Fire Fighter Carcinogen Exposures

Fire fighters are occupationally exposed to combustion products of modern residential and commercial fires which contain many hazardous substances. These include carcinogens (cancer causing chemicals) present during fire responses and at the fire station. Responses to structural fires involve two phases: knockdown in which the fire is controlled and extinguished, and overhaul, in which the structure is examined for potential areas that could reignite such as smoldering items. Years of research have clearly documented exposure to carcinogens in both phases. Recent studies have addressed combustion of all the new synthetic products present in homes, cars and factories. These studies have observed increased smoke density related to synthetics, such as styrene and vinyl based materials.[1]

The International Agency for Research on Cancer (IARC) is part of the World Health Organization and is the authoritative international agency on chemical carcinogens (cancer causing agents). Occupational health experts rely on the IARC to categorize chemicals for their potential to cause cancer in humans. Studies have revealed that fire fighters are commonly exposed to numerous agents that IARC considers known or probable human carcinogens. The following two lists contain the carcinogens commonly encountered by fire fighters, organized by IARC Classification:[2]

IARC Group 1 agents (*known* humans carcinogens)	**IARC Group 2A agents** (*probable* human carcinogens)
▪ arsenic ▪ asbestos ▪ benzene ▪ benzo[a]pyrene ▪ 1,3-butadiene ▪ cadmium ▪ diesel engine exhaust ▪ dioxin ▪ formaldehyde ▪ pentachlorophenol ▪ polychlorinated biphenyls ▪ radionuclides ▪ soot	▪ creosote ▪ dibenz[a,h]anthracene (a polycyclic aromatic hydrocarbon [PAH]) ▪ wood combustion products ▪ shift work affecting circadian rhythm

Fent and colleagues recently published a study of area and personal (monitors worn by fire fighters) air concentrations of combustion byproducts from 12 controlled residential fires with furnishings common in 21st century single family structures.[3] Personal air concentrations of total PAHs and benzene measured from some overhaul firefighters exceeded exposure limits. Median air concentrations on the fire ground were above background levels and highest when collected downwind of the structure and when ground-level smoke was the heaviest. This is important because, as will be discussed below, SCBA use has been much less common during overhaul and outside the burning structure.

A wide range of other chemicals have been detected in smoke, few of which have had their potential for carcinogenicity assessed. In a study of nine municipal structural fires, 144 target volatile organic compounds were quantified in smoke samples.[4] Although more than 123 different chemicals were present in one or more fires, 14 volatile organic compounds predominated across fires including benzene and 1,3-butadiene which are IARC group 1 carcinogens. Lowry and colleagues studied fire fighters' exposures at nearly 100 structural fires.[5] They detected the presence of more than 70 different chemicals in smoke from fire scenes regardless of whether synthetic materials were a major part of the materials burned. Although an older study, the results remain relevant given the long latency (years) for many cancers. Other sources of information on chemicals measured in smoke include the IARC Monograph 98 in which chemicals are listed by IARC carcinogen category.[6] The comprehensive Underwriters Laboratories Inc., University of Cincinnati and Chicago Fire Department study cited above provides additional information on the large number of chemicals to which fire fighters are exposed.[1] An ongoing collaborative study by the Illinois Fire Service Institute, UL Firefighter Safety Research Institute, National Institute for Occupational Safety and Health, Globe Manufacturing Company and U.S. Department of Homeland Security - Federal Emergency Management Agency Assistance to Firefighters Grants Program[7] will also provide essential information when complete.

Research has also confirmed carcinogen exposures during the overhaul phase, a period when fire fighters have traditionally not worn SCBA. An air monitoring study during overhaul in 25 structure fires detected levels of several chemicals at levels above the recommended short-term exposure limits including benzene and, at 22 of the fires formaldehyde, another IARC group 1 carcinogen.[8]

Exposures in Fire Stations

Many of the contaminants that fire fighters encounter during fire responses can be tracked back to the fire stations where they live throughout their shifts when not responding to a call. In a study of dust samples in 26 fire stations in five states, Shen and colleagues documented phosphorous-containing and polybrominated diphenyl ether flame retardant levels that were higher than those previously reported in homes and other occupational settings around the world.[9] Bott et al. measured diesel particulate matter and polycyclic aromatic hydrocarbons in the engine bays, duty offices and dormitory areas of eight fire stations in Queensland, Australia.[10] They reported that operation of fire appliances and mechanical equipment during start of shift checks were the most important contributors to overall engine bay diesel particulate matter concentrations and in the two stations with the highest PAH levels in the engine bays, higher levels were also reported in the dormitories.

Exposure Levels

In contrast to almost every other workforce in the US where occupational controls in the last 40 years have reduced exposures, firefighters continue to be exposed to high levels of carcinogens in smoke because fire suppression and overhaul activities occur in uncontrolled, hazardous environments. Further, smoke now contains combustion products of a more complex range of products due to the increased number of synthetics in US homes and businesses.

In a Harvard study that measured air contaminant levels at more than 200 structural fires. benzene was detected in 181 of 197 of samples taken at fire scenes.[11] Almost 15% of the samples were found to be at or above the OSHA Short Term Exposure Limit of 5 ppm benzene. Another study reported that 50% of the measured benzene levels were more than 10 times the OSHA limit.[12] The authors noted: “Furthermore, in many cases of the worst exposure to these materials respiratory protective equipment was not used owing to the visual impression of low smoke intensity, and thus these levels represent actual direct exposure of the firefighters.”

Incomplete Protection Due to Limitations of Protective Equipment

Fire fighters have only personal protective equipment (PPE), e.g. self-contained breathing apparatus (SCBA) and turn out gear, to prevent exposures. PPE is the least effective of the established workplace controls for exposure reduction (termed the hierarchy of controls which includes more protective options such as substitution with a safer chemical, enclosure of the hazard, and ventilation). PPE does not completely eliminate exposure. This becomes a particular problem in work environments where exposure levels are high, such as fire fighting. Furthermore, in order better detect potential re-ignition areas during overhaul and due to exhaustion after the strenuous knockdown phase, fire fighters may take off their PPE. However, even though exposure levels may no longer be immediately hazardous to life, many carcinogens are still present in the air at the fire scene. Other reasons for incomplete protection include the potential for the air in the SCBA to run out inside a burning building. Finally, turn out gear does not completely prevent dermal exposures due to seams and lack of complete coverage such as on the neck.

Dermal Exposures

The primary route of toxic exposures is through inhalation, but exposure can also occur through dermal absorption and ingestion of contaminated nasopharyngeal secretions and fluids. Thus, dermal absorption of carcinogens in the soot that fire fighters often notice on their skin despite turn out gear is another route of exposure for them. Elevated temperatures, as routinely experienced by firefighters, have been associated with increased dermal absorption.[13] Several studies of urinary metabolites in fire fighters wearing SCBA (discussed below) have implicated dermal exposures.

Biomonitoring

Urinary levels of chemicals in fire fighters provide information on the amounts that enter their bodies despite the protective gear they use. Wingfors and colleagues measured the sum of 14 PAHs on skin and urinary 1-hydroxypyrene (a biological monitoring indicator of exposure to PAHs) in 20 volunteer student fire fighters during a standardized smoke diving exercise.[14] They reported that median levels of each significantly increased 5-fold (21 to 99 ng/wipe) and 8-fold (0.14 to 1.1 µmol mol−1 creatinine), respectively, post exposure. 1-hydroxypyrene was also correlated with dermal exposure.

A study of 27 fire fighters in Ottawa also observed statistically significant increases in urinary PAH metabolites post fire events.[13] In addition, urinary mutagenicity was assessed and found to be significantly increased. PAH concentrations in personal air sampling and on skin were important factors in these increases.

Andersen and colleagues studied 53 recruits participating in a 3-day training course with live-fire training exercises conducted while wearing PPE, including SCBA.[15] Both the sum of 16 dermal PAHs and the urinary excretion of 1-hydroxypyrene increased after the fire fighting exercises and were associated with levels of DNA strand breaks in peripheral blood cells. The authors concluded that PAH exposure during firefighting was associated with genotoxicity.

Carcinogenicity of Fire Fighter Chemical Exposures

Other authoritative organizations for carcinogenicity include:

- The **Environmental Protection Agency (EPA)** charged with regulating chemicals in the environment to protect human health and natural resources.[16]
- The **National Toxicology Program (NTP)** operates under the Department of Health and Human Services to evaluate agents/chemicals of public health concern including performing studies in animal models of chemicals to determine their cancer causing potential.
- The **Agency for Toxic Substances and Disease Registry (ATSDR)** is a public health agency under the Department of Health and Human Services that publishes toxicological profiles based on the latest research.

Arsenic: Fire fighters are exposed to arsenic from its presence in chromated copper arsenate, a wood preservative containing chromium, copper and arsenic. It is a metalloid found on smoke particulates.[1]

Asbestos: Fire fighters are actively involved in building demolition during the overhaul phase which results in exposure in older structures built before the 1980s.

Benzene: Very common constituent in smoke, also considered a Category A known human carcinogen by EPA.[17]

Diesel Engine Exhaust: Fire fighters are exposed to diesel engine exhaust at fires and in many fire stations where fire fighters spend long hours.[18, 19]

Dioxin (2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD)): US NTP considers this combustion product known to be a human carcinogen.[20]

Flame Retardants: Flame retardant have been used in furniture foam, clothing and electronics casings since the 1970s.

Formaldehyde: US EPA Category B1 (Probable human carcinogen)[21]

Polychlorinated biphenyls (PCBs): Fire fighters are exposed to PCBs from their presence in transformers and other electrical equipment. In its monograph on PCBs, IARC lists "first responders to incidents where a transformer has exploded" as one of the potential occupational exposures to PCBs.[22] A study of fire fighters involved in response to a transformer fire in Staten Island, NY detected serum PCB levels that declined over time. This post-exposure decline pattern suggests acute exposure to PCBs in the first responders.[23] Fire fighters who responded to a transformer fire in Binghamton, NY in 1981 showed similar post-exposure declining serum PCB levels.[24]

Polycyclic Aromatic Hydrocarbons (PAH): PAHs are a group of chemicals that are formed during the incomplete burning of coal, oil, wood, garbage, or other organic substances. According to the ATSDR, vehicle exhausts, wildfires, agricultural burning, residential wood burning, and waste incineration (situations similar to those encountered during fire fighting activities), all generate PAHs. There are more than 100 different PAHs, and IARC has classified several as known, probable or possible human carcinogens. Most authorities don't discuss PAHs as a whole; rather, they review each chemical separately although, as noted above, soot, which contains multiple PAHs, is considered Group 1 by IARC. Of the 18 PAHs that are commonly produced during fires, benzo[a]pyrene is an IARC group 1 known human carcinogen and eight others are considered probably or possibly carcinogenic to humans by IARC.[25] Exposure to these agents occurs during knockdown, overhaul and cleaning of equipment and clothing. PAHs may enter the body through inhalation, ingestion, or absorption through the skin. Exposure to 15 PAHs was reported in a recent NIOSH study of fire fighters performing controlled burns.[3]

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