IFV Instituut Fysieke Veiligheid

Exposure to smoke

An overview report of the studies to exposure routes, contamination and cleaning of turn-out gear and the skin barrier function

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Summary

Firefighters being exposed to toxic substances in smoke is a realistic hazard. Some of these toxic substances pose a health risk and can lead to occupational disorders. Therefore it is very important to know which toxic substances firefighters are exposed to and how these substances can be absorbed by the human body and form a potential health risk. In a previously performed literature study, it has been established that there is no causal relationship between exposure to toxic substances in smoke and cancer, despite the fact that in a number of studies it has been shown that among firefighters some cancers occur more often than in the rest of the population. In this research project, the central question was what should be done to minimize the exposure to toxic substances before, during and after the firefighting of firefighters, so that the chance of any (later) health damage is limited as much as possible?

In order to gain more clarity, a number of aspects relating to exposure to toxic substances in smoke were investigated in several (sub-)studies. A model and literature study has determined which toxic substances are most commonly found on the fire-ground and how these substances can be absorbed by the body. The permeability of the skin for toxic substances, as one of the possible absorption routes in the body, has been experimentally investigated to determine if the protective barrier function changes as a result of wearing protective clothing. In another (sub-)study, the degree of contamination with toxic substances of turn-out gear is analysed and the residual contamination remaining after cleaning is investigated. Finally different circulating guidelines of the Safety Regions on proper working in the fire services have been investigated on differences and similarities.

The results of the model and literature study have shown that inhalation is the most important absorption route for many of the 32 most common toxic substances in smoke. However the skin is a probable route for two substances, namely hydrocyanic acid and the polycyclic aromatic hydrocarbon benzo(a)pyrene. This latter substance is carcinogenic. The (sub)study to the skin characteristics has shown that the barrier function of the skin is reduced e.g. the increased moisture of the skin under the influence of wearing protective turnout clothing, It has not been investigated if the decreased barrier function of the skin is of influence on the absorption of benzo(a)pyrene. However previous research has also not shown that people with a severely reduced skin barrier develop more cancer by the absorption of benzo(a)pyrene.
The (sub-)study to the contamination with toxic substances from the 3-layer turnout gear has shown that most of the pollution does not pass the middle layer of the turnout gear. The substances that are toxic to skin can hardly be found on the inner layer and therefore are not of any danger. Although there are no clear exposure standards for harmful polycyclic aromatic hydrocarbons, standards have been set in the European Union for skin contact with these substances in *new* clothing. These standards have sometimes been exceeded for the middle layer of the tested turnout gear, but that result was mainly attributable to one strongly contaminated turnout suit of a training-centre.
After cleaning the turnout gear, the contamination has spread partly over the simultaneously washed suits. It has been found that, with a larger number of suits per wash, more contamination remains in the turnout gear. In order to prevent the relatively clean inner layer of the turnout gear from being contaminated during the cleaning process, it is possibly an idea to clean the dirty outer layers separately from the inner layer in future. Based on the

current results, further research to the complete cleaning process of turnout gear is desirable.

Based on the results of the (sub-)studies and the various occupational hygiene guidelines applied by the Safety Regions in firefighting activities, it can be concluded that there is a great awareness within the Netherlands Fire Services regarding the hazards of exposure to smoke. Firefighters must be familiar with the hazards of exposure to toxic substances in smoke beforehand and take the necessary precautionary measures to prevent exposure to toxic substances in smoke as much as possible. They must protect themselves with all possible measures during the firefighting activities to prevent absorption of toxic substances in smoke by the inhalation route or the skin. Afterwards they must isolate the contaminated (protective) means as soon as possible and ensure that the resources are cleaned as adequately as possible to minimize the chance of being exposed to toxic substances on and in the (protective equipment). Personnel of laundries who are in charge of cleaning the equipment must finally prevent themselves from coming into contact with the toxic substances in the (protective) equipment by use of suitable protective means.

Contents

Introduction

Background

Besides exposure to heat firefighters are at risk for exposure to toxic chemicals in smoke. However in the first place personal protective means are meant for protection against high temperatures and little is known about the protection against toxic chemicals in smoke. Exposure to smoke must be limited to a minimum, because it can lead to occupational related disorders on the long term. For that reason occupational hygiene is an important topic within the fire services. The Knowledge Centre Occupational Safety (KCAV) participates in international groups dealing with the topic and follows all recent developments.

Newspaper articles about firefighters struggling with cancer, died as a result of cancer or died earlier than the life expectancy of the general population were linked to the exposure to toxic chemicals in smoke. Employers within the fire-services took these signals very seriously and the Board of Fire Chiefs asked the KCAV to study the international literature on the relation between the exposure to toxic chemicals in smoke and the appearance of occupational related disorders (Instituut Fysieke Veiligheid, 2016; 2017). The conclusion from this study was that although cancer is more common amongst firefighters it is not clear that this is due to exposure to toxic chemicals in smoke.

There were still several knowledge gaps about the risks of exposure to smoke, the consequences for firefighters being exposed, the usefulness and necessity of the measures to prevent exposure and the effect of the taken measures.

Knowledge gaps still exist regarding the risks of exposure to smoke, the consequences of exposure for humans, the necessity and benefits of measures to prevent exposure and the effect of implemented measures.

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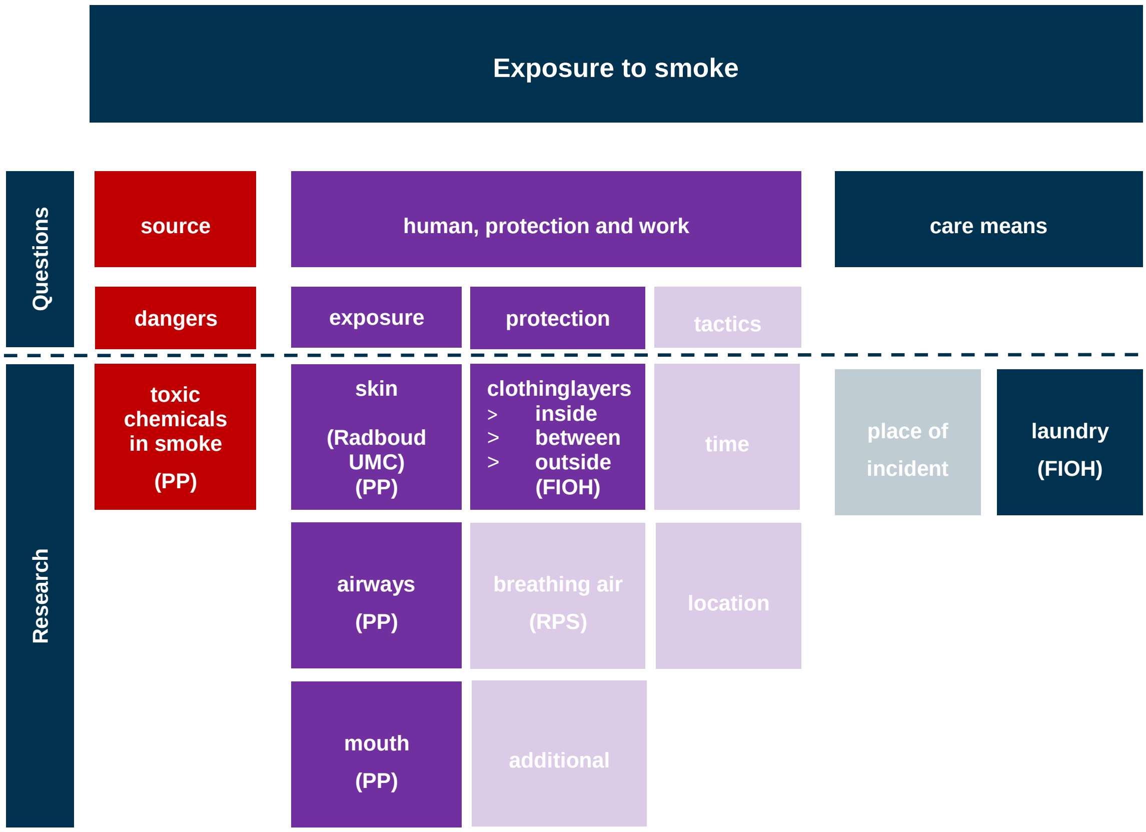
Therefore, again on behalf of the Board of Fire Chiefs, under the direction of the KCAV several studies are started by acknowledged research institutes. That were studies to:

- exposures routes in the human body
- contamination and cleaning of immediately after an incident collected turn-out gear, and
- change of skin barrier due to wearing turn-out gear.

The scheme in figure 0.1 represents the different studies and will be explained later in this chapter.[1]

[1] Only (experimental) research is carried out tot he dark coloured blocks in the scheme and not to the transparent blocks in the scheme.



PP = PreventPartner, RadboudUMC = department dermatology of the Radboud University Medical Centre, FIOH = Finnish Institute of Occupational Health.

Figure 0.1 Schematic overview of the sub-studies

Main research question and sub questions

The main question of the studies to exposure to toxic chemicals in smoke is:

> What is needed to diminish the exposure to toxic chemicals in smoke preceding, during and after an incident to reduce the risk on possible (long term) health damage?

The answer the question above and expert group formulated the following sub questions:

- To which toxic chemicals are firefighters exposed during fire incidents?
- How can these chemicals absorbed by the human body?
- How can firefighters be exposed to these chemicals?
- Which measures can be taken to diminish the exposure preceding, during and after firefighting to reduce the health risks?

Sub-studies

To answer the above question several sub-studies are defined. Most attention is paid to toxic chemicals that are potential carcinogenic to humans.

Literature and model study on absorption routes of toxic substances in smoke caused by fire (Willems, 2017)

The first study (Willems, 2017) is a literature and model study to the most common toxic chemicals in smoke and to the absorption routes in the human body. This study has given more clarity about:

> which toxic substances are the most common in fire
> how they can be absorbed into the body, and
> whether skin exposure is a real absorption route.

Determination of the fire residues from firefighting garments (Laitinen, 2017)

The Finnish Institute of Occupational Health (FIOH) analysed a selection of in fire used turn-out garments of the Amsterdam Fire Services. The used garments were analysed on the most common toxic chemicals and compared with a new suit. After regular cleaning the garments are analysed again.

Skin barrier impairment due to the occlusive effect of firefighter clothing (Van den Eijnde, Heus, Falcone, Peppelman & Van Erp, 2018)

The dermatology department of the Radboud University Medical Centre (UMC) explored the change of the skin barrier function for toxic substances from smoke due to the occlusive effect of wearing protective clothing.

Inventory "clean(er) working" procedures

An inventory was made of the procedures on clean working at the fire services of the different Safety Regions in the Netherlands to:

- see which procedures are used and by which Safety Region
- detect differences between different procedures
- determine if the results of the different sub-studies give rise for adjustments of the procedures

Additional knowledge inventory

Not everything was covered in the sub-studies, like the determination of absorption through the airways and requirements for what is clean and what is clean enough for protective means? For the airway absorption some qualitative tests are carried out and a knowledge event was organized to discuss the clean and clean enough discussion.

The course and the coherence of the sub-studies is shown schematically in the figure below (figure 0.2).

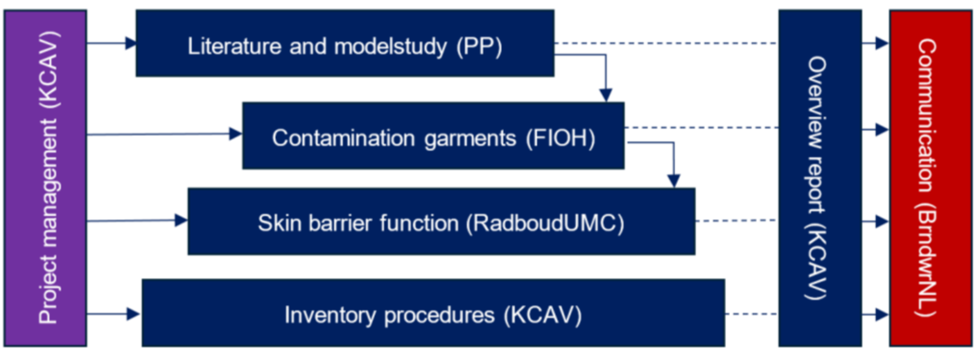


Figure 0.2 Research structure to the danger of exposure to smoke

Goal

In this report the main results off the different sub-studies are presented and are taken into consideration. The aim is to give more clarity on exposure of firefighters and maintenance personnel to toxic chemicals in smoke before, during and after (structural) firefighting.

The performed sub-studies were carried out focussing on toxic chemicals in smoke released at fire, to which firefighters can be directly or indirectly exposed to and the knowledge on absorption routes in the human body and subsequently effects on the human body. This creates a more complete picture of the currently available knowledge and fills up parts of the gaps in the present knowledge.

Limitations

In this report an overview and coherence is given of the results of the different sub-studies and additional knowledge inventories. The sub-studies were concentrated on the four earlier mentioned sub-questions and must be seen in that context. That means that more specific questions possibly need follow-up research.

The complete study is strictly related to health risks due to firefighting activities.

This report is based on five sub-studies, all describing the methods, results and conclusions. It is not the aim of this report to repeat these parts of the different underlying research reports. This report is focussing on the main topics and general results. For more detailed information reference is made to the corresponding research reports.

Coordination and cooperation

Brandweer Nederland installed an expert group that contributed to the formulation of the research questions.

To realize the goal of the project several specialised research institutes (PreventPartner, the Finnish Institute of Occupational Health (FIOH) and the Dermatology department of the Radboud UMC) worked on the different sub-questions and were responsible for their own sub-study. The coordination of the complete study was carried out by the KCAV.

Thanks to the constructive contributions from the members of expert-group, Mark Bokdam, Frans Greven, Clemens Kamp and Maurice Kemmeren, it was possible to write this report. Finally the project-team thanks Bud Pronk from the Amsterdam-Amstelland Fire Services for collecting the contaminated turn-out garments used in this study.

Reading instructions

The methods of the different sub-studies are described in chapter 1. The (integration of the) results are described in chapter 2. In chapter 3 discussion the results are interpreted after which in chapter 4 conclusions are drawn and the main question and sub-questions are answered.

1 Method

1.1 Introduction

In this chapter the research method used is described for each sub-study. For a detailed justification of the methodology of the various studies, reference is made to the corresponding research reports

1.2 Literature and model study absorption routes

A literature and model study is performed to the toxic chemicals in smoke of fire (Willems, 2017). Research to the relevance of different skin models for absorption of toxic chemicals is done in this sub-study, besides other possible ways of absorption of the chemicals. In this sub-study the following questions are answered:

- What are the most common toxic chemicals in smoke of fire?
- Wat are the absorption routes of the most important toxic chemicals in smoke of fire?
- Is skin absorption a realistic absorption route for toxic chemicals in smoke and if so:
    - what is contribution of skin absorption compared to the airway route (nose and mouth) or the digestive route (mouth)
    - which toxic chemicals are most critical for absorption in the body?

To answer above mentioned questions the following steps are taken:
1. Selection of the most common toxic chemicals which can be found in smoke of fire.
2. Grouping of toxic chemicals in absorption routes for single and repeated exposure.
3. Grouping in danger classes.

The sub-study is carried out by a combination of expert sessions, literature research and use of skin models.

1.3 Study to contaminated turn-out garments

A random selection of ten used three layered turn-out garments[2] of the Amsterdam-Amstelland Fire Services is analysed on several toxic chemicals (Laitinen, 2017). The analysed chemicals are:
- Polycyclic aromatic hydrocarbons (16 EPA-PAHs)
- Volatile organic compounds (VOCs)
- Semi-volatile organic compounds (sVOCs)
- Acids
- Dioxins and furans
- Per- and polyfluoroalkylic substances (PFAS's).

[2] The results can be extrapolated to other Safety Regions in the Netherlands, because it is estimated that 80% of the garments in use in the Netherlands is comparable with the garments of the Amsterdam-Amstelland Fire Services.

A selection of the toxic chemicals is based the appearance in smoke from the previous study of Willems (2017) and the possible health effects for humans. Before the start of the analyses a selection is made where samples from the clothing ($4cm^2$) should be taken[3]. These spots were the inside of the collar, the back and breast outer, middle and inner layer (figure 1.1).

Figure 1.1 Sampling spots

To determine whether the right choices regarding sampling have been made the first analyses in the first phases of the sub-study[4] were done with only one contaminated garment that is compared with a new unused garment. This is done to check if the right spots and toxic substances were chosen and in phase three more specific research is done on the other garments. In the final phase of the sub-study is the effect of cleaning on polycyclic aromatic hydrocarbons the garments determined.

The FIOH uses two safety limits for skin exposure of polycyclic aromatic hydrocarbons (PAHs), namely that of the European Chemical Agency (ECHA) (Regulation No. 1272/2013) and a German Standard of the Ausschuss für Produktsicherheit of the Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, the so-called Geprüfte Sicherheit (GS) standard (AfPS GS 2014: 01 PAK).
Both standards apply to safe use on the skin of **new** clothing. There are no standards available for contamination of clothing. The standard of ECHA for individual PAHs is a maximum of 1 mg/kg and the GS standard uses 0.5 mg/kg for individual PAHs and a maximum of 10 mg/kg for all PAHs together on clothing.

After analysis all turn-out garments are cleaned (washed in a washing machine and dried in a drying cabinet) following the manufacturer’s instructions (Appendix 2). After cleaning samples taken just beside the samples taken before washing and are analysed to measure the effect of cleaning on the contamination.
The efficiency of the cleaning process is determined in other words how much contamination stayed into the clothing after cleaning. Also is looked to the effect of three garments compared to two garments into the washing machine.

1.4 Study skin barrier function

To find out if the skin is more sensitive for absorption of toxic chemicals in smoke due to sweating and skin temperature elevation and exploratory study is carried out to the barrier function of the skin (Van den Eijnde et al., 2018). In this sub-study the effect of wearing protective turn-out garments on the skin barrier function is studied with sixteen subjects. In two experimental conditions the barrier function of the skin of the forearm is compared with the barrier function of uncovered skin of the forearm. These conditions were:

> fully with plastic foil covered skin

[3] Based on 1. the locations where most contamination can be expected and 2. the expertise of FIOH.
[4] See the study of Laitinen (2017) fora n explanation of these phases.

> skin covered with a turnout coat[5].

The research protocol consisted of sitting quietly on a chair in a conditioned room with an air temperature of 20 to 22 ° C and a relative humidity between 40 and 60 percent (Figure 1.2).

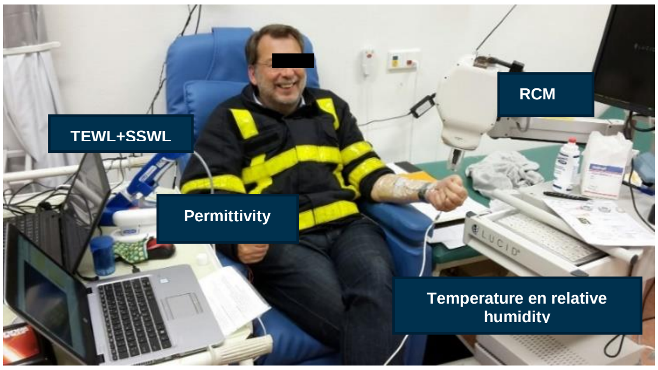


Figure 1.2 Experimental research set-up

The experimental conditions are randomized over both arms of the subjects.

The order of experimental conditions were randomized over the left and right arm of the subjects.
The first ten minutes are meant as acclimation phase. After ten minutes the first non-invasive biomedical parameters (Table 1.3) were measured on the right forearm and after twenty-five minutes the control measurements were performed on the left forearm. Thirty minutes after the control measurements, the two arms are then closed (occlusion), whereby one arm is wrapped in plastic foil and the other arm is closed with a coat of a turn-out garment. At the end of the thirty-minute occlusion phase, the effect of the occlusion was determined by performing the measurements again. Finally, thirty minutes later, the measurements were taken one last time to determine the recovery capacity of the skin.

Table 1.3 Overview of the measured biophysical parameters

Physical parameter	Apparatus	Description
Transepidermal Water Loss (TEWL)	BIOX AqualFlex, Biox Systems Ltd, England	Quantity of water crossing the stratum corneum eliminating sweating
Skin Surface Water loss (SSWL)	BIOX AqualFlex, Biox Systems Ltd, England	The amount of surface water present on the skin
Permittivity of the skin	DHT11-sensor (D-Robotics, England)	Capacitive measurement which correlates with the amount of hydration of the stratum corneum
Skin morphology	Confocal microscopy (RCM)	To measure the upper layers of the skin

[5] Coat made available by the Safety Region. Midden en West Brabant

The locations of the different biophysical measurements are shown in figure 1.4.

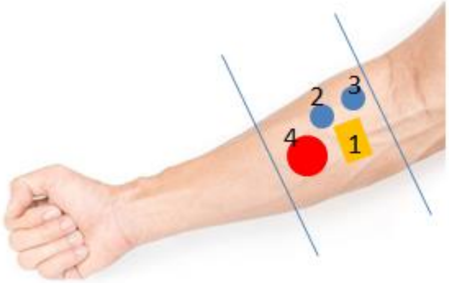


Figure 1.4 Locations of the different measurements on the forearm: 1 = skin permittivity, 2 = TEWL, 3 = SSWL, 4 = Skin morphology

The difference between the thickness of the stratum corneum and the epidermis (figure 1.5) of the control measurements after the acclimatization period and the measurements after occlusion were tested with a paired t-test. Pearson's correlation analysis has been used to determine the relationship between increased temperature and relative humidity after occlusion and transepidermal water loss (TEWL), skin surface water loss (SSWL) and skin permeability. Finally, it is determined whether age and gender influence the measured biophysical parameters.

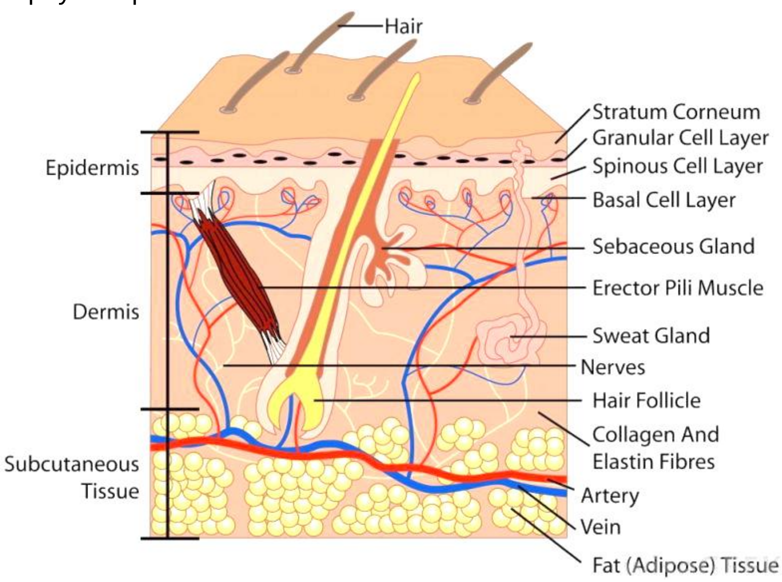


Figure 1.5 Schematic representation of the skin[6]

1.5 Inventory guidelines “clean(er) working”

All health and safety coordinators of the Safety Regions have been asked to send the 'clean(er) working' procedures, which relate to the occurrence of primary and secondary contamination with toxic chemicals in smoke of fire. We looked at differences and similarities between the various guidelines. A summary table in appendix 3 shows the most important issues from the various guidelines per Safety Region.

[6] source: http://www.entwellbeing.com.au/skincare/skin-basics/human-skin-basics/

1.6 Additional knowledge inventory

During the project, it became clear that a number of items were still insufficiently secured in the sub-studies, such as the degree of exposure via the respiration and whether it is possible to determine what is clean (enough) for personal protective equipment. Therefor a number of qualitative tests have been carried out. Because the results of the qualitative tests were insufficient, a follow-up study must be set up in the near future. Finally a knowledge event about cleaning has been organized, as described below.

1.6.1 Knowledge event cleaning of turn-out garments

In order to determine the best way to clean out turn-out garments, a meeting was organized in collaboration with Cleaning Consultancy Delft (CCD). In this meeting, a representative representation of the players in the chain of cleaning of turn-out garments brainstormed about the best methods to clean up garments and to determine whether a standard can be set with requirements about (sufficiently) clean. Attendees were (inter)national representatives from the fire services, the cleaning industry, washing machine suppliers, detergent suppliers, suppliers of firefighters' garments and producers of clothing materials. This meeting started with a general introduction about the changing fire service, the first results of the pollution and cleaning of turn-out garments and six panel discussions with the following topics.

> Various components of a turn-out suit.
> Cleanability of turn-out garments.
> Different cleaning methods for turn-out garments.
> Risk inventory and evaluation and functionality of turn-out garments.
> Design, use and repellency of the turn-out garments.
> Guidelines and / or standards about what is clean (enough).

The meeting ended with a summarizing conclusion of the day and for the future the possibilities to work together in the chain to improve the cleaning and cleanability of turn-out garments of the fire services.

2 Results

2.1 Introduction

This chapter shows the most important results for each sub-study and the relations between the sub-studies, in the last section. Integrating the results of the various sub-studies will provide more insight into the dangers of exposure to toxic chemicals in smoke and the possible measures to be taken to reduce the risks of getting occupational related disorders.

2.2 Literature and model study absorption routes

In this study it was established that the chemicals in the table below (Table 2.1) are the most common toxic chemicals in smoke of fire. Markers are shown for a number of groups of substances (including hydrocarbons).
It has been investigated whether the selected chemicals can be taken orally (through the mouth), through the respiration or through the skin. For oral intake only repeated exposure and for breathing and skin occasional and repeated exposure are mentioned. It has been found that most chemicals enter the body through respiration.

Table 2.1 Overview of 32 selected toxic chemicals in smoke and the absorption danger in the human body

Chemical name	Respiration Occasional exposure	Respiration Repeated exposure	Skin Occasional exposure	Skin Repeated exposure	Oral Repeated exposure
CO - Carbon monoxide					
NO2 - Nitrogen dioxide					
HCN - Blue acid					
SO2 - Sulphur dioxide					
HCL - hydrochloric acid					
Hydrocarbons					
Benzene					
Styrene					
Xylene					
Toluene					
Ethylbenzene					
Hexane					
(mono) Chlorobenzene					
Phenol					
Aldehydes and ketones					
Acrolein					
Formaldehyde					
Acetaldehyde					

Isocyanates					
TDI - 2,4-toluene diisocyanate					
Methyl isocyanate					
Phenyl isocyanate					
Phosgene					
Perfluoroisobutene (PFIB),					
HF - Hydrogen fluoride					
Ultrafine dust/nanoparticles					
PM 2.5					
PM 10					
Polycyclic aromatic hydrocarbons					
Benzo [a] pyrene					
Pyrene					
Dioxins and furans					
TCDD (Tetrachlorodibenzodioxin)					
Furan					
Dibenzofuran					
Metal					
Lead					
Phosphorous pentoxide					

Hazard class	Respiration Occasional exposure	Respiration Repeated exposure	Skin Occasional exposure	Skin Repeated exposure	Oral Repeated exposure
	No danger	No danger	No skin absorption	No skin absorption	No danger
	Little danger	Poisonous	Skin absorption possible	Possible harmful	Small danger
	Dangerous	Harmful	Skin absorption important	Possible carcinogenic	Harmful
	Deadly	Carcinogenic	Not applicable for smoke	Proven carcinogenic	Not applicable for smoke

The above mentioned hazard classes are a summary of the sub-study on absorption routes (Willems, 2017).

The Willems study (2017) showed that skin absorption is a real route for a limited number of chemicals, but this absorption route is usually less obvious to the intake via the respiration. Two chemicals (hydrocyanic acid (HCN) and phenol) are known to be absorbed through the skin in case of occasional skin exposure.
In case of repeated exposure, especially hydrocyanic acid (HCN) and benzo(a)pyrene substances can be absorbed through the skin and are a health hazard. Benzo(a)pyrene is a carcinogen and in combination with simultaneous (skin) absorption of phenol, the carcinogenic properties can be enhanced.
For benzo(a)pyrene, there is also a risk of getting cancer for the absorption route through the digestive tract with repeated exposure. The same also applies to dioxins and furans.

2.3 Sub-study contamination turn-out garments

In the study of the contamination of the three-layered turn-out garments, it was investigated how many polycyclic aromatic hydrocarbons (PAHs), (semi) volatile organic compounds, acids, dioxins and furans and per- and polyfluoralkyl substances are found on the turn-out garments and what quantity of the contamination after cleaning

The results of the first phases of this study have shown that the randomly selected used contaminated turn-out garments contained larger amounts of PAHs than the unused clean turn-out garment. The highest concentrations of PAHs are found in the outer and middle layers of the clothing. The concentration of benzo(a)pyrene, which can be absorbed by the skin, is lower in the contaminated turn-out garments than the standards for **new** clothing (Laitinen, 2017).

The (semi-)volatile organic compounds can mainly be found on the inside of the neck. Striking detail is that the middle layer of the belly of the clean turn-out garment contains higher concentrations of (semi-)volatile organic compounds than the contaminated turn-out garment. This is attributed to the impregnation treatment of the turn-out garments to make them liquid-repellent. The means used for impregnation fall under the (semi-)volatile organic components (Laitinen, 2017). As far as is known, there are no limit values for the presence of (semi) volatile organic compounds on materials.

The water-soluble substances are mainly found in the innermost layers of the contaminated turn-out garments. In the clean turn-out garment no other acids have been detected with the exception of barely detectable amounts of chlorine, sulfuric acid and nitric acid. No limit values are known for the water-soluble substances.
The dioxins, furans and per- and polyfluoroalkylic substances are observed mainly on the outside of the contaminated turn-out garment. Little has been found on the fabrics of the clean turn-out garment, but low concentrations have been found on the contaminated garments. For illustration, the analysis data for perfluorooctanoic acid (PFOA) are given in Figure 2.2. No exposure limit values have been established for PFOA in the Netherlands. Only in Germany and Switzerland a limit value applies for PFOA, namely 5000 ng / m3 (inhalable fraction) in the workplace air for a time-weighted average (tgg) of 8 hours (Visser et al., 2016).

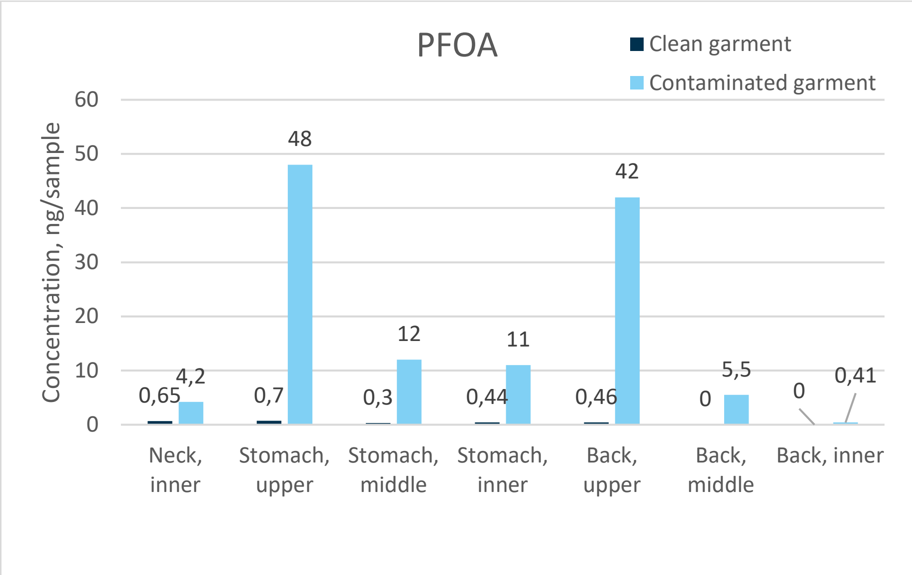


Figure 2.2 The concentration of PFOA in the clean reference turn-out garment (dark blue) and a randomly selected contaminated turn-out garment (light blue) (Laitinen, 2017)

In the next phases of the study, the remaining contaminated turn-out garments for (all) toxic chemicals and after cleaning (only PAHs) were analysed. The cleaning of the turn-out garments is carried out according to the cleaning instructions provided (see appendix 2). In these phases, a closer look was taken at the places where pollution was found in the previous phase. This means that samples from the inside of the neck and all layers of stomach and back have been examined for PAHs. For the research to (semi-)volatile organic compounds, the inside of the neck and the middle layer of the abdomen and back were examined. For acids, only the inner layers of the garments have been examined and hydrocyanic acid (HCN) has been added to the toxic chemicals to be detected, because this chemical can be absorbed through the skin. Samples from the inside of the neck and the outside of the abdomen and chest were examined for dioxins, furans and per- and polyfluoroalkylic substances.

The analysis of the PAHs of the rest of the contaminated turn-out garments has yielded a similar picture as in the previous analysis on one contaminated garment. Most of the contamination can be found in the middle layer of the turnout garments and has exceeded the stricter GS standard for maximum acceptable concentration for PAHs on the back (Figure 2.3).

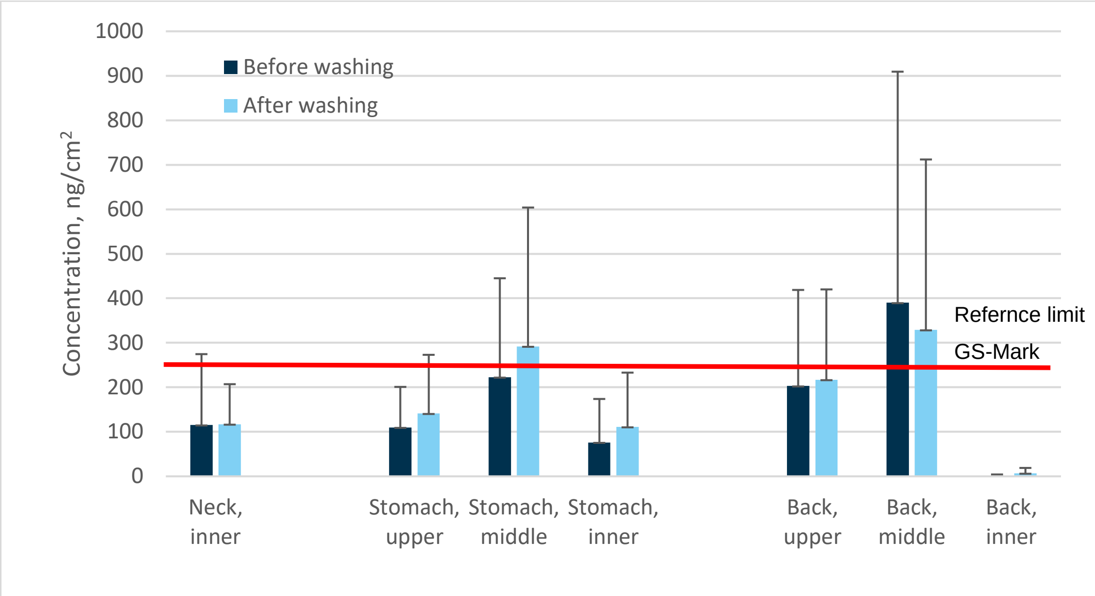


Figure 2.3 The average concentrations and standard deviations of the total amount of PAHs on the contaminated and cleaned turn-out garments (Laitinen, 2017)

The profile of all examined PAHs can be found in Figure 2.4. It is clear that in some cases the ECHA and/or more conservative GS standard have been exceeded. For benzo(a)pyrene absorbed by the skin, only the GS standard has been exceeded. Even after cleaning, the benzo(a)pyrene concentrations found are still above this standard.

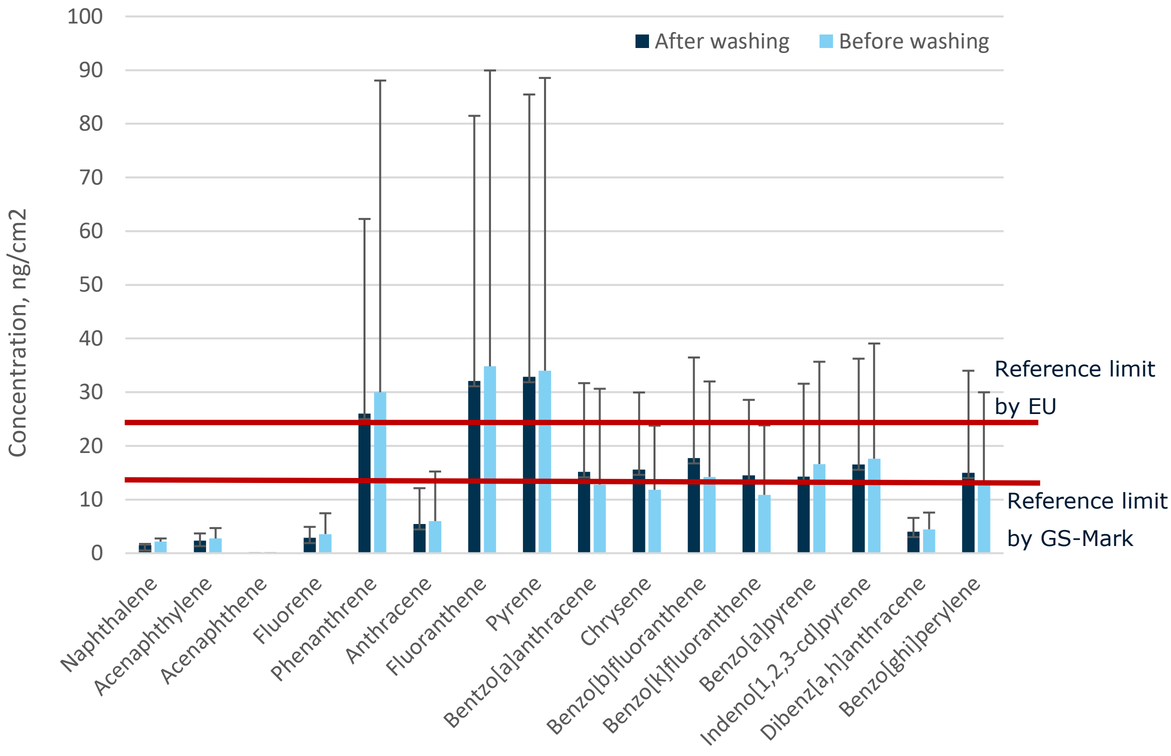


Figure 2.4 The average profile with standard deviation of the detected PAHs from the contaminated clothing before and after washing

However, exceeding the GS standard can be fully attributed to a single turn-out garment (Figure 2.5). This is a turn-out garment that was used at the BOCAS training centre in Amsterdam-Amstelland and may have been exposed relatively more frequently to toxic chemicals in smoke.

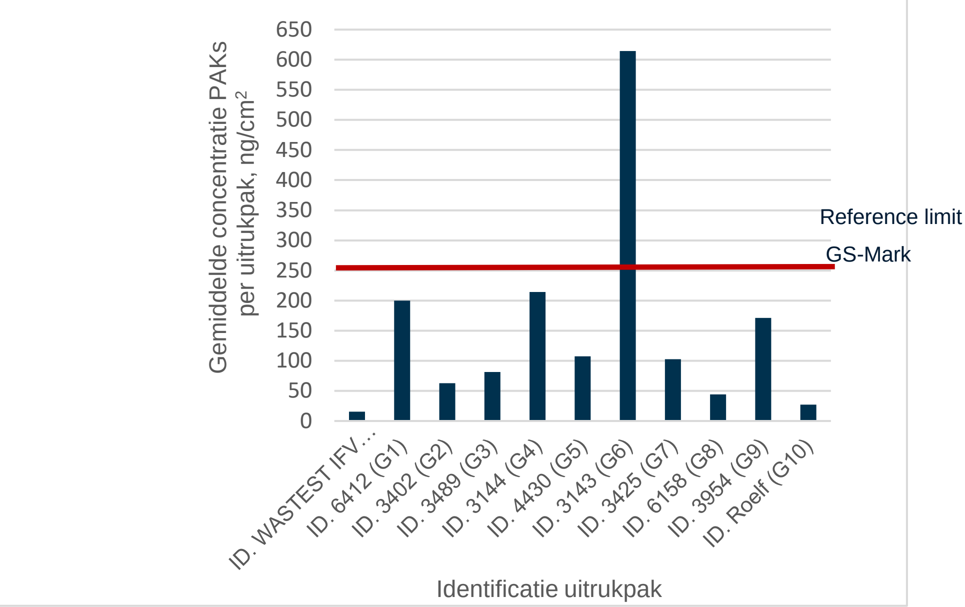


Figure 2.5 The average total concentration of measured PAHs of all individual turn-out garments before cleaning

Furthermore, it has been found that during the washing of contaminated turn-out garments the contamination spread over the garments (figure 2.6). This is called cross-contamination and means that the more heavily contaminated garments have become cleaner, but the less heavily contaminated garments have more contamination than before washing. The red line represents the GS standard for the total content of PAHs.

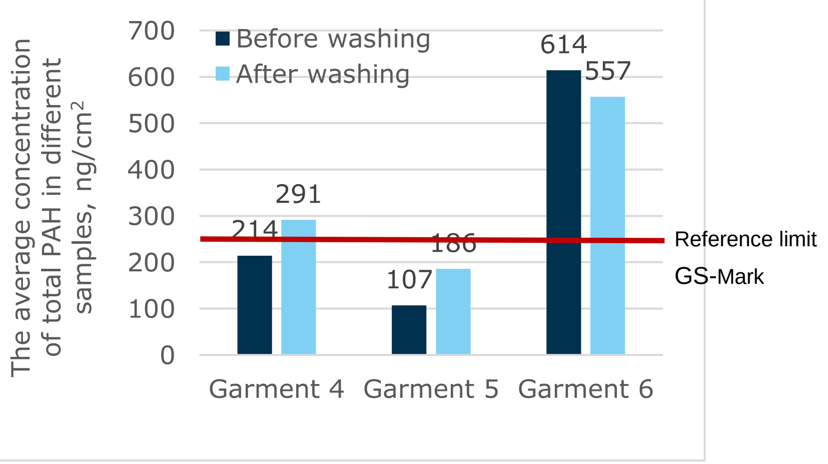


Figure 2.6 The average of the total PAHs in the packs 4, 5 and 6 before and after washing

Finally, the efficiency of cleaning has been determined. Clear differences have been found between the simultaneous cleaning of three turn-out garments in the washing machine and the simultaneous cleaning of two turn-out garments. The efficiency with fewer garments in the machine is higher (figure 2.7) and in accordance with the Finnish cleaning method, in which only one garment is cleaned in the machine. With three turn-out garments, the calculated washing efficiency for serious contamination is about 15 percent and with two turn-out garments that goes up to 40 percent. For comparison: in Finland washing efficiencies of 80 percent were measured (Laitinen et al., 2016).

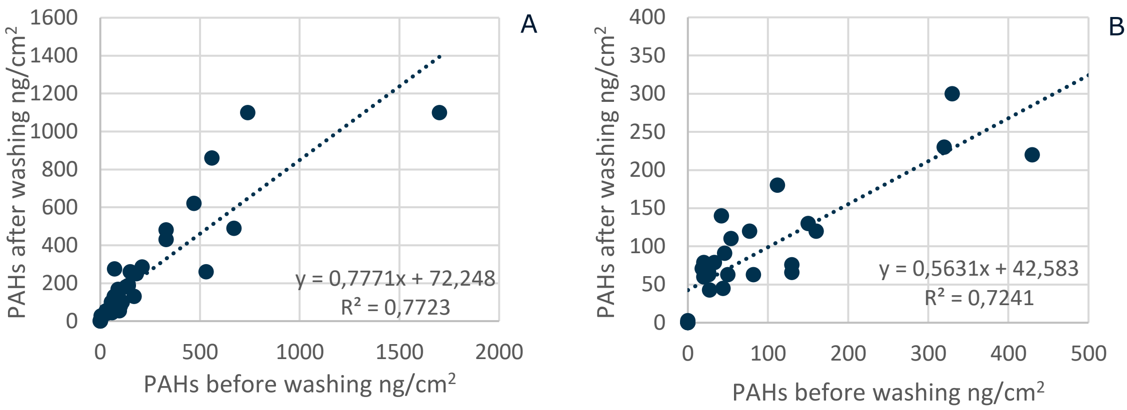


Figure 2.7 The relationship between the PAHs before and after washing: in the left picture (A) the relation can be seen with three garments in a washing machine and right (B) with two garments in washing machine (Laitinen, 2017)

For (semi-)volatile organic compounds and acids, the picture is not different from the analysis with one contaminated turn-out garment that had been investigated in the earlier phase (Laitinen, 2017). The (semi-)volatile organic components are mainly located in the middle layers of the turnout clothing and the acids can be found in the inner layers of the turnout clothing.
In addition to this phase of the research, the question is whether hydrocyanic acid (HCN) can be found, because this substance may be absorbed by the skin and the acids are located on the inside of the turn-out garments where contact with the skin is possible. The HCN concentrations (if already present) are below the detection limit of the analysis techniques. This means that no HCN has been found on the inside of the turn-out garments.

The dioxins, furans and per- and polyfluoroalkylic substances show the same picture as the analysis of the contaminated turn-out garment that was investigated in the first phases. The low concentrations of these chemicals on the outside and in the neck of the packs are very similar to the low concentrations as previously found in the first tested garment.

2.4 Sub-study barrier function skin

The sub-study to the change of skin barrier function due to skin occlusion has shown that there is a significant increase in transepidermal water loss (TEWL) when the skin is closed with a turn-out coat. This increase in TEWL recovers again when the coat has been removed.
Compared to occlusion with a plastic foil tightly around the skin of the forearm, it appears that the TEWL is even greater, but that the skin surface water loss (SSWL) and skin permeability have also increased (Table 2.8).

Table 2.8 Results of the TEWL, SSWL and skin permittivity, thickness stratum corneum (SC) and viable epidermis including stratum corneum thickness at closure with a turn-out coat and plastic foil measured before, immediately after and 30 minutes after occlusion

	Turn-out coat									
	TEWL [g m^{-2} h^{-1}]		SSWL [g m^{-2} h^{-1}]		Permittivity [-]		Stratum corneum thickness [um]		Epidermis and Stratum corneum thickness [um]	
	AVG	S.D.	AVG	S.D.	AVG	S.D.	AVG	S.D.	AVG	S.D.
Baseline	9.61	2.37	0.061	0.029	9.22	4.02	8.20	2.92	40.68	4.16
After occlusion 1st measurement	10.56*	3.38	0.074*	0.060	10.21	4.38	8.95	3.65	42.13	5.90
After occlusion 2ndt measurement	10.05	2.95	0.054**	0.048						
After 30min recovery	9.20	2.18	0.059	0.023	8.83	3.70				

	Plastic foil									
	TEWL [g m^{-2} h^{-1}]		SSWL [g m^{-2} h^{-1}]		Permittivity [-]		Stratum corneum thickness [um]		Epidermis and Stratum corneum thickness [um]	
	AVG	S.D.	AVG	S.D.	AVG	S.D.	AVG	S.D.	AVG	S.D.
Baseline	9.47	2.26	0.062	0.027	8.38	3.64	9.51	3.87	43.40	5.89
After occlusion 1st measurement	15.35*	3.26	0.101*	0.063	34.76*	12.48	8.63	3.17	42.20	4.93
After occlusion 2ndt measurement	12.31*,**	2.68	0.055*,**	0.026						
After 30min recovery	9.18	2.29	0.066	0.043	8.85	3.27				

** Paired t-test significant different compared to baseline measurement (p≤0.05)*
*** Paired t-test significant different compared to 1st measurement (p≤0.05)*

The increased TEWL may indicate a closing effect of the skin. This effect is stronger when the skin is sealed with plastic foil than when the skin is closed with a turn-out coat. When closed with a turn-out coat, the skin temperature is higher than with plastic foil, while in the latter case the relative humidity is higher. However, there is only a significant correlation of these temperature and humidity effects for the permittivity of the skin and not for the parameters TEWL and the SSWL and also only when the skin is sealed with plastic foil (Table 2.9).

Table 2.9 Pearson's correlation coefficients for TEWL, SSWL and permittivity immediately after closure with a turn-out coat and plastic foil with increased relative humidity (ΔRH) and increased skin temperature (ΔT) as a result of the closure

	TEWL		SSWL		Permittivity	
	turn-out coat	foil	turn-out coat	foil	turn-out coat	foil
ΔRH [%]	0.118	0.420	0.404	0.371	0.229	0.542*
ΔT [°C]	-0.120	-0.039	-0.420	-0.509	-0.494	-0.557*

** Significant correlation (p ≤ 0.05)*

An increased relative humidity has a positive correlation with the permittivity of the skin. This means that when the relative humidity increases, permittivity also increases. The increased permittivity may indicate a reduction of the barrier function of the skin. The opposite applies to temperature. A higher temperature leads to a lower permittivity of the skin.

After thirty minutes of recovery time, all values are returned to their original values (without occlusion) and the barrier function of the skin is completely restored again. This indicates a good resilience of the skin by as single occlusion.
The measurements showed no differences in skin thickness measurements due to skin closure.
Finally, looking at the effect of age and gender, a higher age correlates with higher TEWL values and men also have significantly higher TEWL values.

2.5 Inventory procedures “clean(er) working”

2.5.1 General

Sixteen out of twenty five Safety Regions have responded. The results are summarized in a table in appendix 3. It is striking that the guidelines of the Safety Regions are very different in terms of implementation, while the risks of exposure to smoke and soot are identical for all Safety Regions. The current existing national guideline from the Dutch Fire Brigade (2015) leaves room for free interpretation. That is why regional differences can be found. However, the guidance provided by the Safety Regions is unambiguous about the fact that firefighting personnel must keep their breathing apparatus for at least 3 minutes after deployment, to prevent for being exposed to the dangers of evaporation of toxic chemicals. The question is where does the limit of 3 minutes come from, because the largest amount of toxic chemicals in the turn-out garments has only evaporated after about sixty minutes (Horn et al., 2016). Almost all Safety Regions advise their firefighters to wear an FFP3 mask after removing the breathing apparatus to prevent soot particles from being inhaled. This means that consideration has been given to preventing exposure to toxic chemicals as much as possible. The most important agreement is that each Safety Region takes measures to limit exposure to toxic chemicals in smoke and soot of fires.

2.5.2 Important observations[7]

> Guidelines have been published between 2015 and 2018.
> Shutters, windows and doors of the fire-apparatus must be closed all the time (AA, LN, RR, Tw, ZW, Ze, ZHZ).
> Clean clothing on the fire station (AA, Dr, Fr, GZ, IJs, LN, Tw, ZW).
> Rinsing turn-out garments after a fire-incident (AA, BN, Fr, GZ, IJs, RR, ZW, Ze, ZHZ, MWB).
> Turn-out garments immediately in washing bags (AA, BN, Dr, Fr, GZ, IJs, LN, RR, Tw, ZHZ, MWB).
> A single Safety Region advises wearing nitrile gloves under the firefighting gloves (Dr) and others use nitrile gloves after a fire-incident (AA, BN, Fr, GZ, IJs, LN, RR, Tw, Ze, ZHZ, Gr, MWB, NOG). Also latex gloves are used (ZW).

2.5.3 Remarkable observations

> Washing of underwear at home (Tw, BN, ZHZ)
> Use of denials in guideline (ZHZ).
> Differentiation in degree of contamination (light contaminated, contaminated and seriously contaminated) (Ze)
> Driving to fire-station in wet rinsed turn-out gear (Ze).

2.6 Additional knowledge inventory

2.6.1 Knowledge event cleaning on turn-out garments

During the knowledge day about the cleaning of turn-out garments, it became clear that the various players in the supply chain do not look sufficiently together at the product (cleaning of) turn-out clothing.
It is also clear that standards for fire protection of turnout clothing can be made very clear, because it is clear when skin burning occurs. Standards for contamination with toxic chemicals in smoke are much more difficult to set, because it is not always clear which chemicals are present in the turn-out garments. But it is also insufficiently known whether and in what quantities the toxic chemicals are absorbed by the body of the user of the turn-out garments and whether they can eventually lead to (occupational) disorders. And if so, on which term such disorders can be attributed to those toxic chemicals. In short, it is very difficult to set standards on whether turn-out garments are clean (enough) after cleaning. An option is not to determine for each garment whether it is clean after cleaning, but the possibility to examine whether the cleaning process itself can be qualified. Research into the cleaning of turn-out garments will be tackled in 2018 and 2019.

[7] Abbreviations Safety Regions AA=Amsterdam Amstelland; BN=Brabant Noord; Dr=Drenthe; Fr=Fryslân; GZ=Gelderland Zuid; IJs=Ijsselland; LN= Limburg Noord; RR=Rotterdam Rijnmond; Tw=Twente; ZHZ=Zuid Holland Zuid; MWB=Midden en west Brabant; Ze=Zeeland; Gr=Groningen; NOG=Noordoost Gelderland

3 Discussion

3.1 Introduction

The different sub-studies have provided more clarity in the hazards of primary (during firefighting) and secondary (with contaminated means or working in contaminated areas) exposure of firefighters to smoke from fires. This chapter integrates the results from the various sub-studies and the additional knowledge inventory.

3.2 Respiration route

Repressive firefighters are exposed to many toxic substances in smoke during firefighting activities. In the literature and model study (Willems, 2017) 32 toxic chemicals in smoke of fire were selected that are a potential risk of being absorbed into the human body. For these 32 most common toxic chemicals in smoke, the respiratory route is the main absorption route. As a result of fires, these chemicals occur in smoke to such an extent that they also represent a risk for people to develop (occupational) disorders - such as respiratory diseases (e.g. asthma) (Greven, 2011), but also cancer (Guidotti , 2016). Most of these chemicals are especially a risk when they are inhaled. This concerns carbon monoxide, nitrogen dioxide, hydrocyanic acid, sulphur dioxide, hydrochloric acid, hydrogen fluoride, phosgene, some hydrocarbons (benzene, styrene and phenol), polycyclic aromatic hydrocarbons, aldehydes and ketones, isocyanates, furan and phosphorus pentoxide (Willems, 2017). Only a few of the aforementioned substances are on the list of substances with carcinogenic properties of the Ministry of Social Affairs and Employment (Staatscourant, 2018), namely some PAHs (such as benzo(a)pyrene), benzene, furan and formaldehyde).

Most of the toxic chemicals are only at risk when no independent respiratory protection is worn. For this reason, it is therefore recommended by most Safety Regions to wear the respiratory protection for at least another 3 minutes after an indoor fire attack. After such incidents contaminated turn-out garments must be removed at the place of incident. A possible bottleneck for this is the evaporation time (up to 60 minutes) of the turn-out garments (Fent et al., 2017), which means that firefighters can still inhale toxic substances when they have removed their breathing apparatus. Many safety regions (8) therefore also recommend setting up an (FFP3) mask after removing the breathing apparatus. However, this only prevents inhalation of the particles but does allow gasses to pass through.
An incident in Duiven in 2017 has shown that even proper respiratory protection does not always prevent (toxic) chemicals from entering the respiratory mask.

3.3 Skin absorption and contaminated turn-out garments

Willems (2017) has found that only two toxic substances (hydrocyanic acid and benzo(a)pyrene), which are regularly found in smoke, are risky for absorption through the skin.

3.3.1 Contamination turn-out garments

It must be prevented that hydrocyanic acid and benzo(a)pyrene come into contact with the skin. One of these chemicals, benzo(a)pyrene, is known to be a carcinogenic substance. The European Union has set limits for benzo(a)pyrene through the European Chemicals Agency (ECHA), as far as new clothing is concerned. The German Ausschuss für Produktsicherheit of the Bundesanstalt für Arbeitsschutz und Arbeitsmedizin has even imposed a twofold stricter requirement for exposure to polycyclic aromatic hydrocarbons, such as benzo(a)pyrene. The concentrations of benzo(a)pyrene found in the used and contaminated turn-out garments have only exceeded the latter stricter requirement. This can be explained by the fact that one strongly contaminated turn-out garment of a training centre is included in the study, so the current average results cannot be taken as a criterion for the degree of contamination of the garments in use in the Netherlands. This result also indicates that the contamination of the turn-out garments of training centres must be carefully examined

The standards set by the aforementioned organizations apply only to **new** clothing, while there are no standards for used (contaminated) clothing. Although not mentioned as such, the standards assume contact with healthy skin under neutral conditions. Skin occlusion, as happens with protective clothing, leads to a temporary reduction of the barrier function of the skin (Van den Eijnde et al., 2018), which may facilitate absorption of substances such as benzo(a)pyrene through the skin. However, the latter has not been investigated due to ethical aspects.

During firefighting it is by definition not permitted that bare skin is in unprotected contact with the environment. So only if the above mentioned chemicals penetrate to the inner layer of the personal protection can skin contact occur. In the sub-study to the contamination of the turn-out garments, it has been found that the PAHs (including benzo(a)pyrene) come to the middle layer and hardly penetrate into the inner clothing layer. Hydrochloric acid is not even detected at all in the turnout clothing. This means that the risk of skin contact is very small when the turn-out garments consist of a three-layer system
The sub-study to the degree of contamination of the turn-out garments (Laitinen, 2017) showed that the layered clothing has largely prevented benzo(a)pyrene from coming into contact with the skin of the user. Indeed, the contamination hardly goes beyond the middle clothing layer. It is therefore highly questionable whether skin absorption of the carcinogenic benzo(a)pyrene is an important risk for the user of the turn-out garments.

The results of the sub-study to the contamination of the turn-out garments are in line with a study by Wingfors et al. (2017), which calculated the protection factor (PF) of firefighter's garments during an inside attack by the concentrations of PAHs outside the clothing and on the inside of the clothing. The calculated PF for all measured PAHs was 146 and for benzo(a)pyrene 120. This means that the concentration benzo(a)pyrene below the clothing is 120 times lower than outside the clothing and the risk for skin absorption is also limited. Wingfors et al. (2017) have stated that the clothing offers good protection against toxic substances in smoke due to the layering of the clothing. However, the measurements of Wingfors et al. (2017) cannot be compared one-to-one with our results, because in our study (Laitinen, 2017) the actual contamination of the turnout clothing was measured

3.3.2 Warm and wet skin

It has also been studied if other factors such as warm and wet skin influence the primary absorption of toxic substances into the body. Wingfors et al. (2017), for example, have claimed that hot and humid conditions lead to a stronger skin absorption of toxic substances, which could mean that the skin barrier function is reduced under such circumstances. In a recent study by Stec et al. (2018), it is also suggested that skin absorption is the most important absorption route for PAHs. However, they rely on assumptions and have not carried out any direct measurements on skin absorption. In one of the sub-studies it has been shown that the barrier function of the skin decreases as a result of wearing turnout clothing leading to an increase in temperature and wetness of the skin (Van den Eijnde et al., 2018). Benzo(a)pyrene could be absorbed more easily by skin with a decreased skin barrier function. However, large-scale research (Roelofzen, 2013) to patients with eczema, where the skin barrier has largely disappeared, tar ointment with benzo(a)pyrene (van Rooij, 1997) was used as a treatment method for eczema. Long-term use of tar ointment did not lead to more cancer cases among this group of patients (Roelofzen, 2013). In addition, the study by Van den Eijnde et al. (2018) has shown that the skin barrier has recovered rapidly, so that it is not expected that a temporary slight reduction in the skin barrier function will lead to a dangerously increased absorption of toxic substances in the body.

3.3.3 Insufficient closures

Possible exposure can be caused by air flow through inadequate closure (openings) in the personal protective equipment. These openings are possible where different pieces of equipment are connected and the interfaces are not optimal.

Some of the PAHs will get into the clothing openings under the clothes, but that does not mean that they also attach to the clothes. Part of it also goes out via pumping effects through the same openings (Havenith et al., 1988).

The relatively high concentrations of (semi-)volatile organic compounds on the inside of the collar may be the result of a poor connection with the other personal protective equipment. This means that design and compatibility of the various items of personal protective equipment is a point of attention in preventing exposure to toxic chemicals in smoke. In the international standardization world, compatibility of protective equipment is recognized as an important point of attention and an international standard (ISO) is now being developed in this area.

3.3.4 Secondary exposure

Besides primary exposure, secondary exposure can take place when the turnout garments are removed after a firefighting deployment or when maintenance employees have to clean the contaminated turnout garments.
It is therefore important that exposure to toxic chemicals is also prevented during doffing the turnout garments. That means that gloves and respiratory protective equipment must be worn when the garments are removed and put into a sealable bag. Wingfors et al. (2017) have stated that after a deployment, the firefighters must first take off the polluted turnout garments and any other contaminated (protective) means to prevent further exposure to toxic chemicals.
During maintenance when turnout garments are cleaned, the maintenance employees can also come into contact with the (too) high concentrations of benzo(a)pyrene on the outer layer of the turnout garments. It is therefore important that these employees also protect their skin and respiratory tract adequately against so-called 'secondary' exposure to toxic chemicals on the contaminated turnout garments. The chance of secondary exposure for these employees is considerably lower if the protective equipment is offered for maintenance in closed (soluble) bags. At the moment there a study is carried out to the degree of contamination with toxic chemicals from smoke in the workplaces of fire-stations. For the time being, the first results of that research do not give rise to any additional measures (Kamp, 2018).

The contamination with dioxins and furans from the examined turnout garments is so small that they hardly pose a health risk. Moreover, for dioxins and furans the oral route is the most important route for absorption. It is unlikely that this absorption route is a risk for firefighters if the normal hygiene measures are taken into account.

3.3.5 Cleaning turn-out garments

The sub-study to the contamination of the turnout garments has shown that the protective properties against toxic chemicals from smoke are satisfactory, because most of the pollution in the clothing does not go beyond the middle layer of the turnout clothing (Laitinen, 2017). This picture changes when the garments are washed. The contamination then spreads over the different turnout garments in the washing machine, whereby the inner layer is also slightly contaminated (Laitinen, 2018). However, even the most severely contaminated middle layer has not exceeded the ECHA standard for new clothing for benzo(a)pyrene and so spreading over the layers will always lead to values below the standard set by ECHA.
Furthermore, research to the cleaning of the turnout clothing has shown that when three turnout garments are washed at the same time, the contamination is spread over the different garments which not really become much cleaner (Laitinen, 2017). It is important that the study to the effectiveness of the cleaning procedure of the turnout garments has shown that the contamination spreads over the turnout garments (Laitinen, 2017) and that the toxic chemicals also spread over the different layers (Laitinen, 2018). After cleaning the turnout garments it appears that residual contamination remains. After a cleaned turnout garment is used again, contamination can slowly but surely accumulate in the turnout clothing (accumulation of contamination) (Laitinen, 2018). Although cleaning is not optimal, the limits for the individual PAHs for new clothing as set by ECHA, but also the stricter requirements of the Ausschuss für Produktsicherheit are not exceeded.

However it seems better to wash less garments at the same time, for two garments is the washing machine lead to higher washing efficiencies than with three garments at the same time. This is line with the procedures in Finland where only one garment at the same time is washed, leading to washing efficiencies of 80%[8]. So a possible explanation of low washing efficiency in this study is the amount of turnout garments in the washing machine. However the loading of the machines was in line with the specifications of the manufacturer and should not be of influence on the washing efficiency. Other possible explanation were that:

- by coincidence the washing with three garments was with three very contaminated garments,
- the turnout garments were kept in a plastic bag for almost a year,
- the monsters before and after washing were not equally contaminated.

Although the monster were taken at almost the same locations from the turnout garments, the monster are of course not the same monsters.

To prevent the inner layer from being cross-contaminated maybe different layers must be cleaned separately. In particular, the entire cleaning process of turnout garments deserves further research, because there are still too many ambiguities.

For an objective study to cleaning of turnout garments it is necessary to set a standard with requirements for the minimum degree of cleanliness of turnout garments. The present standards for new clothing can be the starting point for such a standard. However for testing, it is necessary to measure the contamination on the turnout garments. Another option is to

[8] The washing and drying process (other detergents and higher drying temperatures) in Finland is not identical to the cleaning process in the Netherlands.

qualify the cleaning process itself and test samples of turnout garments. A cleaning knowledge event about turnout garments did not yet clarify this problem.

The proven concept of rinsing and brushing with water (and soap) the clothing after a firefighting deployment to remove contamination with PAHs (Fent et al. (2017) is carried out by several Safety Regions. About 85% of the contamination from the outer layer can be removed. Water and soap is more efficient than water alone, because cleaning is a combination of the use of water, cleaning detergents and mechanical friction (knowledge event)
Furthermore, wearing of clean clothing is important to limit the absorption of toxic chemicals found in smoke through the skin. In a study to the effects of wearing clean clothing and by nicotine (a volatile organic compound) contaminated clothing showed that clean clothing protected the wearer better (Bekö et al., 2017). In the same study immediately showering after exposure seemed to diminish the skin absorption of nicotine. Although the exposure in the aforementioned study (Bekö et al., 2017) is not directly related to firefighting, immediately showering after a firefighting deployment is an effective means of preventing the absorption of toxic chemicals by the skin. In an ongoing study to health monitoring of firefighters, it will be considered whether the above measures have a positive effect on the health status of firefighters.

3.4 Own interpretation guideline ‘clean(er) working’

Furthermore, it appears that many Safety Regions have become aware of the hazards of exposure to smoke in recent years. Many Safety Regions now also have a guideline on how to deal with exposure to smoke and with by toxic chemicals from smoke contaminated equipment .There are currently differences with regard to the implementation of the guidelines between the Safety Regions, but if one has good reasons to give their own interpretation of the guidelines this should be possible (motivated deviation). Many Safety Regions are now consciously engaged in clean(er) working. Harrison et al. (2018) have shown in an American study that the attitude of firefighters has changed positively, but not all measures are applied by default. Showering afterwards is generally done as standard and that limits the absorption of the pollution through the skin (Bekö et al., 2017). Washing the (dirty) hands is also a measure to prevent toxic chemicals from entering the body via the digestive tract (hand mouth contact). Follow-up steps would be needed to further operationalize the national guideline (Brandweer Nederland, 2015) with the current knowledge and incorporate it into the teaching and learning material for fire training programs.

4 Conclusions

The results of the studies to the hazards of exposure to smoke have led to a number of important conclusions, which have provided more clarity about the risks for firefighters when they are exposed to smoke by fire. The most important conclusions and recommendations from the various sub-studies are presented in this chapter. In addition, answers will be given in the chapter to the pre-set questions of this study.

4.1 Conclusions from the sub-studies

The model and literature study leads to the following conclusions.

- In the event of a single exposure to 32 of the most common toxic chemicals in smoke caused by fire, absorption takes place mainly by the respiratory tract. The exposure then has a direct effect on the airways themselves (including asthma) and some toxic chemicals influence oxygen transport and cell respiration. However, these toxic chemicals are not directly linked to the development of cancer.
- In case of single skin exposure, hydrocyanic acid can lead to adverse health effects, but it concerns specific incidents in which hydrocyanic acid is released and not to 'regular' fires.
- Repeated exposure to toxic chemicals in smoke via the respiratory system is known to lead to respiratory diseases such as asthma. However, other health damage such as cardiovascular diseases and cancer are also possible consequences. Wearing appropriate respiratory protective equipment (in the right way) is therefore very important as long as exposure to smoke is a risk. Smoking and exposure to (diesel) exhaust fumes can exacerbate the effects on health.
- Repeated skin exposure to the polycyclic aromatic hydrocarbon benzo(a)pyrene may cause skin cancer and other forms of cancer. Concomitant exposure to formaldehyde and phenol can enhance this effect.
- For repeated skin exposure to hydrocyanic acid, the same applies as for single exposure.
- Via repeated dirty hand-to-mouth contact, exposure to benzo(a)pyrene and dioxin in smoke is the largest oral absorption risk possibly leading to cancer, but washing well after a fire incident minimizes that risk.

The results of the sub-study to the contamination and cleaning of turnout garments (from the Amsterdam-Amstelland Safety Region) give the following conclusions.

- In general, contamination of solid particles is found mainly in the outer layer of the turnout garments, vapour and gaseous contamination especially in the middle layer (membrane) and the water-soluble chemicals (acids) are also observed on the inside.
- Much of the contamination was also found on the inside of the collar of the turnout clothing and may be the result of poor connection with the other protective equipment.
- Contaminated turnout garments contain considerably more polycyclic aromatic hydrocarbons (PAHs) compared to a new pack, but they are mainly found in the middle layers of clothing.

- Although not applicable to used contaminated turnout clothing, the existing standards (ECHA and AfPS) for new clothing have been exceeded for some PAHs. However, this exceedance was entirely due to one garment of a training centre.
- Other contamination such as (semi-) volatile organic compounds also occur in the middle layers of polluted turnout clothing. For one of the components, the concentration of contamination appeared to be higher in the clean turnout garment. The latter is possibly the result of the post-treatment with impregnating agents containing such a substance.
- Dioxins and furans are found in all layers of the turnout clothing, but also have the highest concentrations in the outer layers of the turnout clothing.
- Cleaning of turnout clothing according to the washing instructions supplied by the Amsterdam-Amstelland Safety Region ensured a spread of the pollution over the different turnout garments in the washing machine.
- The washing efficiency with two garments in a washing machine was higher than with three garments and considerably lower than in Finland, where only one garment is cleaned in the washing machine at the same time.
- The results of this sub-study only apply to garments with an EN469 certificate that have three layers.

Based on the sub-study to the change of the skin barrier function due to skin occlusion, the following conclusions can be drawn

- The transepidermal water loss (TEWL) and water loss of the skin surface (SSWL) increased due to occlusion. This effect is stronger if the skin is completely sealed with plastic foil, than when a turnout coat is worn.
- The permittivity of the skin increases when the skin is completely sealed with plastic foil, but this did not happen when using a turnout coat.
- An increase in both water loss and permittivity indicates a decrease in the barrier function of the skin.

4.2 Overall conclusions

All sub-studies contributed partially to answer the main question of this research project. The sub-question to which toxic chemicals firefighters are exposed to cannot simply be answered, because every fire-incident is different. However the model and literature study did indicate the 32 most important toxic chemicals in smoke of fire to which firefighters are exposed and which can be seen as markers.
In the sub-question about the absorption routes for these toxic chemicals, respiration was mentioned as the most important route. However, two substances, hydrocyanic acid and benzo(a)pyrene, pose a risk when absorbed through the skin. Further research into the reduction of the skin barrier function has shown that although the skin barrier function is temporarily diminished by occlusion it is not expected that skin absorption of (carcinogenic) benzo(a)pyrene increases the risk of getting cancer.
The sub-question how fire service personnel can be exposed to the above mentioned 32 toxic chemicals will be primarily during the fire-incident control. However, because there are toxic chemicals that accumulate in the protective garments, exposure to chemicals on the protective equipment can still lead to secondary respiratory or skin absorption of those chemicals. Workplace personnel of the fire stations can also be exposed during maintenance activities to toxic chemicals on the protective equipment. Because the current research has shown that the contamination has not been completely removed after cleaning, there is also a chance that people mistakenly believe that the cleaned protective equipment does not pose a risk of exposure to toxic chemicals.

The 'clean(er) working' procedures have provided answers to the last sub-question about which measures are taken before, during and after firefighting activities. First of all, it must be ensured that personal protective equipment is in order, that there are showers to wash themselves after an incident and that there is clean clothing to wear after a firefighting deployment. During a firefighting deployment, well-fitting protective equipment must be worn that fits well together (compatible). Afterwards, repressive firefighters must get rid of the (protective) means, preferably washed with water and soap, as soon as possible. During these cleaning operations, contact with the toxic chemicals on the contaminated means should be avoided as much as possible by isolating them from the environment as quickly as possible and wearing respiratory and skin protection.

On the main question of this set of sub-studies “What is needed to diminish the exposure to toxic chemicals in smoke preceding, during and after an incident to reduce the risk on possible (long term) health damage?' were partially answered by the sub-questions. Fire-fighters must be well informed about the dangers of exposure to toxic chemicals in smoke prior to fire-fighting and take the necessary precautionary measures to prevent exposure as much as possible. They must protect themselves as well as possible during the firefighting activities, so that the toxic substances in smoke are not absorbed by the body through the respiratory and skin routes. Afterwards they must isolate the contaminated (protective) means as soon as possible and ensure that the means are cleaned as adequately as possible. This in order to minimize the chance of being exposed to toxic chemicals on and in the (protective) means

Based on various sub-studies, the following overall conclusions can be drawn:

- Smoke contains toxic chemicals from which have carcinogenic properties.
- Most of the toxic chemicals enter through the respiratory system.
- The polycyclic aromatic hydrocarbon (PAH) benzo(a)pyrene can be absorbed through the skin.
- Contaminated turnout clothing contains benzo(a)pyrene that can be absorbed by the skin, as well as other absorbent PAHs, which are mainly located in the middle layer of the clothing.
- The contamination of turnout garments generally remains below the skin exposure standards for new clothing.
- The results for the contamination and cleaning of turnout garments apply to three layered garments and may not be extrapolated to other protective clothing for firefighting.
- There are no indications to date that a reduced skin barrier function for e.g. benzo(a)pyrene causes an increase in cancer cases.
- The washing efficiency of the turnout clothing in this study was at best 40 percent.
- Heavily soiled clothes can cross-contaminate simultaneously washed less soiled clothing.
- Although there is a national clean working procedure, the Safety Regions have their own interpretation and there is no clear uniformity yet.

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Appendix 1
Summary/abstract substudies

Literature and model study on absorption routes of toxic substances in smoke caused by fire

Summary

The Institute for Physical Safety (IFV) has asked the centre of Expertise on Toxic Substances of PreventPartner to provide insight into the most common substances that are released in a fire, what effects these substances can cause in the body and which absorption routes are relevant. An underlying question from the fire service for this study to consider is whether the measures that are now being taken to minimise risks are effective.

This study only focuses on the potential hazards of substances that occur in fire smoke. However, the potential dangers of substances in fire smoke in themselves have no bearing on the actual risk of these substances in fire situations.

To answer the study questions, the following steps have been taken:

1. Selection of the most important (hazardous) substances that can occur in fire smoke.
2. Classification of substances by exposure route (through respiratory tract, skin and mouth) and single/repeated exposure.
3. Classification of substances in hazard classes.

The study was conducted through a combination of expert sessions, surveys of the literature and the use of models. 32 of the most common substances in smoke have been assessed. For this purpose, substances are classified in hazard classes for each exposure route. This is a broad-brush approach.

It is concluded that in the case of one-off (high) exposure the main absorption route is inhalation. The chance of effects caused by these substances that occur during one-off (high) exposure through the skin is seen as small. There are only a limited number of substances that can be absorbed through the skin and that have the potential to cause effects with a one-off (high) exposure.

Even with repeated exposure to substances in smoke from fire, inhalation seems to be the most important absorption route for most substances. The absorption route through the skin is only of importance for a limited number of substances, but it is a real route for these substances. Skin absorption should therefore certainly be included in future risk assessments. The ingestion route through the mouth is seen as the least relevant route, since ingestion by mouth will only take place indirectly through hand-to-mouth contact in relatively small quantities.

As far as the relationship between inhalation and skin hazards is concerned, the absorption of smoke through inhalation is the greatest danger. The risk of unexpected/accidental inhalation of smoke arises if, for example, the mask is removed too soon, if the mask does not connect properly to the face and/or if the person is unprotected at too small a distance from the fire.

It is recommended to make even more sure that inhalation of smoke is prevented, to further reduce hand contact and skin contact with substances and to monitor whether measures taken are effective.

There is also a recommendation to perform follow-up studies in order to get a good picture of the actual risk of substances in smoke caused by fire by combining the actual exposure with the potential hazards of substances.

Determination of the fire residues from firefighting garments (IFV2016-EO-31)

Abstract

The goal of the study was to find out, what kind of chemicals can be found from firefighting garments after normal overhaul. Institute for Safety delivered ten contaminated and one clean firefighting garments to Finland. Finnish Institute of Occupational Health was responsible pretreatment of the samples from the firefighting garments and the analyzing them for volatile organic compounds (VOCs), semi volatile organic compounds (SVOCs), polycyclic aromatic hydrocarbons (PAHs) and water soluble ions. National Institute for Health and Welfare in Finland took care of the analysis of PFAS- and PCDD/PCDF-analyses. A sub-contractor of the Finnish
Institute of Occupational Health was responsible for cyanide –analyses. Diversey Finland Ltd took care of the washing procedure of the garments. The garments were washed at the brand new Finnish fire brigade in Turku according to the instructions given by IFV.

The total concentrations of PAHs in contaminated garment 1 differed from the concentration measured from a clean garment 0. Also the analysed average profile of detected individual PAHs was totally different in clean garment 0 vs. contaminated garment 1. The total concentration of semi volatile organic compounds were higher is contaminated garment 1 in generally, however from the middle layers of clean garment 0 was analysed higher concentrations than from contaminated garment 1.
The explanation for that might be an impregnation procedure used for the protection of clean garment 0. The above mentioned phenomenon was also found in the results of volatile organic compounds. In clean garment 0, the concentration of 4-tertbutylcyclohexylacetate and C16-C18 alkyl benzenes were higher than in contaminated garment 1. These chemical agents might originate from the impregnation liquid. According to the results it seemed that PAHs, VOCs and SVOCs accumulated in the middle layers of tested garments. Watersoluble ions seemed to accumulate on the inner layers of the tested garment 1.

The measured concentration of PCDD/PCDF compounds differed clearly in contaminated garment 1 when compared to clean garments 0. It seemed that they accumulated in the upper layers of tested garments. Also the analysed concentration of PFAS -compounds differed in contaminated garment 1 and in clean garment 0. It seemed that they also accumulated in the upper layers of tested garments.

The extent of contamination level in the garments was estimated by calculating the average concentration of PAHs at different location in the garments. The highest contamination levels were measured from garments G1, G4, G6 and G9. The average concentration of PAHs in these garments were 11 to 39 –fold higher than level measured in clean garment 0. The second highest contamination levels were measured from garments G3, G5 and G7. The average concentration of PAHs in these garments were 5.2 to 6.8-fold higher than level measured in clean garment.

The lowest contamination levels were measured from garments G2, G8 and G10. Their contamination level were 1.7 to 4-fold higher than level measured in clean garment. The highest average concentrations of PAHs were analysed from the middle layers of the back and stomach in garments 2-10. Some of the measured concentrations of benzo[a]pyrene, benzo[a]anthracene and benzo[b]fluoranthene exceeded the level for restriction of selling products by ECHA. The German AfPS (Committee for product Safety) has published requirements for evaluating PAHs from products and testing them for the GS Mark Certifications. Almost all of the measured PAHs concentrations of individual PAHs exceeded that value in garments 2-10. AfPS
have also published a limit value of 10 mg/kg for the sum of PAHs. Some of the samples from inner neck, middle stomach, upper back and inner back exceeded that value in garments 2-10. Measured average total concentration of PAHs (110+91 ng/cm2) were lower in the upper layer of stomach in Dutch garments 2-10 compared to measured average corresponding value (350+180 ng/cm2) in Finnish firefighter's garment. Also the analysed profile of PAHs was different in Finnish study compared to the current study.

The highest concentration of TVOCs were analysed from middle stomach. The most common VOCs were mixture of aliphatic hydrocarbons, phenol, C12-C13-alcohols, benzoic acid, benzyl alcohol, 2-ethyl-1-hexanol, phenoxypropanol, decanal, hexadecane and geranylacetone in garments 2-10. The spectrum of the compounds differed from the results measured from Finnish fire brigades after rescue tasks. The most volatile organic compounds had already evaporated from the tested garments prior to analysis due to long storage time of garments 2-10 in plastic bags before
analyzing. The highest concentration of TSVOCs were analysed from inner neck and the most common SVOCs were various alcohols, carboxylic acids, esters, hydrocarbons and glycol compounds in garments 2-10.

The highest concentrations of water-soluble acids were measured from inner neck in garments 2-10. The highest water soluble residues reflected exposure to hydrochloric acid originating for example from the burning of PVC-plastic. The measured concentration of nitric acid were lower in contaminated Dutch garments 2-10, when compared to corresponding samples from Finnish firefighter's garment, but the results were of the same level in clean garments.

The highest concentration of PCDD/PCDF and PFAS were analysed from stomach in garments 2-10. The most common PCDDs/PCDFs were OCDD, OCDF, 1,2,3,4,6,7,8-HpCDD and 1,2,3,4,6,7,8-HpCDF. The highest concentration of PFAS were analysed from stomach, and the most common PFAS-compounds being PFOA, PFDA and PFDoA in garments 2-10.

The average concentration of PAHs in the garments 2-10 after the washing procedure reflected poor washing efficiency. It seemed that PAHs transfer from more contaminated garments to the less contaminated garments during washing procedure. Comparison between washes showed that washing of three garment simultaneously resulted in a lower washing efficiency than washing of two garment simultaneously. The results of the washing efficiency estimates in current study were
lower than in Finnish study, where washing efficiencies were over 80 %. The washing time and temperature were similar in both procedures, but washing agents and the drying method were different. In additions in the Finnish study was only one garment washed at a time and only upper layers of the garment were studied. As a drying method in Finnish study drum spinning for 90 minutes was used while in the current study the garments were dried in a dryer cabinet. These factors might have impact to the final washing efficiency. Also longer

storage time of garments in the current study compared to Finnish study might also have effect on these results.

According to the results, vaporous contaminants seemed to absorb to the firefighting garments and they were ready to evaporate to the firefighters' breathing zone after smoke diving task. Also firefighting garments contained particular compounds, which also were ready to enter to the firefighters' body through the respiratory and dermal exposure routes. Also contamination of the skin and hands were possible reflecting oral exposure risk from hands to mouth. The worst thing was to find significant concentration of PAH-compounds from the garments after currently used washing procedure. Some of the concentrations exceeded the reference limit value given by GSMark and EU.

From firefighters' point of view it is crucial to ensure that washing efficiency of the garments is much better in future than in current study. It is essential to test factors which effect on washing efficiency. For example how many garments is sensible to wash simultaneously. The results of current study reflects that if garments are very contaminated they should wash alone to prevent cross-contamination of the garments during washing procedure. Another point is to decrease the storage time of the garments as short as possible after contamination before washing. The third
factor might be the drying procedure of the garments. Drum drying has been performed better washing efficiencies than drying cabinet. If washing efficiency still is very low after these improvements, other possible ways such as ozone treatment of the garment or liquid carbon dioxide–method should combine current procedure or the current washing procedure should replace by these new methods.

When washing procedure is good enough and fulfil at least the minimum level of the reference values, in addition of that also attention have to be paid to the handling of contaminated garments. For example in training condition, firefighters have to smoke dive many times and they have to wait the next training session. During the break the contaminated garment have to take off to prevent unnecessary exposure to vapors evaporating from garments to firefighters' breathing zone. Due to high measured concentrations from inner layers of the garment, it is necessary to reduce
dermal exposure by using long sleeved and legged technical underwear to prevent direct skin contact to the garment. Neck has been proved to be vulnerable for dermal exposure in many studies. For the prevention of that, the ergonomic and adjustable collar combined with the use of hood, can decrease exposure significantly. Also particulate and vaporous contaminants try to enter inside to the garment through the sleeves and legs. To prevent that, some sort of cuffs combined with special closures in sleeves and legs are needed in garments. Hand exposure is possible to reduce very efficiently with under gloves made from cotton or leather.

After rescue task already at the fire site all contaminated firefighting garments have to take off and packed to the self-melting bags, wearing under gloves and breathing protectors (lighter) on until then all contaminated equipment have been packed. Transportation of contaminated firefighting garments in self-melting bags have to performed in other location than in crew cabin to prevent firefighters' exposure during transportation to the fire brigade. It also reduce firefighters' exposure
during maintenance of garments, because they can transfer the closed bags directly to the washing machine without opening them. Also replacing contaminated garments to clean ones already at fire site, prevent the contamination of the fire truck.

The maintenance of firefighting garments, compressed air breathing apparatus and other firefighting equipment might exposed firefighters heavily, because the contamination level of these equipment varies a lot. Because of the variation of contamination, it is essential to connect recommendation of firefighters' personal protection level and cleaning technology of the firefighting equipment in maintenance to the fire class in which equipment are contaminated. That improve the management of exposure in various maintenance situations.

Skin barrier impairment due to the occlusive effect of firefighter clothing

Abstract

Introduction: At fire scenes, firefighters are exposed to various potentially harmful substances. The toxicological or even carcinogenic effect due to the contact with hazardous substances in smoke during firefighting operations gets a lot of attention in relation to the potentially increased incidence of cancer among firemen. Even though wearing suitable Personal Protective Equipment, post firefighting studies showed increased biomarkers of carcinogenic combustion products in their bodies. This suggests that besides inhalation skin contamination and the mechanism of dermal absorption can be a possible risk to be reckoned. It is known that occlusion increases the risk of dermal absorption. In this perspective, skin barrier impairment due to the occlusive effect of clothing could be an indirect risk factor responsible for enhanced penetration of the hazardous substances. Until now, the occlusive effect of firefighter clothing has never been studied. The objective of this study is to investigate whether skin barrier impairment occurs during the occlusion due to firemen clothing

Methodology: In this study, the skin barrier of 16 healthy human volunteers is investigated *in vivo* by comparing the occlusive effect of cellophane foil and a firefighter jacket. The total time of occlusion is 30 minutes. The barrier function is evaluated by measuring the Trans Epidermal Water Loss, the Surface Skin Water Loss and the skin permittivity at three time intervals before, immediately after and 30 minutes after occlusion. Also reflectance confocal microscopy is applied to study the skin morphology. A paired comparison is performed between the physical parameters at the different time intervals.

Results: The occluded environment due to the firefighter jacket compared to cellophane foil is significantly more increased in temperature but less increased in humidity.

No significant differences in skin layer thicknesses of the stratum corneum and the viable epidermis were found due to both types of occlusions in this study.

All physical parameters are significantly increased immediately after occlusion with a cellophane foil material. Only the Trans Epidermal Water Loss (TEWL) values immediately after wearing a firefighter coat is significantly increased. All physical parameters are return to normal 30 minutes after occlusion meaning that the skin barrier is fully restored.

Conclusion: The significant increased TEWL is an indication of an occluding effect of wearing a firefighter coat and resulting skin impairment. Although this study is performed with human healthy volunteers, the developed methodology and outcome will be of value for future studies with firefighters. The preliminary results are important for manufactures and there development of innovates less occlusive clothing concepts.

Appendix 2
Washing instructions

Instruction for washing turn-out gear with normal contamination

- The normal contaminated turn-out gear will be rinsed and put in a transparent bag before it is delivered.
- The turn-out gear will be unpacked and registered, the pockets will be checked and emptied. The zippers will stay open and the Velcro is closed.
- The turn-out gear will be washed on 60 degrees Celsius with maintenance of impregnation.
- Per washing machine maximal 5 turn-out gears of Amsterdam-Amstelland and maximal 3 turn-out gears of Zaanstreek Waterland
- For small washing machines do not put in more than 3 turn-out gears.
- Drying of the turn-out gear will happen in a dry-room with 32 degrees Celsius and with dehumidifiers.
- The turn-out pants will be hanged on 2 hangers from the trousers on to the wall mounts
- The turn-out coats will be hanged on a hanger with open Velcro. The cuffs of the sleeves will be pulled outwards.
- After the drying procedure, the garment will be checked on: seams, cracks, membrane, zippers and reflective strips.
- If necessary the clothing will be repaired. In case of bigger damage, the turn-out gear will be send to the supplier.
- If reparation is not possible, the turn-out gear will be disapproved, destroyed and removed from the system.
- Turn-out gear registration, fold the gear and make it ready for transportation

CLAX check

Diversey

Recommended Wash Process

Laundry:	Fire Fighting Uniforms
City:	
Contact:	
Date of visit:	

Classification nr:

Classification: Fire Fighting Uniforms

Textile:

Machine: Washer Extractor

Load factor & Load [kg]: 60-70%

Step	Time [min]	Level	Temp [°C]	Product CLAX	Dosage [g/kg]
Prewash	7	L	30-35	Clax 100S	3.0
				Clax Plus	12.0
Drain	1				
Mainwash	12	L	60	Clax 100S	3.0
				Clax Plus	10.0
Drain	1				
Rinse 1	3	H	Cold	Clax Proof Integral	3.0
Drain	1				
Rinse 2	3	H	Cold		
Drain	1				
Rinse 3	4	M	Cold	Clax Proof	10.0
Final extraction	6				
Total process time:	39	[min]			

Remarks: Drying with outgoing air < 80°C

Version: 2.10

Country:

Appendix 3
Overview 'Clean working'

Actions & means / Safety region	(additional) means	Actions before	Actions during	Actions after	Actions logistics
Amsterdam-Amstelland	Om de procedure te kunnen toepassen verschaft de dienst naast de bestaande Persoonlijke Beschermingsmiddelen (PBM's) repressieve medewerkers met arbeidshygiëne PBM's: > 3 sets onderkleding: een set bestaat uit een lange broek, longsleeve shirt en balaclava > Gele wastassen om vervuilde uitrukpakken in te doen > Omkleedtassen per medewerker op voertuig, deze bevatten een	> Schone onderkleding uitrukgereed klaarleggen bij aanvang dienst of uitruk. > Omkleedtas compleet en paraat. > Trek eigen kleding of kazernekleding uit en onderkleding aan onder je uitrukkleding bij een brandmelding. Of neem je onderkleding & uitrukpak mee bij het verlaten van de kazerne.	> Eigen verantwoordelijkheid voor schone PBM's, > Mens en middelen uit de rook > Houd deuren, ramen en luiken van de voertuigen gesloten. > Beschermende uitrusting goed sluiten; nekflap over uitrukpak en uitrukpak over de schoenen. > Geen sigaretten /tabak in je pak (ivm rookopname)	> Draag nog 3 minuten ademlucht > Afspoelen > Omkleedtas pakken, openritsen en klaarleggen. > Werkhandschoenen uit en nitril handschoenen aan. > Masker, helm en balaclava afzetten. > Afhangen. > Mondkapje opzetten. > Uitrukpak uittrekken. Ook onderkleding uittrekken	> onderkleding apart van joggingpak laten wassen

	trainingspak, waszak, paar nitril handschoenen, mondkapje, label. > Een tent om op straat om te kleden			ivm secundaire vervuiling huid. > Op opengevouwen tas gaan staan. > Schoon shirt / joggingpak aan, laarzen weer aan.	
Hollands-Midden			niets (regionaals)		

Brabant Noord	> Nitril handschoenen onder uitrukhandschoenen
	> Verpakkingsmaterialen:
	    > waszak voor uitrukpak
	    > waszak voor nekflappen
	    > zak voor ademluchtmasker
	    > zak voor persoonlijke materialen (bril, sleutels, telefoon, etc.)
	> Lotion doekjes en garagezeep
	> Schone overkleding (overalls)
	> Reiniging-spray en doekjes Vervuilde materialen zoals portofoon, WBC, ademluchttoestel, etc. kunnen met spray en reinigingsdoekjes worden schoongemaakt.
	> Vuilniszakken voor afval
			> Uit de rook blijven	> Draag nog 3 minuten ademlucht
				> Afspoelen
				> Overkleding beschikbaar
				> Schoon terug naar kazerne
				> Vervuilde materialen naar logistiek centrum
				> Melding in TOP desk
					> Onderkleding zelf thuis wassen

	> Instructiekaart voorgestelde werkwijze				
Drenthe	> Nitril handschoenen > Zeep > Wasdoekjes > Oplosbare waszakken > Speciale waszakken > Vuilniszakken	> Geen rook- en etenswaren in je pak (ivm rookopname) > Kazernekleding blauw als onderkleding beschikbaar > Schone onderkleding op de post leggen	> Alleen BV hoes om ademluchtcilinder > Nitril handschoenen onder blushandschoenen	> Draag nog 3 minuten ademlucht > Mondkapje op > Draag nitril handschoenen > Beschermende kleding in oplosbare waszakken > Onderkleding in speciale waszakken > Reinig alle overige materialen > Spoel voertuig af	> Schone nekflap aan helm > Vuile kleding laten wassen > Onderkleding laten wassen of thuis wassen
Fryslân	> Nitril handschoenen > Mondkapje > Doekjes > Zakken > Schone (vervangende) kleding	> Zorg voor schone pbm's	> Blijf uit de rook > Geen eten en drinken	> Draag nog 3 minuten ademlucht > Gebruik een mondkapje en handschoenen > Reinig de vuile materialen > Spoel de kleding en pbm's af > Doe de kleding in de daarvoor bestemde zakken > Reinig overige spullen en voertuig > Vervoer verontreinigde materialen gescheiden van mensen	

Gelderland Zuid	> Een ‘kratje arbeidshygiëne’ met:
	  > nitril handschoenen,
	  > latex handschoenen,
	  > waszakken,
	  > mondkapjes,
	  > reinigingsdoekjes,
	  > labels, etc.
	> Een Storz-koppeling waar zowel een kraantje als een Gardena tuinslang met spuitpistool aan gekoppeld kan worden.
	> Een zeepdispensor en handdoekdispensor.
		> Schoon setje kleding klaarleggen	niets	> Draag nog 3 minuten ademlucht
				> Gebruik FFP3 mondkapje
				> Afspoelen pak en laarzen
				> Was blushandschoenen met water en zeep
				> Trek nitril handschoenen aan
				> Reinig materialen
				> Plaats schone nekflap
				> Beschermende kleding in waszakken en naar logistiek
				> Onderkleding uit en thuis wassen
				> Handschoenen laten drogen
				> Nitril handschoenen en mondkapje weggooien
				> Gebruikt trainingspak laten reinigen

IJselland	> FFP3 mondkapje > Nitril handschoenen > Waszakken > Arbeidshygiëne joggingspak (tussen regels door) > Tent (tussen regels door)	> Schone pbm’s gereed hebben	niets	> Draag nog minimaal 3 minuten ademlucht > Gebruik nitril handschoenen > Gebruik een schoon FFP3 mondkapje > Bluspak vernevelen > Reinig materialen > Beschermende kleding in waszaken

				> Trek arbeidshygiëne joggingspak aan > afzuiginstallatie op voertuig aansluiten	
Limburg Noord	> Nitril handschoenen > Plastic zakken > Vervangende kleding (koud weer)	> Kleding en douchespullen klaarleggen	> Houd voertuig schoon > Houd luiken en ramen voertuig dicht	> Draag nog 3 minuten ademlucht > Volledig afsproeien > Nitril handschoenen aantrekken > Vervuild materiaal reinigen > Kleding in waszak > Waszakken achter luik, niet in voertuig > Ademluchtflessen inclusief plastic zak in beugels	> Vuile kleding en dienstkleding zelf thuis wassen > Ademluchtplaats medewerker draagt vuilwerkschort, mondkapje en nitrilhandschoenen > Nekflap aanbrengen op schone helm
Rotterdam-Rijnmond	> Zeep > P3 masker > Nitril handschoenen > Plastic zakken > Reinigingsdoekjes > Zeep > Blauwe overall		> Houd voertuig en luiken zo veel mogelijk gesloten > Pas op voor stoomvorming bij een nat bluspak/onder pak.	> Draag nog 3 minuten ademlucht > Gebruik daarna P3 masker > Nitril handschoenen gebruiken > Spoel pak en overige pbm's af en borstel met water en zeep > Helper draagt minimaal mondkapje > Reinig vervuild materiaal	> Ademlucht en nekflap wisselen

				> Afzuiginstallatie op voertuig aansluiten	
Twente	> Nitril handschoenen > Cleaning-kit > Wikkelzak	> Reservekleding en douchespullen klaarkeggen	> Houd voertuigen zo veel mogelijk gesloten, ramen, portieren, maar OOK de luiken!	> Draag nog 3 minuten ademlucht > Trek na inzet handschoenen uit en nitrilhandschoenen aan > Reinig materialen > Kleding in wikkelzakken	
Zaanstad Waterland	> Latex handschoenen > P3 masker	> Schone reservekleding klaarleggen > Voorkom gezichtsbeharing	> Houd ramen en deuren van voertuig gesloten	> Draag nog 3 minuten ademlucht > Pak en PBM's afspoelen > Spoel materiaal af > Gebruik stofmaskers (P3) en latex handschoenen	
Zeeland	> Nitril handschoenen > P3 masker > (garage)zeep > hygiëne kist (washandjes en schoonmaakdoekjes)		> Sluit ramen, luiken en portieren van het voertuig.	> Draag nog 3 minuten ademlucht > laat bluskleding uitdampen met elektrische overdruk ventilator. > Bluskleding, helm, ademlucht en laarzen afborstelen (licht vervuild) en afspoelen met sproeistraal. > Gebruik nitrilhandschoenen en mondkapje voor	> Nitril handschoenen gebruiken > Licht vervuilde bluskleding in kazerne laten uitdampen (vaak wassen is slecht voor kleding) > Vervuilde bluskleding binnenste buiten keren > Bluskleding in rode kliko

				schoonmaak werkzaamheden > In natte bluskleding terug naar kazerne > Besmette kleding (asbest, toxische stoffen, radioactieve stoffen mest) ter plaatse uittrekken	
Zuid Holland Zuid	> Nitril handschoenen > Mondkapje > Zeep en natte (reinigings)doekjes > Plastic zakken	> Reservekleding klaarleggen op kazerne	> Houd het voertuig en luiken zoveel als mogelijk gesloten	> Draag nog 3 minuten ademlucht > Draag mondkapje na afkoppelen ademlucht, chauffeur/ pompbedienaar draagt altijd mondkapje. > Gebruik nitril handschoenen > Spoel pak en overige PBM's af > Verwijder cilinderhoes > Reinig materiaal	> Vervuilde onderkleding thuis wassen
Groningen	> Gele waszakken > Nitril handschoenen > P3 masker			> Draag nog 3 minuten ademlucht	
	>			>	
Midden en West Brabant	> Gele waszakken > Nitril handschoenen > Wegwerpwashand	> niets	> niets	> Draag nog 3 minuten ademlucht > Draag FP3 masker na afkoppelen ademlucht	> Uitrukpakken in zak in wasbak

				> Spoel pak en overige middelen af. Gebruik bij ademluchttoestel ook zeep en borstel > Trek bluskleding uit en trek trainingspak over onderkleding > Reinig blushandschoenen met water en zeep en laat ze drogen > Wissel van blushandschoenen > Na afloop douchen > Zorg dat verbruiksmiddelen worden aangevuld	> Overige middelen in daarvoor bestemde bakken > Vervuilde onderkleding en trainingspak laten wassen
Noord Oost Gelderland	> FP3 masker > nitril handschoenen	> Geen sigaretten in bluskleding		> Draag FP3 masker na afkoppelen ademlucht > Gebruik nitrilhandschoenen > Reinig TS	> Douchen na afloop