Firefighter Cancer Research Priorities Workshop

Report on the highlights from the 2022 Firefighter Cancer Research Priorities Workshop

January 2024

Occupational Cancer Research Centre

Health Canada Santé Canada

Workshop and Report Team

Tracy Kirkham
Associate Director and Senior Scientist, Exposure, OCRC | Assistant Professor (Status), Dalla Lana School of Public Health, University of Toronto

Paul A. Demers
Director and Senior Scientist, Epidemiology, OCRC | Professor (Status), Dalla Lana School of Public Health, University of Toronto

Paul A. White
Senior Scientist, Environmental Health Science and Research Bureau, Health Canada

Dave Stieb
Public Health Physician/Epidemiologist (retired), Environmental Health Science and Research Bureau, Health Canada

Kate Jardine
Lead, Knowledge Translation and Exchange, OCRC

Tiffany Lieu
Specialist, Knowledge Translation and Exchange, OCRC

Rachel Tyli
Laboratory Medicine and Pathobiology, University of Toronto

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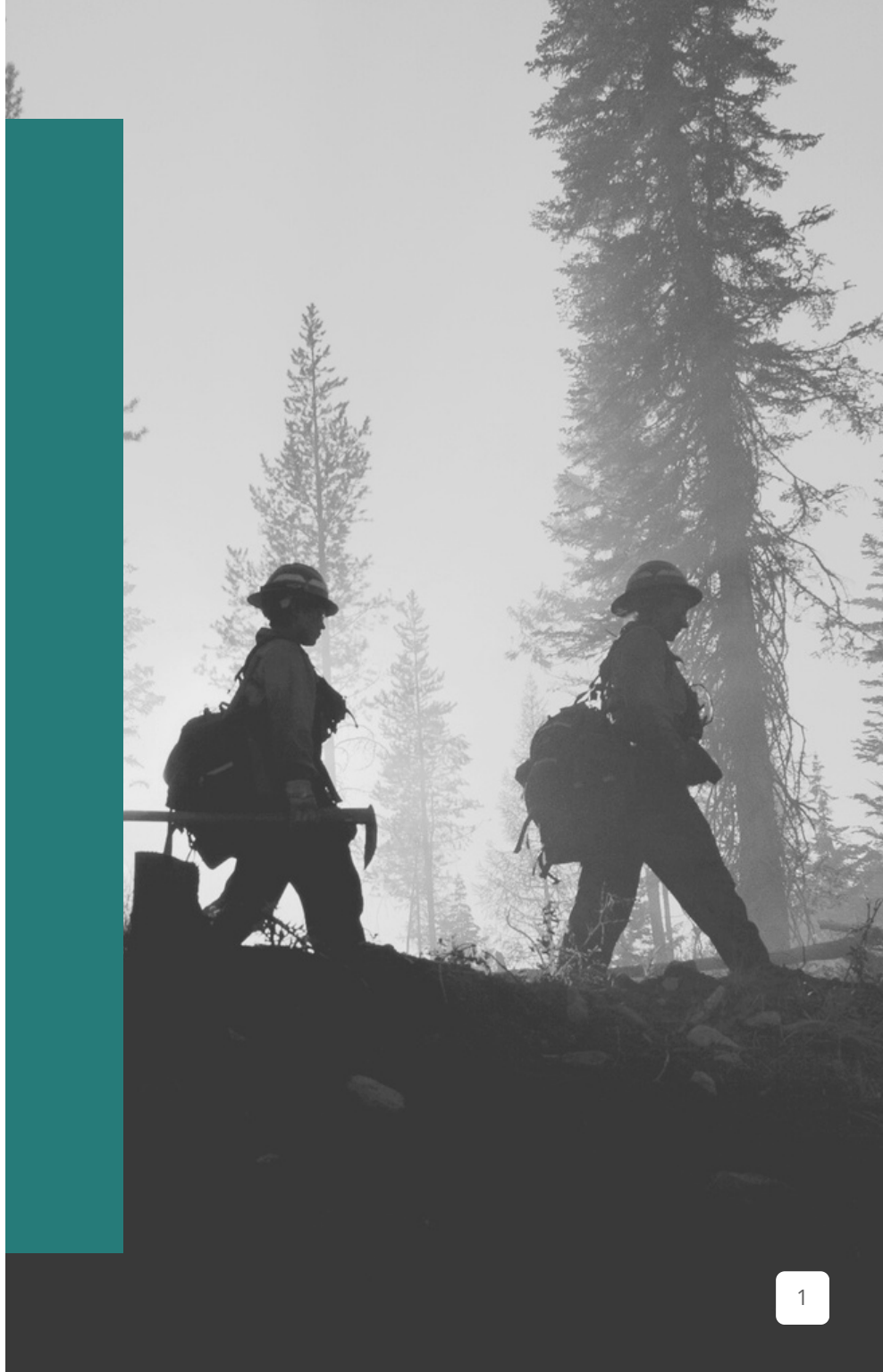

Land Acknowledgement

The land on which the workshop was held is the un-ceded, un-surrendered Territory of the Anishinaabe Algonquin Nation. The land on which OCRC operates has been the traditional land of the Huron-Wendat, the Seneca, and the Mississaugas of the Credit for thousands of years. Today, this land is still home to many Indigenous people from across Turtle Island, and we are grateful to have the opportunity to work here.

Funding Acknowledgement

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Occupational Cancer Research Centre

Occupational Cancer Research Centre,
Ontario Health
525 University Avenue, 5th Floor
Toronto, Ontario M5G 2L3

Telephone: 416-217-1849

Email: ocrc@ontariohealth.ca

Website: www.occupationalcancer.ca

Table of Contents

List of Abbreviations

AhR	Aryl hydrocarbon receptor
AIRS	Australian Incident Reporting System
DEE	Diesel engine exhaust
DNA	Deoxyribonucleic acid
FCI	Firefighter Cancer Initiative
FFAP	Firefighter Action Plan
FPC	Firefighters Preventing Cancer
IARC	International Agency for Research on Cancer
IRSST	Institut de recherche Robert-Sauvé en santé et en sécurité du travail
NFR	National Firefighter Registry
NIOSH	National Institute for Occupational Safety and Health
OCRC	Occupational Cancer Research Centre
OHS	Occupational Health and Safety
PAH	Polycyclic aromatic hydrocarbon
PFAS	Per- and polyfluoroalkyl substances
PPC	Personal protective clothing
PPE	Personal protective equipment
RNA	Ribonucleic acid
SOP	Standard operating procedures
UV	Ultraviolet
WHO	World Health Organization

Executive Summary

About the Workshop

Firefighters are exposed to a wide range of known and suspected carcinogens. Due to the growing concern around firefighting and cancer in Canada, Health Canada and the Occupational Cancer Research Centre co-sponsored a workshop on firefighter cancer research priorities. The workshop was held in Ottawa, Canada on December 8-9, 2022. Workshop participants exchanged information on the current state of knowledge regarding cancer and firefighting and discussed knowledge gaps and priorities for research on cancer and firefighting.

The objectives of the workshop were to:

1. Provide an overview of past and ongoing research in Canada and internationally.
2. Identify gaps in firefighting and cancer research in Canada and internationally.
3. Identify priorities for firefighting and cancer research.
4. Identify specific priorities for Canada, and the resources needed to address them.

This report includes summaries of the presentations, and outlines the major knowledge gaps, research priorities, and capacity needs discussed at the workshop.

Presentations

The workshop began with presentations outlining the state of the science regarding (i) epidemiological links between firefighting and cancer, (ii) the nature of firefighters' exposure to carcinogens, and (iii) mechanistic links between firefighting and cancer. This was followed by a series of short presentations highlighting current and recent Canadian research on firefighting and cancer, and the capacity and expertise available for this type of research in Canada. Finally, international firefighting researchers presented overviews of their research models as examples of research methods and processes that could be applied in Canada. Each presenter highlighted knowledge gaps and directions for future research.

Knowledge Gaps Identified at the Workshop

Knowledge gaps were identified by presenters throughout the workshop, and further evaluated through a series of breakout sessions and broader group discussions. The key gaps fall into the categories of underrepresented populations, epidemiology studies, exposure studies, mechanistic and toxicology studies, intervention studies, behavioural studies, knowledge translation, data collection and data resources, governance and government action, and health surveillance and screening.

Research Priorities Identified at the Workshop

Ten research priorities were identified and agreed upon by workshop participants. The priorities relate to intervention research, personal protective equipment, surveillance data collection and/or data sharing, cancer screening, biomarkers of effect and mechanistic evidence, legislation, exposures and effects across different types of firefighting, impacts on firefighters' spouses and families, knowledge translation, and understudied populations.

Research Capacity in Canada

Strengths and weaknesses related to Canada's ability to conduct firefighter research were discussed by participants. Strengths include accessible electronic health data, collaborative partnerships, experienced researchers, access to laboratory infrastructure, a non-litigious framework, and support from government, firefighter communities, funding agencies and the public. Weaknesses include the lack of centralized/federal oversight of firefighting, lack of funding, lack of leadership, challenges in engaging with or promoting change among certain firefighter groups, and difficulties creating large studies, particularly for underrepresented populations.

Research Priorities for Canada

Research priorities were selected by the report authors as priorities for Canada based on their importance during workshop discussions and the capacity available in Canada to address the knowledge gap. These priorities include studies investigating
1) underrepresented populations, particularly wildland firefighters;
2) exposure interventions, including those that examine the effect of control strategies on biomarkers of exposure and effect;
3) mechanistic effects linked to cancer; and
4) exposure, including improved exposure assessment for epidemiology research.

Background and Overview of the Workshop

Workshop Drivers

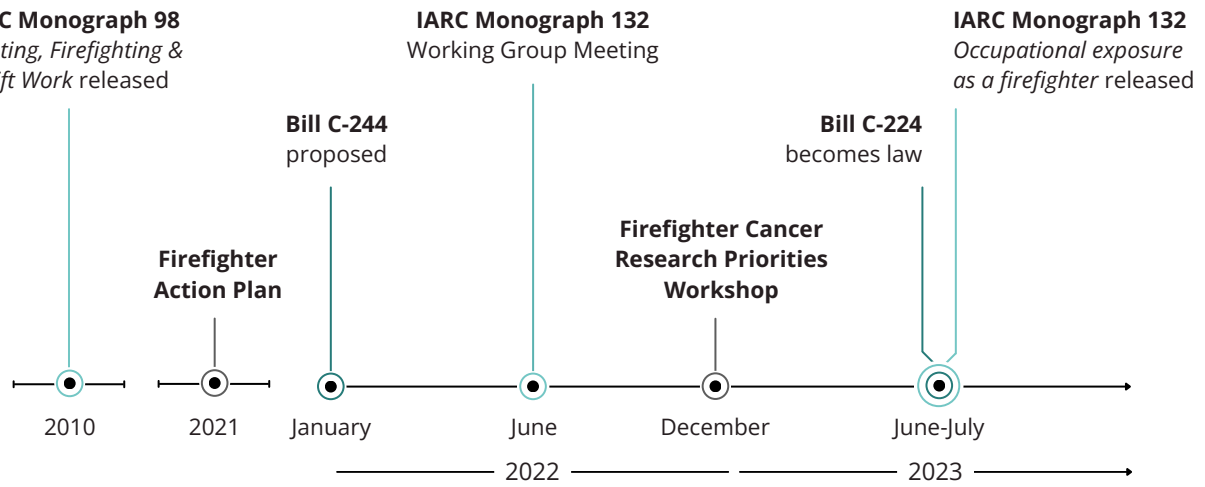
Due to the nature of their work, firefighters are exposed to a wide range of known and suspected carcinogens. These include exposures encountered while at fires (e.g., combustion products and building materials) and when not at fires (e.g., shift work, diesel engine exhaust). Fire-related contaminants can also be transported to the fire truck, fire hall/station, personal vehicle, or home on contaminated gear and clothing, increasing the risk of exposure.

Firefighters' exposures are thought to vary widely and may depend on many different factors including the:

- type of firefighting,
- work status (e.g., career vs. volunteer),
- type of material being burned and/or type of fire (e.g., structure vs. vehicle vs. wildland),
- role at the fire (e.g., suppression vs. command and control),
- availability and use of different exposure controls, and
- type of non-fire related tasks.

Over the past few decades, there has been a growing body of evidence that firefighters have an increased risk of cancer. Consequently, several steps have been taken, both in Canada and internationally, to evaluate the evidence and introduce policies to better protect firefighters. This includes evaluations of the carcinogenicity of occupational exposure as a firefighter, the Firefighter Action Plan, and the *National Framework on Cancers Linked to Firefighting Act.*

Timeline of key workshop drivers



IARC Evaluations of Firefighting

In 2007, the International Agency for Research on Cancer (IARC) classified "occupational exposure as a firefighter" as possibly carcinogenic to humans (IARC Group 2B) for three cancer types (1).

In 2021, additional research published since the initial evaluation in 2007 prompted IARC to launch a re-evaluation of the relationship between firefighting and cancer.

The Working Group, which met in Lyon, France June 7-14, 2022, was made up of 25 scientists from eight countries, including four from Canada. They concluded that "occupational exposure as a firefighter" is carcinogenic to humans (IARC Group 1) for seven cancer types (2). A summary of their evaluation was published in July 2022 in *Lancet Oncology* (3).

Comparison of IARC Monographs that Evaluate Firefighting

2007

IARC Monograph 98
Limited Evidence of Increased Risk:

- Testicular Cancer
- Non-Hodgkin Lymphoma
- Prostate Cancer

2022

IARC Monograph 132
Sufficient Evidence of Increased Risk:

- Bladder Cancer
- Mesothelioma

Limited Evidence of Increased Risk:

- Testicular Cancer
- Non-Hodgkin Lymphoma
- Prostate Cancer
- Colon Cancer
- Melanoma of the Skin

About IARC

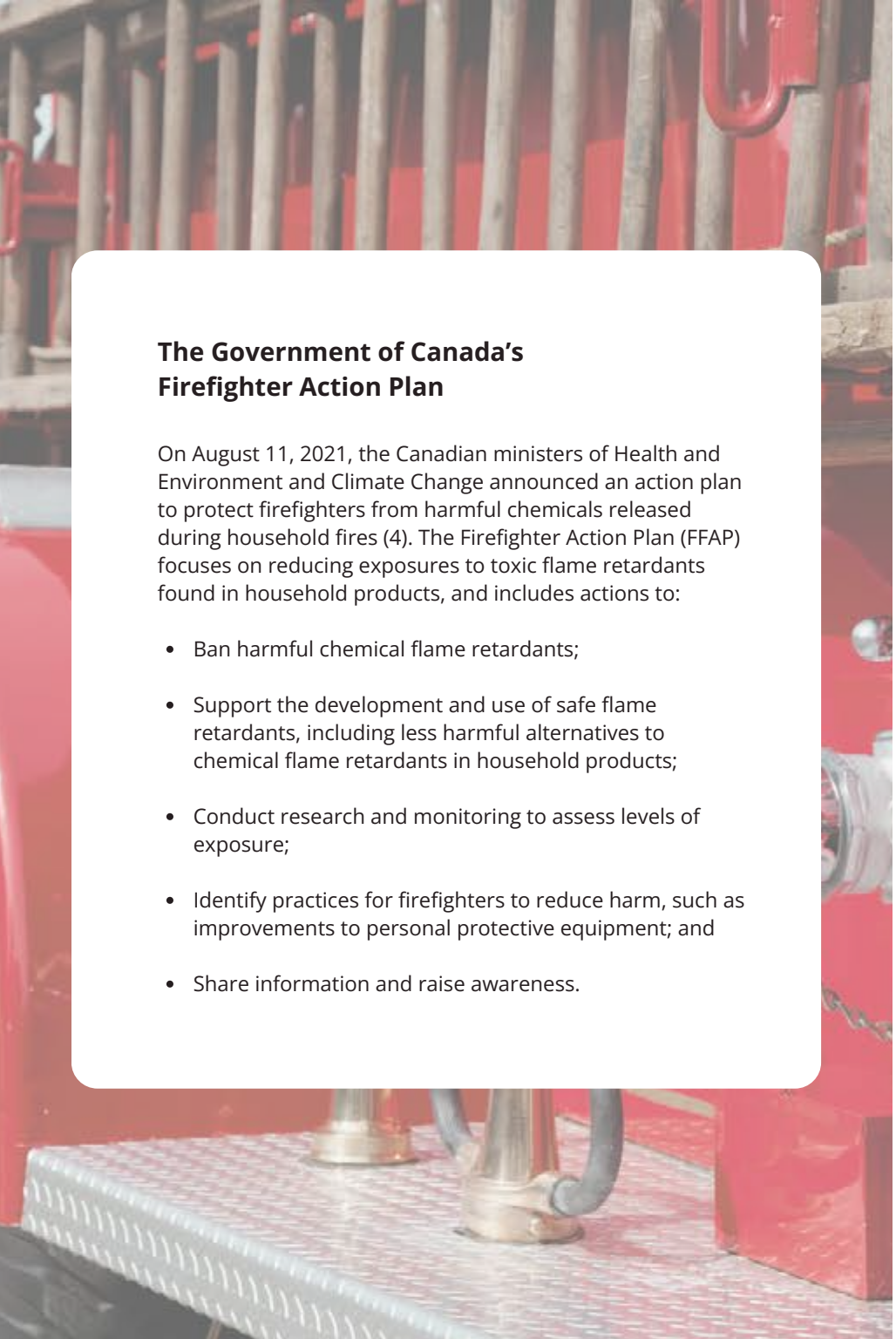
The International Agency for Research on Cancer (IARC) is a specialized agency of the World Health Organization (WHO), founded in 1965.

What IARC does:

IARC's mission is to promote international collaboration in cancer research. The IARC Monographs Program identifies and evaluates causes of cancer in humans and is the leading international agency for the classification of causes of cancer. IARC classifies hazards into four categories depending on the strength of the evidence that they increase the risk of cancer in humans:

IARC Classification System

1	Carcinogenic to humans
2A	Probably carcinogenic to humans
2B	Possibly carcinogenic to humans
3	Carcinogenocity not classifiable



The Government of Canada's Firefighter Action Plan

On August 11, 2021, the Canadian ministers of Health and Environment and Climate Change announced an action plan to protect firefighters from harmful chemicals released during household fires (4). The Firefighter Action Plan (FFAP) focuses on reducing exposures to toxic flame retardants found in household products, and includes actions to:

- Ban harmful chemical flame retardants;
- Support the development and use of safe flame retardants, including less harmful alternatives to chemical flame retardants in household products;
- Conduct research and monitoring to assess levels of exposure;
- Identify practices for firefighters to reduce harm, such as improvements to personal protective equipment; and
- Share information and raise awareness.

The *National Framework on Cancers Linked to Firefighting Act*

An *Act to establish a national framework for the prevention and treatment of cancers linked to firefighting* was proposed as Bill C-224 in January 2022, and officially became law in June 2023 (5,6).

The purpose of this national framework is to "raise awareness of cancers linked to firefighting with the goal of improving access for firefighters to cancer prevention and treatment." The Act outlines measures that may be included in the framework to reach this goal, including promoting research, data collection and knowledge sharing related to cancers among firefighters.

***The National Framework* may include measures to:**

- Explain and support research on the link between firefighting and certain types of cancer.
- Identify the training, education and guidance needs of health care and other professionals related to the prevention and treatment of cancers linked to firefighting and compile information relating to those needs.
- Make recommendations respecting regular screenings for cancers linked to firefighting.
- Promote research and improve data collection on the prevention and treatment of cancers linked to firefighting.
- Promote information and knowledge sharing in relation to the prevention and treatment of cancers linked to firefighting.
- Prepare a summary of existing standards that recognize cancers linked to firefighting as occupational diseases.

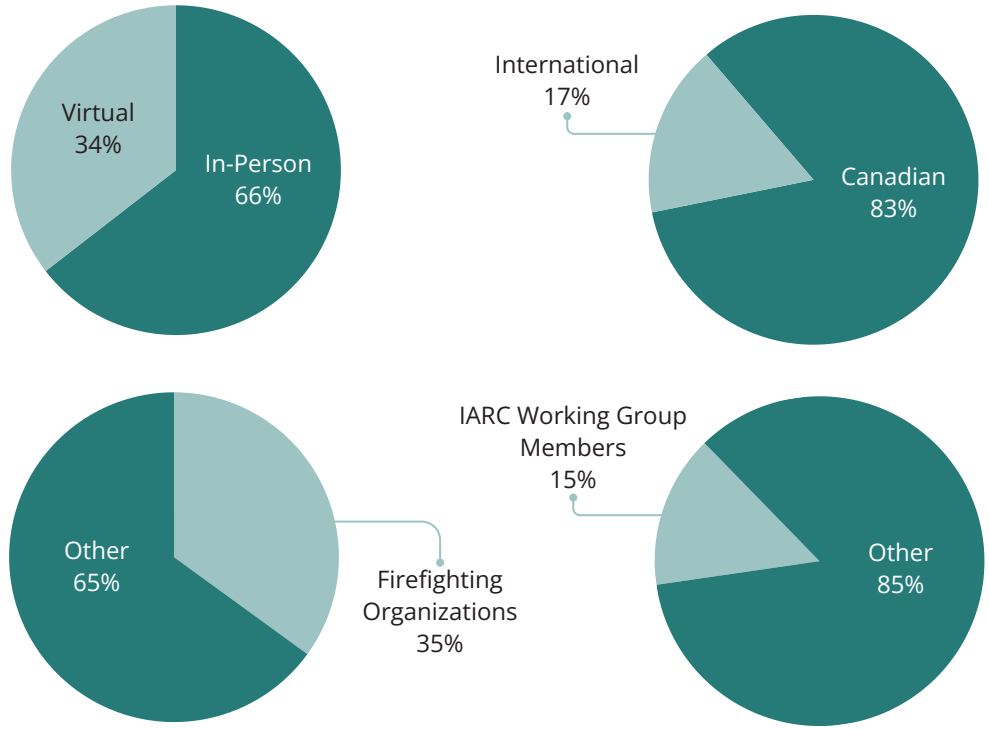
About the Workshop

Due to the growing concern around firefighting and cancer in Canada, a workshop on firefighter cancer research priorities was held in Ottawa, Canada on December 7-8, 2022. The workshop was co-sponsored by the Occupational Cancer Research Centre and Health Canada.

Participants

The workshop brought together approximately 70 participants for two days to exchange information on the current state of knowledge regarding cancer and firefighting, and to discuss current knowledge gaps and priorities for research, especially in Canada. A full list of the workshop attendees and their affiliations are in Appendix 1. The participants included representatives of many career and volunteer fire services, firefighting associations and unions; key governmental agencies; and Canadian and international researchers, 11 of whom were members of the IARC Working Group that evaluated firefighting.

Participant Breakdown



Firefighter Representation

Union Representatives

Management Representatives

Military **Wildland** **Indigenous** **Federal** **Municipal**

Workshop Structure

The first day of the workshop began with presentations summarizing the published research evidence considered in IARC's evaluation of the carcinogenicity of occupational exposure as a firefighter (i.e., IARC Monograph 132). The presentation topics corresponded to the three sub-groups of evidence assessed by the IARC Monograph 132 Working Group: exposure evaluation, epidemiological evidence, and mechanistic considerations. This was followed by a series of short presentations highlighting current research on firefighting and cancer in Canada, and presentations on international research initiatives.

Day two focused on identifying knowledge gaps and research priorities using a series of breakout sessions and broader open group discussions.

This report includes summaries of the presentations, and outlines the major gaps, priorities, and capacity needs discussed at the workshop. The workshop agenda and biographies of the speakers are availablein Appendix 2 and 3.

Workshop Objectives

1. Provide an overview of past and ongoing research in Canada and internationally.
2. Identify gaps in firefighting and cancer research in Canada and internationally.
3. Identify priorities for firefighting and cancer research.
4. Identify specific priorities for Canada, and the resources needed to address them.

What do the IARC Monograph Sub-Groups Evaluate?

A

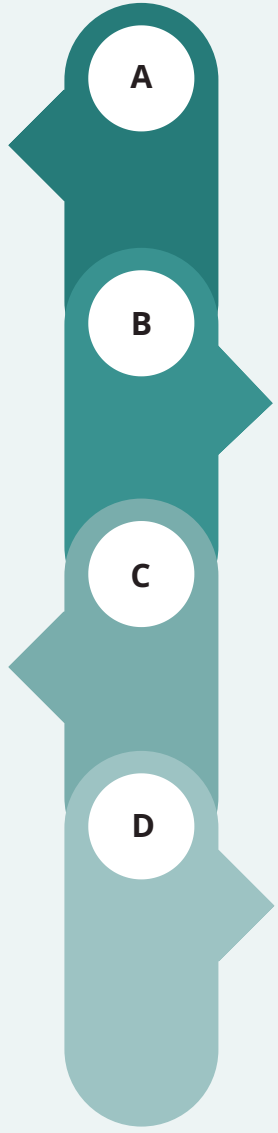
Epidemiology

- The epidemiology sub-group reviews studies measuring the risk of cancer in humans who have been exposed to the hazard under investigation. They assess the risk for each cancer site independently.

C

Exposure

- The exposure sub-group reviews studies that measure the hazard in different environments to identify where the hazard can be found, its physical and chemical properties, and who and how people may be exposed to the hazard.
- The exposure sub-group also reviews the quality of the exposure assessment methods used in epidemiology studies to assist the epidemiology sub-group's evaluation.



B

Mechanistic Data

- The mechanism sub-group reviews studies that examine whether the hazard displays any of the 10 key characteristics of human carcinogens (see below).
- The weight of the evidence is used to evaluate support for each of the key characteristics separately and determine whether the hazard:
  1. Is genotoxic,
  2. Induces epigenetic alterations,
  3. Induces oxidative stress,
  4. Modulates receptor-mediated effects,
  5. Induces chronic inflammation,
  6. Alters DNA repair or genomic instability,
  7. Is immunosuppressive,
  8. Causes immortalization,
  9. Is electrophilic or metabolically activated,
  10. Alters cell proliferation, cell death or nutrient supply.

D

Animal Studies

- The animal studies sub-group reviews experimental studies that measure the risk of cancer in animals exposed to known levels of the hazard.
- For firefighting, there were no animal studies to evaluate.

Overview of Published Research

The workshop began with three presentations outlining the state of the science regarding (i) epidemiological links between firefighting and cancer, (ii) the nature of firefighters' exposure to carcinogens, and (iii) mechanistic links between firefighting and cancer. Each presenter concluded with statements regarding knowledge gaps and directions for further research within the respective research area.

All three presenters were members of the IARC Working Group that evaluated the carcinogenicity of firefighting. The aim of these presentations was to provide workshop attendees with background knowledge on what is known about the risks of cancer among firefighters.

1. EPIDEMIOLOGICAL RESEARCH ON CANCER AMONG FIREFIGHTERS
   Dr. Robert (Doug) Daniels
2. EXPOSURE ASSESSMENT IN RESEARCH ON FIREFIGHTERS
   Professor Deborah Glass
3. MECHANISTIC EVIDENCE FOR THE CARCINOGENICITY OF FIREFIGHTING
   Dr. David DeMarini

NOTE: presentation summaries were approved by the speakers, and key takeaways were provided by each speaker.

Epidemiological Research on Cancer Among Firefighters

Dr. Robert (Doug) Daniels, US National Institute of Occupational Safety and Health

Dr. Daniels provided an overview of published epidemiological studies of firefighters and cancer. He discussed epidemiology's role in characterizing and managing cancer risks among firefighters, and the strengths and limitations of current epidemiological research. Dr. Daniels also provided a summary of the epidemiological findings published by the IARC Working group, identifying that there was sufficient evidence from epidemiological studies that firefighting causes mesothelioma and bladder cancer. He also noted that the group found limited evidence that firefighting may cause colon, prostate, and testicular cancer, as well as melanoma and non-Hodgkin lymphoma.

Dr. Daniels identified gaps in the epidemiological research that could help facilitate a greater understanding of the risks of firefighting. He reported that most studies have focused on white male career firefighters in urban fire departments, and more research is needed to understand cancer risks in other populations, including women, volunteer firefighters, wildland firefighters, and minorities. As well, the relationship between firefighters' exposures and their cancer risk is not well defined, and better exposure metrics are needed. Finally, intervention research is needed to understand the impact of interventions and controls to reduce exposure and disease outcomes, and secondary prevention to promote early disease diagnosis.

KEY TAKEAWAYS

- Methods used to assess cancer risks are imperfect; however, current epidemiologic studies generally support a link between firefighting exposure and cancer.
- Most research participants have been white male career firefighters employed in urban departments; therefore, more research is needed to clarify risks in understudied groups, such as minorities, women, volunteers, and wildland firefighters.
- Interventional research is needed to examine cancer prevention in the fire service, such as tobacco cessation, lifestyle modification (e.g., diet, obesity, and exercise), engineering controls, PPE use, and operating procedures for minimizing exposure.

Exposure Assessment in Research on Firefighters

Professor Deborah Glass, Monash University

Professor Glass discussed firefighters' occupational exposures and the methods used to assess exposure in epidemiologic studies. She reported that firefighters may be exposed to many hazards including combustion products from fires and motorized equipment or vehicles, building materials containing asbestos and silica, flame retardants, firefighting foams containing per- and polyfluoroalkyl substances (PFAS), heat, ultraviolet (UV) radiation, and shiftwork, among others. She highlighted that while there are data available to characterize the types of hazards firefighters may be exposed to, understanding the extent of exposure for individuals, for example in cohort studies, is much more challenging.

Firefighters' exposures may vary depending on the setting (e.g., municipal, rural, wildland, or other setting), type of incident, stage of fire, role on the fire crew, training, and access to protective equipment, and this information is often not available for epidemiologic studies. Since firefighters are exposed to a complex and varied mixture of exposures, it is also difficult to identify the health risks attributable to specific exposures. Changes in exposure over time can also make exposure assessment challenging for epidemiologic studies, such as reductions in the use of PFAS foams, increases in car and plastics fires, and longer, hotter fires resulting from climate change with increasing impact on urban areas.

Prof. Glass identified several gaps in exposure research. She reported that most studies have looked at male municipal firefighters from developed countries, identifying the need for exposure characterization for other types of firefighters, such as wildland, volunteer, seasonal, military, airport, non-suppression (e.g., trainers, fire investigators), female, Indigenous, and older firefighters; and firefighters from low- and middle-income countries. She also reported a need to identify effective exposure controls, including improved personal protective equipment (PPE), controls for diesel engine exhaust in fire halls, and strategies to identify and mitigate heat stress.

KEY TAKEAWAYS

- Firefighters are exposed to many different hazards which vary with the type of fire and firefighter role.
- The hazards have changed and are changing, making interpretation of risks more complex.
- Data on the health risks for firefighters other than male municipal firefighters from developed counties is very limited.

Mechanistic Evidence for the Carcinogenicity of Firefighting

Dr. David DeMarini, Scientist Emeritus, US Environmental Protection Agency

Dr. DeMarini's presentation provided an overview of published mechanistic evidence, discussed the role of the mechanistic evidence in IARC's evaluation process, and outlined the five mechanisms (out of 10) of carcinogenicity identified by the IARC Working Group for occupational exposure as a firefighter: genotoxicity, epigenetic alterations, oxidative stress, chronic inflammation, and receptor modulation. He reported that the evidence for genotoxicity of exposures during firefighting is related to the formation of polycyclic aromatic hydrocarbon (PAH)-DNA adducts, increases in urinary mutagenicity, and the formation of DNA strand breaks in blood cells and chromosomal damage in buccal cells. Changes in the methylation of cancer-related genes and changes in the expression of microRNAs linked to cancer support epigenetic alterations. Studies showing oxidative damage of both DNA and lipids provided evidence to support the mechanism of oxidative stress. Additional studies showed evidence supporting the assertion that combustion-derived PAHs can enter cells and bind to the aryl hydrocarbon receptor (AhR), thus stimulating a cascade of cancer-related cellular processes by modulating receptor-mediated effects. Dr. DeMarini noted evidence indicating that occupational exposure as a firefighter contributes to chronic inflammatory stress through increases in airway markers of inflammation and exposure-related bronchial hyper-reactivity.

Dr. DeMarini concluded his presentation by outlining the need for research related to alterations in DNA repair, immunosuppression, and cellular immortalization, as well as additional targeted research investigating the incidence and severity of genetic damage linked to firefighting. He emphasized the importance of study design considerations for any research investigating mechanism-aligned effects in firefighters, such as sample collection timing and control for extraneous exposures. He also noted the need for studies that investigate genotoxic effects on germ cells, and the concomitant potential for heritable genetic effects.

KEY TAKEAWAYS

- Firefighting as an occupation exhibited strong evidence for 5 key characteristics of carcinogens: genotoxicity, epigenetic alterations, oxidative stress, chronic inflammation, and receptor-modulated effects.
- Studies in both municipal (structural) and wildland firefighters showing that that firefighting causes mutagenic urine is especially important because urinary mutagenicity is a risk factor for bladder cancer, which is one of the cancers associated with firefighting as an occupation.
- Further support for the carcinogenicity of firefighting as an occupation could be provided by studies using DNA sequencing to determine the frequency and types of mutations in blood cells of firefighters versus non-firefighters.

Overview of Recent and Ongoing Research in Canada

The following presentations gave an overview of current and recent Canadian research on firefighters. The presentations highlighted the strengths and research capacity available in Canada and identified some of the gaps and challenges associated with firefighter research in Canada. A list of published Canadian papers on cancer and firefighting is also provided in Appendix 4.

1. INNOVATIONS FOR ASSESSING OCCUPATIONAL EXPOSURE TO CARCINOGENS IN POPULATION-BASED STUDIES
   Dr. Victoria Arrandale
2. FROM RESEARCHERS TO THE FIELD: GETTING SOLUTIONS INTO THE HANDS OF FIREFIGHTERS
   Dr. Claire Austin
3. STUDIES OF WILDLAND FIREFIGHTERS
   Dr. Nicola Cherry
4. EXPOSURE TO CHEMICALS AMONG MONTRÉAL FIREFIGHTERS
   Dr. Jonathan Chevrier
5. DIESEL ENGINE EXHAUST AND CONTROLS IN ONTARIO FIRE HALLS
   Dr. Tracy Kirkham
6. RECENT AND ONGOING RESEARCH FROM THE IRSST
   Dr. France Labrèche
7. THE FIREFIGHTERS PREVENTING CANCER (FPC) TOOL
   Dr. Patrick McGrath
8. SURVEILLANCE STUDIES OF FIREFIGHTERS AT OCRC
   Dr. Jeavana Sritharan
9. OCCUPATIONAL EXPOSURES OF FIREFIGHTERS TO (GENO)TOXICANTS OF CONCERN
   Dr. Paul White

NOTE: presentation summaries were approved by the speakers, and key takeaways were provided by each speaker.

Innovations for Assessing Occupational Exposure to Carcinogens in Population-Based Studies

Dr. Victoria Arrandale, Dalla Lana School of Public Health, University of Toronto

Dr. Arrandale presented on her ongoing work using two emerging methods, high-resolution metabolomics and passive wristband samplers, to assess organophosphate flame retardant exposure. In this study, firefighters, paramedics, and office workers provide blood and urine samples and wear a silicone wristband for 24 hours. Results from this study will shed light on the amount of flame retardants that workers touch, inhale and ingest, and will help in assessing the feasibility of these methods for exposure assessment in larger epidemiological studies.

This study will help us determine whether newer omics approaches have value as tools for exposure assessment in occupational epidemiology.

From Researchers to the Field: Getting Solutions into the Hands of Firefighters

Dr. Claire Austin, Science and Technology Branch, Environment and Climate Change Canada

Dr. Austin highlighted the importance of translating research into practical interventions to reduce firefighters' exposures and occupational disease. She discussed the need for behavioural interventions to improve the use of personal protective equipment by firefighters, and the need for certified respirators designed for wildland firefighting.

Health and safety regulations need to include wildland firefighter respiratory protection.

Studies of Wildland Firefighters

Dr. Nicola Cherry, Department of Medicine, University of Alberta

Dr. Cherry presented results from a study of PAH exposure among wildland firefighters. The study found that both inhalation and dermal exposure contributes to PAH levels (i.e., biomarkers) in the urine of wildland firefighters, which can exceed the recommended limits. She also presented on a new study linking Alberta wildland firefighters' exposure records to administrative health records. This is the first long-term cohort study of wildland firefighters. Dr. Cherry emphasized the need for more research on the exposures and health outcomes experienced by this understudied group.

Exposures in wildland firefighters are significant and warrant sound intervention studies.

Exposure to Chemicals Among Montréal Firefighters

Dr. Jonathan Chevrier, Department of Epidemiology, Biostatistics & Occupational Health, McGill University

Dr. Chevrier is currently conducting a pilot study collecting blood and urine samples to identify chemical exposures among Montréal firefighters. The goal of the study is to quantify exposures to chemicals among firefighters, identify activities and behaviours associated with exposure, and determine whether exposure is associated with adverse health outcomes. He highlighted the need for research evaluating exposure mixtures in firefighting, non-cancer risks associated with firefighting (e.g., cardio-metabolic, endocrine and reproductive effects), and the impact of current mitigation methods, as well as determining behaviours that may alter exposure.

Firefighters are exposed to a complex mixture of chemicals. Behaviours while active (e.g. positioning while resting) and inactive (e.g. equipment storage) may be associated with exposure.

Diesel-Engine Exhaust and Controls in Ontario Fire Halls

Dr. Tracy Kirkham, Occupational Cancer Research Centre, Ontario Health

Dr. Kirkham presented on a study measuring diesel engine exhaust (DEE) in Ontario fire halls and firefighters' awareness of DEE controls used at their workplace. Low levels of DEE were measured in living quarters in fire halls; however, firefighters had a low awareness of DEE controls used in their workplace. Dr. Kirkham commented on the importance of research evaluating 1) the awareness of and adherence to controls, and 2) methods to improve adherence to increase control effectiveness.

Understanding worker awareness of hazards and controls, and behaviours is critical in protecting their health.

Recent and Ongoing Research from the IRSST

Dr. France Labrèche, Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) and the Université de Montréal

Dr. Labrèche presented on IRSST's current and past research, including a review of epidemiological literature on risk of cancer among firefighters; an evaluation of new technologies to reduce thermophysiological stress of protective clothing; radon exposures in workplaces (including four fire stations); and the development of a simple infrared imaging method to detect leaks in PPE and assess respirator fit. Dr. Labrèche identified the need for standardized exposure data from different fire combat stages and fire sources (e.g., solar panels, electric vehicles), standardized tests on the durability of protective clothing, and validation of PPE cleaning and maintenance procedures.

Major gap: exposures from new fire sources, e.g., electric and hydrogen batteries.

The Firefighters Preventing Cancer (FPC) Tool

Dr. Patrick McGrath, Department of Psychiatry, Dalhousie University

Dr. McGrath presented on a self-report tool to assess behaviours and attitudes around exposure controls for firefighters. The tool collects information on the perceived importance of an exposure-mitigating action for cancer prevention; whether the action is carried out regularly; if the action would be done in the future if resources were available; and barriers to performing the action. Dr. McGrath identified the need for research on the impact of behaviour on cancer prevention, the link between cancer and long-term biomarkers of contamination, and the impact of resource availability, national and local policy, understaffing, and diversity of workforce on cancer outcomes.

Research on what people do and think is critical in preventing cancer in firefighters.

Surveillance Studies of Firefighters at OCRC

Dr. Jeavana Sritharan, Occupational Cancer Research Centre, Ontario Health

Dr. Sritharan presented findings from six linkage-based studies published between 2017 and 2022 that included firefighters and other protective service groups. Key findings included an elevated risk of prostate cancer among firefighters and police. Dr. Sritharan identified the lack of exposure data and information on firefighters' work duties and employment duration as a challenge for linkage-based studies. Research priorities highlighted by Dr. Sritharan include improving exposure surveillance and exploring shared risk factors across firefighters and other protective service groups.

Multiple large studies underscore the importance of enhancing exposure surveillance across all protective services groups.

Occupational Exposures of Firefighters to (Geno)Toxicants of Concern
Dr. Paul White, Environmental Health Science and Research Bureau, Health Canada

Dr. White presented on firefighter's exposures to PAHs during live fires. He reported increases in PAH metabolites in urine after attending a fire, and that dermal contact is an important route of exposure. Another study to examine the efficacy of three dermal decontamination methods found that only detergent and water removed a significant amount of PAHs from the skin; none of the methods reduced the internal dose. Follow-up work is measuring firefighters' occupational exposures to flame retardants and PFAS. He noted a lack of information on genetic damage attributable to firefighters' exposures to combustion emissions.

Dermal contact is an important determinant of PAH exposure, and some dermal decontamination methods cannot effectively reduce the internal dose.

Relevant Research Models and Programs Outside of Canada

Invited international firefighting researchers provided an overview of their current research models, which may provide guidance on ways to address some of the current gaps in firefighter cancer research in Canada. The presentations highlighted the strengths of their programs, the challenges faced in their development, and gaps in their research area.

The aim of these presentations was to provide information on research methods and processes that could be applied in Canada, identify lessons learned in developing these research programs, and generate ideas for future firefighter research in Canada.

1. US NATIONAL FIREFIGHTER REGISTRY
   Dr. Kenny Fent
2. FLORIDA FIREFIGHTER CANCER INITIATIVE
   Dr. Alberto Caban-Martinez
3. AUSTRALIAN FIREFIGHTER HEALTH STUDY
   Professor Deborah Glass
4. WILDLAND FIREFIGHTER HEALTH RESEARCH
   Dr. Kathleen Navarro

NOTE: presentation summaries were approved by the speakers, and key takeaways were provided by each speaker.

US National Firefighter Registry

Dr. Kenny Fent

US National Institute for Occupational Safety and Health (NIOSH)

Dr. Fent presented a brief overview of the National Firefighter Registry (NFR), an exciting new initiative recently launched by NIOSH. The NFR is a voluntary registry that aims to monitor and evaluate cancer and cancer risk factors among US firefighters. The NFR collects firefighters' self-reported personal, demographic, work history, and lifestyle information through an online portal, which will be linked to records from fire departments to track trends and patterns in exposure, and to cancer registries and other health information databases to track health outcomes among enrolled firefighters. Dr. Fent identified several gaps that could be addressed through the NFR, such as demographic and regional differences in cancer risk, exposure-response relationships, the impact of controls, cancer risk modifiers, prevalence of rare cancers and other chronic illnesses, and cancer risk by job category. He also discussed the challenges inherent in a voluntary registry, such as ensuring the cohort is large enough and representative of the US fire service. He highlighted the need to develop a comprehensive communications plan and relationships with firefighting organizations and advocacy groups to disseminate information about the registry and drive recruitment.

- The National Firefighter Registry aims to generate detailed knowledge about cancer in the fire service through a voluntary registry that reflects USA's diverse firefighters.
- A major challenge of the NFR will be to obtain large numbers of participants, while minimizing the potential for selection bias.

Florida Firefighter Cancer Initiative

Dr. Alberto Caban-Martinez, Miller School of Medicine, University of Miami

The Firefighter Cancer Initiative (FCI) is a transdisciplinary collaboration between researchers and clinicians at the Sylvester Comprehensive Cancer Center at the University of Miami and firefighter unions and organizations. The FCI was established in 2015 and is the most comprehensive, ongoing program on firefighter cancer research and prevention in the world. Its goal is to understand and address the excess burden of cancer among firefighters. The FCI is a Florida-based national, comprehensive, multifaceted initiative with different programs that focus on firefighter cancer control and prevention. The first is epidemiologic and includes a dedicated State-based firefighter cancer registry, the firefighter annual cancer survey cohort, and various other cohort studies. The second is focused on environmental sampling and occupational exposure assessment, including a personal exposure reporting system, studies focused on a wide variety of exposures using a range of methods, and a national firefighter tumour bank. The third is focused on firefighter-centric cancer screening and other medical monitoring, education, and survivorship programs. The FCI includes projects from across the cancer control continuum, from prevention to detection and diagnosis, to treatment and survivorship.

- Firefighters face an elevated risk for specific types of cancers.
- The FCI emphasizes prevention, early detection, and enhanced safety practices to reduce cancer risk.

Australian Firefighter Health Studies

Professor Deborah Glass, Monash University

Professor Glass presented an overview of the Australian Firefighter Health Studies, focusing on the findings for volunteer firefighters, the largest studies of cancer among volunteer firefighters in the world. Studies of both paid and volunteer firefighters, as well as firefighter training personnel and Defence firefighters have been completed. She described differences between volunteer and career firefighters that may impact their exposure and health outcomes including location (rural vs. urban); fire type (landscape vs. structural), which may influence the duration of fire and recovery times; age distribution; and gender distribution. She described some of the advantages and limitations of studying health outcomes among Australian firefighters. The Australian Incident Reporting System (AIRS) systematically includes incidents attended by both volunteer and career firefighters and collects information about all fire and non-fire incidents attended, including false alarms. It includes information on the type of incident and extinguishing medium and identifies individuals who attended the fire, although not their role or time spent on site. AIRS is an important source of information on potential exposure. Professor Glass reported limitations to Australian epidemiological studies of firefighters, such as the lack of data on ethnicity and individual smoking behaviour.

- Volunteer firefighters differ from paid firefighters in their demographic profile and in the types of fires they attend.
- The Australian Incident Reporting System is a valuable source of information on the fires attended by individual firefighters.

Wildland Firefighter Health Research
Dr. Kathleen Navarro, Office of Wildland Fire, US Department of the Interior

Dr. Navarro summarized her and other US research assessing exposure to wildfire smoke and the long-term health risks among wildland firefighters. Her presentation discussed the challenges in measuring exposure in the extreme conditions of a fire environment. She highlighted the lengthy recruitment process and the importance of coordinating with firefighter groups before the study was funded, which allowed for refinement of the study goals and identification of achievable research methodology. She discussed the extensive collaboration that was required between researchers and study partners due to the complexity of field research in remote locations and the need to quickly adapt to changing work schedules and locations. Dr. Navarro also spoke about the challenges of operating laboratory equipment in remote field locations with minimal services (e.g., electrical, internet, delivery services), the need for advance planning, and solutions such as generators and internet hotspots.

Dr. Navarro also shared recommendations, including using air resource advisors to monitor smoke, locating command posts and camps in areas with the least smoke exposure practicable, limiting shift length, minimizing mop up, and developing a medical surveillance program for wildland firefighters.

Research Gaps and Priorities

Research gaps and priorities were raised during presentations, breakout sessions, and open discussions. For breakout sessions, workshop participants were split into seven in-person round table groups and two virtual groups. Breakout groups were a mix of research, government, and firefighting representatives. All groups were asked to discuss **three questions** with respect to cancer research priorities and report their findings back to the larger group for open discussion.

Breakout Session Questions

- What are the most important gaps that have been identified in terms of areas of research and types of firefighting?
- What are the highest priorities for firefighter and cancer research?
- In terms of expertise and resources, which of the identified gaps and priorities is Canada best positioned to fill?

Workshop Research Gaps

Over 500 gaps related to understanding cancer risks among firefighters were recorded during the workshop presentations and discussions. Recorded gaps came from a range of researchers, firefighter groups (union and service), and government representatives. Many gaps were identified multiple times by different workshop attendees. The wide range of participation suggests the workshop presents a balanced view of research gaps.

The gaps were extracted from workshop notes, combined when appropriate, and organized into 10 broad themes related to researcher and stakeholder interests. The 10 themes can be categorized further into:

1) health research studies,

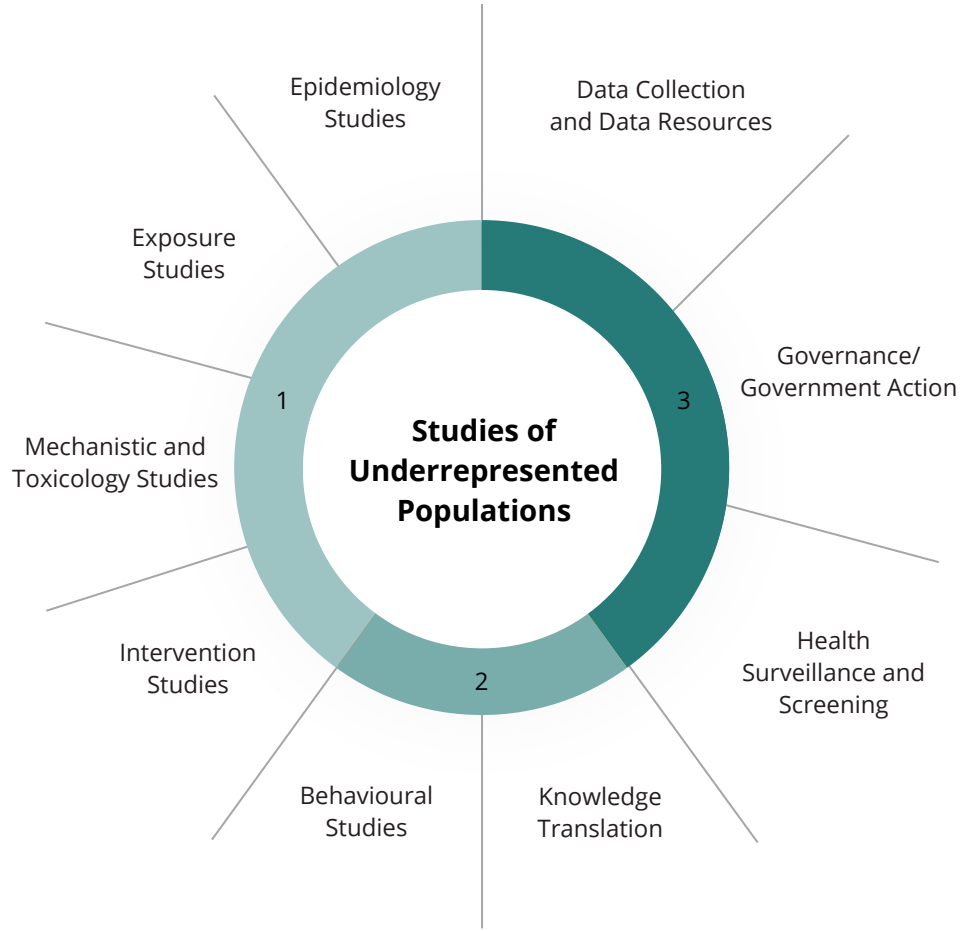
2) behaviour and communication, and

3) data management and governance topics.

Underrepresented populations was a cross-cutting theme across each of these three topics.

Detailed list of gaps available in supplemental information at www.occupationalcancer.ca/resources/ffcrpw/.

Firefighter Cancer Research Gap Themes



Studies of Underrepresented Populations

The existing research on firefighters has focused on white male structural firefighters working in urban environments for career fire services (i.e., paid). The lack of research representing other types of firefighters was a central theme that overlapped with all other themes. It was also the most frequently mentioned gap that emerged during the workshop.

Findings from studies of white male firefighters may not appropriately describe other firefighter populations and may underestimate other firefighting groups' risks. For example, physiological differences based on personal characteristics could influence both exposures (e.g., PPE fit for females) and health risks (e.g., background health risks by ethnicity). Different types of firefighting may introduce unique exposures (e.g., aviation) or may differ with respect to access to training and/or resources (e.g., volunteers) that may influence awareness of workplace controls or the workplace culture regarding use of controls. Different types of firefighting jobs (e.g., prevention, suppression) or roles within suppression (e.g., command and control) may also highly influence exposure. Most studies focus on suppression firefighters; exposures and risks for other types of firefighters or support jobs are unknown.

Examples of underrepresented populations identified in the workshop include:

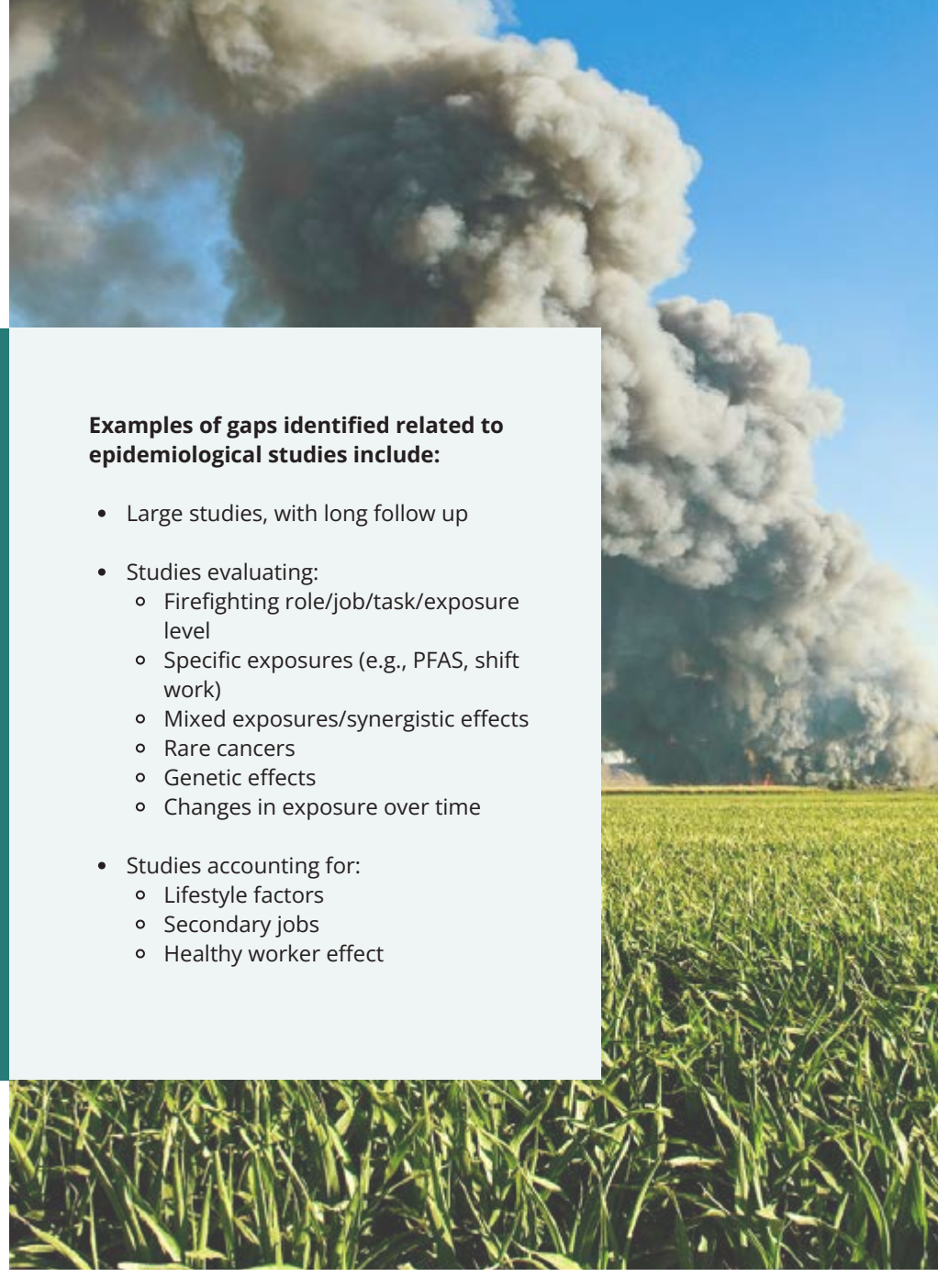
- Personal characteristics
  - Non-white ethnicities
  - Females
  - Firefighters in low- and middle-income countries
- Types of firefighting
  - Aviation
  - Indigenous fire service
  - Industrial
  - Military
  - Part-time/seasonal
  - Rural/remote areas
  - Volunteer
  - Wildland
  - Wildland urban interface
- Non-suppression jobs
  - Fire investigators
  - Fire trainers
  - Other jobs at wildland fires (e.g., heavy equipment operators, pilots)

Epidemiology Studies

Attendees noted that most epidemiology studies focus on white male urban firefighters. The historically small proportion of female and non-White firefighters often results in these groups being omitted from the studies.

For most studies, exposure to firefighting has been defined as 'occupation as a firefighter,' with no information on exposure levels or type of firefighting activities. This crude measure of exposure limits studies' ability to investigate dose response relationships (i.e., an indication of how risk increases with increasing exposure) that provide more evidence on firefighting cancer risk.

Another large gap in the epidemiological research that was identified were studies that account for confounders. Confounders are factors that may influence firefighters' cancer risks that are not from firefighting exposures, such as smoking or diet. Due to the culture of firefighting, many firefighters also hold secondary jobs, which may contribute to their cancer risk. Not considering these factors can mask true exposure-response relationships.



Examples of gaps identified related to epidemiological studies include:

- Large studies, with long follow up
- Studies evaluating:
  - Firefighting role/job/task/exposure level
  - Specific exposures (e.g., PFAS, shift work)
  - Mixed exposures/synergistic effects
  - Rare cancers
  - Genetic effects
  - Changes in exposure over time
- Studies accounting for:
  - Lifestyle factors
  - Secondary jobs
  - Healthy worker effect

Exposure Studies

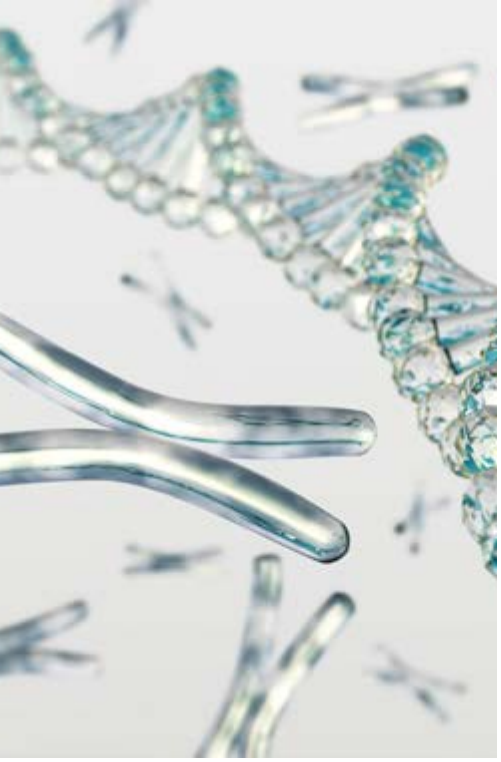
A large gap identified in the workshop discussions was information characterizing exposures among different types of firefighters, stage of firefighting, and personal characteristics of the firefighters; and identifying when and where multiple exposures exist together. This gap is also an issue for non-fire related exposures, where even less information has been characterized. This information could help identify which firefighters may be at higher risk of exposure and cancer.

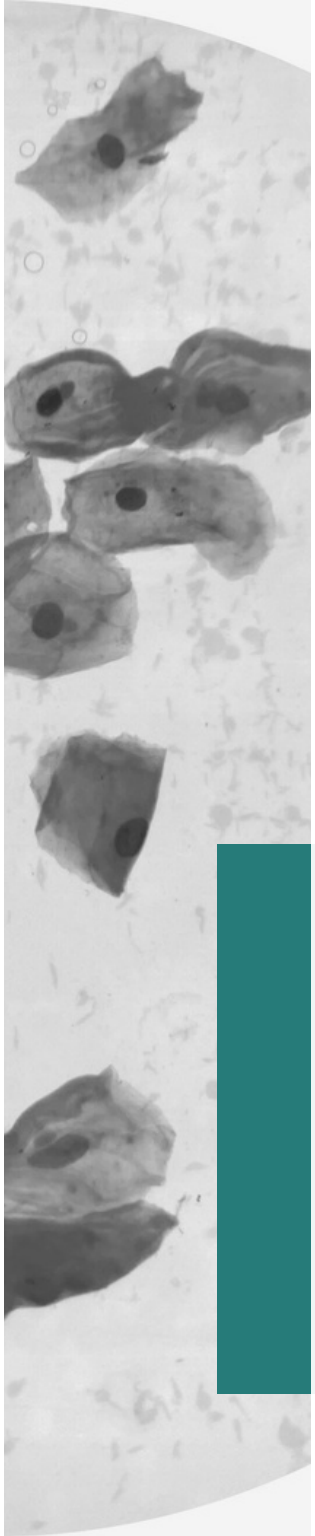
Attendees mentioned that sampling during live fires is logistically challenging, which may explain the lack of studies measuring exposures at live fires, rather than exposures at training fires or prescribed burns. It is unclear how representative this data is compared to exposures encountered at live fires, which may contain a wider range of fuel sources.

Further, it was frequently mentioned that there is little information on how external exposures are absorbed into the body, the amount of the external exposure that is absorbed into the body (i.e., biomarkers of exposure), or what effects are manifested when exposures are absorbed (i.e., biomarkers of effect). Part of this is due to the lack of easy testing methods. These are shared gaps that influence intervention and mechanistic studies. absorbed (i.e., biomarkers of effect). Part of this is due to the lack of easy testing methods. These are shared gaps that influence intervention and mechanistic studies.

Examples of gaps related to exposure studies include:

- Exposures of interest
  - Non-fire exposures (e.g., UV, shiftwork, heat stress)
  - Emerging exposures (e.g., PFAS, lithium fires)
  - Chemical mixtures
  - Live fires vs. training fires
- Characterization of exposures by:
  - Fire type/source/stage
  - Firefighting groups/job/role/task
  - Gender
  - Behaviours
- Biomonitoring
  - Dermal absorption
  - Correlations with air/skin exposure
  - Rapid testing methods
  - Biomarkers of effect (e.g., disease-related physiological changes)





Mechanistic and Toxicology Studies

Workshop discussions noted that studies conducted to date only examined five key characteristics of carcinogens (i.e., genotoxicity, epigenetic alterations, oxidative stress, chronic inflammation, and receptor-mediated effects). Although some information pertaining to chronic inflammation is available, more definitive studies are needed. In addition, studies of (i) alterations in genomic stability, (ii) immunosuppression, (iii) cellular immortalization, (iv) metabolic activation of combustion-derived carcinogens, and (v) alterations in cell proliferation are lacking.

Attendees noted a lack of studies that examined the incidence of cancer-related physiological changes in exposed firefighters (i.e., biomarkers of effect). More specifically, studies that examine the incidence of genetic damage, mutations and chromosomal abnormalities in selected populations of cells (e.g., peripheral blood lymphocytes, buccal cells, male germ cells, and urothelial cells). Due to the complexity of the exposure scenarios (e.g., remote locations), studies of wildland firefighters must be well-designed, employing consistent robust assessment methodologies.

Examples of gaps related to mechanistic and toxicology studies include:

- Other key characteristics of carcinogens
- Early cancer-related physiological changes (i.e., biomarkers of effect)
- Under-represented populations and firefighting scenarios
- Consideration of exposure complexity in the design of mechanistic studies (e.g., sample collection timing)
- Selection of effect biomarkers (i.e., biomarkers aligned with cancer-related Adverse Outcome Pathways)

Intervention Studies

Research on interventions to reduce exposure and related health effects was also identified as a key gap. Workshop attendees noted that there has been little research evaluating the effectiveness and impact of existing control strategies, or how to improve control adherence to ensure firefighter protection.

In addition to evaluating existing controls, the lack of creative or innovative interventions was noted, particularly for wildland firefighters where standard firefighting PPE and controls may not be feasible or available. With the changing firefighter population, understanding how controls work for female firefighters (e.g., PPE fit) was also identified as an important gap and discussed at length.

The attendees also noted the lack of standardized interventions such as standardized tests for PPE and personal protective clothing (PPC) durability, PPE/PPC cleaning/decontamination methods and PPE/PPC training programs across all firefighting groups. The lack of standardization and centralization overlaps with several other knowledge gap themes.

Examples of specific gaps related to intervention studies include:

- Types of intervention strategies
  - Regulatory controls
  - Training
  - Quick/easy short-term interventions
  - Engineering controls
- PPE/PPC
  - Female fit
  - Standardized tests for durability
- Effectiveness of controls
  - PPE/PPC
  - Education and training methods
  - Workplace practices
  - Cleaning/decontamination procedures
- For specific exposures (e.g., heat stress, foams)

Behavioural Studies

An important theme that emerged throughout discussions was the poor understanding of firefighters' behaviours related to health and safety. It was discussed that understanding firefighters' behaviours was important for understanding their risk of exposure and health outcomes. For example, firefighters' behaviours may influence how they learn or adhere to different control measures, influencing their potential exposures. Little is known about which methods would work to change or improve the health and safety culture within the firefighting community. It is also unknown how these behaviours differ by firefighter group such as female, volunteer, or wildland firefighters.

Examples of gaps related to behavioural studies includes studies that investigate:

- Barriers and facilitators related to:
  - Adherence to controls
  - Participation in research
  - Implementation of control practices
- Firefighter culture related to health
- Methods to change behaviour/culture

Knowledge Translation

Related to the behavioural studies gaps, attendees discussed that little is known about the best methods to communicate with firefighters to ensure that scientific research appropriately reaches the firefighter communities. The lack of formal knowledge translation in some research was thought to limit the implementation of research recommendations or result in impractical recommendations. Attendees stressed the importance of stakeholder involvement and engagement throughout the research process, i.e., from inception through to development of recommendations and dissemination.

Examples of gaps related to knowledge translation include:

- Stakeholder involvement/engagement throughout the research process
- Effective communication of research/health and prevention resources
  - Clear and accessible
  - Addressing generalizability
  - Recommendations for action

Data Management and Governance

Attendees identified three themes that fall under data management and governance. Although firefighting communities and/or government agencies may be better positioned to address these gaps, there are aspects that could be addressed by researchers.

One of the most mentioned gaps throughout the workshop was the lack of data, which was thought to impact research capabilities and limit the ability to identify firefighters for large epidemiology studies. Although firefighter groups collect some data, stakeholders reported that the data is often not collected in a standardized way, nor is it shared with other groups. A lack of harmonization can make it more difficult to conduct cancer research and protect firefighters' health. The absence of national oversight for standards, policies, regulations, compensation, and incident reporting was thought to be critical in the lack of data collection. Attendees discussed the lack of firefighter national health surveillance and screening programs. From a research perspective, a lack of early screening methods and effective screening protocols was identified.

Lastly, due to federal authority over reserve lands (First Nations communities), provincial occupational health and safety (OHS) legislation and regulations are not applicable or enforced. This creates a major gap for First Nations fire service to implement or manage a robust OHS program that includes all components of fire service activity from PPE standards, training, records management, and health surveillance. The Canada Labour Code Part II incorporates safe working environments but lacks the specific regulatory framework prescribed by provincial OHS legislation and regulations. Compounding this lack, First Nations reserves remain the only jurisdiction in Canada with no fire protection legislation (e.g., building codes, reporting, enforcement).

Examples of gaps related to data management and governance:

A

Data Collection and Data Resources

- Centralization of data (e.g., incident and exposure data)
- Firefighter registry
- Information on non-occupational risk factors
- Differences between (and within) firefighting groups
  - Types of equipment used, training methods/materials
  - Type/frequency of incidents
  - Work shift patterns
  - Secondary jobs
- National surveillance systems (e.g. exposure, cancer)
- Leadership and research expertise
- Laboratory infrastructure
- Funding (e.g., for research, control implementation, First Nations OHS)
- Development of guidelines for exposures with no occupational exposure limits

B

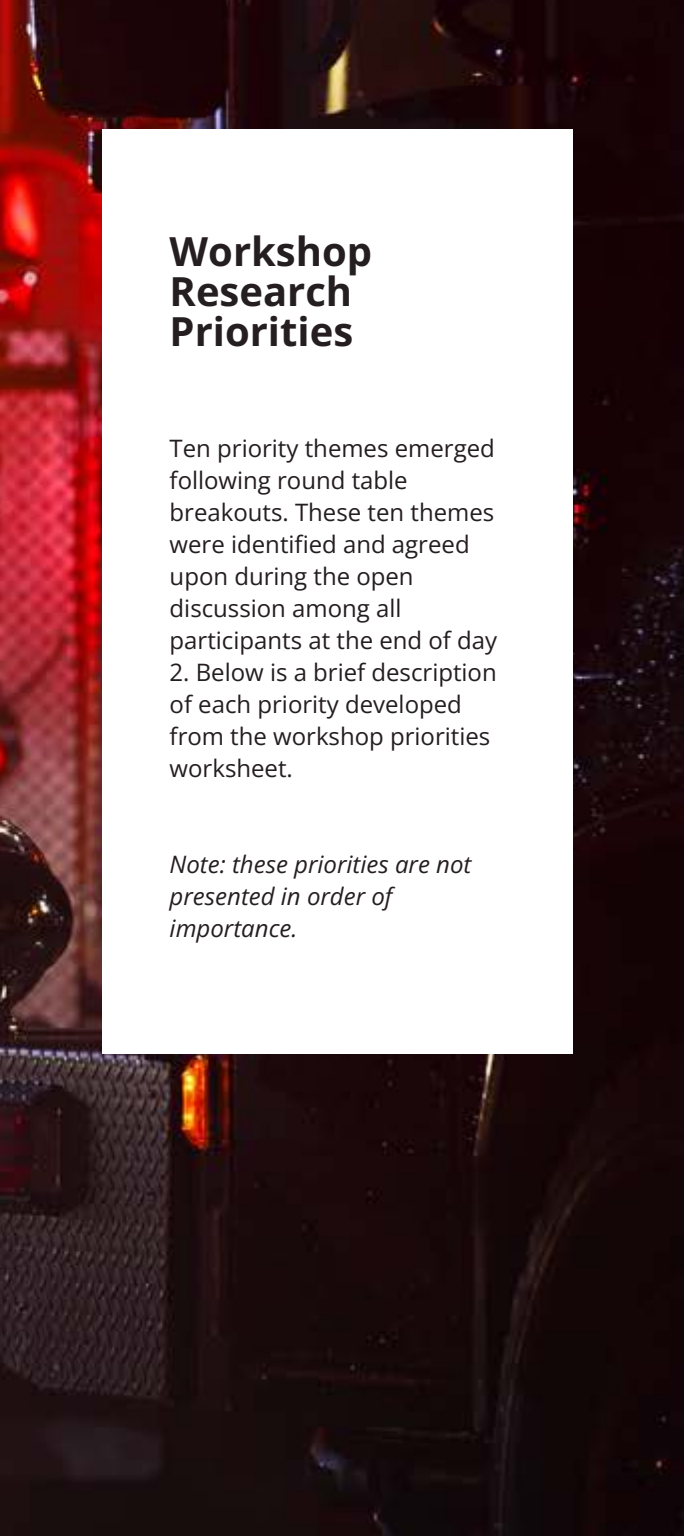
Governance/Government Action

- National harmonization and standardization across groups
  - Compensation policies
  - Occupational health regulations, best practices, and guidelines
    - Occupational exposure limits
    - Controls
    - Education
  - Standards (e.g., PFAS, building codes, etc.)
  - Incident data collection
  - Development of Fire Protection and OHS legislation and regulations for First Nations jurisdiction
- Federal oversight and responsibility
- Firefighter identification
  - Incorporation of occupation into health systems
  - Methods to identify firefighters in administrative data sources

C

Health Surveillance and Screening

- Standardized monitoring programs
- Early implementation (e.g., baseline)
- Development of early screening methods



Workshop Research Priorities

Ten priority themes emerged following round table breakouts. These ten themes were identified and agreed upon during the open discussion among all participants at the end of day 2. Below is a brief description of each priority developed from the workshop priorities worksheet.

Note: these priorities are not presented in order of importance.

Intervention research

Studies identifying the most effective strategies to reduce firefighter exposures are needed, particularly focusing on PPE and effective education programs. Further research is also needed to understand the current use of available controls and identify barriers that contribute to non-compliance. Further research is needed to determine if exposure control compliance varies by hazard or type of control to assist in developing effective education tools.

Personal protective equipment (PPE)

Although PPE also falls under intervention studies, it was determined to be of special importance. Research is needed on the unintended impacts of wearing PPE, such as heat stress during use. Advancements in respiratory protection are also needed. Respiratory protection research targeted for wildland firefighters was a noted priority.

Surveillance data collection and/or data sharing

Work is needed to standardize how fire organizations operate and how they collect data (e.g., coding systems, protocols, interventions) at a national level, across all firefighting types. Standardization of data collection will enable comparisons to be made across jurisdictions and firefighting types. Partnerships between the research community and firefighting communities are needed to build trust and identify research needs with respect to data quality and data sharing.

Cancer screening

To develop effective firefighter screening protocols, advancements are needed to identify early biomarkers of disease-related effects and improve methods for measuring these biomarkers. In addition to identification and effectiveness of methods, research is needed to understand barriers and expectations of (cancer) screening programs from both the medical and firefighting communities and methods to improve communication between these two groups.

Biomarkers of effect and mechanistic evidence

Progress is needed to fully understand the ten key characteristics of carcinogens (e.g., chronic inflammation and oxidative stress) and their relationship to firefighter cancer risk. Effect biomonitoring studies are needed to understand the link between exposure, internal dose, and health impact.

Legislation

Legislation is needed to harmonize workers' compensation and regulations (e.g., occupational exposure limits, restrictions on the use of hazards in building materials, emerging hazards) across jurisdictions in Canada for all firefighting groups. Harmonization would ensure equal treatment of firefighters and decrease firefighters' exposures.

Exposures and effects across different types of firefighting

Additional research is needed describing exposures and health effects by different firefighter characteristics, firefighting group, role/job, fire type, and fire stage. This should include evaluation of non-fire related carcinogen exposures such as UV radiation.

Impacts on firefighters' spouses and families

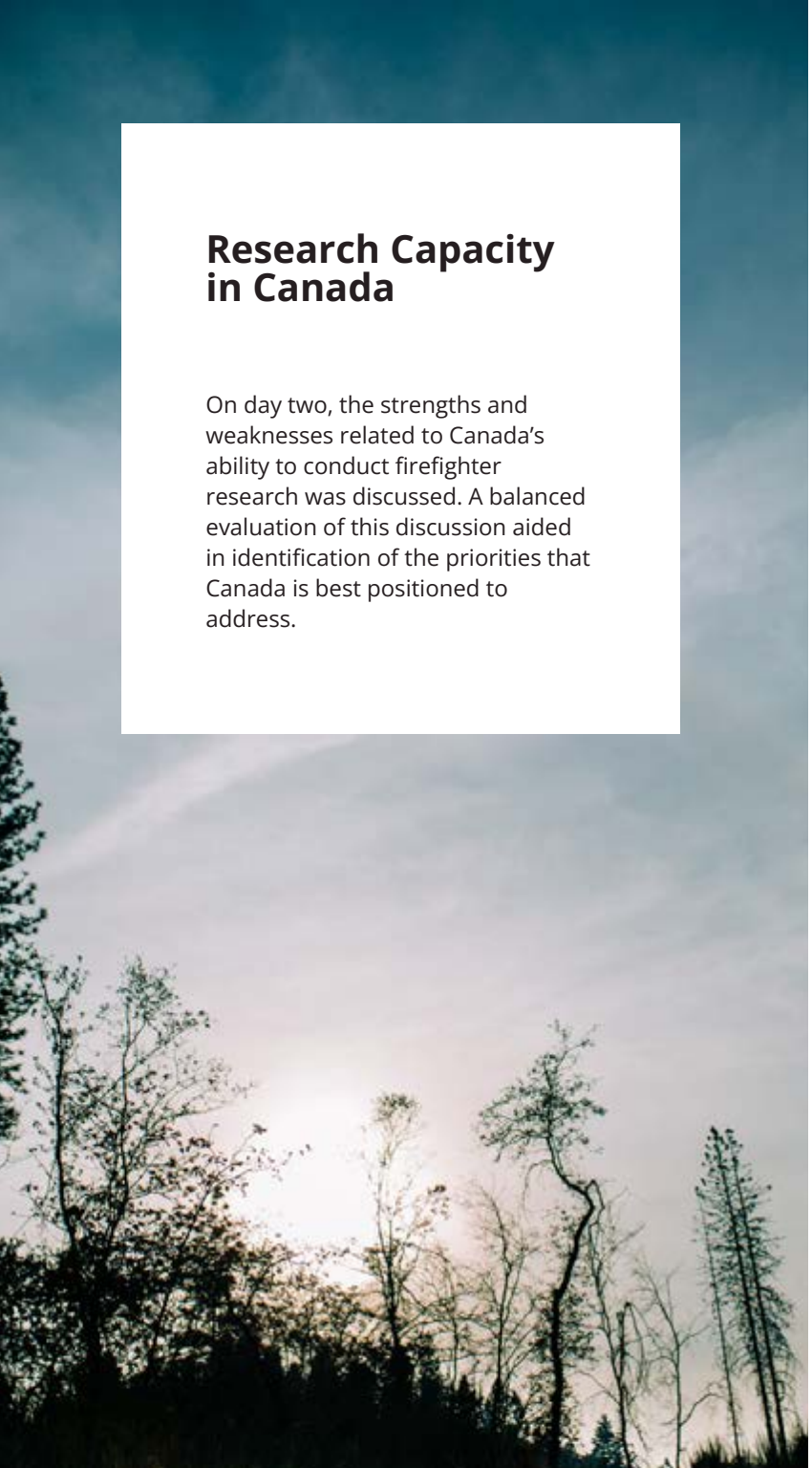
Studies evaluating the health effects of firefighting on firefighters' families are needed. This includes both measuring exposure risk (e.g., from contaminated clothing brought home for cleaning or transported in family vehicle), and cancer risks among offspring.

Knowledge translation

Research is needed to identify effective methods to communicate and disseminate research results. This will help ensure all firefighter groups receive the research knowledge and understand the implications and recommendations of the findings.

Understudied populations

There is an overarching need to appropriately increase research focus on understudied populations. This will increase the ability to understand differences in exposure, effects, knowledge translation, and culture/behaviour among these groups.



Research Capacity in Canada

On day two, the strengths and weaknesses related to Canada's ability to conduct firefighter research was discussed. A balanced evaluation of this discussion aided in identification of the priorities that Canada is best positioned to address.

Strengths

- Accessible and linkable administrative health data from universal healthcare system
- Existing collaborative relationships between firefighter community and researchers
- Strong international collaborations and networks
- Internationally recognized firefighting researchers (experienced, knowledgeable, and collaborative)
- Research laboratory infrastructure and lab networks
- Non-litigious framework
- High level of support from:
  - Government (e.g., *National Framework on Cancers Linked to Firefighting Act,* Statistics Canada)
  - Firefighter communities (improved recruitment and research dissemination)
  - Research and funding agencies (e.g., Canadian Cancer Society)
  - The public

Weaknesses

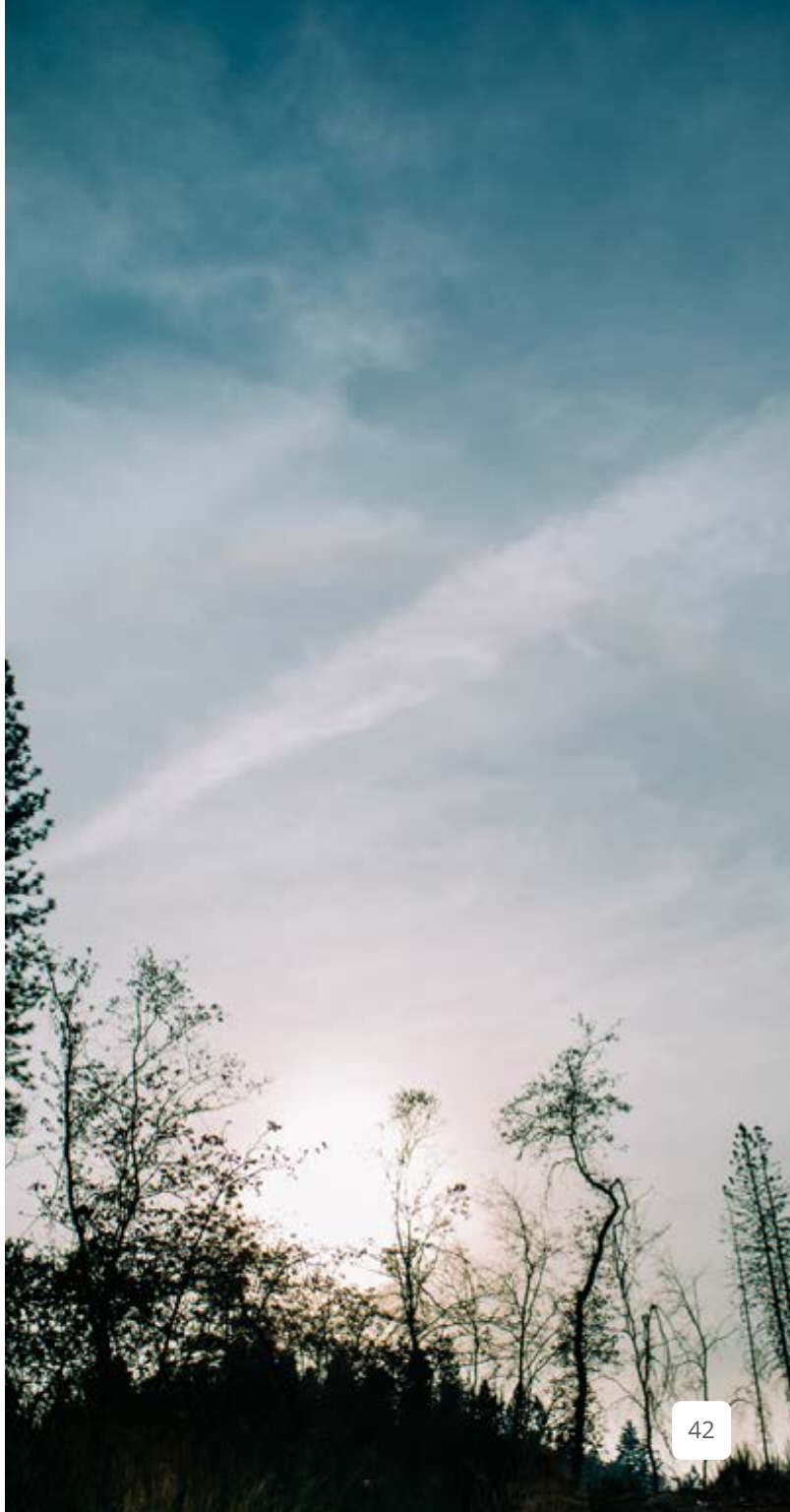
- Lack of centralized/federal oversight in firefighting communities across Canada
- Lack of operational funding for:
  - Large research initiatives
  - Implementing research to practice
  - Building research capacity, e.g., recruiting new researchers
- Lack of leadership in implementing interventions, including overseeing research funding and data collection
- Cultural challenges in firefighting community: minority engagement, firefighters' preconceptions, and education
- Difficulties in creating large cohorts, particularly for underrepresented populations

One of the greatest strengths in Canada is the excellent electronic health data available throughout the country. This data is easily assessable and linkable, making large epidemiologic research studies and disease surveillance possible across jurisdictions. Canada also has a strong network of epidemiologists and exposure assessment researchers to carry out such studies. A limiting factor in conducting these studies is access to centralized/accessible service data from all fire services.

Canada possesses laboratory infrastructure to assess exposures and effects. This is paired with a strong network of scientists who can work collaboratively to characterize exposures and lead intervention studies. Exposure and effect biomonitoring studies are logistically challenging and require substantial research funds for large initiatives; however, well-designed collaborative studies could contribute significantly to the existing literature.

There is also strong support for this research in Canada from both government and firefighting communities. Parliamentary support is evidenced by the introduction of the *National Framework on Cancers Linked to Firefighting Act*, which could result in new research opportunities. Canadian firefighter associations, such as the Canadian Association of Fire Chiefs and the International Association of Fire Fighters, are supportive of cancer research and can facilitate by providing researchers with needed contextual information, participating in research, and disseminating key research findings. Strengthening existing, and building new, relationships between researchers and firefighter organizations will be crucial to successful future research in Canada, an identified priority.

Several challenges also exist to research on firefighting in Canada. Firefighters work across different jurisdictions in Canada, including federal, provincial, and municipal levels. There is limited interconnectivity between jurisdictions, and no central organization to provide oversight or collect and harmonize data. Occupational health usually falls under provincial jurisdiction, which can make national-level research challenging to undertake. There is also limited funding available for research, especially long-term, applied, multidisciplinary studies.



Research Priorities for Canada

Given the research capacity in Canada to conduct firefighter cancer research, four overarching priorities were identified as priorities Canada is well positioned to address. These priorities were selected based on the importance of the priority as discussed during the workshop, and Canada's capacity to conduct research to fill the existing knowledge gaps.

1. STUDIES INVESTIGATING UNDERSTUDIED POPULATIONS
2. STUDIES INVESTIGATING EXPOSURE INTERVENTIONS
3. MECHANISTIC STUDIES ON FIREFIGHTER CANCER RISK
4. STUDIES MEASURING EXPOSURE AND IMPROVED EXPOSURE ASSESSMENT FOR EPIDEMIOLOGY RESEARCH

1 Studies Investigating Understudied Populations

For the most part, cancer research on firefighters has focused on career (paid) structural firefighters working in urban environments. Due to the lack of information on how exposures differ between firefighting groups, it is unknown if the results from these studies can be used to make general conclusions about the risk of cancer to all firefighting groups.

Wildland firefighters are one understudied population of interest that was frequently identified in the workshop as a priority. Their exposure patterns are thought to be potentially different from structural firefighters. They fight fires with a different smoke composition over longer periods of time, often without rest periods outside of the affected area. They also have limited protective equipment (e.g., respirators) or clean water for decontamination. Although access to wildland fire sites can be challenging, the increasing frequency of wildfires in Canada underscores the increasing importance and opportunities for exposure studies among this group.

Other groups of interest include volunteer, firefighters in remote areas, military, and aviation firefighters. Volunteer firefighters may lack resources, support and training compared to career firefighters that may cause differences in their exposures. Military and aviation firefighters may experience exposures to some hazards more frequently than other firefighters, such as hazardous chemicals in some firefighting foams.

Challenges in identifying and obtaining employment information on some firefighter groups, such as volunteer firefighters, may contribute to the lack of research investigating their risk of cancer. Strengthening relationships between researchers and different firefighting communities, and established collaborations with international researchers with experience investigating understudied groups of firefighters, could increase Canada's capacity to address this priority.

Cancer research on firefighters has also focused on white male firefighters. Physiological differences between demographic groups (females, visible minorities, and Indigenous peoples) may result in different exposures, exposure uptake/metabolism, or genetic predispositions that increase their risk of certain cancers. This also limits the understanding of female reproductive cancers. Epidemiology studies typically aim to include all ethnicities and genders in the analysis of cancer risk; however, in firefighting studies, these populations are often omitted due to the small numbers in the population being studied. Canada is well-suited to address this priority as there is an increasing number of female firefighters. Large studies of wildland and volunteer firefighters may also include more understudied populations, including the participation of Indigenous firefighting organizations or individuals. Canada can also link large numbers of participants to personal health data across the country, making large studies with longer follow up possible to investigate these populations.

2 Studies Investigating Exposure Interventions

Reducing or eliminating exposures is key in preventing occupation-related cancers. How well interventions work during firefighting is widely unknown. Research focusing on identifying the most effective control strategies for fire and non-fire related hazards is needed. Incorporation of biomarkers of exposure, as well as biomarkers of early effects that have been linked to cancer (e.g., genetic damage in selected cell populations), is crucial in understanding the effectiveness of controls, particularly for controls that reduce exposures at the worker (e.g., PPE). Canada is well positioned to address these gaps, having experienced and knowledgeable researchers as well as the required research laboratory infrastructures to carry out advanced analysis.

Intervention research on improved PPE is needed overall and for specific groups such as wildland and female firefighters. Traditional PPE/PPC used by structural firefighters is often too bulky for wildland firefighters. Advancements in portable and lightweight PPE/PPC is needed to address their unique needs. Further, PPE/PPC is typically designed for men, which may result in a poor fit on female firefighters, indicating the need for the development of equipment designed specifically for females.

Validation of effective cleaning (i.e., of PPE/PPC, skin, and fire equipment at fire scenes and/or PPE/PPC decontamination upon returning from a fire) and maintenance procedures can lead to the development of improved standard operating procedures (SOPs). This may include identification of effective decontamination products, as well as the most effective timing and method of cleaning.

Lastly, behavioural research is needed to understand the barriers that influence if, and when, firefighters use the interventions. Understanding barriers and adherence is important in understanding effectiveness in real world situations. These findings can help Canadian fire organizations and researchers further improve education and training programs.

3 Mechanistic Studies on Firefighter Cancer Risk

An improved understanding of the pathological mechanisms of cancer initiation can be used to develop techniques to measure cancer-related biomarkers of effect. This can then be used for early detection of cancer in firefighters. Workshop attendees highlighted the need for information on genetic damage of selected cell populations (e.g., urothelial cells) and its association with exposure to combustion emissions. Further studies are needed on the genotoxic effects on germ cells and the potential for heritable genetic effects (i.e., effects passed onto firefighters' offspring).

Attendees also highlighted a need for additional research on key characteristics of occupational exposure as a firefighter that may contribute to cancer. These include alterations in genomic stability and DNA repair, immunosuppression, cellular immortalization, metabolic activation of combustion-derived carcinogens, and alterations in cell proliferation. Canada has the expertise and infrastructure to design and implement studies investigating mechanism-aligned effects. Such studies will improve understanding of the relationship between firefighting and cancer incidence.

4 Studies Measuring Exposure and Improved Exposure Assessment for Epidemiology Research

Further research is needed to understand how exposures (measured using air, skin, and/or biomonitoring samples) change by firefighter demographic/personal characteristics, tasks, or groups to support primary prevention research. For example, exposure characterization can be used to help identify groups of firefighters that are at higher risk of being exposed. Identification of high-risk groups, or situations/locations likely to result in high exposures, can lead to the implementation of targeted exposure control interventions. Additionally, it is important for researchers to identify and characterize emerging hazards introduced from changing technologies (e.g., increase in lithium battery use, flame retardant use) to protect firefighters' health.

The current lack of exposure data and the poor understanding of how exposures vary among firefighters limits the ability to conduct epidemiology research that investigates the risk of cancer with increasing exposure levels (i.e., dose response). Most cancer studies have used crude measures of exposure such as 'ever exposed' or duration of employment to assign exposure. Few cancer studies have incorporated more advanced exposure assessment, and those that did primarily focused on fire-related exposures such as number of fires or time at fires. Future studies should also consider firefighters' exposures to non-fire related carcinogens, and the potential effects of the complex mixture of carcinogen exposures in firefighting. Exposure measurement data obtained across a wide range of firefighting groups/characteristics may provide detailed exposure information that could be used to estimate exposures for groups of firefighters, improving exposure assessment methods in cancer studies.

Canada has a collaborative set of researchers from various specialities, with access and skills to conduct and analyze exposure monitoring samples (air, skin, biomonitoring). Access to workplaces and/or workers is essential to conduct workplace exposure studies. The existing collaborative relationships between the firefighter community and researchers further increases the likelihood of success in workplace measurement research in Canada.

Workshop Conclusions

It is well recognized that firefighters are exposed to a wide range of known and suspected carcinogens and have an increased risk of cancer. The goal of this workshop was to bring together various researcher and stakeholder groups to discuss the state of knowledge and identify research gaps and priorities related to cancer risk among firefighters to inform future research directions, build relationships, and facilitate future collaborations. Although a wide range of knowledge gaps and research priorities were noted, four specific research priorities were identified for Canada. The most important priority identified is the need for more studies of underrepresented populations, particularly wildland firefighters, but also volunteer, women, and Indigenous firefighters. This was a cross-cutting theme throughout the workshop discussions of all other priorities. The three other Canadian priorities included studies investigating exposure interventions, the mechanisms through which firefighting increases the risk of cancer, and firefighter exposures and exposure assessment.

Canada has strong research capacity to address these priorities, including experienced researchers with the needed range of expertise, laboratories, and institutional support; strong infrastructure for conducting population-based studies, including accessible electronic health data; and a supportive firefighting community. To make substantial progress in addressing these research priorities will require the cooperation and collaboration of researchers, firefighter organizations, and government agencies across federal, provincial, and territorial jurisdictions. This will include not only the development and administration of targeted, competitive funding, but also sustained political support to ensure the feasibility of long-term projects, and the ability to adapt to shifting priorities caused by climate change, technological advances, and emerging issues. With the release of IARC Monograph 132 and establishment of the National Framework on Cancers Linked to Firefighting Act, there is interest at both the federal and provincial/territorial levels of government to support firefighter cancer research. This workshop report can be used to establish funding priorities and ensure that research funding is directed towards knowledge and prevention needs that have been collectively identified by stakeholders from across firefighting, research, and government organizations in Canada.

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Appendix 1. Workshop Participants

NAME	AFFILIATION
Alberto Caban-Martinez	Department of Public Health Sciences, University of Miami
Alexandra Long	Existing Substances Risk Assessment Bureau, Health Canada
Amy Hall	Research Directorate, Veterans Affairs
Blaine Wiggins	National Indigenous Fire Safety Council (NIFSC)
Blair Winger	Canadian Forces Fire Marshall's Office, Canadian Forces
Brian Godlonton	Canadian Council of Fire Marshall's Office and Fire Commissioners (CCFMFC)
Cathy Campbell	Existing Substances Risk Assessment Bureau, Health Canada
Cheryl Peters	Cancer Prevention, BC Center for Disease Control
Chris Bussey	Union of Canadian Transport Employees
Claire Austin	Science and Technology Branch, Environment and Climate Change Canada
Colin Murray	Risk Analysis Unit, WorkSafeBC
Cristina St. Pierre	Ontario Ministry of Labour, Immigration, Training and Skills Development
Dave Stieb	Environmental Health Science and Research Bureau, Health Canada
David DeMarini	Scientist Emeritus, US Environmental Protection Agency
Dean MacDonald	Natural Resources Management Branch, Parks Canada
Deborah Glass	School of Public Health and Preventive Medicine, Monash University
Don MacFadgen	Risk Analysis Unit, WorkSafe BC
Errol Thomson	Environmental Health Science and Research Bureau, Health Canada
Fateme Kooshki	Dalla Lana School of Public Health, University of Toronto
France Labrèche	Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST)
Graham Pawlett	Volunteer Firefighters of Canada (CVFSA)
Heather Simpson	Canadian Interagency Forest Fire Centre (CIFFC)

NAME	AFFILIATION
James Morden	Office of Environmental Health, Health Canada
Jean-Michel Billette	Centre for Population Health, Statistics Canada
Jeavana Sritharan	Occupational Cancer Research Centre, Ontario Health
Jeff Burgess	Department of Community, Environment and Policy, University of Arizona
Jennifer Keir	Department of Biology, University of Ottawa, Health Canada
Jill MacLeod	Occupational Cancer Research Centre, Ontario Health
Jim Petrik	Department of Biomedical Sciences, University of Guelph
Jonathan Chevrier	Department of Epidemiology and Biostatistics, McGill University
Kathleen Henderson	Winnipeg Airports Authority and Canadian Airports Council (CAC)
Kathleen Navarro	Office of Wildland Fire, US Department of the Interior
Karina Thomas	Ministry of Jobs, Economy and Northern Development, Government of Alberta
Kenny Fent	National Firefighter Registry Program, US NIOSH (National Institute on Occupational Safety & Health)
Kimberly O'Connell	Eastern and Northern Ontario Regions, Occupational Health Clinics for Ontario Workers (OHCOW)
Lawson Greenberg	Centre for Health Data Integration, Statistics Canada
Leah Kosolofski	Winnipeg Airports Authority and Canadian Airports Council (CAC)
Len Garis	Canadian Centre for Justice and Community Safety Statistics, Statistics Canada, University of the Fraser Valley
Les Karpluk	Fire Chief, Waskesiu Fire Department
Leonna MacKinnon	Existing Substances Risk Assessment Bureau, Health Canada
Max Debia	Department of Environmental and Occupational Health, School of Public Health, Université de Montréal
Mike McCulley	BC Wildfire Service, BC Ministry of Forests
Minh Do	Canadian Forces Health Services, Department of National Defense
Miriam Diamond	Department of Earth Sciences and School of the Environment, University of Toronto

NAME	AFFILIATION
Neil McMillan	International Association of Firefighters (IAFF)
Nicola Cherry	Division of Preventive Medicine, University of Alberta
Patrick McGrath	Department of Psychiatry, Dalhousie University
Paul Demers	Occupational Cancer Research Centre, Ontario Health
Paul White	Environmental Health Science and Research Bureau, Health Canada
Rachel Ma	Dalla Lana School of Public Health, University of Toronto
Rachel Tyli	Laboratory Medicine and Pathobiology, University of Toronto
Rebecca Kong	Canadian Centre for Justice and Community Safety Statistics, Statistics Canada
Richard Amnotte	Canadian Association of Fire Chiefs (CAFC)
Rick Dunning	Canadian Forces Fire Marshall's Office, Canadian Forces
Robert Daniels	World Trade Center Health Program Division, US National Institute for Occupational Safety and Health
Rocio Aranda-Rodriguez	Environmental Health Science and Research Bureau, Health Canada
Stella Gwini	School of Public Health and Preventive Medicine, Monash University
Steve Lemon	BC Wildfire Service Headquarters, BC Ministry of Forests
Tanya Navaneelan	Occupational Cancer Research Centre, Ontario Health
Tina Saryeddine	Canadian Association of Fire Chiefs (CAFC)
Tracy Kirkham	Occupational Cancer Research Centre, Ontario Health
Victoria Arrandale	Dalla Lana School of Public Health, University of Toronto
Win Wah	School of Public Health and Preventive Medicine, Monash University
Xiangning Fan	Alberta Jobs, Economy and Northern Development
Yves Lacasse	Chief Warrant Officer Canadian Forces Fire Marshal, Canadian Armed Forces

Appendix 2. Workshop Agenda

Day 1: Presentations on Firefighter Research Landscape

9:00 AM — **Welcome and introductions**
Paul Demers and Paul White

9:30 AM — ***Overview of published research and knowledge gaps***
Chaired by Paul White, Health Canada

Overview of published epidemiologic evidence and knowledge gaps
Robert (Doug) Daniels

Overview of published exposure evidence and knowledge gaps
Deborah Glass

Overview of published mechanistic evidence and knowledge gaps
David DeMarini

11:00 AM — ***Overview of recent and ongoing research in Canada***
Chaired by Paul White | Feat. Canadian Researchers:

Victoria Arrandale
Claire Austin
Nicola Cherry
Jonathan Chevrier
Tracy Kirkham
France Labrèche
Patrick McGrath
Jeavana Sritharan
Paul White

1:30 PM — ***Relevant research models and programs outside of Canada***
Chaired by Tracy Kirkham | Feat. International Researchers:

Kenny Fent | US National Firefighter Registry
Alberto Caban-Martinez | Florida Firefighter Cancer Initiative
Deborah Glass | Australian Firefighters Health Studies
Kathleen Navarro | Wildland Firefighter Health Research

4:00 PM — **Wrap-up and discussion of Day 2 agenda**

Day 2: Discussion of Knowledge Gaps and Research Priorities

9:00 AM — **Stakeholder views on knowledge gaps and research priorities**
Brief statements and open discussion

10:15 AM — **Breakout sessions to discuss knowledge gaps and research priorities**

1. What are the most important gaps that have been identified in terms of areas of research (e.g., epidemiology, exposure, and biomonitoring) and types of firefighting (e.g., municipal, volunteer, wildland, Indigenous, aviation, and military)?
2. What are the highest priorities for firefighter and cancer research?
3. In terms of expertise and resources, which of the identified gaps and priorities is Canada best positioned to fill?

11:30 AM — **Brief summaries by table chairs**
(i.e., identified gaps and priorities)

1:00 PM — **Open discussion**
To finalize statements of overall gaps and priorities

2:00 PM — **Open discussion**
Canadian priorities, resources needed and potential funding mechanisms

3:15 PM — **Closing remarks and next steps**
Paul Demers and Paul White

Appendix 3. Presenter profiles

Dr. Victoria Arrandale | Dalla Lana School of Public Health, University of Toronto

Dr. Arrandale is an Assistant Professor with the Dalla Lana School of Public Health at the University of Toronto, as well as a Registered Occupational Hygienist and exposure scientist. She is currently working on a study of organophosphate ester (OPE) flame retardant exposure among firefighters and paramedics, with a plan to expand the study to include PFAS (per- and polyfluoroalkyl substances).

Dr. Claire Austin | Science and Technology Branch, Environment and Climate Change Canada

Dr. Austin is a Physical Science Senior Officer at Environment and Climate Change Canada. She has been a guest lecturer at the National Research Council fire laboratory and has served on several technical committees related to firefighter respiratory protection including work with the National Fire Protection Association and the Canadian Standards Association. She was an invited specialist on the first IARC Working Group that evaluated the carcinogenicity of firefighting in 2007.

Dr. Alberto Caban-Martinez | Miller School of Medicine, University of Miami

Dr. Caban-Martinez is an Associate Professor, Associate Provost, and Vice Chair of Research with the Miller School of Medicine at the University of Miami as well as an occupational epidemiologist and osteopathic physician. He is the Deputy Director, and an investigator of occupational and environmental carcinogen exposure, of the Firefighter Cancer Initiative at the Sylvester Comprehensive Cancer Center. Additionally, he was a member of the IARC Working Group that evaluated the carcinogenicity of firefighting in 2022.

Dr. Nicola Cherry | Department of Medicine, University of Alberta

Dr. Cherry is an occupational epidemiologist and Professor with the Faculty of Medicine and Dentistry at the University of Alberta where she serves as the Tripartite Chair of Occupational Health. She has been studying occupational exposure among firefighters since the Fort McMurray wildfire of 2016 and has published several papers on the topic. Her current focus is on long-term exposures among wildland firefighters.

Dr. Jonathan Chevrier | Department of Epidemiology, Biostatistics and Occupational Health, McGill University

Dr. Chevrier is an Associate Professor of epidemiology at McGill University and a Canada Research Chair in global environmental health and epidemiology. He has been researching the health impacts of exposure to environmental contaminants, including endocrine-disrupting chemicals, for the past 20 years. He is currently completing a pilot study on chemical exposure and associated health outcomes among Montréal firefighters and police officers.

Dr. Robert (Doug) Daniels | National Institute for Occupational Safety and Health, US Centers for Disease Control and Prevention

Dr. Daniels is an epidemiologist and health physicist with the US National Institute for Occupational Safety and Health (NIOSH) and the World Trade Center Health Program. He is the Director of NIOSH's Fire Fighter Cancer Study and has authored many publications on firefighting and cancer. In addition, he was a member of the IARC Working Group that evaluated the carcinogenicity of firefighting in 2022.

Dr. Paul Demers | Occupational Cancer Research Centre, Ontario Health

Paul is an epidemiologist and Director of the Occupational Cancer Research Centre (OCRC) based in Ontario Health, Professor at the Dalla Lana School of Public Health at the University of Toronto and Clinical Professor at the School of Population and Public Health at the University of British Columbia. He has authored many publications on cancer and chronic diseases in firefighters. He chaired the IARC Working Group that evaluated the carcinogenicity of firefighting in 2022.

Dr. David DeMarini | US Environmental Protection Agency

Dr. DeMarini is a Scientist Emeritus at the US Environmental Protection Agency (USEPA), and retired Professor in the Gillings School of Global Public Health at the University of North Carolina-Chapel Hill. He has researched the mutagenicity and carcinogenicity of combustion emissions for 40 years and authored more than 200 papers on the subject. He chaired the IARC mechanism subgroup that evaluated the carcinogenicity of firefighting in 2022.

Dr. Kenny Fent | National Institute for Occupational Safety and Health, US Centers for Disease Control and Prevention

Dr. Fent is a Research Industrial Hygienist at the National Institute for Occupational Safety and Health (NIOSH) and a Commander in the U.S. Public Health Service. He has published over 45 technical reports and journal articles including work on assessing dermal and inhalation exposures to combustion byproducts in firefighters. In addition, he serves on technical advisory committees for the National Fire Protection Association and leads the National Firefighter Registry. He is currently working on a comprehensive study of cardiovascular and carcinogenic risks among firefighters.

Professor Deborah Glass | School of Public Health and Preventive Medicine, Monash University

Professor Glass is an Associate Professor with the School of Public Health and Preventive Medicine at Monash University in Melbourne, Australia. She has led multiple studies on the risk of cancer among firefighters, including studies on the effects of per- and polyfluoroalkyl substances (PFAS), the risks among paid and volunteer firefighters, and the effects of bush fires on frontline firefighters. Her work informed the IARC Working Group that evaluated the carcinogenicity of firefighting in 2022; she co-chaired the exposure assessment subgroup at the monograph meeting.

Dr. Tracy Kirkham | Occupational Cancer Research Centre, Ontario Health

Dr. Kirkham is an occupational hygienist and exposure scientist at the Occupational Cancer Research Centre (OCRC) based at Ontario Health and an Assistant Professor with the Dalla Lana School of Public Health at the University of Toronto. She has been an author on several publications on cancer, chronic diseases, and toxicant exposures in firefighters, and was a member of the IARC Working Group that evaluated the carcinogenicity of firefighting in 2022.

Dr. France Labrèche | IRSST and Department of Environmental and Occupational Health, Université de Montréal

Dr. Labrèche is an Associate Clinical Professor with the Department of Environmental and Occupational Health at the Université de Montréal and a Senior Researcher at the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST). She has been researching occupational cancer for almost 25 years and has served as an expert in the epidemiology of occupational cancers for numerous organizations including the Workers' Compensation Board of Québec, the National Cancer Institute's Occupational and Environmental Epidemiology Branch and the French Agency for Food, Environmental and Occupational Health & Safety.

Dr. Patrick McGrath | Department of Psychiatry, Dalhousie University

Dr. McGrath is a Professor Emeritus with the Department of Psychiatry at Dalhousie University. He served as vice-president of research, innovation, and knowledge translation at the Nova Scotia Health Authority for 10 years. He has published over 400 articles, book chapters, abstracts, comments and editorials, 14 books and 5 internationally translated and distributed patient manuals. His startup, 90Second Health Letters, is currently pursuing cancer prevention efforts among firefighters.

Dr. Kathleen Navarro | Office of Wildland Fire, US Department of the Interior

Dr. Navarro works for the US Department of the Interior, Office of Wildland Fire. Previously while working for NIOSH, her research focused on characterizing firefighters' exposure to chemicals from smoke, understanding pathways of exposures and developing practices to reduce exposure. To complete her dissertation, she became qualified as a wildland firefighter and spent one fire season working as a crewmember on a Type 1 Interagency Hotshot crew. While working for the US Forest Service, she conducted research quantifying exposure to smoke for the public and wildland firefighters and estimating the risk of lung cancer and cardiovascular disease mortality among wildland firefighters.

Dr. Jeavana Sritharan | Occupational Cancer Research Centre, Ontario Health

Dr. Sritharan is a Scientist at the Occupational Cancer Research Centre (OCRC) based at Ontario Health and an Assistant Professor with the Dalla Lana School of Public Health at the University of Toronto. She currently leads the surveillance team at OCRC and has published extensively on occupational health including several studies of cancer risk among firefighters that contributed to the IARC monograph in 2022.

Dr. Paul White | Environmental Health Science and Research Bureau, Health Canada

Dr. White is a genetic toxicologist with the Environmental Health Science and Research Bureau at Health Canada in Ottawa. He has been involved in several studies that assessed firefighters' exposure to carcinogenic PAHs (polycyclic aromatic hydrocarbons) and other organic mutagens. His current work concerns the efficacy of dermal decontamination for reducing exposures to PAHs and other mutagens. He was an invited specialist of the 2022 IARC Working Group that evaluated the carcinogenicity of occupational exposure as a firefighter.

Appendix 4. Published Canadian Papers on Cancer and Firefighting

By Canadian authors or using Canadian data

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