Research into smoke as an occupational risk in the fire service; a review of the literature

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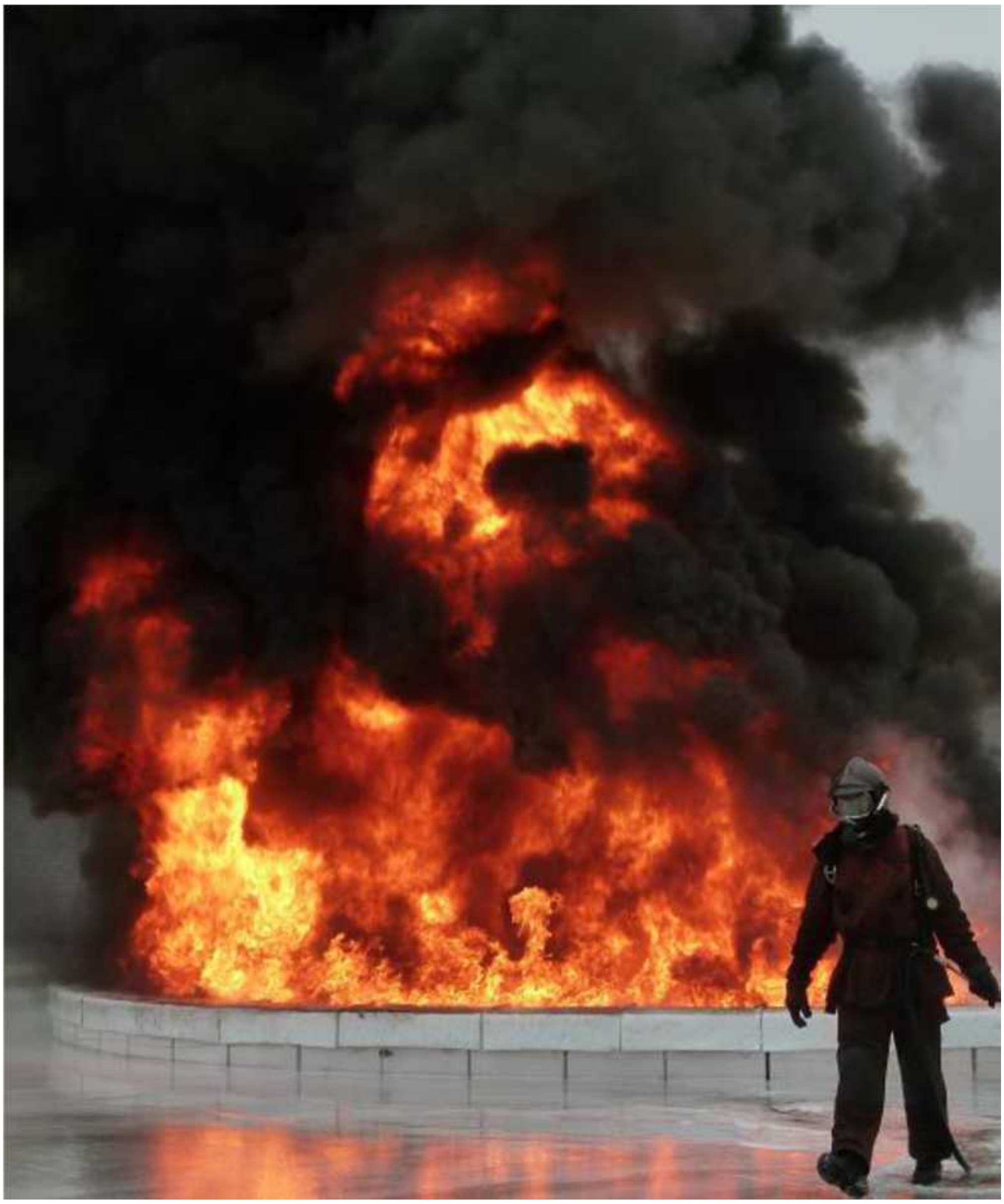

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## Summary

The Occupational Safety Knowledge Centre has commissioned the Dutch Fire Department to conduct a review of the literature on the possible occurrence of certain forms of cancer among firefighters in relation to fire-fighting activities. For this purpose, numerous databases of scientific literature have been consulted and assessed for their suitability for this research. In the context of fires, dangerous gases and substances occur in the smoke. The most important carcinogens are: benzene, toluene, ethylbenzene, xylenes, styrene, aliphatics, phenols, aldehydes, ketones, poly-aromatic hydrocarbons, dioxins, particulate matter and (heavy) metals. 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 triggers for the development of cancer. Disruption of the biorhythm is also mentioned in the literature as a cause for developing cancer. All this indicates that there are several factors that play a role in the development of cancer, but do not necessarily lead to cancer.

This review of the literature shows that there is no direct evidence that firefighters develop cancer to an increased degree. Nevertheless, the above risk factors for this profession cannot be ruled out. In the (foreign) literature, increased incidences for the following cancers are mentioned: 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 cannot be conclusively concluded that exposure to these risk factors leads to a greater chance of developing these types of cancer. This therefore requires further investigation.

# Content

# 1 Introduction

The purpose of the recently launched IFV Employment Safety Knowledge Centre is to develop, apply and guarantee knowledge for the safety, health and welfare of the personnel of the Safety Regions. The Knowledge Centre focuses on the areas of attention of occupational diseases, occupational hygiene, resistance and personal protective equipment.

Fire service activities in particular carry great risks for safety, health and well-being. In order to protect themselves against these risks, firefighters use personal protective equipment and are regularly inspected to determine whether they are still capable of operating for the fire service. In spite of these (precautionary) measures, residual risks always remain, which in the short or long term can cause damage to the health and well-being of firefighters.

For example, there has recently been a lot of attention to the possibly increased incidence of cancer among firefighters, among other things as a result of coming into contact with dangerous substances in smoke during fire fighting activities. In 2010, the IARC[1], an agency of the World Health organisation (WHO), classified the occupation of fire fighter as potentially carcinogenic due to exposure to flue gases and particles. At the Dutch Centre for Occupational Diseases (NCVB) firefighters are not registered as an occupational group. This means that there is no recorded information available about occupational diseases in the fire service. The Dutch Fire Department 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. In addition, the Dutch Fire Service has asked for an opinion on the possible measures to limit the risk as much as possible. This will be provided in a separate document (KCAV, 2015). This report merely describes the results and conclusions of the review of the literature.

Operational assistants when taking part in fire fighting activities[2] can be exposed to high temperatures and hazardous substances in smoke (such as soot particles, residue, heavy metals and asbestos). In order to be able to perform work during firefighting, firefighters are protected against fire itself and high temperatures. For this purpose, they wear protective clothing and respiratory protective equipment, which must offer adequate protection to prevent (even at high effort levels) then from being unprotected against fire and high temperatures in the context of a fire. In addition, this protective equipment must of course also protect them against the ingestion of released hazardous substances by the respiratory system, skin, eyes and digestive tract. The risks of exposure to smoke as a hazardous substance in a fire have been estimated to be lower than in the case of accidents involving hazardous substances (OGS). Smoke by definition contains dangerous substances, many of which are also carcinogenic. A number of years ago, the RIVM (Mennen and van Belle, 2007) published laboratory research into the emissions of hazardous substances in fires with a number of specific commonly used materials, and in addition to covering 50 large fires they included the data from the Environmental Accident Service (MOD) in their reports. Thus they outlined a picture of which hazardous substances can be released in combustion. Exposure to these harmful substances entails risks such as (certain forms of) cancer, respiratory diseases, inflammatory reactions, cardiovascular diseases and poisoning. In addition to the danger of direct contact with these harmful substances, some of the harmful substances are absorbed by

[1] International Agency for Research on Cancer (IARC). IARC Monographs on the evaluation of carcinogenic risks to humans, volume 98:painting, firefighting, and shiftwork. Lyon, France:IARC, 2010.
[2] This includes all activities that have to do with firefighting, so also cleansing activities.

and/or stick to personal protective equipment. This means that firefighters are exposed to a secondary source of hazardous, possibly carcinogenic, substances that can be absorbed via the respiratory system if no respiratory protection is worn after an incident.

## 1.1 Trigger

In recent years, international research has greatly increased knowledge about the substances that occur in smoke during (major) fires (Mennen and van Belle, 2007, Fabian et al., 2010). There has also recently been publicity about the alleged relationship between the greater risk of getting cancer among firefighters and the pollution of personal protection equipment, about which, however, there is still a great deal of confusion.

The Board of Chief Fire Officers (RBC) has thus asked the Occupational Employment Safety Knowledge Centre to give as clear a picture as possible of cancer in the fire service on the basis of the existing scientific literature.

## 1.2 Objective and question

In recent years, much research has been conducted in the United States, Australia, Canada and the Scandinavian countries into the harmfulness for humans of substances released during fires. In this review of the literature, relevant national and international articles and reports that have been published in recent years are surveyed for the types of cancer that occur in firefighters and the possible causes for them are identified. The primary focus is on the harmful substances that are released during fire fighting and on the ways in which (respiratory system, digestive tract, eyes and/or skin) firefighters are exposed to these harmful substances.

The aim of this review of the literature is to draw scientific conclusions from the (international) publications in order to provide a good picture of the current state of affairs on this subject. Based on these results, the Dutch Fire Service will be able to develop policy with measures to limit as much as possible the risks of fire fighting activities in relation to getting cancer. For this purpose, an advisory document will be drawn up separately by the Occupational Employment Safety Knowledge Centre of the Institute for Physical Safety. This report therefore merely describes the results and conclusions of the review of the literature. It is worth noting that although there are differences in building styles, use of fire retardants and methods of action between different countries, the hazardous substances that are released during fires are largely the same and therefore the risks to health are comparable.

The main question of this review of the literature is:

- To what harmful factors as a result of fire-fighting activities, which can lead to occupational diseases 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 can 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?
- Are there other predisposing factors that can lead to an increased incidence of cancer in firefighters?

In this (non-exhaustive) review of the literature, the above questions have been answered as well as possible and placed in the perspective of the Dutch context. In Chapter 2 the research methods are described. Chapter 3 indicates what data on the Dutch Fire Service population are missing. Chapter 4 deals with factors that can lead to occupational diseases and in particular cancer among firefighters. Chapter 5 presents the state of affairs in the international literature regarding the most common forms of cancer among firefighters. A consideration of the results found and the conclusions is given in Chapters 6 and 7. Recommendations for follow-up steps are given in a separate memorandum (KCAV, 2015).

# 2 Method

## 2.1 Review of the literature

For this research use has been made of sources that had already been collected by stakeholders. These sources have been selected on scientific quality. In addition, use has been made of the *viadesk* platform of the Occupational Safety Working Group of the Dutch Fire Service.

Lastly, a final check has been carried out on Pubmed[3], Researchgate[4] and Google Scholar[5] to see if there were any important scientific articles missing in our own databases. The result was:

- Pubmed about 80 scientific articles about cancer among firefighters. No new information,
- Researchgate: approx. 80 publications (largely overlapping with Pubmed),
- Google Scholar: no further additional sources.

### 2.1.1 Analysis of the articles

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 fire fighting activities. Then these substances have been 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, we have looked at which forms of cancer are more prevalent among firefighters than in the general population in the countries concerned.

On the basis of available data on the prevalence in the general Dutch population of various forms of cancer that are relatively common among firefighters, a calculation has been made of what that means for the annual number of cases of cancer among the Dutch Fire Service population.

Lastly, it has also been examined whether other factors than exposure to hazardous substances are mentioned in the literature that could possibly lead to an increased risk of contracting cancer.

### 2.1.2 Expert group

[3] 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.
[4] ResearchGate is a network dedicated to science and research. Connect, collaborate and discover scientific publications, jobs and conferences.
[5] Google scholar is an internet search engine that makes the full text of scientific articles from various disciplines searchable.

The first draft report was discussed in a session with experts[6] (in particular Hazardous Materials Advisors) from different regions[7]. Then a second draft was sent to those same members of the expert group for a round of written comments. Based on this, a final draft report was drawn up for the steering committee of the Occupational Employment Safety Knowledge Centre.

[6] Frans Greven, Irene van der Woude, Huib Fransen, Hans Klamer and Clemens Kamp.
[7] Safety Region Rotterdam Rijnmond, Safety Region Midden West Brabant, Safety Region Groningen.

## 3 Key figures on the fire service

Due to the lack of statistics on Dutch Fire Service personnel, additional information about Dutch firefighters had to be obtained in order to get a clear picture of the actual situation among firefighters, such as:

- Numbers of (former) firefighters sick due to cancer
- Numbers of (former) firefighters who have died from (consequences of) cancer

Inquiries at health and safety services of the fire service show that they too do not have such data available. Contact has been made, among other things, with the Arbo-Unie, where one of the occupational doctors, Dr Hein Hendriks, is conducting an investigation in the Gooi Vechtstreek region. As soon as more is known, he will report to us[8].

Further information is also desired about:

- Number of deployments and exposure duration,
- Degree and manner of use of respiratory protection,
- Degree of exposure to carcinogens outside the fire service,
- Presence of carcinogenic substances in the body (medical screening),
- Number of heat training sessions (= realistic practice) during:
    - Gas-fired training (clean combustion),
    - Wood-fired training (baskets of up to 1 $m^3$ pallet wood fired in the room),
    - Flash-over training (excess of unburned harmful gases).

Lastly, it is important to have more information about:

- Concentrations of carcinogenic substances in fire fighting activities,
- Degree and manner of exposure of persons to the ingestible fraction of hazardous substances in smoke,
- Degree of filtering of the fraction present,
- Substances in urine and blood related to carcinogenic substances.

It has been found that this information is not or insufficiently documented or not freely accessible.

Follow-up research should lead to more clarity as to what such (in-depth) information can yield with regard to research into smoke as a risk for occupational diseases in the fire service. Possible sources of data include Efectis, RIVM and fire service training centres.

[8] It is now known that his research in the Safety Region Gooi and Vechtstreek has resulted in two cases of active firefighters who have received cancer (testis cancer and non-Hodgkin) and have been cured.

# 4 Pre-disposing factors for occupational diseases

The fact that someone is exposed to carcinogenic substances and factors does not mean that this person will certainly get cancer. However, there is an increased risk of getting the relevant type of cancer that comes with the exposure. How high that risk is depends, in particular, on which carcinogenic substances are involved, how many persons are exposed and how long they have been exposed for. No data is available in the Netherlands about the relationship between cancer mortality and carcinogenic substances at work. Exposure to harmful substances that are carcinogenic can also lead to other (occupational) disorders such as respiratory diseases and inflammatory reactions.

According to the Working Conditions Act (Arbeidsomstandighedenbesluit, 1997), employers are required to pay close attention to and record the work situation and exposure to carcinogenic substances on the work floor.

This record should state which carcinogenic substances are used, the reason why these substances cannot be replaced by less hazardous substances, the associated risks and hazards. In firefighting, persons are also exposed to carcinogenic substances, but whether and which carcinogenic substances these are is not always known in advance.

As far as is known, in the past employers in the fire service in the Netherlands did not investigate exposure to carcinogenic substances on the work floor (residential, outdoor and vehicular fires and wildfires and/or cleansing activities).

## 4.1 Hazardous substances in smoke

During fire fighting, substances are released that are hazardous to (public) health when ingested by the airways, digestive tract, eyes and through the skin. When exposed to hazardous substances in a fire, firefighters protect themselves against these substances by wearing personal protective equipment.

Substances released in a fire, in addition to water vapour and carbon dioxide, include carbon monoxide, nitrogen oxides, dust particles (soot), PAHs (polyaromatic hydrocarbons) and volatile organic compounds (VOCs, including benzene, toluene, styrene, chloromethane) (Mennen van Belle, 2007). In their 2007 study, Mennen and van Belle made a systematic inventory of the substances released during 50 large fires, which had been analysed by the Environmental Accident Service (MOD) in the previous ten years. In addition, by means of an extensive review of the literature, they collected data from studies with combustion experiments on a laboratory scale and from other field measurements during fires. In all cases, the measurements are based on concentrations of substances occurring in the (outside) air and deposition of substances in the environment.

The extent to which substances are released depends on the materials that are burned, on the conditions (temperature, ventilation, humidity, degassing, compounds and amount of oxygen) during the fire and on the fire-fighting method applied (water, foam, quantities of extinguishing agent, etc.). In addition, specific substances may form in particular fires. A well-known example is hydrochloric acid and dioxins, which originate from the combustion of PVC, and sulphur dioxide, which is released during the combustion of rubber-like materials

(Mennen van Belle, 2007). In general, for fires, the worse the combustion conditions, the more harmful substances are formed. This means that more and more harmful carcinogenic substances may be released in connection with cleansing work. The following tables show the most important gaseous substances and particles (dust-bound), which are released in a fire (from: Mennen and van Belle, 2007). It should be borne in mind that this list is not complete.

According to Fabian, et al. (2010), carcinogens include asbestos, benzene, styrene, formaldehyde, polycyclic aromatic hydrocarbons (PAHs), other hydrocarbons, phthalate esters and certain heavy metals (arsenic (= metalloid[9]), cadmium, chromium and nickel). Fabian et al. (2010) carried out an analysis of the combustion gases and particles generated from domestic fires and car fires, simulated real-scale fire tests and small-scale fire tests. Of course, the data cannot be translated one-to-one into the Dutch context, but the carcinogenic substances they found in the US (Fabian et al., 2010) are also mentioned in the above analysis by Mennen and van Belle (2007).

Formaldehyde is measured in all fires and in (too) high concentrations, according to NIOSH[10]-directives, found in fires in the living room, bedroom, kitchen and attic (Fabian, et al., 2010). Chromium has also been measured in most cases but like the concentrations of the other metals found did not exceed harmful exposure limits set by NIOSH. Benzene and styrene could only be measured in half or fewer of the fires. The other carcinogenic substances could not be measured in all fire scenarios (Fabian et al., 2010).

The tables below (Table I and II, taken from Mennen and Belle, 2007) provide an overview of the most important gases and substances that are released during fires.

[9] Metaloid, semi-metal or semi-metal is an element that has properties intermediate between metals and non-metals.
[10] NIOSH is the National Institute of Occupational Safety and Health in the United States.

*Table I Overview of the most important gaseous components that can be released in different types of fire.*

| **Type of fire or material** | **CO** | **$NO_X$** | **HCN** | **$SO_2$** | **HCl** | **BTEXS** | **Other aromatics** | **Aliphates** | **Aldehydes and ketones** | **Other components** |
|---|---|---|---|---|---|---|---|---|---|---|
| Plastics C-H [1)] | ++ | ± | - | - | - | ++ | + | + | + | Phenols |
| PVC and PVC-like [1)] | ++ | ± | - | - | +++ | ++ | + | + | + | Chlorinated aromatics and alipates, *vinyl chloride, phosgene* (see section 4.3.1) |
| Plastics O [1)] | ++ | ± | - | - | - | ++ | + | + | ++ | Phenols, alcohols, furans, carboxylic acids, esters, methyl methacrylate |
| Plastics N [1)] | ++ | + | ++ | - | - | ++ | + | + | + | Ammonia, isocyanates, nitriles, amines, urea |
| Plastics S [1)] | ++ | ± | - | ++ | - | ++ | + | + | + | Carbon disulfide, hydrogen sulfide. sulfuric acid, sulphur trioxide |
| Additives in plastics [2)] | (++) | (+) | (+) | (+) | (++) | (++) | (+) | (+) | (+) | Phthalates. HBr, brominated. chlorinated and oxygen-containing hydrocarbons [1)], organophosphorus compounds |
| Rubber and car tires | ++ | ± | (±) | ++ | (±) | +++ | ++ | + | + | Phenols, furans, alcohols, esters, isocyanates, nitriles, cyanobenzenes, thiazoles and thiophenes |
| Oil and fuels derived from them | + | ± | - | + | - | ++ | ++ | + | ± | Phenols |
| PCB oils and transformers [4)] | ++ | ± | - | - | ++ | ++ | ++ | + | ± | Vinyl chloride, chlorinated aromatics, chlorinated alkanes, phenols, alcohols, |
| Paints, solvents, pesticides and other | ++ | ± | (++) | (++) | (+++) | ++ | + | + | (+) | Ammonia, nitriles, isocyanates, phosgene, chlorinated and |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| chemicals | | | | | | | | | | oxygen-containing hydrocarbons[3)], carbon disulfide, carbonyl sulfide, |
| Wood, paper and cardboard | +++ | + | - | (+) | - | ++ | + | + | ++ | Phenols, furans, ammonia, nutrients, isocyanates |
| Waste [5)] | + | (+) | (++) | (+) | (++) | (+++) | + | (++) | + | Various compounds[5)] |
| Cocoa | ++ | + | ++ | - | - | + | + | ++ | ± | Nitriles |
| Buildings [5)] | + | ± | (+) | (+) | (+) | (++) | + | + | (+) | Various compounds[5)] |

BTEXS = collective name for benzene, toluene, ethylbenzene, xylenes and styrene

1) The plastics are analogous to the set-up of Table 4.1, divided into plastics with exclusively carbon and hydrogen (C-H), plastics with chlorine groups (PVC and PVC-like), plastics with oxygen groups (O), plastics with nitrogen groups (N) and plastics with sulphur groups (S).

2) These are additives used in plastics and textiles. There are both organic and metallic additives. The potential components for both groups of additives which can be released in fires are included in this table.

3) They are the same chlorinated and oxygenated components as are released in the combustion of chlorine and oxygenated plastics.

4) This means transformers with PCB-containing oil. In principle transformers may no longer contain PCB-containing oil but, in practice, these sometimes occur m the waste stage.

5) With these groups of materials the emissions are highly dependent on the composition, both in terms of size and in terms of the diversity of compounds created.

*Table II Overview of the most important substance-bound components that can be released in different types of fire.*

| Type of fire or material | Fine dust | PAHs and biphenyls | Dioxins | Other organic components | Lead | Zinc | Buyer | Other elements |
|---|---|---|---|---|---|---|---|---|
| Plastics C-H 1) | +++ | +++ | - | - | - | - | - | - |
| PVC and PVC-like 1) | +++ | +++ | ++ 2) | Chlorinated PAHs, PCBs | - | - | - | - |
| Plastics O 1) | +++ | +++ | - | Phenols, alcohols, furans, carboxylic acids, esters | - | - | - | - |
| Plastics N 1) | +++ | +++ | - | Nitro-PAHs | - | - | - | - |
| Plastics S 1) | +++ | +++ | - | Sulphur-containing PAHs | - | - | - | - |
| Additives in plastics 3) | (++) | (++) | (+) | Phthalates, organochromic and organophosphorus compounds | (+) | (+) | (+) | Barium, cadmium, chromium, cobalt, nickel, antimony, titanium, calcium, arsenic, selenium, mercury, phosphorus |
| Rubber and car tires | ++ | +++ | - | Sulphur PAHs, organosulfur and organobromium compounds, | - | ++ | - | Bromine |
| Oil and fuels derived from them | +++ | ++ | - | Organosulfuride bindings, sulphur PAHs | - | - | - | Nickel, vanadium |
| PCB oils and transformers 4) | ++ | +++ | +++ | Chlorinated PAHs | - | - | - | Iron, aluminum chrome, antimony, cadmium, tin, barium |
| Paints, solvents, pesticides and other chemicals | ++ | +++ | (+++) | Various compounds 3) | (+) | (+) | (+) | Various compounds 3) |
| Wood, paper and cardboard | + | ++ | (+) | Aldehydes, furans, phenols | - | - | - | - |

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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Waste[3)] | (+++) | (+++) | (++) | Various compounds[3)] | (+) | (+) | (+) | Various compounds[3)] |
| Cocoa | ++ | + | - | Nitriles, carboxylic acids, fatty acid esters | - | - | - | - |
| Buildings[3)] | ++ | ++ | (++) | Various compounds[3)] | ++ | ++ | ++ | Barium, cadmium, chromium, nickel, antimony, tin, titanium |

1) The plastics are analogous to the design of Table 4.1, classified m plastics with exclusively carbon and hydrogen (C-H), plastics with chlorine groups (PVC and PVC-like), plastics with oxygen groups (O), plastics with nitrogen groups (K) and plastics with sulphur groups (S).

2) The emission factor for dioxins in the combustion of PVC are not high compared with those of other chlorinated substances. Because great quantities of PVC are often involved, the final size of the dioxin emissions can still be substantial.

3) These are additives used in plastics and textiles. There are both organic and metallic additives. For both groups of additives the potential components that can be released during fires are included in this table.

4) This means transformers with PCB-containing oil. In principle transformers can no longer include PCB-containing oil, but in practice this still sometimes happens in the waste stage.

5) In these groups of materials, the emissions are highly dependent on the composition, both in terms of size and in terms of the diversity of compounds created.

Table III shows whether or not certain gases or substances are carcinogenic and what the possible absorption channels are in the body. There is not (yet) any information available about harmful concentrations of these substances.

*Table III Carcinogenicity of gases and substances that can be released during fires.*

| Gaseous components | Recording[11] | Carcinogen[12] | Substances and aerosols | Recording | Carcinogen |
|---|---|---|---|---|---|
| CO | l/h | No | Fine dust | l | Yes |
| $CO_2$ | l/s/h | No | PAHs and biphenyls | l/s/h | Yes |
| $NO_2$ | l | No | dioxins | l/s/h | Yes |
| HCN | l/h | No | Other organic components | NNB | NNB |
| $SO_2$ | l/s/h | No | Lead (compounds) | l/s/h | Yes |
| HCI | l/s/h | No | Zinc (compounds) | l/s/h | Yes |
| BTEX[13]/ aromatics | l/s/h | Yes | Copper compounds) | l/s/h | Yes |
| aliphates | l/s/h | Yes | Asbestos | l | Yes |
| aldehydes and ketones | l/s/h | Yes | Other elements | NNB | NNB |
| phenols | l/s/h | Yes | | | |

According to Mennen and van Belle (2007), further research is needed into the following harmful and potentially carcinogenic substances that could be released during fires:

- isocyanates,
- brominated flame retardants,
- brominated dioxins,
- nitro-PAHs,
- sulphur-PAHs,
- furans,
- nitriles,
- hydrogen fluoride (HF),
- hydrogen bromide (HBr).

## 4.2 Presence of hazardous substances in smoke

[11] Absorption through airways (l), digestive tract (s) and/or skin (h).
[12] www.msdshazcom.com.
[13] BTEX collective name for, among others, benzene, toluene, ethylbenzene, xylenes and styrene.

The carcinogenic PAHs mainly enter the body through nutrition and inhalation. A small amount is absorbed through the skin (https://www.rivm.nl/Onderwerpen/B/Binnenmilieu/Chemische_stoffen_in_huisstof/Polycyclische_Aromatische_Koolwaterstoffen_PAK_s). Less than 1% of the carcinogen liquid benzene is absorbed through the skin, probably as a result of the high degree of evaporation of benzene (Fent et al., 2013). In a humid environment, more benzene will be dissolved as a result of the water solubility of benzene (Fent et al., 2013).

Susan Shaw et al. (2013) have shown in a small sample (12 Californian firefighters) increased concentrations of a number of these substances (including brominated flame retardants and brominated dioxins) in the blood serum of firefighters after fighting a fire. They conclude that in view of the studies into increased incidences of cancer among firefighters these results demonstrate the importance of monitoring firefighting personnel.

A study published by Kirk and Logan (2015) states that the protective clothing retains many more carcinogenic substances than expected and that the concentrations of these substances in the microclimate are lower than normal in an industrial environment. This also means that skin exposure to carcinogenic substances is lower than might be expected based on the concentrations of these substances in the environment. It is true that carcinogenic substances can be detected under clothing. Sometimes the concentrations of carcinogenic substances after a training deployment at the fire service are just as high as after a full industrial shift.

Alexander and Baxter (2014) showed in a case study that the carcinogen diethyl phthalate occurs on the clothing in much larger concentrations than the PAHs. Gloves and "firehoods" (balaclavas) are particularly contaminated. They consider that further research is necessary.

Based on biomarkers in urine samples from test subjects, Fent et al. (2014) concluded that PAHs can be absorbed through the skin, but in particular in the neck area where the "firehoods" or neck flaps are located, because there is direct contact with the skin and the degree of protection there is also lower. Neck flaps are cleaned much less often compared to the rest of the equipment and so according to them it is obvious that this is the main source of absorption of PAHs through the skin, although they have not performed any skin absorption measurements. It is unclear whether increased concentrations in the urine also lead to an increased risk of developing cancer.

Measurable concentrations of the following carcinogenic substances were found on the balaclavas (a type of ski mask) and gloves from firefighters (Fabian et al. 2010):

- arsenic,
- chrome,
- nickel,
- PAHs,
- phthalate ester.

Fabian et al. (2010) thus confirm that the skin of firefighters can also be exposed to various inorganic (metal-containing) and organic carcinogens, but that does not conclusively indicate whether these substances are absorbed by the skin. The majority of these substances do not exceed the legally established hazardous limit values laid down in the USA. However, limit values are not the same everywhere, and further research will have to show whether limit values are exceeded in Europe and in the Netherlands.

It cannot be excluded, according to Fabian et al. (2010), that simultaneous exposure to several carcinogenic substances can have a reinforcing effect, but they have not measured the potential risk of contamination of carcinogenic substances due to inadequate or incomplete cleaning of the personal protective equipment.

In a study by CENTEXBEL (Verminck, 2014), this question was investigated, but for the time being this study appears to have insufficient reliability because the sample size is one. Because the reporting of that study is confidential, these data cannot be included in this review.

Section 5.2 examines in detail which forms of cancer can occur in the fire service's working area as a result of exposure to hazardous substances.

## 4.3 Other carcinogenic factors

Although this review of the literature focuses on carcinogenic substances that are released as a result of fire fighting activities, other causes leading to cancer cannot be excluded. Fire-fighters also have to deal with a number of factors specific to their occupational group, which are briefly discussed in the following paragraphs. Although there is speculation about it (Magnusson and Hultman, 2014), nothing is known about the absorption of harmful substances by warm and moist skin (which occurs at high exercise levels). Lastly, in the long term cancer can also arise from (neglected) inflammatory reactions that are the result of exposure to harmful substances.

### 4.3.1 Lifestyle and firefighters

The scope of this review does not allow for extensive research into the lifestyle of firefighters. However, the topic crops up in a number of international studies and, given its importance, it is included in this report.

The "Healthy workers" effect (in particular Glass et al 2014, Greven 2011, Guidotti, 1995) is mentioned. This is the effect that occurs when you select fit and healthy persons for a specific occupation. Glass et al. (2014) also found that the Australian firefighting population smokes less in comparison with the general population. Both effects could offset the exposure to other carcinogenic factors, as a result of which the effect of these factors is not reflected in an increased incidence of cancer among firefighters.

Although Greven et al (2011) also mention the "Healthy workers" effect, firefighters are more affected by respiratory diseases on average and they also find that a higher percentage of the Dutch Fire Service population (30%) smokes compared to the entire Dutch population (25%) (STIVORO, 2012).

BMI, or Body Mass Index, is a measure of overweight. Overweight is, apart from smoking, the most important risk factor for cancer that the person himself can have an influence on (www.wkof.nl/nl/kanker/risicofactoren-voor-kanker). It is known that among American firefighters more than 70% are overweight (Wilkinson, et al., 2014) and that this is an important cause of various health-related disorders. Greven (2015) also has unpublished results on increased BMI in a sample of Dutch Fire Service personnel. No data is available on dietary habits and alcohol use by the Dutch Fire Service.

Pukkala et al. (2014), on the other hand, do not see any major differences in lifestyle between the Scandinavian fire service population and the rest of the Scandinavian (working) population.

### 4.3.2 24-hour services

Irregular working hours with disruption of the day-night rhythm can lead to disorders such as cancer. In a meta-analysis of Megdal et al. (2005) it was concluded that (female) shiftwork employees and (female) aviation cabin crew have an approximately 50% higher risk of getting breast cancer compared to persons who do not have a disruption of the day-night rhythm. One possible cause for this is the suppression of levels of melatonin, which has an anti-carcinogenic and anti-oxidative effect. Although firefighters were not part of the study population, there is a chance that they too will have a higher risk of breast cancer if they regularly have a deployment at night. These statistics could be requested in a follow-up study.

Davis and Mirrick (2006) reported an increased incidence of prostate cancer among cabin crew and other shiftworkers including firefighters, but were not (yet) able to demonstrate that this was due to irregular working hours because they did not conduct any intervention studies. Pukkala et al. (2014) also see an increased incidence of prostate cancer among firefighters as a result of irregular work.

### 4.3.3 Other exposure to carcinogens

Carcinogenic substances, such as perfluoroalkyl acids (PFAAs), have been found in foam-forming extinguishing agents. These substances cause, in addition to an increase in LDL cholesterol, a risk of contracting breast cancer (Laitinen et al. 2014).

Inhaling (diesel) exhaust fumes, which contain a number of the same carcinogenic substances as fires, can lead to the development of lung cancer. Apart from animal studies, there are no studies showing the causal relationship between inhaling exhaust fumes and getting cancer. However, Garrity (1998) indicates that exposure to exhaust fumes creates a potentially increased risk of cancer and this is also endorsed by the "International Agency for Research on Cancer" (IARC, 2010). Extraction of harmful exhaust gases is the norm nowadays, but exposure in the past could lead to cancer in the present.

In the past, asbestos was also present in personal protective equipment (such as gloves and helmets) (Pukkala et al. 2014) and in brake linings of the fire service vehicles that were regularly blown clean in the barracks (Weges, J., 2015). Although it has been suggested that the use of communication equipment leads to an increased incidence of cancer (Milham, 2009), there are no scientific studies that demonstrate that there is a causal relationship between radiation as a result of the use of communication equipment and the chance of getting cancer. There are, in any case, directives (e.g. European Directive 2013/35/EU, 2013) on the maximum exposure to electromagnetic radiation as a result of the use of, for example, communication equipment.

# 5 Risks for firefighters of exposure to smoke from fires

## 5.1 General

To be able to classify cancer as an occupational disease in the fire service, as mentioned in the main question of this research, occupational disease must first be defined. A useful definition (https://www.beroepsziekten.nl/content/wanneer-komt-ziekte-door-het-werk) of an occupational disease is that it is a disease attributable to exposure at work. This yields three important elements for establishing a case (Verbeek, 2012), namely:

- it must be a disease,
- there must be some form of exposure,
- there must be a relationship between these two.

The six-step plan (https://www.beroepsziekten.nl/het-zes-stappenplan-voor-beroepsziekten) is a method for making occupational diseases demonstrable. When there is a suspicion of an occupational disease ("step 0"), it is important to systematically map a number of aspects. In this way, it can be checked whether the disorder or illness is indeed an occupational disease: a clinically observable disease or condition as a result of a stress that has occurred predominantly (>50%) in employment or working conditions. This involves the following steps:

1. determining the condition/disease,
2. determining the relationship with work,
3. determining the nature and level of causal exposure,
4. checking other possible explanations and the role of individual sensitivity,
5. concluding and reporting,
6. introducing and assessing preventive measures and interventions.

For a condition to be characterised as an occupational disease, all six steps must be met.

## 5.2 Risk of cancer in the fire service in the Netherlands

In 2010, the IARC, an agency of the World Health Organisation (WHO), classified the firefighting occupation as potentially carcinogenic as a result of exposure to flue gases and particles. In the US, Canada and Australia, a number of cancers are recognised by the government as an occupational disease in the fire service. Although the awareness of the fire service is growing, no in-depth research has been conducted into (former) firefighters.

At the Dutch Centre for Occupational Diseases (NCVB) the fire service is not registered as an occupational group. This means that there is no recorded information about occupational diseases available for the fire service occupation. In the scientific literature on this subject there seems to be a perceptible trend towards the idea that the incidence of cancer among firefighters is slightly increased. Most studies show that cancer among firefighters is about 2 to 10 percent more common (Lemasters et al., 2006; Daniels, et al, 2014, 2015; Glass et al., 2014; Pukkala et al., 2014; McGegor, DB 2005, 2007, a , b, c, Ahn et al, 2012, Stang et al., 2003).

Several studies have shown that some cancers occur significantly more often among firefighters than among the rest of the population (Table IV). Based on this foreign literature, there are indications that this could concern the following forms of cancer:

- Skin cancer,
- Bladder cancer,
- Testicular cancer (also called testis cancer),
- Prostate cancer,
- Lung cancer (especially mesothelioma),
- Non-Hodgkin.

*Table IV     Incidence ratios[14] of cancer in firefighters [15]*

| Cancers | Lemasters[16] (2006) | Glass[17] (2014) | Pukkala (2014) | Daniels (2014) | Daniels[18] (2015) | Ahn (2012) |
|---|---|---|---|---|---|---|
| All forms | 1.05 | 1.08 | 1.06 | 1.09 | *0.96* | 0.97 |
| | (25 studies) | (N = 1208) | (N = 2536) | (N = 4461) | (N = 2609) | (N = 446) |
| Melanoma | 0.67 | 1.45 | 1.25 | 0.72 | - | - |
| | (2 studies) | (N = 209) | (N = 109) | (N = 32) | | |
| Testis | *2.02* | *1.44* | *0.51* | 0.75 | - | - |
| | (4 studies) | (N = 31) | (N = 9) | (N = 15) | | |
| Prostate | *1.28* | 1.23 | 1.13 | 1.03 | *0.90* | 1.32 |
| | (13 studies) | (N = 325) | (N = 660) | (N = 1261) | (N = 832) | (N = 9) |
| Mesothelioma | 1.03[19] | *1.33* | *1.55* | 2.29 | 1.05 | - |
| | (19 studies) | (N = 11) | (N = 17) | (N = 35) | (N-382) | |
| Bladder | 1.20 | *0.85* | *1.11* | 1.12 | *1.01* | 1.60 |
| | (11 studies) | (N = 23) | (N = 194) | (N = 316) | (N-172) | (N = 17) |
| Non-Hodgkin | *1.51* | *0.98* | *1.04* | 0.99 | *1.07* | 1.69 |
| | (8 studies) | (N = 6) | (N = 82) | (N = 170) | (N = 92) | (N = 18) |

N-values are the absolute numbers of persons with cancer in these studies. Cursive values are **not** significant incidence ratios.

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[14] Bouter, L.M., van Dongen, M.C.J.M. and Zielhuis, G.A. (2008). Epidemiological research. Design and Interpretation. 5th revised edition Bohn, Stafleu van Loghem, Houten.
[15] At an incidence of 1.00 the number of cases among firefighters is equal to the number of cases of the entire population. Lower than 1.00 indicates that the probability for the relevant population is lower and higher than 1.00 indicates a higher probability for that population.
[16] This is a meta-analysis and the number of studies is mentioned on which the meta-analysis is based.
[17] For male professional firefighters.
[18] Based on the exposure duration of fire fighting activities.
[19] Based on lung cancer.

Although some incidence ratios are significant, in many of the significant cases the absolute numbers are so small that one cancer case more or less already makes a big difference to the incidence ratio. As a result, the conclusion that the risk of cancer among firefighters may or may not be increased compared to the rest of the population cannot be drawn.

Although in several studies there seems to be a link between fire fighting activities and getting cancer, the numbers of cancer cases are relatively small compared to the total study population. Clear causal conclusions cannot therefore be established. In a recent study by Daniels et al. (2015) by NIOSH[20] this is pointed out once again. Moreover, according to Daniels et al. (2015), other researchers did not take the full exposure duration into account. In their recent study they did research and there appeared to be an effect for some cancers (lung cancer and leukemia). According to them, more firefighters die as a result of these two forms of cancer. In addition, the incidence of lung cancer is also higher among firefighters. Based on exposure duration, they do not see an increased risk of other forms of cancer. In addition, they indicate that there appears to be a link between the fire service and getting cancer, but they indicate that this conclusion must be handled carefully, because there are too few data to designate fire fighting activities as the only factor. The World Health Organisation (WHO) concluded five years ago (IARC, 2010) that on the basis of the available knowledge there is limited evidence that occupational exposure of firefighters to hazardous substances can lead to cancer. Based on this, the WHO classified occupational exposure of firefighters as potentially carcinogenic (class 2B, see also table V).

Table V International classification of carcinogenicity for humans by the IARC

| | |
|---|---|
| Group 1 | Carcinogenic to humans |
| Group 2A | Probably carcinogenic to humans |
| Group 2B | Possibly carcinogenic to humans |
| Group 3 | Not classifiable as to its carcinogenicity to humans |
| Group 4 | Probably not carcinogenic to humans |

The scientific literature on the most frequently mentioned forms of cancer in the fire service is discussed below. The most important studies (Lemasters et al., 2006; Daniels, et al., 2014; Daniels et al., 2015; Glass et al., 2014; Pukkala et al., 2014; McGegor, DB 2005, 2007 a, b, c; Ahn et al., 2012; Stang et al. 2003 ) are those that provide as complete a geographic picture as possible and that have recently appeared in America, Australia, Europe and Asia. In order to form a picture of how many specific cancer cases this concerns, it has been indicated on the basis of figures from the Dutch population how many firefighters would contract specific forms of cancer if there were no difference in risk factors. This is based on the total active fire service population of 25,000 persons (Statistics Netherlands, 2014).

There seems to be a trend to finding that the above forms of cancer are more common among firefighters, but in the scientific studies the conclusion is that clear evidence is lacking for cancer in the fire service as a result of occupational factors. To substantiate this for the Dutch

[20] NIOSH is National Institute of Occupational safety and Health, Atlanta USA

Fire Service, in addition to statistics from the target group follow-up studies are also needed.

### 5.2.1 Skin cancer (melanoma)

Skin cancer occurs in the Netherlands, measured among all residents, more than 15,000 times a year (www.cijfersoverkanker.nl). This means that there should be about 22 cases per year among firefighters if the incidence for firefighting personnel is the same as for the rest of the population.

Glass et al. (2014) in Australia and Lemasters et al. (2006 in the US) found a higher incidence of skin cancer among firefighters compared to the rest of the population. Pukkala (2014) also found an increased incidence of skin cancer among firefighters in the Scandinavian countries. Daniels (2014, 2015) and Ahn et al (2012) do not mention this form of cancer in their study.

### 5.2.2 Bladder cancer

Bladder cancer is diagnosed more than 3,000 times a year in the Netherlands (www.cijfersoverkanker.nl). It is about 4 times more common in men than in women. Since the firefighting population mainly consists of men, this form of cancer should also occur more often among firefighters compared to the entire population. So if the incidence is the same, 4 firefighters will get bladder cancer every year. It is important to remember that smoking is the most important causal factor for bladder cancer.

The Australian study (Glass et al., 2014) shows no increase in bladder cancer among firefighters. In the US, Lemasters et al. (2006) found a higher incidence of bladder cancer, but Daniels et al. (2014; 2015) failed to confirm that result. Pukkala et al. (2014) found an increase in bladder cancer among firefighters in the Scandinavian study. Ahn et al. (2012) found that bladder cancer in particular was more common among Korean firefighters.

### 5.2.3 Testicular cancer

Approximately 800 new cases of testicular cancer occur in the Netherlands every year for the entire population (www.cijfersoverkanker.nl). For the firefighting population, this means 1 new case per year.

Glass et al. (2014) found no significant differences between (occupational) firefighters and the rest of the male population for testicular cancer. Pukkala et al. (2014) also found no increase in testicular cancer in the Scandinavian firefighter population. Lemasters et al. (2007) concluded that testicular cancer is likely for firefighters because they found a strongly increased incidence for this cancer among firefighters in their meta-analysis. Ahn et al (2012) do not mention this form of cancer in their study.

### 5.2.4 Prostate cancer

Approximately 11,000 new cases per year occur among all residents of the Netherlands (www.cijfersoverkanker.nl). For firefighters this means 15 new cases per year.

In the Australian study of Glass et al. (2014), there is a significant increase in prostate cancer among occupational firefighters compared with the entire Australian population. Pukkala et al. (2014) also saw an increased incidence of prostate cancer among firefighters in the Scandinavian countries. Zeegers et al. (2004) saw a lower (non-significant) incidence of prostate cancer among firefighters in the Netherlands. Lemasters (2006) also found an increased incidence of prostate cancer among firefighters in their meta-analysis, while Daniels et al. (2014) found a lower incidence for prostate cancer. Ahn et al. (2012) see a higher incidence of prostate cancer in South Korea, but the numbers are very small and so there are not (yet) any conclusions to be drawn.

### 5.2.5 Pulmonary cancer (mesothelioma)

Approx. 550 new cases per year (www.cijfersoverkanker.nl) among the entire Dutch population. For firefighters this means 1 new case per year.

In Australia, the incidence of mesothelioma was higher for firefighters employed for less than 10 years, but the firefighting population did not significantly differ from the entire Australian population (Glass et al 2014). Pukkala et al. (2014) had very few cases of mesothelioma in their firefighting population and thus conclusions about this type of cancer are not possible. Daniels et al. (2015) see an increased risk of mesothelioma if exposure duration to the carcinogen is taken into account as a factor. Ahn et al (2012) do not mention this form of cancer in their study.

### 5.2.6. Non-Hodgkin

In the Netherlands, non-Hodgkin has about 4,000 new cases per year among the general population (www.cijfersoverkanker.nl). For firefighters this means 6 new cases per year.

Sometimes non-Hodgkin (lymphoma) is mentioned in the studies, but in fact only the study of Lemasters et al. (2006) shows a clearly increased incidence of this type of cancer. Pukkala et al. (2014) also see a slight increase, but this is entirely attributable to firefighters aged over 70. The numbers of firefighters with non-Hodgkin is generally small. Ahn et al. (2012) also see an increase among South Korean firefighters, but they also note that the numbers are too low to draw firm conclusions. Glass et al. (2014) and Daniels et al. (2015) do not see a higher incidence for non-Hodgkin among firefighters in Australia and the US, respectively.

# 6 Discussion

In view of the wording of the remit and the available time, we have only considered exposure to hazardous substances as a result of fire-fighting activities. It has not been investigated whether other tasks (such as THV, IBGS and diving) also result in exposure to carcinogenic factors that could lead to a higher incidence of cancer among firefighters.

Although there is a statistical trend in the scientific literature to observe that for some cancers the incidence is higher compared to the general population, there are no causal links between exposure to smoke and getting cancer among firefighters. Nevertheless, in contrast to the Dutch Centre for Occupational Diseases (NCVB), 5 years ago the WHO classified occupational exposure of firefighters as potentially carcinogenic. The NCVB concludes in its most recent study (of Molen et al., 2015) that foreign studies show slightly increased incidences and mortality rates among firefighters, but that is still insufficiently clear as regards the type of cancer and the nature of the risky exposure. In addition, there is no data on cancer and mortality due to cancer in firefighters. Because it cannot be established beyond any doubt that cancer in firefighters is a disease attributable to exposure at work (Verbeek et al., 2012), cancer cannot yet be classified as an occupational disease by the NCVB. Despite the fact that the NCVB has noticed that slightly higher incidences and mortality rates are observed among firefighters in foreign studies, this has not been examined further. To get more clarity on this in the future, it is important that unambiguous health recording of firefighters takes place from now on.

According to the Working Conditions Act, employers are required to keep and register all work with carcinogenic substances. It is very difficult to comply with this in firefighting activities, because, unlike workers who work professionally with (known) carcinogenic substances, firefighters do not know to which substances and for how long they are exposed. This fact also makes it difficult to demonstrate that firefighters (despite the necessary precautionary measures) may or may not develop cancer after exposure to carcinogenic substances. So far, the fire service has also not kept records of exposure to carcinogenic substances.

In addition, demonstrating the presence of carcinogenic substances alone is not enough. It is important to know how large the concentrations are, the amount that is present on and in the equipment of the individual and the fraction that could be absorbed by the human body and then excreted through the natural path. The part that remains in the body poses a potential risk of developing cancer. Since such studies have not been carried out, the Dutch situation cannot support the conclusion that the presence of carcinogenic substances leads to an increased risk of cancer among firefighters.

Daniels et al. (2015) further indicate that the duration of exposure to harmful substances is an important factor, but is not included in most studies because the relevant data are missing. In their study, it appears that when looked at it only a slightly increased incidence of lung cancer was found.

Because it is now clear that there are carcinogenic substances in smoke, it is important to limit exposure to these substances as much as possible. This means that sufficient protective equipment must be worn during the work, but also that the exposed substances must be cleaned. This is described on the basis of "best practices" by (Magnusson and Hartlund, 2014) and is known as the Skeleftea model. Various initiatives have also been started in the Netherlands to implement the Swedish model, which, under the direction of a project group established by the Dutch Fire Service, should lead to uniform guidelines.

# 7 Conclusions

The main question of whether there are factors among firefighters which could lead to cancer can be answered in the affirmative. These factors include:

- lifestyle factors,
- disruption of the biorhythm,
- exposure to hazardous substances.

Conclusions regarding the sub-questions of this study are given below.

The focus in this 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 are:

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

If adequate measures are not taken, direct contact with these substances may 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 that generally 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 openings in the clothing and the thinner protective textile layer of the balaclava or of wearing insufficiently cleaned PPEs that are in contact with the skin.

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

As a result of exposure to the carcinogenic substances mentioned, there is a statistical trend towards the conclusion that the following types of cancer are more common among firefighters:

- skin cancer,
- bladder cancer,
- testicular cancer (also called testicular cancer),
- prostate cancer,
- lung cancer (especially mesothelioma),
- non-Hodgkin.

Nevertheless, it is not the case that on the basis of the available literature a causal connection can be established to an increased chance of getting (these forms of) cancer in the fire service as a result of exposure to carcinogenic substances, because it is unclear how many of these substances are absorbed by the body and/or whether possible inclusion does indeed lead 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.

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