Research into smoke as an occupational risk in the fire service; part 2, supplement to the review of the literature

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Introduction

In 2015, the Occupational Employment Safety Knowledge Centre (KCAV) provided an overview of the literature that firefighting personnel run when exposed to smoke during firefighting activities in particular.

On the basis of that overview, recommendations were made for follow-up activities to investigate how firefighters can do their job as safely and healthily as possible. For this purpose, a number of subprojects have been proposed that are intended to provide more insight into the specific risks for the Dutch fireman and woman.

This report provides a supplement with regard to the latest information in the scientific literature about the dangers of exposure to toxic substances in smoke, and current studies elsewhere in the world will be highlighted.

In addition, other (sub) projects are conducting studies into gaps in knowledge about exposure to smoke for Dutch firefighters. For example, a pilot study is being conducted into the degree of contamination with toxic substances from firefighting clothing in use. An overview is also provided of the routes of absorption of toxic substances in the human body and more specifically how skin absorption of toxic substances in smoke takes place. Separate reports will be made about these (partial) studies.

Content

Summary

The Knowledge Centre for Occupational Safety(KCAV) was commissioned by the Fire Services in the Netherlands to study the latest scientific literature on exposure to smoke.

This is in addition to a literature review published in 2015 on smoke as an occupational hazard for firefighters. A total of thirteen recent publications and a book were published after the previously published literature study. As concluded before the major carcinogens are: benzene, toluene, ethyl benzene, xylenes, styrene, aliphatic compounds, phenols, aldehydes, ketones, poly-aromatic hydrocarbons, dioxins, particulate matter, and (heavy) metals. In the present report is a list of all known carcinogens published by the International Agency Research on Cancer of the World Health Organisation is fully recorded and completed with a 2016 published book on health risks in the fire services. This report also identifies the leading knowledge institutes in cancer research related to firefighting.

The newly published articles and the (ongoing) investigations give no reason to rewrite the earlier conclusions showing that direct evidence is lacking that firefighters develop cancer at a higher rate due to exposure of hazardous materials in smoke. Yet there is for this profession a statistically significant increased risk of cancer, especially testicular cancer, prostate cancer, and non-Hodgkin, because these types of cancer occur more often amongst firefighters.

1 Introduction

1.1 Background

Recent attention has been paid to the possibly increased incidence of cancer among firefighters, in particular as a result of coming into contact with hazardous substances in smoke during firefighting activities. In 2010, the World Health Organisation (WHO) (IARC, 2010) classified occupational exposure in the fire service as possibly carcinogenic as a result of exposure to flue gases and particles. At the Dutch Centre for Occupational Diseases (NCVB) the fire service is not treated as an occupational group. This means that there is no registered information about occupational diseases available for the fire service as an occupation. The Dutch Fire Service has commissioned the Safety Research Centre at the Institute for Physical Safety (IFV) to conduct a review of the literature on the relationship between cancer and the activities of the fire service. A first report was published last year (Heus, 2015). In addition, the Dutch Fire Service asked for an opinion on the possible measures to limit the risk as much as possible. This has been provided in a separate document (KCAV, 2015).

The previous review of the literature investigated the possible causes of the occurrence of certain cancers among firefighters in relation to fire-fighting activities. It is known that hazardous gases and substances are present in smoke during fires. The main carcinogens in smoke have been described as benzene, toluene, ethylbenzene, xylenes, styrene, aliphatics, phenols, aldehydes, ketones, polyaromatic hydrocarbons, dioxins, particulate matter, and (heavy) metals (Heus, 2015). These substances can cause cancer in the event of direct exposure, but can also lead to inflammatory reactions. Inflammatory reactions themselves can eventually lead to cancer. Lifestyle factors such as obesity, smoking, alcohol use and stress are also possible causes for the development of cancer.

Disruption of the biorhythm is also mentioned in the literature as a cause for contracting cancer. All this indicates that there are several factors that play a role in the development of cancer, but do not inevitably lead to cancer.

The earlier review of the literature (Heus, 2015) concluded that there is no direct evidence that firefighters develop cancer to an increased degree. Nevertheless, the above risk factors for this occupation cannot be ruled out. In the (foreign) literature, increased incidences are mentioned for the following cancers: skin cancer, bladder cancer, testicular cancer (also testis cancer), prostate cancer, lung cancer (especially mesothelioma) and non-Hodgkin. Because the literature is not unambiguous and there is no proven causal link, it could not be conclusively concluded that exposure to these risk factors leads to a greater chance of developing these types of cancer. This required further research as described in the memorandum with recommendations (KCAV, 2015).

The following recommendations could lead to results that can be achieved in the medium term:

- *Medical screening for health-threatening factors, particularly through institutions such as the RiVM.*
- *Retention of health statistics of (former) firefighters.*
- *Hotline for occupational (near) accidents and diseases.*
- *Advice on adapting protection (for example advice on the "firehood" for indoor work*

and realistic training)

Launch of simultaneous follow-up study into:

- *Weak spots in the protective equipment.*
- *Degree of contamination with carcinogens in the protective equipment.*
- *Determining concentrations of bioavailable carcinogenic substances on personal protective equipment (and on the person in question).*
- *Effect and method of cleaning protective equipment.*
- *Epidemiology of (occupational) diseases in the fire service.*
- *Research on the skin as a barrier function.*
- *Creation of a database with health parameters for (former) firefighters.*
- *Prevention of carcinogens in blood and urine.*
- *Concentrations of carcinogenic substances in different types of fire.* (KCAV, 2015).

1.2 Trigger

In recent years, international research has greatly increased knowledge about the substances that occur in smoke during (major) fires and their relationship with the development of cancer in firefighters. In order to be more specific about the situation of the Dutch Fire Service, the identified gaps in the knowledge should be filled in. The Board of Chief Fire Officers (RBC) has asked the KCAV to draw up a research plan for this and to link it as much as possible to (ongoing) research elsewhere in the world. Part of that plan is an update with the most recent literature (after 2015) on exposure to smoke and also indicating which research institutions are currently investigating the effects of exposure to smoke for firefighters. For clarification, this update also refers to previous studies.

1.3 Objective and question

In recent years, a large amount of research has been carried out in the United States, Australia, Canada and the Scandinavian countries into human damage caused by substances released during fires (Heus, 2015). In the present literature update, recently published publications on harmful substances in smoke and the relation with cancer prevention are discussed and it is indicated which knowledge institutions are currently working on (experimental) research into smoke exposure of firefighters.

The results give the Dutch Fire Service the task of developing policy with measures to limit the risks of fire-fighting activities in relation to cancer as much as possible.

The main question of this (and the previously conducted) review of the literature is:

- To what harmful substances as a result of firefighting activities, which could lead to <u>occupational diseases</u> with the focus on cancer, are firemen exposed to an increased extent compared to the general Dutch population?

The subquestions to answer are:

- What harmful substances, which could lead to cancer, are released during fires (both residential fires, industrial fires and wildfires)?
- How can firefighters come into contact with these carcinogenic substances?
- Does contact with these substances lead to an increased risk of getting cancer?

In this supplement to the previous review of the literature, the above questions have been answered and placed as well as possible in the perspective of the Dutch context. In Chapter 2 the research methods are described. In Chapter 3 and 4 a complete overview is given of which substances can be released in a fire and what the risks of these substances could be. Chapter 5 briefly indicates the content of the most important ongoing studies. In Chapter 6 an assessment is provided, and finally a number of conclusions are drawn.

2 Method

2.1 Method

For this supplement to the report published in 2015 (Heus, 2015), Pubmed[1], Researchgate[2] and Google Scholar[3] have been rechecked to see if important scientific articles have been published in 2015 and 2016 on the consequences of exposure to smoke in firefighters, possibly leading to cancer. In total, 13 articles and reports and one book were found that meet the scientific quality requirements and fit within the subject of this supplementary survey. In addition, relevant previous studies are also referred to when necessary.

2.1.1 Sources

The scientific articles have been selected for research into the effects of (carcinogenic) substances released during (fighting) fires and possibly leading to cancer in firefighters.

This means that it is first established which substances are generally released during fires and firefighting activities. Then these substances are examined in respect of the absorption channels by the human body and whether or not they are carcinogenic. In addition, on the basis of the available scientific literature, it has been examined which forms of cancer occur more frequently in firefighters than in the general population in the countries concerned. The starting point here is the WHO report published in 2010 (IARC, 2010).

2.1.2 Definitions

The following terms are used in the text:

Epidemiology	The scientific study of the occurrence and spread of diseases within and between populations
Incidence	The number of new cases of a disease per unit of time, per number of the population.[4]
Metabolites	The intermediate or end products that arise after the processing of a given substance in a biological system or "living being" (bacteria and other single-cell organisms, investments, animals). Metabolites include: amino acids, adenosine triphosphate or ATP, glucose, adrenaline, alkaloids and glycosides.
Mortality	The mortality, indicated in relation to the total number of individuals in

[1] PubMed comprises more than 24 million citations for biomedical literature from MEDLINE, life science journals and online books. Citations may include links to full-text content from PubMed Central and publisher web sites.
[2] ResearchGate is a network dedicated to science and research. Connect, collaborate and discover scientific publications, jobs and conferences.
[3] Google scholar is an internet search engine that makes the full text of scientific articles from different disciplines searchable.
[4] Usually the incidence is reported per thousand persons per year and sometimes per hundred thousand per year.

question, usually in percent or per mille.

Retrospective	Looking backwards. For example, in persons with a specific disease, it is checked whether they have a common factor that could have had a causal effect

3 Substances in smoke

The report published in 2015 and entitled "Research into smoke as an occupational risk in the fire service; a review of the literature" (Heus, 2015) provides a concise overview of the possible carcinogenic substances in smoke and possible pathways in the body. In addition to the above report, a complete overview is now given of all the (possibly/probably) carcinogenic substances that the WHO reports in smoke during firefighting activities (IARC, 2010). (Table I). In addition, a list has recently been published (Guidotti, 2016a). This list is placed next to that of the IARC and deviations are indicated in italics in the Table below.

Table I IARC evaluations of chemicals measured in fire and cancer locations in humans[5]

Chemicals measured at fires	**Evaluation**[6]	**Human evidence for carcinogenicity**	**Cancer in humans (Only for Group 1 chemicals)**
Acetaldehyde	2B	Inadequate	
Acrolein	*3*		
Antimony	*2B*		
Arsenic-	1	Sufficient	Skin, lung, liver (angiosarcoma)
Asbestos	1	Sufficient	Lung, mesothelioma, laryngeal, gastrointestinal tract
Benz [a] anthracene	2B	Inadequate	
Benzene	1	Sufficient	Leukaemia
Benzo [b] fluoranthene	2B	No data	
Benzo [k] fluoranthene	2B	No data	
Benzofuran (coumarone)	2B	No data	
Benzo [a] pyrene	1	No data	Lung, bladder, skin
1.3-Butadiene	1	Sufficient	Lymphatic system
Cadmium	1	Sufficient	Long
Chlorine alkanes	*2B*		

[5] Partly based on the IARC fabric list http://monographs.iarc.fr/ENG/Classification/latest_classif.php
[6] Groups IARC Monographs:1 (chemical is carcinogenic to humans), 2A (chemical is probably carcinogenic to humans), 2B (chemical may be carcinogenic to humans) and 3 (chemical cannot be classified as carcinogenic).

Chemicals measured at fires	**Evaluation[6]**	**Human evidence for carcinogenicity**	**Cancer in humans (Only for Group 1 chemicals)**
Chlorobenzenes	*2B/3*		
Chrysene	2B	Inadequate	
Dibenz [a, h] anthracene	2A	Inadequate	
Dichloromethane (methylene chloride)	2B	Inadequate	
Ethylbenzene	2B	Inadequate	
Formaldehyde	1	Sufficient	Nasopharynx (nasal cavities) and leukaemia
Fosgen	*??*		
Furaan	2B	Inadequate	
Fine dust	*??*		
Glutaraldehyde	*??*		
Indeno-1,2,3- [cd] pyrene	2B	Inadequate	
Isoprene	2B	Not available	
Carbon dioxide	??		
Carbon (total)	2B	Inadequate	
Methylene chloride	*2A*		
Napthalene	2B	Inadequate	
Nitrilen	*2B/3*		
2-Nitroamisols	2B	Inadequate	
Perfluorooctanoic acid (PFOA) - *Polytetrafluoroethylene (PTFE)*	*2B* *??*		
Pesticides	*??*		
Polychlorophenols - Pentachlorophenol - 2,4,6-Trichlorophenol	2B	Limited	
Polychlorinated biphenyls ((aroclor; 54%) (chlorodiphenyl) combined)	2A	Limited	
Polychlorinated dibenzodioxins[7]	3		
Radioactivity (γ-activity)	1	Sufficient	All locations
Radionuclides (α-particle radiation)	1	Sufficient	All locations

[7] Polychlorinated dibenzo para-dioxins are classified as a group in Group 3

Chemicals measured at fires	**Evaluation**[6]	**Human evidence for carcinogenicity**	**Cancer in humans (Only for Group 1 chemicals)**
Radionuclides (β-particle radiation) 1	1	Sufficient	All locations
Soot (particles)	1[8]	Sufficient	Lung, esophagus, liver
Silica (crystalline)	1	Sufficient	Long
Silica (amorphous)	3	Inadequate	
Nitrogen dioxide	*??*		
Styrene	2B	Limited	
2,3,7,8-tetrachloro dibenzo-paradioxin	1	Limited	Lung, non-Hodgkin's lymphoma, sarcoma
Tetrachloroethane	*2B*		
Tetrachlorethylene (perchlorethylene)	2A	Limited	Neck, esophagus, non-Hodgkin lymphoma
Toluene diisocyanates	2B	Inadequate	
Trichlorethylene	1/2A	Limited	Liver and bile ducts, non-Hodgkin's lymphoma, kidney cells
Trichloromethane (chloroform)	2B	Inadequate	
Triphenylene	3	Inadequate	
Vinyl chloride	*1*		
Hydrogen cyanide	*??*		
Hydrogen fluoride	*??*		
Xylene	*3*		
Hydrochloric acid	*??*		
Sulphur dioxide	*??*		
Sulphuric acid[9]	1	Sufficient	Lung and laryngeal cancer

(to (IARC, 2010; Guidotti, 2016a)) Italics are for the substances mentioned by Guidotti

[8] (IARC, 1987)
[9] Evaluation of work-related exposure to strong inorganic acid mists with sulphuric acid

4 Risks for firefighters from exposure to smoke

The WHO also indicated how certain carcinogenic substances are absorbed into the human body and what possible disorders they could lead to. This does not mean that these disorders will actually occur on exposure to these substances, because factors such as concentrations and the duration of exposure also play a role. Table II gives an overview of carcinogenic substances in smoke and the possible disorders resulting from exposure to these substances (IARC, 2010).

Table II Toxicokinetics and metabolism for (a number of) carcinogenic substances in smoke

Chemicals in smoke	Inclusion in body	Spread in body	Metabolism in body	Excretion through	Mechanism	Cancer
Particles	Breathing	Lungs	Depending on the solubility of particles	Macrophage phagocytosis	Ignition	Carbon: lung cancer, Hodgkin (in the presence of PAHs). Diesel exhaust gas: lung, bladder, prostate cancer, non-Hodgkin, multiple myeloma
Acetaldehyde	Breathing (45-70%)	Bloodstream	Acetic acid	Insufficient data available	DNA damage including acetaldehyde DNA byproducts	nasopharyngeal carcinoma
Benzene	Respiration (20-80%), Skin (<1%)	Fat tissue, bone marrow and urinary tract	Metabolism mainly in liver and bone marrow. Metabolites are carcinogenic	Half-life 42 minutes to 12 hours	Benzene metabolites hydroquinone and 1,4-benzoquinone inhibit topoisomerase II and microtub	Leukaemia

					ule functions, and cause oxidative stress and DNA damage	

Chemicals in smoke	Recording in body	Spread in body	Metabolism in body	Excretion through	Mechanism	Cancer
1.3-Butadiene	Breathing (>40%)	Widely spread throughout the body	Urinary tract metabolites 1,2-dihydroxylbuty I mercapturic acid and monohydroxy-3-butenyl mercapturic acid	Half-life 2-10 h	1.3-butadiene causes DNA compounds and damage and causes proliferation of cells	Lymphohaematopoietic
Formaldehyde	Respiration (100%) Skin (3.4% in rats)	Mainly local for metabolism	Conversion to CO2 and other monocarbon compounds in all tissues	Half-life 1 min (rats)	DNA crosslinking, Chromosomal changes and cell proliferation. Gene mutations and chromatoid exchange	nasopharyngeal carcinoma and sinonasal cancer, leukaemia
PAHs	Mainly breathing Skin (about 20% for pyrene)	After skin exposure highest concentrations in liver, kidney, adipose tissue and lungs	Metabolism in all tissues. 1-hydroxypyrene is used as an indicator for total exposure	Half-life after skin exposure 30 hours for benzo [a] pyrene	Metabolites of PAH oxidize and diol epoxides form stable DNA structures and induce mutations. Other mechanisms are also assumed	Lung, bladder, skin, possible prostate
PCBs	Breathing Skin (variable Depending on solvent)	Highest concentrations in adipose tissue	Liver metabolism	Half-life (work exposure) 1-24 years	Covalent alteration of proteins and DNA, possibly increased cell	Liver and bile ducts

					division with subsequent body damage as a result of free radicals	
Styrene	Breathing 60-70%	Broadly spread with highest concentrations in adipose tissue	Liver metabolism	Half-value in blood fast phase (0.58 h) and slow phase (13.0 h).	Mainly as urinary metabolites 0.7-4.4% exhalation Unchanged protein and DNA additives, Others	Lymphohaemat opoietic (blood cancer)

Chemicals in smoke	Inclusion in body	Spread in body	Metabolism in body	Excretion through	Mechanism	Cancer
					genotoxicity	
Sulphur dioxide	Breathing (40->90% in rabbits)	Mainly in upper respiratory tract	Sulphite and bisulfite in airways	Excreted by urine as sulphate	Conflicting outcomes	Lung cancer
Sulphuric acid	Breathing (50-87%)	Mainly in upper airways	Converted to sulphate for absorption in the blood	Excess sulphate excreted by urine	DNA damage	Esophagus, nasal cavity, lung

(to (IARC, 2010))

Firefighters can come into contact with the substances mentioned in the table above in various ways. Primarily due to inadequate personal protection, secondarily due to the removal of the personal protective equipment in which particles are released and/or harmful gases are still being released from the personal protective equipment. Lastly, (fire service) persons can also be exposed to harmful substances when transporting their personal protective equipment or cleaning it.

Exposure to these substances can take place, as indicated earlier (Heus, 2015), through the respiratory system, the digestive tract or the skin.

Since fire-fighting occupies a limited part of the working time, other sources of exposure to harmful substances should not be excluded. Much of this exposure takes place without the wearing of protective equipment, and the risk of contamination is greater than during firefighting activities. Examples are frequent exposure to PAHs other than fire-related exposure to PAHs such as coal gasification, burning of food (barbecuing) and cigarette smoke (Polycyclic aromatic hydrocarbons, 2015). In addition, firefighters are also exposed to harmful and possibly carcinogenic substances during emergency activities along the (motorway) trip. In this context, respiratory protection is often not used.

On the basis of urine samples from natural firefighters it has been found that the metabolites of PAHs are higher in them than in non-firefighters and that absorption by inhalation takes place because of the gaseous state of the incorporated PAHs (Oliveira, et al., 2016). Much of the exposure, incidentally, occurs as a result of the inhalation of indoor air in the barracks. This presupposes that secondary contamination takes place as a result of evaporation from clothing.

However, concentrations of PAHs in urine were below the limit values set by the American Conference of Governmental Industrial Hygienists for all firefighters investigated (Oliveira, et al., 2016).

According to Bronaugh and others, transport of harmful substances through the hair follicles and sweat glands from the skin to the capillary vascular bed can be disregarded, because the hair follicles and the sweat glands only cover 1% of the skin surface (Bronaugh, et al., 1992). In a follow-up study, a more detailed investigation will be carried out into the different absorption and transport possibilities of the body and the role played by the skin as a barrier to the absorption of harmful substances by the body.

In addition, many studies lack the discrimination capacity (= power) to specify the increased risk of cancer among firefighters (Guidotti, 2016a). The same book (Guidotti, 2016a) mentions that it is often said that there is insufficient data to say anything about the risk of cancer, but the opposite is true. There is no occupational group to which so much research has been devoted in recent years. The problem, however, is that the most frequently cited cancer forms are rare among firefighters and there are too few cases to make a significant distinction. Moreover, many studies with a "negative" result do not receive any attention or are not even published. This means that the currently available literature gives an overestimate of the actual risk of cancer for the fire safety occupation (Guidotti, 2016b). Although Ahn and Sook (Ahn & Sook, 2015) do find an increased mortality rate among Korean firefighters for certain cancers related to occupational exposure, they also underline the findings of Guidotti.

Daniels et al. (Daniels, et al., 2015) found a significant increase in lung cancer and leukaemia mortality for firefighters, linked to the actual duration of exposure. Their findings reinforce evidence of a causal link between firefighting activities and cancer. Because of the small scale effects, they report that the results must be interpreted with caution and that a follow-up study should be conducted.

In a further analysis of the "Australian Firefighters' Health Study - Final Report" (Glass, D., Sim, M. Pircher, S. Del Monaco, A. Dimitriadis, C., Miosge, J., 2014) , in which it is assumed that voluntary firefighters who did not experience any fires had an influence on the final results, it was shown that among volunteers who had experienced fires the incidents were even lower than for volunteers who had not experienced any fires. Overall it appeared once again that the incidence of cancers and mortality due to cancer among (voluntary) firefighters are lower than among the rest of the population. The exception is a significantly increased incidence for prostate cancer (Glass, D., Sim, M. Pircher, S. Del Monaco, A. Dimitriadis, C., Miosge, J., 2015a). In addition, Glass and others also conducted research into military firefighters, where they also found no increased incidence or mortality in relation to cancer. They warn of the lack of discriminating character of this study (Glass, D., Sim, M. Pircher, S. Del Monaco, A. Dimitriadis, C., Miosge, J., 2015b).

5 Large-scale studies

In a number of places around the world, (experimental) research has been carried out into the dangers of exposure to smoke for firefighters. The most important institutions are Monash University (Centre for Occupational and Environmental Health) in Australia, the Illinois Fire Service Institute (in collaboration with Skidmore College, Underwriter's Laboratories (UL) and the National Institute for Occupational Safety and Health (NIOSH)) in the United States and the Finnish Institute of Occupational Health (FIOH) in Finland. All these studies take a different approach, and the combination of such studies will eventually lead to greater clarity about the causal link between exposure to carcinogens and the development of cancer.

5.1 Monash University

In Australia, a major retrospective epidemiological study was conducted from 2011 to 2015 into the mortality and incidence of cancer in various subgroups within the firefighting population. The subgroups can be distinguished on the basis of, in particular, type of work, number of years in the fire service and number of incidents involved.

The specific goals of this study were:

- Research into the differences in causes of death between the normal population and those of (subpopulations of) firefighters. The primary focus was death due to cancer, cardiovascular disorders, respiratory diseases and trauma.
- Research on the number of cancer cases in general and for specific cancers compared with the rest of the population.
- Comparing the mortality and the incidence of cancer for various subgroups within the fire service cohort.
- Taking into account research into the increased risk of other health effects for occupational firefighters and voluntary firefighters.

Broadly speaking, the mortality due to cancer and the incidence of cancer of firefighters are not very different from the rest of the Australian population (Glass, D., Sim, M. Pircher, S. Del Monaco, A. Dimitriadis C., Miosge, J., 2014).

5.2 Illinois Fire Service Institute

In contrast to the epidemiological study at Monash University, experimental research has been conducted at the Illinois Fire Service Institute (IFSI) into exposure to heat and smoke for firefighters. The direct relationship between cancer and exposure to heat and smoke can therefore not be established in this study.

In June 2016, a delegation from the Amsterdam Fire Service and the IFV visited the IFSI during ongoing experiments on the effects of firefighting activities on the contamination of protective equipment and on physiological parameters (blood pressure, heart rate and blood composition)

Various practical experiments are carried out in this multi-year research program. With such experiments you the idea is to gain more insight into what the combined exposure to heat and smoke does to a person during fire-fighting deployments. During the experiments, firefighters and instructors are monitored before, during and after a firefighting deployment. Several fire scenarios in a room with different building materials are staged to see the different effects of heat build-up, smoke and fire development on the physical stress of firefighters.

Participants in the study measured blood pressure, heart rate, respiratory rate and core temperature of the body during deployment. In addition, samples of urine, blood and (exhalation) air samples were taken to investigate what happens after exposure to heat and smoke during a deployment. Wipe samples of the skin around the neck and neck were also taken to see which substances are present on the skin.

Evaporation from protective clothing was measured and the amount of harmful substances that remain on the clothing was determined.

During the visit striking differences were found in working methods between the American firefighters and the Dutch. This means that the research results cannot be translated one-on-one to the working conditions of the Dutch fire service.

The beauty of this partnership between various American institutions is that the research results are directly translated into educational content for the fire service and standards for (resources for) firefighters.

5.3 Finnish Institute of Occupational Health

In Finland, a research program is being conducted at the Finnish Institute of Occupational Health (FIOH) into the pollution of protective clothing from firefighters. They are particularly exposed to carcinogenic substances such as PAHs, but also during cleansing activities the risks of exposure are substantial, because protection is often less good than during firefighting.

One result of this smoke exposure study is that increased concentrations of inflammatory markers and stress hormones have been found in the body. Project leader Juha Laitinen gives the emphatic advice, because of these results, to follow the correct procedures during a deployment, but also during the maintenance of the resources. A further recommendation from this research program is the creation of a database with health records.

A recent study within the Finnish program investigated to what extent the "Skelleftea model" developed in Sweden[10] (Magnusson & Hultman, 2014) contributes to reducing the absorption of carcinogens in the body (Laitinen, Lindholm, Aatamila, Hyttinen, & Karisola, 2016). The original model has been adapted to the Finnish situation by adapting the incident site to occur in chemical incidents. The result has been a reduction in the total exposure to hazardous chemicals in persons who worked according to the adapted "Skelleftea model". Other initial results are that the persons with the poorest protection show the highest concentrations of

[10] The Skelleftea model involves clean working at the fire service and was developed in Sweden. It means that you attend an incident clean and that after an on-site deployment you take out the dirty PPAs and transport them separately from the crew. The firefighters go back to the barracks in 'clean' clothing.

inflammatory markers and stress hormones and that washing processes are important in cleaning the clothes. There is now intensive contact with FIOH to collect additional data that is specific to the Dutch context.

6 Assessment

This supplementary review of the literature underlines the conclusions from the previously conducted review of the literature that in a fire carcinogenic substances are released that can lead to cancer if the protection against these substances is inadequate (Heus, 2015). However, an extensive list of (potentially) carcinogenic substances in smoke (Table I) is now included and an indication to which forms of cancer these substances can lead (Table II). It is also indicated how strong the relationship between exposure and getting cancer is.

The most cited meta-analysis is from Lemasters (LeMasters, et al., 2006) in which for four cancers it is established that there is a significant relationship with firefighting activities. After adding two additional meta-analyses that have since appeared as mentioned in the IARC Monographs (IARC, 2010), there are three further types of cancer (prostate, testicle and non-Hodgkin) that could possibly be linked to firefighting activities. According to the IARC Monographs, there is limited evidence for an increased risk of cancer among firefighters for these three forms of cancer. It is important to monitor firefighters for the risks they run off being exposed to carcinogens and for the relevant health parameters.

Most of the studies quoted to date about the exposure of firefighters are based on total working hours, but according to one study by Dahm and colleagues, this leads to misclassification by as much as 30% (Dahm, Bertke, Allee, & Daniels, 2015) and the number of fire deployments and the time spent at the fire are more suitable for recording exposure to smoke.

A study by Fent and colleagues (Fent, et al., 2015) looked at the uptake of VOCs including benzene as a result of evaporation from protective clothing. They find high values in the exhalation air of firefighters, which strongly correlate with the evaporation values of the clothing. However, the limit values for short-term exposure to these substances are not exceeded, but it is unknown what the effects on health are from frequent short-term exposure below the limit values. Fent et al. presuppose uptake through the skin and through respiration during removal of the protective clothing and travel in the cabin of the vehicle (Fent, et al., 2015). In their study and that of Pleil and others (Pleil, Stiegel, & Fent, 2014), respiratory intake during firefighting is considered unlikely because respiratory protection is worn at that time. However, they have not measured the direct skin absorption and therefore cannot rule out absorption through the airways during firefighting. Especially not because it is known that the respiratory protective equipment does not always provide adequate protection during heavy exertion (Den Hartog & Heus, 2003).

Different techniques of firefighting in the US also lead to potentially different situations and different exposure risks. It has been clearly observed during the experiments in Illinois that American firefighters put on their breathing mask later and also regularly "lose" their helmet during the work (Kemmeren & Mol, 2016).

Studies that do not show a relationship between, for example, firefighting activities and cancer, and the so-called "negative" effect studies are often not referred to or are not published in the first place, because such studies are less interesting for publishers (Guidotti, 2016b). This may create an image that the alleged relationship between exposure and cancer is stronger than it actually is.

Lastly, it is important to take into account technical developments in which protective clothing is increasingly ventilated to reduce the heat stress, but this increase in ventilation should never be at the expense of protection against harmful substances in smoke (McQuerry, DenHartog, Barker, & Ross, 2016).

7 Conclusions

This supplement to the previous review of the literature does not yield any different conclusions from those drawn earlier. These conclusions are again included below.

The focus in this follow-up study was on the detailed study of exposure to hazardous substances that are released during fires. In a fire, a number of carcinogenic substances are released to which Dutch Fire Service personnel may be exposed during firefighting. The most important substances as mentioned in the previous study are:

- benzene,
- toluene,
- ethylbenzene,
- xylenes,
- styrene,
- aliphates,
- phenols,
- aldehydes,
- ketones,
- poly-aromatic hydrocarbons,
- dioxins,
- fine dust, and
- (heavy) metals.

This report contains a complete list of all known substances to date, as mentioned in Tables I and II.

If adequate measures are not taken, direct contact with these substances could result in cancer through inhalation or ingestion through the digestive tract and in some cases through the skin. It is therefore important to wear respiratory protective equipment and protective clothing which in principle provide primary protection against these substances.

Critical places in the protective equipment are the connections of the different pieces of protective equipment and the neck flap and/or balaclava, because direct contact between the skin and the hazardous substances is possible as a result of the openings in the clothing and the thinner protective textile layer of the balaclava or wearing insufficiently cleaned PPEs that are in contact with the skin.

Secondary contamination can occur through exposure to contaminated (protective) agents. It is therefore important also to be adequately protected during cleaning of contaminated (protective) equipment.

As a result of exposure to these carcinogens, there is a statistical link between exposure to carcinogenic substances in smoke and the following types of cancer in firefighters:

- testicular cancer (also called testis cancer),
- prostate cancer,

- non-Hodgkin.

It is virtually impossible to establish a causal link between exposure to smoke and cancer in humans, because more factors than just exposure to smoke (Heus, 2015) play a role in contracting cancer. The available literature therefore does not establish a causal relationship between exposure to smoke and cancer, but notes that some types of cancer occur more often in firefighters (statistical correlation). It is not possible to determine how much of the carcinogenic substances are absorbed by the body and/or whether absorption also leads to the development of cancer. However, there is an increased risk for firefighters, because they can come into contact with carcinogenic substances during the performance of their work. It is therefore important to minimise exposure to these substances as much as possible.

In this study the emphasis is placed on exposure to harmful substances in smoke as a risk of getting cancer. Other factors such as lifestyle, disruption of the biorhythm and exposure to other carcinogens have therefore been disregarded.

Because the available studies are based on the occurrence in firefighters outside the Netherlands, where the mode of operation is different and the protection can be different, it is necessary that on the basis of (scientific) research further information is obtained about the Dutch context with regard to pollution of clothing and possible uptake routes in the body. In order to be able to make specific recommendations for Dutch firefighters, data from Dutch firefighters must also be available. A recommendation has been provided on the research to be carried out. A pilot study into the pollution of clothing will be carried out in Finland by the FIOH. A study of exposure routes and absorption through the skin is being carried out by Radboud University. In addition, a link will be sought with the IFSI's ongoing investigation.

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