommendations are oriented around major industries where carcinogenic exposures occur and where the burden of occupational cancer is high. While there are some existing policy initiatives, they may be at an early stage of development or require more rigorous legislation than what currently exists. In some instances, there are policies that prevent or reduce exposure through avenues other than the Ministry of Labour. Overall, this report highlights where opportunities for action can occur and provides evidence to support the proposed recommendations. General policy recommendations can be applied across many occupational carcinogens found in Ontario.

Results for priority carcinogens

Solar ultraviolet (UV) radiation

The sun is the main source of exposure to broad spectrum UV radiation.[13] Solar UV radiation includes wavelengths in the electromagnetic spectrum between 100 and 400 nanometres.

It comprises UVA , UVB and UVC radiation, all of which cause cancer (however, UVC is entirely filtered out by the Earth's atmosphere and not a concern for human exposure).[14] Solar UV radiation can cause melanoma and non-melanoma skin cancers, depending on the exposure patterns. Intermittent sun-intensive activities, such as sunbathing and holidays, are associated with melanoma skin cancer and basal cell carcinoma (a sub-type of non-melanoma skin cancer). However, cumulative exposure, such as long-term occupational exposure, is strongly linked to non-melanoma skin cancer (NMSC), and in particular, the squamous cell carcinoma sub-type.[15] Associations have also been observed between solar UV radiation and cancers of the lip, and in or around the eye.[15] Other health effects associated with exposure to solar UV radiation include heat stress and sunburn, retinal injury and cataracts[16].

Exposure

Solar UV radiation is one of the most common occupational carcinogen exposures in Ontario, second only to shift work. All outdoor workers are at risk of solar UV radiation exposure. The largest industrial groups exposed include construction, agriculture, and transportation and warehousing. Other industries where exposures occur include administrative and support industries (where building services workers are captured), government services (a large government employee group that includes public works, landscaping and grounds maintenance workers), and arts, entertainment and recreation (e.g., grounds maintenance, amusement park operators, and recreation and sports attendants) (Figure 3).

Of the nearly half a million workers exposed to solar UV radiation in the province, 15 percent are exposed to low levels, 26 percent to medium levels and 58 percent to high levels. Low-level exposure occurs in jobs where some outdoor work is expected, such as among truck drivers and courier service drivers. Medium-level exposure occurs in occupations that entail a mix of indoor and outdoor work, but where workers are outdoors less than 75 percent of the workday, such as heavy equipment operators. Finally, high-level exposure occurs in occupations where workers are expected to be outside for at least 75 percent of the workday, including landscapers, construction workers and farmers. Overall, the largest occupational groups exposed are landscaping and ground maintenance workers, construction trades helpers, and farmers and farm managers.

Burden

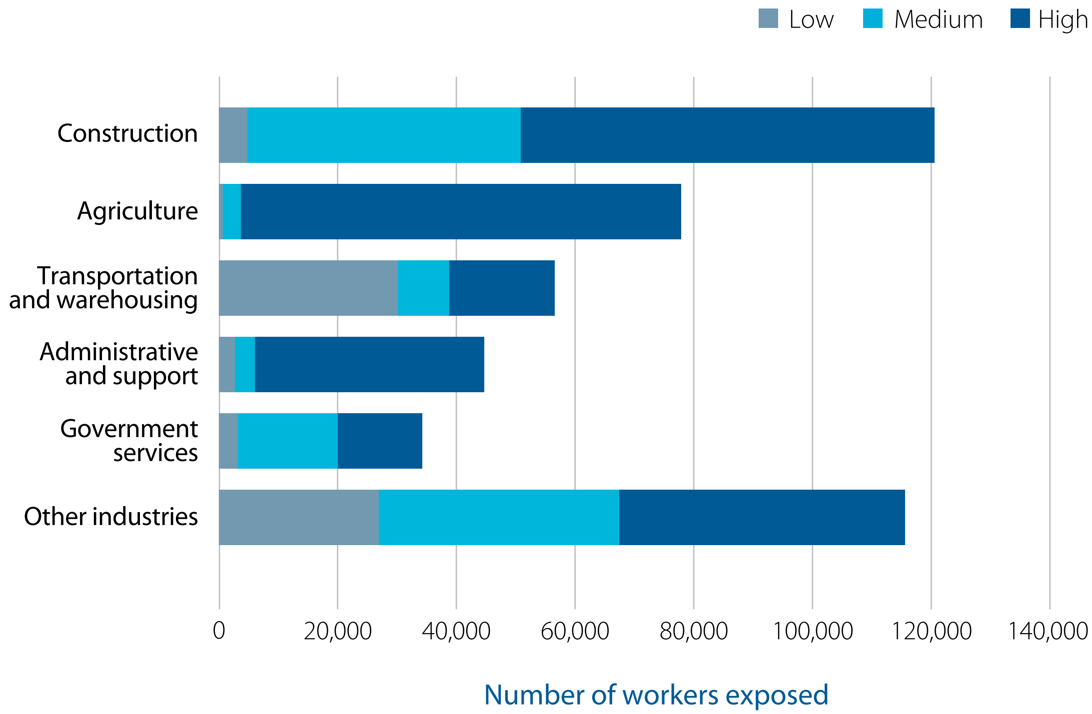
Approximately 1,400 NMSC diagnoses annually are caused by occupational solar radiation exposure in Ontario (Figure 4), which accounts for 5.1 percent of the estimated total NMSCs diagnosed each year in the province.

The greatest burden of NMSC lies in the construction and agricultural industries, a finding that is consistent with the distribution of exposure by industry (Figure 3). Of the government services workers, outdoor parks and recreation workers are most at risk of NMSC. Other industries where an excess of NMSC occurs due to occupational exposure to solar UV radiation include mining, forestry and logging.

Exposure reduction strategies

The best way to protect workers from solar UV radiation is to provide shade. If no natural sources of shade are available, shade structures can be built. The design, placement and use of the shade structure must maximize protection.[17-19] The UV protection factor rating for shade materials should be at least 40 for maximum protection.[17] Other engineering controls include modifying reflective surfaces and tinting windows on vehicles.[18,19] Scheduling shifts to minimize time spent in the sun during peak UV hours (between 11 a.m. and 3 p.m.), and distributing outdoor and indoor tasks across workers to minimize individual exposure can have a significant impact on daily exposure.[20] Sun awareness training should also be implemented in workplaces to raise awareness of the risks associated with solar UV exposure and available protective measures.[18,19] Sun Safety at Work Canada provides resources on how small and large workplaces can develop and implement sun safety programs.[17]

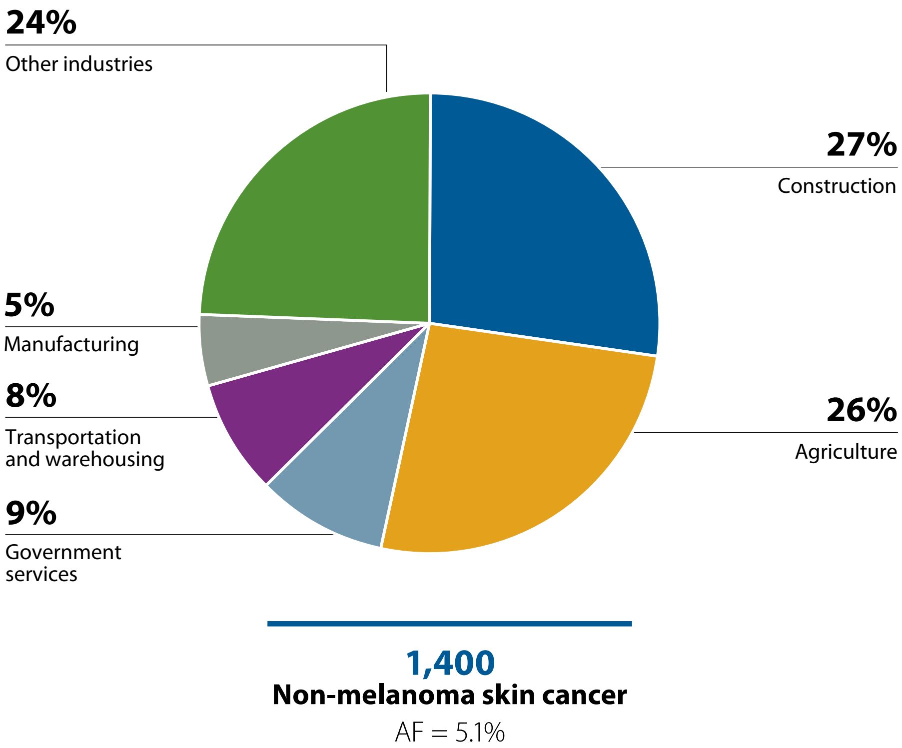
FIGURE 3 Number of workers occupationally exposed to solar ultraviolet (UV) radiation by level of exposure and industry in Ontario



POLICY RECOMMENDATIONS FOR SOLAR UV RADIATION

1. **Require all workplaces with workers that work outdoors for part or all of the day to develop a comprehensive, multi-component sun safety program**. This recommendation is in line with the Cancer Council of Australia's position on sun protection in the workplace.[21] Sun safety programs include a risk assessment to identify workers at high risk of exposure and scenarios where high exposure may occur, sun protection control measures, and sun protection policy and training to facilitate the management of solar UV radiation risk. Employers are responsible for protecting workers from solar UV radiation.[17] The Sun Safety at Work Canada project provides resources on how workplaces can develop their own workplace sun safety program.

FIGURE 4 Industry breakdown of non-melanoma skin cancers (NMSCs) attributed to occupational solar ultraviolet (UV) radiation exposure



NOTES:
AF: attributable fraction

> In 2016, the Canadian government committed to a government-wide asbestos strategy, including an asbestos ban for 2018. However, asbestos is still present in insulation and other building materials from the past,[23] some previously manufactured products, and newly imported asbestos-containing products.[26]

Asbestos

Asbestos is the commercial term for six different types of related mineral fibres.[22] It is characterized by its heat resistance, tensile strength, insulation and friction properties, as well as its ability to be woven.[13] Asbestos was widely used as insulation in buildings and as a fireproofing agent from the 1930s to the 1980s[23]. In 1990, its use as insulation in buildings was no longer permitted.[23] In addition, vermiculite insulation, which was accidentally contaminated with asbestos, was imported to Canada from Libby, Montana until 1990.

Canada was historically a major global producer and exporter of asbestos.[24] In 2012, the last asbestos mines in Canada closed due to a lack of funding.[25] In 2016, the Canadian government committed to a government-wide asbestos strategy, including an asbestos ban for 2018. However, asbestos is still present in insulation and other building materials from the past,[23] some previously manufactured products, and newly imported asbestos-containing products.[26] Asbestos continues to be used in industry, construction and commercial sectors, and can be found in a number of goods, including building materials (e.g., shingles, tiles, cement) and friction materials (e.g., brake linings, automobile clutch pads).[13,27]

There is well-established scientific evidence that all forms of asbestos cause lung cancer and mesothelioma, a rare but aggressive form of cancer of the lining of the lungs and other organs.[28] Asbestos also causes cancer of the larynx and ovary, and there is some evidence that it causes increased risk of colorectal, pharynx and stomach cancers.[28] Smokers who are occupationally exposed to asbestos have a greatly increased risk of developing lung cancer.[13] Asbestos-related cancers diagnosed today are the result of exposure that took place up to 50 years ago.[29] In addition to cancer, asbestos causes asbestosis, a condition characterized by the formation of scar tissue in the lungs.[30]

Exposure

Occupational asbestos exposure occurs from inhaling fibres released from asbestos-containing products and building materials.[31] Para-occupational, or "take-home" exposure, is when a family member is exposed to asbestos-contaminated clothing brought home from the worker. Para-occupational exposure can put family members at increased risk of mesothelioma.[32]

CAREX Canada estimates that approximately 52,000 workers are occupationally exposed to asbestos in Ontario annually.[33] Most occupational exposure (91 percent) occurs in construction, primarily due to the maintenance, renovation and modification of existing public, residential and commercial buildings. Other workers that may be exposed include brake repair workers, and people who repair and maintain ships in the manufacturing industry.[33]

Burden

Approximately 630 lung cancers, 140 mesotheliomas, 15 laryngeal cancers and less than five ovarian cancers are caused by occupational asbestos exposure each year in Ontario (Figure 5). These cancers account for 7.8 percent of lung cancers, 80.7 percent of mesotheliomas, 3.8 percent of laryngeal cancers and 0.4 percent of ovarian cancers diagnosed annually in the province. Of the mesotheliomas, approximately five (one percent) are from para-occupational asbestos exposure. The remaining mesotheliomas are likely due to environmental asbestos exposure.

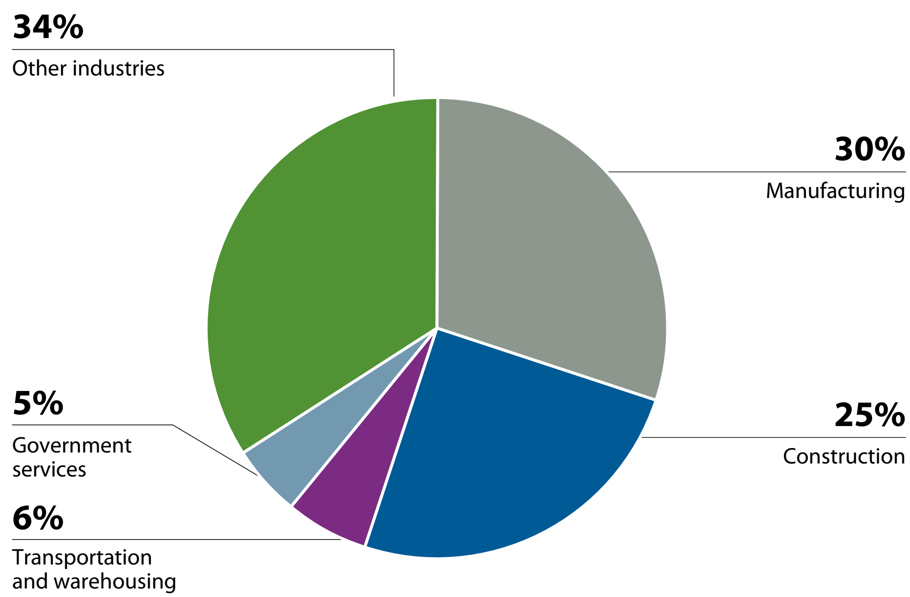
More than half (55 percent) of lung cancers and mesotheliomas caused by occupational asbestos exposure are diagnosed among workers who were employed in manufacturing and construction (Figure 5). Approximately 10 percent of these cancers occur in the transportation and storage sector, and in government services. Cancers in workers in the government services are likely due to the extensive use of asbestos in government buildings, particularly those built before the 1980s. The remaining third of cases occurs in industries such as communication and other utilities, trade, educational services and mining.

Exposure reduction strategies

In December 2016, the federal government announced a government-wide strategy to manage all forms of asbestos, including a comprehensive asbestos ban by 2018.[34] The government-wide strategy will include creating new regulations that ban the manufacture, use, import and export of asbestos and products containing asbestos under the Canadian Environmental Protection Act 1999; establishing federal workplace health and safety rules to limit exposure; changing Canada's international position regarding the listing of asbestos as a hazardous material; expanding the asbestos-containing federal building registry; and working with provincial and territorial governments to change provincial, territorial and federal building codes.[34]

The Canadian government has proceeded to implement its strategy, which includes publicly releasing its regulatory approach on asbestos. As of July 2017, the federal government has amended the Canadian Labour Code to lower the exposure limit for airborne chrysotile asbestos to as close to zero as reasonably possible, but not exceeding 0.1 fibres per cubic centimeter (f/cc), in alignment with the American Conference of Governmental Industrial Hygienists (ACGIH) limits.[35] The legislative landscape surrounding asbestos in the workplace is evolving rapidly and is expected to change significantly in the coming year. While Ontario currently has a set of regulations to control exposure to asbestos and manage asbestos-containing materials, the changes at the federal level will help cover gaps in asbestos management that fall outside of provincial jurisdiction.

FIGURE 5 Industry breakdown of total lung cancers and mesotheliomas attributed to occupational asbestos exposure



630
Lung cancer (AF = 7.8%)

140
Mesothelioma* (AF = 80.7%)

15
Laryngeal cancer (AF = 3.8%)

<5
Ovarian cancer (AF = 0.4%)

NOTES:
* Includes an estimated five cases of mesothelioma attributed to para-occupational asbestos exposure.
AF: attributable fraction

Currently, there are a number of measures that can be adopted by workplaces to reduce occupational exposure to all forms of asbestos. For example, asbestos-containing materials in buildings can be safely removed (following strictly regulated procedures) where the likelihood of exposure to workers is high. Handling or remediating asbestos is highly regulated and controlled. Only trained workers with appropriate personal protective equipment are allowed to perform these tasks. Engineering and administrative controls can be implemented for people who must work near or with asbestos. Engineering controls include using a vacuum equipped with a high-efficiency particulate air (HEPA) filter and brush attachment, and using wet processes. Administrative controls include prohibiting eating, drinking or smoking in areas where asbestos is present, and providing showers, lockers, change rooms and laundering facilities at the worksite, which can also help reduce para-occupational (take-home) exposures among family members of asbestos-exposed workers.[36,37] Other practices when handling asbestos are summarized in the Ontario Ministry of Labour Guide to the Regulation Respecting Asbestos on Construction Projects and in Buildings and Repair Operations.[38] It is important to recognize that these exposure reduction strategies do not completely eliminate occupational asbestos exposure, a goal that can only be achieved over time through a comprehensive asbestos ban and eventual removal from all building components in the long term.

POLICY RECOMMENDATIONS FOR ASBESTOS

1. **Create a public registry of all public buildings and workplaces that contain asbestos**. A provincial registry informs the public and workers about where all forms of asbestos exist in buildings.[39] This recommendation adds to existing legislation which mandates testing for asbestos on construction projects, in buildings and in repair operations and can help to identify buildings that require regular inspection.[38,40]

   Saskatchewan is the first Canadian province with a mandatory online public building registry.[41] This registry, maintained by the Labour Relations and Workplace Safety Ministry, includes all buildings owned by the provincial government, health regions, crown corporations and public schools.[42] A similar federal registry includes all buildings owned or leased by Public Services and Procurement Canada, but is growing and aims to include federal buildings owned or leased by other government departments.[43]

   In Ontario, it is recommended that a public registry include all workplaces, particularly those built before 1980, when asbestos was widely used in building construction. Data entered in the registry could be standardized, and freely and easily accessible to the public and workers (e.g., online and on paper notices in buildings). The registry should also contain information about current measures and plans to remediate or control asbestos exposure in buildings.

2. **Establish an inter-ministerial working group to address occupational asbestos exposure**. Preventing occupational exposure to all forms of asbestos is a complex issue that necessitates a coordinated approach by multiple government agencies. For example a working group led by the Ontario Ministries of Labour, Environment and Climate Change, Health and Long-Term Care, and Infrastructure is necessary to address all the diverse issues associated with asbestos, such as occupational health and safety, safe disposal, public health, and building renovation and abatement. Relevant stakeholders from these areas could be involved to help address specific issues.

   An inter-ministerial working group has been established in British Columbia, and could serve as a model for creating a similar working group in Ontario. The working group will engage with the federal government and stakeholders to support the implementation of the federal asbestos ban.[44]

Diesel engine exhaust

Diesel engine exhaust (DEE) is a complex mixture of gases and particulates produced from burning diesel fuel.[31] Diesel engines are used in vehicles on-road and off-road (e.g., trains, ships) and in industrial equipment (e.g., in mining, construction).[45] DEE has been classified as a known carcinogen based on evidence that it causes lung cancer.[46] There is limited, but growing, evidence that DEE causes bladder cancer.[46,47] DEE exposure has also been associated with respiratory effects (e.g., increased airway resistance, respiratory inflammation) and adverse cardiovascular health outcomes.[48]

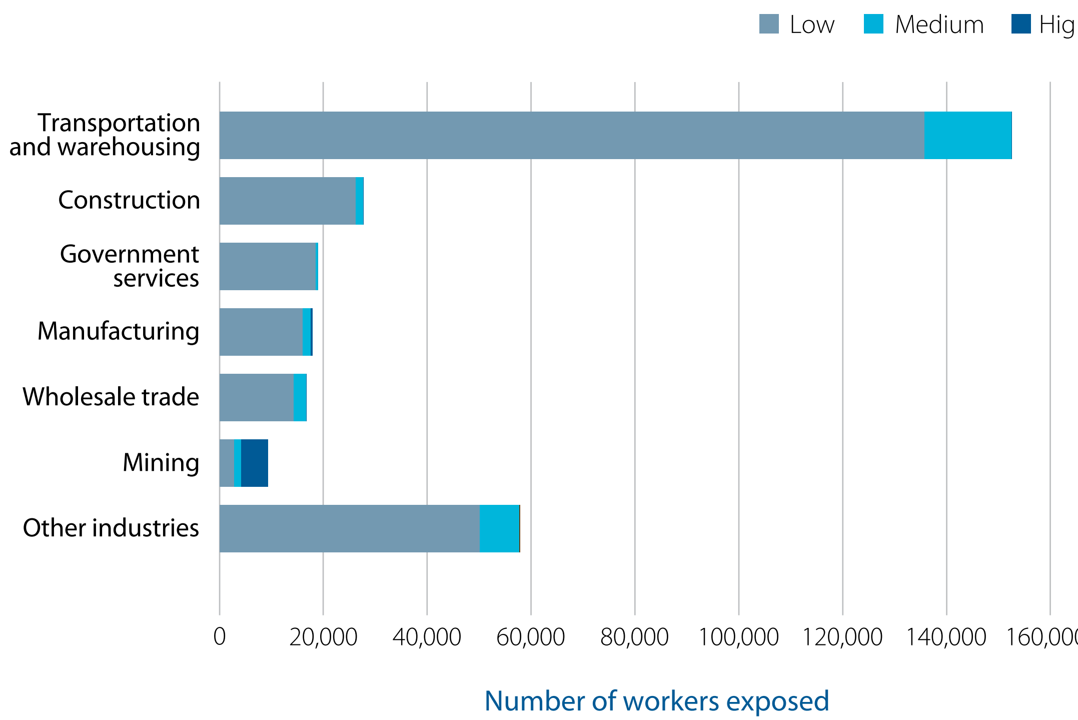
Exposure

The primary route of exposure to DEE is inhalation.[31] CAREX Canada estimates that approximately 301,000 workers in Ontario, or nearly five percent of the province's working population, are occupationally exposed to DEE. The majority of workers occupationally exposed to DEE in Ontario are drivers of diesel engine vehicles or heavy equipment, including firetrucks and ambulances (Figure 6).[33]

Approximately 88 percent of affected workers are exposed to low levels of DEE.[33] Workers are exposed to low levels of DEE if they work above ground, work near traffic-related sources of diesel exhaust or are bystanders (i.e., working near, but not operating, diesel equipment). Truck drivers are the primary group exposed to low levels, but low-level exposures also occur in transit drivers, heavy equipment operators and firefighters, among others. Generally, exposure levels for truck, bus and taxi drivers range from 1 to 10 $\mu g/m^3$ elemental carbon (EC).[49]

Approximately 11 percent of affected workers are exposed to moderate levels of DEE and two percent are exposed to high levels of DEE. Workers are exposed to moderate levels if they repair or maintain diesel-powered equipment; for example, mechanics are exposed to concentrations of approximately 20 to 40 $\mu g/m^3$ EC.[49] High levels of exposure occur in people who work in underground mines, where diesel-powered equipment is commonly used and ventilation is poor. Exposure concentrations typically range from 30 to 660 $\mu g/m^3$ EC in underground mines.[49]

FIGURE 6 Number of workers occupationally exposed to diesel engine exhaust (DEE) by level of exposure and industry in Ontario



CAREX Canada estimates that approximately 301,000 workers in Ontario, or nearly five percent of the province's working population, are occupationally exposed to DEE.

Although there are relatively few workers exposed to high levels of DEE, from a health standpoint, these exposures are significant because cancer risk increases with level of exposure. This increased risk is reflected in the burden estimates.

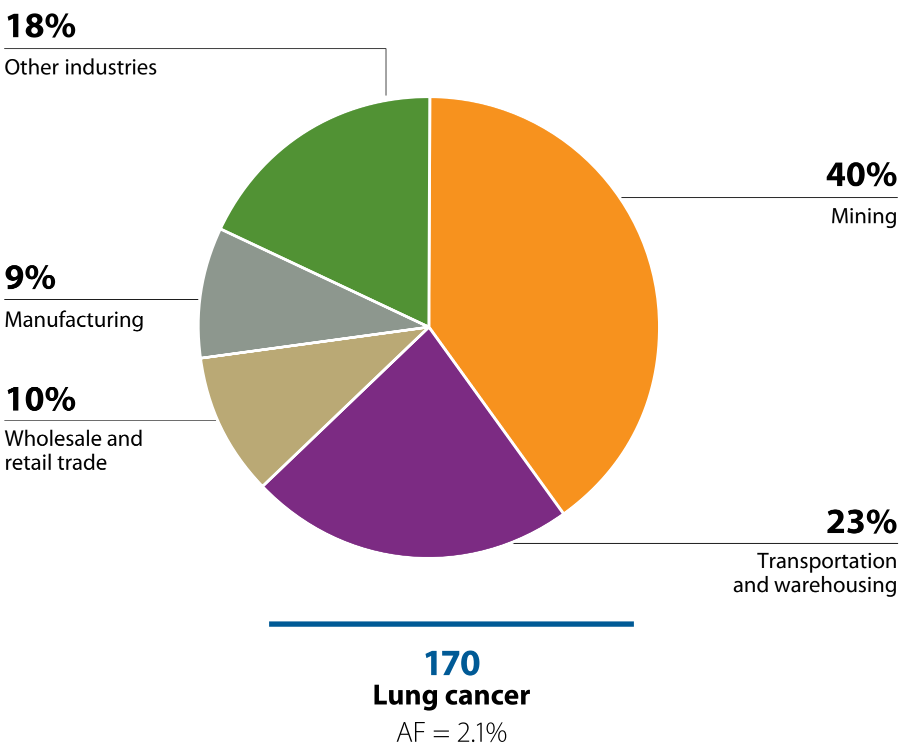
Burden

Approximately 2.1 percent of lung cancer cases (170 cases) diagnosed annually in Ontario are from occupational exposure to DEE (Figure 7). The burden of lung cancer is highest in mining, where workers are exposed to high levels of DEE, as well as in transportation and warehousing, where most exposure occurs. In Ontario, 2.3 percent of bladder cancer cases (45 cases) diagnosed annually may be from occupational exposure to DEE (Figure 8), with most cases in transportation/warehousing.

Exposure reduction strategies

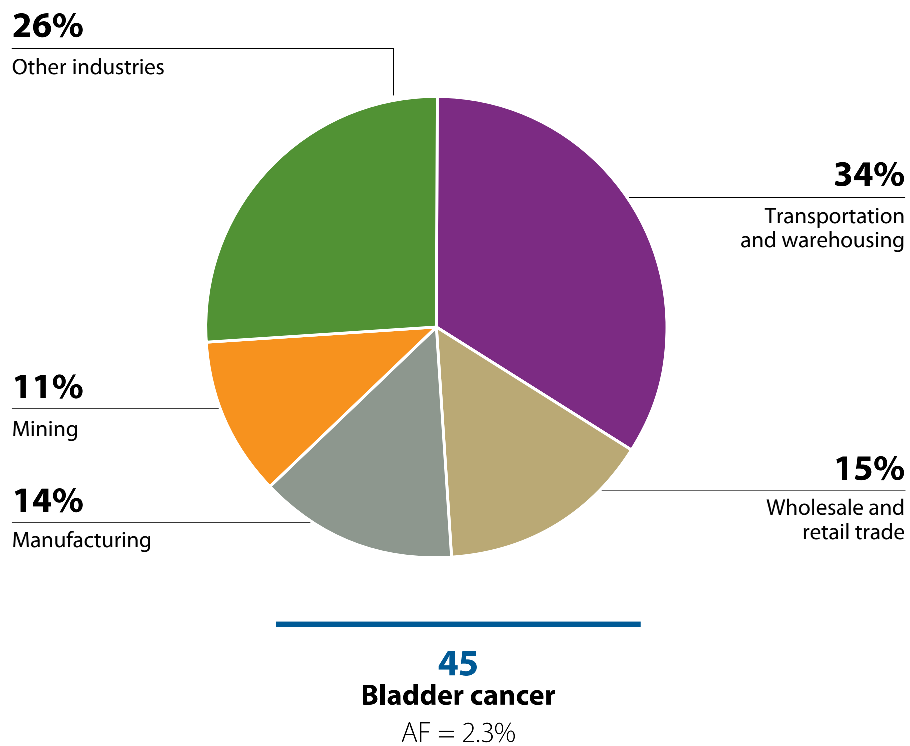
DEE is one of the most common occupational carcinogen exposures in Ontario. Efforts to prevent and control occupational exposure can also contribute to reducing environmental emissions that affect the general population, such as emissions from trucks and buses.

FIGURE 7 Industry breakdown of total lung cancers attributed to occupational diesel engine exhaust (DEE) exposure



NOTES:
AF: attributable fraction

FIGURE 8 Industry breakdown of total bladder cancers that may be attributed to occupational diesel engine exhaust (DEE) exposure



NOTES:
AF: attributable fraction

Substitution options (e.g., in truck transport) include using diesel fuel alternatives, such as natural gas, electricity and propane;[50] replacing old engines with low-emission diesel engines or rebuilding old engines and performing regular engine maintenance;[51] using reformulated diesel (i.e., diesel made with lower ratios of its hazardous constituents) or biodiesel fuel;[52] or using low sulfur diesel fuel, which has been shown to reduce sulfur dioxide and carbon-containing particulate emissions overall.[53,54]

Engineering controls that can be implemented include installing pipe exhaust extenders and using enclosed pressurized cabs equipped with HEPA filters to better isolate the worker from the exhaust;[52] implementing exhaust treatment systems (e.g., tailpipe filters, oxidation catalytic converters) to help to reduce the overall amount of harmful exhaust being released into the air;[52] and implementing technology to automatically turn off idling vehicles.[51] Indoor areas should be adequately ventilated with positive pressure ventilation to keep diesel out of the indoor work environment and/or should use exhaust extraction devices to remove diesel engine exhaust from the indoor work environment (e.g., tail pipe exhaust extraction systems used in fire halls).[50,52,55] Provincial regulation governing miners and mining mandate some engineering requirements related to controlling DEE, such as requirements for air flow.[56]

Finally, administrative controls include reducing engine idling, maintaining engines and vehicle bodies regularly; running engines outdoors; and implementing job rotation or scheduling work to minimize the number of workers near a diesel engine in operation.[52,53]

For more information on controlling exposure to DEE in mining, please refer to the United States Department of Labor's "Practical Ways to Reduce Exposure to Diesel Exhaust in Mining—A Toolbox".[53]

POLICY RECOMMENDATIONS FOR DIESEL ENGINE EXHAUST

1. **Adopt occupational exposure limits of 20 µg/m³ elemental carbon for the mining industry and 5 µg/m³ elemental carbon for other workplaces**. The Ontario Occupational Health and Safety Act (OHSA) prescribes occupational exposure limits for many of the gases and particulates found in DEE.[57] Limits for exposure to total carbon and elemental carbon, which is used as a surrogate for the carcinogenic effects of DEE, have been set for underground mines under Regulation 854 (Mines and Mining Plants).[56] However, the OHSA does not currently prescribe limits for elemental carbon. Other jurisdictions, including Finland, have implemented standards of 100 µg/m³ elemental carbon.[58] The Finnish Institute for Occupational Health recommends occupational exposure limits of 20 µg/m³ elemental carbon for the mining industry and 5 µg/m³ elemental carbon for other workplaces,[59] based on evidence of health effects and feasibility considerations. These more stringent limits would substantially reduce exposure and protect worker health given the large number of workers occupationally exposed to DEE in Ontario and growing scientific evidence demonstrating adverse health effects of DEE, even at low concentrations.[60,61]

2. **Upgrade or replace old on-road and off-road trucks and diesel engines**. Engine replacement and/or installation of engineering controls are better able to reduce overall DEE emissions than administrative controls, such as maintenance.[51] Regulations that outline allowable emissions for new models of on-road vehicles and engines were implemented under Canada's Environmental Protection Act from 2001 to 2012.[62] However, immediate significant decreases in diesel particulate matter are not expected, since older engines are not covered under these regulations and can continue to be used until they need replacement.[48] For off-road diesel engines, there are regulations that limit emissions, such as Off-Road Compression-Ignition Engine Emission Regulations (SOR/2005-32), and Marine Spark-Ignition Engine, Vessel and Off-Road Recreational Vehicle Emission Regulations.[63,64] Upgrading or replacing old off-road diesel engines is a larger challenge than on-road diesel engines. There is a precedence of mandating the transition to upgraded or newer on-road engines in other jurisdictions, such as California.[65] Upgrading old engines or vehicles may be costly, so regulations could be rolled out incrementally and accompanied with financial supports for companies affected (e.g., through financial awards or tax credits).[66]

Silica (crystalline)

Silica is a common mineral that can be found in soil, sand and rocks.[13] Crystalline silica is used for a number of purposes, including as an abrasive, insulator, and filler, but it is also a dust produced from processes in a variety of industries. It is found in a number of industries, including glass and ceramics, electronics and optical components.[28]

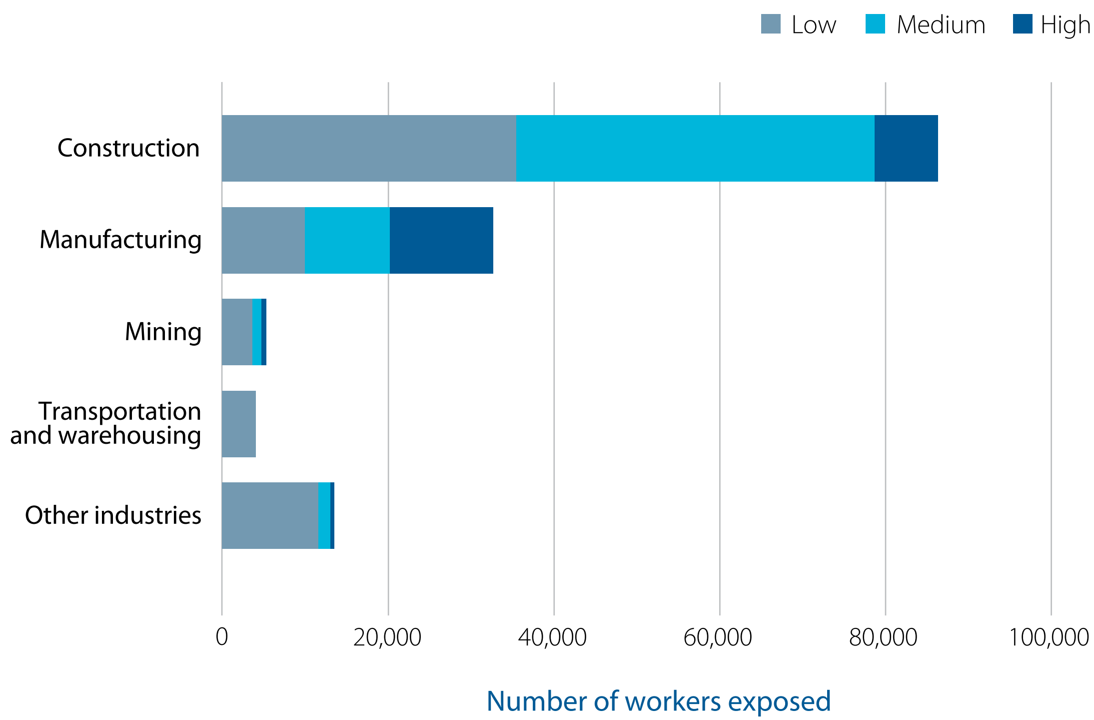
There is strong and consistent evidence that fine crystalline silica dusts can cause lung cancer if they pass deep into the lungs.[26] Silicosis, an incurable condition that causes lung tissue to scar, thicken and stiffen, is the most prevalent non-cancer health effect associated with occupational exposure to silica.[67] Other health effects include autoimmune and chronic kidney disease, and chronic obstructive pulmonary disease (a condition that makes it increasingly hard to breathe).[67,68]

Exposure

Inhalation is the only route of exposure that is linked to cancer risk. CAREX Canada estimates that 142,000 workers are occupationally exposed to silica in Ontario.[33] Of these people, approximately 45 percent are exposed to low levels of silica, 40 percent to medium levels and 15 percent to high levels.[69]

Silica exposure occurs in a vast number of industries and occupations due to its ubiquity in the environment and common materials, and use in various processes.[70] Exposure occurs during activities that release fine silica dusts, such as grinding, cutting, drilling or chipping.[71] Most exposure occurs in the construction industry at low and moderate levels among construction tradespersons and helpers, such as plumbers, plasterers and bricklayers (Figure 9). Another major group in which exposure occurs is heavy equipment operators, who are employed across multiple industry sectors. Over half of the workers with high exposures work in the manufacturing sector. Workers in the underground mining industry are particularly susceptible to exposure due to limited ventilation.

FIGURE 9 Number of workers occupationally exposed to crystalline silica by level of exposure and industry in Ontario



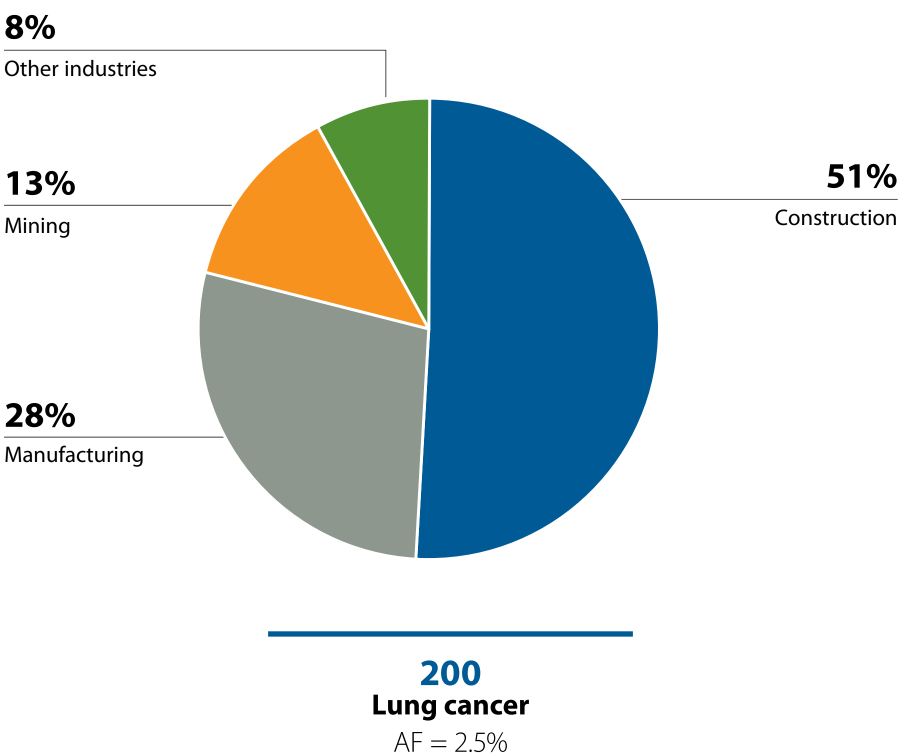
Burden

Approximately 200 lung cancers are caused by occupational silica exposure each year in Ontario, primarily in the construction, manufacturing and mining industries (Figure 10). These cancers amount to 2.5 percent of all lung cancers diagnosed annually in the province. The distribution of burden reflects the distribution of silica exposure by industry.

Exposure reduction strategies

Where possible, safer substitutes for silica-containing products should be considered to provide the highest level of protection against exposure. Alternatives are available for specific processes. For example, silica in sand-blasting operations may be replaced by garnet, alumina, cereal husks and/or high pressure water.[72] Likewise, sandstone grinding wheels can be replaced with aluminum oxide wheels, and silica

FIGURE 10 Industry breakdown of total lung cancers attributed to occupational crystalline silica exposure



NOTES:
AF: attributable fraction

bricks in furnaces can be replaced with magnesite or aluminum oxide bricks.[72] Where materials cannot be eliminated, processes that generate respirable crystalline silica (crystalline silica that can be breathed in) could be eliminated. For example, ensuring a smooth surface while pouring concrete eliminates the need to grind rough concrete.

Where substitutes or process changes are not available, engineering controls provide the next best level of protection. These controls include using local exhaust ventilation with dust collectors and filters,[68] process enclosure to prevent the release of dusts into the workplace and during the disposal of waste from vacuums and ventilation systems,[73] mechanized processes[68] and placing workers in enclosed cabs with filtration systems.[74] Furthermore, workers should be trained to select processes and tools that are least likely to generate respirable dusts.[72]

Administrative controls that can be employed include maintaining good housekeeping practices (e.g., using vacuums and wet sweeping methods instead of dry sweeping or cleaning with compressed air), maintaining dust control equipment, removing excess dust from clothing and skin, and removing work clothes at the work site.[68]

Tools have been developed to assist employers in implementing exposure controls and safe work practices. For example, the BC Construction Safety Alliance's Silica Control Tool houses data on worker exposure to respirable crystalline silica associated with different materials and work practices.[75] The Silica Control Tool allows employers to conduct risk assessments and implement the controls necessary to reduce crystalline silica levels to acceptable levels. The tool works by estimating the exposure level associated with specific tasks, tools and/or materials, as well as by providing information on how to control exposure and develop a corresponding exposure control plan.

POLICY RECOMMENDATIONS FOR SILICA

1. **Include construction project employers and workers in the Designated Substances Regulation**. At the moment, construction project employers and workers are exempt from the Designated Substances Regulation (O. Reg. 490/09).[76] As a result, construction project employers have less prescriptive requirements relating to exposure assessment and control as well as worker medical examinations, for example. In 2017, an exemption for the construction industry was removed from the Ontario OHSA (O. Reg. 833), meaning the occupational exposure limits for silica (O. Reg. 833) now apply to construction worksites. Given the large amount of silica on construction projects and the associated cancer burden, it is recommended that construction project employers and workers be legally required to comply with O. Reg. 490/09 to strengthen exposure reduction in construction workers. Including construction project employers and workers in the Designated Substances Regulation should lead to expanded monitoring and control of hazardous exposure, as well as improved medical surveillance of workers that would detect health effects earlier, when the impacts can be better mitigated.

Welding fumes, chromium (VI) compounds and nickel compounds

This section examines welding fumes, chromium (VI) compounds (also known as hexavalent chromium) and nickel compounds. These three carcinogens have been grouped together because workers may be exposed to chromium (VI) compounds and nickel compounds through welding fumes. Although exposure estimates for chromium (VI) compounds and nickel compounds include welders, burden estimates for exposures to chromium (VI) compounds and nickel compounds do not include welders because welders were already accounted for in the burden estimates for welding fumes.

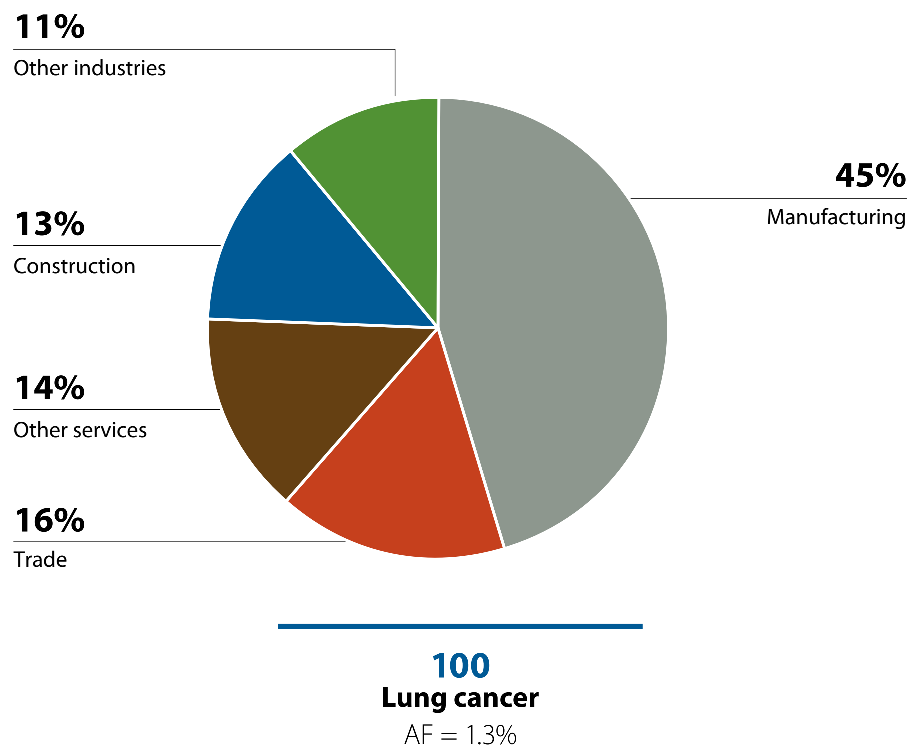
Welding fumes

Welding fumes are a mixture of metallic oxides, including iron, nickel, chromium (VI), cadmium and lead. Welding fumes are formed when metals that are heated above their melting point vaporize and then subsequently condense to form fine particles.[77] The composition of welding fumes varies based on the materials being welded.[78] Welding fumes as a group are known to cause lung cancer.[77] Other health effects include irritation of the respiratory system and skin, kidney damage and emphysema.[78]

CAREX Canada estimates of exposure for welding fumes as a whole have not been generated. The Occupational Cancer Research Centre (OCRC) estimates that 375,000 people in 2011 had worked at some point as welders and had been exposed to welding fumes from 1961 to 2001. There were 169,000 workers exposed in the year 2000 alone. Based on this past exposure, OCRC estimates that approximately 100 cases of lung cancer are diagnosed each year in Ontario due to occupational exposure to welding fumes. These cases amount to 1.3 percent of lung cancer cases diagnosed annually. By industry, most of these lung cancer cases are diagnosed in manufacturing, followed by trade, other services (e.g., metal repair shops) and construction (Figure 11).

Chromium (VI) compounds and nickel compounds are common components of welding fumes that are also known to cause lung cancer.[28] The next sections will describe exposure to and occupational cancer burden of these individual metals, followed by exposure prevention controls and policy recommendations.

FIGURE 11 Industry breakdown of total lung cancers attributed to occupational welding fume exposure



NOTES:
AF: attributable fraction

Chromium (VI) compounds

Chromium (VI) is primarily produced as a product or by-product in manufacturing processes.[28] Chromium (VI) compounds have been used as corrosion inhibitors, as well as in pigments, metal finishing, wood preservatives, catalysts and leather tanning.[28,79] There is strong evidence that it causes lung cancer, and some evidence of its potential to cause cancer of the nose and nasal sinuses.[28] Other health effects include occupational asthma, eye irritation and damage, respiratory irritation, kidney and liver damage, pulmonary congestion and swelling, and allergic skin reactions from skin contact.[80]

Exposure

Inhalation (e.g., through welding) and skin contact (from non-welding processes) are the primary routes of occupational exposure. Of the approximately 39,000 workers who are exposed to chromium (VI) in Ontario, 85 percent are exposed to low levels, 11 percent to medium levels and four percent to high levels. In particular, high-level exposures occur in metalworkers and industrial painters and coaters, and medium level exposures occur in welders (Figure 12). Occupations that work with forming or shaping of metal products have the largest number of exposed workers and include welders, machine operators and mechanics. Printing press operators are another largely exposed occupation group due to the use of chromium in pigments.

Burden

Approximately 25 lung cancers each year are caused by occupational exposure to chromium (VI) compounds in Ontario, which accounts for 0.3 percent of lung cancers diagnosed annually in the province. These results exclude the burden of cancer caused by occupational exposure to welding fumes, which have been accounted for in a separate analysis (results summarized in the welding fumes section).

The bulk of the burden lies in the manufacturing industry (Figure 13), particularly in metal coating, auto manufacturing and metal fabrication. Workers with the greatest burden of lung cancer are machine operators and assemblers who process mineral ores, metal or other substances before manufacturing (e.g., via grinding, buffing, smelting).

FIGURE 12 Number of workers occupationally exposed to chromium (VI) compounds by level of exposure and industry in Ontario

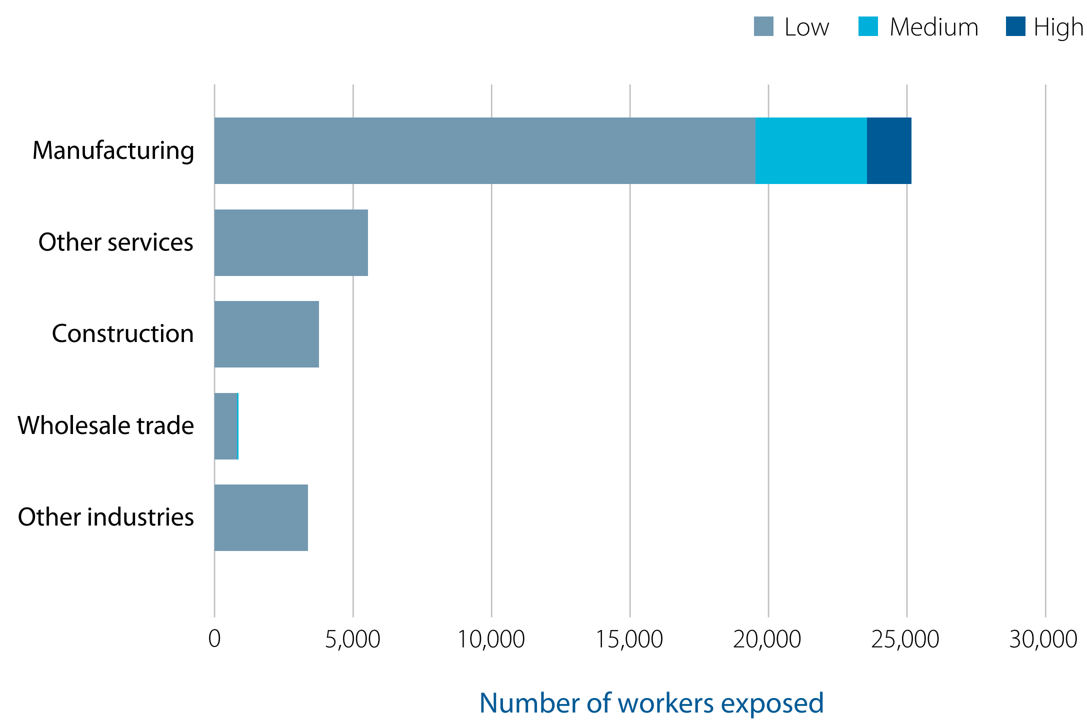
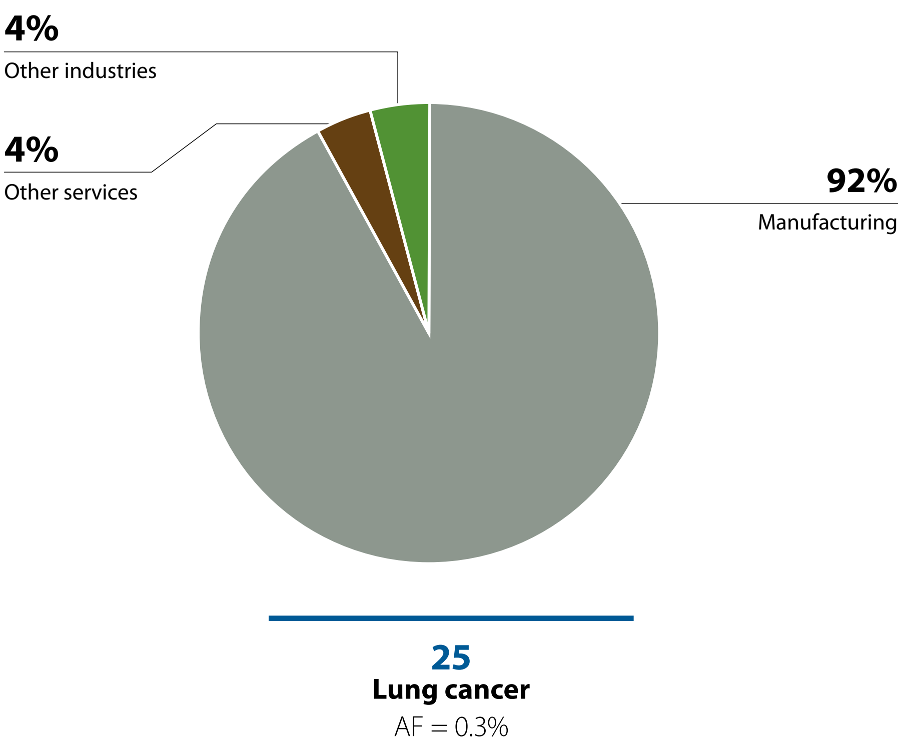


FIGURE 13 Industry breakdown of total lung cancers attributed to occupational exposure to chromium (VI) compounds



NOTES:
AF: attributable fraction

Nickel compounds

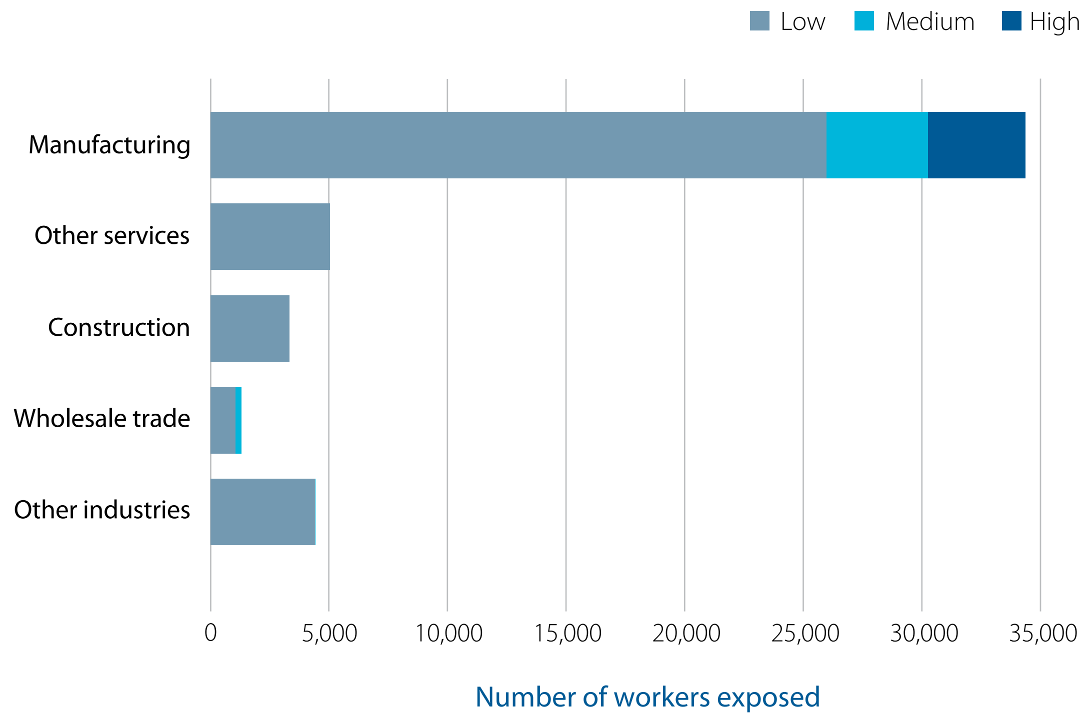
Nickel is a naturally occurring metal commonly used to form alloys, such as stainless steel, and in applications such as batteries, electroplating, ceramics and chemical reactions.[28] There is strong evidence that nickel and its compounds cause lung and sinonasal cancers.[28] Nickel is also associated with chronic bronchitis, decreased lung function, and allergic skin reactions.[81]

Exposure

Inhalation (e.g., through welding) and skin contact (from non-welding processes) are the primary routes of occupational exposure. Of the approximately 48,000 workers who are exposed to nickel in Ontario, 82 percent are exposed to low levels, nine percent to medium levels and nine percent to high levels (Figure 14).[33] Exposure patterns are similar to chromium (VI) compounds; occupations that work with forming or shaping metal products have the largest number of workers exposed. Welders are the single largest exposed occupation group and they are exposed at high, medium and low levels. High and medium level exposures occur in metalworkers and machine tool operators, dental technologists and metal plating operators.

> Occupations that work with forming or shaping metal products have the largest number of workers exposed to nickel. Welders are the single largest exposed occupational group.

FIGURE 14 Number of workers occupationally exposed to nickel by level of exposure and industry in Ontario



Burden

Approximately 80 lung cancers each year are caused by nickel exposure in Ontario (Figure 15), which accounts for one percent of all lung cancers diagnosed annually in the province. These results exclude the burden of cancer caused by occupational exposure to welding fumes, which have been accounted for in a separate analysis (results summarized in the welding fumes section).

The burden of cancer due to occupational nickel exposure follows the same pattern as chromium (VI), with the greatest number of cancers occurring in the manufacturing industry. Workers with the greatest burden of lung cancer are machine operators and assemblers who process mineral ores, metal or other substances before manufacturing (e.g., via grinding, buffing, smelting).

Exposure reduction strategies for welding fumes, chromium (VI) compounds, and nickel compounds

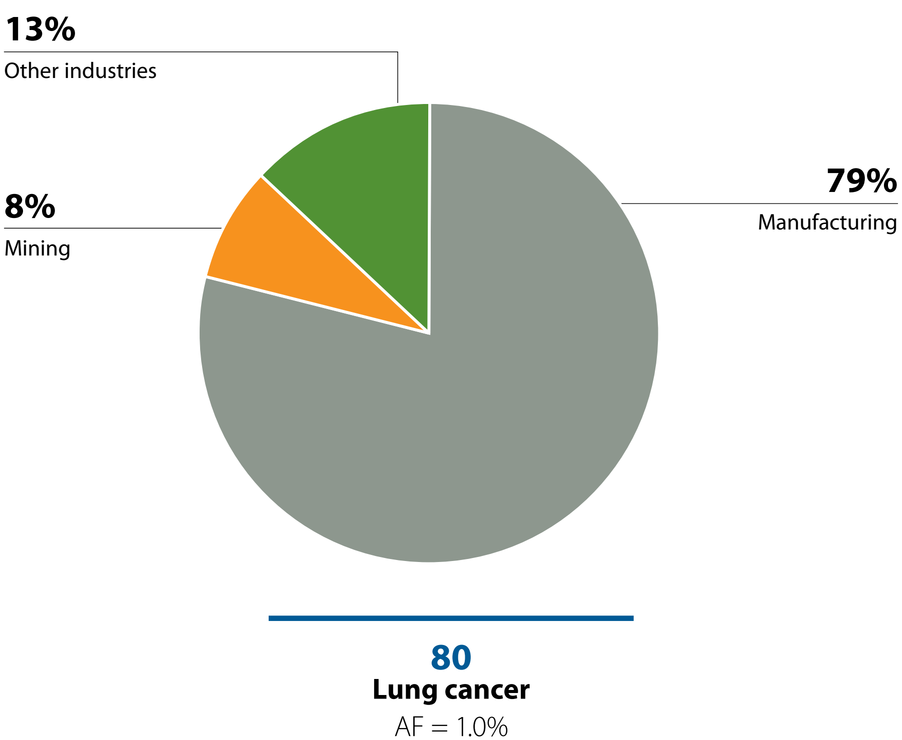
There is some overlap in the control methods used for welding fumes, chromium (VI) compounds and nickel compounds. Ventilation and isolation of workers are common engineering controls used to reduce worker exposure to all three agents. Closed systems with properly maintained negative pressure relative to the surroundings may be used to isolate workers.[82] Local exhaust ventilation is generally more effective than general exhaust and should be used when there are specific point sources. General ventilation may be employed when emission sources are mobile.[82]

Administrative controls common to the three agents include rotating employees through areas of higher production (which includes training employees to perform different tasks) and maintaining engineering controls.[83,84] Other administrative controls include using wet methods or HEPA filter vacuums to clean surfaces, providing and promoting the use of change rooms and washing facilities, ensuring the proper classification and disposal of waste materials, and restricting smoking, eating and drinking in work areas.[83-85] Operations that lead to the highest levels of exposure may be scheduled at times when the fewest employees are working.[86]

To reduce exposure to welding fumes overall, choosing a different rod or type of welding can be substituted for those that generate lower amounts of gases and fumes, although more rigorous approaches may be needed.[87] For more information on controlling exposure to welding fumes, refer to the Government of Canada's *Guide to health hazards and hazard control measures with respect to welding and allied processes.*[88]

For chromium (VI) and nickel compounds, specific technologies can be implemented to reduce the overall generation of dusts or fumes.[89] These technologies include chemicals to reduce the surface tension of the solution, specific tools that minimize agitation of solutions, and physical barriers to contain mists during plating.[90] Other technologies can be implemented to ensure that optimal conditions for exhaust ventilation are maintained. For

FIGURE 15 Industry breakdown of total lung cancers attributed to occupational exposure to nickel compounds



NOTES:
AF: attributable fraction

example, in electroplating processes for chromium (VI) compounds and nickel compounds, level indicators, alarms or automatic dosing can be used to ensure that sufficient levels of solutions are maintained for the proper functioning of the local exhaust ventilation system.[89]

Finally, the American Conference of Governmental Industrial Hygienists has an evidence-based biological exposure limit for chromium (VI) compounds and is currently considering a biological exposure limit for nickel compounds.[91] Workplaces can consider implementing biological monitoring programs for workers exposed to chromium (VI) compounds and nickel compounds. Biological monitoring is the ongoing identification and quantification of total exposure from all routes (e.g., inhalation and skin) among individual workers. It can help reduce exposure by identifying workers who are exposed above levels determined for occupational settings and by monitoring changes in exposure over time, which has been done for workers exposed to chromium (VI) compounds and nickel compounds in the electroplating industry.[92]

POLICY RECOMMENDATIONS FOR WELDING FUMES

1. **Introduce ventilation requirements in Ontario Occupational Health and Safety (OHS) legislation for welding activities**. Exposure to all welding fumes should be controlled. Welding fumes are now recognized as definite human carcinogens by the International Agency for Research on Cancer[77] and general guidelines have been published for welding ventilation by the Standards Council of Canada.[93] However, there are no mandatory standards on the implementation and use of general and local exhaust systems during welding processes. Ventilation regulations have been implemented in state and federal Occupational Safety and Health Act (OSHA) standards in the United States. For example, local exhaust is required if lead, cadmium or beryllium are welded on, and a minimum air flow is specified.[94,95] It is recommended that ventilation requirements be introduced into Ontario OHS legislation for welding activities (e.g., as a regulation within the OHSA).

Environmental tobacco smoke (ETS) at work

Environmental tobacco smoke (ETS), also known as second-hand smoke, is a mixture of solid particles and gases released from burning cigarettes and exhaled cigarette smoke.[96] This mixture contains numerous carcinogenic substances, including benzene, formaldehyde, benzo(*a*)pyrene and acrolein.[96,97] ETS is a well-established carcinogen that causes lung cancer.[96] A large study that examined the effects of ETS exposure in workplaces found that the risk of lung cancer increased by 24 percent among non-smoking workers who were exposed to ETS. Among workers whowere classified as highly exposed to ETS, the risk of lung cancer increased by 100 percent.[98] Other health effects associated with ETS exposure include heart disease, exacerbation of asthmatic and allergic reactions, and premature death.[97,99,100]

Exposure

The 2006 Ontario Smoke-Free Act prohibits smoking in almost all enclosed workplaces,[101] including the inside of any place, building, structure, restaurant, bar patio or vehicle that is covered by a roof. Exceptions have been made for residential care and psychiatric facilities, facilities for veterans, and hotels, motels or inns where controlled smoking areas may be permitted for residents of those facilities.[101] Furthermore, smoking within nine metres of entrances and exits of hospitals, and healthcare and psychiatric facilities is prohibited. While the legislation does not restrict smoking in outdoor workplaces,[101] some municipalities have bylaws prohibiting smoking on some public grounds, such as municipal parks.

Despite a legislated smoking ban in indoor workplaces, data from the Canadian Tobacco Use Monitoring Survey (CTUMS) indicates that exposure to ETS in workplaces, including indoor workplaces, still occurs.[102] In 2012, 21 percent of Ontarians reported being exposed to ETS in their workplaces. The proportion of workers exposed to ETS varied by occupation, ranging from 9 percent in art, culture, recreation and sport occupations, to 55 percent in processing, manufacturing and utilities, and 49 percent in trades, transport and equipment operators. Approximately 28 percent of workers reported being exposed to ETS even if they specified that their workplaces were smoke-free, and three percent of workers reported not having any smoking restrictions in their workplaces. Workers who were exposed to ETS and who reported a lack of workplace restrictions mostly included trades persons, transport and equipment operators, as well as workers in natural and applied sciences, art, culture, recreation and sport, among others.

Burden

As a result of occupational exposure to ETS in the past, particularly before the year 1990, an estimated 50 lung, 10 pharynx and five larynx cancers are diagnosed each year in non-smokers in Ontario. In non-smokers, these cancers account for 8.5 percent of lung, 7.1 percent of pharynx and 7.6 percent of larynx cancers diagnosed annually. The attributable fraction of lung cancers due to occupational exposure to ETS is similar for non-smoking men and women (0.7 percent and 0.6 percent, respectively). Most lung cancers occur in manufacturing, wholesale and retail trade, healthcare, finance/insurance and government services. Burden estimates are focused on non-smokers due to difficulties in separating the impact of personal smoking and ETS exposure on cancer risk.

POLICY RECOMMENDATIONS FOR ETS

1. **Build on successes by strengthening enforcement of smoke-free workplace legislation**. Significant progress has been made over past decades to reduce exposure to ETS in workplaces through legislation, increased awareness of the health effects associated with ETS exposure and population-wide changes in smoking behavior.[103] Current occupational exposure to ETS is substantially less than in the past, and in the future, the burden of associated cancers is expected to be lower than the present cancer burden. However, according to 2012 CTUMS data, approximately 28 percent of workers in Ontario report occupational exposure to ETS, and some report a lack of smoke-free policies in their workplaces, despite current legislation (e.g., sales and service workers, trades and transportation workers).[102] The 2006 United States Surgeon General's report concluded that any exposure carries some risks to respiratory health.[100] Smoking bans have been evaluated as the most effective measure for reducing ETS exposure.[104] Further efforts must be jointly taken by health units and the Ontario Ministry of Health and Long-Term Care to enforce smoke-free legislation in workplaces. In addition, these two groups can work together to promote smoking cessation programs to workers in all sectors, such as by providing support at public health units for workplace interventions.

Radon

Radon is a radioactive gas that is released when naturally occurring uranium and thorium in soil decay.[105] Radon can enter indoor and underground spaces through openings and cracks in buildings,[106] and can accumulate to high concentrations in confined areas or where ventilation is poor.[107] Because radon is denser than air, levels tend to be highest in basements and underground areas.[107] Radon is a known cause of lung cancer.[15,108] Smokers who are exposed to radon have a greatly increased risk of lung cancer.[15]

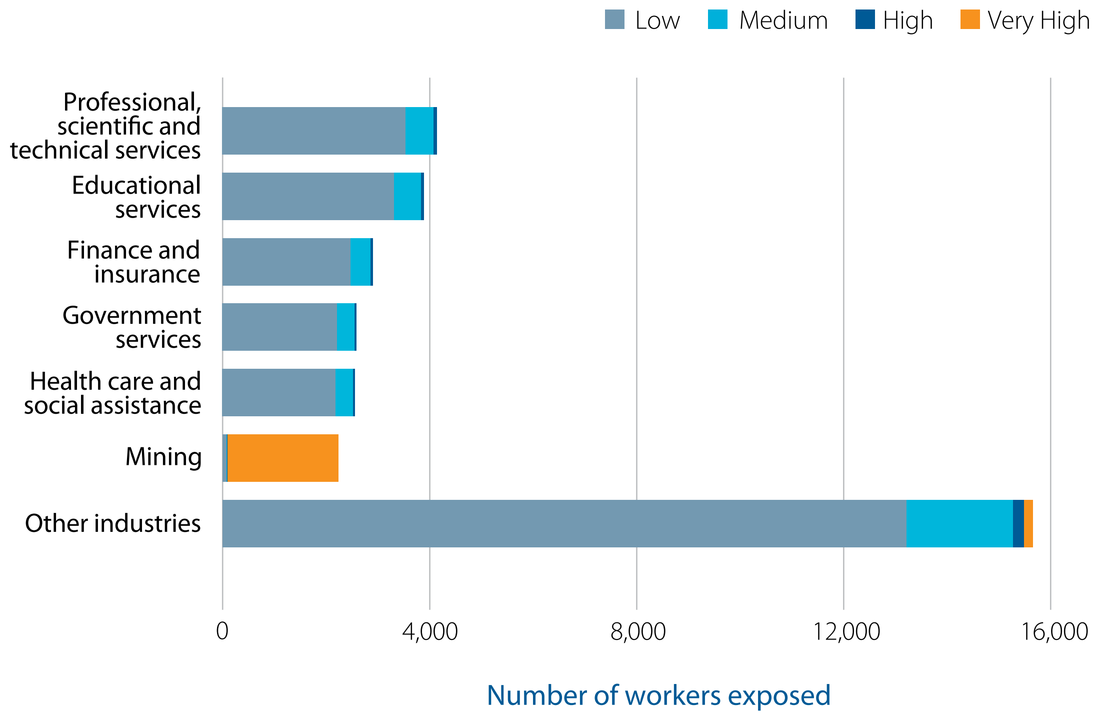
Exposure

Approximately 34,000 workers are occupationally exposed to radon in Ontario. Of these people, 80 percent are exposed to low levels (200 to 400 Bq/m³), 12 percent to moderate levels (400 to 800 Bq/m³) and one percent to high levels (greater than 800 Bq/m³). Seven percent of workers in underground occupations are estimated to be exposed to very high levels, where radon concentrations tend to be higher due to greater contact with soil and poor ventilation.[31] The workers exposed to very high radon levels include miners, mine service workers, industrial mechanics and subway operators. However, most radon-exposed workers are primarily found in indoor, above ground workplaces, where radon may enter through gaps in building foundations (Figure 16). The level of exposure among these workers varies based on background levels of radon in the soil and building characteristics (e.g., ventilation, age).

Burden

Approximately 60 lung cancers each year are caused by occupational radon exposure in Ontario, which accounts for 0.34 percent of all lung cancers diagnosed annually in the province. The burden of occupational cancer due to radon exposure is highest in mining, the industry with the highest historical levels of exposure, and in manufacturing, and finance and insurance. The remaining industries with excess cancers due to occupational radon exposure are summarized in Figure 17. Burden of cancer in non-mining industries is associated with low to medium levels of

FIGURE 16 Number of workers occupationally exposed to radon by level of exposure and industry in Ontario



The burden of occupational cancer due to radon exposure is highest in mining, the industry with the highest historical levels of exposure, and in manufacturing, and finance and insurance.

exposure and greater numbers of workers employed compared to mining. Other affected industries include professional scientific and technical services, and educational services.

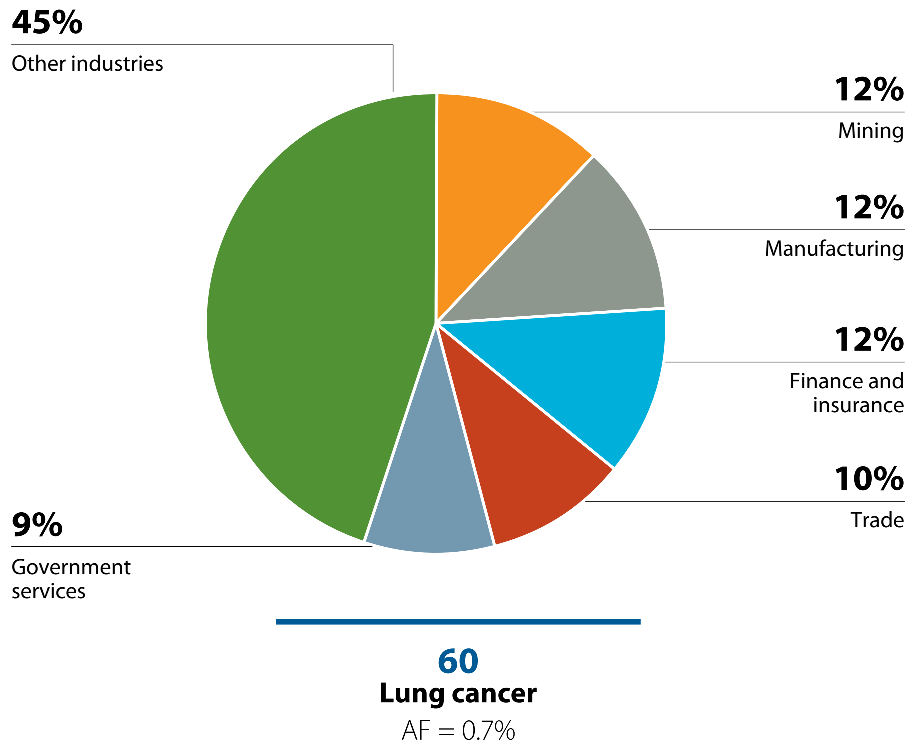
Exposure reduction strategies

Radon is colourless and odourless, and levels vary considerably based on a number of factors (e.g., geographical location, building age, foundation, ventilation). For these reasons, it is difficult to predict whether radon is present in the workplace. As a result, monitoring occupational radon levels and using personal monitors when workplace levels are high are important for exposure reduction. Long-term measurements should be conducted to account for seasonal variation in radon concentration.

The Federal Provincial Territorial Radiation Protection Committee has developed Naturally Occurring Radioactive Materials (NORM) Guidelines. These guidelines are applicable to workers engaging in NORM activities (e.g., mining, water treatment facilities, tunnelling and underground work), as well as any workplace where workers are incidentally exposed (i.e., as a result of the workplace being indoors).[109] According to the NORM Guidelines, radon levels should be measured in all workplaces. Because background levels cannot be distinguished from radon generated in the workplace, the total radon exposure needs to be measured in any workplace. NORM emphasizes reducing radon levels to less than 200 Bq/m^3 in occupied areas. However, the World Health Organization recommends lowering levels in indoor residential spaces to less than an annual average concentration of 100 Bq/m^3 based on evidence of elevated lung cancer risks at very low levels of exposure.[110] Cancer Care Ontario also recommends levels of less than 100 Bq/m^3 for homes in Ontario.[111]

For background levels lower than 800 Bq/m^3, NORM guidelines recommend changes in workplace practices and controls to limit access to high radon areas, in addition to periodic workplace monitoring.[107] Where levels exceed 800 Bq/m^3, NORM guidelines recommend that workers be informed of their status as radiation-exposed workers, the associated health risks, applicable occupational exposure limits and measured workplace levels. An exposure reduction program, engineering and administrative controls, personal protective equipment and periodic worksite assessments are also recommended.[107] All uranium mine and mill workers are currently monitored for their annual radon exposure through the National Dose Registry. In cases where radon is derived from NORM, such as materials processing, raw materials that are low in NORM materials can be selected.[112]

FIGURE 17 Industry breakdown of total lung cancers attributed to occupational radon exposure



NOTES:
AF: attributable fraction

Possible remediation strategies in above-ground indoor workplaces include sub-floor depressurization for foundations and basements in contact with soil to maintain a negative pressure gradient, sub-floor ventilation for buildings where the ground floor is not in contact with soil, floor sealing and membranes to reduce cracks that radon may enter through, increased ventilation and the removal of subsoil.[113]

POLICY RECOMMENDATIONS FOR RADON

1. **Develop explicit and specific regulation of radon in indoor air in Ontario occupational health and safety regulations**. Currently, there is no specific regulation of radon for all workers in Ontario's occupational health and safety laws. The NORM guidelines are considered the industry standard for NORM protection in workplaces. There is also the general duty clause of the Ontario OHSA pertaining to physical agents (i.e., sources of energy that may cause injury or disease, such as noise, vibration, radiation). Regulation 854 (Mines and Mining Plants) addresses workplaces responsibilities with respect to radon progeny in underground mines, while Regulation 332/12 (Building Code Act, 1992) covers workplace responsibilities for radon 222 and radon progeny concentration levels within specific geographic locations. However, there are radon-exposed workers in other industries and geographical areas who are not covered by these regulations. Radon-specific regulations in Ontario could span all aspects of employer and employee responsibilities, including, but not limited to, the above recommended occupational exposure limit of 100 Bq/m^3, regular work site inspection, training on exposure measurement and mitigation, and public and worker notification.

2. **Implement 100 Bq/m^3 of radon in air as the exposure standard for remediation in all underground and above-ground work areas**.[111] This recommendation aligns with the limit recommended for the protection of the public in the *Environmental Burden of Cancer in Ontario* report.[114] Radon may infiltrate any work area. The NORM guidelines for radon management could be incorporated into legislation, which should also be amended to the more rigorous annual average limit of 100 Bq/m^3 as recommended by the World Health Organization.[115] Workers may be exposed to radon both at home and at work, making it important to apply this stringent annual average limit at work to reduce potentially cumulative risks of lung cancer. Legislative language should be added about conducting long-term radon tests, requiring remediation when levels exceed 100 Bq/m^3 and clarifying when a government inspection should be initiated.[115]

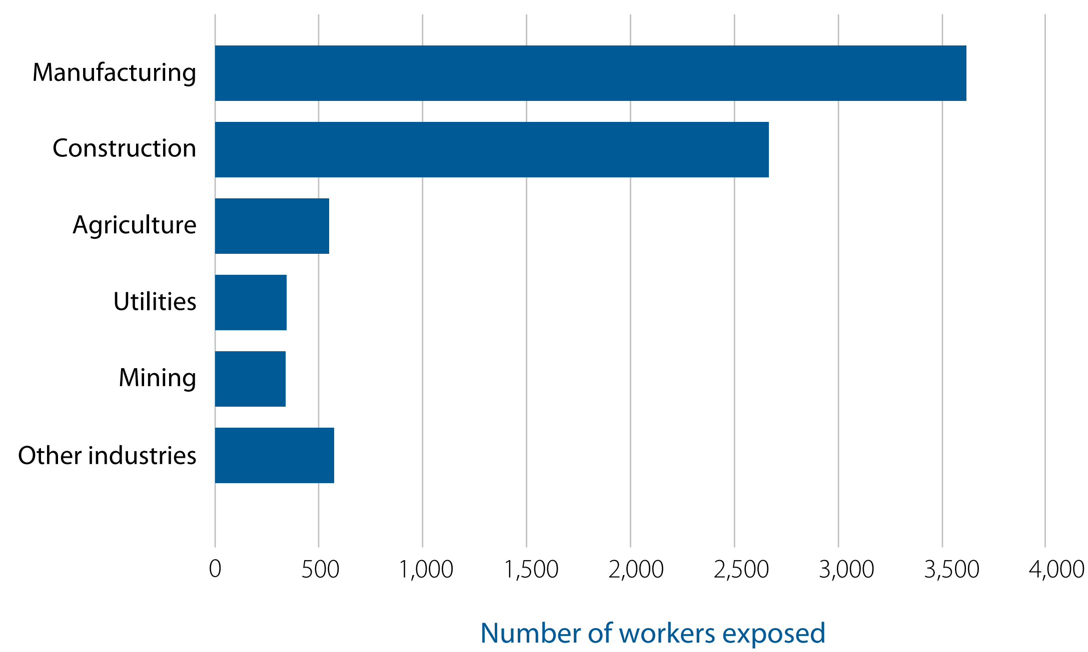
Arsenic

Arsenic is a metalloid used in wood preservatives and metal, mining, glass-making and semiconductor industries.[28] Examples of applications that use arsenic include batteries, alloys, pigments, high-power microwaves, computer chips and antifouling agents in paints.[28] There is strong evidence that arsenic causes lung cancer from inhalation, as well as skin cancer primarily from food sources and bladder cancer primarily from water sources.[28] Other health effects associated with long-term exposure to arsenic include nerve damage and skin effects, such as the formation of corns or warts.[116] Short-term exposure may lead to respiratory, kidney and cardiovascular damage.[116]

Exposure

Inhalation and skin contact are the primary routes of exposure to arsenic in workplaces. Approximately 8,000 workers are exposed to arsenic in Ontario.[33] Most exposure occurs in the manufacturing and construction industries (Figure 18) through contact with wood that has been treated with arsenic (e.g., in carpenters and construction trades labourers). Exposure occurs in a wide variety of other occupations, including farmers and machine operators.

FIGURE 18 Number of workers occupationally exposed to arsenic by industry in Ontario



Burden

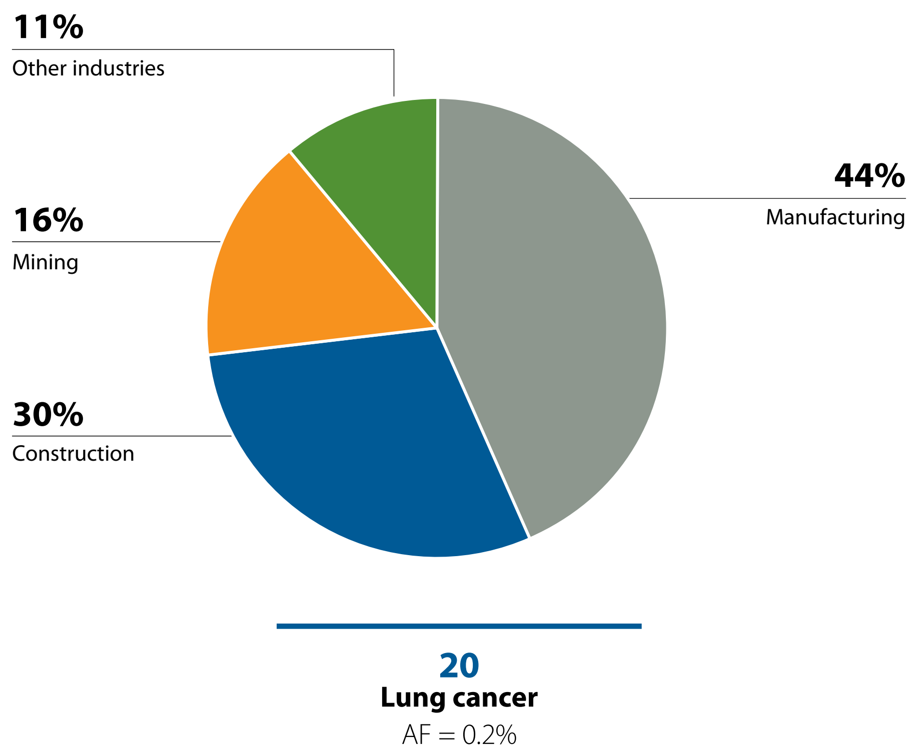
Approximately 20 lung cancers each year in Ontario are due to occupational arsenic exposure (Figure 19), which accounts for 0.2 percent of all lung cancers diagnosed annually in the province. These burden results mirror the exposure patterns, with most of the burden occurring in workers in the manufacturing and construction industries. Occupations with the greatest burden are trades helpers, construction workers and machine operators. The number of arsenic-related skin and bladder cancers was not calculated because the routes of exposure for these cancers are not occupational.

Exposure reduction strategies

In construction and manufacturing, elimination of the use of arsenic-treated wood could lead to substantial reductions in exposure. Standard engineering and administrative controls may be implemented to reduce occupational exposure to arsenic in other industries.[117] For example, equipment and ventilation should be properly installed, operated and maintained to ensure that exposure is well controlled. Change rooms, showers and laundering facilities at the workplace are also recommended. Protective clothing should be laundered at least weekly. Workspaces should be regularly cleaned using vacuums with HEPA filters or by wet methods. In certain occupations, regular air monitoring and health assessments may be a part of the workplace occupational health and safety strategy.[117] Finally, workers should be educated in the health effects associated with arsenic exposure, and trained on how to properly use equipment and control measures. Overarching policy recommendations, presented later in this report, can be applied to arsenic.

> In construction and manufacturing, elimination of the use of arsenic-treated wood could lead to substantial reductions in exposure.

FIGURE 19 Industry breakdown of total lung cancers attributed to occupational arsenic exposure



NOTES:
AF: attributable fraction

Benzene

Benzene is a volatile organic compound primarily used in the manufacture of chemicals, including plastics, dyes, detergents, drugs and pesticides.[118] It also occurs naturally in petroleum products and can be found in crude oil and gasoline.[118] Benzene has been classified as a known carcinogen based on evidence that it causes acute myeloid leukemia (AML).[118] There is limited evidence that benzene causes acute lymphocytic leukemia (ALL), chronic lymphocytic leukemia (CLL) and multiple myeloma.[118] Benzene exposure can also cause bone marrow damage, which can lead to changes in blood production and the number of circulating blood cells, as well as a suppressed immune system.[119,120]

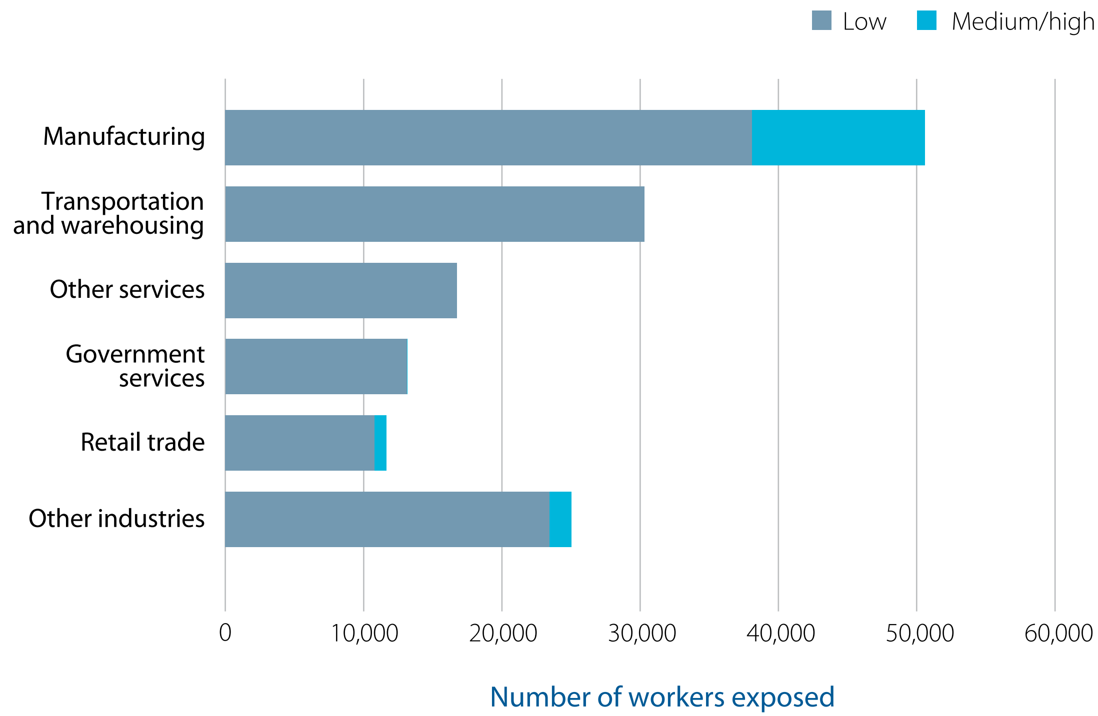
Exposure

CAREX Canada estimates that approximately 147,000 workers in Ontario are occupationally exposed to benzene.[33] Of these workers, 90 percent are exposed to low levels and 10 percent are exposed to medium or high levels. Occupations exposed to medium or high levels of benzene in the manufacturing industry include mineral and metal processing workers, as well as printing machine operators because benzene can be found in inks. Although overall exposure levels are lower, large numbers of Ontario motor vehicle and transit drivers and mechanics are exposed to benzene through motor vehicle exhaust (Figure 20).

Burden

Approximately 10 leukemia cases (all AML, ALL and CLL cases combined) and less than five multiple myeloma cases each year are due to occupational exposure to benzene in Ontario. These cancers account for 0.5 percent of leukemia and 0.2 percent of multiple myeloma cases diagnosed annually. Most leukemia cases from occupational exposure to benzene occur in manufacturing (38 percent), followed by transportation/warehousing (17 percent), trade (11 percent), other services (11 percent) and government services (11 percent).

FIGURE 20 Number of workers occupationally exposed to benzene by level of exposure and industry in Ontario



Exposure reduction strategies

A number of substitution options are available for benzene. For example, alcohol and cyclohexane can be used as solvents instead of benzene.[121] The toxicity of substitutes should be considered before implementation. Engineering controls include using local, non-sparking ventilation hoods and process enclosure through, for example, fume hoods and glove boxes.[121,122] Furthermore, automated systems can be used to dispense benzene. Back-up controls, such as double mechanical pump seals, can be introduced to control exposure in case of equipment failure.[121,122] Administrative controls include training programs to educate workers on potential exposures and appropriate workplace practices, as well as monitoring programs to better assess workplace exposure.[121] Hygiene practices, such as not eating, drinking or smoking in areas where benzene is used or stored, should be followed. Other administrative controls include establishing protocols for cleaning up spills, and storage and product labelling.[121] Overarching policy recommendations, presented later in this report, can be applied to benzene.

Results for carcinogens of secondary interest

Polycyclic aromatic hydrocarbons (PAHs)

PAHs are made up of a large class of over 100 organic compounds that form during the incomplete combustion or "pyrolysis" of organic material such as coal, oil, gas, wood, garbage and charbroiled meat.[13, 123] PAHs tend to occur as complex mixtures and are therefore considered to be a single group of substances.[13] Benzo(*a*)pyrene is a commonly found PAH that is often used as a marker for PAHs in general.

In 2010, the International Agency for Research on Cancer (IARC) evaluated the carcinogenicity of 63 PAHs and eight occupational exposures associated with specific industries that have increased PAH concentrations.[123] There was strong animal and mechanistic evidence that benzo(*a*)pyrene can cause lung cancer in humans, but limited or insufficient evidence for the carcinogenicity of the other compounds.[124] Occupational exposures to PAHs during certain work processes are associated with lung and non-melanoma skin cancer.[123] There was weaker evidence for the association between PAHs and bladder cancer.[123,125] Other health effects associated with exposure to PAHs include decreased immune function, kidney and liver damage, asthma-like symptoms, cataracts and degradation of red blood cells.[126]

Approximately 134,000 workers in Ontario are exposed to PAHs in a variety of occupations.[31] The prevalence of exposure is highest in chefs, cooks and mechanics. Other occupations with relatively large numbers of exposed workers are firefighters, service station attendants, machinists and welders, machine operators and cashiers.

Approximately 134,000 workers in Ontario are exposed to PAHs in a variety of occupations.[31] The prevalence of exposure is highest in chefs, cooks and mechanics.

An estimated 60 lung, 15 skin and 30 bladder cancer cases are due to occupational exposure to PAHs each year in Ontario. These cancers account for 0.8 percent of lung, 0.1 percent of skin and 1.3 percent of bladder cancer cases diagnosed annually. The occupations with the highest number of PAH-associated lung and bladder cancers are machine operators and assemblers in manufacturing. Trades helpers, construction and transportation labourers account for the greatest number of associated skin cancers.

There are a number of engineering and administrative measures that can be used to control occupational exposure to PAHs. Engineering controls include implementing local exhaust ventilation systems,[127] implementing systems to capture and remove PAHs from the air, and ensuring that workers are enclosed and separated from contaminated air.[128] Examples of administrative controls are maintaining ventilation and other control systems, employing wet cleaning methods where appropriate, limiting exposure duration by adjusting workers' schedules and limiting overtime hours.[128]

Artificial ultraviolet radiation (UVR)

Major sources of artificial UV in occupational settings include welding arcs, medical and dental treatments and practices, curing lamps and disinfection processes.[15,16] Occupational exposure to artificial UVR causes ocular (eye) melanoma.[15] Of the approximately 48,000 workers who are exposed to artificial UVR in Ontario, 58 percent are exposed to high levels, 27 percent to medium levels and 15 percent to low levels.[33] Occupations with the highest numbers of exposed workers are welders (28,000 exposed to high levels) and medical technologists and technicians (5,800 exposed to medium levels).

Burden estimates were calculated only for ocular melanoma in welders because it represents the only occupational exposure and cancer outcome assessed by IARC. It is estimated that approximately five ocular melanoma cases are due to occupational artificial UVR exposure annually in Ontario, which account for five percent of ocular melanoma cases diagnosed each year. Exposure control measures include containing artificial UVR with opaque materials, equipping high-power UV sources with systems to shut off the power source when the protective enclosure is open, increasing distance between workers and the source, and wearing UV-blocking safety eyewear.[129]

Wood dust

Wood dust is produced as a by-product of wood working.[13] Wood dust causes sinonasal and nasopharyngeal cancer.[28] Other health issues associated with exposure to wood dust include respiratory effects (e.g., asthma, bronchitis and chronic lung function impairment),[130,131] dermatitis[132] and the development of allergic symptoms.[132,133]

The primary route of exposure to wood dust is inhalation.[31] CAREX Canada estimates that 92,000 workers in Ontario are exposed to wood dust, approximately 25 percent of whom are exposed to low levels, 50 percent to medium levels and 25 percent to high levels.[33] Approximately half of exposed workers are employed in the home construction industry. Other industries where workers are exposed to wood dust include forestry (e.g., logging), wood product and furniture manufacturing (e.g., sawmills) and educational services (e.g., wood working shops in elementary and secondary schools). High levels of exposure occur in the two latter industries.

Less than five sinonasal cancers and less than five nasopharyngeal cancers are attributable to occupational exposure to wood dust annually in Ontario, which account for 3.2 percent of sinonasal and nasopharyngeal cancer cases diagnosed each year. The risk of sinonasal and nasopharyngeal cancers due to occupational wood dust exposure is highest in the construction industry, followed by manufacturing. Other industries with potentially higher risks are educational services, trade and forestry.

Local exhaust ventilation with filtration systems is the primary engineering control used to limit exposure to wood dust.[132] Ventilation systems can be modified to optimize dust capture (e.g., via hood extensions, auxiliary ventilation systems, computerized systems).[134-136] Administrative controls include using work processes that minimize dust production (e.g., using planes rather than sanders), regularly cleaning and maintaining dust collection equipment and ventilation systems, and using wet cleaning methods or vacuums equipped with high-efficiency particulate air (HEPA) filters.[137]

Formaldehyde

Formaldehyde is a chemical primarily used in the production of industrial resins and other chemicals, such as acetylenic chemicals and methylene diphenyl diisocyanate.[13,138] It may be used as a pesticide, antimicrobial agent, tissue preservative, and preservative in food and cosmetic products.[13] Formaldehyde has been classified as a known carcinogen that causes nasopharyngeal cancer and leukemia.[118] There is also some evidence that formaldehyde may cause sinonasal cancer.[118] Other health effects of skin and inhalation exposures include skin lesions, contact dermatitis, and respiratory and eye irritation.[139]

CAREX Canada estimates that approximately 63,000 workers are exposed to formaldehyde in Ontario.[33] Of these workers, 71 percent are exposed to low levels, 27 percent to medium levels and two percent to high levels. Over 60 percent of all formaldehyde-exposed workers are employed in the manufacturing industry as assemblers and machine operators.

Less than five leukemia cases, less than five nasopharyngeal cancer cases and possibly less than five sinonasal cancer cases are from workplace exposure to formaldehyde each year in Ontario. These cancers account for 0.1 percent of leukemia 0.8 percent of nasopharyngeal cancer and 0.2 percent of sinonasal cancer cases diagnosed in Ontario annually. Risks of leukemia, nasopharyngeal cancer and sinonasal cancer due to occupational exposure to formaldehyde are highest in the manufacturing industry, followed by healthcare.

Ventilation is the main engineering control used to limit formaldehyde exposure.[140] Local exhaust ventilation and process enclosure may be necessary where general ventilation is not adequate. Non-sparking ventilation systems and explosion-proof equipment should be used to prevent fires. Eyewash and safety showers should be provided if there is a chance of splashing.[140] Administrative controls include training workers and labelling mixtures or solutions that contain formaldehyde.[141] Impermeable clothing and goggles should be used to prevent skin exposure.[141]

Carcinogens of special interest

This section summarizes current knowledge about potential carcinogens that are relevant in Ontario, many of which are emerging issues in occupational cancer research.

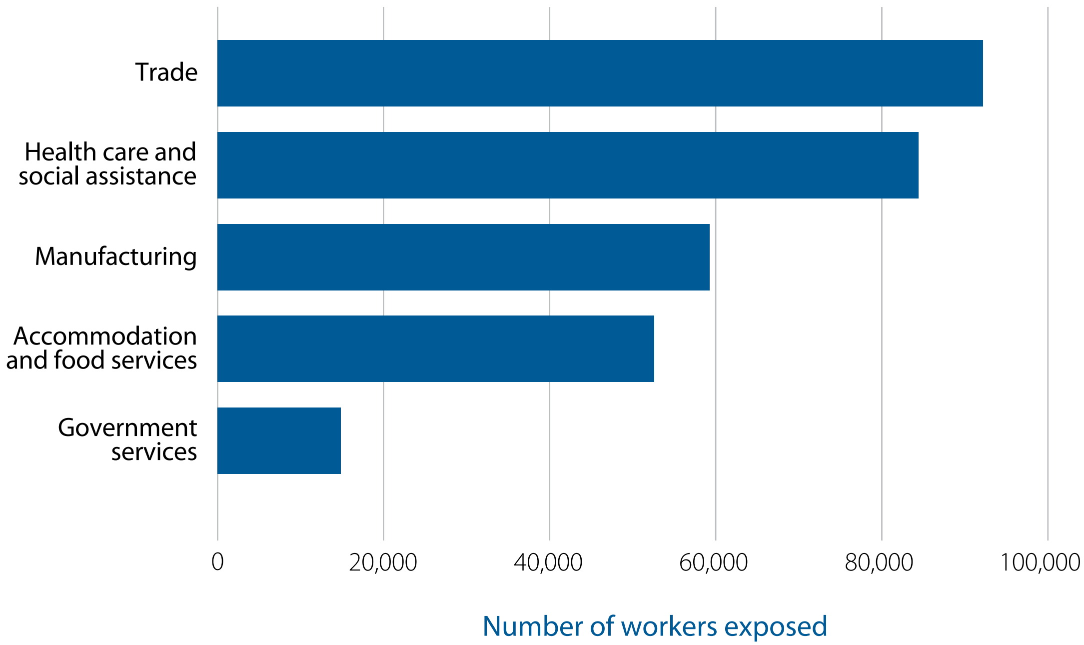
These topics require additional investigation to determine their potential for carcinogenicity, their exposure prevalence in Ontario and their contribution to cancer burden in the province. Because of these knowledge gaps, a precautionary approach is recommended in the absence of explicit policy- and workplace-based prevention recommendations.

Shift work involving circadian disruption

Shift work is generally defined as a pattern of work in which people work schedules that extend beyond traditional or standard work hours (e.g., 9 a.m. to 5 p.m.), up to a 24-hour period.[142] Rotating and night shift work are particularly associated with harmful health effects that are believed to be related to the disruption of the body's natural day–night (i.e., circadian) rhythm and a misalignment of melatonin release.[143] In 2007, IARC classified shift work involving circadian disruption as a probable (IARC Group 2A) cause of breast cancer.[144] The strongest evidence came from studies in nurses that demonstrated elevated female breast cancer risk associated with long-term rotating and night shift work (i.e., 20 years or more).

CAREX Canada estimates that approximately 830,000 men and women work regular night and rotating shifts in Ontario.[145] The industries in Ontario with the greatest numbers of women working regular night or rotating shifts are trade, healthcare and social assistance, and manufacturing. Shift work is also common in accommodation and food services, as well as government services (Figure 21).

FIGURE 21 Number of female workers in the top regular night and rotating shift work industries in Ontario



> In Ontario, approximately 2.0 to 5.2 percent of breast cancers diagnosed annually are probably associated with shift work.

In Ontario, approximately 2.0 to 5.2 percent of breast cancers diagnosed annually are probably associated with shift work. In other words, shift work may be responsible for 180 to 460 new cases of breast cancer each year. This range reflects uncertainty about the strength of association between breast cancer and shift work, a probable carcinogen according to IARC. Shift work is a priority for reassessment by IARC before the year 2019.

Studies published since 2007 have generally supported earlier findings that shift work may be associated with breast cancer.[146,147] Emerging evidence suggests that shift work may be associated with other types of cancer, such as prostate,[148,149] but these findings have been limited with respect to their strength and consistency. There is a need for additional research using improved, consistent definitions of shift work. The biological pathways that might be involved are also not fully understood. While shift work is necessary in some industries, including healthcare, emergency response and law enforcement, it is a common practice in enterprises that elect to operate 24/7. This trend, and mounting evidence suggesting carcinogenicity, makes shift work an important issue for further investigation.

Although shift work cannot be completely banned or easily substituted in all industries and occupations where it is essential, the adverse health effects of shift work may be prevented via several workplace-based measures. The strongest evidence is for rotating schedules that move rapidly from morning-afternoon-evening shifts, which has been shown to improve sleep quality and quantity.[150,151] There is less evidence for other types of interventions, such as the use of controlled light exposure and behavioural strategies. Medications (other than melatonin) to improve sleep or wakefulness have been associated with adverse health effects in several studies.[150] The Employment Standards Act of Ontario does not have any restrictions on the timing of a worker's shift, but does provide requirements for daily rest and rest between shifts.[152] Workplaces can take initiative by promoting strategies to minimize the effects of shift work, such as improved shift scheduling.

Antineoplastic agents

Antineoplastic agents, also known as chemotherapy drugs, are used to treat cancer and other health conditions. Most antineoplastic agents are non-selective, meaning they affect cancerous and non-cancerous cells. This makes them potentially hazardous to workers who treat or handle these drugs.[153] Short-term occupational exposures to high levels of antineoplastic agents may lead to dermatitis, hypersensitivity, nausea and vomiting,[154] while low-level, long-term exposures may lead to cancer, birth defects, and toxic effects on reproduction and organs.[155] There are currently 115 antineoplastic agents identified by the National Institute for Occupational Safety and Health (NIOSH).[156] IARC has assessed 21 different antineoplastic agents[28,46,157-160] and of those, eight[i] have been classified as definitely carcinogenic (IARC Group 1), seven[ii] as probably carcinogenic (IARC Group 2A) and six[iii] as possibly carcinogenic (IARC Group 2B).[156]

CAREX Canada estimates that approximately 75,000 workers are exposed to antineoplastic agents in Canada.[161] Occupations across Canada with the largest number of exposed workers include pharmacy technicians (23,000), nurses (21,000) and pharmacists (20,000).[161,162] Of the 75,000 exposed workers, over 75 percent are women and 48 percent are exposed in hospital settings; 75 percent of these workers are exposed to moderate levels of antineoplastic agents and six percent to high levels. Given that approximately 40 percent of Canada's population lives in Ontario, the numbers exposed in this province are likely to be high.

The use of antineoplastic agents is expected to increase as the Canadian population ages.[163] These agents represent a large group of compounds that target cancer cells through a number of different pathways in the body.[164] While antineoplastic agents are often grouped together for exposure assessment purposes, long-term occupational exposures to these compounds can result in different cancer risks. Some agents are more potent carcinogens and workers may be exposed to combinations of these drugs. Furthermore, depending on the levels and duration of exposures, the cancer risks to exposed workers will vary.[165]

Antineoplastic agents have been recognized as an occupational hazard since the 1970s.[153] There are a number of available control measures that cover all aspects of the drug administration process in healthcare and veterinary settings (e.g., from receiving and storage, to drug preparation, transportation, administration, and cleaning and disposal). Control measures include using containment devices and closed-system drug transfer devices, ventilated cabinets for mixing or preparing drugs, clean rooms, designated rooms or kennels for treating patients or animals with cancer, job rotation, storing drugs separately from other drugs and food or drink, routine inventory and housekeeping, and training and informing workers of the hazards associated with exposure.[166-170] Under the Occupational Health and Safety Act[171] and Ontario Regulation 67/93: Health Care and Residential Facilities,[171] employers in healthcare and residential facilities in Ontario are mandated to develop, establish and put into effect measures and procedures to protect workers who may be exposed to antineoplastic agents. Overall, there is a need for further research on the effectiveness of available control measures and development of new control measures.[172,173]

i Arsenic trioxide, busulfan, chlorambucil, cyclophosphamide, etoposide, melphalan, tamoxifen, thiotepa
ii Azacitidine, carmustine, cisplatin, doxorubicin, lomustine, procarbazine, teniposide
iii Amsacrine, bleomycin, daunorubicin, mitomycin, mitoxantrone, streptozocin

Nanomaterials

Engineered nanomaterials are man-made substances with one dimension between 1 and 100 nm.[174] Nanomaterials are made up of a diverse group of substances of variable chemical composition that occur in particle or filament form. Engineered nanomaterials have unique physical properties (e.g., optical, magnetic and electrical) due to their size and surface area to volume ratio, and are increasingly being used in a number of fields, such as construction, electronics and medicine.[174,175] Currently, nanomaterials can be found in more than 1,300 commercial products, including textiles, medical equipment, fuel additives, cosmetics and plastics.[176]

In 2014, IARC assessed the carcinogenicity of a several nanomaterials and exposures that occur under one work scenario and found variable carcinogenic potentials.[177] In particular, a specific nanotube (multi-walled carbon nanotube-7) was classified as possibly carcinogenic (IARC Group 2B) based on evidence of mesothelioma in rats. There were no available studies examining cancer in humans. Other nanotubes were not classified due to insufficient animal or human evidence.

IARC's assessment covers just a few of the nanomaterials currently being used and manufactured. The wide range of behaviours of specific nanomaterials makes it difficult to assess each material's toxicity. There is an overall lack of exposure and toxicity data because it is unclear how to measure exposure in a way that is meaningful when assessing a material's toxicity.[178] It is also difficult to differentiate nanomaterials from background levels of non-engineered materials, such as diesel exhaust particulates.[178] This lack of data, in conjunction with a lack of a unified exposure sampling approach, makes it difficult to draw meaningful conclusions from existing exposure assessments.[179] Furthermore, exposure assessments tend to focus on select nanomaterials (carbon nanotubes, in particular).

Overall, there are many uncertainties in the field of nanomaterial exposure and risk. It is not currently known how many workers are potentially exposed, and in which industries they work. Standardized risk and exposure assessment methods are needed to provide a risk-based approach for setting occupational exposure limits and to further inform policy.[180] Until then, best practices for managing occupational risks from nanomaterials and control measures commonly used for other substances should be employed.[181] Evidence shows that engineering controls currently used to reduce the impact of dust and particulate matter, such as enclosure and ventilation (e.g., local exhaust ventilation with high-efficiency particulate air or HEPA filters), and personal protective equipment, can effectively reduce the concentration of specific airborne nanomaterials.[178,181,182] The concerted and timely efforts of stakeholders, research organizations and government will be imperative in identifying vulnerable workers and risks, and the overall success of exposure prevention efforts.

Pesticides

Pesticides are a broad group of substances that are used to prevent or control pests. There are many different types of pesticides used in a range of settings and for various reasons. For instance, herbicides can be used on farms to control weeds, while insecticides may be applied in greenhouses or outdoors to control insect pests. There are hundreds of individual pesticides registered for use in Ontario.

Few individual pesticides have been assessed for carcinogenicity by IARC. The pesticides that were evaluated most recently are some commonly used chemicals worldwide and selected substances of longstanding concern, which include glyphosate,[183] 2,4-D,[184] malathion,[183] diazinon,[183] parathion,[183] lindane,[185] tetrachlorvinphos,[183] DDT,[185] pentachlorophenol,[186] aldrin[186] and dieldrin.[186] A summary of their IARC evaluations is presented in Table 2.

Most pesticides recently evaluated by IARC were classified as "probable" carcinogens, with fewer assessed as "definite" or "possible" carcinogens. An evaluation of probable carcinogenicity generally means that the pesticide is more likely to be carcinogenic than not, but there are important gaps in knowledge that need to be addressed. Typically, the human epidemiological evidence is limited and there is more evidence available from animal studies. Mechanistic studies provide supportive evidence about how the pesticide may exert its carcinogenic effects through different pathways in human cells.[188] All three types of evidence (human, animal and mechanistic) are weighed by IARC to make a decision regarding carcinogenicity.[189]

TABLE 2 Summary of results of recent evaluations (2015–2016) of pesticide carcinogenicity by the International Agency for Research on Cancer (IARC)

PESTICIDE	IARC CLASSIFICATION[a]	CANCER SITE(S)	CURRENTLY CLASSIFIED FOR USE IN ONTARIO?[187]
Lindane	Definite	Non-Hodgkin lymphoma	No
Pentachlorophenol	Definite	Non-Hodgkin lymphoma, multiple myeloma	Yes
Glyphosate	Probable	Non-Hodgkin lymphoma	Yes
Malathion	Probable	Non-Hodgkin lymphoma, prostate	Yes
Diazinon	Probable	Non-Hodgkin lymphoma, leukemia, lung	Yes
DDT	Probable	Non-Hodgkin lymphoma, liver, testis	No
Aldrin	Probable	--	No
Dieldrin	Probable	Breast, Non-Hodgkin lymphoma, other	No
2,4-D	Possible	--	Yes
Parathion	Possible	--	No
Tetrachlorvinphos	Possible	--	Yes

NOTES:
[a]Definite human carcinogen = IARC Group 1, probable human carcinogen = IARC Group 2A, possible human carcinogen = IARC Group 2B

Regulations and workplace practices are generally used to reduce the potential human health risks associated with pesticide exposure. Before a pesticide can be used or sold in Ontario, it must be registered under the federal Pest Controls Products Act (Pest Management Regulatory Agency or PMRA)[190] and be classified under the provincial Pesticides Act (Ontario Ministry of Environment and Climate Change). The PMRA determines if current health and environmental protection standards are appropriate when pesticides are used according to their label directions. Pesticide labels are legal documents with explicit instructions on pesticide handling. Although there are occupational exposure limits for some pesticides in Ontario, it can be challenging to measure pesticide exposure in workers and to enforce limits.

Many well-known hazardous pesticides have been banned in Ontario and Canada, such as DDT, but certain chemicals that are currently used may pose cancer risks and/or other adverse health outcomes. In occupational settings, a variety of protective measures can reduce pesticide exposure. The hierarchy of controls (Figure 22) outlines examples of control measures that range from eliminating specific hazardous pesticides (most effective) to using personal protective equipment (least effective).[191] A culture of workplace health and safety can also facilitate pesticide exposure reduction.

FIGURE 22 Hierarchy of controlling occupational exposure to pesticides

ELIMINATION/ SUBSTITUTION OF HAZARD	ENGINEERING CONTROLS	ADMINISTRATIVE CONTROLS	PERSONAL PROTECTIVE EQUIPMENT
▪ Eliminate or ban pesticides ▪ Use lower toxicity pesticides ▪ Integrated Pest Management (IPM)	▪ Use equipment that reduces pesticide drift ▪ Manage pesticide spills ▪ Use enclosed cabs	▪ Follow pesticide label instructions (e.g. re-entry intervals, application rates, etc.) ▪ Obtain formal pesticide training and education ▪ Worker scheduling	▪ Use gloves, masks, aprons, coveralls, and/or long sleeved clothing ▪ Change clothes, handwash, and/or shower after pesticide handling or re-entry

Most effective **Least effective**

Sedentary work

Sedentary behaviour is defined as any waking activity with a low energy usage level while in a prolonged sitting or reclining position.[192] It is not simply the absence of moderate-to-vigorous physical activity.[193] Sedentary behaviour has different physiological and health effects than physical inactivity.[194,195] Some examples of common sedentary behaviours are television viewing, computer use and driving. In Ontario, a large share of sedentariness in adults takes place at work, especially in industries and occupations where sitting is the main working body position. A person can have a sedentary job despite having an otherwise physically active lifestyle, which is the profile for nearly one-third of Canadian adults.[196]

There is some evidence from population-based studies that suggests an association between sedentary work, occupational sitting time and increased colon cancer risk.[197,198] Of the few studies that have investigated this relationship by anatomical sub-types, distal colon cancer risk increased significantly with the number of years of sedentary work[199] and decreased with fewer hours of occupational sitting time in the longest-held job.[200] Overall, sedentary work is a challenging area to study because there is not a consistent definition used in research, little is known about colorectal cancer risks by sub-type and sex, and there is a lack of evidence regarding possible biological explanations.

Sedentary work is a high priority for assessment by IARC by the year 2019.[201] CAREX Canada has also identified sedentary work as an emerging issue for exposure assessment.[202] Because sedentary work and colorectal cancer are both common, research on this topic has a large potential for population health impact. While scientists continue to investigate this issue, a precautionary approach can be adopted by Ontario workers. Workplace-based interventions for reducing occupational sitting time need further investigation, and possibly include implementing sit–stand desks, information and guideline-based counselling by occupational physicians, and computer prompts to get up and move around.[203]

General policy recommendations to prevent occupational cancer in Ontario

The Occupational Health and Safety Act (OHSA) is Ontario's primary legislation for workplace health and safety. It is a legal framework that outlines the rights and duties of all workplace parties.

The OHSA establishes procedures for identifying and controlling workplace hazards and enables the law to be enforced. The OHSA has undergone periodic amendments since being established in 1979. These changes, in particular, emphasized that employers and workers share a responsibility to ensure that prevention policies are being followed, and in turn that workplaces are healthy and safe. Nevertheless, it is clear in the OHSA that employers have the greater responsibility for workplace health and safety.

The OHSA also contains a number of regulations that relate to specific requirements for certain workplaces (e.g., mines, construction sites), designated substances and workplace hazardous materials. In the case of toxic substance use, the OHSA gives power to the director of the Ministry of Labour to restrict the use of toxic substances or to prescribe control measures to reduce overall exposure (e.g., specific engineering controls, administrative controls, personal protective equipment). In some regulations, the implementation of engineering controls are explicitly prioritized over administrative controls and personal protective equipment, which are known to provide less protection.

The Occupational Disease Action Plan was recently initiated by the Ontario Ministry of Labour. The Occupational Disease Action Plan is focused on aligning the efforts of the Occupational Health and Safety System and partners towards the prevention of hazardous exposures in Ontario workplaces and the subsequent reduction in incidence and burden of occupational disease. This initiative is expected to increase awareness of occupational disease hazards across the Occupational Health and Safety System. In the case of silica, this increased awareness may lead to more communication from Occupational Health and Safety System partners about employer responsibilities under the Designated Substance Regulation. As a result, more employers may conduct an assessment of exposure and implement control programs where exposure is likely. In addition, increased awareness may lead to investment in inspection and enforcement that can help ensure that existing regulations are properly followed and that hazardous workplace exposures are being appropriately controlled, particularly for designated substances in Ontario that are associated with a large cancer burden.

Other pieces of legislation may affect occupational exposure to carcinogens in Ontario workers. According to the Workplace Hazardous Materials Information System (WHMIS) Regulation (R.R.O. 1990, Reg. 860), employers have a duty to inform workers about the hazardous information of products or substances that are received or produced in the workplace. Workers also need to receive instruction on safe use, storage, handling and disposal, as well as how to read and interpret hazardous product labels and materials safety data sheets. Nearly all workers in Ontario are covered by this regulation.[204] More consistent high-quality WHMIS training by employers can help ensure that workers receive a high level of training on using or handling carcinogens. Introducing a WHMIS training standard, for example, can help with this. Federal government workers in Ontario are covered by the Canada Labour Code. Diesel engine laws and regulations set out by the Ontario Ministry of Environment and Climate Change and the Ministry of Transportation directly affect workers' exposure to diesel engine exhaust. This fact highlights the need for inter-ministerial approaches to preventing occupational carcinogen exposure, where applicable.

The general policy recommendations listed below acknowledge the presence of existing laws and regulations governing or related to occupational health and safety in Ontario. They address current gaps in the policies themselves and how they are applied by suggesting opportunities to augment or enforce what is already in place. Examples are drawn from other jurisdictions where possible. These recommendations apply to all of the primary and secondary carcinogens included in this report.

Strengthen occupational exposure limits (OELs)

OELs for most of the carcinogens in this report are covered by Regulation 833: Control of Exposure to Biological or Chemical Agents and Regulation 490/09: Designated Substances. These regulations prescribe specific limits that levels are not to exceed. Existing Ontario OELs should continue to be reviewed annually by the Ontario Ministry of Labour, and should continue to be accompanied by a public commentary period, hosted by the Ontario Ministry of Labour. OELs should be strengthened to align with recent evidence on health effects and to be at least as protective as limits set by the American Conference of Governmental Industrial Hygienists (ACGIH). It is possible that workers may develop cancer at levels of exposure that are lower than the ACGIH limits, which is why it is important for Ontario to keep abreast of the latest scientific evidence on cancer and other health effects.

> Existing Ontario OELs should continue to be reviewed annually by the Ontario Ministry of Labour, and should continue to be accompanied by a public commentary period, hosted by the Ontario Ministry of Labour.

One example of how Ontario's current limits can be brought in line with ACGIH and recent scientific research is by addressing silica exposure. In Ontario, the OEL for silica differentiates between two forms (quartz and cristobalite) based on values proposed by ACGIH in the 1980s. Growing scientific evidence has demonstrated the adverse health effects of silica. In 2005, seven Canadian provinces and the federal government implemented a more rigorous OEL of 0.025 mg/m³ for all forms of silica.[69] It is recommended that Ontario's OEL for silica be changed to the more rigorous level of 0.025 mg/m³.

In addition to silica, it is recommended that health-based OELs be adopted for other carcinogens:

- chromium (VI) compounds: 0.025 mg/m³ (ceiling limit 0.1 mg/m³) for water-soluble compounds in alignment with the British Columbia OEL;[205,206]
- nickel compounds: 0.05 mg/m³ for insoluble inorganic nickel compounds; 0.05 mg/m³ for elemental, soluble inorganic nickel compounds; 0.001 ppm for nickel carbonyl; and 0.1 mg/m³ for nickel subsulfide; in alignment with the OELs in British Columbia;[205, 206]
- formaldehyde: 0.3 ppm; ceiling limit in alignment with the 2016 ACGIH limits;[91] and
- wood dust: 0.5 mg/m³ western red cedar; 1 mg/m³ for other species in alignment with the 2016 ACGIH limits.[91]

Toxics use reduction

The Toxics Reduction Act (TRA) aims to reduce the use and creation of toxic substances to prevent pollution and protect human health.[207] The TRA requires facilities to quantify the use, creation, transformation, releases and disposal of toxic substances, and to prepare plans to reduce the use or creation of the substances. The implementation of the plans is voluntary. In addition, the act only requires ranges of use to be reported.

The TRA focuses on the health of the general public. All provisions of the TRA can be amended to more explicitly incorporate worker exposure and health. This approach can include, but is not limited to, expanding the living list of substances in the TRA to contain well-established occupational carcinogens that are used in Ontario and that contribute substantially to cancer burden (e.g., diesel engine exhaust). Of the carcinogens included in this report, only asbestos and benzene are currently covered by the TRA.

An important component of toxics use reduction is substituting hazardous compounds with safer alternatives. For example, trivalent chromium has been identified as a much safer alternative to chromic acid, a chromium (VI) compound.[208] In Massachusetts, many industries have substituted formaldehyde-based resins with soy- and water-based resins.[209] These and other types of substitutions for carcinogens have been shown to lead to long-term declines in the use of carcinogens and releases of carcinogens in the environment.[210] Workers and their representatives could be included in the development of toxic use reduction plans.

As of 2016, only 40 percent of facilities covered by the TRA have actually committed to taking action to prevent the use of at least one toxic substance.[211] Other jurisdictions with toxics use reduction acts, such as Massachusetts, have had greater success in the implementation of prevention activities due to increased funding, support and training for program planning and implementation.[212] It is recommended that a similar approach be taken in Ontario. For example, sustained support to workplaces can be provided through the creation of an institution similar to the Toxics Use Reduction Institute in Massachusetts (e.g., with funding and support from the Ministries of Labour, and Environment and Climate Change), which would likely increase the number of facilities that take preventive measures.

Exposure registries and exposure surveillance

Under the provincial OHSA, workers must be informed if they are working with hazardous substances. Exposure surveillance and exposure registries can help prevent occupational exposure by providing a regular and standardized method of informing workers of potential exposures. Increased exposure surveillance is possible through the increased routine inspection and enforcement efforts from public health and the Ministry of Labour. Standardizing data and summarizing information on registries can help identify where there is a heightened need for inspection, enforcement, training and remediation. Furthermore, registries can facilitate future research on prevention, monitoring exposure trends over time and assessing impact of new regulations to reduce exposure. In addition to monitoring known hazardous substances, registries should monitor levels of new chemicals that are introduced into workplaces to facilitate the early detection of potentially hazardous or carcinogenic substances. Registries should be public, free and easily accessible to employers, employees and the general public (e.g., on a website or on a certificate in the workplace) to have the greatest impact on exposure prevention. For example, public notice of radon test results should be mandatory to inform not only workers, but also the public of potential exposure. In the case of asbestos, inspection of worksites before construction to confirm whether asbestos-containing products are present is mandated, but it is recommended that all workers are informed, including those who work or enter in buildings that contain asbestos (e.g., teachers, firefighters).

> **Exposure surveillance and exposure registries can help prevent occupational exposure by providing a regular and standardized method of informing workers of potential exposures.**

Include construction project employers and workers in the Designated Substances Regulation

Current occupational health and safety legislation can be broadened to provide greater protection for workers in the construction industry. Specifically, construction project employers and workers are exempt from the Designated Substances Regulation (O. Reg. 490/09, section 14),[76] which is reserved for substances known to be particularly hazardous to the health and safety of workers. This means that the provisions for silica (and asbestos) as outlined in this regulation do not apply to construction workers. Efforts are currently being made to remove the exemption for construction workers in the Designated Substances Regulation (O. Reg. 490/09, section 14). In 2015, there was a public consultation on amending O. Reg. 490/09 so that it applies to workers engaged in construction, ensuring that they are afforded the same protection as other third party workers exposed to a designated substance at a host employer's workplace. At the time of writing, this consultation proposal is still under review. Given the large amount of these exposures on construction projects and their associated cancer burden, it is recommended that construction project employers and workers be legally required to comply with O. Reg. 490/09.

Conclusion

In summary, this report demonstrates that exposure to commonly found occupational carcinogens is responsible for a significant number of cancers in Ontario.

The estimates of the burden of occupational cancer presented in this report are substantial given that exposure in occupational settings is largely preventable. In particular, solar ultraviolet radiation, asbestos, diesel engine exhaust and silica contribute most significantly to the burden of occupational cancer. These four carcinogens should be prioritized for exposure prevention and control because they present the best opportunity for making a large health impact. Specific and general policies targeting prevention are a promising way to reduce the burden of occupational cancer and protect public health. These policies may originate from labour, as well as environment, health and other Ontario ministries vested in preventing occupational cancer. A comprehensive and inter-sectoral approach will be imperative in enacting positive change.

References

1. Statistics Canada. Table 102-0564. Leading causes of death, total population, by sex, Canada, provinces and territories (age standardization using 2011 population), annual (CANSIM) [Internet]. 2017 [cited May 25, 2017]. Available from: http://www5.statcan.gc.ca/cansim/a05?lang=eng&id=1020564.

2. Statistics Canada. CANSIM Table 281-0033: Survey of Employment, Payrolls and Hours (SEPH), average weekly hours for employees paid by the hour, by overtime status and detailed North American Industry Classification System (NAICS) [annual hours] [Internet]. 2016 [cited 2017 March 9]. Available from: http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/labr82-eng.htm.

3. Rushton L, Hutchings SJ, Fortunato L, Young C, Evans GS, Brown T, et al. Occupational cancer burden in Great Britain. Br J Cancer. 2012;107 Suppl 1:S3-7.

4. Nurminen M, Karjalainen A. Epidemiologic estimate of the proportion of fatalities related to occupational factors in Finland. Scand J Work Environ Health. 2001;27(3):161-213.

5. Fritschi L, Driscoll T. Cancer due to occupation in Australia. Aust N Z J Public Health. 2006;30(3):213-9.

6. Steenland K, Burnett C, Lalich N, Ward E, Hurrell J. Dying for work: The magnitude of US mortality from selected causes of death associated with occupation. Am J Ind Med. 2003;43(5):461-82.

7. Leigh JP, Markowitz SB, Fahs M, Shin C, Landrigan PJ. Occupational injury and illness in the United States. Estimates of costs, morbidity, and mortality. Arch Intern Med. 1997;157(14):1557-68.

8. Fingerhut M, Nelson DI, Driscoll T, Concha-Barrientos M, Steenland K, Punnett L, et al. The contribution of occupational risks to the global burden of disease: summary and next steps. Med Lav. 2006;97(2):313-21.

9. Peters CE, Ge CB, Hall AL, Davies HW, Demers PA. CAREX Canada: an enhanced model for assessing occupational carcinogen exposure. Occup Environ Med. 2015;72(1):64-71.

10. The University of British Columbia. Canadian Workplace Exposure Database (CWED). [Internet]. 2017 [cited June 19, 2017]. Available from: http://cwed.spph.ubc.ca/.

11. CANJEM. Occupational Exposure Information System [Internet]. 2017 [cited May 24, 2017]. Available from: http://www.canjem.ca/.

12. Centers for Disease Control and Prevention. The National Institute for Occupational Safety and Health - Hierarchy of Controls [Internet]. U.S. Department of Health & Human Services 2016 [cited January 31, 2017]. Available from: https://www.cdc.gov/niosh/topics/hierarchy/.

13. National Toxicology Program (NTP). Report on Carcinogens, 14th edition. Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service, 2016.

14. Centers for Disease Control and Prevention. NIOSH Workplace Safety and Health Topic - Sun Exposure [Internet]. 2016 [cited January 31, 2017]. Available from: https://www.cdc.gov/niosh/topics/sunexposure/.

15. International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to humans. Volume 100D. A review of human carcinogens. Part D: Radiation. Lyon: International Agency for Research on Cancer, 2012.

16. Ontario Ministry of Labour. Ultraviolet Radiation in the Workplace [Internet]. Government of Ontario. 2009 [cited January 31, 2017]. Available from: https://www.labour.gov.on.ca/english/hs/pubs/uvradiation/.

17. Sun Safety at Work Canada (SSAWC). Enhancing Sun Safety in Canadian Workplaces [Internet]. 2016 [cited January 27. 2017]. Available from: https://sunsafetyatwork.ca/.

18. Work Safe Victoria. Sun Protection For Construction And Other Outdoor Workers [Internet]. 2005 [cited January 27, 2017]. Available from: https://www.worksafe.vic.gov.au/__data/assets/pdf_file/0014/210128/ISBN-Sun-protection-for-outdoor-workers-2016-08.pdf.

19. The Cancer Council Australia. Skin cancer and outdoor work A guide for employers Skin Cancer and Outdoor Work: A Guide for Employers [Internet]. 2007 [cited February 10, 2017]. Available from: http://www.cancer.org.au/content/pdf/PreventingCancer/BeSunsmart/Skincanceroutdoorworkbooklet.pdf.

20. Parisi A, Kimlin M. Effects of simple measures to reduce the occupational solar UV exposure of outdoor workers. Journal of Occupational Health and Safety – Australia and New Zealand. 1999;15(3):267-72.

21. Cancer Council Australia. Position statement - Sun (UV) protection in the workplace [Internet]. [cited May 11, 2017]. Available from: http://wiki.cancer.org.au/policy/Position_statement_-_Sun_(UV)_protection_in_the_workplace#_ga=2.123600523.1454004978.1494535107-308207790.1492965606.

22. Canadian Centre for Occupational Health and Safety. OSH Answers Fact Sheets - Asbestos [Internet]. 2015 [cited January 30, 2017]. Available from: https://www.ccohs.ca/oshanswers/chemicals/asbestos/whatis.html.

23. Government of Canada. Health risks of asbestos [Internet]. 2017 [cited January 31, 2017]. Available from: http://healthycanadians.gc.ca/healthy-living-vie-saine/environment-environnement/air/contaminants/asbestos-amiante-eng.php.

24. Virta RL. Worldwide Asbestos Supply and Consumption Trends from 1900 through 2003. Reston, Virginia: U.S. Geologic Survey Circular 1298, 2006.

25. Canadian Labour Congress. Ban asbestos: What are we asking for? [Internet]. 2015 [cited January 31, 2017]. Available from: http://canadianlabour.ca/ban-asbestos-what-are-we-asking.

26. Innovation, Science and Economic Development Canada. Trade Data Online [Internet]. Government of Canada. 2016 [cited February 10, 2017]. Available from: https://www.ic.gc.ca/eic/site/tdo-dcd.nsf/eng/home.

27. Ontario Ministry of Labour. Appendix 2: A Guide to the Regulation Respecting Asbestos on Construction Projects and in Buildings and Repair Operations [Internet]. 2011 [cited February 10. 2017]. Available from: https://www.labour.gov.on.ca/english/hs/pubs/asbestos/asbst_app2.php.

28. International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to humans. Volume 100C. A review of human carcinogens. Part C: Arsenic, Metals, Fibres and Dusts. Lyon: International Agency for Research on Cancer, 2012.

29. Marrett LD, Ellison LF, Dryer D. Canadian cancer statistics at a glance: mesothelioma. CMAJ. 2008;178(6):677-8.

30. CAREX Canada. Asbestos [Internet]. 2016 [cited January 26, 2017]. Available from: http://www.carexcanada.ca/en/asbestos/.

31. CAREX Canada. Surveillance of environmental and occupational exposures for cancer prevention [Internet]. 2017. Available from: http://www.carexcanada.ca/en/.

32. Linton A, Vardy J, Clarke S, van Zandwijk N. The ticking time-bomb of asbestos: its insidious role in the development of malignant mesothelioma. Crit Rev Oncol Hematol. 2012;84(2):200-12.

33. CAREX Canada. Surveillance of environmental and occupational exposures for cancer prevention: Profiles & Estimates [Internet]. 2017. Available from: http://www.carexcanada.ca/en/profiles_and_estimates.

34. Government of Canada. News Release: Government of Canada to ban asbestos [Internet]. 2016 [cited April 20, 2017]. Available from: https://www.canada.ca/en/innovation-science-economic-development/news/2016/12/government-canada-asbestos.html.

35. Canada Gazette. Regulations Amending Certain Regulations Made Under the Canada Labour Code [Internet]. Government of Canada. 2017 [cited July 20, 2017]. Available from: http://gazette.gc.ca/rp-pr/p2/2017/2017-07-12/html/sor-dors132-eng.php.

36. Work Safe Alberta. Workplace Health and Safety Bulletin: Control of Asbestos During Brake Maintenance and Repair. Edmonton, AB: Government of Alberta; 2009.

37. WorkSafeBC. Safe Work Practices for Handling Asbestos [Internet]. 2017 [cited June 19, 2017]. Available from: https://www.worksafebc.com/en/resources/health-safety/books-guides/safe-work-practices-for-handling-asbestos.

38. Ontario Ministry of Labour. A Guide to the Regulation Respecting Asbestos on Construction Projects and in Buildings and Repair Operations [Internet]. 2011 [cited July 19, 2017]. Available from: https://www.labour.gov.on.ca/english/hs/pubs/asbestos/.

39. Veglia A, Pahwa M, Demers PA. Establishing a policy framework for the primary prevention of occupational cancer: a proposal based on a prospective health policy analysis. Safety and Health at Work. 2016.

40. Ontario Ministry of Labour. Regulation Respecting Asbestos on Construction Projects and in Buildings and Repair Operations: Made Under the Occupational Health and Safety ACT, Revised Statutes of Ontario, 1990, Chapter O.1, As Amended: O. Reg. 278/05, As Amended by O. Reg. 493/09, O. Reg. 422/10, O. Reg. 479/10 (2011).

41. Canadian Cancer Society. Saskatchewan legislature makes history [Internet]. 2013 [cited September 18, 2017]. Available from: http://www.cancer.ca/en/about-us/for-media/media-releases/saskatchewan/2013/saskatchewan-legislature-makes-history/?region=sk.

42. Government of Saskatchewan. Saskatchewan Asbestos Registry [Internet]. 2015 [cited April 20, 2017]. Available from: Establishing a policy framework for the primary prevention of occupational cancer: a proposal based on a prospective health policy analysis.

43. Public Services and Procurement Canada. National inventory of asbestos in Public Services and Procurement Canada buildings [Internet]. 2017 [cited April 20, 2017]. Available from: https://www.tpsgc-pwgsc.gc.ca/biens-property/invamiante-asbestosinv-eng.html.

44. BC Gov News. Province takes next steps on asbestos [Internet]. 2017 [cited April 20, 2017]. Available from: https://news.gov.bc.ca/releases/2017JTST0095-000776.

45. Benbrahim-Tallaa L, Baan RA, Grosse Y, Lauby-Secretan B, El Ghissassi F, Bouvard V, et al. Carcinogenicity of diesel-engine and gasoline-engine exhausts and some nitroarenes. Lancet Oncol. 2012;13(7):663-4.

46. International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to humans. Volume 100A. A review of human carcinogens. Part A: Pharmaceuticals. Lyon: International Agency for Research on Cancer, 2012.

47. Latifovic L, Villeneuve PJ, Parent M-É, Johnson KC, Kachuri L, Harris SA. Bladder cancer and occupational exposure to diesel and gasoline engine emissions among Canadian men. Cancer Med. 2015;4(12):1948-62.

48. Health Canada. Human health risk assessment for diesel exhaust [Internet]. Government of Canada. 2016. Available from: http://healthycanadians.gc.ca/publications/healthy-living-vie-saine/exhaust-diesel-gaz-echappement/index-eng.php.

49. Pronk A, Coble J, Stewart PA. Occupational exposure to diesel engine exhaust: a literature review. J Expo Sci Environ Epidemiol. 2009;19(5):443-57.

50. Safe Work Australia. Guide to managing risks of exposure to diesel exhaust in the workplace. Canberra, Australia: Government of Australia 2015.

51. Occupational Cancer Research Centre. Controlling diesel particulate matter in underground mines [Internet]. 2017 [cited April 24, 2017]. Available from: http://www.occupationalcancer.ca/2017/controlling-dpm-in-mining/?gwcpp_catid=95.

52. Canadian Centre for Occupational Health and Safety (CCOHS). Diesel Exhaust: Hazardous to your Health [Internet]. 2012 [cited January 27, 2017]. Available from: http://www.ccohs.ca/newsletters/hsreport/issues/2012/06/ezine.html.

53. Mine Safety and Health Administration. Practical Ways to Reduce Exposure to Diesel Exhaust in Mining [Internet]. United States Department of Labor (USDA). [cited January 27, 2017]. Available from: http://arlweb.msha.gov/S&HINFO/TOOLBOX/DTBFINAL.htm.

54. McClellan RO, Hesterberg TW, Wall JC. Evaluation of carcinogenic hazard of diesel engine exhaust needs to consider revolutionary changes in diesel technology. Regul Toxicol Pharmacol. 2012;63(2):225-58.

55. Nederman. Fire and Emergency Stations [Internet]. 2017 [cited July 20, 2017]. Available from: http://www.nederman.com/en/industry_solutions/fire_and_emergency_stations.

56. R.R.O. 1990, Reg. 854: Mines and Mining Plants; under Occupational Health and Safety Act, R.S.O. 1990, c. O.1 [Internet]. 2017 [cited April 24, 2017]. Available from: https://www.ontario.ca/laws/regulation/900854?_ga=1.32320506.598987579.1449518543.

57. Government of Ontario. Control of Exposure to Biological or Chemical Agents, RRO 1990, Reg 833 [Internet]. CanLII. 2016. Available from: http://www.canlii.org/en/on/laws/regu/rro-1990-reg-833/latest/rro-1990-reg-833.html?searchUrlHash=AAAAAQA-UmVnLiA4MzM6IENPTlRST0wgT0YgRVhQT1NVUkUgVE8gQklPTE9HSUNBTCBPUiBDSEVNSUNBTCBBR0VOVFMAAAAAAQ&resultIndex=1.

58. Toxicology Excellence for Risk Assessment. Occupational Exposure Limit Evaluation: Diesel Particulate Matter. Cincinnati, OH: 2014.

59. Tyoterveyslaitos. Dieselpakokaasujen tavoitetasoerustelumuistio; pg. 3. Helsinki, Finland: 2015.

60. Vermeulen R, Portengen L. Is diesel equipment in the workplace safe or not? Occup Environ Med. 2016;73(12):846-8.

61. Silverman DT. Diesel exhaust causes lung cancer: now what? Occup Environ Med. 2017.

62. CAREX Canada. Diesel Engine Exhaust [Internet]. 2016 [cited May 11, 2017]. Available from: http://www.carexcanada.ca/en/diesel_engine_exhaust/.

63. Environment and Climate Change Canada. Marine Spark-Ignition Engine, Vessel and Off-Road Recreational Vehicle Emission Regulations (SOR/2011-10) [Internet]. 2017 [cited May 27, 2017]. Available from: http://www.ec.gc.ca/lcpe-cepa/eng/regulations/detailReg.cfm?intReg=109.

64. Environment and Climate Change Canada. Off-Road Compression-Ignition Engine Emission Regulations (SOR/2005-32) [Internet]. 2017 [cited May 26, 2017]. Available from: http://www.ec.gc.ca/lcpe-cepa/eng/regulations/detailReg.cfm?intReg=88.

65. California Environmental Protection Agency. Air Resources Board. Truck and Bus Regulation: On-Road Heavy-Duty Diesel Vehicles (In-Use) Regulation [Internet]. 2016 [cited April 24, 2017]. Available from: https://www.arb.ca.gov/msprog/onrdiesel/onrdiesel.htm.

66. Diesel Technology Forum. Retrofitting America's Diesel Engines - A Guide to Cleaner Air through Cleaner Diesel [Internet]. 2006 [cited May 25, 2017]. Available from: http://dieselforum.org/files/dmfile/Retrofitting-America-s-Diesel-Engines-11-2006.pdf.

67. Environment Canada & Health Canada. Screening Assessment for the Challenge: Quartz and Cristobalite. Ottawa, ON: Government of Canada, 2013.

68. Workplace Safety & Prevention Services (WSPS). Silica in the Workplace [Internet]. 2011 [cited January 27, 2017]. Available from: http://www.wsps.ca/WSPS/media/Site/Resources/Downloads/SilicaWorkplace_Final.pdf?ext=.pdf.

69. CAREX Canada. Silica (Crystalline) [Internet]. 2016 [cited January 26, 2017]. Available from: http://www.carexcanada.ca/en/silica_(crystalline)/occupational_estimate/.

70. International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to humans. Volume 68. Silica, some silicates, coal dust and para-aramid fibrils. Lyon: International Agency for Research on Cancer, 1997.

71. Occupational Safety and Health Administration (OHSA). Fact Sheet: Crystalline Silica Exposure Health Hazard Information [Internet]. 2002 [cited April 19, 2017]. Available from: https://www.osha.gov/OshDoc/data_General_Facts/crystalline-factsheet.pdf.

72. Ontario Ministry of Labour. Silica on Construction Projects [Internet]. 2011 [cited February 10, 2017]. Available from: https://www.labour.gov.on.ca/english/hs/pubs/silica/.

73. Canadian Centre for Occupational Health and Safety. OSH Answers Fact Sheets: Silica, quartz [Internet]. 2015 [cited January 3, 2017]. Available from: https://www.ccohs.ca/oshanswers/chemicals/chem_profiles/quartz_silica.html.

74. The National Institute for Occupational Safety and Health (NIOSH). Engineering Controls Database: Best Practices for Dust Control in Metal/Nonmetal Mining – Controlling Respirable Silica at Surface Mines – Enclosed Cab Filtration Systems [Internet]. 2015 [cited June 21, 2017]. Available from: https://wwwn.cdc.gov/niosh-ecd/Detail.aspx?id=84.

75. BC Construction Safety Alliance. Silica Control Tool [Internet]. 2017 [cited May 29, 2017]. Available from: http://www.silicacontroltool.com/about_this_tool_login.php.

76. Occupational Health and Safety Act. Ontario Regulation 490/09. Designated Substances [Internet]. [cited May 26, 2017]. Available from: https://www.ontario.ca/laws/regulation/090490.

77. Guha N, Loomis D, Guyton KZ, Grosse Y, El Ghissassi F, Bouvard V, et al. Carcinogenicity of welding, molybdenum trioxide, and indium tin oxide. Lancet Oncol. 2017.

78. Canadian Centre for Occupational Health and Safety. OSH Answers Fact Sheets: Welding - Fumes and Gases [Internet]. 2017 [cited April 20, 2017]. Available from: https://www.ccohs.ca/oshanswers/safety_haz/welding/fumes.html.

79. Agency for Toxic Substances and Disease Registry. Toxicological profile for chromium. Atlanta, GA: US Department Of Health And Human Services, 2012.

80. Fenske RA. State-of-the-art measurement of agricultural pesticide exposures. Scand J Work Environ Health. 2005;31 Suppl 1:67-73; discussion 63-5.

81. Agency for Toxic Substances and Disease Registry. Toxicological Profile for Nickel. Atlanta, GA: U.S. Department of Health and Human Services, 2005.

82. National Institute for Occupational Safety and Health. Criteria for a recommended standard: Occupational exposure to hexavalent chromium [Internet]. Department of Health and Humnan Services. Centers for Disease Control and Prevention. 2013 [cited February 24, 2017]. Available from: https://www.cdc.gov/niosh/docs/2013-128/pdfs/2013_128.pdf.

83. Australian Institute of Occupational Hygienists (AIOH). Nickel and its compounds - Potential for occupational health issues [Internet]. 2016 [cited March 1, 2017]. Available from: https://www.aioh.org.au/documents/item/101.

84. Nickel Producers Environmental Research Association. Safe use of nickel in the workplace: A guide for health maintenance of workers exposed to nickel, its compounds and alloys. Third Edition. 2008.

85. Occupational Safety and Health Administration. Hexavalent chromium [Internet]. U.S. Department of Labor. 2009 [cited February 27, 2017]. Available from: https://www.osha.gov/Publications/OSHA-3373-hexavalent-chromium.pdf.

86. Lee WJ, Purdue MP, Stewart P, Schenk M, De Roos AJ, Cerhan JR, et al. Asthma history, occupational exposure to pesticides and the risk of non-Hodgkin's lymphoma. Int J Cancer. 2006;118(12):3174-6.

87. Occupational Safety and Health Administration. OSHA Fact Sheet: Controlling hazardous fume and gases during welding [Internet]. 2013 [cited April 24, 2017]. Available from: https://www.osha.gov/Publications/OSHA_FS-3647_Welding.pdf.

88. Human Resources and Social Development Canada. Guide to health hazards and hazard control measures with respect to welding and allied processes [Internet]. Government of Canada. 2015 [cited July 20, 2017]. Available from: https://www.canada.ca/en/employment-social-development/services/health-safety/reports/guide-welding.html.

89. Health Canada. Consumer Product Safety: Pesticide Label Search [Internet].]: Health Canada; 2016 [cited 2016 November 29]. Available from: http://www.hc-sc.gc.ca/cps-spc/pest/registrant-titulaire/tools-outils/label-etiq-eng.php.

90. Occupational Safety and Health Administration. OSHA FactSheet: Controlling hexavalent chromium exposure during electroplating [Internet]. U.S. Department of Labor. 2013 [cited February 24, 2017]. Available from: https://www.osha.gov/Publications/OSHA_FS-3648_Electroplating.pdf.

91. American Conference of Governmental Industrial Hygienists (ACGIH). 2016 TLVs and BEIs [Internet]. 2016. Available from: https://www.acgih.org/forms/store/ProductFormPublic/2016-tlvs-and-beis.

92. Beattie H, Keen C, Coldwell M, Tan E, Morton J, McAlinden J, et al. The use of bio-monitoring to assess exposure in the electroplating industry. J Expo Sci Environ Epidemiol. 2017;27:47-55.

93. Canadian Centre for Occupational Health and Safety. OSH Answers Fact Sheets: Welding-Ventilation [Internet]. 2012 [cited April 25, 2017]. Available from: https://www.ccohs.ca/oshanswers/safety_haz/welding/ventilation.html.

94. Welding Fume Control: Regulations and Processes [Internet]. 2008 [cited April 25, 2017]. Available from: http://courses.washington.edu/envh557/protected/misc%20docs/WeldingFume.pdf.

95. United States Department of Labor. Regulations (Standards - 29 CFR) [Internet]. [cited April 25, 2017]. Available from: https://www.osha.gov/pls/oshaweb/owasrch.search_form?p_doc_type=STANDARDS&p_toc_level=0&p_keyvalue=.

96. International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to humans. Volume 100E. A review of human carcinogens. Part E: Personal Habits and Indoor Comubstions. Lyon: International Agency for Research on Cancer, 2012.

97. Canadian Centre for Occupational Health and Safety (CCOHS). OSH Answers Fact Sheets. Environmental Tobacco Smoke (ETS) [Internet]. 2017 [cited March 7, 2017].

98. Stayner L, Bena J, Sasco AJ, Smith R, Steenland K, Kreuzer M, et al. Lung cancer risk and workplace exposure to environmental tobacco smoke. Am J Public Health. 2007;97(3):545-51.

99. Leone A, Giannini D, Bellotto C, Balbarini A. Passive smoking and coronary heart disease. Curr Vasc Pharmacol. 2004;2(2):175-82.

100. U.S. Department of Health and Human Services. The Health Consequences of Involuntary Exposure to Tobacco Smoke: A Report of the Surgeon General. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, Coordinating Center for Health Promotion, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health, 2006.

101. Government of Ontario. Smoke-Free Ontario Act, S.O. 1994, c. 10 [Internet]. Queen's Printer for Ontario. [cited March 13, 2017]. Available from: https://www.ontario.ca/laws/statute/94t10.

102. Statistics Canada. Canadian Tobacco Use Monitoring Survey (CTUMS). February to December 2012. Public use data. 2013.

103. Ontario Tobacco Research Unit. Smoke-Free Ontario Strategy Monitoring Report [Internet]. 2016 [cited April 22, 2017]. Available from: http://otru.org/wp-content/uploads/2016/02/OTRU_2015_SMR_Full.pdf.

104. McNabola A, Gill LW. The control of environmental tobacco smoke: a policy review. Int J Environ Res Public Health. 2009;6(2):741-58.

105. Agency for Toxic Substances and Disease Registry. Toxicological Profile for Radon. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service, 2012.

106. Johnson JR, Morley D, Phillips B, Copes R. Radon in British Columbia work places. Richmond, BC: WorkSafeBC, 2009.

107. Ontario Ministry of Labour. Radon in the workplace [Internet]. 2016 [cited January 31, 2017]. Available from: https://www.labour.gov.on.ca/english/hs/pubs/gl_radon.php.

108. Health Canada. Radon - Another Reason to Quit [Internet]. [Ottawa, ON2014 [cited 2017 January 26]. Available from: http://www.hc-sc.gc.ca/ewh-semt/pubs/radiation/radon_smokers-fumeurs/index-eng.php.

109. Health Canada. Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials (NORM) [Internet]. 2013 [cited March 15, 2017]. Available from: http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/norm-mrn/index-eng.php.

110. World Health Organization. WHO Handbook on Indoor Radon [Internet]. 2009 [cited April 25, 2017]. Available from: http://apps.who.int/iris/bitstream/10665/44149/1/9789241547673_eng.pdf.

111. Cancer Care Ontario. 2016 Prevention System Quality Index [Internet]. 2016 [cited March 29, 2017]. Available from: https://www.cancercare.on.ca/common/pages/UserFile.aspx?fileId=363932.

112. Johnson J, Morley D, Phillips B, Copes R. Radon in British Columbia Work Places. Richmond, BC: WorkSafeBC, 2009.

113. International Atomic Energy Agency. Safety Reports Series, No. 33: Radiation protection against radon in workplaces other than mines Vienna, Austria: International Atomic Energy Agency, 2003.

114. Cancer Care Ontario & Public Health Ontario. Environmental Burden of Cancer in Ontario [Internet]. 2016 [cited May 23, 2017]. Available from: https://www.cancercare.on.ca/cms/One.aspx?portalId=1377&pageId=361353.

115. Radon in indoor air: A review of policy and law in Canada [Internet]. Canadian Environmental Law Association (CELA). 2014 [cited March 30, 2017].

116. Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Arsenic [Internet]. US Department of Health and Human Services. 2007 [cited March 1, 2017]. Available from: https://www.atsdr.cdc.gov/toxprofiles/tp2.pdf.

117. National Occupational Health and Safety Commission. Arsenic and its Compounds [Internet]. Australian Government Publishing Service. 1989 [cited March 15, 2017]. Available from: https://www.safeworkaustralia.gov.au/system/files/documents/1702/arsenicanditscompounds_1989_pdf.pdf.

118. International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to humans. Volume 100F. A review of human carcinogens. Part F: Chemical agents and related occupations. Lyon: International Agency for Research on Cancer, 2012.

119. Health Canada. Benzene in Indoor Air [Internet]. 2013 [cited January 31, 2017]. Available from: http://www.hc-sc.gc.ca/ewh-semt/pubs/air/benzene_fs-fi/index-eng.php.

120. Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile For Benzene. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service, 2007.

121. Work Safe Alberta. Workplace Health and Safety Bulletin: Benzene at the Work Site. Edmonton, AB: Government of Alberta, Employment and Immigration Services; 2010.

122. Canadian Centre for Occupational Health and Safety (CCOHS). OSH Answers Fact Sheets: Benzene [Internet]. 2017 [cited January 27, 2017]. Available from: https://www.ccohs.ca/oshanswers/chemicals/chem_profiles/benzene.html.

123. International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to humans. Volume 92. Some Non-heterocyclic Polycyclic Aromatic Hydrocarbons and Some Related Exposures. Lyon: International Agency for Research on Cancer, 2010.

124. Straif K, Baan R, Grosse Y, Secretan B, El Ghissassi F, Cogliano V. Carcinogenicity of polycyclic aromatic hydrocarbons. Lancet Oncol. 2005;6(12):931-2.

125. Driscoll TR, Carey RN, Peters S, Glass DC, Benke G, Reid A, et al. The Australian Work Exposures Study: Occupational Exposure to Polycyclic Aromatic Hydrocarbons. Ann Occup Hyg. 2016;60(1):124-31.

126. Abdel-Shafy HI, Mansour MSM. A review on polycyclic aromatic hydrocarbons: Source, environmental impact, effect on human health and remediation. Egypt J Pet. 2016;25(1):107-23.

127. dell'Omo M, Muzi G, Marchionna G, Latini L, Carrieri P, Paolemili P, et al. Preventive measures reduce exposure to polycyclic aromatic hydrocarbons at a graphite electrode plant. Occup Environ Med. 1998;55(6):401-6.

128. Committee AES. Australian Institute of Occupational Hygienists (AIOH). Polycyclic aromatic hydrocarbons (PAHs) and occupational health issues. Tullamarine, Australia: 2016.

129. Ontario Ministry of Labour. Control Measures-Ultraviolet Radiation in the Workplace [Internet]. 2009 [cited April 28, 2017]. Available from: https://www.labour.gov.on.ca/english/hs/pubs/uvradiation/gl_uvrad_4.php.

130. Jacobsen G, Schaumburg I, Sigsgaard T, Schlunssen V. Non-malignant respiratory diseases and occupational exposure to wood dust. Part II. Dry wood industry. Ann Agric Environ Med. 2010;17(1):29-44.

131. Jacobsen G, Sigsgaard T, Schaumburg I. Non-malignant respiratory diseases and occupational exposure to wood dust. Part I. Fresh wood and mixed wood industry. Ann Agric Environ Med. 2010;17(1):15-28.

132. Work Safe Alberta. Workplace Health and Safety Bulletin: Health Effects From Exposure to Wood Dust. Edmonton, AB: Government of Alberta, Employment and Immigration Services; 2009.

133. Estlander T, Jolanki R, Alanko K, Kanerva L. Occupational allergic contact dermatitis caused by wood dusts. Contact Dermatitis. 2001;44(4):213-7.

134. The National Institute for Occupational Safety and Health (NIOSH). Control of Wood Dust from Horizontal Belt Sanders [Internet]. 1996 [cited May 10, 2017]. Available from: https://www.cdc.gov/niosh/docs/hazardcontrol/hc4.html.

135. The National Institute for Occupational Safety and Health (NIOSH). Control of Wood Dust from Shapers [Internet]. 1996 [cited May 10, 2017]. Available from: https://www.cdc.gov/niosh/docs/hazardcontrol/hc5.html.

136. The National Institute for Occupational Safey and Health (NIOSH). Control of Wood Dust from Automated Routers [Internet]. 1996 [cited May 20, 2017]. Available from: https://www.cdc.gov/niosh/docs/hazardcontrol/hc6.html.

137. SafeWork NSW. Wood Dust - Health Hazards and Control [Internet]. 2011 [cited May 10, 2017]. Available from: http://www.safework.nsw.gov.au/__data/assets/pdf_file/0005/101588/Wood-dust-health-hazards-and-control-fact-sheet-SW08419.pdf.

138. Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Formaldehyde. Atlanta, GA: U.S. Department of Health and Human Services, Service PH; 1999.

139. Goyer N, Bégin D, Beaudry C, Bouchard M, Carrier G, Lavoué J, et al. Formaldehyde In The Workplace. Montreal, QC: Institut de recherche Robert-Sauvé en santé et en Sécurité du travail (IRSST), 2006.

140. Canadian Centre for Occupational Health and Safety (CCOHS). OSH Answers Fact Sheets: Formaldehyde Solutions [Internet]. 2016 [cited January 27, 2017]. Available from: https://www.ccohs.ca/oshanswers/chemicals/chem_profiles/formaldehyde.html.

141. Occupational Safety and Health Administration. OSHA FactSheet: Formaldehyde [Internet]. 2011 [cited April 9, 2017]. Available from: https://www.osha.gov/OshDoc/data_General_Facts/formaldehyde-factsheet.pdf.

142. Stevens RG, Hansen J, Costa G, Haus E, Kauppinen T, Aronson KJ, et al. Considerations of circadian impact for defining 'shift work' in cancer studies: IARC Working Group Report. Occup Environ Med. 2011;68(2):154-62.

143. Fritschi L, Glass DC, Heyworth JS, Aronson K, Girschik J, Boyle T, et al. Hypotheses for mechanisms linking shiftwork and cancer. Med Hypotheses. 2011;77(3):430-6.

144. International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to humans. Volume 98. Painting, firefighting, and shiftwork. Lyon: International Agency for Research on Cancer, 2010.

145. CAREX Canada. Shiftwork exposure estimates by province (customized data request) [Internet]. 2017 [cited May 12, 2017]. Available from: http://www.carexcanada.ca/en/.

146. Jia Y, Lu Y, Wu K, Lin Q, Shen W, Zhu M, et al. Does night work increase the risk of breast cancer? A systematic review and meta-analysis of epidemiological studies. Cancer epidemiol. 2013;37(3):197-206.

147. Wang F, Yeung KL, Chan WC, Kwok CC, Leung SL, Wu C, et al. A meta-analysis on dose-response relationship between night shift work and the risk of breast cancer. Ann Oncol. 2013;24(11):2724-32.

148. Rao D, Yu H, Bai Y, Zheng X, Xie L. Does night-shift work increase the risk of prostate cancer? a systematic review and meta-analysis. Onco Targets Ther. 2015;8:2817-26.

149. Papantoniou K, Castano-Vinyals G, Espinosa A, Aragones N, Perez-Gomez B, Burgos J, et al. Night shift work, chronotype and prostate cancer risk in the MCC-Spain case-control study. Int J Cancer. 2015;137(5):1147-57.

150. Neil-Sztramko SE, Pahwa M, Demers PA, Gotay CC. Health-related interventions among night shift workers: a critical review of the literature. Scand J Work Environ Health. 2014;40(6):543-56.

151. Canadian Centre for Occupational Health and Safety (CCOHS). OSH Answers: Rotational Shiftwork [Internet].]: CCOHS; 2010 [cited 2017 March 29]. Available from: https://www.ccohs.ca/oshanswers/ergonomics/shiftwrk.html.

152. Ontario Ministry of Labour. Hours of work [Internet].]: Queen's Printer for Ontario; 2015 [cited 2017 March 29]. Available from: https://www.labour.gov.on.ca/english/es/pubs/guide/hours.php.

153. Connor TH, McDiarmid MA. Preventing occupational exposures to antineoplastic drugs in health care settings. CA Cancer J Clin. 2006;56(6):354-65.

154. NIOSH. Preventing occupational exposures to antienoplastic and other hazardous drugs in health care settings [Internet]. Centers for Disease Control and Prevention. National Institute for Occupational Health and Safety. 2004 [cited March 21, 2017]. Available from: https://www.cdc.gov/niosh/docs/2004-165/pdfs/2004-165.pdf.

155. Pan American Health Organization. Safe handling of hazardous chemotherapy drugs in limited-resource settings [Internet]. 2013 [cited March 22, 2017]. Available from: http://www.paho.org/hq/index.php?option=com_docman&task=doc_view&Itemid=270&gid=24983&lang=en.

156. U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health (NIOSH). NIOSH list of antineoplastic and other hazardous drugs in healthcare settings, 2016 [Internet]. [cited March 21, 2017]. Available from: https://www.cdc.gov/niosh/docs/2016-161/pdfs/2016-161.pdf.

157. International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to humans. Supplement 7. Overall Evaluations of Carcinogenicity: An Updating of IARC Monographs Volumes 1 to 42. Lyon: International Agency for Research on Cancer, 1987.

158. International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to humans. Volume 26. Some antineoplastic and immunosuppressive agents. Lyon: International Agency for Research on Cancer, 1987.

159. International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to humans. Volume 50. Pharmaceutical Drugs. Lyon: International Agency for Research on Cancer, 1990.

160. International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to humans. Volume 76. Some antiviral and antineoplastic drugs, and other pharmaceutical agents. Lyon: International Agency for Research on Cancer, 2000.

161. CAREX Canada. Antineoplastic agents [Internet]. 2017 [cited March 24, 2017]. Available from: http://www.carexcanada.ca/en/antineoplastic_agents/occupational_estimate/.

162. Hall AL, Demers PA, Astrakianakis G, Ge C, Peters CE. Estimating National-Level Exposure to Antineoplastic Agents in the Workplace: CAREX Canada Findings and Future Research Needs. Ann Work Expo Health. 2017.

163. Hoppe-Tichy T. Current challenges in European oncology pharmacy practice. J Oncol Pharm Pract. 2010;16(1):9-18.

164. Nussbaumer S, Bonnabry P, Veuthey JL, Fleury-Souverain S. Analysis of anticancer drugs: a review. Talanta. 2011;85(5):2265-89.

165. Vyas N, Yiannakis D, Turner A, Sewell GJ. Occupational exposure to anti-cancer drugs: A review of effects of new technology. J Oncol Pharm Pract. 2014;20(4):278-87.

166. The National Institute for Occupational Safety and Health. Preventing occupational exposures to antineoplastic and other hazardous drugs in health care settings. [Internet]. Department of Health and Human Services. Centers for Disease Control and Prevention 2004 [cited March 24, 2017]. Available from: https://www.cdc.gov/niosh/docs/2004-165/pdfs/2004-165.pdf.

167. The National Institute for Occupational Safety and Health. Workplace solutions - Safe handling of hazardous drugs for veterinary healthcare workers [Internet]. Department of Health and Human Services. Centers for Disease Control and Prevention. 2010 [cited March 24, 2017]. Available from: https://www.cdc.gov/niosh/docs/wp-solutions/2010-150/pdfs/2010-150.pdf.

168. Public Services Health & Safety Association. Safe handling of hazardous drugs in healthcare [Internet]. [cited March 24, 2017]. Available from: https://www.pshsa.ca/wp-content/uploads/2013/11/PSHSA-Whitepaper-Safe-Handling-of-Hazardous-Drugs-in-Healthcare.pdf.

169. Safe handling of cytotoxics [Internet]. Cancer Care Ontario. 2013 [cited March 24, 2017]. Available from: https://www.cancercare.on.ca/common/pages/UserFile.aspx?fileId=293473.

170. WorkSafeBC. Best practices for the safe handling of hazardous drugs. [Internet]. 2015 [cited March 24, 2017]. Available from: https://www.worksafebc.com/en/resources/health-safety/books-guides/best-practices-safe-handling-hazardous-drugs?lang=en.

171. O. Reg. 67/93: Health care and residential facilities. Queen's Printer for Ontario, 2013 [Internet]. [cited March 24, 2017]. Available from: https://www.ontario.ca/laws/regulation/930067#BK20.

172. Hon CY, Teschke K, Chua P, Venners S, Nakashima L. Occupational Exposure to Antineoplastic Drugs: Identification of Job Categories Potentially Exposed throughout the Hospital Medication System. Saf Health Work. 2011;2(3):273-81.

173. Suspiro A, Prista J. Biomarkers of occupational exposure do anticancer agents: a minireview. Toxicol Lett. 2011;207(1):42-52.

174. National Institute of Environmental Health Sciences. Nanomaterials [Internet]. National Insititutes of Health. US Department of Health and Human Services. 2016 [cited March 15, 2017]. Available from: https://www.niehs.nih.gov/health/topics/agents/sya-nano/.

175. Umwelt Bundesamt. Fact sheet: Use of nanomaterials in coatings [Internet]. Federal Environment Agency. 2014 [cited May 26, 2017]. Available from: https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/use_of_nanomaterials_in_coatings_0.pdf.

176. United States Environmental Protection Agency. Research on nanomaterials [Internet]. 2016 [cited March 27, 2017]. Available from: https://www.epa.gov/chemical-research/research-nanomaterials.

177. International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to humans. Volume 111. Some Nanomaterials and Some Fibres. Lyon: International Agency for Research on Cancer, 2017.

178. Schulte PA, Roth G, Hodson LL, Murashov V, Hoover MD, Zumwalde R, et al. Taking stock of the occupational safety and health challenges of nanotechnology: 2000-2015. J Nanopart Res. 2016;18:159.

179. Brouwer DH, van Duuren-Stuurman B, Berges M, Jankowska E, Bard D, Mark D. From workplace air measurement results toward estimates of exposure? Development of a strategy to assess exposure to manufactured nano-objects. J Nanopart Res. 2009;11:1867-81.

180. Kuempel ED, Geraci CL, Schulte PA. Risk assessment and risk management of nanomaterials in the workplace: translating research to practice. Ann Occup Hyg. 2012;56(5):491-505.

181. Best Practices Guidance for Nanomaterial Risk Management in the Workplace, Second Edition; Report R-899 [Internet]. Institut de recherche Robert-Sauve. 2015 [cited June 21, 2017]. Available from: http://www.irsst.qc.ca/media/documents/PubIRSST/R-899.pdf?v=2017-06-20.

182. 182. Methner MM. Engineering case reports. Effectiveness of local exhaust ventilation (LEV) in controlling engineered nanomaterial emissions during reactor cleanout operations. J Occup Environ Hyg. 2008;5(6):D63-9.

183. Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). Agronomy Guide for Field Crops - Publication 811 [Internet]. 2017 [cited July 5]. Available from: http://www.omafra.gov.on.ca/english/crops/pub811/p811toc.html.

184. International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to humans.. Volume 113. 2,4-Dichlorophenoxyacetic acid (2,4-D) and some organochlorine insecticides. Lyon: International Agency for Research on Cancer, 2016.

185. Loomis D, Guyton K, Grosse Y, El Ghissasi F, Bouvard V, Benbrahim-Tallaa L, et al. Carcinogenicity of lindane, DDT, and 2,4-dichlorophenoxyacetic acid. Lancet Oncol. 2015;16(8):891-2.

186. Guyton KZ, Loomis D, Grosse Y, El Ghissassi F, Bouvard V, Benbrahim-Tallaa L, et al. Carcinogenicity of pentachlorophenol and some related compounds. Lancet Oncol. 2016.

187. Health Canada, Pest Management Regulatory Agency. Pesticide Label Search [Internet]. 2017 [cited April 6, 2017]. Available from: http://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php.

188. Smith MT, Guyton KZ, Gibbons CF, Fritz JM, Portier CJ, Rusyn I, et al. Key Characteristics of Carcinogens as a Basis for Organizing Data on Mechanisms of Carcinogenesis. Environ Health Perspect. 2016;124(6):713-21.

189. George L, Granath F, Johansson AL, Cnattingius S. Self-reported nicotine exposure and plasma levels of cotinine in early and late pregnancy. Acta Obstet Gynecol Scand. 2006;85(11):1331-7.

190. Health Canada. Consumer Product Safety: The regulation of pesticides in Canada [Internet].]: Health Canada; 2009 [cited 2017 March 29]. Available from: http://www.hc-sc.gc.ca/cps-spc/pubs/pest/_fact-fiche/reg-pesticide/index-eng.php.

191. Weinberg JL, Bunin LJ, Das R. Application of the industrial hygiene hierarchy of controls to prioritize and promote safer methods of pest control: a case study. Public Health Rep. 2009;124 Suppl 1:53-62.

192. Sedentary Behaviour Research N. Letter to the editor: standardized use of the terms "sedentary" and "sedentary behaviours". Appl Physiol Nutr Metab. 2012;37(3):540-2.

193. Yates T, Wilmot EG, Davies MJ, Gorely T, Edwardson C, Biddle S, et al. Sedentary behavior: what's in a definition? Am J Prev Med. 2011;40(6):e33-4.

194. Katzmarzyk PT. Physical activity, sedentary behavior, and health: paradigm paralysis or paradigm shift? Diabetes. 2010;59(11):2717-25.

195. Tremblay MS, Colley RC, Saunders TJ, Healy GN, Owen N. Physiological and health implications of a sedentary lifestyle. Appl Physiol Nutr Metab. 2010;35(6):725-40.

196. The Conference Board of Canada. The Economic Impact of Reducing Physical Inactivity and Sedentary Behaviour. Ottawa: The Conference Board of Canada, 2014 Contract No.: 6436.

197. Cong YJ, Gan Y, Sun HL, Deng J, Cao SY, Xu X, et al. Association of sedentary behaviour with colon and rectal cancer: a meta-analysis of observational studies. Br J Cancer. 2014;110(3):817-26.

198. Schmid D, Leitzmann MF. Television viewing and time spent sedentary in relation to cancer risk: a meta-analysis. J Natl Cancer Inst. 2014;106(7).

199. Boyle T, Fritschi L, Heyworth J, Bull F. Long-term sedentary work and the risk of subsite-specific colorectal cancer. Am J Epidemiol. 2011;173(10):1183-91.

200. Simons CC, Hughes LA, van Engeland M, Goldbohm RA, van den Brandt PA, Weijenberg MP. Physical activity, occupational sitting time, and colorectal cancer risk in the Netherlands cohort study. Am J Epidemiol. 2013;177(6):514-30.

201. International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to humans.. Internal Report 14/002. Report of the Advisory Group to Recommend Priorities for IARC Monographs during 2015-2019. Lyon: International Agency for Research on Cancer, 2014.

202. CAREX Canada. Emerging Issues [Internet].]: CAREX Canada; 2017 [cited 2017 March 29]. Available from: http://www.carexcanada.ca/en/emerging_issues/.

203. Shrestha N, Ijaz S, Kukkonen-Harjula KT, Kumar S, Nwankwo CP. Workplace interventions for reducing sitting at work. Cochrane Database Syst Rev. 2015;1:CD010912.

204. R.R.O. 1990, Reg. 860: Workplace Hazardous Materials Information System (WHMIS) [Internet]. 2017 [June 29, 2017]. Available from: https://www.ontario.ca/laws/regulation/900860.

205. WorkSafeBC. Table of Exposure Limits for Chemical and Biological Substances [Internet]. 2016 [cited May 12, 2017]. Available from: https://www.worksafebc.com/en/resources/law-policy/ohs-guidelines/table-exposure-limits-chemical-biological-substances?lang=en.

206. WorkSafeBC. Prevention Manual Update 2016-6 July 15, 2016 [Internet]. 2016 [cited May 26, 2017]. Available from: https://www.worksafebc.com/en/resources/law-policy/prevention-manual-previous-amendments/update-package-2016-6-prevention-manual-july-2016?lang=en&direct.

207. Government of Ontario. Ontario Toxics Reduction Program: A Guide for Regulated Facilities [Internet]. 2016 [cited May 12, 2017]. Available from: https://www.ontario.ca/page/ontario-toxics-reduction-program-guide-regulated-facilities.

208. Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH). Authorisation list [Internet]. European Chemicals Agency. 2016 [cited March 29, 2017]. Available from: https://echa.europa.eu/addressing-chemicals-of-concern/authorisation/recommendation-for-inclusion-in-the-authorisation-list/authorisation-list.

209. Toxics Use Reduction Institute. Formaldehyde fact sheet [Internet]. University of Massachusetts Lowell. 2013 [cited May 12, 2017]. Available from: http://www.turi.org/TURI_Publications/TURI_Chemical_Fact_Sheets/Formaldehyde_Fact_Sheet/Formaldehyde_Fact_Sheet.

210. Toxics Use Reduction Institute (TURI). Opportunities for Cancer Prevention: Trends in the Use and Release of Carcinogens in Massachusetts. Methods and Policy Report #29 [Internet]. Toxics Use Reduction Institute, University of Massachusetts Lowell. 2013 [cited June 29, 2017]. Available from: http://www.turi.org/TURI_Publications/TURI_Methods_Policy_Reports/Opportunities_for_Cancer_Prevention_Trends_in_the_Use_and_Release_of_Carcinogens_in_Massachusetts._2013/Carcinogens_Report.

211. Government of Ontario. Minister's Report on Toxics Reduction 2016 [Internet]. 2016 [cited May 12, 2017]. Available from: https://www.ontario.ca/document/ministers-report-toxics-reduction-2016.

212. Canadian Environmental Law Association. Letter RE: EBR Registry Number 011-1191 Amendment O. Reg. 455/09 [Internet]. 2011 [cited May 12, 2017]. Available from: http://www.cela.ca/sites/cela.ca/files/768EBR-OReg455.pdf.

Occupational
Cancer
Research
Centre

Ontario
Cancer Care Ontario

525 University Avenue, 3rd Floor
Toronto, ON M5G 2L3
416.217.1849
occupationalcancer.ca

620 University Avenue
Toronto, ON M5G 2L7
416.971.9800
publicaffairs@cancercare.on.ca
cancercare.on.ca