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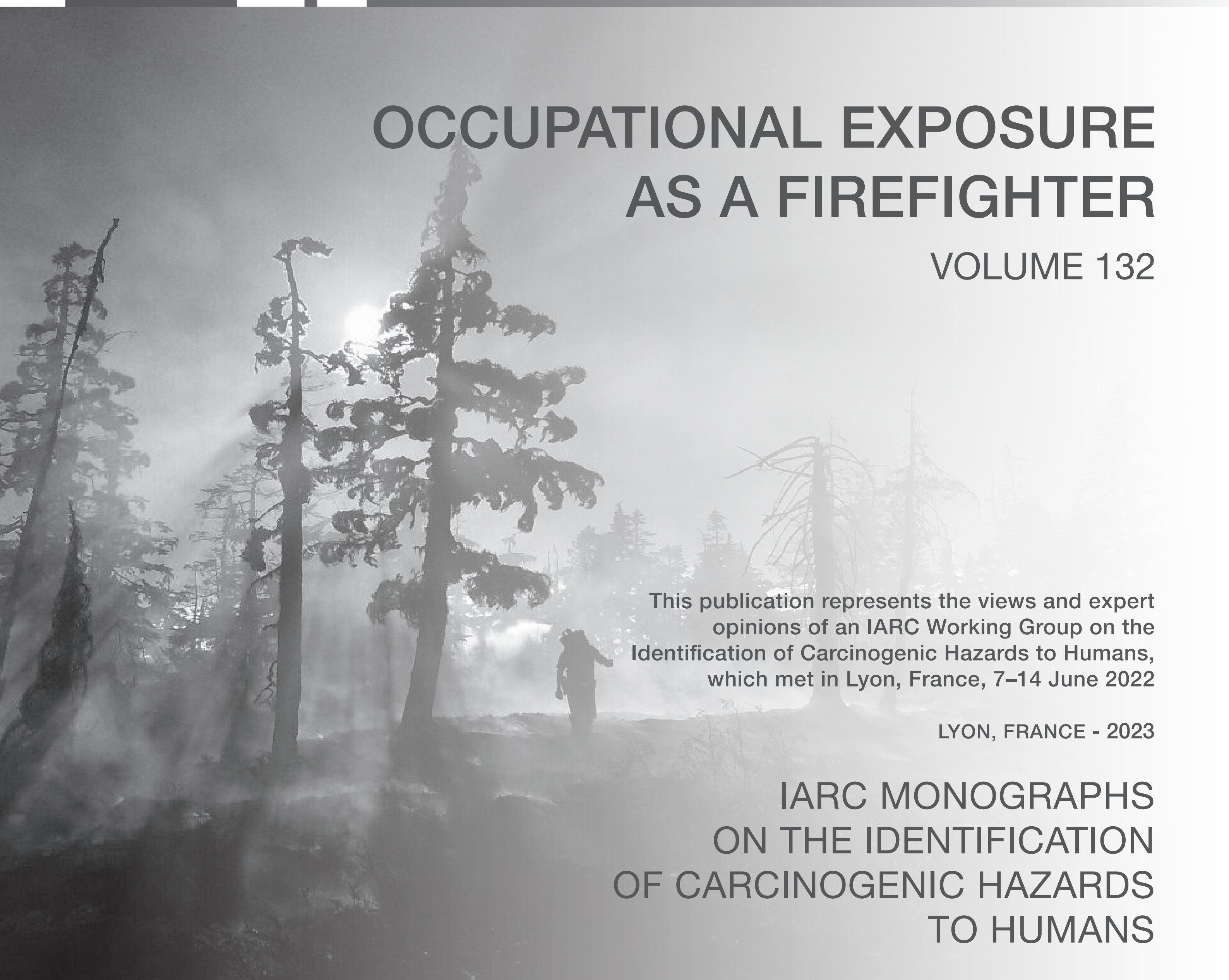

OCCUPATIONAL EXPOSURE AS A FIREFIGHTER

VOLUME 132

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IARC MONOGRAPHS ON THE IDENTIFICATION OF CARCINOGENIC HAZARDS TO HUMANS

International Agency for Research on Cancer

World Health Organization

GENERAL REMARKS

This one-hundred-and-thirty-second volume of the *IARC Monographs* contains evaluations of the carcinogenic hazard to humans of occupational exposure as a firefighter.

Firefighting was previously classified by IARC as *possibly carcinogenic to humans* (*Group 2B*) (IARC, 2010a) on the basis of *limited* evidence of carcinogenicity in humans and *inadequate* evidence regarding carcinogenicity in experimental animals. Data in humans generally lacked exposure–response information, and findings among studies were inconsistent, although the evidence of excess risk appeared strongest for cancers of the testis and prostate, and non-Hodgkin lymphoma.

The Advisory Group to Recommend Priorities for the *IARC Monographs* that met in 2019 recommended that occupational exposure as a firefighter be evaluated with high priority (IARC, 2019a; Marques et al., 2019).

A summary of the findings of this volume appears in *The Lancet Oncology* (Demers et al., 2022).

Definition and scope of the agent

The Working Group carefully considered the scope of the agent under evaluation in this monograph. There is substantial heterogeneity in potential exposures in the firefighting occupation and in the nature of the occupation itself, which presented a challenge for defining the scope of "occupational exposure as a firefighter". Firefighting duties involve diverse types of fire, emergency, and disaster responses, as well as specialized training events. Firefighters are exposed to a complex mixture of combustion emissions and a wide range of other chemical and physical agents. Firefighters responding to catastrophic events (such as building collapse, release of radioactive material, or chemical spills) may be exposed to agents that are not typically generalizable to the majority of people in the occupation worldwide. Work conditions can also involve night shift work, extreme physical activity, heat exposure, dehydration, and stress. In addition, people employed in the firefighting occupation can work as career or volunteer firefighters; have full-time, part-time, or seasonal employment; or work in a municipal or rural setting. Moreover, firefighter trainers might only (or primarily) be exposed to active firefighting under training scenarios. Given this diversity, the Working Group decided to adopt a broad scope in their definition of the agent and considered all exposures and types of firefighting employment as part of the agent. Any activity required or exposure incurred as part of the duties of the occupation (including firefighter training) was considered as part of the agent definition. Exposure to specific agents that are common during the course of duties for the majority of firefighters (e.g. fire smoke) was considered informative for the consideration of intensity of exposure, but employment in the occupation itself (either career or volunteer) was all that was required to meet the definition for inclusion in the review.

Gaps in the epidemiological literature on firefighting and cancer

Although firefighting occurs throughout the world, epidemiological studies of cancer among firefighters were available primarily from the USA, Canada, western and northern Europe, and Australia, with few studies identified in Asia. Consequently, studies of cancer among firefighters in other locations were not assessed in this evaluation. Studies of firefighters in low- and middle-income countries (including China and all countries of Africa and Latin America) were, in particular, unavailable. Nonetheless, the Working Group identified a large number of epidemiological studies with which to perform a systematic review and meta-analysis. The quality of the exposure assessments in these studies varied, with many studies assessing only having ever worked in the firefighting occupation and a small minority of studies assessing quantitative estimates of the number and types of fire response over time during firefighting. Studies with a detailed quantitative assessment of exposure to specific agents in the occupation were generally lacking. There were no studies of cancer in humans in which biological markers were measured as part of the exposure assessment.

Impact of climate change on occupational exposure as a firefighter

As much as 25–50% of the particulate matter with a diameter of ≤ 2.5 μm ($PM_{2.5}$) in ambient air across the USA is estimated to derive from wildland fires (Burke et al., 2021), and it is expected that there will be an increasing trend in the number and intensity of wildland fires associated with climate change (Ellis et al., 2022). Thus, wildland fires alone will engage more people in firefighting in the coming years, increasing the number of exposed firefighters and their subsequent cancer burden, as documented in the present monograph. Consequently, the evaluation of occupational exposure as a firefighter as *carcinogenic to humans* (*Group 1*) takes on added importance regarding the impact of these exposures. Very few studies of cancer in humans included wildland firefighters or measured exposure to rural or wildland fires; however, mechanistic studies in exposed firefighters found similar evidence of key characteristics of carcinogens in both wildland and municipal firefighters (see below). Accordingly, the Working Group concluded that its evaluation of occupational exposure as a firefighter should be presumed to apply to all firefighters, including men and women, and to all firefighting settings (e.g. municipal, wildland, vehicular) and employment arrangements (career, part-time, volunteer).

Relevance of previous *IARC Monographs* evaluations

The present evaluation of occupational exposure as a firefighter is supported by previous evaluations by the *IARC Monographs* programme of various combustion emissions and of many of the individual agents to which firefighters are exposed. Complex mixtures and combustion emissions previously evaluated by the *IARC Monographs* programme as *carcinogenic to humans* (*Group 1*) include tobacco smoke (IARC, 2004, 2012b), indoor emissions from coal (IARC, 2012b), diesel exhaust (IARC, 2013), and particulate matter from air pollution (IARC, 2015b). Relevant complex occupational exposure circumstances include exposure as a chimney sweep (soot) and in aluminium production (polycyclic aromatic hydrocarbons, PAHs) (IARC, 2012c). Exposure to indoor emissions from biomass, primarily wood, is *probably carcinogenic to humans* (*Group 2A*) (IARC, 2010b). Some individual agents in combustion emissions that have been evaluated by IARC as human carcinogens (*Group 1*) and with documented exposures to firefighters include benzo[*a*]pyrene (IARC, 2010c), acrolein (IARC, 2021b), polychlorinated biphenyls (PCBs) and dioxin-like PCBs with specific toxicity equivalency factors (IARC, 2015a), asbestos (IARC, 2012a), dioxins (IARC, 1997, 2012c), benzene (IARC, 2012c, 2018), formaldehyde (IARC, 2006, 2012c), styrene (IARC, 2019b), and night shift work (IARC, 2020).

For these agents, mechanistic evidence is available for a variety of key characteristics of carcinogens; however, the levels of evidence and the terminology used to characterize the evidence according to the Preamble to the *IARC Monographs* (IARC, 2019c) have evolved over time. These details are described in Section 4.1, Evidence relevant to key characteristics of carcinogens. For firefighting, nearly all the available mechanistic data were in humans, and adequate exposure data were available; no cancer studies in experimental animals were available to the Working Group.

As documented in the present monograph, occupational exposure as a firefighter can result in exposures to PAHs from fire effluents and diesel exhaust. PAHs cause cancer of the urinary bladder (IARC, 2010c; 2021a), and there is *limited* evidence for exposure to diesel engine exhaust and cancer of the urinary bladder in humans (IARC, 2013). Supporting this observation is the finding of urinary mutagenicity in firefighters, which reflects exposure to a mixture of PAHs from smoky coal emissions and also by exposure to diesel exhaust (Wong et al., 2021). Although no reports have assessed the exposure of firefighters to aromatic amines, this chemical class contributes to the mutagenicity and carcinogenicity of combustion emissions (DeMarini & Linak, 2022), causes bladder cancer and urinary mutagenicity (IARC, 2010d), and is the product of the metabolism (by nitro-reduction) of nitroarenes (nitro-PAHs) in diesel exhaust (IARC, 2013); thus aromatic amines are another plausible causal agent that would support the observed association between firefighting and bladder cancer.

Despite the heterogeneity of the exposures, the exposure data show that firefighters working over a range of firefighting conditions are exposed to PAHs, including dermally. These data provide coherence across diverse settings and are consistent with the mechanistic role of PAHs in the mutagenicity and carcinogenicity of a wide variety of combustion emissions (DeMarini & Linak, 2022), making the evaluation generally applicable to firefighters.

Lung cancer findings

There was *inadequate* evidence that occupational exposure as a firefighter causes lung cancer. This finding was unexpected, and the Working Group concluded that negative confounding by smoking was a plausible explanation for the deficit in lung cancer seen among firefighters compared with the general population. Another factor may be that firefighters are potentially exposed to endotoxins, which are components of lipopolysaccharides derived from the outer membrane of Gram-negative bacteria (Lundin & Checkoway, 2009). Endotoxins modulate levels of circulating inflammatory and immunological-response markers that are possibly associated with lung carcinogenesis (Lundin & Checkoway, 2009), and exposure to endotoxins in occupations with high exposure to organic dusts has been linked to decreased risk of lung cancer (Lenters et al., 2010). Although endotoxins are released during the indoor burning of wood (Semple et al., 2012), no studies have measured exposure of firefighters to endotoxins. However, indoor combustion of biomass fuel (primarily wood) has been classified as *probably carcinogenic to humans* (*Group 2A*), with *limited* evidence supporting a positive association with lung cancer in humans (IARC, 2010b). This finding, which has also been supported by a subsequent meta-analysis (Bruce et al., 2015), somewhat reduces the plausibility of endotoxin exposure as a major reason for the lack of excess lung cancer risk seen in firefighters compared with the general population.

Scope of systematic review

Standardized searches of the PubMed database (NCBI, 2022) were conducted for the agent and for each outcome (cancer in humans, cancer in experimental animals, and mechanistic evidence, including the key characteristics of carcinogens). For cancer in humans, searches were also conducted in the Web of Science (Clarivate, 2022) and Embase (Elsevier, 2022) databases. The literature tree for the agent, including the full set of search terms for the agent name and each outcome type, is available online.[1]

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[1] The literature tree for the present volume is available at: https://hawcproject.iarc.who.int/assessment/666/ (occupational exposure as a firefighter).

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