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ENVIRONMENTAL HAZARDS IN FIREFIGHTERS' WORK. A SHORT REVIEW

The following work covers several issues. It discusses environmental factors identified in the scientific literature, especially pollutants emitted during fires that can be found crucial in terms of their contribution to occupational exposure among firefighters. Moreover, the authors described the issue of transferring pollutants indoors on the surface of items of clothing, equipment, and other elements by firefighters, which is commonly indicated in many studies. It was shown that this occurrence can be a secondary source of numerous substances inside rooms, in which firefighters stay before or after fire and rescue operations. Chronic and long-term exposure in the context of causing life-long health hazards (including carcinogenic effects) has a greater impact than occasional staying in a highly polluted environment (for instance during an extinguishing action). Due to the above, the summary of the following work contains recommendations concerning subjects of studies that need to be soon conducted to decrease the level of occupational exposure of firefighters caused by environmental factors.

1. INTRODUCTION

During the decade 2012–2022, the number of actions related to extinguishing fires taken by firefighters in Poland varied from over 106 000 to almost 185 000 yearly. In addition, the number of reports related to other necessary actions to eliminate the effects of other local threats ranged between 263 000 and 428 000 [1]. Even though the statistics show that most of the actions taken by firefighters do not concern fire events, the level of exposure during all such events (fires) is enormous. Not only is it connected with a direct health and life hazard during an extinguishing action but also with specific thermodynamic conditions that firefighters are subject to, as well as with inhalation and

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dermal exposure to the whole range of pollutants present in smoke. Thus, every extinguishing action is an event that contributes to a constant increase in firefighter's body burden. Accumulation of factors and prolonged time of occupational exposure have resulted in stating officially that the firefighter profession is carcinogenic to humans [2]. High concentrations of toxic chemicals have been observed during such processes as combustion and pyrolysis of plastics (fires of waste and storage facilities, industrial plants, vehicles, etc.) but also when aforementioned processes concern materials of natural origin (forest fires, burning grass, etc.). It does not mean that every fire event is related to the same qualitative and quantitative exposure of the body. However, differences concerning particular fire environments, depending on the quality and composition of materials that are subject to a fire, can have a lower impact on the level of lifelong body exposure than even smaller differences in the atmospheric conditions that firefighters experience daily.

2. DIRECT EXPOSURE

Firefighters are exposed to the impact of numerous harmful substances [3]. Years-long studies have proved that fire smoke contains i.a. volatile organic compounds (VOC), including one especially crucial group, i.e., monocyclic aromatic hydrocarbons, known under the BTEX (benzene, toluene, ethylbenzene, xylene isomers) initialism, polycyclic aromatic hydrocarbons (PAHs), as well as hydrogen cyanide (HCN), aldehydes and several other compounds [4–8]. Some of the latter, such as formaldehyde, 1,3-butadiene, vinyl chloride, and polychlorinated biphenyls (PCBs) are classified as carcinogens or possible human carcinogens [9, 10].

The fire environment also includes particles of aerosol dispersed phase, commonly known as particulate matter (PM), which are prime pollutants for human life and health [11, 12]. The way and scale of the impact of PM on human health are determined by several factors. Firstly, due to its size (particles with a diameter between 10 nm and 100 μm) [13], PM easily migrates to the human body and can accumulate in different parts of its respiratory system (inhalation exposure). Secondly, gases, as well as different types of hydrocarbons, can be (and practically always are) adsorbed on particles of aerosol disperse phase (PM-bounds) [12, 14] and transferred deeper into the human body with such particles. It is generally assumed that only particles of smaller sizes (cumulated in the PM2.5 fraction) enter deeply the respiratory system [11, 15]. However, this process depends on a few factors, i.a. the way and frequency of breathing, as well as individual features of the particular person [15]. In the case of firefighters, a key factor can be the physical effort that makes breathing faster and deeper, which in turn causes more particulate matter (PM) to be transferred to the lungs. The latter statement has been confirmed by studies conducted, e.g., in sports facilities [16, 17]. Consequently, health exposure from inhalation is significantly higher.

Having noted multiple types of hazards, especially the carcinogenic one, in 2007 IARC (International Agency for Research on Cancer) classified the firefighter profession as a part of group 2B, which means possibly carcinogenic to humans [18]. Numerous studies on determining the cause of the increase in the incidence of oncological diseases among firefighters are currently being carried out. Based partly on the results of such research, in June 2022, IARC changed the classification of the firefighter profession from group 2B into group 1, which means "carcinogenic for humans" [2].

The most extensive cohort study that has been conducted so far included 29 993 representatives of the discussed professional group who worked in San Francisco, Chicago, and Philadelphia [19]. The study proved that incidence and mortality related to oncological diseases among firefighters is higher in comparison to the general population. Findings concerned especially the respiratory, digestive, and urinary systems [19]. The strongest correlation was observed for malignant pleural mesothelioma, in the case of which, the values of SIR (standardized incidence ratio) and SMR (standardized mortality ratio) obtained for firefighters were 2.29 and 2.00, respectively [19], while the SMR value determined for the US society regardless the cause of death was 0.99 [19]. Further studies [20] confirmed an increased risk of neoplasia among firefighters and pointed out additional types of oncological diseases they are especially prone to, i.e., leukemia, lung cancer, melanoma, and multiple myeloma [20]. Increased incidence and mortality for various types of cancer among the discussed group in comparison with the general population have also been confirmed by other cohort studies that included the group of about 16 000 firefighters in five Scandinavian countries, i.e., in Denmark, Finland, Iceland, Norway, and Sweden [21]. The strongest correlation, similarly, to the USA, was observed for lung cancer (adenocarcinoma), melanoma, and prostate cancer. In the newest work, Marjerrison et al. [22] present the results of studies carried out in Norway. The connections between performing work as a firefighter and oncological diseases are being analyzed all over the world, not only in the USA and in Europe. The scientific literature presents also examples of results of cohort studies from other parts of the world, for example from Australia [23].

It needs to be also stressed that similar analyses have been conducted far before. The work by LeMasters et al. [24] includes a review of dozens of studies concerning the cancer risk among firefighters. It states that about 10 types of cancer are significantly related to their work. The most crucial correlation was observed for multiple myeloma, non-Hodgkin's lymphoma, as well as prostate and testicular cancer [24]. The work indicates possible causes of increased incidence and mortality for the particular examples of diseases. It was suggested that they could be connected with exposure to various chemical compounds or their combinations, pathways of pollutants penetration into vulnerable organs, as well as indirectly with the variability of biochemical and physiological routes of exposure [24].

3. SECONDARY EXPOSURE

The greatest exposure of firefighters to toxic substances takes place during rescue operations and training. However, in such cases, they use equipment items and personal protective equipment (PPE) that hampers or reduces the ingress of pollutants into the human body in different ways up to a minimum [25, 26]. Thus, it is worth paying attention to the rest of the time of duty, for example, a way back from the scene of a fire, cleaning work in the fire and rescue unit, etc., when PPE is not used [27]. In such a situation, both PM and other gases can penetrate the firefighter body more easily, all the more so because equipment items and personal protective equipment used in fire and rescue operations can be (and usually are) the secondary source of various chemical compounds [5, 28].

Several works [5, 20, 29] have proved that many substances, including non-volatile and semi-volatile compounds that come from the processes of combustion and pyrolysis, can settle and/or penetrate the structure of personal protective equipment, e.g., special clothing. Moreover, they cumulate on parts of firefighters' bodies that are not covered by PPE, leaving characteristic tarry stains [26, 27] in which the presence of PAH was identified [26] while conducting an experiment based on determining such compounds in special tissues, which after training in extinguishing fires were used by firefighters to clean the neck uncovered by clothing [26]. It means that some volatile and semi-volatile compounds transferred on the surface of PM cumulate in different places, both on the body surface and the surface of PPE. Toxic and carcinogenic substances, both the ones that can be found on PPE items and the body surface penetrate the human body in different ways – some of them directly through the skin or vulnerable organs such as eyes, and the others indirectly, i.e., by respiratory tract [19, 26–28]. Firefighters usually inhale massive amounts of dangerous solid substances while taking off PPE items, e.g., special clothing, a balaclava, and gloves, or moving by polluted equipment items, when particles cumulated on them along with adsorbed volatile and semi-volatile compounds are set in motion and start floating in the air [5]. Other studies [30] prove that various combustion products, i.a. volatile organic compounds (VOC), including some PAH, as well as hydrogen cyanide (HCN) penetrate special clothing resulting in not only dermal exposure. Such substances undergo the process of off-gassing (desorption) and become secondary sources of pollution. Thus, PPE can be treated as a secondary source of inhalation exposure [30–32]. This process can occur in the place of the event, but also in the fire and rescue vehicle's cabin, in the cloakroom, the garage, and other rooms [12, 33–35].

The literature review revealed that there are numerous publications concerning toxic chemical compounds that are present in the fire environment [3, 4, 12] and their possible impact on firefighters' health condition [5, 6, 8, 11, 26, 29]. In contrast, there are significantly fewer articles related to the air quality inside different rooms in fire and rescue units, however, the issue of pollutant presence inside such buildings has also been noticed by some authors [14, 28, 33, 35, 36]. There are also publications concerning settling on and/or penetrating the structure of personal protective equipment items by some chemicals [5, 20, 29]. Nevertheless, the scale of the off-gassing (desorption) process of harmful substances from various equipment items and personal protective equipment of firefighters has not been thoroughly studied and described. Another not well-studied issue is the influence of the desorption process on the air quality inside, only partly mentioned in some works [30–32]. They present qualitative and quantitative analyses of volatile organic compounds (VOCs) that may be subject to off-gassing (desorption) from equipment items and personal protective equipment (PPE). Nonetheless, the abovementioned works lack the assessment of the impact of discussed substances on the air quality in different zones where firefighters stay. It has not been presented explicitly how the off-gassing (desorption) process can influence the long-term exposure of firefighters and, in turn, their health.

The results of the first experiment which was to show the rate of release of particular volatile compounds from firefighters' special clothing used in extinguishing action were presented only this year [37]. An experiment involved passively measuring the concentrations of selected volatile compounds in the air of a room where firefighters' special clothing (previously exposed to emissions from simulated fires) was stored. The study included simulations of fires involving three types of materials: wood, processed wood (OSB/fiberboard), and a mixture of plastics. The experiment demonstrated that a single set of firefighter's special clothing can cause secondary indoor air emissions of benzene, toluene, ethylbenzene, *m*,*p*-xylene, *o*-xylene, styrene, isopropylbenzene, and *n*-propylbenzene at a total level of 10–44 $\mu g \cdot h^{-1}$. Toluene was the most intensively emitted chemical compound. Regardless of the burned material, the special clothing was exposed to before. Its rate of release from a single set of firefighter special clothing ranged between 4.4 and 28.6 $\mu g\ h^{-1}$. Thus, it can be roughly estimated that during a 24-hour duty period, 36–65 μg of benzene alone and 240–1063 μg of total BTEXS can enter the indoor air from a single set of firefighter special clothing.

The off-gassing (desorption) process of toxic substances can occur in every place where there are clothing or equipment items penetrated by discussed chemical compounds, thus it increases the number of individuals who are possibly subject to their exposure. Such individuals are not only firefighters who directly participate in fire and rescue operations but also other firefighters and civilian workers of the particular fire and rescue unit. Moreover, in the aforementioned locations, individuals do not use self-contained breathing apparatuses (commonly known as respiratory protection apparatuses), which significantly increases inhalation exposure.

4. SUMMARY AND RECOMMENDATIONS

The problem of increased exposure of firefighters to oncological diseases in comparison to the general population has been the subject of numerous studies [19–24]. However, they are mostly based on values of the standardized incidence ratio (SIR) and the standardized mortality ratio (SMR), which do not allow estimating the real level of exposure to carcinogenic factors while fulfilling the duty.

Taking into account a gap in the matter of determining and systematizing the scale of hazards related to exposing firefighters to carcinogens emitted secondarily from special clothing and other personal protective equipment (PPE) it seems to be necessary to determine especially the scale of secondary pollution of indoor air with particular volatile compounds, as well as to describe this process quantitatively. A special approach needs to be taken in the case of exposing firefighters to carcinogens desorbed from special clothing directly after terminating fire and rescue operations, in a rescue vehicle's cabin. This place needs to be treated as a priority because it is the first enclosed space where firefighters do not use self-contained breathing apparatuses and where they stay with polluted equipment items and personal protective equipment (PPE). Inhalation exposure related to being exposed to and the synergic impact of all emitted substances in connection with the limited cubature of a cabin allows us to make a statement that rescue vehicle cabins are an especially crucial type of enclosed space.

Another issue is determining the total time and compounds that are emitted secondarily. Having such data and studying the quality of indoor air will finally allow defining places where possible exposure to secondarily emitted compounds is the greatest. After doing so it will be possible to develop thorough strategies aimed at reducing the exposure of firefighters to various substances in different circumstances out of fire and rescue operations.

The subject of intense general studies must be pollutants that have already been identified as priorities in the environment of firefighter's work, i.e., particulate matter (PM), polycyclic aromatic hydrocarbons (PAHs) and monocyclic aromatic hydrocarbons (MAHs) of the BTEX group (mainly benzene, toluene, ethylbenzene, xylene isomers, as well as styrene).

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