

HAZARD OF CHEMICAL SUBSTANCES CONTAMINATION OF PROTECTIVE CLOTHING FOR FIREFIGHTERS – A SURVEY ON USE AND MAINTENANCE

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Abstract

Objectives: The objective of the work was to analyze the impact of selected factors concerning the use and maintenance of firefighters' protective clothing worn during rescue operations on the hazard of contamination by chemical substances. **Material and Methods:** The participants were firefighters (N = 688) from rescue and firefighting units of the State Fire Service in Poland, aged <30, 31–40, 41–50 or >60 years, with different seniority: up to >21 years of service. The survey questionnaire developed by the authors was used. The questionnaire was available online. The Statistica 10.0 statistical package using the χ^2 test was applied in the analysis of the significance of the results. **Results:** As reported by the vast majority (>60%) of the firefighters, the maintenance was carried out after recording an average or a high level of contamination. It was pointed out that removal of the contaminants from protective clothing was difficult (83%). The surfaces of the legs and sleeves of protective clothing were the most contaminated areas. A feeling of discomfort was observed (90%) after returning from firefighting operations due to fire, smoke, or combustion residues. **Conclusions:** It is necessary to conduct training and information actions concerning the use and maintenance of protective clothing and the harmfulness of chemicals contaminating the garments used by firefighters. Int J Occup Med Environ Health. 2022;35(2):235–48

Key words:

questionnaire, firefighters, health hazard, protective clothing, maintenance, chemical contamination

INTRODUCTION

The working environment of firefighters is characterized by the presence of many hazardous factors. It has been widely emphasized that firefighters are exposed to flame, radiant heat, or to contact with hot objects during rescue operations. The hazardous factors include hot microclimate, excessive noise, physical load, oxygen-poor working environment, as well as occupational stress. How-

ever, the work of a firefighter is associated not only with the aforementioned hazards. During rescue operations, firefighters are exposed to chemicals emitted during fires of buildings and in open spaces. These substances are characterized by a harmful effect on the human body. Their properties can be toxic, corrosive, flammable, explosive or sensitizing. Harmful chemicals that can leave

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their traces in the organism are the elements accompanying most rescue and firefighting operations [1,2].

In Poland, there are approx. 30 500 firefighters employed in 501 units of the State Fire Service and approx. 490 000 rescuers in almost 16 000 units of the Volunteer Fire Service, who are exposed to harmful chemicals [3]. In 2013–2017, there were nearly 134 000 fires in Poland. Fires of residential houses (21% of total fires), agricultural facilities, including crops (25%) and forests (4%) were the most common ones [4]. In Europe, almost 240 000 persons were employed as firefighters in the 22 EU Member States in 2019 [5].

Considering the type and intensity of hazardous factors during firefighting activity, we can distinguish:

- basic clothing for firefighters compliant with the EN 469:2020 standard [6],
- clothing for special fire-fighting operations compliant with the EN 1486:2007 standard [7].

Basic protective clothing for firefighters is intended for use in rescue and firefighting operations as well as in disaster relief operations. It is made of fabrics, or fabrics with membrane coating. Clothing for special firefighting operations is used when entering the flame. Most often it is made of aluminized film glass fabric.

Protective clothing for firefighters should protect in the first place against flame, effects of high temperature and heat. Considering the fact that it is used in different conditions it should also provide protection against soaking, cold and poor visibility. The requirements specified in EN 469:2020 [6] refer to fabrics and material systems used in firefighter clothing. The garments for firefighters are multi-layered. The outer layer is a fabric with non-flammable properties. The middle layer is a membrane that protects against water penetration. The inner layer is the lining, most often with a warming layer, closest to the user's skin.

An important issue, increasingly recognized by the firefighters' community, is the contamination of the surface

of personal protective equipment with chemicals. According to the literature reports, the residues of combustion products are deposited on firefighters' personal protective equipment, including protective clothing covering the trunk and the limbs. Not only protective clothing, but also the skin of the hands, neck and back is contaminated with chemical substances during the activities performed by firefighters [8].

Protective clothing is necessary for protection against heat and flames, but also plays a part in preventing dermal exposure to chemicals. The development of more heat- and fire-resistant clothing made from materials such as aramid polymers (eg., Nomex, Kevlar) or polybenzimidazole (PBI) may enable firefighting activities to be performed closer to the fire, potentially leading to higher risk of exposure to combustion products [9]. It should be taken into account that the clothing designed for the firefighter consists of several layers: an outer fabric with non-combustible properties, a membrane protecting against moisture, an insulating material and lining. As the chemicals are deposited on the garments, they can penetrate into the structure of the material and then permeate through the successive layers of materials [10]. As a consequence, that may lead to direct contact of chemical substances with the skin. The literature of the subject emphasizes that absorption of harmful chemicals through the skin is facilitated due to the increased temperature of the firefighters' skin during rescue operations [11,12]. Stec et al. [13] assumed dermal absorption to be the main route of exposure. Firefighters can also be exposed to chemicals from inadequately cleaned protective clothing and equipment [10,14]. Taking into account that semi-volatile organic compounds are highly lipophilic, Alexander and Baxter [11] supposed that phthalate diesters would be absorbed through the skin easily, especially at elevated temperature present at the sites of firefighting operations. It is therefore important to take action to reduce the level of hazardous chemicals. Baum [15]

conducted research the purpose of which was to determine whether the use of Class A compressed air foam can reduce the levels of carcinogenic combustion byproducts and reduce the risks to the firefighting personnel to create the rationale for potentially retrofitting the Amboy Fire Protection district 2 fire engines with a Compressed Air Foam System (CAFS). Based on the results of 11 live fire tests he found that the use of a Class A CAFS reduced the levels of benzene and formaldehyde as compared to water-only application, and that brand B that contained ethyl alcohol in its chemical makeup caused lower-level readings for benzene and formaldehyde when compared to brand A that contained lauryl alcohol [15].

The removal of contaminants from firefighters' protective clothing requires a cleaning process to be performed. Inspections carried out in fire brigade units indicate that the maintenance of clothes for firefighters in terms of washing frequency, reimpregnation and correctness of maintenance processes requires more attention [16]. On the one hand, it is emphasized that inappropriate maintenance of clothes for firefighters can lead to a loss of their protective properties. Clothing soiled with hydrocarbons, lubricants, oils reflects much less thermal radiation and has a reduced resistance to ignition, making the firefighter exposed to higher heat levels [17]. On the other hand, it has been pointed out that a fire may produce a large number of carcinogenic substances, including polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds, as well as persistent, bioaccumulative, and toxic substances. The substances harmful for the firefighters' health may get to their organisms mainly by deposition from air (through the respiratory tract, inhalation), by oral route or by contact with contaminated surfaces like clothing (through the skin) [18]. The study conducted by Van Rooij et al. [18] showed differences in PAH absorption between anatomical sites. He noted significant, but low, regional variation in dermal absorption rate of PAH. The absorption rate at the skin of the shoul-

der was 2 times higher compared to the forearm skin ($p \leq 0.5$). Besides the differences in PAH absorption between anatomical sites, it was found that the residual amount after washing also differed significantly depending on the anatomical location [18].

The most dangerous chemical substances are [2,11,19,20]:

- isocyanates (absorption routes – the respiratory tract, the skin, the gastrointestinal tract);
- volatile organic compounds – styrene, benzene, o-xylene, ethylbenzene, heptane, 1-ethyl-3-methylbenzene, 3-methylhexane (absorption routes – the respiratory tract, the gastrointestinal tract, the skin);
- polycyclic aromatic hydrocarbons (PAH) – benzo(a)pyrene, benzo(a)anthracene, benzo(e)pyrene, benzo(b)fluoranthene, benzo(j)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluoren, phenanthrene, pyrene and indeno(1,2,3-cd)pyrene (absorption routes – the respiratory tract, the skin);
- phthalates – butyl benzyl phthalate (BBP), di (2-ethylhexyl) phthalate (DEHP) (absorption routes: the respiratory tract, the gastrointestinal tract, the skin);
- inorganic combustion products – CO, CO₂, NO (absorption – through the respiratory tract, by inhalation).

Some of these chemicals are known carcinogens, such as benzo(a)pyrene and benzo(a)anthracene [21]. Thermal degradation of polymers found in buildings produce volatile organic compounds such as methane, benzene, toluene, in addition to monomers like ethylene, styrene, phenol, formaldehyde, 1,3-butadiene, phenol, and isoprene [22]. More and more literature reports mention that the work of a firefighter is associated with a distant effect of the development of malignant tumors. The most common ones include melanoma, leukemia, multiple myeloma, cancers of the esophagus, brain and kidneys [23,24]. The presumed carcinogens found in the firefighting environment include acrolein, benzene, formal-

dehyde, perchloroethylene and some polycyclic aromatic hydrocarbons [15]. Multiple studies have identified a range of contaminants in a post-fire environment [25]. Asphyxiants, irritants and carcinogens have been found to be present in concentration levels up to IDLH (Immediately Dangerous to Life or Health). Each of these chemicals has the potential to cause long-term harm to the respiratory and cardiovascular systems, as well as the skin, on inhalatory and dermal exposures. The combined effect of multiple chemicals, at various concentrations, coupled with current individual health conditions is impossible to identify. Benzene, chromium, formaldehyde, and aromatic hydrocarbons are a few of the chemicals that have all been found to be present in post-fire environments at the levels that exceed limits [25].

The objective of the work was to analyze the impact of selected factors concerning the use of firefighters' protective clothing used during rescue operations on the hazard of chemical contamination. The survey was aimed at obtaining data on the maintenance of firefighters' protective clothing, taking into account the clothing items that become the most contaminated, the conditions and frequency of clothing maintenance, the visual assessment of the removal of contaminants in the washing process, the feeling of comfort/discomfort associated with the use of contaminated protective clothing. This pilot survey of firefighters was used to evaluate the habits and trends among firefighters concerning the usage and maintenance of protective clothing.

MATERIAL AND METHODS

Questionnaire

The questionnaire survey was addressed to firefighters participating in rescue operations. The questionnaire was designed by the authors and available online. After posting the questionnaire on the website, the Regional Commands of the State Fire Service in Poland in the selected areas of the country (Łódź, Olsztyn, Gdańsk, Toruń,

Poznań, Białystok, Lublin, Katowice, Opole, Kraków) were asked to participate in the surveys and provide the access data to the questionnaire to the interested subjects. The survey was anonymous. The survey questionnaire is available from the authors of the publication.

The survey questionnaire contained 13 questions: 10 closed single choice questions (in 1 case with the opportunity to provide an individual descriptive response) and 3 multiple choice questions. The first 3 closed single choice questions were used to characterize the group of respondents and concerned their age, number of the years of service and position held. The further 7 questions of the survey concerned the indication of the parts of protective clothing that get most contaminated (soiled) during rescue operations, the knowledge of the maintenance instructions (washing) of the protective clothing used, the frequency of maintenance (washing) of protective clothing, the detergents used for washing, the assessment of the removal of contaminants from the outer garments after washing. The remaining 3 questions concerned the perceived comfort of use of the garments after the firefighting action was completed and whether it would be advisable to have a second set of outer protective clothing.

Participants

The study received widespread interest from the firefighters' community. Approximately 700 respondents took part in the survey. Completed questionnaire forms were received from 688 firefighters employed in the fire and rescue units of the State Fire Service in Poland. Of the total number of subjects surveyed:

- 39% (N = 266) were watch/section/crew commanders,
- 31% (N = 216) were firemen acting as drivers or equipment operators,
- 30% (N = 206) worked as rescue and firefighting personnel.

The majority of respondents (around 80%) had had a long time of service as firefighters (>5 years). The largest group

were firefighters with very long experience within the 11–20 years range – 42% (N = 286). The demographic characteristic of these 688 firefighters are listed in Table 1.

Statistics

The data was compiled using Spreadsheet software (Microsoft Office Excel 2007). The analysis of significance of the results of the responses to the survey was carried out using Statistica v. 10.0 using the χ^2 test to assess the relationship between the distribution of the response rates for one variable versus the other variable.

The results for which the calculated test probability p met the assumption $p < 0.05$ were considered statistically significant.

For the calculation of structure indicators, the questions to which respondents could have given ≥ 1 answer used the number of persons (N = 688) surveyed in the denominator. This applies to the questions concerning:

- indication of the most contaminated (soiled) parts of protective clothing during the rescue and firefighting operation,
- frequency of maintenance of protective clothing.

RESULTS

Elements of protective clothing

undergoing the heaviest contamination

Firefighters were found to have noted contamination on various pieces of protective clothing. Figure 1 shows the firemen's responses identifying the elements most likely to be contaminated. The results of the study indicate the potentially heaviest contamination of the surface of the legs and knees of special firefighter suit trousers, protecting the lower limbs. As many as 84% of firefighters (575 people) selected that location.

Further statistical analysis of the relationship between the type of the firefighter's work (rescuer, rescuer driver/operator of special equipment, watch/section/crew commander) and the protective clothing elements most pol-

Table 1. Demographic characteristics of the male group of firefighters (N = 688) from the State Fire Service in Poland, March–April 2020

Variable	Participants [%]
Age	
≤30 years	33
31–40 years	44
41–50 years	21
>50 years	2
Service	
<5 years	21
5–10 years	24
11–20 years	42
>20 years	13

luted (hem of the trousers legs, trousers legs at the level of the thighs, lower part of the jacket, hem of the sleeves, sleeves at the level of the arms, jacket zipflap, collar) did not show significant associations between the variables tested ($p > 0.05$) (Table 2). It can therefore be concluded that the firefighters identified the most contaminated clothing elements regardless of their position.

Contamination of the firefighter protective suit during rescue operations necessitates its maintenance. There-

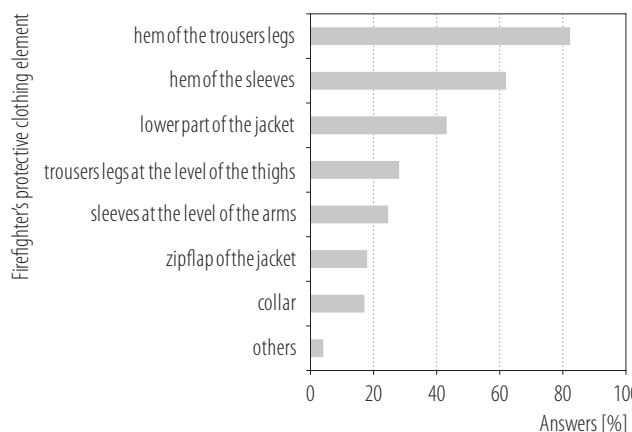


Figure 1. Firefighter's protective clothing elements undergoing the heaviest contamination during rescue operations, State Fire Service in Poland, March–April 2020

Table 2. Results of an analysis of the relationship between the firefighter's workstation and the types of protective clothing elements most polluted, State Fire Service in Poland, March–April 2020

Clothing element	Participants (N = 688) [n (%)]			χ^2	p
	rescuer (N = 206)	rescuer driver/ equipment operator (N = 216)	watch/section/ crew commander (N = 266)		
Hem of the trousers legs	176 (85)	178 (82)	214 (80)	2.01	0.366
Trousers legs at the level of the thighs	70 (34)	87 (40)	84 (32)	4.11	0.128
Lower part of the jacket	100 (48)	99 (46)	121 (45)	0.49	0.781
Hem of the sleeves	142 (69)	135 (62)	165 (62)	2.82	0.244
Sleeves at the level of the arms	67 (32)	63 (29)	74 (28)	1.27	0.531
Zipflap of the jacket	35 (17)	33 (15)	52 (19)	1.55	0.460
Collar	32 (15)	30 (14)	48 (18)	1.58	0.454

fore, the survey paid considerable attention to the maintenance-related issues.

More than a half of the respondents (52%, N = 358) expressed the opinion that they were familiar with the maintenance instructions for protective clothing. A selective, partial knowledge of the maintenance instructions was indicated by 40% (N = 275) of the surveyed firefighters, which seems to be a fairly large group. It should be considered positive that only a small group of the respondents – 3% (N = 24) stated that they did not know the exact instructions. Only 5% (N = 31) admitted that they had not read the maintenance instructions.

A half of the firefighters (N = 345) indicated that the maintenance process was carried out in accordance with the instructions for use, attached to each piece of special firefighter suit while 29% (N = 199) reported some differences in the maintenance process compared to the instructions. On the other hand, 16% (N = 111), which is a large group of people, were not familiar with maintenance instructions and a further 5% (N = 33) admitted that they did not pay attention to them. The above indicates that there is still a need for periodic training of firefighters on the proper use of protective clothing, complying with maintenance requirements.

The maintenance of protective clothing used during rescue operations – according to the responses given by firefighters actively involved in rescue and firefighting actions – was most frequently carried out after an average (31% of the respondents) or even a high degree (30% of the respondents) of pollution was noted (Figure 2). It is noteworthy that the vast majority, as many as 61% of the respondents, represented such an approach to the maintenance of special protective suits. This indicates that the occupational exposure of firefighters resulting from the effects of harmful chemicals deposited on the surface of protective clothing as well as other types of personal protective equipment (such as special gloves or footwear during rescue operations) is sometimes underestimated.

The most desirable action, the maintenance of clothing after each instance of soiling, was noted only for 17% of respondents (Figure 2). The responses of the survey participants indicate that protective clothing is more often subjected to cleaning in the case of visible heavy soiling than of less visible small impurities. The results of the study signal that some firefighters using protective clothing are partially aware of

the danger. This is indicated by maintenance not after each, but after 2–3 rescue operations (11%, $N = 77$). It can be concluded that firefighters have a premonition and know that clothing used in more actions (eg., 5 or 10) is much more contaminated and can pose a risk. Contamination with harmful substances may settle on the body in contact with the skin, or be inhaled. There is a need to promote appropriate behavior among firefighters with respect to the maintenance of protective clothing and a need to inform firefighters about the harmfulness of the deposited chemicals. This should increase the frequency of protective clothing maintenance procedures after its use.

The survey also obtained responses indicating that protective clothing was not maintained at all (Figure 2). Such answers were given by 1% of the respondents ($N = 7$). The reasons for the lack of maintenance of protective clothing, whether this was due to the lack of technical capacity to carry out the maintenance process or the light-heartedness of the respondents, were not given. Account should also be taken of the cases where clothing gets severely damaged or soiled already during the first action and is withdrawn from further use.

A statistically significant relationship ($p = 0.008$) was found between the number of years of service and the frequency of maintenance of protective clothing used by firefighters for the selected response “every 3 months”. It was noted that such a response was given more often by firefighters with a seniority of 5–10 years than by other groups. For other correlations, there was no significant impact of seniority on maintenance frequency ($p = 0.117$ – 0.912).

One third of the survey participants (254 subjects) used a product recommended by the manufacturer for the maintenance of firefighters' protective clothing. This is good news, as the type of detergent can affect the effectiveness of removing contaminants, including harmful chemicals, from the garment surfaces. A slightly larger group of the respondents – 40% ($N = 277$) reported

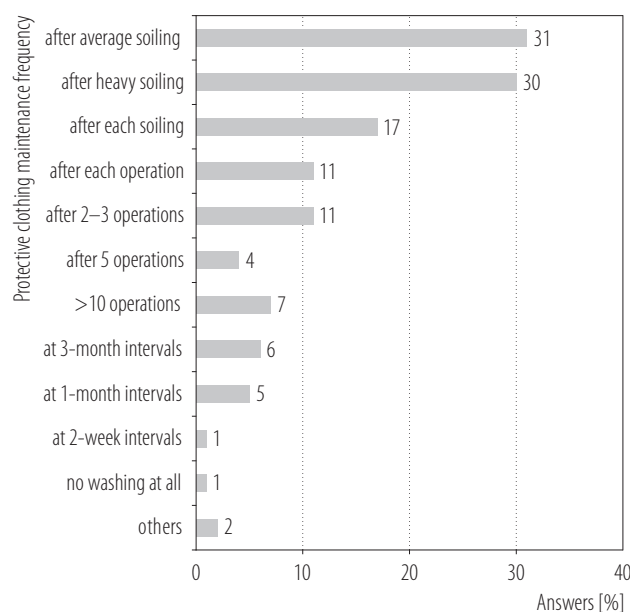


Figure 2. Frequency of maintenance of protective clothing, State Fire Service in Poland, March–April 2020

that they used a powder/liquid intended for home use. Some respondents did not pay attention to the cleaning agents used for the maintenance of protective clothing, using any available product (23%, $N = 157$). It can be concluded that the predominant group of subjects using maintenance products other than those recommended by the manufacturer were not informed of the importance of using the appropriate preparation.

Firefighters commenting on the degree of removal of contaminants from outer protective clothing during the maintenance process found in the vast majority (83%) that it was difficult to eliminate the soiling and that it was still visible. This may indicate that the garments subjected to maintenance are too dirty. Oils, fats, tar, soot and lubricants – according to the responses obtained from firefighters – were the types of dirt considered the most difficult to remove from protective clothing (Figure 3). In total, such answers accounted for 72 % of the responses. Firefighters emphasized that their experience indicated difficulties in removing biological contaminants such as blood (11%, $N = 74$) as well as paint and varnish

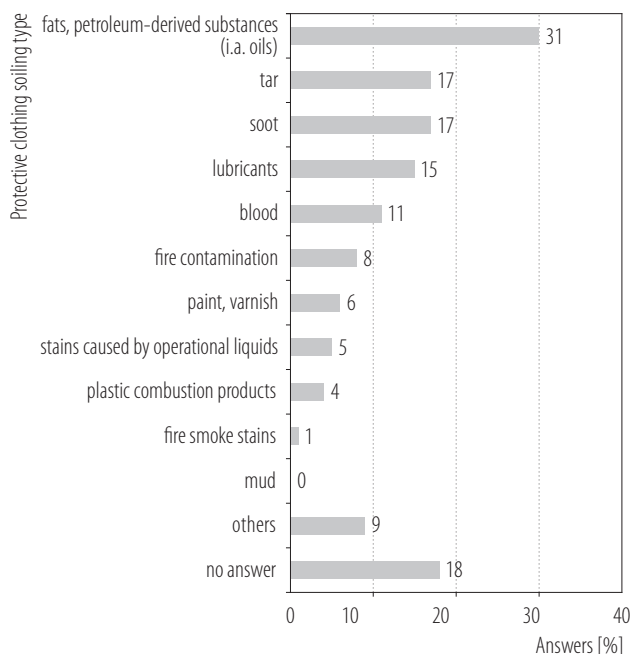


Figure 3. Types of soiling on protective clothing identified by firefighters as the most difficult to remove, State Fire Service in Poland, March–April 2020

stains (6%, $N = 41$). Analysis of the statements shows that the vast majority of respondents were aware of the types of hazardous chemicals involved in rescue operations, including firefighting. However, it is difficult to determine whether the respondents were aware of the very harmful effects of chemicals deposited on protective clothing. It was not reflected in the frequency of clothing maintenance.

There was no significant relationship between the length of service of firefighters and the visual assessment of the effectiveness of maintenance of protective clothing declared by the respondents ($p > 0.05$). It was found that seniority is not a factor that influences the assessment of the degree of removal of impurities from protective clothing.

Information on the health impact of participation in rescue operations

The majority of respondents observed discomfort after returning from firefighting operations due to fire smoke or combustion residues (Table 3). About 90% ($N = 619$)

of the surveyed firefighters felt uncomfortable. Only 10% ($N = 69$) of them felt that work did not affect their well-being and very rarely or never felt discomfort caused by participating in a firefighting operation.

Similarly, a large proportion of the respondents also pointed to a perceptible odor from the dirt deposited on protective clothing (83%, $N = 571$), 13% ($N = 89$) of the respondents considered that smell to be of moderate intensity and only 3% of the respondents (22 people) stated that the smell was perceptible to a small extent only. It should be borne in mind that the perception of smell of the firefighter's protective clothing may have been dependent on the nature of the rescue operation, the type of burning objects and the duration of the action. Nevertheless, almost all firefighters emphasized that they sensed a smell that could affect the feeling of discomfort after returning from the operation.

There was no significant correlation between the type of cleaning agent ("recommended by the manufacturer of clothing," "powder/liquid for household use," "any agent available," "I do not care which one") used for the maintenance of special firefighter suits by the surveyed group of firefighters and their discomfort ("never," "very rarely," "from time to time," "often," "almost always") after return-

Table 3. Impact of participation in the firefighting operation (effects of fire smoke, combustion residues) on well-being in firefighters from the State Fire Service in Poland, March–April 2020

Variable	Participants ($N = 688$)	
	n	%
A feeling of discomfort after returning from a firefighting operation	688	100
never	17	2.5
very rarely	66	10
from time to time	179	26
often	230	33.5
almost always	196	28

ing from rescue operations ($p = 0.751$). Also, studies of the correlation between the type of the cleaning agent and the sensation of smell from dirt deposited on the outerwear after the firefighting operation (“yes,” “moderate,” “slight,” “none”) did not confirm significant dependencies ($p = 0.390$).

DISCUSSION

As demonstrated by the survey results, the maintenance of protective clothing for firefighters used in rescue operations was not carried out frequently enough. A vast majority of the firefighters (>60%) declared that maintenance was carried out after an average or high degree of contamination was noted. Only a small group (approx. 15%) undertook maintenance of the garments after each use. Research indicates that only a proportion of firefighters using protective clothing were aware of the danger posed by debris deposited on the surface of the garments. They tried to clean the clothes as often as possible, without causing the chemicals contained in the stains to penetrate into the deeper layers. This may indicate insufficient information among firefighters on the harmfulness of chemicals contaminating the clothing materials, their carcinogenic and mutagenic properties, often demonstrated even at low doses. It should be mentioned that the statements of firefighters indicate that having a spare set of protective clothing would facilitate its maintenance.

The results of surveys conducted among professional firefighters by Jakobsen et al. [9] indicated positive changes regarding the working conditions with implication for exposure to potential occupational carcinogens in Norwegian fire departments from 1950 until today. Jakobsen et al. described working conditions in Norwegian fire departments from 1950 until today, with special attention toward work conditions and practices that could influence the exposure to occupational carcinogens. His study was based on a survey carried out among Norwegian fire

departments. A historical overview of how the exposure-modifying factors have changed could add nuanced information to exposure metrics for future epidemiological studies.

According to Jakobsen et al., a significant change concerning handling and cleaning of contaminated personal protective equipment and gear took place around 2010. For all except 1 department, there were no set standards for cleaning of turnout gear until 2000. Now, dirty clothing and gear is washed after each use. So, some changes in working conditions with implication for carcinogen exposure were identified there over the years. The routines implemented around 2010 with respect to the handling and cleaning of used gear and protective clothing should mark a reduction in exposure to potential carcinogens. Now, in every department dirty gear is washed after each use in a contaminated environment. Similar results were found for the transport of used gear. Jakobsen et al. found it interesting that although there were variations between different Norwegian fire departments, the overarching trends in working conditions were similar throughout the country. He stated, focusing on department-specific work conditions, that a peak risk of carcinogen exposure occurred during the 1970s and 1980s.

Comparing their research results with the results of Pedersen's et al. study [26] concerning the working conditions of firefighters in Denmark, Jakobsen observed that there were differences between fire departments in Norway and in Denmark. Assignment to chemical clean-ups seems to have occurred earlier in Denmark (early 1970s) than in Norway (1980s and 1990s). These differences showed that working conditions may vary geographically, even between countries as similar as Denmark and Norway.

In Poland, surveys have shown that there is a gradual improvement in the cleaning of protective clothing. It is visible that the clothing is assigned for cleaning after a shorter period of use than a few or a dozen years ago. As noted by Kahn et al. [27], the perception of the culture

of “toughness” among firefighters is changing. The soiled firefighter’s protective suit is not always perceived as a sign of pride. Kahn et al. conducted a pilot survey of firefighters in the southeastern region of the United States in order to identify the safety practices, use of protective gear and injuries. The results of his research indicated that almost 40% of firefighters did not clean their gear regularly. This presented a considerable long-term risk to firefighters due to the carcinogenic nature of many chemicals entrapped in the soiled gear.

One of the most important questions was why firefighters did not use their personal protective clothing properly. According to the authors, this was partly due to a culture of “toughness” in which using clean gear was seen as weakness. Many firefighters reported a culture in which dirty gear was seen as a sign of pride and clean gear was seen as the mark of a new and inexperienced firefighter. The survey showed that older, more experienced firefighters were more likely to have been burned. So, the rates of gear cleaning may be influenced by cultural factors. Kahn et al. concluded that the guidelines of maintenance should be developed and promoted for ensuring firefighters’ safety.

Banks et al. [14] observed that the levels of PAHs deposition on Australian firefighters’ skin and protective equipment were comparable to the data reported in other studies on firefighters in Canada, Sweden and the United States.

Recent studies highlight the importance of proper cleaning of turnout gear since carcinogens can persist and accumulate in clothing, leading to continuous exposure outside of firefighting situations [8,28]. In the survey, the firefighters stated that it was difficult to remove contaminants from protective clothing (83%). Very often the contaminants remained visible, even when using the maintenance products recommended by the garment manufacturer. This is in line with previous research by Abrard et al. [22]. He showed that the use of water wash procedure for personal protective equipment (jacket, overtrousers, gloves)

was not sufficient to remove some substances contaminating protective clothing. Washing procedure used by Abrard et al. included a hot water washing cycle with the use of a non-ionic surfactant; a washing phase with a detergent containing surfactants, sequestering agents, additives, and enzymes and finally, a rinsing phase; and a fluorinated waterproofing treatment.

He observed a significant deposit of benzo[a]pyrene (BaP) on the outer surface after a single fire training session. He noted that BaP concentration of the textile clothing sample increased by 44% after the washing procedure and concluded that some PAHs, in particular the BaP, are probably more difficult to remove than others. BaP is not soluble in water. It is possible that the washing procedure was not adapted to the physicochemical characteristics of this contaminant. Also Kirk et al. [10] noted in their studies that the levels of some compounds remained above pre-exposure levels after washing.

Most firefighters observed discomfort (90%) after returning from firefighting operations due to fire smoke or combustion residues. It indicates that the firefighters are aware of the impact of harmful factors present during rescue operations on their health. Engelsman et al. [29] conducted an interesting analysis of studies of firefighters exposed to occupational pollutants. As it follows from that analysis, firefighters are exposed to a wide range of toxic chemicals due to fire smoke, potentially exceeding the range of exposure of other occupations. The synergistic and/or antagonistic effects of chemical exposure have not been considered to date. However, the presence of many chemicals that affect firefighters at the same time can cause more discomfort after the rescue operations have been completed. This is a new issue in the context of the occupational exposure of firefighters. This is particularly of interest when considering urban firefighters, as they were found to be occupationally exposed to PAHs, benzene, per- and polyfluoroalkyl substances (PFASs), metals, flame retardants and pesticides [29].

An important issue is to adjust the size of the protective clothing to the user, which is important in the case of personal protective equipment for women firefighters. The use of PPE dedicated to women firefighters may reduce their contamination and thus reduce exposure to chemicals contained in them.

As reported by Watkins et al. [30] based on an international survey (840 women firefighters from 14 different countries: United Kingdom, Ireland, United States, Canada, Australia, New Zealand, Europe, aged $M \pm SD$ 40 ± 9 years; time as a firefighter $M \pm SD$ 13 ± 8 years), only 42% of women firefighters had the access to female-specific PPE. There is a need for education into heat exposure, chemical substance exposure, gynecological issues and their effects on women firefighters' fertility and cancer risk. Watkins et al. noted that the number of women firefighters is increasing worldwide, as a result of many bodies introducing recruitment quotas and targets for women. Women firefighters are estimated to represent roughly 6.3% of firefighters. The authors concluded that there was a lack of research into the association between contaminant exposures and breast and ovarian cancers, likely as a consequence of the reduced population size in comparison to male firefighters, with women previously having been excluded from many cancer risk assessments.

One of the scarce biomonitoring studies to measure environmental chemical exposures to perfluoroalkyl substances (PFAS) among firefighters, including women as compared to the general population (office workers) was conducted by Trowbridge et al. [31]. These chemicals have been associated with adverse health outcomes including breast cancer and breast tumor development. Perfluoroalkyl substances are ubiquitous in the environment and have been found in dust, food, and humans worldwide. Firefighting foams may be an important source of PFAS exposure. The studies by Trowbridge et al. demonstrated that 7 of 12 PFAS congeners were detected in the least 70% of the study population, and 4 congeners (PFHxS,

PFOA, PFOS, and PFNA) were detected in 100% of participants. Women firefighters are exposed to higher levels of some PFAS compared to office workers, suggesting that some of these exposures may be occupationally related. Multivariate models showed that congeners exposure was higher in firefighters compared to office workers after controlling for age, race and ethnicity, and education.

The authors of the survey expected that, for family reasons, longer-term firefighters would pay more attention to health-promoting behaviors than their younger colleagues. However, there was no clear correlation between seniority and the frequency of maintenance of protective clothing. The majority of firefighters (61%) regardless of their time of service, declared the maintenance of protective clothing, including the removal of chemical contaminants, after recording a medium or high degree of soiling. Heavy soiling is likely to have occurred after a period of 3 months of the garment use by firefighters with a seniority of 5–10 years, as they gave such an answer more often than other age groups. The obtained results indicate a further need for information on the importance of maintenance in the removal of residues of harmful chemicals, both among young people with short experience and among middle-aged people with much longer experience in firefighting. It is noteworthy to link the seniority of firefighters to health-promoting behaviors regarding the frequency of clothing maintenance.

Limitations

One of the limitations of the presented study is the fact that it was attended by firefighters from several Provincial Commands of the State Fire Service in Poland in the selected areas of the country. Surveying higher numbers of firefighters from other country regions will shed additional light on these issues.

Additionally, this survey is subject to limitation due to the arbitrary division of firefighters into subgroups

with a short duration of service (<5 years), a medium duration of service (5–10 years), a long duration of service (11–20 years) and a very long duration of service (>21 years), which was introduced at the characteristics of participants. The statistical analyses carried out often looked at the relationship between the “length of service” variable and other variables. A different division into subgroups would allow additional statistical analysis that might obtain new conclusions.

Another limitation is that the survey contained 2 questions to which the respondents could have given ≥ 1 answer. The number of responses was not limited, the respondents mostly gave several, averaged 3, responses. In future studies, attention should be paid to limiting the answers to multiple choice questions to a specific number.

CONCLUSIONS

The majority of the group of firefighters surveyed indicated that the surfaces of the legs and sleeves of the special firefighter suit are soiled most heavily in the conditions of rescue operations. Therefore, the aforementioned clothing items should be used as samples in the testing of harmful chemicals content.

Contamination of a firefighter’s protective clothing during rescue operations necessitates cleaning during the maintenance process. Most firefighters indicated the knowledge of the maintenance process instructions. However, it is difficult to determine its frequency. The study has shown that a small proportion of firefighters try to clean their clothing as often as possible to prevent accumulation of a lot of dirt resulting in harmful chemicals contacting the user’s skin and penetrating into the deeper layers of the garment. This may indicate that only a part of the firefighters’ community is fully aware of the dangers posed by contamination of clothing surfaces with harmful substances, including carcinogenic chemicals.

The survey confirmed that very often firefighters’ protective clothing is assigned for maintenance when it is too

contaminated. This causes difficulties in removing dirt during the maintenance process and presence of the contaminants even after maintenance has been completed. This may affect the accumulation of harmful substances in protective clothing.

Due to the excessive discomfort felt by the respondents after the use of protective clothing during rescue operations, partly as a result of a perceptible unpleasant odor from dirt on the outer protective clothing, the need for maintenance immediately after the end of the operation becomes important.

The results of the survey indicate that training on the use and maintenance of personal protective equipment, including the protective outerwear, should be provided for firefighters. The training should cover the issues related to the harmfulness of chemicals that contaminate the protective clothing used by firefighters.

Further studies are needed in order to achieve a better knowledge of individual firefighters’ exposure. It will also be necessary to find a maintenance procedure that significantly reduces the chemical substance load.

There is an evident need to promote appropriate behaviors among firefighters with respect to the maintenance of protective clothing and a need to inform firefighters about the harmfulness of the chemicals deposited on the PPE.

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