Minimising firefighters' exposure to toxic fire effluents

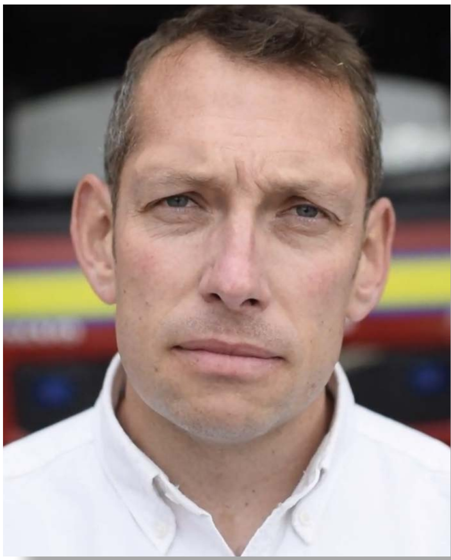
Best Practice Report

An independent report by UCLan with a foreword by FBU General Secretary Steve Wright

Commissioned by FBU



FOREWORD



Almost every firefighter knows of a colleague or former colleague who has been diagnosed with cancer or another serious illness. Many will know someone who has died. But there is a shocking lack of research into the long-term health effects of firefighting in the UK.

This lack of research is why the Fire Brigades Union commissioned independent, ground-breaking research, led by Professor Anna Stec and her team at the University of Central Lancashire (UCLan), into the link between firefighters' occupational exposure to toxic fire effluents, and cancer and other diseases.

This report does two things. Firstly, it sets out evidence of the elevated risk that firefighters face as a result of their work. Secondly, and most importantly, it gives clear and authoritative guidance to fire and rescue services across the UK about the measures they can take to minimise occupational exposure to contaminants.

As this report sets out, firefighters are exposed to contaminants long after a fire has been extinguished. Toxic fire effluents can be absorbed by the skin, as well by breathing and ingesting. The report sets out a path to a safer future, identifying where health and safety practices are currently failing and building on existing good practice.

As well as summarising available evidence through a literature review, Professor Stec and her team have undertaken contaminant testing on-site at a number of fire stations in the UK, analysing over 1,000 samples. They also conducted a survey of more than 10,000 firefighters. And they analysed existing decontamination practices in the UK and across the world.

The scientific study and basis for the production of this guidance will also be of value to those with a broader interest in the exposure of firefighters to toxic fire effluents and debris.

Ahead of this report's initial release, the House of Commons Environmental Audit Committee recommended that the Health and Safety Executive (HSE) implement its recommendations on improving firefighters' work environments. The government then instructed the HSE to monitor the research, and to ensure fire and rescue services identify risks to firefighters. In 2024, the HSE informed the FBU that it would take steps to inspect fire and rescue services on prevention against exposure to contaminants.

The research is jointly funded by UCLan and the Firefighters 100 Lottery. If you want to support this vital work, which has continued with further health monitoring and investigations of occupational exposure, buying a lottery ticket remains an excellent way to do so. Everyone who supports the lottery is helping to support this research.

The FBU is extremely proud to have commissioned and funded this ground-breaking project. We dedicate it to all those in the fire and rescue service whose lives have, and continue to be, effected by cancer and other diseases.

Health and safety is not a luxury, and we must all do what we can to make work safer for firefighters: Remember the dead, fight for the living.

Steve Wright
FBU general secretary

Best Practice Report Minimising Firefighters' Exposure to Toxic Fire Effluents

University of Central Lancashire
UCLan

We dedicate this report to all firefighters who are battling with, or who have lost their battle with, cancer.

BE AWARE, STAY SAFE

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ACKNOWLEDGMENT

This work was commissioned and funded by the Fire Brigades Union (FBU).

SUMMARY

In 2022, an International Agency for Research on Cancer (IARC, World Health Organization) Monographs Working Group concluded that occupational exposure as a firefighter is carcinogenic to humans (Group 1) (IARC 2023).

As the best practice report, this document aims to help protect firefighters' health by highlighting some of the risks and common sources and suggesting preventative measures for minimising exposure to contaminants and best practice for the decontamination of FRS personnel and firefighting equipment after exposure to toxic fire effluent. It provides background information, statistics, resources and actions vital for improving firefighters' health and well-being, keeping them safe and preventing the contamination which otherwise will lead to serious health conditions resulting in either life-changing problems and/or premature death,

The authors and contributors acknowledge that practice from one FRS to the next can vary significantly, and that this practice is based largely on what works best for a specific Service taking into account the number of personnel and local risks, knowledge and experience. This interim report is therefore written with the expectation that it will build on and improve existing practices. It is intended that this is adopted by the fire sector as the best practice. The scientific study and basis for the production of this guidance, will also be of value to anybody with a broader interest in exposure of firefighters to fire effluents and debris.

ABOUT THE AUTHOR

Professor Anna Stec is a world leader in the area between fire safety and public health. She brings a diverse portfolio of research interests including quantification of toxic hazards in fires, understanding the factors that affect fire gas toxicity, and the relationship between the physiological effects of the concentration and dose of different toxicants.

Prof Stec was a member of the expert panel on Dame Judith Hackitt's Review of Building Regulations; a special advisor to the Scientific Advisory Group set up by the Prime Minister and chaired by Sir Patrick Valance on the contamination following the Grenfell Tower fire; an expert witness to the Grenfell Tower Inquiry; provided oral evidence to the House of Commons Environment Audit Committee; was the only international member of a US National Academies of Sciences, Engineering and Medicine (NASEM) investigation on wildland fires; and invited specialist on Invited Specialist on the International Agency for Research on Cancer (IARC) Working Group and co-author of Monograph 132 on firefighter cancers. Currently, she serves as a member of the Academic Reference Group for His Majesty's Inspectorate of Constabulary and Fire & Rescue Services (HMICFRS). She is also one of the Scientific Experts at the Specialist Advisory Groups (SAGs) on Persistent Organic Pollutants (POPs) in the circular economy for the Scottish Government.

Prof Stec is a member of several scientific and conference programme committees and journal editorial boards. She is a Fellow of both the Institution of Fire Engineers (FIFireE) and the Royal Society of Chemistry (FRSC), and chartered scientist of the Science Council. She is also UK's designated principal expert on the ISO Fire Threat to People and the Environment subcommittee (ISO TC92/SC3).

CONTRIBUTORS

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METHODS

Literature Review

A number of existing international guidance documents were also reviewed along with published academic literature in order to identify worldwide best practices for minimising contamination of firefighters and their PPE.

UK FRS Decontamination Policies

In 2019, UK FRSs were asked to provide details of their decontamination policies for consideration in this best practice document. 80% of all UK FRSs returned information or procedures regarding:

- PPE decontamination, maintenance, storage, cleaning, repair and replacement;
- Guidance on clothing worn under PPE;
- Details of any cleaning facilities at local stations;
- Details of any training documents that are issued to firefighters.

UK National Firefighter Survey

Data was additionally collected via an online national survey, in which 64 questions assessed the everyday practices and personal experiences of firefighters with regards to fire effluent exposure and decontamination. In 2019/20, the survey was run for 4 months by the University of Central Lancashire (UCLan) assisted by the Fire Brigades Union (FBU) The survey was supported by a number of FRSs in respect of allowing staff paid time to complete the questions. The survey amassed a total of 10, 659 responses (10, 653 of which were included in further analyses). Results of the survey are referenced throughout this best practice document.

Detailed results of the survey can be found in four open-access published manuscripts:

- Contamination of UK firefighters personal protective equipment and workplaces https://www.nature.com/articles/s41598-022-25741-x
- Cancer incidence amongst UK firefighters: https://www.nature.com/articles/s41598-022-24410-3

- Culture and awareness of occupational health risks amongst UK firefighters: https://www.nature.com/articles/s41598-022-24845-8
- Mental health of UK firefighters: https://www.nature.com/articles/s41598-022-24834-x

UK FRS Contaminant Testing

A key part of this stage involved UCLan's team visiting FRSs to measure levels of identified contaminants harmful to health at various workplaces. These measurements were used to inform targeted best practice recommendations within this best practice document.

LIST OF ABBREVIATIONS

APF	Assigned Protection Factor
BaP	Benzo(a)pyrene
FBU	Fire Brigades Union
FDS	Flexi Duty System
FFP	Filtering Face Piece
FRS	Fire and Rescue Service
HEPA	High Efficiency Particulate Air filter
HFRs	Halogenated Flame Retardants
HBr	Hydrogen Bromide
HCl	Hydrogen Chloride
HSE	Health and Safety Executive (UK)
MDI	Methylene Diphenyl Diisocyanate
NIOSH	National Institute for Occupational Safety and Health
OIC	Officer in Charge
OSB	Oriented Strand Board
PAH	Polycyclic Aromatic Hydrocarbons
PBDEs	Polybrominated Diphenyl Ethers
PCBs	Polychlorinated Biphenyls
PCDD	Polychlorinated Dibenzo-p-dioxins
PCDF	Polychlorinated Dibenzofurans
$PM_{2.5}$	Particulate Matter with a diameter <2.5μm
PM_{10}	Particulate Matter with a diameter <10μm
PPE	Personal Protective Equipment
RDS	Retained Duty System
SCBA	Self-contained Breathing Apparatus
SVOC	Semi-volatile Organic Compound
SVF	Synthetic Vitreous Fibre
TCPP	Tris(1-chloro-2-propyl)phosphate
TDI	Toluene Diisocyanate
UCLan	University of Central Lancashire
VOC	Volatile Organic Compound
WHO	World Health Organisation

KEY RECOMMENDATIONS

Key recommendations are divided into two subgroups:

<u>For Fire Personnel:</u>

- Respiratory protective equipment (e.g. SCBA) should be worn at all times whilst firefighting This should also include during salvage and turning over activities and other activities undertaken by FRS personnel (and/or others) after firefighting has been completed, but whilst the building contents are still 'gassing off'. Respiratory protective equipment should be one of the last items of PPE removed during de-robing (after decontamination).
- PPE that is suspected of being contaminated should be transported back to the station or workplace in an air-tight container to prevent cross-contamination.
- Avoid eating, drinking or smoking with unwashed hands whilst wearing, or after de-robing PPE that may be contaminated.
- After attending a fire incident, all personnel should change into a set of clean, dry clothes as soon as possible, ideally before re-entering the appliance (or FDS vehicle).
- PPE should be clean and should be thoroughly decontaminated after every incident to avoid a build-up of toxic contaminants. PPE should be inspected for wear and damage on a regular basis, and replaced as necessary.
- It is important to protect areas of exposed skin and airways when cleaning soiled PPE/equipment. This requires appropriate respiratory protection (e.g. face masks or face coverings) and gloves.
- "Shower within an hour" when returning to the station from an incident, or following a live fire training exercise.
- Regular health screening and recording attendance at fire incidents over the course of a firefighter's career is strongly advised and will be key to the longer-term monitoring and management of health.

For Fire and Rescue Services:

- Every Fire and Rescue Service (FRS) must have fully risk-assessed decontamination procedures (en-route to, during and after fire incidents), and ensure all relevant staff are trained in implementing these procedures.
- All FRS personnel should receive regular and up-to-date training on the harmful health effects of exposure to toxic fire effluents, and how these exposures can be reduced, minimised or eliminated.
- All FRSs should have policies in place for the routine care, maintenance, inspection and professional cleaning of PPE.
- Establishing and strictly maintaining "designated zones" within the fire station must be a priority for preventing cross-contamination. PPE should never be worn in areas of the station designated a clean zone (e.g. kitchens, living quarters etc.) and should be stored away from personal items.
- To reduce secondary exposures, appliance cabs and equipment from emergency response vehicles should be cleaned and decontaminated on a regular basis, especially after incidents where exposure to any combustion products occurred.

INTRODUCTION

Chemical and building regulations are designed to ensure that exposure to materials within residential, commercial and industrial buildings are safe. However, there are currently no requirements to consider how the safety of those materials might change in the event of a fire – i.e**. there are no requirements to measure and quantify the toxic fire effluents produced by burning materials.** There are no restrictions on the use of products capable of emitting lethal quantities of toxic effluents during a fire. Compared with natural materials (wood, wool, cotton, leather, etc.), widely used synthetic polymers (derived from oil) burn more quickly, have faster flame spread, generate more heat and produce not only higher numbers of hazardous gases and particulates, but also much higher concentrations of toxic chemicals. Firefighters are therefore at an increased risk of exposure to toxic fire effluents and subsequently at an increased risk of suffering adverse health outcomes.

Firefighters' exposure to toxic fire effluents will depend on:

- Fire Scenario (fire conditions)
- Fuel (materials involved in the fire)
- Specific toxicants released during and post fire
- Contamination from fire debris/residues
- Type, frequency and duration of fires attended
- The tactics employed at the incident
- The extinguishing medium used
- Use of Personal Protection Equipment
- Hygiene facilities and practices
- Time between contamination and the use of hygiene facilities and practices

Contaminants, Toxicity and Exposure Pathways

*Harm to health depends on the **toxicity** of the contaminant, but also on the **exposure pathways** via which an individual is exposed to the contaminant, and the **dose** (amount) of the contaminant an individual is exposed to (Duffus & Worth, 2006).*

Fires produce a cocktail of toxic, irritant and carcinogenic chemicals – the composition of which varies depending on the specific materials burning and the fire conditions. They can be released in the form of particulates which will include aerosols, dusts, fibres, smoke and fumes or gases and vapours.

Some of these fire effluents (e.g. carbon monoxide, hydrogen cyanide and acid gases) have *immediate* adverse effects on health after only a single or short exposure (e.g. asphyxiation). This is known as **acute toxicity.**

However, most other fire effluents (e.g. volatile organic compounds, or polycyclic aromatic hydrocarbons) have much *longer-term* adverse effects on health, causing conditions which are more complex and can develop more slowly e.g. cancer, cardiovascular (related to the circulatory system which comprises the heart and blood vessels) and neurological (nervous system) diseases. This is known as **chronic toxicity**. Repeated exposure to even very small amounts of chronic toxicants over time increases the likelihood of developing long-term health conditions.

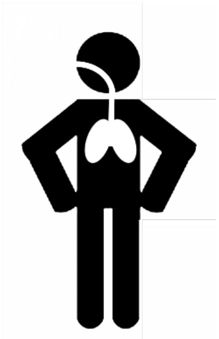
Acute and chronic toxicants can be then further classified according to the specific types of adverse effects they have on health. These classifications are referenced throughout this guide, and include:

- **Carcinogens**; substances which cause cancer (e.g. benzene, PAHs etc.).
- **Teratogens;** substances that can harm the foetus if exposure occurs during pregnancy (e.g. lead compounds, ethylene oxide, formamide etc.).

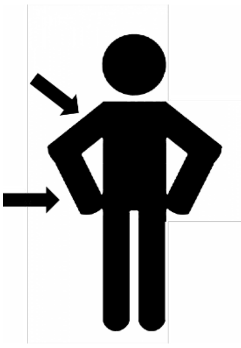
- **Sensitisers;** substances which result in an allergic type hypersensitivity reaction (e.g. of skin or lungs) (e.g. chromium, formaldehyde, isocyanates etc.).
- **Irritants;** substances which react in contact with moisture on/within the body and cause an inflammatory response (e.g. hydrogen chloride, hydrogen bromide, sulphur dioxide, nitrogen oxides etc.).

It has been proven that combinations of different chemicals which are not particularly harmful individually can give rise to entirely new hazardous effects. Moreover, the effects of chronic toxicants may be cumulative, and can remain latent for a long time before any symptoms arise or are even measurable. (Heys et al., 2016)

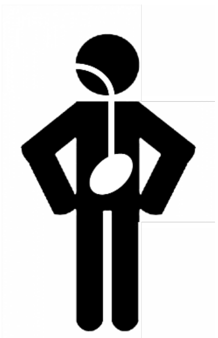
Firefighters may be exposed to toxic contaminants via multiple **exposure pathways**:



Inhalation. Many gases, vapours, mists, dusts and fibres released during fires can be inhaled through the lungs. The amount of contaminant inhaled by a person is directly linked to the volume of air inspired and expired, which increases with physical exertion. Normal breathing frequency at rest is 12-20 breaths per minute (approx. 7-14 litres of air). However, under extreme stress, firefighters with normal lung capacity can metabolise up to 100 litres of air per minute (Swedish Civil Contingencies Agency, 2015).



Dermal Absorption occurs when a toxicant comes into contact with an individual's skin. There are many situations in which firefighters' skin comes into contact with harmful substances e.g. through direct contact with soot (touching the skin with contaminated hands or with gloves that have been in contact with fire debris) or when an area of skin is exposed in a smoky environment. Absorption of toxicants via the skin will vary depending on exposure time, the quantity and type of substance, location and the surface area of the skin. The physical demands of firefighting (wearing breathing apparatus, performing rescues, post fire activities etc.) and the high temperatures in which firefighters operate increases their blood flow, sweating rates and body temperature. Together with the body's reduced water content, this leads to increased dermal absorption of fire effluents.



Ingestion (through the gastro-intestinal tract) occurs when a toxicant is swallowed. Exposure to contaminants via ingestion may occur when food or drink is contaminated with fire effluents, e.g. if eating/drinking with soiled hands. In addition, when fire gases or particulates have entered the upper respiratory tract via inhalation, they may be carried via mucous and saliva into the digestive system and absorbed into the body.

*

EXAMPLES OF TOXIC FIRE EFFLUENTS

The below examples illustrate some of the most common types of toxic contaminants that firefighters might be exposed to at fire incidents. Table 1 (page 21) further expands these examples, summarising the key sources of each group of common fire contaminants as well as the overall type of toxicity and/or health effects they have.

Volatile and Semi-Volatile Organic Compounds (VOCs/SVOCs)

Complex mixtures of VOCs/SVOCs are generated as incomplete combustion products during fires, and many of them are known to be significantly damaging to human health and the environment. Important examples of these compounds are benzene, styrene, and phenol, formed in the majority of fires. Benzene is of particular toxicological significance as it is a precursor of carcinogenic polycyclic aromatic hydrocarbons (PAHs) as well as being a known carcinogen in its own right. They are environmentally persistent and able to bioaccumulate in fatty tissues (Anna A. Stec, 2017).

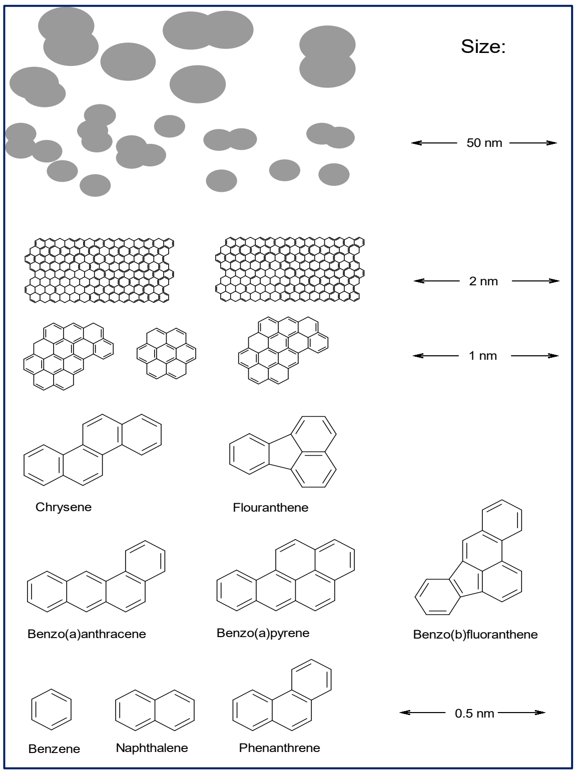


***Figure 1**: Soot formation which is made from VOCs/SVOCs precursors of PAHs*

* *Chimney Sweep's carcinoma* was the first reported form of occupational cancer i.e. cancer caused by occupational exposures (in this case, exposure to particles of soot), and was first identified by Percivall Pott in 1775.

Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons are aromatic hydrocarbons with two or more fused benzene rings (see above, Figure 1). These are large molecules composed of several aromatic rings fused together (example is shown in Figure 2). Many PAHs are carcinogens and environmental pollutants. The molecular size of PAHs strongly influences their distribution between gas and condensed phases and is directly relevant to their toxicity. Smaller PAHs (fewer than four fused rings, e.g. naphthalene, phenanthrene) mainly exist in the gas phase. The tendency to adsorb onto organic carbon (e.g. soot particles) increases with increasing molecular size, so the larger compounds (more than four fused rings, such as benzo(a)pyrene) occur in the atmosphere mainly as particulates (Blomqvist et al., 2010).

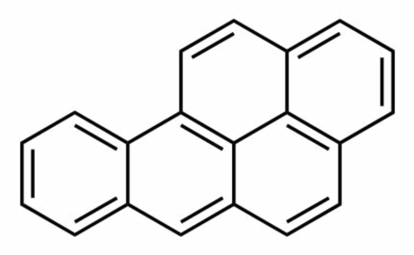


***Figure 2**: Chemical structure of Benzo(a)pyrene (BaP)*

Historically, benzo(a)pyrene (BaP) has been identified as the most toxic PAH species and is used as a reference toxicant for other PAHs. However, recent studies have identified 7,12- dimethylbenzo(a)anthracene as being twice as toxic as BaP. Both compounds have been identified in deposits collected from firefighters' working environments (Stec et al., 2018).

Particulates

Particulate matter is made up of a mixture of small solid and/or liquid particles. The toxic effect of these particles depends on their size and how deeply they are able to penetrate the respiratory tract. Figure 3 shows the deposition zones for different particle sizes within the respiratory tract. Larger particles tend to be trapped in the upper respiratory tract where they are a eventually returned to the oesophagus to be excreted then through the gut (where they are ingested like food).

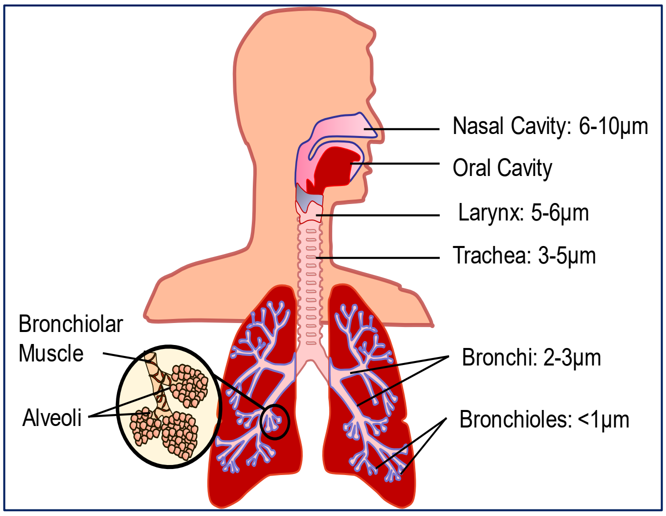


***Figure 3**: Deposition zone for particulate matter in the respiratory tract*

The smallest particles (less than 1 μm), penetrate into the lung interstitium (between the alveolar surface and the blood capillaries), where they can be particularly dangerous, causing interstitial and luminal oedema. They can also cross the air-blood barrier and enter the blood stream, triggering dangerous immune responses from white blood cells, including polymer fume fever and increased platelet stickiness. This can lead to heart attacks or oedema (flooding of the lung) and ultimately death.

Many toxicants, including molecular PAHs, absorb onto carbonaceous particles and therefore travel deep into the lung, rather than being trapped further up (Blomqvist et al., 2010; Anna A. Stec, 2017).

*WHO studies estimate a staggering **0.5% increase in daily mortality per 10 μg m^{-3} of PM$_{10}$** (particulates with a size of 10 μm or smaller)*.
(World Health Organization, 2005)

Isocyanates

These are potent respiratory sensitisers which can trigger asthma, and even death after a single exposure. Isocyanates are commonly identified in fire effluents from burning nitrogen-containing fuel. Due to their versatility and wide range of applications, isocyanate containing products can be found in significant quantities throughout the built environment. They are widely used in the manufacture of polyurethanes, used as foams in soft furniture and building insulation, as solids for resilient elastomers, and liquids and sprays for paints. The two main products in the isocyanate market, with an approximate market share of 90%, are both di-isocyanates: toluene-di-isocyanate (TDI) and diphenylmethane-di-isocyanate (MDI).

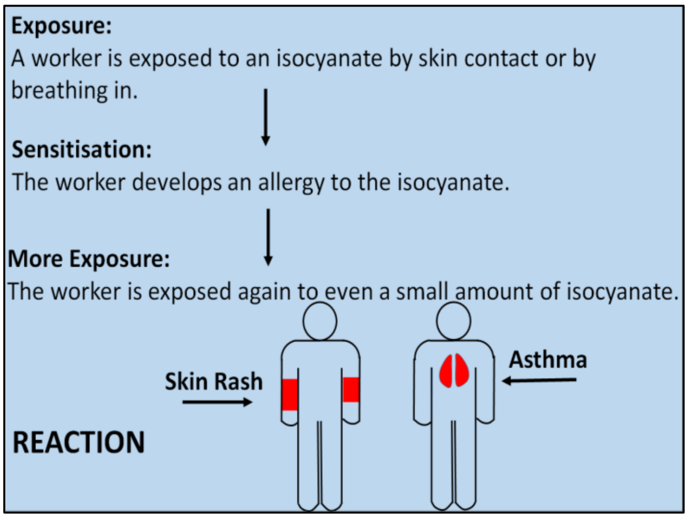


***Figure 4**: Sensitization caused by an exposure to isocyanates*

Halogenated Dioxins

Polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDFs) are toxic, chemically and thermally stable, and have a tendency for being easily adsorbed on the surface of particulate matter. PCDD/Fs formation is favoured at lower temperatures typical of fires. Numerous studies on animals have confirmed that some dioxins are carcinogenic and/or mutagenic (A A Stec et al., 2013).

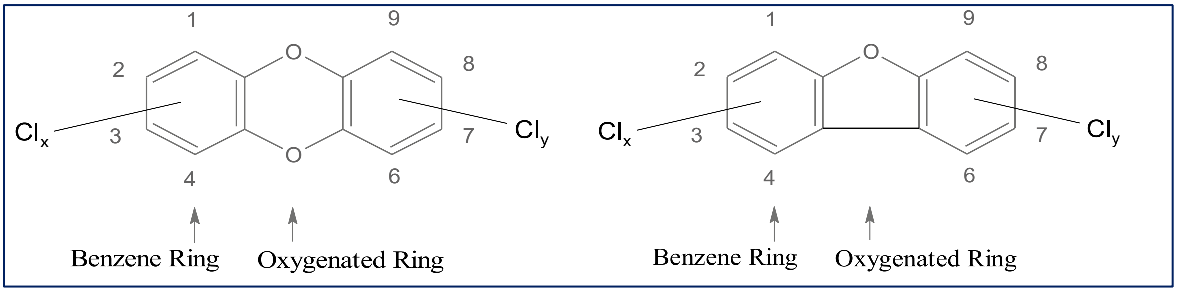


Figure 5: *Structure of (a) polychlorinated dioxins and (b) polychlorinated dibenzofurans PCDF*

PCDD/Fs have been identified in abundance around the collapsed World Trade Center in 2001 (Litten et al., 2003) and, more recently (together with other persistent organic fire pollutants), they were identified in soil following the Grenfell Tower fire (Stec et al., 2019).

Halogenated Fire Retardants (HFRs)

Halogenated flame retardants (containing chlorine or bromine) have proven effective in suppressing ignition. HFRs act by releasing hydrogen bromide (HBr) or hydrogen chloride (HCl) which interferes with gas phase free radical reactions, reducing heat release, but typically producing more hydrogen cyanide and carbon monoxide, smoke and other products of incomplete combustion. The dense smoke obscures escape routes and contaminates property, while the resultant halogen acids are highly corrosive irritants. Many flame retardants are toxic before they decompose.

Figure 6: *Polyurethane foam containing halogenated flame retardants (TCPP)*

They are typically added at loadings of 10 to 20% - thus a flame retarded UK sofa could contain over 1 kg of toxic tris(1-chloro-2-propyl)phosphate (TCPP) (Mckenna et al., 2018).

Synthetic Vitreous Fibres (SVFs)

Synthetic vitreous fibres are commonly used in building products, such as insulation materials (polyurethane, phenolic or polyisocyanurate foams). Recently, concerns have been raised over the health hazards posed by these fibres. Studies on the aftermath of the World Trade Center showed that synthetic vitreous fibres were one of the most significant health damaging contaminants (via dermal irritation and inhalation) after the fire (Lippmann, 2014; Lippmann et al., 2015).

Figure 7*: An example of SVFs found in building insulation products*

Airborne SVFs, like other particulate matter, are released in fires and can be suspended in air (as dust or ash), which can then be inhaled and deposited in the lungs (ATSDR (The Agency for Toxic Substances and Disease Registry), 2018).

Minimum critical fibre lengths for asbestosis (interstitial fibrosis), mesothelioma and lung cancer have been found to be ~2 μm, ~5 μm and ~15 μm, respectively. For asbestosis and lung cancer, fibres with diameters >0.15 μm appear to be most significant (as thinner fibres can be more readily cleared via the lymphatic system) whilst for mesothelioma (and other lesions of the mesothelium), fibre diameters <0.1 μm seem to be the most pathogenic (Lippmann, 2014)

Group of chronic fire effluents	Possible sources	Name of specific fire effluent	Carcinogenic	Teratogenic	Sensitising	Reproductive	Neurological	Pulmonary	Respiratory	Haematological
SVOC/VOCs	Released in almost every fire. Emitted by an extensive range of household and industrial products, including (but not limited to) cleaning products, aerosols, fuels, furnishings, and building materials May be given off over the lifetime of a material, or at high concentrations when a material burns.	Benzene	+	+		+	+	+	+	+
		Styrene		+		+	+		+	+
		Toluene		+			+			
		Phenol		+			+		+	+
		Acetaldehyde	+	+				+	+	+
Isocyanates	Used in the production of polyurethane, polyisocyanurate foams, fillers and coatings or any other nitrogen-containing fuels. May be given off over the lifetime of a material, or at high concentrations when a material smoulders or burns.	Methyl Isocyanate (MIC)		+	+	+		+	+	
		2,4-and 2,6-toluenediisocyanate (TDI)	+	+	+		+	+	+	
PAHs	PAHs are a family of hydrocarbon compounds which are produced in virtually all uncontrolled fires, since they are made up primarily from carbon. They are persistent and generally non-volatile at room temperature, though adhere to airborne particulates so may be found in debris or in the air.	Benzo[a]pyrene	+	+		+				
		Benzo[a]anthracene	+			+			+	
		Benzo[b]fluoranthene	+	+						
		Chrysene	+	+		+		+		
		Fluoranthene			+			+		+
		Naphthalene	+	+			+			+
PCCD/PCDFs	Persistent, bioaccumulative and toxic released from halogen (chlorine) containing fuels, such as PVC windows, cables, fire retardants.	2,3,7,8 TCDD	+	+		+		+		
		2,3,7,8 TCDF		+						
PCBs	PCBs are found in electrical equipment, and are commonly released at electrical and waste fires, though may be found in effluent from any building fire from materials containing chlorine (see above).	3,3´,4,4´,5,5´-hexaCB	+	+		+			+	
		2,3,4,4´,5-pentaCB	+	+	+	+		+	+	
		2,3,3´,4,4´,5,5´-heptaCB			+	+	+	+	+	
PFOA/PFOS	PFOA and PFOS are released from furniture, carpets, electronics, electrical wire casing, firefighting foams.	Perfluorooctanoic acid (PFOA)	+	+			+		+	
		Perfluorooctane sulphonic acid (PFOS)	+	+			+		+	
Flame retardants	Gas phase halogenated organophosphorus flame retardants are used in almost all combustible insulation foams (phenolic, polyurethane, polyisocyanurate), upholstered furniture, mattresses etc.	Tris(1-chloro-2-propyl) phosphate (TCPP)	+			+	+			
		Tris(2-chloroethyl) phosphate (TCEP)	+			+	+			

Table 1: *Common fire effluents, the sources from which they originate and their longer-term effects on firefighters' health.*

FIREFIGHTER OCCUPATIONAL HEALTH RISKS: CANCERS AND DISEASES

Cancers

Over 4% of UK serving firefighters who responded to the survey have already been diagnosed with cancer.

(FBU & UCLan National Firefighter survey)

The International Agency for Research on Cancer (IARC) has classified many of the substances that firefighters are exposed to as human carcinogens or probable human carcinogens (IARC, 2010). Chronic toxicants are predominantly associated with delayed or chronic effects and disorders such as genotoxicity, mutagenicity, carcinogenicity, neurological disorders etc., which generally occur due to repeated exposure to toxins. Common fire effluents, the sources from which they originate and their longer-term effects on firefighters' health are listed in Table 1. Unlike other countries such as America, Canada and Australia the occupation of firefighting within Great Britain has not been recognised or recorded as an occupation 'at risk' of cancer.

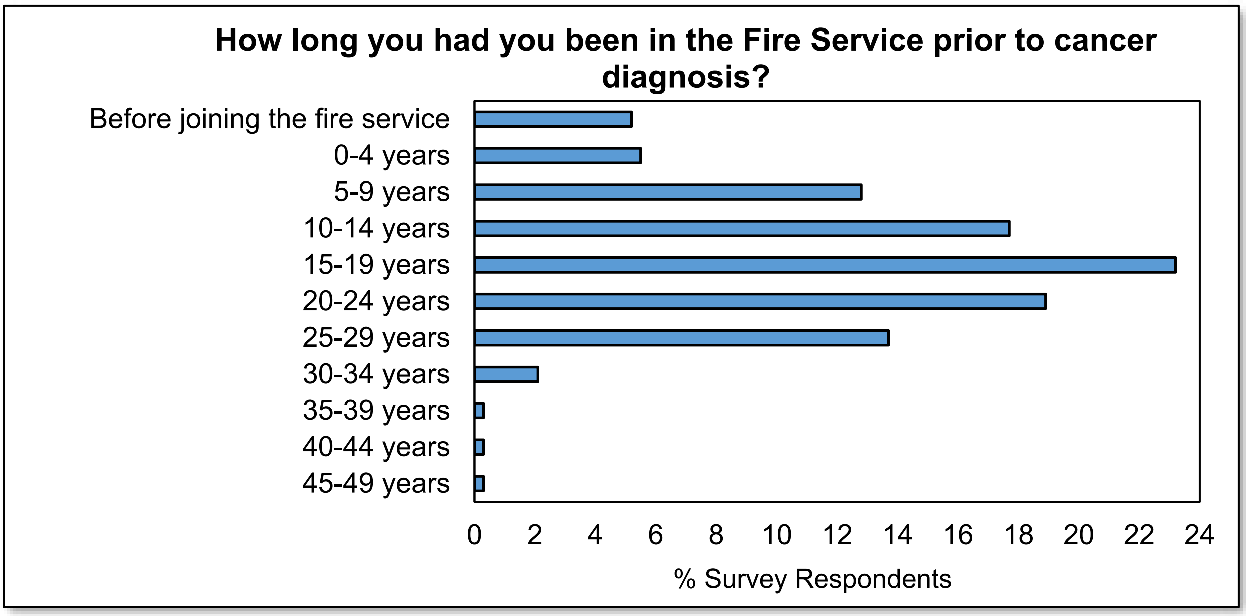


***Figure 8**: % of Respondents to the FBU & UCLan National Firefighter survey who indicated they had received a cancer diagnosis, and the length of time they had served in the Fire Service before their first diagnosis. Results show the responses from 4.1% of all serving firefighters who completed the survey.*

However, the occurrence of disease and cancer among firefighters is higher than expected. There are a number of studies worldwide indicating elevated incidences of certain diseases and cancers within firefighters (Jalilian et al., 2019; LeMasters et al., 2006; Navarro et al., 2019; Petersen et al., 2018; Pukkala et al., 2014). According to a study conducted by NIOSH, USA firefighters have a 9 percent higher risk of being diagnosed with cancer and a 14 percent higher risk of dying from cancer than the general U.S. population (Daniels, 2017). There also appears to be a significantly elevated number of premature deaths amongst firefighters worldwide. Data from the FBU & UCLan National Firefighter survey shows that over 4% of serving firefighters who responded have already been diagnosed with cancer (survey excluded retired firefighters). Their specific cancers are listed in Figure 9.

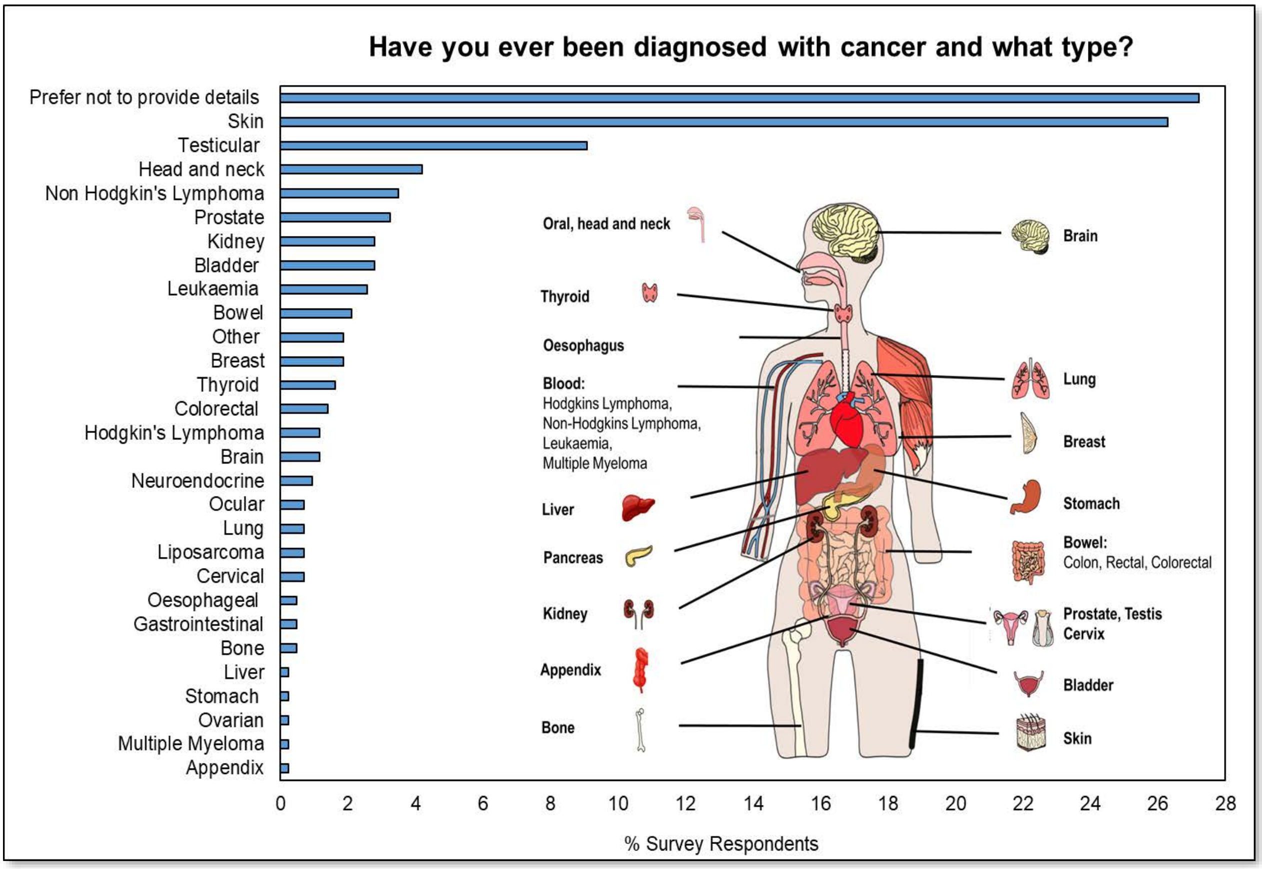


Figure 9: *% of respondents to the FBU & UCLan National Firefighter Survey who indicated that they had received a cancer diagnosis, excluding those who received their diagnosis before joining the Fire Service (4% of all respondents to this question including those which omitted to indicate when they received their first diagnosis (1%). A further 0.2% indicated they had been diagnosed with cancer prior to joining the Fire Service).*

A number of studies also present a likely latent period for firefighters between the first exposure and diagnosis of cancer, Table 2. It is found that brain cancer or leukaemia typically develop within 5 years, solid tumours such as: testicular, bladder, colorectal, kidney, skin melanoma, multiple myeloma, non-Hodgkin's lymphoma, prostate or lung cancers develop in about 10 to 15 years, oesophageal cancer up to 25 years and mesothelioma 30 to 40 years (Daniels et al., 2014, 2015; T. Guidotti, 2014; T. I. Guidotti, 2007; LeMasters et al., 2006). However, this data should be reviewed carefully as firefighters have different types of roles and activities, and will be exposed to a complex and changing mix of exposures (different fuels and combustion products, multiple exposure routes etc.) – all of which may impact this latent period and lead to earlier occurrences.

Primary Site Cancers	Exposure to Smoke (Minimum Service)
Brain cancer Leukaemia	5 years
Breast cancer Testicular cancer	10 years
Bladder cancer Colorectal cancer Kidney cancer Lung cancer Multiple Myeloma Non-Hodkin's Lymphoma Prostate cancer Skin cancer Ureter cancer	15 years
Oesophageal cancer	25 years
Mesothelioma	30-40 years

***Table 2**: Possible latent period for firefighters between the first exposure and diagnosis of cancer (Daniels et al., 2014, 2015; Guidotti, 2014; Guidotti, 2007; LeMasters et al., 2006).*

Diseases

Over 86% of UK serving firefighters who responded indicated they do not smoke.

(FBU & UCLan National Firefighter survey)

Firefighters are expected to have less premature deaths and diseases, since as a group they are generally healthier than the general population. This is widely known as the "Healthy Worker Effect", and considers the physical demands of the job, the necessity to pass fitness tests and the requirement to undergo medical checking on a regular basis (Chowdhury et al., 2017).

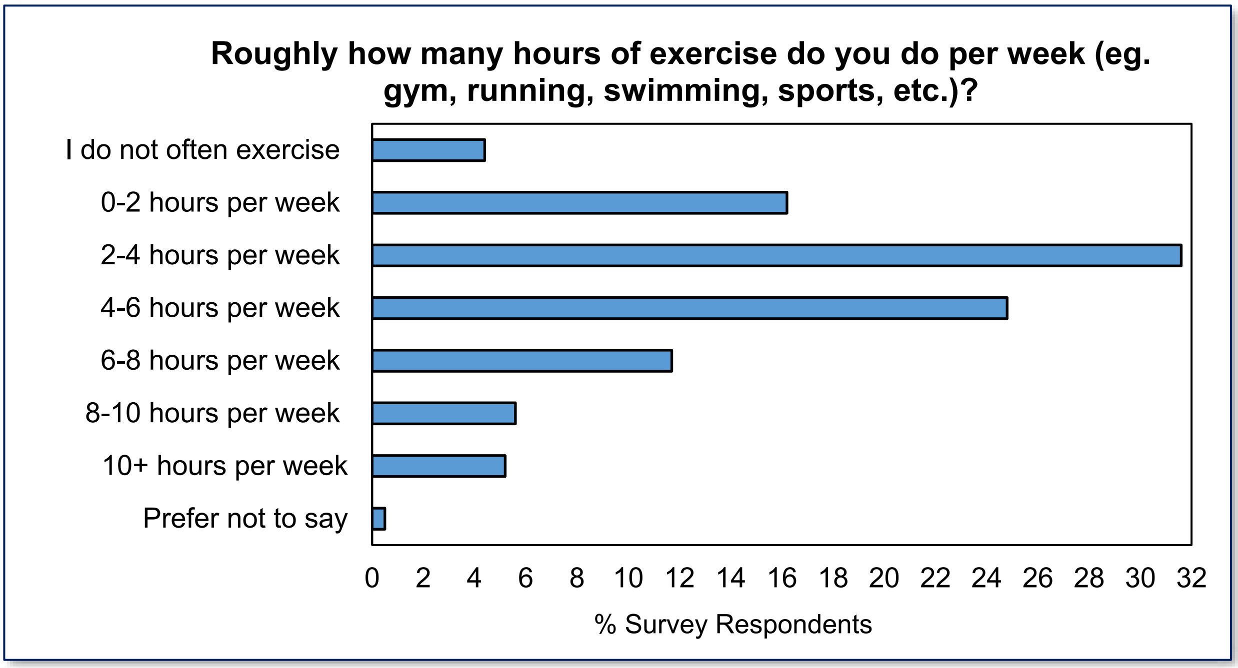


***Figure 10**: % of Respondents to the FBU & UCLan National Firefighter survey who indicated the number of hours of exercise they did per week. According to recent YouGov studies, on average, about 62% of Britons manage only a single 30 minute exercise session a week (Smith, 2020).*

In the US, it was found that 45% of on-duty deaths among US firefighters were caused by **coronary heart disease** (heart diseases, heart attacks, stroke and congestive heart failure) (Kales et al., 2003). Researchers have shown that exposure to cardio-toxic substances such as hydrogen cyanide, carbon monoxide or particulate matter may accelerate vascular disease. Increased risk of heart attacks leading to death may also be caused by heat stress, exertion, dehydration, shift work, stress-related to responding to fire calls or the physical demands of the tasks encountered at the incident (T. Guidotti, 2014). Other studies show a direct link between high blood pressure (hypertension) and diabetes (blood sugar too high), cholesterol, and lack of physical fitness (Kales et al., 2003; Maqbool et al., 2018).

61% of UK serving firefighters who responded indicated they have problems with their sleeping.

(FBU & UCLan National Firefighter survey)

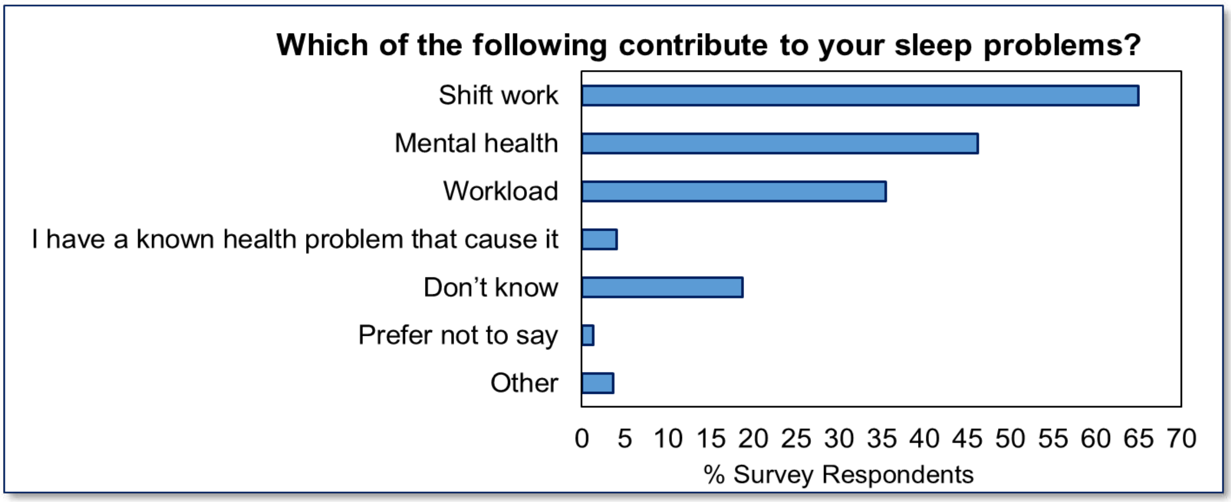


Figure 11: *% of Respondents to the FBU & UCLan National Firefighter survey who listed factors contributing to their lack of sleep. 61% of National Firefighter survey responders indicated problems with their sleeping.*

During simulated firefighting activities, a majority of firefighters may lose over 1% of body weight in fluid loss, enough to affect mental function, strength, and dexterity. (Walker et al., 2016; Woodbury & Merril, 2019, Horn et al., 2012)

Heat stress, heat exhaustion and heat stroke resulting from prolonged and frequent exposures to high temperatures, especially in full protective gear, can not only lead to hyperthermia (core temperature >40.5 °C), but also dehydration, which can exacerbate **heart, kidney, liver, and gastrointestinal tract diseases** (Cheshire, 2016, Shaw & Tofler, 2009). The physical demands of firefighting and the high temperatures in which firefighters operate can lead to profuse sweating. Heavy and thick personal protective clothing restricts cooling, making sweating ineffective, disturbing the body's thermoregulatory processes and water balance. Recent research involving US firefighters at training exercises has shown that over half of study subjects were dehydrated before beginning firefighting activities (Horn et al., 2012). During simulated firefighting activities, a majority of the studied US firefighters lost over 1% of their body weight in fluid loss, enough to affect mental function, strength, and dexterity. In addition, increased blood flow, sweating rates and body temperature together with the body's reduced water content also increase dermal intake of fire effluents (Walker et al., 2016; Woodbury & Merrill, 2019, Horn et al., 2012). The kidneys are known to be particularly susceptible to damage from environmental toxicants (Vervaet et al., 2017), so a combination of dehydration, coupled with repeated exposure over a number of years, may go some way towards explaining the elevated risk of kidney disease deaths reported (Roncal-Jimenez et al., 2015).

Cirrhosis of the liver may be caused from the long-term exposure to fire effluents.
(Daniels et al., 2014; Haddock et al., 2012)

Information on non-malignant **liver diseases** and non-alcohol related mortality within the fire service is sparse and inconsistent (Daniels et al., 2014; Haddock et al., 2012). There are a number of factors that may affect the digestive systems of firefighters. Increased cirrhosis mortality may come from exposures to chemical toxicants or other infectious diseases, which may also account for acute renal dysfunction (Daniels et al., 2014). It is recognised that long-term exposure to specific components of fire effluent (e.g. acrolein) causes irritation and damage to gastrointestinal epithelial tissue, while other fire effluent components (e.g. PCBs) are associated with histologic changes in the liver (Faroon et al., 2008; Graveling & Crawford, 2010; Kim et al., 2017).

There are already numerous amounts of research into firefighters' deaths from diseases of the **central nervous system (neurological disorders)**. However, data (standard mortality rates) vary significantly between those studies (Beaumont et al., 1991; Jalilian et al., 2019; LeMasters et al., 2006; Pukkala et al., 2014). Motor neurone disease (MND) occurs when motor neurone cells progressively stop working effectively. Causes include genetics and exposure to environmental toxicants. Chemicals thought to contribute to this disease include certain metals (lead, mercury, aluminium, cadmium, chromium), benzene, formaldehyde, polychlorinated biphenyls, polychlorinated (or brominated) dibenzodioxins and furans (Ash et al., 2017; Peters et al., 2017; Steenland et al., 2006; Sutedja et al., 2009). More recently, exposure to environmental neurotoxins such as PBDEs or halogenated organophosphorus flame retardants (commonly used in furniture or insulation materials), have also been positively linked to various neurological disorders (Abou-donia et al., 2016; Tang et al., 2011; Wood, 2016). It is suggested that diesel exhaust emissions might also be a risk factor for these disorders (Dickerson et al., 2018). Central nervous system neuron regeneration may also be affected by heavy work load or stressful activity that reduces sleep quality and melatonin levels (Cherry, 2002).

Central Nervous System or neurological diseases have also been positively linked to long-term exposure to fire effluents.
(Abou-donia et al., 2016; Tang et al., 2003; Wood, 2016)

A high number of studies show that frequent, prolonged and direct exposure to smoke elevates breathing rates, resulting in deposition of smoke particles in the **respiratory tract.** It is known that fine particles can be one of the best single indicators for the impact of combustion product inhalation on lung health (Swiston et al., 2008). Studies have suggested that exposure of lung epithelial cells to fine particles promotes inflammation due to alveolar macrophage response (Hiraiwa & Eeden, 2013). This may contribute to the increased incidence of chronic respiratory diseases within firefighters. Exposure to wood smoke (through exposure without proper use of sufficient breathing apparatus at wildland fires, or in the case of instructors not wearing breathing protection at firefighter training exercises) is found to have a marked effect on the respiratory immune system and at high doses can produce long-term or permanent lesions in lung tissues. These effects seem most strongly associated with the respirable particle size range that is thought to be most damaging to human health (Naeher et al., 2007).

In one recent UK pilot study, it was suggested that repeated exposure to high temperatures may adversely affect the **immune system** of firefighters (Richardson, n.d.). Typically, the most common sites of infection are lungs (pneumonia), urinary tract (kidney), and abdomen (peritonitis, appendicitis) (Ross et al., 2018). This raises the question of whether these deaths indicate that firefighters have an elevated risk of dying from infection.

Due to the large gender disparity in fire services globally there is very limited evidence concerning the health effects of firefighting activities and exposure to contaminants in female firefighters.

CONTAMINATION: CONTROLLING AMOUNT AND EXPOSURE TO TOXINS

Contamination Types

The inherent toxicity of fire effluent components cannot be controlled. Neither can the inherent physical properties of these effluents, which make certain exposure pathways viable. However, what ***can*** be controlled to some extent is the **amount** (or "dose") of fire effluents which firefighters are exposed to. Personal protective equipment (PPE) is designed to protect firefighters by reducing or completely restricting the amount (dose) of toxic effluents firefighters are exposed to via multiple exposure pathways (see "Contaminants, Toxicity and Exposure Pathways" and "Personal Protective Equipment" sections).

However, when PPE or equipment becomes ***contaminated*** it loses its efficacy at protecting firefighters against exposure to toxic fire effluents. In fact, contaminated PPE may even *increase* the dose of toxic fire effluents firefighters are exposed to.

The most common types of contamination are summarised below (National Operational Guidance (NFCC), 2020):

Figure 12*: An example of surface contamination*

Surface contamination occurs when contaminants are present on the outer layer of a material but have not been absorbed into the material (e.g. Figure 12). Surface contaminants are usually easy to detect and easy to remove to a reasonably achievable and safe level (dust, fibres etc.).

Permeation of contaminants occurs when contaminants are absorbed *into* a material (e.g. Figure 13). If not removed, contaminants may continue to permeate further through the material. Factors that influence permeation include:

- *Temperature*; increased temperatures generally increase the rate of permeation. Conversely, lower temperatures will generally slow down the rate of permeation – as temperature changes the physical properties of contaminants (e.g. increasing temperature may increase the viscosity of liquids, or vaporise contaminants to gases, which are then able to flow more freely into materials). Increasing temperature may also alter structure of materials – making it easier for contaminants to pass through.

Figure 13*: An example of contaminants permeation*

- *Contact time*; the longer a contaminant is in contact with an object, the greater the probability and extent of permeation.
- *Concentration*; molecules of the contaminant will flow from areas of high concentration to areas of low concentration. Generally, the greater the concentration, the greater the potential for permeation to occur.
- *Chemical and physical properties*; gases, vapours and low-viscosity liquids tend to permeate more readily than high viscosity liquids or solids.

Permeated contaminants are often difficult or impossible to detect and remove. Permeation through protective clothing could cause exposure inside the suit.

Figure 14*: An example of direct contamination*

Direct contamination occurs via direct physical contact with a contaminant or any contaminated object (during the fire incident, the turning over process or the decontamination process). Helmet, gloves and boots are the most common areas that get directly contaminated. Both surface contamination and permeation can occur through a direct contamination pathway.

Figure 15*: An example of cross contamination*

Cross (or secondary) contamination occurs when a person or object that is already contaminated makes contact with a person or object that is not contaminated and subsequently contaminates that person/object (National Operational Guidance (NFCC), 2020) (e.g. storing contaminated gloves within a clean helmet). Both surface contamination and permeation can occur through a cross contamination pathway.

Personal Protective Equipment

Firefighters' fire gear is not designed to prevent combustion gas particles from coming into contact with the body (Swedish Civil Contingencies Agency, 2015).

In line with HSE regulations on personal protective equipment (PPE) at work, all users should be trained on the use and limitations of each type of protective clothing that is provided. In the UK, firefighters' PPE (helmet, tunic, leggings, gloves, boots and respiratory protection) must conform to BS EN 469:2005 for performance requirements (heat resistance, surface wetting, resistance to water penetration, heat transfer from flame and radiation, etc.) (British Standards Institution, 2006). However, **there is currently no UK requirement for PPE to protect against toxic gases and particulates**.

Firefighter's protective clothing shall be designed to provide protection for the firefighter's torso, neck, arms to the wrists, and legs to the ankles during firefighting (British Standards Institution, 2020). Where protection is provided by a two-piece suit, it shall be determined that an overlap between the jacket and trousers shall always be retained. In addition, the wrists and ankles shall remain covered when wearing appropriate sized clothing in an upright position (British Standards Institution, 2020). All external pocket flaps shall be stitched down or capable of fastening the pocket closed. All pockets in the garment shall be designed in such a way to prevent entry of heat, flame, or hot material, exception for external radio pockets (British Standards Institution, 2020).

The biggest suppliers of PPE in the UK are Ballyclare and Bristol - which both provide managed options for monitoring and laundering PPE, as well as for inspection of garments for damage or loss of functionality – although it should be noted that not all FRAs choose this option.

NOTE: In the US, the fabric of the fire hood must block 90% of particulates (between the size of 0.1μm and 1.0μm) according to US NFPA (ASTM International, 2017; Lee et al., 2015; National Fire Protection Association, 2018). These particle-blocking fire hoods are beginning to enter the UK market, and may become more popular in the future, potentially influencing a change in protection standards for UK PPE.

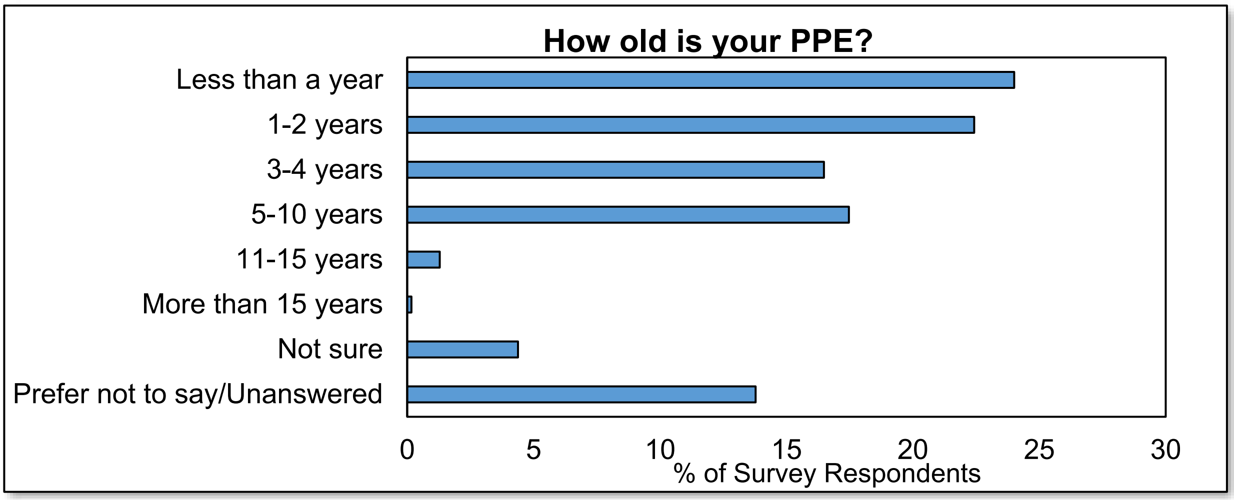


Figure 16: *% of Respondents to the FBU & UCLan National Firefighter Survey indicating the age of their PPE.*

The replacement cycle for fire kit can be relatively long (Figure 16), which means that the clothing may be subjected to repeated and regular contamination during its service life and may no longer be able to effectively perform its protective function from toxic contaminants (references below). It has been shown that organic contaminants can be transferred from the fabric of PPE to the skin. These contaminants can then penetrate deeper dermal layers, with the potential for systemic toxic effects i.e. effects which target multiple sites of the body (Burke & Sparer, 2018; Fent et al., 2013; Ladaresta et al., 2018; Stec et al., 2018). This decreased functionality of PPE garments can occur before the garment appears visibly damaged to the naked eye (Rezazadeh & Torvi, 2011).

Exposure to fire effluent via contaminated PPE most commonly occurs:

- During removal and storage of contaminated PPE (Fent et al., 2013).
- During PPE gassing-off (in vehicles, and non-work environments by hanging up heavily contaminated PPE in a room without ventilation or during drying (Fent et al., 2017; Harrison et al., 2018; Rogula-kozłowska et al., 2018).
- When transferring contaminants from contaminated PPE to workwear and/or directly to the skin during washing (Harrison et al., 2017).
- Via cross contamination with clean garments during domestic laundering cycles (Mayer et al., 2019; Stapleton et al., 2005).

Helmet

Due to its function and design, the helmet can become contaminated on both inside and outside surfaces. As it is worn on the head it has very close contact with both skin and airways. Ideally, helmets should have removable soft goods (cradle) which can be separated and more thoroughly cleaned (according to manufacturers' recommendations).

Fire Hood (Flash Hood)

Many fire hoods fail to provide a barrier against superfine particles and soot, which absorb a variety of hazardous chemicals including carcinogens.

It is recommended that fire hoods should be washed immediately after return to the station, after every fire incident. This is because:

- Protective fire hoods are in direct contact with the skin during a fire incident.
- Sweat allows contaminants to pass through the fire hood and onto skin more efficiently.
- Dermal absorption rates for the relatively thin skin on the scalp, forehead, jaw and behind ears are much faster than the dermal absorption rates for thicker skin on e.g. palms of hands.
- The face and neck have been identified as areas at significant risk of dermal exposure to products of combustion and potential carcinogens (Stec et al., 2018).

The skin's permeability increases with temperature.
For every 5ºC increase in skin temperature, absorption of toxins via skin increases 400%.

(Firefighter Cancer Support Network, 2013)

NOTE: Further research is required to verify these figures. However, a number of other studies have found that increasing skin temperature leads to an increase in skin permeability (Park et al., 2008; Jones et al., 2003). Absorption of contaminants through the skin is likely increased by temperature via enhanced blood flow to the surface of the skin, increased skin hydration due to sweating, and the opening of skin pores (Jones et al., 2003). A study of Italian military firefighters found that skin temperature increased by an average of 10% during firefighting activities (Del Sal et al., 2009). This is roughly in agreement with previous studies (reviewed in (Barr & Gregson, 2010). For example, Romet and Frim (1987) found skin temperature to rise from 34.5 to 37.4 °C during the most demanding firefighting activities (Romet & Frim, 1987).

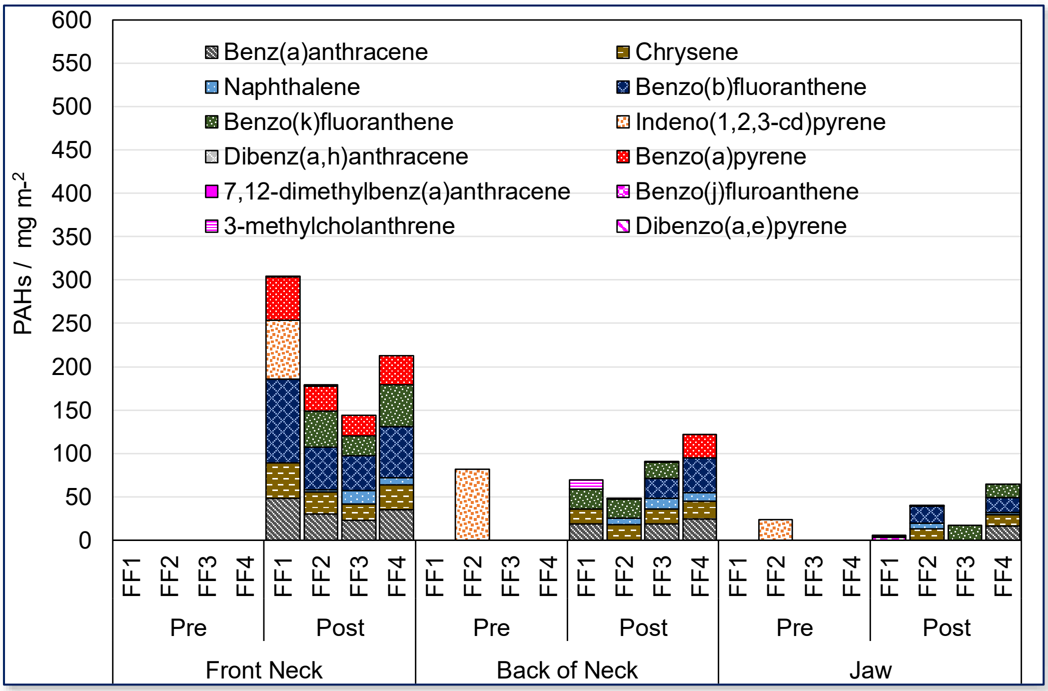


***Figure 17**: Concentrations of toxic PAHs, collected from the front and back of the neck and jaw. Samples were collected pre- and post-exposure from an instructor (FF1) and three trainees (FF2-FF4) attending training (Stec et al., 2018).*

Fire Gloves

Figure 18: Example of common, but **not recommended** practice, whereby fire gloves (which are subject to considerable contamination) are stored in helmets – leading to cross contamination.

Fire gloves must meet the requirements of BS EN 374-3 and selection should be made according to the hazard encountered. A dual glove system may afford the best protection (British Standards Institution, 2003). This normally consists of a laminated inner glove having good chemical resistance with an outer elastomeric glove affording protection against mechanical abuse as well as having some degree of chemical resistance.

Firefighters' protective gloves are probably the clothing that is most subjected to contamination. It is the item which is the most difficult to wash and dry simply and effectively whilst retaining its shape and function. Firefighters' gloves are often made with leather or leather-like material, meaning they are sensitive to machine-washing. They also have a tendency to lose their shape if they are cleaned and dried carelessly.

Since gloves and fire hoods differ considerably from one Service to another, personnel should be made aware of the most appropriate cleaning guidelines for the type of PPE provided.

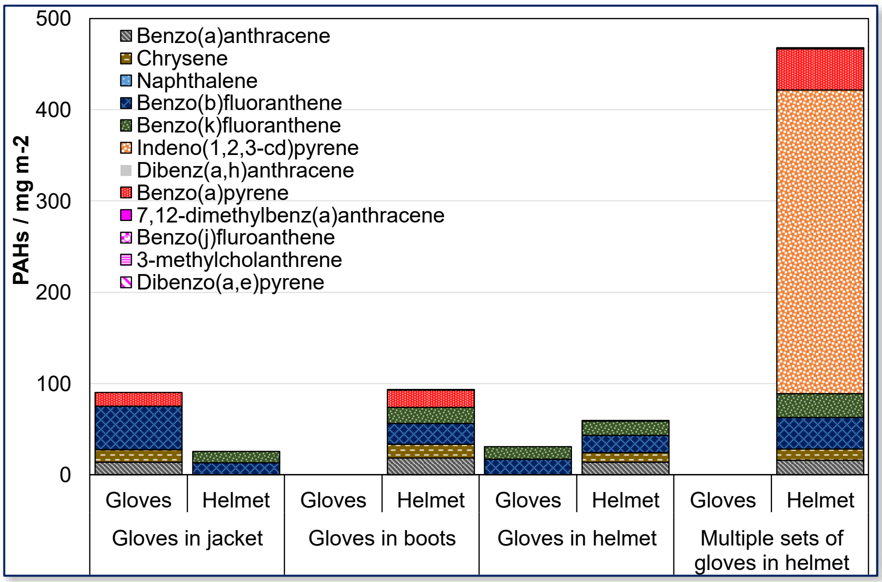


***Figure 19**: Concentrations of toxic PAHs on PPE clothing, stored in different configurations (Stec et al., 2018).*

Respiratory Protection

Respiratory protective equipment in the workplace is divided into two main types (Health and Safety Executive, 2013):

- **Breathing apparatus** – Worn where there is an irrespirable and/or contaminated atmosphere. This needs a supply of breathing quality air from an independent source (e.g. air cylinder or air compressor)
- **Respirator (filtering device)** – This uses filters to remove contaminants in the air. They should never be used for protection in fire situations or where there is any possibility of reduced oxygen levels. They should always be subject to appropriate face-fit assessment.

A Respirator (filtering device) must never be used in place of a compressed air breathing device (SCBA or airline).

Breathing Apparatus

Studies by National Institute for Occupational Safety and Health (NIOSH) show that even self-contained breathing apparatus (SCBA) worn and evaluated as fully operational becomes contaminated within 25 minutes of use in firefighting situations (Fent et al., 2013). These results signify that there is a build-up of toxicants (e.g. PAHs, VOCs) within firefighters' ensembles (jacket, leggings, boots, helmet, fire hood, fire gloves etc.), especially with repeated use. This results in increased toxic exposure to firefighters from just their ensemble (Alexander, 2012; Baxter et al., 2014; Kirk & Logan, 2015).

Firefighters are often tempted to prematurely remove breathing apparatus (without replacing it with any other form of respiratory protection) so that they can move more effectively.

(FBU & UCLan National Firefighter survey)

- Selecting an effective respirator and filter is not always possible, as firefighters will rarely know what specific contaminants are present at fire incidents. In these situations, breathing apparatus better protects firefighters from unknown and/or undetected toxins in smoke.
- Maintenance, examination and testing of compressors for BA should be carried out according to the manufacturer's instructions.
- Air compressors can generate and concentrate a wide range of contaminants, therefore extra care in assuring air quality should be taken.

NOTE: Across the US there are an increasing number of purpose-built machines to decontaminate PPE and SCBA. These machines are not currently widespread across the UK albeit we are aware UK FRSs are starting to consider this option.

BA should not be removed prematurely or donned too late.

Respirator (filtering device)

Specialists have developed criteria for the selection of proper, adequate respirators. One of these criteria is the "Assigned Protection Factor" (APF). The APF is a number rating that indicates how much protection a respirator is capable of providing. For example, respiratory protective equipment with an APF of 10 will reduce the wearer's exposure by at least a factor of 10 if used properly, or, to put it another way, the wearer will only breathe in one-tenth or less of the amount of contaminant present in the air (Health and Safety Executive, 2013). A summary of available respirators is provided in Table 4.

- **Particle filters.** Certain respirators are fitted with particle filters, which trap particles present in the air (e.g. dust, mist, fume, smoke, micro-organisms). However, these filters **do not** trap gases or vapours, organic liquid mists and sprays, or give any protection against oxygen-deficient atmospheres. Some manufacturers may recommend the use of pre-filters (coarse filters) to protect the main filters.

  Particle filters are assigned one of three ratings, depending on their filtration efficiency; FFP1, FFP2 or FFP3 (Table 3; where FFP stands for "*filtering face piece",* sometimes simply abbreviated to "P" as in Table 4). If the filter is compatible for use with a fan-assisted respirator, it will also be marked with the symbol "TH" or "TM". If a colour coding system is used, particle filters will bear a white label. Respirators fitted with particle filters should only be re-used if they are specifically indicated as re-useable.

Filtration Efficiency Rating	Protection Level against dust, solid and liquid aerosols	Filter Capacity % removal of particles ≥ 3 μm	Occupational Exposure Limit	APF
FFP1	Low	At least 80%	4x	4
FFP2	Moderate	At least 94%	12x	10
FFP3	High	At least 99%	50x	20

Table 3*: The filtration efficiency ratings assigned to particle filters and the relative levels of protection they provide. These filters are assessed against a "safe" level of exposure known as an "Occupational Exposure Limit". The table indicates how many times over this limit the level of particulates can be while particle filters are still able to protect wearers*

- **Gas/vapour filters** are designed to remove gases or vapours as specified by the manufacturer. They do not protect against particles, or oxygen-deficient atmospheres. These filters have a limited capacity for removing gases/vapours, so after some time the gas or vapour will begin to pass straight through the filter and into the wearer's respiratory system (Health and Safety Executive, 2013).

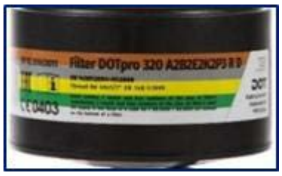
Gas/vapour filters are usually divided according to the type of substance they provide protection against. Filters are marked with a letter to indicate type of substance, and a number to indicate the filter's capacity, and comply with a standard colour coding system (Table 4) (Health and Safety Executive, 2013).

Caution: The capacity of a filter is assigned based on laboratory testing under well-controlled conditions. Therefore, this capacity may not always be an accurate indicator of the filters' performance under uncontrolled conditions in the field – where some substances may permeate the filter before the assigned capacity is reached.

RESPIRATOR FILTERS		
Colour Code	**Filter Type**	**Contaminants Protected Against**
	P	Particles
	A	Gases and vapours of organic compounds with boiling point > 65 ºC
	AX	Gases and vapours of organic compounds with boiling point < 65 ºC
	B	Inorganic gases and vapours, e.g. hydrogen cyanide, chlorine, etc.
	E	Sulphur dioxide, hydrogen chloride
	K	Ammonia and organic ammonia derivatives
	CO	Carbon monoxide
	Hg	Mercury vapour
	NO	Nitrous gases including nitrogen monoxide, nitrogen dioxide
	Reactor	Radioactive iodine including radioactive methyl iodide

Table 4: *Standard colour coding system for respirator filters*

- **Multi-gas filters** contain filters for more than one type of gas or vapour. The types of gas/vapour these filters protect against along with their capacity are marked as above (e.g. A1B2 filters protect against organic vapour with capacity class 1 and inorganic gases with capacity class 2). Multi-gas filters are heavier, and harder to breathe through in practice. These filters must be checked against the manufacturer's instructions on proper use and replacement intervals.

  NOTE: If performance against mixtures of gases is needed, it may be safer to consider using breathing apparatus.

- **Combined filters** are designed against both particles and specific gases or vapours. This type of filter will carry markings for particles and vapours, e.g. A2P3 filters protect against organic vapours with a filter capacity of class 2 and high efficiency for filtering out particles (Health and Safety Executive, 2013).

Respirator (filtering device)							
	Disposable half mask: particle filter	Reusable half mask: half mask particle filter	Reusable half mask: gas/ vapour filter	Full face mask, particle filters	Full face mask: gas/vapour filter	Powered (fan-assisted) masks	Powered (fan-assisted) hoods/helmets
							
Effective for particles	V	V	X	V	X	V*	V*
Effective for gas/vapour	X	X	V	X	V	V*	V*
APF4 types	V	V	X	V	X	X	X
APF10 types	V	V	V	V	X	V	V
APF20 types	V	V	X	X	V	V	V
APF40 types	X	X	X	V	X	V	V
Continuous wear time	Less than 1 hour	Less than 1 hour	Less than 1 hour	Less than 1 hour	Less than 1 hour	More than 1 hour	More than 1 hour

Table 5: *Summary of the most common filtering devices (respirators) (Health and Safety Executive, 2013) *Only protects against particle or gas/vapour when the appropriate filter is fitted.*

Appliance and Appliance Bay

Appliances and other vehicles can be contaminated both externally (during the fire incident) and internally (via contaminated PPE and equipment).

Manufacturers of emergency vehicle apparatus have been actively designing new and improved decontamination enhancements. Some of these features include:

- Inclusion of automated dispensing of disinfectant inside the cab, thus reducing emergency responders' exposure to harmful pathogens.
- HEPA air filtration systems (removing contaminated particles).
- Creation of non-SCBA seats to help prevent contamination from BA sets entering the cab.
- Seat surfaces that enhance a cleaner environment inside the cab (i.e. easy to wipe down).
- External compartments to store SCBAs on a pull-out locker for easier access and/or for the storage of fire kit with exterior access only.

Allowing the appliance or any other vehicle to idle in the appliance bay must be avoided (both when the appliance bay doors are still shut and/or appliance doors are opened)

NOTE*: this practice was observed when visiting UK FRS stations for indoor contaminant testing and in the FBU & UCLan National Firefighter survey.*

DECONTAMINATION

Decontamination is a process defined as:

"The removal of hazardous substances (bacteria, chemicals, radioactive materials) from employees' bodies, clothing, equipment, tools and/or sites to the extent necessary to prevent the occurrences of adverse health and/or environmental effects." (Business Dictionary, 2020).

The key phases of a decontamination procedure consider decontamination en-route to an incident, at a fire incident, en-route back to the fire station, and at the fire station itself. These phases exist in a cycle (Figure 20). Examples of good fire effluents decontamination practice can be found in the Appendix.

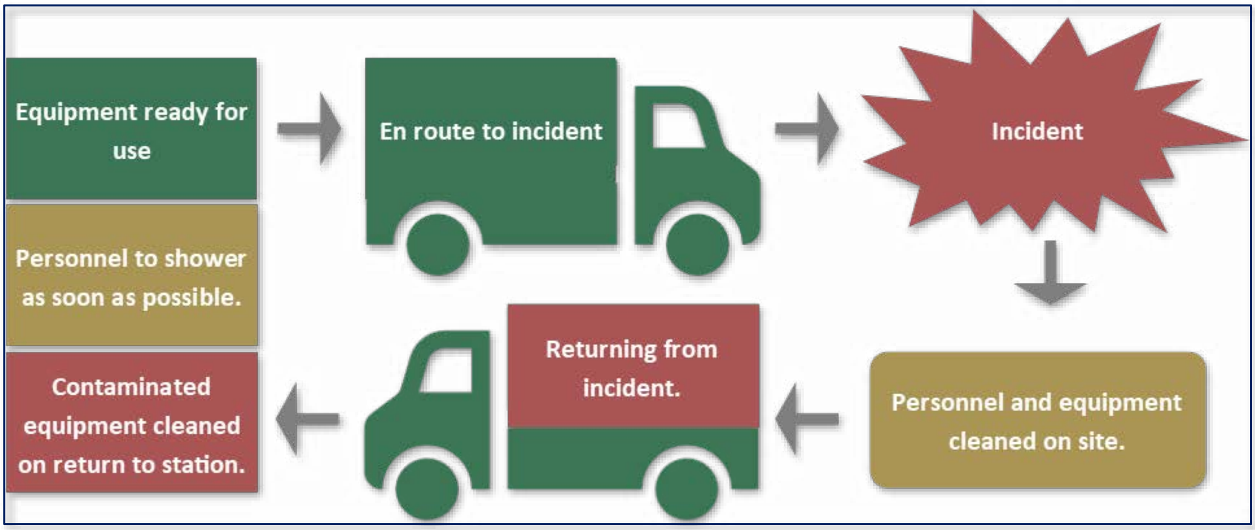


***Figure 20**: The decontamination cycle (adopted from Swedish Civil Contingencies Agency, 2015).*

FIRE INCIDENT: MINIMISING CONTAMINATION

It should be ensured that all FRS staff arriving at an incident have effective personal protective equipment and are adequately trained and briefed for the work they are to undertake within the cordon. At all stages of the decontamination procedure the Incident Commander must consider the safety of FRS personnel, the public, members of other emergency services and voluntary agencies attending incidents.

All Services should have procedures in place which detail how exposure to fire effluent and debris will be minimised en-route to, during and after incidents.

A decontamination procedure is a prescriptive set of steps which must be carefully planned and followed to ensure a thorough, safe and successful decontamination process. The specific steps of a decontamination procedure will vary according to the type of incident etc. However, the steps of a **generic** decontamination procedure should be **fully risk assessed** and should include:

1. **Pre-planning**; this step should ensure:
    - All required risk assessments are in place.
    - All operational crews are fully trained and familiar with decontamination guidance and are able to implement decontamination procedures.
    - Tools required for decontamination procedures are accessible following any fire incident.
    - Workplace facilities are prepared for further decontamination procedures once back from the incident.
    - A risk-assessed waste disposal procedure is in place for contaminated waste.
    - Decontamination procedures are available and accessible such that they may be read-out during the decontamination process or may be provided as e.g. a pictorial walkthrough of the decontamination and safe undress process.
    - Sufficient personnel to implement the plan.

2. **Briefing;** i.e. briefing personnel and firefighters e.g. on potential hazards and appropriate conduct of decontamination methods.
3. **Designating decontamination areas and zones**; identifying suitable locations in which to safely carry out decontamination procedures which minimise risk of re-contamination.
4. **PPE decontamination**; reducing or removing contamination from external surfaces or layers of PPE e.g. using dry and/or wet methods.
5. **De-robing**; safely removing external layers of personal protective equipment or chemical protective clothing.
6. **Checking for remaining contamination**; examining PPE for visible contamination, or contamination risks e.g. gaps or tears in the clothing etc.
7. **Personal decontamination**; washing hands, face and any other exposed areas of the body with soap and water, wipes etc.
8. **Dressing**; safe dressing and welfare considerations e.g. hydration, rest, food.
9. **Recording;** i.e. documenting any specific exposures, levels of exposure, exposure risks etc.
10. **Managing contaminated PPE;** safely storing and managing transport of PPE and equipment back to the fire station.
11. **Follow up;** conduct more thorough PPE and personal decontamination on return to the fire station e.g. laundering, showering etc.

Decontamination procedures should emphasise thoroughness, not speed.

Minimising Contamination at Fire Incidents

Poor and ineffective decontamination procedures can lead to unnecessary exposure to toxins. Listed below are some good general practice recommendations on arrival and at the fire incident scene which should be considered for incorporation into decontamination procedures:

En route

- Appliance windows, doors and air vents should be closed on approach to an incident.
- If possible, fire crews should be briefed on potential combustion products released in the fire (and types of materials involved in the fire) before arriving at the incident.

On-site

- Incident commanders and crew should position appliances at a safe distance away from the hazard ('hot') zone.
- Personnel should be positioned upwind of an incident, wherever possible.
- Contact with obviously contaminated areas should be limited where possible, avoiding areas that contain potentially hazardous materials.
- If possible, contaminated areas should not be knelt in or laid in unless immediate personal safety requirements makes this unavoidable
- Direct contact with the face/mouth should be avoided while on-site.
- The preferable method of consuming liquids is by means of a squeeze bottle with an attached drinking tube as used by athletes (limiting contact with face/mouth).
- Full personal protective equipment, including SCBA, should be worn **at all times** (including during fire and turning over). This is absolutely crucial for protecting firefighters against inhaling toxicants.

Full PPE and appropriate respiratory protection must be worn throughout the entire incident, including during salvage and turning over.

- PPE should fit well, and should ideally have been fitted for the individual wearer by the provider. There should be adequate overlap between all garments, ensuring that no part of the body is exposed.
- Respiratory protection should be worn in line with the manufacturer's instructions and in accordance with local risk assessments – it should fit well and, where appropriate, form an airtight seal around the wearer's nose and mouth.

- Clothing and PPE should be correctly fitting, correctly worn and clean, to reduce the potential for dermal exposure from previously soiled garments. This includes tunics, leggings, fire hoods, gloves and base layer.
- A filter mask should be easily and quickly available for sudden emergencies.
- Gloves should be worn when making up the hose/equipment.
- Moisture wicking undergarments should be worn beneath PPE. This will help ensure the wearer does not overheat, and will help reduce dermal absorption of toxicants.
- Cotton liner gloves worn under fire gloves may help to reduce exposure to debris, as well as reducing irritation due to sweating or heat.

NOTE: Reducing exposure to fire debris and effluent should be considered important, but should not be done at the detriment of thermal protection or adequate hydration. Fatigue should not come as a result of decontamination. Rather, decontamination should be worked into the standard routines at the fireground, and should be accounted for when evaluating rest periods.

RETURN TO THE WORKPLACE FROM FIRE INCIDENTS

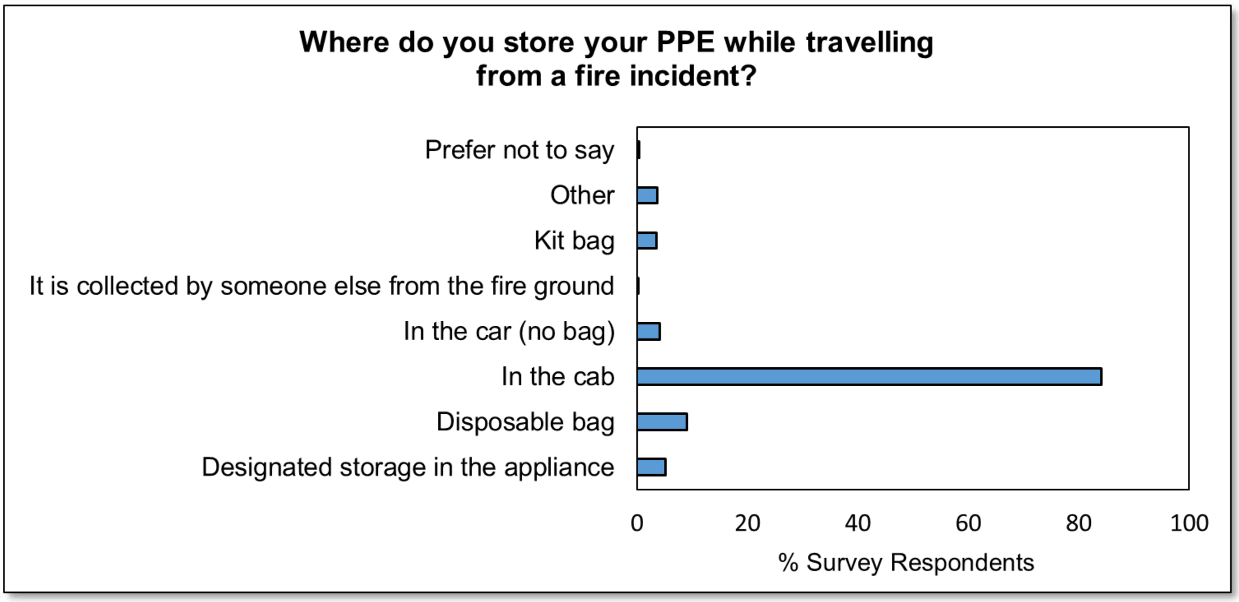


Figure 21: *% of Respondents to the FBU & UCLan National Firefighter survey who indicated that the most prevalent current practice is to store PPE in the cab of a vehicle or appliance.*

- Contaminated PPE and equipment should be cleaned on site wherever possible, ***prior* to transportation** while using respiratory protective equipment**.** If this is not possible, all PPE (such as tunic, leggings, helmet, gloves) should be bagged at the scene (in bags of at least 6 mm thickness which are then twisted and taped/knotted shut to minimize secondary exposure to any contaminants gassing off). All bags should be secured outside of the fire appliance cab in a locker.

- Soiled PPE should be stored should be placed into appropriate containers/bags to prevent cross-contamination. Water-soluble bags (approved for use in the laundry process) or other similar bags should be used for this purpose. If PPE is wet, the water-soluble bag should be placed into another container/bag to prevent cross contamination in the event that the water-soluble bag starts to dissolve.

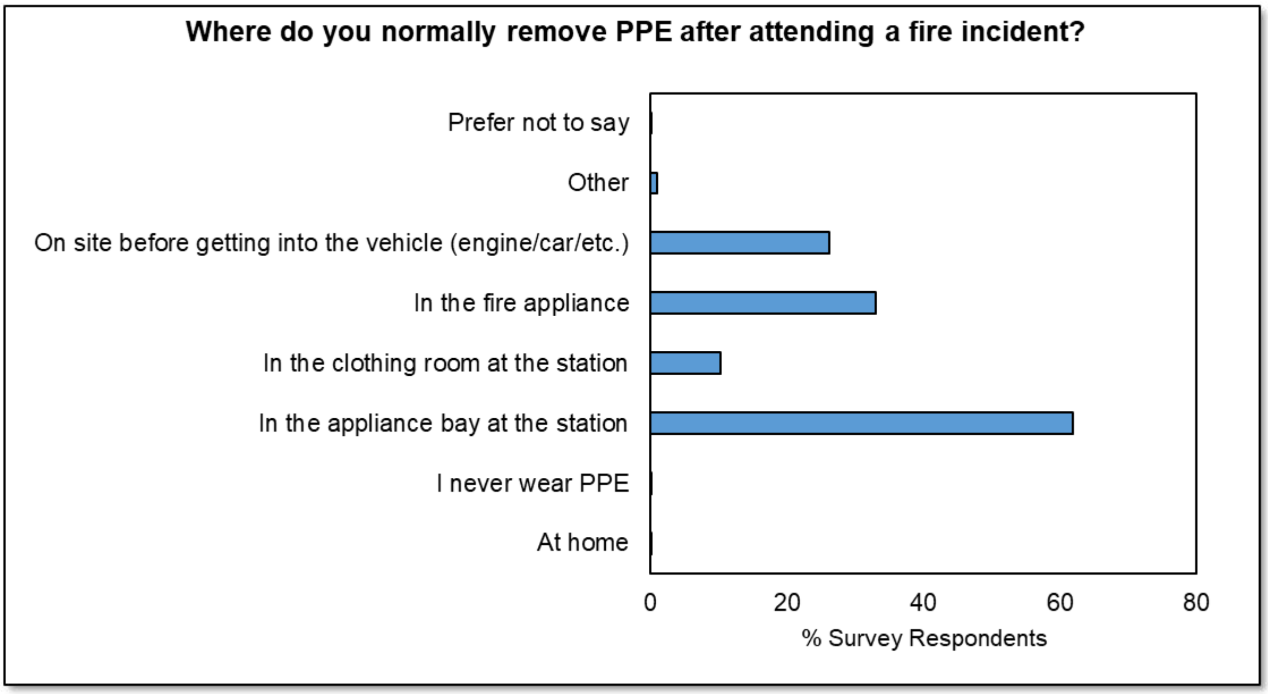


Figure 22: *% of Respondents to the FBU & UCLan National Firefighter Survey indicating that the most prevalent practice is to remove PPE at some point after re-entering the appliance. Participants were able to choose more than one answer to this question.*

- Soiled BA kits and any other equipment (such as thermal imaging cameras, radios etc.) **should not be stored** in the appliance or vehicle cab. If they must be stored in the cab they should be cleaned prior to transportation (according to manufacturer's recommendations).

It is strongly advised that FRSs encourage all operational personnel to record and monitor their attendance at fire incidents over the course of their career.

- Contaminated hose should be placed in an airtight storage device in the same way as fire kit and respiratory protection in order to reduce the amount of volatile effluents and particles spread during transportation and handling.

- It is a common practice to clean the exterior of a helmet to remove any heavy particulate. However, when cleaning the interior, care must be taken not to saturate any fabric, including the liners. Interiors can be wiped down with wipes. They may be washed with soapy water only according to manufacturer's instructions.

- Boots often have deep tread soles which trap dirt and waste from the fire ground. A boot which is not decontaminated therefore functions as an effective spreader of contamination.

- All personnel should wash their hands, head, neck, jaw, throat, face, and any other exposed skin areas as deemed necessary with soap and water. Where this is not practical, wipes should be provided as a minimum. This should not be considered a substitute for a thorough shower (within an hour) on return to the station.

- All personnel should have a clean, dry change of clothes which is taken to every incident. Personnel should change into clean clothes **before re-entering the appliance** (Figure 22). This avoids a rapid decrease in body temperature and reduces skin exposure to contaminants through sweat and water that dries on the workwear. If this is not possible or suitable, undergarments should be changed as soon as possible on return to the station.

Wipes may be effective, but do not replace a shower.

"Shower within an hour" when returning to the station from an incident, or a live fire training exercise.

FIRE STATION: CONTAMINATION CONTROL

Recent research findings show that debris and contamination from fire is transferred back to fire stations, resulting in continual exposure of firefighters to potentially harmful toxicants (see Section "Additional considerations for FRS personnel responding in their personal or FRS provided vehicles vehicles" for consideration of exposure to contaminants away from the fire station). In fire stations, higher concentration levels of carcinogens, such as PAHs, phosphorous flame retardants and polybrominated diphenyl ethers (PBDEs, organobromine compounds that are used as flame retardant) in air, debris and dust samples were identified when compared to workplaces not associated with fire. They were particularly found in more soiled areas of stations, with "dirty" areas such as BA rooms and PPE storage areas. One study has identified PAHs in kitchens and appliance bays in stations (Baxter et al., 2014, Shen et al., 2015, Shen et al., 2018).

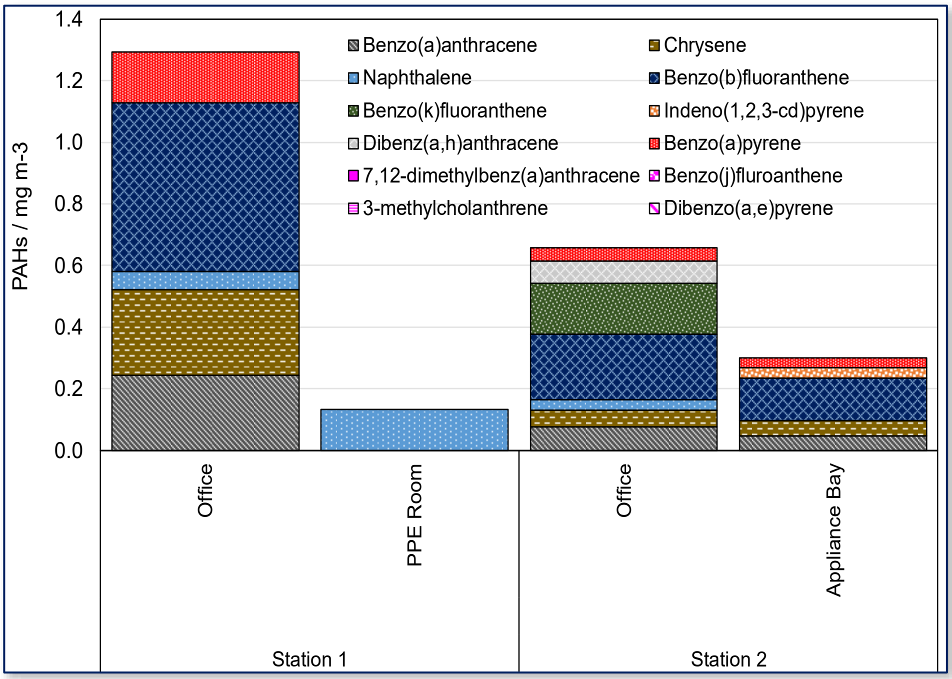


***Figure 23**: Concentrations of toxic PAHs collected from two stations showing contamination in the general use offices, PPE storage room (with internal ventilation) and appliance bay (Stec et al., 2018).*

Designated Zones

It is important to control the spread of harmful substances on return to the fire station, prior to further decontamination and repair. This can be achieved by the designation of “contamination zones” at the fire station, similar to the designation of decontamination zones at the fire incident (Table 6).

	Hazard level	Locations	Function
Red zone	**Dirty area**	Appliance bay Appliance washdown Operational washdown Workshop Operational equipment store Compressor room Dirty kit collection Briefing/debrief room	These are primarily operational areas. Ideally, there should be a decontamination at source policy, but the red area has a medium risk of cross contamination or exposure to carcinogens. If leaving a red area, staff should not be able to enter a green area without passing through a transitional zone (amber) with the opportunity to wash and change clothes.
Amber zone	**Transitional area**	WC/showers Lockers Laundry In-use kit room Drying room / cabinet BA servicing / wash area General equipment store Cleaners’ store	A transitional space between red zones and green areas where firefighters and staff can clean and remove contamination. The risk of exposure to contamination or carcinogens is low. Firefighting kit can be worn in this area if suitably clean.
Green zone	**Clean area**	Public entrance Reception Community room Public WC Personnel main entrance Meeting rooms and offices Quiet rooms / prayer rooms Briefing / training room Recreational rooms Mess area / kitchens Bedrooms / Dormitories Gym IT Comms rooms	Clean areas within a station where food is prepared or consumed and clean only tasks are carried out. I.e. office tasks. No firefighting kit is to be worn and there should be no risk of exposure to contamination from carcinogens.

***Table 6**: Designation of contamination zones within the Fire Station. Designating contamination zones will depend on the layout and needs of the individual station. Where it is impossible to separate red and green zones by a transitional amber zone (e.g. due to station layout) a risk assessment and guidance must assess how contamination will be managed in those areas.*

The following should be considered and accounted for when designating contamination areas within the fire station:

- How contaminated clothing and equipment is moved or transported within the workplace should be looked at in detail.
- Every effort must be made to ensure clean areas (areas where personnel spend time when not responding to an incidient) are kept free of any contaminated clothing or equipment.
- It should be clear to personnel which designated zone they are in, e.g. clean or dirty, through the use of signage, or colour-coded feature walls, floor markings etc.
- Any area where PPE or equipment must be taken, such as PPE rooms and BA servicing areas, must be clearly marked, and kept clean.
- The amount of spent time in enclosed "dirty" areas of the station, such as PPE storage spaces and BA cleaning rooms, must be kept to a minimum.
- The layout of the station should permit safe and efficient movement when responding to a call-out, but must discourage the movement of staff from clean to dirty areas without first passing through a transitional (amber) area.
- Direct and un-obstructed paths of travel into the Appliance Bay must be achievable under emergency response conditions. This ensures response times can be kept to a minimum.
- All personnel should receive training on the contamination zones, and the rationale for their designation.

PPE, drills and operational equipment must be prohibited in "clean" areas (e.g. sleeping areas, lecture rooms etc.), and only allowed within designated "dirty" areas (e.g. appliance bay etc.).

- Existing stock of buildings should be reviewed to maximise the principle of red, amber, green zones.

- Newly designed stations and other FRS buildings should ensure there is only one way for contaminated clothing or equipment to enter the building. They should be planned with "red-amber-green" layout, whereby any entrace place is deemed contaminated, intermediate zones where cleaning occurs denoted as "amber", and every other area of the station, including all offices, dormitories, mess areas, recreational spaces and training rooms, be kept free of soiled PPE or equipment at all times.

Personal Decontamination

Key notes from UK FRS submitted documents:

Only 22% FRS in the UK provided information regarding personal washing and decontamination following an incident (mostly as FBU guidance displayed on posters).

Personal decontamination should be the top priority upon returning to the fire station from fire incidents.

- Having showers at the fire station is **essential**.
- Adequate shower facilities must be available to all responders, regardless of their gender identity.
- A **"FIRST IN, FIRST OUT"** system should be used if showering facilities are limited, whereby firefighters that have been exposed the longest, in the worst conditions, should clean up and remove the highest amount of accumulated toxins first.

"Shower within an hour" when returning to the station from an incident, or a live fire training exercise.

Contamination Control at the Fire Station

Chief fire officers must enforce PPE/clothing decontamination procedures and ensure all personnel are fully trained and follow the rules (Figure 25).

- Each station should have a cleaning schedule in place to ensure there is no build-up of contaminants in the working environment (on surfaces etc.), and to ensure that PPE/clothing is regularly cleaned.
- PPE must be kept only within allocated PPE storage areas.
- Any area into which PPE or equipment must be taken, such as appliance bays, PPE rooms should be clearly marked, and kept as clean as reasonably possible. BA servicing areas must be kept in a sterile condition.

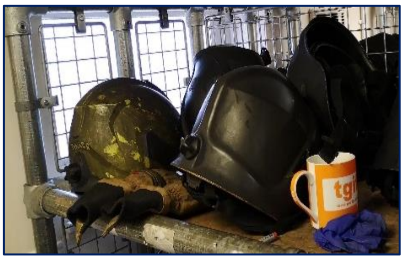


***Figure 24**: An example of bad practice – where a mug is left in the vicinity of heavily contaminated PPE.*

- Each station should provide or make arrangements to wash base layer garments (clothing worn by firefighters under their PPE) that have been worn to a fire incident.

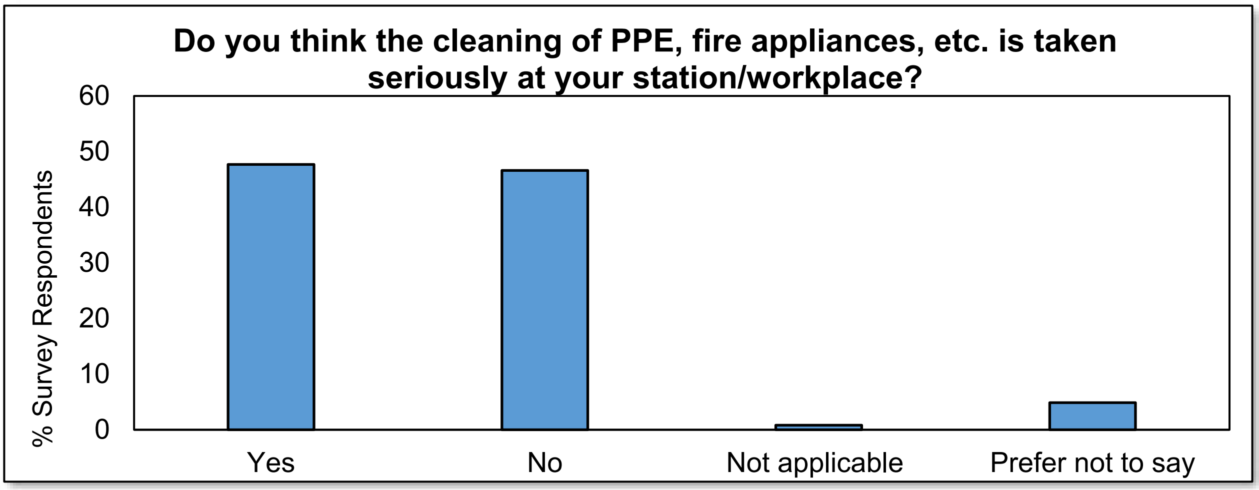


***Figure 25**: The high prevalence of "no" answers to this question in the FBU & UCLan National Firefighter Survey indicates that decontamination procedures need to be more seriously enforced.*

- Drying rooms should be clearly identified as only being suitable for PPE, or only being suitable for non-PPE items such as personal clothing, bedding, towels, etc. – and not suitable for both. The separation of personal items and PPE items is vital for preventing cross contamination.

- Any airtight containers used for transportation of contaminated PPE should be thoroughly cleaned before being reused to prevent a build-up of potential contaminants and potential cross contamination.

Figure 26: *An example of poor drying room set-up.*

- If possible, air quality should be actively monitored – especially where it is impossible for personnel to avoid spending extended periods of time in enclosed "dirty" spaces e.g. BA workshops, facilities without proper ventilation etc.

Decontaminating PPE and Clothing

Below is a list of general considerations for the decontamination of PPE/clothing at the fire station. It is important that every Service puts in place a procedure for sending PPE away for professional cleaning:

- All articles of clothing and/or equipment that were exposed to contaminants should be properly cleaned as specified in BS 8617 (British Standards Institution, 2019).

- Thorough, routine cleaning should include the cleaning of PPE interiors- thus, until the interior of PPE has also been cleaned and dried, the gear should be considered out of service.

- Slightly contaminated PPE e.g. with a slight smell of smoke but with no visible soiling, should hung in a well ventilated area away from clean PPE e.g. an outdoor covered area, or well-ventilated outhouse.

- Following fire incidents, cleaned PPE ensembles should be hung on racks to reduce drying times and to allow for continued gassing-off. Fans may facilitate this process.

Gloves and respiratory protection is recommended during decontamination of soiled PPE/clothing.

On-Site and Professional PPE Cleaning

It is important to protect skin and airways when cleaning soiled PPE/equipment.

This requires appropriate respiratory protection (e.g. dust masks) and gloves.

Wearers may be required to undertake the routine cleaning (general brush, rinse or dry) of their issued firefighters' PPE. Where possible, and where contamination type and levels allow, routine cleaning should be undertaken or begin at the emergency scene, as specified in BS 8617 (British Standards Institution, 2019). Where this is not possible, routine cleaning should be undertaken immediately in an appropriately designated area on return to the station. It is recommended that more advanced cleaning is carried out by an authorised FRS laundry services provider.

- Following fire incidents, PPE which is visibly and heavily soiled with fire debris, or has a strong smell of smoke, should be placed for collection by the professional laundry service. This PPE should be stored outside wherever possible, or at the very least in a well-ventilated area well away from workplaces or recreational areas. Outdoor, lockable "grit bins" are ideal for this purpose (Figure 27).

Figure 27: *PPE awaiting collection by professional laundry services should be stored outdoors or in a well-ventilated area, e.g. a lockable grit bin.*

- A log book should be kept by the individual, Service, and/or laundering provider which detailsthe number of professional washes the PPE has undergone, as well as any repairs and reapplication of treatments.

Improper cleaning or laundering can destroy clothing or worsen its protective performance.

Studies show that the tear resistance and seam strength decrease with application of laundering and that decontamination efficiency markedly varies.
(House & Squire, 2004; Keir et al., 2020; Mayer et al., 2019; Stull et al., 1996)

Gloves

- Soiled gloves should be sent for professional cleaning by the service provider along with tunics and leggings. Where Services have gloves that cannot be thoroughly cleaned, they should consider replacing them with gloves that can be cleaned.
- Gloves that are free of soiling or the smell of smoke may be stored in a designated kit bag away from sources of contamination.

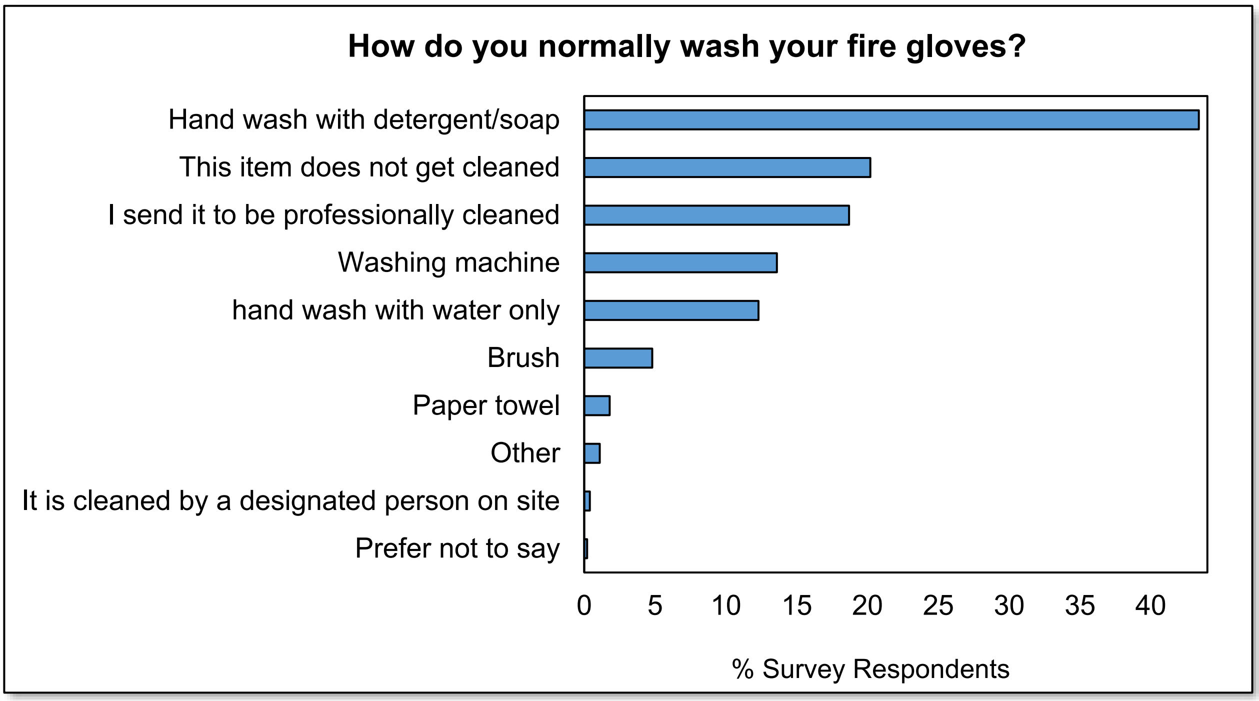


***Figure 28**: % of Respondents to the FBU & UCLan National Firefighter Survey who provided details on how they washed their gloves. **NOTE**: Respondents could choose more than one answer to the survey questions, thus totals will exceed 100%.*

- Gloves should **not** be stored inside helmets, boots, pockets or other enclosed parts of PPE. They should be clipped onto the outside of tunics or trousers, where clips or velcro attachements exist (Figure 29). Alternatively, in-use gloves should be stored in a well ventilated space. Designated shelving, hooks or clips in the PPE storage area specifically for gloves is also appropriate (provided both gloves and storage areas are cleaned on a regular basis).

Figure 29: *Gloves should be a stored in a well-ventilated area, and **not** in any enclosed areas of PPE. Instead, gloves should be stored on external clips of tunics or on designated shelving/hooks.*

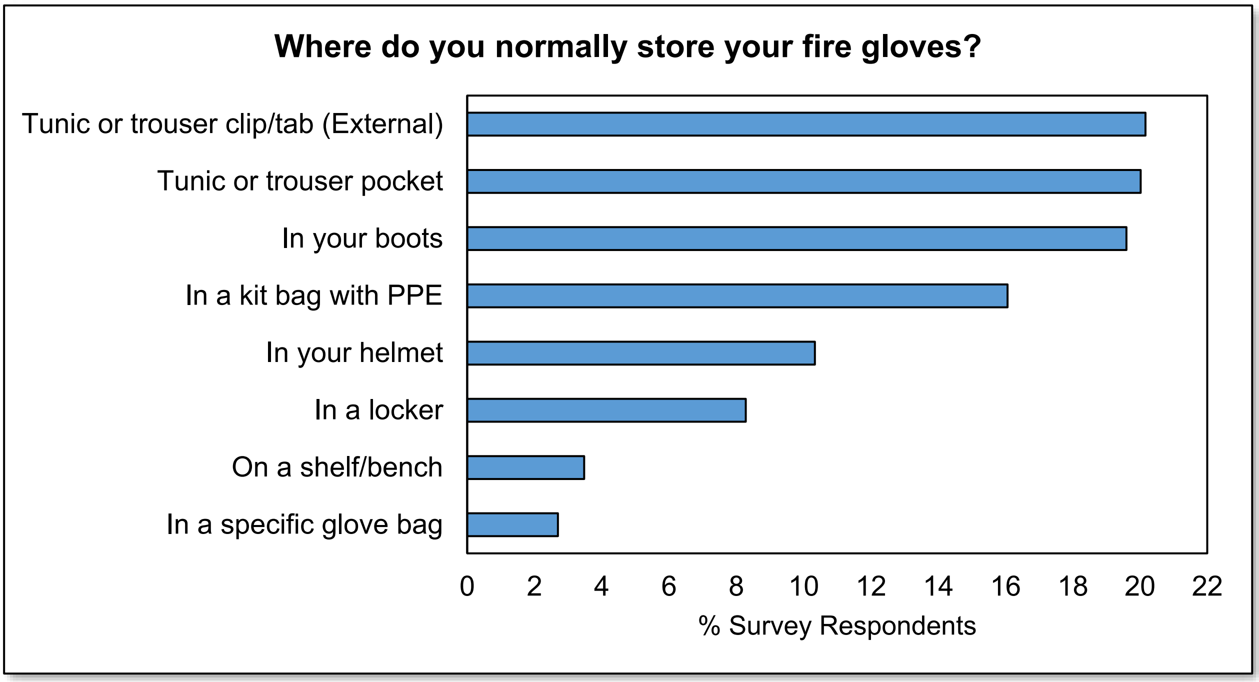


Figure 30: *% of Respondents to the FBU & UCLan National Firefighter Survey who indicated where they stored their fire gloves. Storing fire gloves in enclosed areas of PPE appears relatively prevalent in common practice. **NOTE**: Respondents could choose more than one storage location in answer to the survey question, thus totals will exceed 100%.*

Fire Hood

- Fire Hoods should not be dried without first washing them.
- Contaminated fire hoods should not be stored with any other clothing.
- Fire hoods **should not be taken home** and should **not be washed at home** as they will cross-contaminate other clothing.

NOTE: A second PPE set, particularly a second fire hood, is important for ensuing that firefighters do not have to wear contaminated clothing after firefighting. A second set of PPE provides firefighters with clean PPE to wear while the contaminated set is still being washed and dried or sent for professional cleaning.

Breathing Apparatus

Whether or not a firefighter will attend post-fire incidents without BA has been crossed tabulated, from the national survey, with their role, and with training. Those who reported attending fewer than 1-2 fires per month have been excluded from the analysis. From the bar graph, it can be seen that as the seniority of role increases, the likelihood of attending post-fire incidents without BA decreases. Additionally, whole-time firefighters report being significantly more likely to attend post-fire without BA than RDS firefighters. There is no significant difference in attending post-fire without BA between men and women, or based on ethnicity.

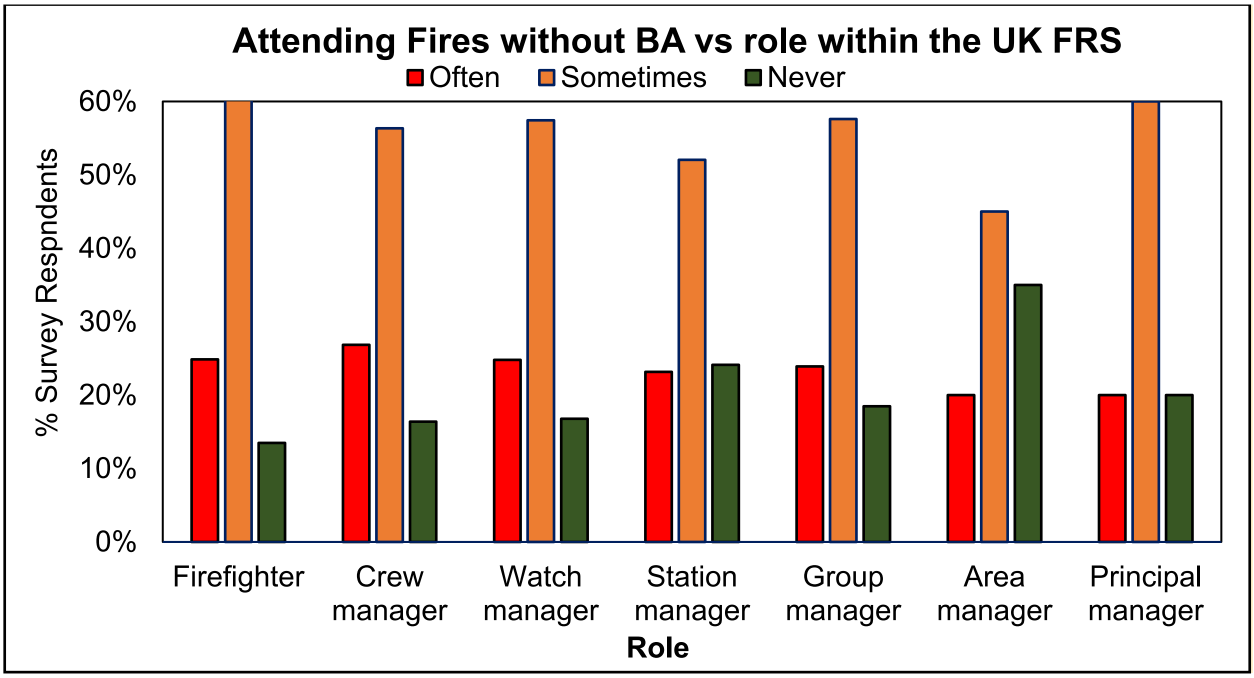


***Figure 31**: % of Respondents to the FBU & UCLan National Firefighter Survey on attending fires without BA*

- An area of the station should be designated for the cleaning of BA sets.
- BA sets and facemasks should be cleaned according to the manufacturer's instructions with an appropriate cleaning agent or soap and water, **after every use** at a fire incident. Appropriate PPE should be worn when cleaning BA sets.
- BA sets prepped for use on call-outs should not have a noticeable smell, or visible soiling.

Figure 32: *BA mask filters after and before the cleaning*

PPE Records

As a minimum, the following records should be kept for each item of firefighters' PPE:

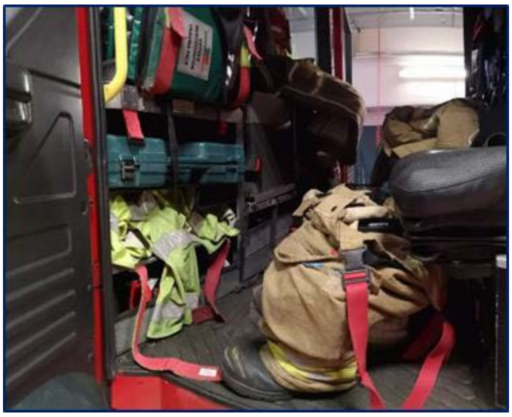
- person(s) to whom the item has been issued
- date and condition when issued
- manufacturer and model name or design
- manufacturer's identification number, lot number, or serial number
- month and year of manufacture
- date(s) and findings of advanced inspection(s)
- date of specialist/advanced cleaning
- date(s) of repair(s), who performed the repair(s), brief description of repair(s) and batch number of repair materials

NOTE: *It might be appropriate to include a picture of the repair*

- date of PPE retirement
- date and method of disposal of PPE

Appliances and Appliance Bays: Contamination Control

- Disposable gloves should be used whenever handling soiled equipment.
- Any vehicle driven through a contaminated area must be washed down, including the undercarriage, chassis, and cab. Ideally, this must be done in fresh air.
- Soiled hoses (having large quantities of the fire incident debris, dust, soot, particles and contaminants which may become partially airborne) should be soaked in water until washed and cleaned thoughroughly. Gloves and respiratory protection, and possibly fire full gear should be worn to prevent any skin contact with contaminants.



- Appliance cab air/pollen filters must be inspected regularly and replaced if any visible contaminant is present.
- Ideally, no potentially contaminated equipment should be stored or transported in the appliance cab.
- No equipment with a designated use for interior firefighting should be housed, bracketed, stored or otherwise kept in the passenger compartment of any response vehicle.

Lockers and equipment e.g. hoses, hand tools, thermal imaging cameras, power tools, piercing nozzles, branch pipes, crowbars, Halligan tools, lines, spades etc. should be cleaned at the incident before further washing/wiping down with disposable cloths, wipes or water spray as appropriate back at the workplace.

- All equipment, including SCBA sets and cylinders, tools, radio straps, and appliance cab etc. should be thoroughly cleaned using wipes, water or any available cleaner, according to the manufacturer's recommendations. Soft bristle scrub brushes can be also used to assist decontamination.

- Appliance bay doors should be opened **prior** to starting the engine, or an exhaust system should be used to facilitate the removal of deisel exhaust fumes.

- The appliance bay should be well ventilated, ideally with bay doors kept open, especially on return from a fire incident. Appliances should also be well ventilated on return from a fire incident e.g. by leaving windows and doors open.

To reduce secondary exposures, appliance cabs and tools should be cleaned and decontaminated on a regular basis, especially after incidents where exposure to any combustion products occurred.

BA WORKSHOPS: CONTAMINATION CONTROL

- BA workshops should be well ventilated with open windows or doors, or have an air filtration system fitted.
- If particulate matter is frequently generated intentionally for training purposes, then monitoring should be in place to assess exposure of BA technicians to those contaminants.
- Surfaces and workspaces should be kept clean from dust and soot, by cleaning with warm soapy water.
- BA sets should be clean of visible soiling and the smell of smoke **before** they are returned to BA workshops.
- Where BA sets cannot be cleaned before being sent to workshops they should be sent in an airtight container (Figure 33). On receipt at workshops, but before assessment by BA workshop personnel, BA sets should be allowed to ventilate outdoors, or in a well-ventilated space away from personnel working spaces, until all smell of smoke has completely dissipated.
- If BA sets have been returned to BA workshops in a soiled condition they should be washed according to manufacturer instructions at the workshop, before maintenance work is carried out.
- Disposable gloves should be used when handling BA sets which are visibly soiled or have a smell of smoke.
- Respiratory protection, such as particulate masks, should be available if there are heavily soiled BA sets, and there is the potential for debris, such as soot, to become airborne during the maintenance work.

***Figure 33**: BA airtight container*

- After handling soiled sets, personnel should wash their hands and any other exposed area of skin using soap and water.
- BA workshops should consider the use of Contamination Zones (see “Contamination Zones” Section), whereby contamination is managed through restricting the areas within a location in which potentially contaminated items can travel, be stored/worn and/or be decontaminated.

TRAINING CENTRES: CONTAMINATION CONTROL

- Live fire training should only involve the burning of clean plywood or untreated and fire-retardant free OSB.
- Training centres should designate Contamination Zones according to the level of risk from contamination.
- Where there is the potential for fire effluent to be blown into office spaces, or other “clean” areas, there should be adequate ventillation or air filtration measures to keep exposure as low as reasonably possible as well as routine testing to monitor contamination levels.
- Where it is not possible to stop all fire effluent from being blown into the building due to the design of the building, all the doors and windows should be shut during training, and the workplace should be routinely monitored for at least VOCs and particulates.

- There should be provisions at each training facility to wash base layers that have been worn to a fire incident.

Instructors and Trainees

- Training instructors and trainees should wear adequate respiratory protection whenever there is the potential for exposure to effluents. If the instructor needs to brief students about the behaviour of the burn, this must be done in fresh, clean air.
- Training instructors and trainees should stand upwind of the burn if they are not wearing respiratory protection.
- Time and facilities must be provided and built into training programmes for training instructors and trainees to have a shower as soon as possible after exposure to fire effluents or debris. This may be immediately after a burn, or at the end of the training session.
- Skin and airways must be protected during cleaning of soiled PPE and equipment, e.g. by using dust masks and disposable gloves.
- Hands and face and any other exposed skin should also be cleaned after carrying out any cleaning of soiled PPE or equipment.
- Adequate respiratory protection and clothing must be provided to any personnel who are involved with cleaning buildings or containers where burns take place.

PPE and equipment

Soiled clothing, including undergarments with a smell of smoke, must not be taken home until they have been washed.

- Training instructors should have an adequate number of changes of PPE such that they do not wear soiled garments. This should include tunics, leggings, fire hoods and gloves.

- Lightly contaminated PPE, such as that with a slight smell of smoke but no visible soiling, should be allowed to hang in a well ventilated area, such as an outdoor covered area, or well-ventilated outhouse.

- PPE which is visibly soiled with fire debris, or has a strong smell of smoke, should be placed for collection by a professional laundry service.

- Soiled PPE which is awaiting collection by a laundry service should be stored outside wherever possible, or at the very least in a well-ventilated area which is well away from workplaces or recreational areas. Outdoor, lockable "grit bins" are ideal for this purpose.

***Figure 34**: BA sets and masks should be cleaned after each wear according to the manufacturer's instructions*

- BA sets and face masks should be cleaned thouroughly, according to the manufacturers instructions, every time they are used (Figure 34).

Training facilities use many more respiratory protection devices compared to FRSs. To facilitate quick and thorough decontamination of compressed air breathing apparatus and other PPE thoroughly, it may be more efficient to use a purpose-built machines (see "Respiratory Protection" section).

ADDITIONAL CONSIDERATIONS FOR FRS PERSONNEL RESPONDING IN THEIR PERSONAL OR FRS PROVIDED VEHICLES

Fire investigators must never be permitted to enter post fire incidents without the proper PPE and SCBA.

- At all incidents post fire, fire investigators must wear appropriate PPE and RPE.
- Where fire gloves are not required, heavy gauge nitrile gloves should be worn to reduce dermal contact with contaminants.
- Disposable paper suits may reduce the amount of soiling on PPE or clothing, reducing laundering requirements.
- Disposable overshoes may reduce the amount of soiling on boots, reducing the possibility of contamination being transported into the car, workplace or home.
- Clothing or PPE becoming soiled, or having a smell of smoke, should be removed at the incident and changed for a clean set of clothes.
- Soiled clothing or PPE must not be transported in cars (or personally owned vehicles), it should be bagged or stored in an airtight container thus keeping the PPE gassing-off away from passengers (Figure 35).
- Fire investigators should wash their hands and any other exposed area of skin as soon as possible after contact with fire debris. There should be washing facilities on site. Wipes should be provided as a minimum.
- After exposure to fire debris or fire effluent, fire investigators must return to a FRS venue with showering facilities to have a shower as soon as is reasonably possible (this will allow them to remove contamination as well as stop spreading toxic chemicals in their vehicle and home, potentially exposing family members).

***Figure 35**: PPE with visible soiling, or the smell of smoke, should be bagged or stored in an airtight container.*

- Soiled clothing or PPE should be sent to for professional cleaning by the Service provider. Soiled clothing, including undergarments with a smell of smoke, should not be taken home until they have been washed.

Fire investigators and RDS firefighters must be able to shower prior to leaving the workplace so that they do not carry contaminants home.

HEALTH SCREENING

Many firefighters begin work at a young age and typically remain in the profession their entire working lives, until retirement. This means that there is plenty of opportunity and time for them to be exposed to large quantities of harmful and toxic substances.

- Health screening should be provided to any staff who have or have previously had regular exposure to fire effluent.
- Getting an annual health screening and evaluation is essential, as early detection is the key to survival.
- Regular lung function screening should be provided for personnel who are regularly exposed to smoke, such as training instructors or personnel working within live fire training facilities.
- Training on the potential long-term health effects of exposure to fire debris and fire effluent should also be provided to all personnel on a regular basis.
- It is important that firefighters get an annual physical and make sure their healthcare provider is informed of their increased cancer risks.

EARLY DETECTION SAVES LIVES

“***Screening increases the chances of detecting certain cancers early, when they are most likely to be curable***”

(World Health Organization, 2020).

Keeping Records

Documentation of exposures at all incidents has become a priority in the fight against occupational cancer. Tracking exposures can help firefighters better understand their risks, more effectively communicate these risks to their healthcare provider.

Therefore, it is crucial to keep detailed records of every fire incident attended and of any other relevant exposures. Recording exposures as soon after the event as possible will help to preserve details of the exposure which might otherwise fade with memory. It may also be beneficial to share such records with the occupational health department, such that a proper health screening and check-up can be organised for personnel on an annual basis.

Documentation should cover only the role undertaken during the incident. Incident Commanders and other fire personnel will be exposed to differing levels of fire effluent throughout an incident. Key points which should be recorded are listed for consideration below, along with an example of a template which might be used to record this information:

- **Annual health screening and check-up information**; to ensure that a firefighter is in good health and able to perform the essential functions of the job. This information also provides a baseline for correlating any health diagnoses with exposure history, and allows early identification of any potential health issues.
- **Role and incident-specific exposures**; It is vital that firefighters record details about a fire incident, but also all role-specific actions at the incident which might influence the type and level of exposure. This should include:
    - date, type and length of the fire incident,
    - incident number of the incident recorded by FRS,
    - if possible, types of products involved in the fire,
    - actions undertaken at the incident (including approximate duration/s) during the fire and during turning over,
    - the type and length of potential exposure (dermal, inhalation etc.),
    - evidence of contamination (hands, face, neck etc.),
    - actions taken for personal decontamination and level of decontamination achieved.

- **PPE maintenance, training and/or fitting information**; e.g. use of correct donning and doffing procedures, proper care for PPE etc. This information will ensure that a firefighter is well-equipped with properly fitted PPE and that the PPE is in good condition as per the manufacturer's specifications. It is important to record the type, age and number of on-site and/or professional washes for all PPE.

- **Health symptoms**; if any health symptoms arise at any point (cough, dry mouth, loss of sense of smell, soot in the nose, etc.), symptoms and length of time the symptoms persisted must also be recorded, and checked by a health care provider.

Documentation can be seen as a chore, but it should be valued as a tool to better the workplace and working conditions.

Example: A USA Occupational Exposure Tracking Form

A UK version is currently being developed.

Occupational Exposure Tracking Form

Incident Information

Date: _____________ Time: _______________ Incident #: _____________________

Location: _______________________________

Incident Type *(Description of this incident)*

☐ Structure Fire ☐ Heavy Rescue ☐ Standby

☐ Car Fire ☐ EMS Incident

☐ Hazmat ☐ Investigation

☐ Other ____

Personal Protection Equipment *(List of PPE used during this incident)*

☐ Helmet ☐ SCBA ☐ Suppression Boots ☐ Station Uniform

☐ Suppression/Work Gloves ☐ Station Boots ☐ Fire Hood ☐ Safety Glasses

☐ Other ____

Operational Role *(List of roles assumed during this incident)*

☐ Interior Fire Operations ☐ Interior Investigations/Monitoring

☐ Exterior Fire Operations ☐ Driver/Pumper Operations

☐ Overhaul ☐ Standby

☐ Other ____

Possible Exposures *(List of potential hazardous materials encountered during this incident)*

☐ Products of Combustion ☐ Hazardous Materials ☐ Airborne Dust ☐ Construction Debris ☐ Diesel Exhaust

☐ Other _____________________________________

Signs/Symptoms *(List of signs or symptoms experienced during or after this incident)*

☐ Cough ☐ Head Ache ☐ Nausea

☐ Wheeze ☐ Chest Pain ☐ Vomiting

☐ Sore Throat ☐ Dizziness ☐ None

Other _________________

Notes: ____

PREGNANCY, MATERNITY AND FERTILITY

The job of firefighting presents many potential hazards to healthy reproduction. It poses physical hazards such as drastic temperature variations, extreme and unpredictable physical exertions and demands, psychological stress etc. Firefighters may also be exposed to biological or radiation hazards as well as many toxic and persistent contaminants released from fires (Mcdiarmid et al., 1991).

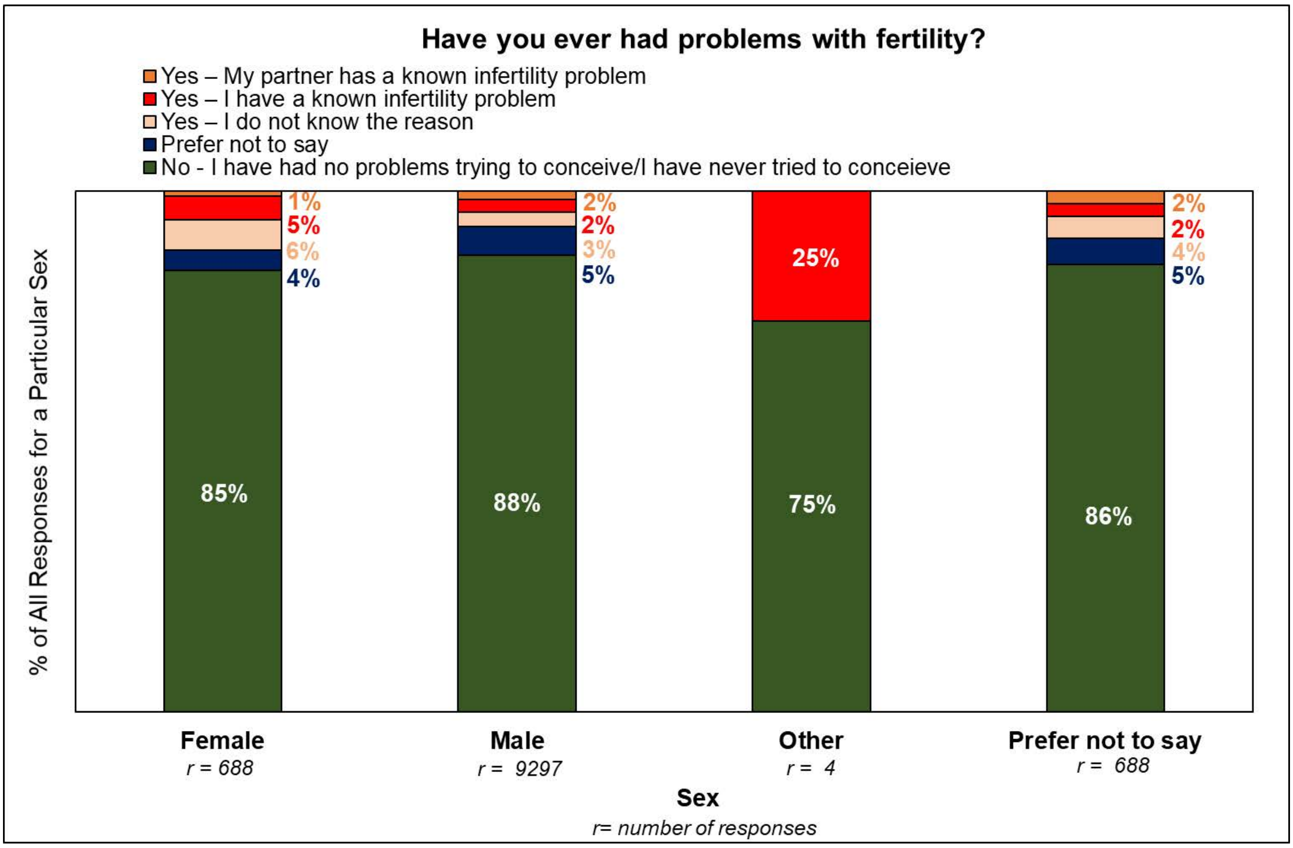


Figure 36: *% of Respondents to the FBU & UCLan National Firefighter survey who indicated whether they had suffered problems with fertility, grouped by sex.*

Results from one study showed that nearly a quarter (25%) of studied US female firefighters' first pregnancies ended in miscarriage (compared to 10% in the general US population). Rates of pre-term deliveries were also reported to be high among this population.

(Jahnke et al., 2018)

Exposure to contaminants during pregnancy can be harmful not only to mothers, but also to the developing foetus. The foetus is more sensitive to much lower doses of contaminants than an adult (Scheuplein et al., 2002). Contaminants which are inhaled, ingested or dermally absorbed by the mother can enter the blood stream and expose the developing foetus through the umbilical cord (Mitro et al., 2015). There may also be more indirect harmful effects to the foetus, for example by disrupting hormones in the mother's body which are important for maintaining a healthy fetal environment (Mitro et al., 2015).

Real risks to foetuses from hazardous exposure occurs mostly in the first trimester. For example, high heat exposure leads to elevated core body temperature which is known to be a serious risk factor for neural tube disorders in foetuses, such as spina bifida.

It is therefore important that every action is taken to protect pregnant firefighters from exposure to contaminants and physical stresses. The following must be considered for protecting the health of pregnant firefighters and their unborn children:

- Fully risk assessed procedures should be devised for the protection of pregnant firefighters. All relevant staff should be fully aware of, and trained in, implementing these procedures. These should cover: duty re-assignment; adverse consequences to the pregnant firefighter's safety; maternity leave; return to work.

- To capture all adjustments and considerations that may be required during the changes that take place during pregnancy it is recommended that risk assessments are revised on a regular basis and/or when they are believed to no longer be suitable and sufficient.

- Pregnant firefighters should inform their FRS (line manager, human resources or occupational health - as preferred) as soon as pregnancy is suspected – so that protective measures can be put into place as early as possible (FBU, 2008; National Joint Council for Local Authority Fire and Rescue Services, 2009).

- Pregnant firefighters must be reassigned to non-operational duties away from exposure to contaminants and the hazards of physical stress and exertion, noise or heat (e.g. long hours without sleep, driving engines under emergency conditions, etc.) (FBU, 2008).

Every FRS needs to be aware of risks related to pregnancy and firefighting activities.

Firefighters who are Nursing Mothers

Even after pregnancy, babies can continue to be at risk of exposure to the contaminants that their mothers are exposed to through the ingestion of breast milk. Contaminants that have built up in the mothers' tissues over months or years can be passed directly onto infants in concentrations that are much higher than any single exposure event their mother may have experienced (Nickerson, 2006). In addition, those contaminants can be eliminated from the body much faster when breast feeding (Nickerson, 2006). This emphasizes the importance of minimising exposure to such contaminants at all times, even before pregnancy and breast feeding.

The same precautions which are applied to pregnant firefighters are applied to breastfeeding firefighters (Council of the European Communities, 1992).

- On return to work after maternity leave, firefighters have the right to resume the position they held under their original contract of employment and on terms and conditions not less favourable than those that would have been applicable if they had not been absent.

- Breast feeding firefighters must be reassigned to non-operational duties in order to minimise exposure to harmful contaminants.

- To ensure avoidable exposure to contaminants is minimised the FRS should consider any requests from employees to work different/part time hours (flexible working) on their return from maternity leave.
- A safe and private space within a "clean" zone of the station or work environment should be provided for breastfeeding firefighters to pump breast milk if required.

- Facilities to store expressed milk should be provided in “clean” zones of the station or work environment as requested. The FRS should provide access to a refrigerated storage facility and reasonable time for expressing breast milk.

Contaminants can be passed to babies through their mothers’ breast milk.

TRAINING AND AWARENESS

In order to provide positive motivation for change, it is necessary to communicate the risks posed by poor or non-existent contamination control routines. When firefighters gain knowledge and awareness of contaminants and their effects on health, it becomes much easier to introduce improvements and implement changes.

The Badge of Honour

The **"Badge of Honour"** attitude refers to firefighters being proud of having soiled PPE because it may give the impression to others that they are more qualified or hardworking. This attitude still appears to be prevalent in the UK FRS (see Figure 37). Dispelling the sentiments behind the badge of honour attitude will therefore require dedicated training for firefighters, and increased awareness among the UK FRS more broadly.

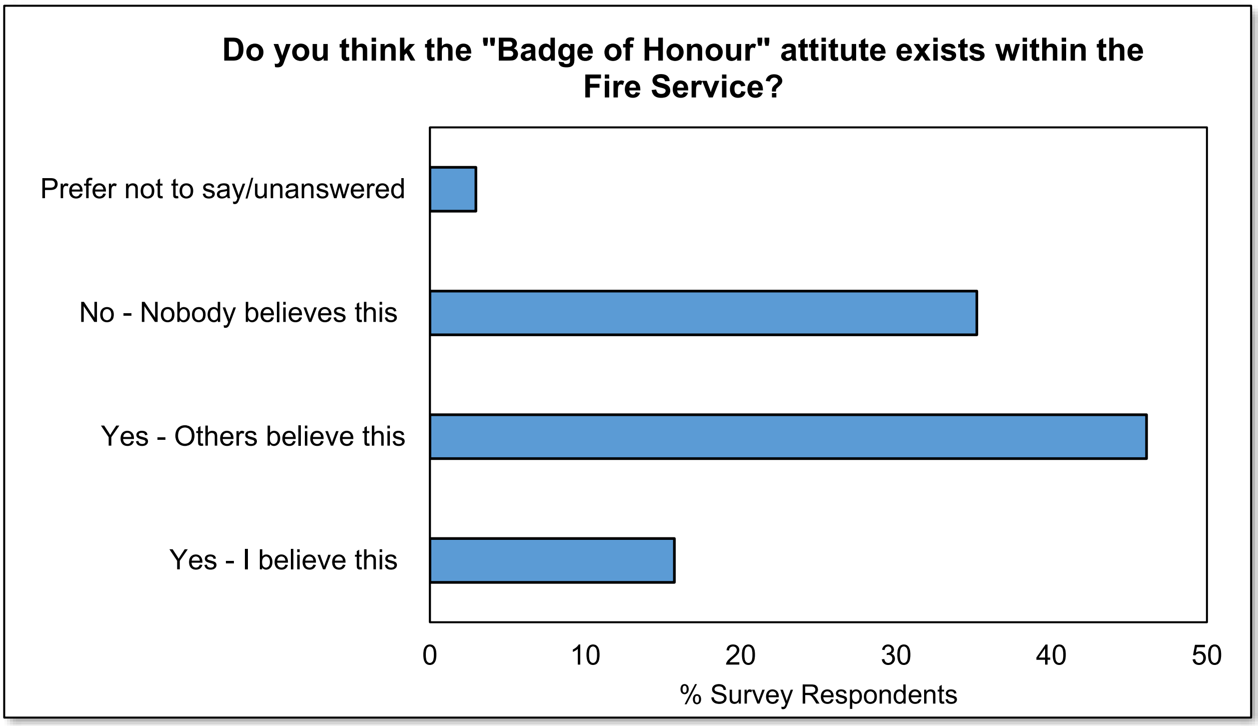


Figure 37: *% of Respondents to the FBU & UCLan National Firefighter Survey who indicated whether they thought the "Badge of Honour" attitude exists within the Fire Service*

Awareness

Key notes from UK FRS submitted documents:

- Training on the wearing, fitting and use of PPE appears to be fairly consistent across Services, with firefighters being trained on how the PPE can protect them in fires, and the importance of correctly fitting PPE to ensure adequate overlap and range of movement.
- There is limited documentation related to training on contaminants and their toxic effects. The most common distribution of such information is through FBU posters and circulars.
- The responses collected show that only 2 FRS provided evidence of dedicated training on the importance of keeping PPE clean and avoiding cross contamination in order to keep firefighters healthy.

When people routinely and repeatedly find themselves in similar circumstances, such as attending fire incidents, they tend to develop **habitual blindness**. Habitual blindness means that a person subject to repeated experience of the same situation or phenomenon becomes numb to it and stops reacting to, or even noticing the circumstances in question (Miller et al., 2001; Swedish Civil Contingencies Agency, 2015).

An individual with their own negative experiences of an event (e.g. resulting in illness or accident) generally assesses similar events as being much higher risk than others who have not had this negative experience. Such individuals are generally more careful. But as time passes, this caution diminishes (Weinstein, 1989). This phenomenon puts firefighters at risk of gradually resuming bad habits and routines, even after those routines may have led to illness or accidents (Reason, 1997; Swedish Civil Contingencies Agency, 2015).

"ONE FOR ALL, AND ALL FOR ONE"

Teamwork is crucial for changing behaviour.

Firefighters' behaviour is heavily influenced by the behaviour of colleagues. It is difficult for a single individual to break a harmful pattern alone. Knowledge and awareness must therefore be disseminated and accepted throughout the workplace if it is to have the intended impact.

It is well documented that risk perception differs significantly between women and men. Studies show that safety awareness is generally better among women than among men (Swedish Civil Contingencies Agency, 2015). Men have been found to struggle to immediately see the positive benefits of safety measures compared to women and have been reported to be overall less concerned about safety measures than women (particularly when assessing risks to an individual). Studies found that men tended to feel that they already had sufficient information and knowledge concerning risks and safety issues. Given the gender balance of the UK FRS, firefighters may be more likely to underestimate health risks in the work environment when compared to groups with a more even gender distribution (Gustafson, 1998; Swedish Civil Contingencies Agency, 2015).

Training

The majority of responses to the FBU & UCLan National Firefighter Survey indicated that firefighters had not received training on the potential health effects of exposure to smoke and gases, and that this majority would find this type of training useful (Figure 38). Of those that *did* receive training on the health effects of smoke and gases, the majority indicated that they found this training useful.

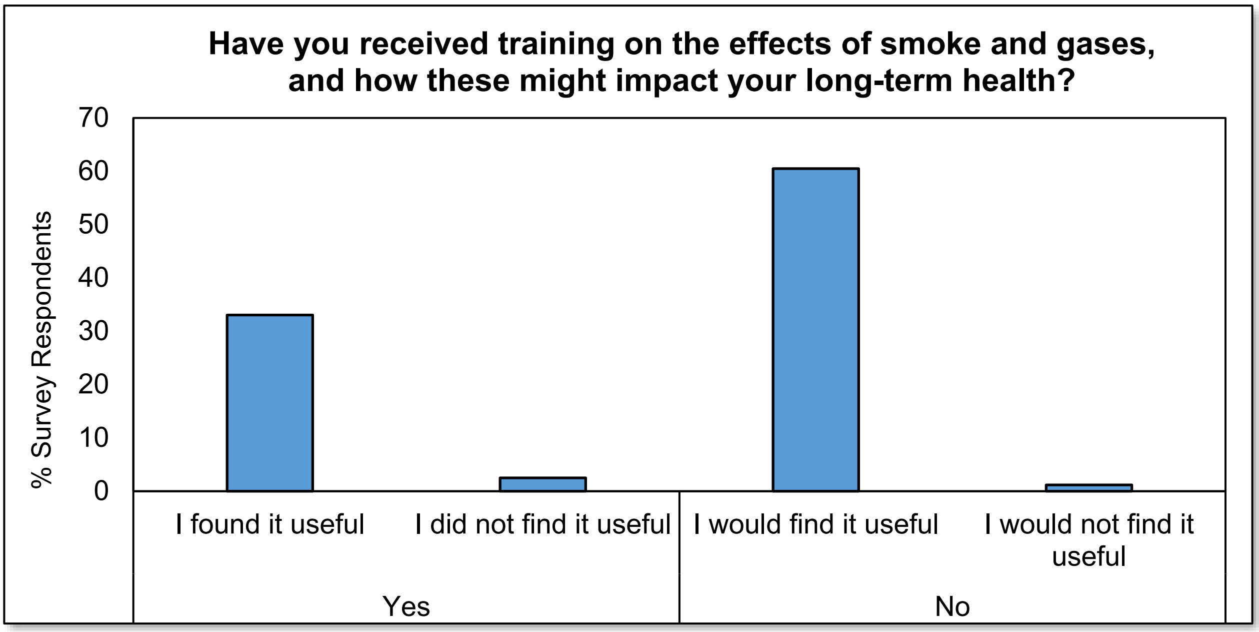


***Figure 38**: % of Respondents to the FBU & UCLan National Firefighter Survey indicated they would find training on the effects of smoke and gases useful.*

Key considerations for implementing such training on a wider scale are listed below:

- It is essential that firefighters and maintenance personnel are trained in the selection, use, care and maintenance of all personal protective equipment.

- In line with HSE regulations on PPE at work, all wearers of respiratory protection should have up to date training on the protection and limitations of the equipment. This should be the case for all respiratory protection, whether it is full SCBA, half face respirators, particulate masks, dust masks or other equipment.

- Training should be provided to all personnel on-site, including support staff, who may be exposed to fire effluent from live fire training burns.

- In additional to training, there should also be documentation on-site, which details the risks of chronic exposure to fire effluent and debris, as well as measures to reduce the risk. This may be in the form of posters, or documentation such as this guidance.

- A list of resources should be available to personnel which provides information about minimising contamination risks, cancer in firefighters, and other health risks associated with exposure to fire effluent and debris.

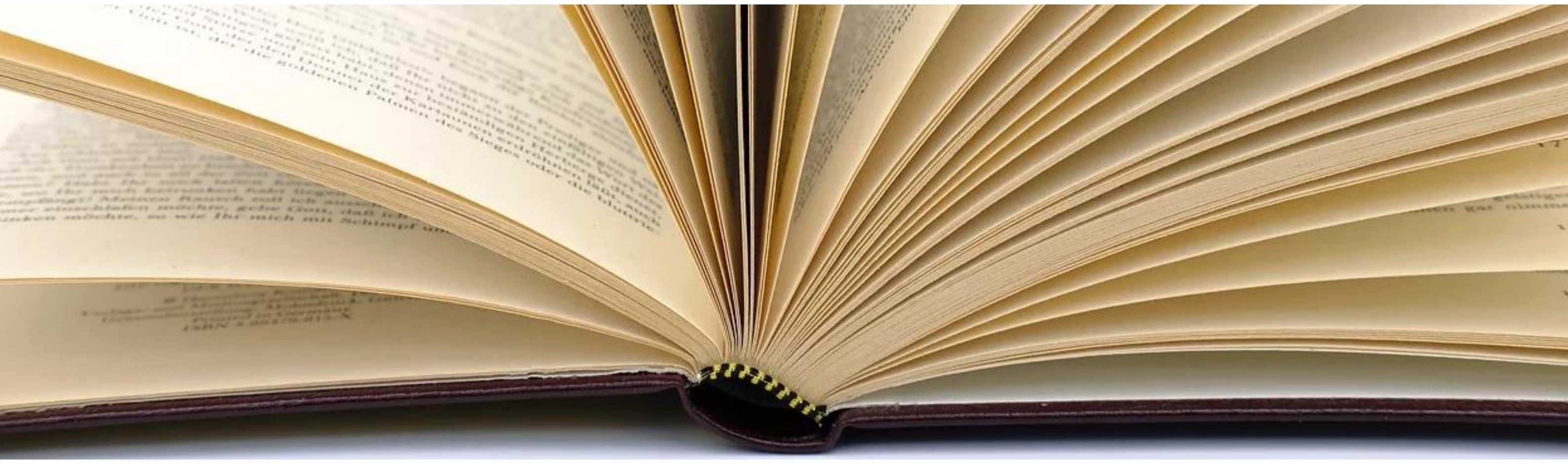
TRAINING ON THE ACUTE AND CHRONIC TOXICANTS produced by fires should be provided to all fire personnel at all levels of the organisation, including training instructors, BA workshop technicians, fire investigators and other personnel who may come into regular contact with fire debris or fire effluent. This training should cover:

1. **Fire effluents: their release, toxicity and hazardous effects on firefighter's health:**

- Potential sources of acute and chronic toxicants.
- Relationship between fire conditions and the types and quantities of acute and chronic fire effluents released.
- Health effects which can arise from exposure to both acute and chronic toxicants.
- Exposure pathways for toxicants (inhalation, ingestion, dermal absorption).

2. **The best practices and prevention methods to reduce contamination and exposure to fire toxins:**

- Purpose and limitations of PPE, including the limitations of each available type of respiratory protection.
- Different pathways via which toxicants are transported from the fire ground to the workplace.
- Protocols for cleaning equipment and PPE.
- Methods for reducing personal exposure to chronic toxicants.



GLOSSARY

A

Acute toxicity - adverse health effects occurring within a short time period of exposure to a single dose of a chemical or as a result of multiple exposures over a short time period e.g. 24 hours.

Adverse (health effect) - a harmful effect on health.

Aerosol - a colloidal suspension of liquid or solid particles dispersed in gas having a negligible falling velocity (generally considered to be less than 0.25 m/s).

Alveolar - concerning the aveloli of the lungs. Alveoli are structures within the lungs resembling microscopic "air sacs", which facilitate exchange of oxygen and carbon dioxide between the lungs and blood.

Appliance - The fire fighting vehicle utilised by the fire station for the purpose of answering emergency 'call outs'.

Appliance bay - The location within the fire station where the appliances are stationary and awaiting an emergency call out.

Asphyxiation - deprivation of oxygen which can result in unconsciousness, suffocation and ultimately death.

B

BA servicing area - the area dedicated to the servicing of breathing apparatus.

Base layer - the layer of clothing worn directly beneath PPE, for example, t-shirt and trousers.

Bioaccumulate - the ability of a chemical to become concentrated in the tissues of living organisms.

Biocide - a chemical substance capable of destroying harmful organisms (e.g. some bacteria and other microorganisms).

Breathing Apparatus (BA) - self-contained, positive pressure, respiratory protective equipment.

C

Cancer - Collective name for illnesses involving uncontrolled cell growth that destroy cell tissue.

Carcinogen - A chemical or physical agent capable of causing cancer.

Cardio-toxic - Specifically toxic to the heart and circulatory system.

Chronic - Occurring for a prolonged period.

Chronic toxicity - Adverse health effects in a living organism resulting from repeated exposures to a chemical for a significant part of the organism's lifespan.

Cirrhosis - Excessive scarring of the liver which is caused when the liver tries to repair itself after damage (e.g. due to disease or excessive alcohol consumption).

Cilia - microscopic, hair-like structures on the surface of cells which help to move/transport substances through the body.

Circadian Rhythms - Daily cycles of behavioural and physical biological changes that occur within the body. The sleep-wake cycle is an important example of a circadian rhythm and is largely affected by changes in daylight.

Cleaning - process by which an item of personal protective equipment (PPE) is made serviceable and/or hygienically wearable again by removing any dirt or contamination.

Combustion gases, Combustion products - Energy-rich residues from incomplete combustion, in gas and particle form, which are expelled from fire.

Concentrated - increase the concentration of a substance i.e. increase the amount of a contaminant over a given area or volume.

Contamination - occurs when a substance adheres or is deposited on people, equipment or the environment, thereby, creating a risk of exposure and possible injury or harm.

NOTE: Contamination does not automatically lead to exposure but may do.

Compressed air - Air which has been compressed under pressure for transportation or use

Corrosive - A substance that chemically attacks a material with which it has contact.

Cross contamination - occurs when a person or object that is already contaminated makes contact with a person or object that is not contaminated.

D

Debris - solid remains of a material following combustion. For example, char or partly burned material

Decomposition - chemical reaction whereby a substance breaks down into its constituent elements. In the case of acetylene this means carbon and hydrogen. This reaction gives out a great deal of heat.

Decontamination - decontamination is the physical and/or chemical process of reducing contamination to minimise the risk of further harm occurring and to minimise the risk of cross contamination to a level as low as reasonably practicable.

Decontamination Area - the area containing the FRS (and possibly other emergency services') decontamination staff, equipment and structures. It is a suitable area initially established outside the inner cordon, at first uncontaminated by the initial release, which becomes contaminated by the managed and controlled movement of people who require decontamination. Prior to decontamination commencing, the inner cordon will be adjusted to encompass the decontamination area.

Degradation - the continuing action of chemical attack to which chemical protective clothing may be subject to in use or during storage.

Dermal - of, or related to, the skin.

Dose - the amount of a substance which an individual is exposed to.

Dust - solid particles generated by mechanical action, present as airborne contaminant (less than 0.076 mm in size).

E

Effluent - gases, aerosols and airborne particulates produced from a fire.

Ensemble - A firefighter's full set of personal protective clothing, which when worn correctly, minimises the thermal effects on their body.

Epithelial (cells or tissues) - Cells which form a thin layer of tissue on the outer layer of the body's surface (e.g. skin epithelial cells), or which line cavities within the body (e.g. lungs, and organs of the digestive system).

Exposure - exposure occurs when a harmful substance enters the body through a route, for example, inhalation, ingestion, absorption or injection.

F

Fire kit - The firefighter's personal protective clothing which, when worn correctly, minimises the thermal effects on their body.

Foetus - The unborn child developing in the mother's womb.

Fumes - Airborne solid particles (usually less than 0.0001mm) that have condensed from the vapour state.

FRS - Fire and Rescue Service – provided by a fire authority under the *Fire and Rescue Services Act 2004*.

G

Gas - Gas is one of three classical states of matter. Near absolute zero, a substance exists as a solid. As heat is added to this substance it melts into a liquid at its melting point, boils into a gas at its boiling point. What distinguishes a gas from a liquid or solid is the vast separation of the individual gas particles.

Genotoxic - A chemical or agent which is capable of damaging genetic material within cells, which can lead to mutations. These mutations can result in adverse health effects, such as the development of cancer.

H

Hazard - A hazard is anything that may cause harm.

Hydrocarbons - Compounds which are composed of atoms of hydrogen and carbon only.

Hypersensitivity - an adverse immune response e.g. an allergic reaction, which can be caused by exposure to a chemical substance.

I

Inflammatory - causes inflammation type immune response within the body.

Ingestion - Taking food, drink or other substances into the body by swallowing it.

Inhalation - Drawing air, or other substances, into the airways and lungs.

Incomplete combustion - Combustion without sufficient oxygen input, which means that residual products from the fuel remain or spread. This is always applicable to some extent in accidental fires.

Inspired - to take air in (to the lungs) i.e. to breathe in.

Irritant - substances which can cause inflammatory immune responses to occur in the body.

K

Kit room - The area within the station used for the storage of in-use Personal Protective Equipment. May also be referred to as the PPE room, Muster Bay or Gear Room.

L

Laundering - Process intended to remove soiling and/or stains by treatment (washing) with an aqueous detergent solution and normally including rinsing, extracting and drying.

Latent Period - The period of time between infection, or exposure to a disease-causing agent, and the onset of symptoms e.g. the period of time between exposure to contaminants and the appearance of cancer.

Lesion - An area within tissues, organs etc. which has suffered damage or abnormal changes e.g. caused through injury or disease.

M

Macrophage - A type of cell responsible for destroying foreign pathogens (e.g. bacteria and viruses) and the body's own damaged/dying cells.

Melatonin - A hormone produced by the body which helps to regulate sleep cycles.

Mutagenic - Chemical or physical agent that can cause a change in the genetic material of a living cell.

N

Neural Tube Disorders - Birth defects of the brain, spine or spinal cord.

Neurological Disorders - Disorders which affect the brain, spine, spinal cord and nerves.

P

PAH - polycyclic aromatic hydrocarbons.

Particle - a small portion of matter, such as soot, and small parts of residual substances from combustion.

Permeation - the process by which fire effluent chemical moves through a protective clothing material on a molecular level.

Persistence - Persistence of chemicals indicates that they are stable and long-lived in the environment, resisting degradation, e.g. lead, cadmium, mercury and many manmade organics.

Personal protective equipment (PPE) - Any clothing or equipment intended to provide protection to the user. This may be from heat, toxicants, or other hazards. In this document it should be taken to mean tunics, leggings, fire hoods, gloves, helmets and boots, unless otherwise stated.

Practicable - Capable of being done in the light of current knowledge and resources.

Pulmonary oedema - Production of watery fluid in the lungs.

R

Renal Dysfunction - Failure of the kidneys to perform their function within the body.

Residue - condensed effluent. For example, the soot left on surfaces following exposure to smoke.

Respirable dust - that fraction of total inhalable dust which penetrates to the gas exchange region of the lung.

Respiratory sensitiser - a substance that may cause sensitisation in the respiratory system on inhalation, causing, for example, asthma, rhinitis etc.

Risk - risk is the probability that somebody could be harmed by a hazard or hazards, together with an indication of how serious the harm could be.

Risk Assessment	-	a risk assessment is simply a careful examination of what, could cause harm to people, in order to weigh up whether enough precautions have been taken or more should be done to prevent harm. The law does not expect the elimination of all risk, but the protection of people as far as is 'reasonably practicable'.
RPE	-	respiratory protective equipment.

S

Safety	-	A state where exposure to hazards has been controlled to an acceptable level.
Sensitiser	-	A substance that can causes allergic type hypersensitivity reactions within the body.
Smoke	-	Particulate matter, usually less than 0.0005 mm in diameter, in air resulting usually from combustion, including liquids, gases, vapours and solids.
Solid	-	Solid is one of the classical states of matter. It is characterised by structural rigidity and resistance to changes of shape or volume. Unlike a liquid, a solid object does not flow to take on the shape of its container, nor does it expand to fill the entire volume available to it like a gas does.
Standard Mortality Rate	-	The observed rate of mortality (death) within a given population standardised against the expected rate of mortality for that population.
Support staff	-	Refers to staff that have a support role in relation to the Service and not having a fire fighting role to play.
Surface contamination	-	Hazardous materials adhering to a vertical surface or resting on a horizontal surface.

T

Teratogen - chemical or physical agent that can cause defects in a developing embryo or foetus when the pregnant female is exposed to the harmful agent.

Thermoregulatory Process - Biological processes within the body which control and maintain the body's core temperature.

Toxicity - the degree to which something is toxic.

Toxicant - a substance that has the potential to have a detrimental effect on health.

Toxin - poisons produced inside the body. May be produced by the body as a result of exposure to a toxicant.

V

Vapour - vapour refers to a gas phase at a temperature where the same substance can also exist in the liquid or solid state, below the critical temperature of the substance. If the vapour is in contact with a liquid or solid phase, the two phases will be in a state of equilibrium.

Vascular Disease - Disease which affect the blood vessels (veins and arteries).

Ventilated - allowing the free movement of air to circulate within a room, building, etc.

VOC - volatile organic compounds. Compounds that cause damage to organs and the nervous system.

W

Washing - to remove contamination from clothing by or as by the action of water, detergent and mechanics

Workshop - an area of benching and lockable storage, may be within the appliance bay or in a dedicated building. Dedicated to the upkeep and maintenance of appliances.

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APPENDIX

Decontamination procedures should aim to:

- Minimise the risk of people being exposed to contaminants.
- Enable responders to remove contaminated clothing, personal protective equipment and respiratory protective equipment without being exposed to hazardous materials.
- Stop hazardous materials being spread beyond the decontamination area.

Decontamination Methods

Although breaches and/or failures of PPE can happen, poor decontamination is the most common cause of exposure to harmful fire effluents.

There are several specific methods which can be used for decontamination. These methods can be broadly divided into two basic categories: "**dry" (or "physical") decontamination methods** and **"wet" (or "chemical") decontamination methods**. Each of these types of methods is discussed in further detail below.

Dry (physical) decontamination

These methods involve physically removing the contaminant from the contaminated person or object. These methods are often easy to perform and work by reducing the amount (dose) of a contaminant, thus reducing its potential to cause harmful health effects. However, the contaminants generally remain chemically unchanged (National Operational Guidance (NFCC), 2020). Common examples of dry decontamination practices include:

- **Absorption;** this involves soaking up liquid contaminants/hazardous materials to prevent the liquid spreading to (and contaminating) a larger area, e.g. wiping off PPE and other equipment with sponges, absorbent pads, towels or disposable cloths.

- **Brushing or scraping;** this method uses physical movement to remove a contaminant in both dry and wet decontamination scenarios, e.g. using a coarse brush to remove contaminated debris from fire boots.

- **Isolation and dispersal;** a two-step process in which contaminated articles are first removed to, and isolated within, a designated area by “bagging and tagging” the articles. The bagged articles are then further packaged in a suitable transportation container for disposal at an approved hazardous waste facility.

- **Vacuuming;** involves the use of vacuums to collect a range of contaminants including hazardous dusts, fine powders etc. The vacuum must be designed and approved for this specific application. High Efficiency Particulate Air (HEPA) filters physically capture the contaminant but must be replaced frequently.

  NOTE: The use of vacuums in fire related incidents may not be effective for wet personal protective equipment and clothing.

- **Evaporation or gassing-off;** the process via which contaminants are left to evaporate or gas-off. The effectiveness of this method can be limited for porous surfaces for very large quantities of materials (National Operational Guidance (NFCC), 2020).

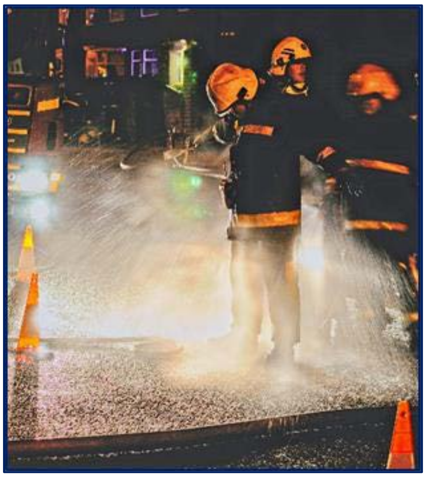
Wet (chemical) decontamination

These methods generally involve removing contaminants by some type of chemical process. They are typically conducted over a dam which is designed to contain the run-off (for larger numbers of firefighters, a Hughes shower may be more appropriate). At the end of the process, the Environment Agency should be consulted to identify the most appropriate disposal method for the run-off (National Operational Guidance (NFCC), 2020).

Wet decontamination methods include:

- **Dilution/washing;** uses cold/warm water, or soap and water solutions to flush the contaminants from protective clothing and equipment. The use of soap or detergents helps to remove oils, greases, dirt, grime, etc.

- **Chemical degradation;** the process of altering the chemical structure of the contaminant through the use of a second chemical or material. Commonly used degradation agents include calcium hypochlorite bleach, sodium hypochlorite bleach, sodium hydroxide (household drain cleaner), sodium carbonate slurry (washing soda), calcium oxide slurry (lime) etc. Chemical degradation is primarily used to decontaminate structures, vehicles and equipment and should **not** be used on chemical protective clothing, and **never** applied directly to the skin. Technical advice must be obtained from product specialists to ensure that the solution used is appropriate for the specific contaminant.



- **Solidification;** a process by which a contaminant physically or chemically bonds to another object. This method is primarily used to decontaminate equipment and vehicles. Commercially available solidification products can be used for the clean-up of spills (National Operational Guidance (NFCC), 2020).

Effectiveness of Decontamination Methods

Studies on the effectiveness of various decontamination methods have shown that no single decontamination method is successful in removing all (100%) of contamination (Figure 39). However, some methods have been found to be more effective than others (National Operational Guidance (NFCC), 2020). Generally, methods that use some form of scrubbing with detergent appear to be more effective. Additionally, methods which use hose reels or main jet/spray branches appear to out-perform portable shower units, when used alone.

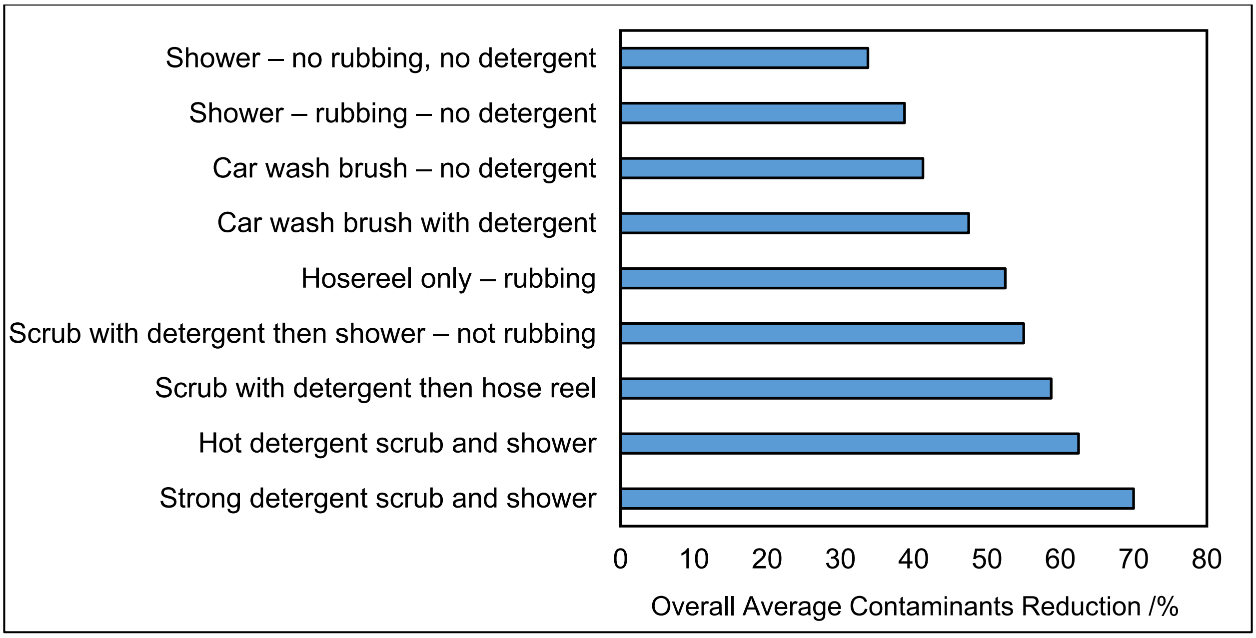


***Figure 39**: Effectiveness of decontamination methods, as studied by the Home Office Fire and Research and Development Group (1995)* (National Operational Guidance (NFCC), 2020)

No single decontamination method will work for *every* hazardous materials incident. Therefore, a variety of different methods may be needed for effective decontamination.

Decontamination Equipment

A variety of equipment is available to facilitate the kinds of decontamination methods described above. It is recommended that this equipment be stored together as a portable set for easy access at incidents. In the USA decontamination buckets as a pre-packaged "kit" available for purchase are becoming popular. While similar products may not be currently available in the UK, it may be valuable to replicate the concept. For information the list below details the contents of a typical decontamination bucket available in the US. UK FRSs may wish to adopt this approach and assemble their own.

Decontamination buckets should ideally be stored in every appliance, and should contain (Hamilton County Fire Chiefs Association, 2018):

- Laminated set of decontamination notes
- 1 x 25-30 Litre bucket with the lid and sides labelled DECON KIT
- 2 x disposable (breathable) dust and waterproof clothing (overalls) (consider also gas or liquid tight suits to cover BA)
- Barrier tape, poles, cones or signs
- Disposable latex or nitrile gloves
- 2 x packs of “Fire Wipes” or “Baby Wipes” for wiping face, neck, arms and hands
- 2 x bottles of water
- 1 x soft and hard brush for removing fire debris such as insulation fibres and soot
- 5-10 Litre plastic pump sprayer or 1 x 15 foot section of garden hose with adapter for discharge with nozzle
- 4 gear bags or 200 Litre (minimum 6 millimetre thick) rubbish bags to put contaminated gear into
- Bag of cable zip ties
- 1 x bottle of Dishwashing detergent
- 1 x bottle of multipurpose cleaner concentrate
- Labels and permanent markers.

In addition to the decontamination bucket, it the following items should also be available:

- 2 x large PVC liners for dam (disposable)
- pH paper (roll)
- Water containment system and pump
- Dry encapsulation material (Fuller’s earth)
- 2 x blue oil absorbent pads (disposable)
- 2 x yellow chemical absorbent pads (disposable)
- 1 x pack of paper towels (disposable)
- Megaphone (to assist decontamination)
- 1 x 750 mL Grease Off degreaser spray

Decontamination Areas

Decontamination methods should be conducted within designated areas (both at fire incidents and at the fire station). This ensures that contaminants and hazardous waste are properly contained and avoids re-contamination.

Cordons and zones

At any fire incident where hazardous materials are released or suspected, strict cordon control is essential to managing contamination. Cordons are an effective method of controlling resources and maintaining safety on the incident ground. They may be defined by a series of markers (e.g. cones, traffic tape, etc.) and must be continuously monitored and adapted to reflect changes in hazards, weather etc. (see considerations for designating decontamination areas below) (National Operational Guidance (NFCC), 2020).

Cordons should be designated on arrival of the FRS to an incident as part of the control, safeguarding and coordination of an immediate response. Designation of cordons should consider and encompass several specific "zones" (see Figure 40):

- **HOT ZONE**; where contaminants are generated and released - poses an immediate health and safety threat to all located within the zone. Entry to this zone should be restricted to the minimum numbers of people for work to be undertaken safely and effectively. Effective PPE required for working within the 'hot' zone.
- **WARM ZONE**; contaminants are not generated in this zone, but may still enter the zone via the movement of people or vehicles. Represents a lower immediate risk to health and safety compared to the hot zone.

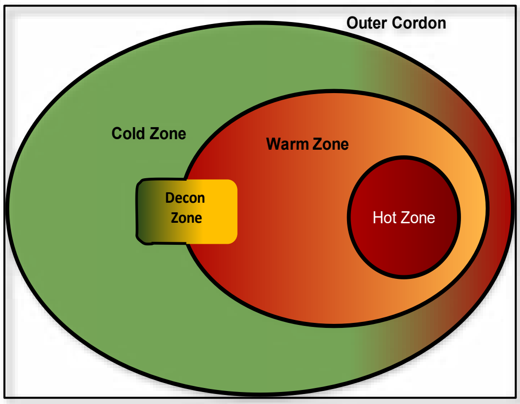


***Figure 40**: Zones within the decontamination area*

- **COLD ZONE**; free from contaminants. It is the area within which key operational command positions and other essential activities will be set up (National Operational Guidance (NFCC), 2020).
- **DECON ZONE**; the decontamination (decon) zone forms the interface between the cold and warm zones (Figure 41). It is set-up in the cold zone on the boundary of the warm zone and at minimal travel distance from the hot zone. It contains FRS (and possibly other emergency service) decontamination staff, equipment and structures (Figure 41 example and typical layout). The decontamination zone should be established by the commander **before** crews are committed into the hot zone. Decontamination equipment should be set up by crews wearing firefighting PPE. Once set up, only personnel wearing the appropriate PPE will be permitted to enter and operate inside this zone (National Operational Guidance (NFCC), 2020).

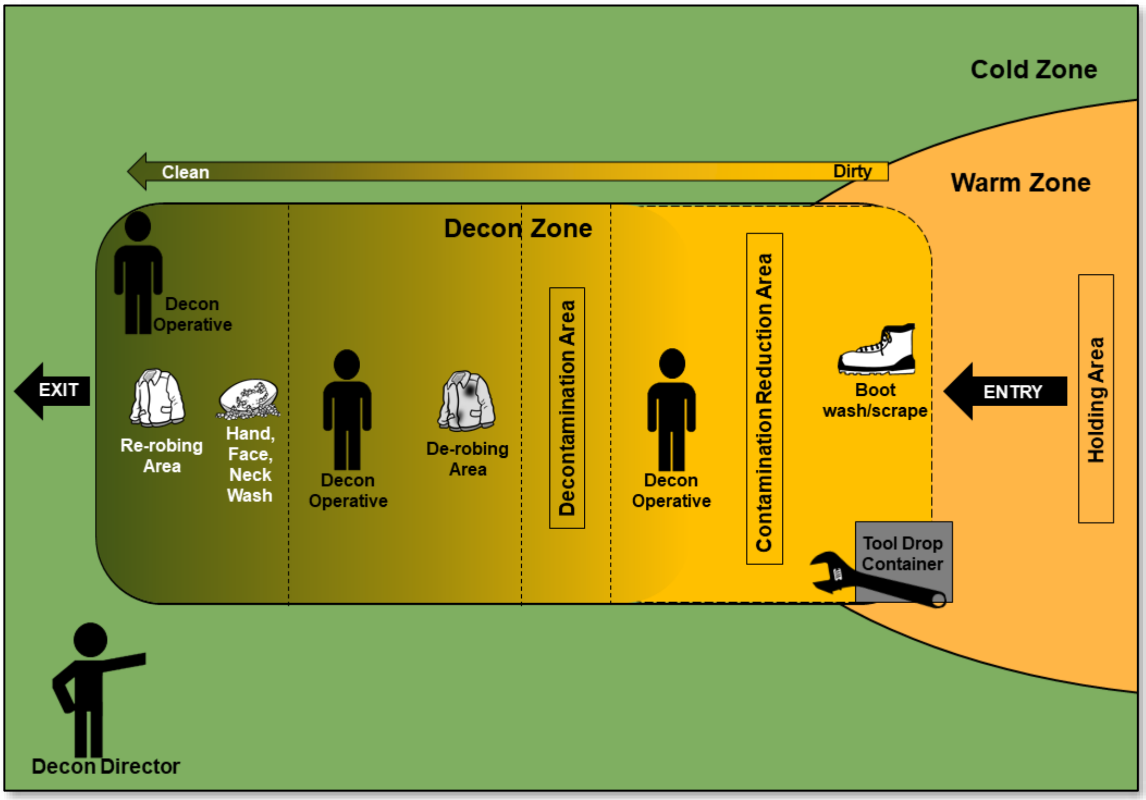


Figure 41: *Typical layout of the decontamination zone. The layout presented above aims to minimise the spread of contaminants. However, this layout may need to be altered as appropriate to the specific fire incident and decontamination procedures.*

General Considerations for Decontamination Areas

When choosing locations to designate as decontamination areas at the fire incident, the following should be taken into account (National Operational Guidance (NFCC), 2020):

- Type and level of contamination.
- Weather conditions (temperature, precipitation, etc.).
- Access/egress routes to/from the hot zone.
- Wind direction.
- Slope of the ground.
- Location of breathing apparatus entry control.
- Location of a pumping appliance, and availability of hose reel for washing off and damping down.
- Sufficient distance from the hot zone to the decontamination area to ensure that no airborne contamination can reach the decontamination area.
- Surface material and porosity (grass, gravel, asphalt, etc.).
- Availability of water.
- Location of drains, sewers, and watercourses.
- Access for oncoming vehicles.
- Likely numbers of personnel requiring decontamination.
- Welfare of staff (hydration).

Once a location has been designated as a decontamination area, the following should be taken into consideration when preparing the area for decontamination methods:

- Containment of wash-down water and run-off.
- Accessibility of a spare supply of breathing air (extra SCBA).
- Accessibility of a supply of industrial-strength rubbish bags.
- Clearly marking specific boundaries within the decontamination area (i.e. not just by laying a rope on the ground).
- Clearly marking entry and exit points, ensuring the exit point is upwind and away from the incident and contaminated areas.
- A waiting location at the entry point where contaminated personnel can await their turn for decontamination without spreading contamination further.
- Protection of personnel from adverse weather conditions.

Decontamination Team and Protective Clothing

Knowledgeable personnel (decontamination officers, incident commanders etc.) should pre-determine the type of incident, level of decontamination and decontamination methods required during incident preparation.

The decontamination process requires a team of dedicated personnel to conduct successfully. For initial decontamination this team may simply take the form of a “buddy” system, whereby two firefighters assist each other with initial decontamination or decontamination reduction efforts. For full decontamination this team should be comprised of several specialist operatives, including a Decontamination Leader/Officer/Director (appliance commander), Dirty and Clean Operatives and Support (crew) members.

The role of **Decontamination Leaders/Officers/Directors** should include:

- Assessing types of contaminants and contamination level
- Ensuring correct set-up of the decontamination zone
- Instructing crews on the most appropriate decontamination methods
- Nominating roles for each crew member and ensuring they have correct PPE
- Supervising wet decontamination methods and preparing required decontamination solutions with chemicals/ additives
- Safeguarding contaminated staff
- Remaining outside of the decontamination area
- Informing the Incident Commander* when the team and the decontamination zone is set up and ready to accept personnel for decontamination.
  **Only the Incident Commander can declare the decontamination zone open,* but they should take guidance from the decontamination leader.*

The role of **Dirty/Clean Operatives** should include:

- Remaining within the appropriate areas of the decontamination zone to prevent cross-contamination:
    - Clean Operatives should remain within the clean areas of the decontamination zone, and should wear disposable suit, breathing apparatus and chemical resistant gloves.
    - Dirty Operatives should remain within the dirty areas of the decontamination zone and should wear chemical protective clothing and breathing apparatus (cylinder or airline).
- Acting on the directions of the decontamination leader/officer.

The team leader will advise on the most appropriate PPE for decontamination operatives which, in most circumstances, will be disposable, breathable, dust and waterproof clothing (overalls), full face mask with appropriate filters, neoprene gloves, gas or liquid tight suits and clean BA.

Waste and Disposal

The decontamination process generates several forms of contaminated, potentially hazardous waste. It is important that this waste is contained and disposed of appropriately:

- Waste from decontamination may contain persistent organic pollutants which may lead to the environmental damage. Any waste / run-off must be contained either in waste bags or the decontamination dam.
- Contaminated wipes, nitrile gloves, suits or any other disposable items should be double bagged in plastic bags for appropriate disposal by specialist hazardous materials recovery contractors. If these contractors are not present, then this waste should be handed over to the local authority.
- Equipment shown as disposable should be disposed of <u>on scene</u> if the item has been used.
- All equipment **unused,** or not identified as disposable (and which has been decontaminated if used), should be returned to station in order to be re-used.
- Each fire appliance should have one decontamination equipment box.

- A stock of spare equipment should be kept at the station to immediately replace items used at an incident.

Any runoff from decontamination methods that is not contained will eventually enter sewers and water courses, or if it sinks into the ground will ultimately reach the water-table. It is therefore important to contain this run-off and dispose of it appropriately.

Decontamination good-practice considerations

There are number of considerations that have to take place during decontamination process. If they are poorly carried out it can lead to a further unnecessary health hazards. These are:

- Where appropriate, crew should assist each other in rinsing off debris and products of combustion in a systematic and thorough manner (starting from the collar line and working down).
- During the decontamination process visual and audio communication will be restricted. All personnel should therefore be fully aware of decontamination procedures, and should face each other and stand on the spot during the process.
- Personnel carrying out decontamination should make sure they are properly hydrated (both prior to and after the process).
- Caution needs to be taken when entering the decontamination zone, especially where this involves stepping up onto, and off of, a mat or raised platform, and where the use of water introduces the risk of slips, trips and falls.
- Decontamination should be conducted from top-to-bottom, i.e. starting at the collar line or helmet and working down.

Hands and face should be washed (with soap or by using wipes), especially before firefighters handle any food or drink.

- Loss of air supply during the decontamination process should to be carefully considered ***before*** decontamination starts. Members with the lowest air supply should be decontaminated first. Where possible, personnel should remain under air until the decontamination process is complete.
- Respiratory protective equipment should be the last item removed in safe undressing procedures (see an example of a full safe undressing procedure).
- Personnel should be careful not to saturate the inner lining of the PPE. PPE should be kept operationally dry on the interior, while the exterior is rinsed cleaned. Soft bristle scrub brushes and department-approved soap/cleaner may facilitate the cleaning process.
- Areas most likely to accumulate contaminants should receive special focus when wiping, scrubbing, brushing or spraying PPE e.g. creases, folds and joins in chemical protective clothing, under webbing or straps etc. Care should be taken not to force contaminants beneath the layer of personal protective equipment.
- Zips and other joins in personal protective equipment and chemical protective clothing should be sponged before they are opened to avoid water entering the wearers' base layer
- If personnel who are not wearing protective clothing become contaminated – they must replace their clothing, remove contamination from exposed locations (e.g. by wiping or washing) and shower as soon as possible. If any health symptoms occur medical advice should be sought.

Appliance tank water or any water used in the decontamination process must come from a clean, municipal (hydrant) water source, not from a stagnant or potentially contaminated water source.

An Example of Safe Undressing Procedure for Emergency Decontamination of Personnel in Firefighting PPE

The below example is replicated from London Fire Brigade's decontamination procedures.

SAFE UNDRESSING PROCEDURE	
	Nominate roles: • Decontamination Leader/Officer • 2 x Decontamination operatives. • Minimum of 1 Support Staff.
Decontamination operatives:	• As a minimum don FPS 7000 face mask with P3 filter and neoprene or other reusable gloves. • Consider the use of a loud hailer. • Avoid kneeling down, and carry out the safe undressing procedure at arm's length to prevent unnecessary contact with the wearer. • Ensure the outside of suit does not touch the wearer during disrobe. • If any obvious cross contamination is observed immediately report it to seek decontamination advice.
Wearer:	If necessary, use your gloved hands to lean on operatives for support
Support Staff	Lay out a salvage sheet beside the wearer to provide a 'clean path' onto which to stand. Also, provide a charged hose-reel set on flush.
Wearer	Step into reusable bag with operatives' assistance if required.
Decontamination operatives	If the wearer is wearing BA maintain the face mask seal and remove the BA set from the wearers shoulders – one operative should continue to support the weight of the BA set whilst the second operative continues the disrobe process. Move BA to a hanging rack.
Decontamination operatives	Remove wearers helmet and gloves and place clear of wearer – instruct wearer not to touch contaminated firefighting PPE with unprotected hands, even in an attempt to assist in the disrobe.
Decontamination operatives	Provide wearer with nitrile gloves ensuring they are donned unfasten Velcro on fire tunic fully and then unfasten zip. Remove tunic from shoulders – <u>ensuring tunic is turned inside out as removed.</u>
Decontamination operatives	Grasp the cuff of the tunic and instruct the wearer to withdraw their arm – remind them of the need to work their thumb out of the thumb loop.

	Remove nitrile gloves and then place their arm across their chest without coming into contact with contaminated clothing. Repeat on other arm. (If necessary, use your gloved hands to lean on operatives for support)
Decontamination operative(s)	Keep tunic inside out and place clear of the wearer.
Decontamination operative(s)	Pull fire hood over the head (from back to front) being careful not dislodge BA face mask. Allow fire hood to remain looped around the supply hose of the BA set.
Support Staff	Provide dis-robe pack and wearers footwear if available.
Decontamination operative(s)	Remove leggings braces from shoulder and allow to fall to waist.
Decontamination operative(s)	Roll down leggings – inside out – to boot level. Grasp each boot, in turn, and instruct wearer to step from boot onto salvage sheet.
Decontamination operative(s)	Remove wearers face mask and reset first breath button on lung demand valve.
Wearer	Move away from decontamination zone for assessment by Incident Commander
Wearer (if showered)	Should then dry themselves and dress using the dressing packs provided or other alternative clothing
Leader	Ensure that ensure that BA sets, helmet, fire-coat, gloves, boots and leggings are double bagged and sealed with cable ties. Emergency decontamination gloves should be removed, double bagged and sealed.
ALL:	Check for any areas of exposure, then dress and proceed to breathing apparatus entry control and then complete any necessary records. If suspected of cross contamination (in fire kit and SCBA) then proceed to the decontaminated process as described above.
ALL:	As a final precaution wash hands and face.
Additional Point:	If required, responders who have completed the safe undressing procedure should be directed to the Ambulance Service for monitoring and / or medical care.

Table 7: *Example of a safe undressing procedure during the decontamination process.*

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Contamination of UK firefighters personal protective equipment and workplaces

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Firefighters' personal protective equipment (PPE) is a potential source of chronic exposure to toxic contaminants commonly released from fires. These contaminants have also been found in fire stations. However, little research characterises the routes via which fire contaminants travel back to fire stations. The UK Firefighter Contamination Survey provides information on firefighters' PPE provision, decontamination, and storage practices. All serving UK firefighters were eligible to take part in the survey, which comprised 64 questions. A total of 10,649 responses were included for analysis, accounting for roughly 24% of the UK's firefighting workforce. Results revealed that most firefighters (84%) de-robe contaminated PPE/workwear after re-entering the appliance cab. There was a significant decreasing tendency to send PPE for cleaning after every incident with increasing seniority of role, length of service, and fire attendance frequency. Around one third of firefighters cleaned PPE after every incident. A number of issues were linked to external professional cleaning services, e.g. shrinkage, fit, turn-around time, and stock of reserve/pooled PPE. PPE storage was found to be a potential source of cross contamination, with almost half of firefighters (45%) indicating clean and dirty PPE is not stored separately. More than half of firefighters (57%) stored fire gloves (an item sent for professional decontamination by only 19% of firefighters, and never cleaned by 20%) within other items of PPE such as helmets, boots and tunic/trouser pockets. The survey's results can be used to target gaps in decontamination measures within UK Fire and Rescue Services.

Firefighters are directly exposed to potentially large quantities of toxins on a regular basis when attending fires[1,2]. This puts firefighters at an increased risk of developing adverse health outcomes and emphasises the importance of managing those risks by implementing controls which protect against exposure[3,4]. Personal protective equipment (PPE) is one of the most important control measures for firefighters[5] as it is often impossible to implement higher-level controls in the dynamic and transient working conditions presented by fire incidents[6] and where firefighters are (necessarily) in close proximity to exposure sources[4].

In the UK, a firefighters' PPE ensemble typically comprises fire tunic (jacket) and trousers, boots, helmet, fire gloves, fire hood and respiratory protective equipment[7] (and may vary according to hazard[6]). Additionally, a layer of "workwear" (t-shirt, trousers etc.) is worn beneath this ensemble. While PPE is designed to keep firefighters safe from several hazards (e.g. extreme heat, surface wetting etc.)[8], a growing body of literature calls into question the efficacy of its protective function with regards to contaminant exposure[5,9]. For example, Mayer et al.[10] demonstrated potential diffusion of toxic gases/vapours through firefighters' turn-out jackets, reporting measured concentrations of benzene, toluene and naphthalene inside firefighters' turn-out jackets which matched concentrations measured outside[10]. Studies have also documented particulates (including polycyclic aromatic hydrocarbons (PAHs)) penetrating interfaces of PPE ensembles, which may then transfer directly to the skin and/or workwear[11].

Currently, there is no UK standard which requires firefighters' PPE to protect against chemical or biological agents (i.e. particulates, fire gases etc.)[8], remaining an area in need of further research and development[5]. In other countries, such research/development has led to innovations such as particle-blocking fire hoods, which have been adopted in the USA[12]. Still, there are other routes via which PPE may contribute to firefighters' exposure to contaminants that require careful consideration. For example: when de-robing, handling, and storing contaminated PPE[13]; PPE that is gassing-off[14]; when donning or handling PPE which has been insufficiently decontaminated, or has been cross contaminated through storage or during domestic laundering cycles, etc[15].

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If not adequately controlled, these exposures may negate any future improvements in the design and protective function of firefighters' PPE ensembles.

Recent studies have also focused on measuring contaminant levels in the air/dust at fire stations where firefighters and support workers spend a considerable amount of their time[16,17]. Higher concentrations of polycyclic aromatic hydrocarbons, organophosphorus flame retardants, polybrominated diphenyl ethers etc. have all been found in the air and/or in dust collected from fire stations[16–18], most likely brought back to the station on contaminated PPE or equipment after firefighting activities. Particular attention has recently been paid to per-fluorinated compounds in fire stations, as these compounds are not only used in firefighters' PPE, but are also a major ingredient of certain firefighting foams[19,20].

While current research serves to evidence the extent of PPE and workplace contamination, relatively little research focuses on the routes via which contaminants are allowed to travel from fire incidents back to stations. The UK Firefighter Contamination Survey addresses this evidence gap by assessing firefighters' experiences and behaviours on a range of topics including health (cancer[21] and mental health[22]), PPE contamination/decontamination practices, and culture/habits and training[23]. This manuscript explores firefighters' capacity for occupational exposure to fire contaminants through their PPE (i.e. PPE provision, maintenance, storage, fit etc.) and workplace. The results of the survey are intended to inform targeted contamination control measures within UK Fire and Rescue Services (FRSs), as part of a wider research project which aims to protect firefighters' occupational health.

Methods

Survey design. The UK Firefighter Contamination Survey consisted of 64 questions (Supplementary File S1). Questions of specific relevance to this manuscript are outlined in Table S1 (demographics), Table S2 (PPE) and Table S3 (workplace contamination). Remaining questions are analysed in other manuscripts[21–23].

Branching logic was used to route participants through the survey based on answers to previous questions. The survey was piloted with a small subset of firefighters, and questions rephrased for clarity according to feedback. Ethical approval for the survey was granted by the University of Central Lancashire Ethics Committee, and all analyses were conducted in accordance with relevant guidelines and regulations.

The survey ran through Jisc software[24], for a period of 3 months between November 2019 and February 2020. A link to the survey was distributed to participants via email through the Fire Brigades Union (FBU). The survey took approximately 20 min to complete and was supported by UK Fire and Rescue Services (FRSs) with respect to allowing firefighters dedicated time within their workday in which to complete it.

Participants. All currently serving (i.e. excluding retired) UK firefighters were eligible to participate, regardless of specific role or employment contract type. Firefighters were invited to anonymously complete the survey online. Informed consent was obtained from all participants.

Analysis. Free text answers were manually coded for analysis according to the most commonly appearing themes.

Analyses conducted for this manuscript predominantly involved generating summary statistics for survey questions/responses. Where appropriate, survey questions were cross-tabulated in order to explore trends or correlations between variables. Statistical tests encompassed the following: chi-squared test (for differences between survey and general population demographics), *z* score test for difference in proportions, Kendall correlation, crude odds ratios, and chi-squared test for trend. These analyses were conducted in Excel (Office 365), or by using the statsmodels.api module for Python 3[25].

P-values for *z* scores and chi-squared tests are quoted in-text below. For Kendall correlation tests, the correlation coefficient (tau-b) is presented alongside the p-value, giving an indication of the strength of correlation on a scale of 0–1.

Results and analysis

The responses of 10,649 firefighters were included in analyses (Supplementary File S2), representing approximately 24% of the UK's total firefighter workforce (Supplementary File S3).

Demographics. The demographic characteristics of surveyed firefighters are displayed in Table 1. Participants tended to be white, male firefighters between the ages of 35–54, who work wholetime contracts and attend between 1–2 fires per week and 1–2 fires per month (Table 1). Surveyed firefighters were not significantly different to the English firefighter population (roughly 7% of which are female) with respect to sex ($p > 0.05$)[26]. However, participants were significantly different with respect to age, ethnicity and employment type ($p < 0.05$)—whereby the survey under-represents younger age categories, retained firefighters, and firefighters who belong to an ethnic minority.

All UK Fire and Rescue Service (FRS) locations, except for the Isle of Scilly and Jersey, were represented in the survey (Supplementary File S2, Fig. S1). As might be expected given that London and Scotland are the largest FRSs in the UK, participants from London (13%) and Scotland (13%) FRSs made up the largest proportions of all surveyed firefighters.

PPE age. Only firefighters with individually issued PPE were able to answer questions about the age of their PPE—the results of which are displayed in Fig. 1. The majority (86%) of surveyed firefighters had individually issued PPE. Approximately 13% of firefighters had PPE from a shared, "pooled stock".

		Proportion of surveyed firefighters/% (n = 10,649)
Sex	Male	87.1
	Female	6.4
	Other	0.0
Ethnicity	White	94.0
	Mixed race	1.3
	Black	0.5
	Asian	0.4
	Other	0.3
Age	< 24	2.6
	25–34	19.6
	35–44	34.3
	45–54	38.5
	55 +	4.0
Employment type*	Wholetime	73.9
	Retained	11.5
	Wholetime/retained	10.7
	Flexi-duty	3.1
	Other	0.4
Role	Firefighter	59.2
	Crew manager	18.0
	Watch manager	16.9
	Station manager	3.9
	Group manager	1.1
	Area manager	0.2
	Principal manager	0.1
	Other	0.2
Avg. no. fires attend	I do not attend fires	1.1
	< 1 per year	0.3
	1–2 per year	4.1
	1–2 per month	38.8
	1–2 per week	37.0
	> 3 per week	17.4
Years of service	0–9	23.5
	10–19	40.1
	20–29	31.6
	30–39	3.9
	40 +	0.4

Table 1. Participant Demographics. The proportion of total surveyed firefighters belonging to each demographic category. *Wholetime firefighters work full-time contracted hours/shift patterns. Retained firefighters do not have contracted hours but are kept on a paid "retainer" contract, remaining on-call for emergencies. Wholetime/retained firefighters represent wholetime firefighters who work a second retained contract outside of wholetime hours. Flexi-duty firefighters work full-time contracted hours in a more flexible shift pattern.

There was an increasing trend in PPE age with increasing years of service (tau-b = 0.13, $p < 0.05$), fire attendance frequency (tau-b = 0.10, $p < 0.05$), and seniority of role (tau-b = 0.05, $p < 0.05$). However, while the relationship between these variables is significant, the effect of one upon the other is very small.

PPE fit. Almost 10% of all surveyed firefighters expressed concern over the fit of their PPE. Around 70% of these firefighters (n = 739) detailed their concerns as free text (Supplementary File S2, Fig. S2). The most common issues mentioned were:

- Poor PPE fit after washing; PPE shrinking after being sent for professional cleaning.
- Inconsistent sizing; fit varies between same item/size of PPE—e.g. due to different suppliers, varied PPE ages etc.
- Availability of different PPE sizes; poorly tailored to individual body dimensions, firefighters falling "between sizes", poorly fitted to female bodies.

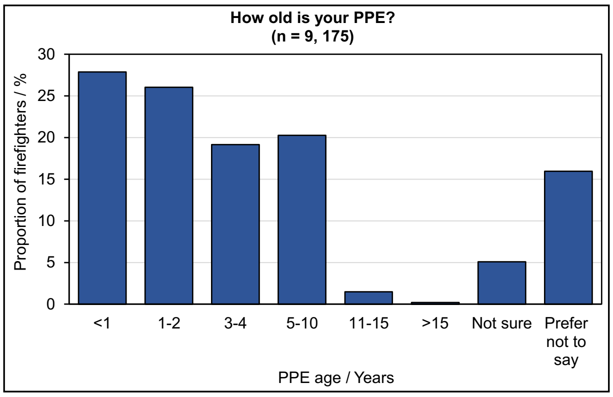

Figure 1. Age of UK Firefighters' PPE. Proportion of firefighters with individually issued PPE indicating the age of their PPE.

- Availability of spare or shared PPE; lack of stock necessitates wearing of ill-fitting PPE from pooled/reserve stock, e.g. while individually issued PPE sent away for professional cleaning.
- PPE irregularly (re-)fitted; fit not updated to match changing body shape/size of wearer.
- Uncomfortable or impractical; fit uncomfortable, restrictive, or makes wearer too hot.

Several items of PPE received specific mention amongst firefighters' concerns over PPE fit:

- Gloves; generally ill-fitting and impractical.
- Boots; too tight, impractical.
- Helmets; generally ill-fitting or uncomfortable.
- Tunics; too short, small or tight.
- Leggings; too short, small or tight.
- Trousers; too short, small or tight.
- Braces/straps; too loose, requiring constant adjustment.

Firefighters using pooled PPE were significantly more likely to report concerns over fit compared to firefighters with individually issued PPE (crude OR = 2.5, 2.1–2.9). A significantly larger proportion of female firefighters expressed concerns over PPE fit compared to male firefighters ($p < 0.05$), being over 3 times more likely to report ill-fitting PPE than their male colleagues (crude OR = 3.1, 2.6–3.8).

At the fire incident. Firefighters were asked about their use of respiratory protective equipment (RPE) while attending fires, including at the early stages of a fire, and post-fire, Fig. 2.

Around 84% (n = 8938) of surveyed firefighters indicated that they often or sometimes attend fires without RPE (Fig. 2). The most common reasons were: habit (46%, n = 4122), "nobody else wears it" (20%, n = 1777) and "time constraints" (17%, n = 1559, Fig. 2).

Around 14% (n = 1245) of firefighters provided other reasons for not wearing RPE; most commonly indicating that RPE was not considered necessary for every task or fire incident. RPE was also described as "uncomfortable" and "impractical", causing over-exertion, over-heating, difficulty breathing, difficulty communicating and/or hindering vision and movement. Several items of RPE (e.g. disposable dust masks) were also specifically cited as being poor quality, or unfit for purpose. Breathing apparatus (BA) was also cited as too heavy, impractical or time consuming for use at all incidents/post-fire activities.

Returning from the fire incident. The proportion of firefighters remaining in PPE and workwear for specific lengths of time after attending a fire are displayed in Fig. 3 and Table S7 (Supplementary File S2).

In general, the proportions of firefighters remaining in PPE for given lengths of time did not significantly differ from expected across length of service, role and employment type categories (Supplementary File S2, Table S7). Most firefighters remained in PPE for up to an hour after attending a fire (Fig. 3A).

There was a slight increasing tendency for firefighters to remain in PPE for the shortest time periods (i.e. < 30 min) the more frequently they attend fires (Table S7). Firefighters attending fires on at least a weekly basis were significantly more likely to remain in PPE for < 30 min, while those attending fires on a monthly or yearly basis were significantly less likely to remain in PPE for < 30 min (Table S7).

Only 26% of surveyed firefighters would de-robe contaminated PPE on-site, before re-entering the appliance/vehicle cab. Most surveyed firefighters (62%) indicated that they would de-robe PPE in the appliance bay back at the station (Fig. 3B). There was a significant association ($p < 0.05$) between de-robing on-site and length of service, role, and fire attendance frequency—whereby senior and longer serving firefighters were increasingly likely to de-robe onsite, whereas firefighters attending fires more frequently were less likely to do so.

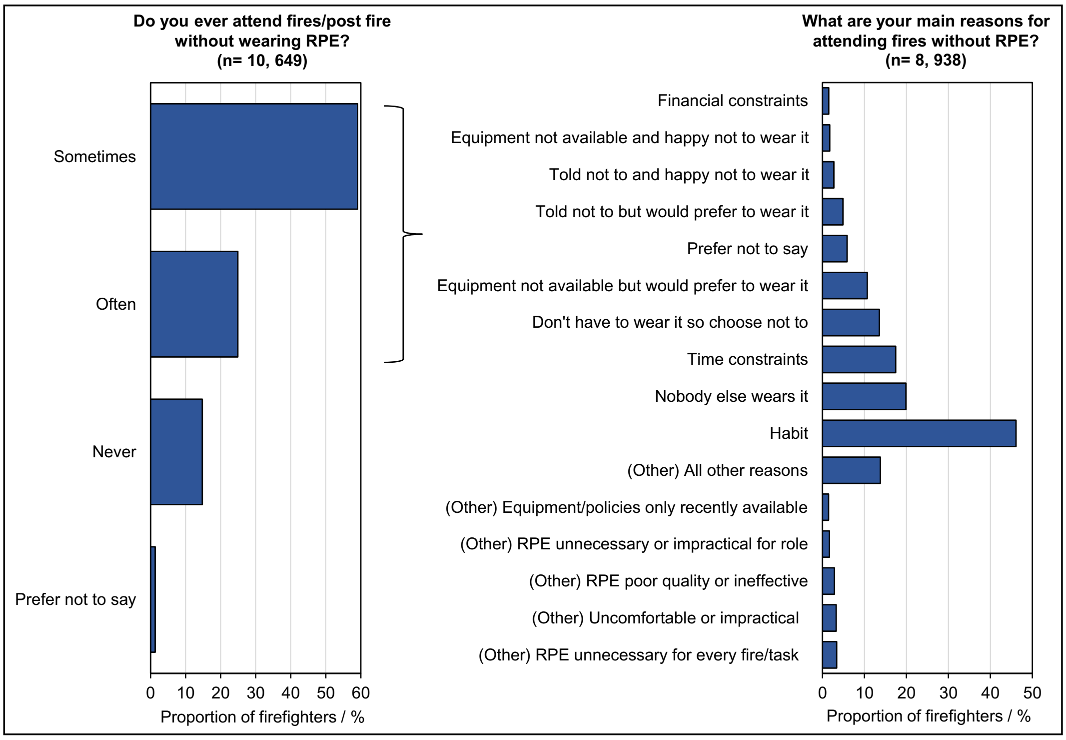

Figure 2. Attending fires without respiratory protective equipment. Proportion of total surveyed firefighters who attend fires without respiratory protective equipment (RPE), and their reasons for doing so. Note that firefighters were able to indicate more than one reason.

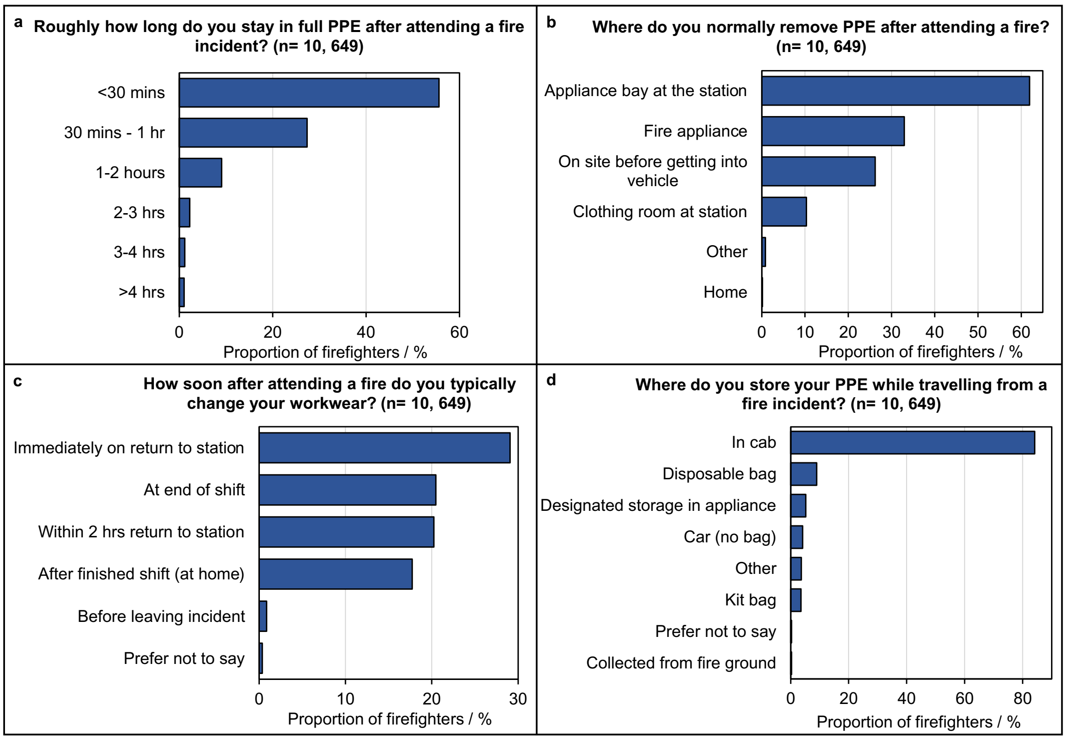

Figure 3. PPE de-robing and storage after fire incidents. Proportion of total surveyed firefighters indicating: (**A**) how long they would normally remain in PPE after attending a fire, (**B**) where they would normally de-robe PPE after a fire, (**C**) how long they would normally remain in workwear after a fire, and (**D**) where PPE is normally stored while travelling back from a fire incident. Note, firefighters were able to select multiple answers to the questions presented in this figure.

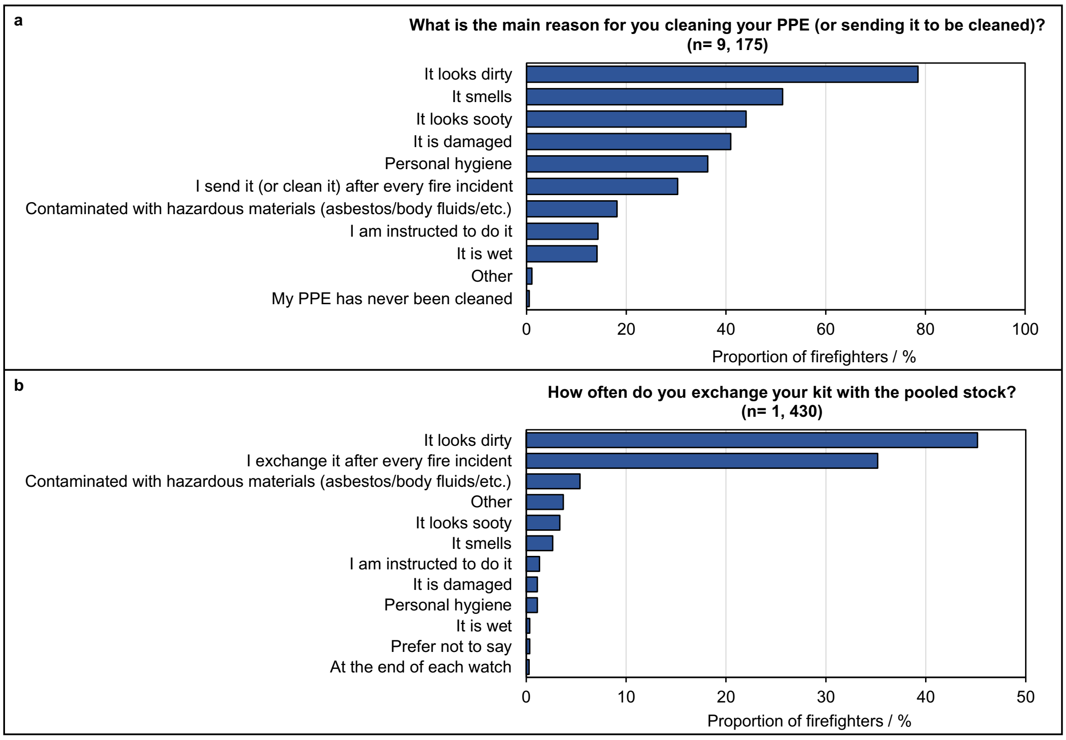

Figure 4. Reasons for cleaning/exchanging PPE in the UK Fire and Rescue Service. (**A**) The proportion of firefighters with individually issued PPE indicating their reasons for cleaning their PPE. (**B**) The proportion of firefighters with pooled PPE indicating their reasons for exchanging PPE with the pooled stock.

Less than 1% of total surveyed firefighters indicated that they would change their workwear before leaving the fire incident (Fig. 3C). Compared to the total surveyed population, firefighters with senior roles were significantly more likely to remain in workwear until the end of a shift or until they had returned home (Supplementary File S2, Table S8). Flexi-duty and retained firefighters were also more likely to remain in workwear for the longest time periods, while a significantly larger proportion of wholetime firefighters changed workwear soon after returning to the station (Table S8). Firefighters attending fires more frequently were also significantly more likely to remain in workwear until the end of a shift (Table S8).

The majority of surveyed firefighters (84%) indicated that PPE was stored in the cab of the appliance while travelling back from fires (Fig. 3D). Only 5% of firefighters indicated that there was a dedicated area of the appliance specifically for the storage of contaminated PPE. The main reason given for selecting "other" was that PPE was still worn while travelling back from an incident and was thus not "stored".

At the station. *PPE decontamination.* Figure 4A,B presents the most common reasons firefighters clean/exchange their PPE.

There was a decreasing tendency to clean PPE after every fire with increasing seniority of role, length of service or fire attendance frequency. The association between these variables was found to be significant ($p < 0.05$) in both firefighters with individually issued and pooled PPE (Supplementary File S2, Figs. S3,S4).

Most firefighters exchanging pooled PPE indicated that PPE was generally received clean and odourless (46%), or at least stained but otherwise clean and odourless (39%). However, 12% of firefighters indicated that pooled PPE either smells of smoke (5%) or appears dirty (7%).

PPE decontamination methods. Table 2 presents the proportion of firefighters who use specific PPE decontamination methods, and the proportion of firefighters who send PPE for professional cleaning on a regular basis.

The associations between demographic variables and the proportions of firefighters sending specific items of PPE for professional cleaning are presented in Supplementary File S2 (Table S9, and Figs. S5,S6). In general, the proportion of firefighters sending PPE for professional cleaning on at least a monthly basis decreased with length of service and seniority of role, but increased with fire attendance frequency for all items of PPE assessed.

Approximately 14% of firefighters with individually issued PPE indicated taking PPE home for cleaning (versus 85% who do not). Of those (n = 1, 314), 92% transported PPE home in a personal vehicle (versus 5% using a service vehicle and 2% using "other" modes of transport). Most (88%) confirmed using a home washing machine to launder their PPE (vs 11% who did not).

No significant associations were found between the tendency to take PPE home and length of service ($p > 0.05$), or seniority of role ($p > 0.05$). However, a significant association was found for fire attendance frequency

	Proportion of firefighters / %			
	Tunic/Trousers (n = 9, 175)	Fire hood (n = 9, 175)	Gloves (n = 10, 605)	BA set (n = 10, 605)
PPE cleaning method				
I send it to be professionally cleaned	90	63	19	1
Washing machine	11	35	14	n/a
Brush	5	0	5	22
Hand wash with detergent/soap	2	2	43	80
Hand wash with water only	2	0	12	11
It is cleaned by a designated person on site	1	1	0	1
Other	1	0	1	5
Paper towel	1	0	2	35
These items do not get cleaned	0	3	20	4
Prefer not to say	0	0	0	1
Professional cleaning frequency				
More than once per week	0	0	0	n/a
Every week	1	1	0	
Every other week	4	3	1	
Every month	18	11	3	
Every other month	38	26	6	
Twice per year	26	23	8	
Once per year	6	8	4	
PPE not sent for professional cleaning	5	27	71	
Prefer not to say	2	2	1	

Table 2. PPE cleaning methods and frequency of professional PPE cleaning in the UK Fire and Rescue Service. Firefighters were able to select multiple cleaning methods. Note that only firefighters with individually issued PPE were able to answer questions about the cleaning of tunic/trousers and fire hoods. Fire gloves are issued on an individual basis as standard, thus trends concerning fire gloves represent firefighters with individually issued and pooled stock PPE. It is not (currently) standard practice to send breathing apparatus (BA) for external professional cleaning in the UK.

($p < 0.05$), whereby firefighters were increasingly likely to take PPE home for cleaning the more incidents they attend.

Workplace contamination. Fire appliances were specifically mentioned by over 20% of firefighters providing free-text concerns over workplace/PPE cleaning ($n = 4072$), the interiors of which were cited as being poorly or rarely cleaned.

Around 85% of surveyed firefighters indicated that they work in stations with a designated zoning system for keeping clean/dirty areas separate, while 14% indicated no such system was in place. However, less than half of firefighters working in stations with a designated zone system (45%) thought that the designated area system was well adhered to.

The majority of surveyed firefighters also indicated that their workplace smelt of fire smoke (87%). Most firefighters (69%) indicated that this smell was only present immediately after a fire, however 18% of firefighters indicated that it was always present. Just 13% of firefighters indicated that their workplace did not smell of smoke.

PPE storage. While 54% of surveyed firefighters indicated that clean and dirty items of PPE are stored separately, a similar proportion (45%) indicated that they are not. Storage locations for clean and/or dirty PPE are displayed in Fig. 5A. Firefighters with pooled PPE were significantly more likely to store PPE in appliance bays (clean or dirty) compared to firefighters with individually issued PPE ($p < 0.05$) (Supplementary File S2, Tables S10,S11), whereas a significantly larger proportion of firefighters with individually issued PPE stored PPE (clean or dirty) in personal vehicles ($p < 0.05$). Clean, individually issued PPE was also significantly more likely to be stored in a personal locker than clean, pooled-PPE ($p < 0.05$) (Tables S9,S10).

Notably, a significantly larger proportion of flexi-duty firefighters indicated storing dirty PPE in personal vehicles ($p < 0.05$) (65% versus around 5% for other employment types).

Storage locations for fire gloves are displayed in Fig. 5B. More than half of all firefighters (57%) store their fire gloves within other PPE items i.e. within helmets (14%), boots (28%) and/or tunic/trouser pockets (28%). Half of these firefighters indicated that clean/dirty PPE is not stored separately (50%), and 21% indicated that their fire gloves were never cleaned at all. Similarly, 48% of firefighters storing fire gloves in a kit bag with other items of PPE indicated that clean/dirty PPE is not stored separately, with 20% indicating their gloves were never cleaned.

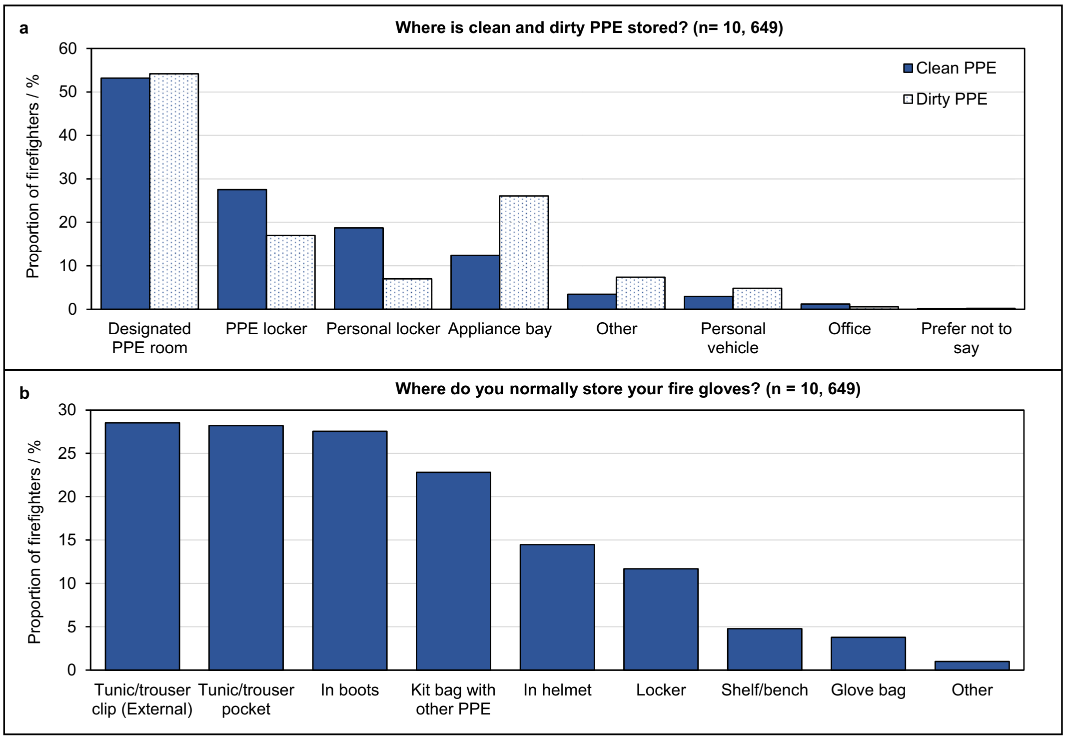

Figure 5. PPE storage in the UK Fire and Rescue Service. The proportion of total surveyed firefighters indicating: (**A**) where clean and/or dirty PPE is normally stored, and (**B**) where fire gloves are normally stored. Note that firefighters were able to select more than one location for the storage of clean/dirty PPE and fire gloves.

The practice of storing fire gloves in other items of PPE was significantly associated with length of service ($p < 0.05$), and fire attendance frequency ($p < 0.05$) (Fig. S7), whereby an increasing proportion of those serving longer and those attending fires frequently store fire gloves in other items of PPE. A significant association was also found for seniority of role, where a decreasing proportion of those in more senior roles stored their gloves in other items of PPE (Fig. S7).

Discussion

PPE provision and fit. The UK Firefighter Contamination Survey uncovered considerable variation in terms of PPE provision and decontamination practices. For example, analysis of free text suggested the standards and types of RPE issued to firefighters were highly variable, and that policies regarding the use of RPE were not enforced, leaving firefighters to make their own judgements. These judgements often deemed RPE unnecessary for open/outdoor fires, fire inspections/investigations, and post-fire activities e.g. damping down or tuning over. In fact, a majority of firefighters indicated that they would often/sometimes attend fires without any RPE- a risk of direct exposure to fire toxins.

The issuing of pooled versus individual PPE was another source of variation, with no clear trends in terms of demographics or geographic region for the use of pooled over individually issued PPE, suggesting variable PPE issuing policies in the UK Fire and Rescue Service.

The survey revealed concerns over the fit of pooled PPE, where firefighters were significantly (twice) more likely to report concerns over fit compared to firefighters using individually issued PPE. Similarly, poor fit and overall condition of reserved stock were given as reasons for firefighters avoiding sending personally issued PPE for professional cleaning on a more frequent basis (e.g. "We only have 2 sets and if we don't have them we have to wear pooled gear which is ill fitting, old and not to the same standard.").

It should also be noted that, regardless of whether PPE was pooled or individually issued, female firefighters were over 3 times more likely to express concerns over the fit of their PPE compared to male firefighters (OR = 3.1, 2.6–3.8). This issue has been repeatedly reported in literature concerning the ergonomics of firefighters' PPE over the last two decades[27], and appears to have persisted in the UK FRS despite the increasing proportion of female firefighters in the Service[26].

As well as compromising comfort and mobility[27,28], it is plausible that poorly fitting PPE may increase a firefighter's risk of direct contaminant exposure e.g. as over-sized garments allow contaminants to penetrate gaps in interfaces, or under-sized garments leave skin/workwear exposed.

PPE maintenance and decontamination. A larger proportion of firefighters (46%) wore PPE less than 2 years old. This is in line with the recommendations of the current British Standard (BS8617) which states that

PPE should be replaced at least every 10 years (or sooner if damaged)[29]. However, around 2% of firefighters were found to have PPE which was over 10 years old, suggesting that this standard may not always be strictly adhered to. PPE has been found to become increasingly susceptible to damage as its age and number of wears increases. This puts firefighters at increased risk of exposure to fire toxins able to infiltrate damaged PPE layers. It is therefore vital that PPE is regularly inspected for damage.

The lighter colour of modern firefighting ensembles is designed to facilitate such inspection[30]—providing contrast against the darker colour of carbonaceous deposits and/or damaged areas. As such, "it looks dirty" was the most common reason surveyed firefighters (79%) gave for cleaning their PPE. However, toxic contaminants and gases which have permeated the fabric of PPE will not be visible. It is therefore important that PPE is thoroughly decontaminated after every fire incident, and not only when it visually appears dirty. Around one third of surveyed firefighters with individual/pooled PPE indicated that PPE is cleaned after every fire incident. Poor uptake of decontamination of such regularity has been documented in US firefighters, who raised concerns over PPE drying time and time-consuming decontamination procedures[31].

Most firefighters indicated that PPE was sent for professional cleaning less than every month (Fig. 5). Further, not all items of PPE were routinely sent for professional cleaning. While the majority of firefighters sent tunic/trousers for professional cleaning (90% with individually issued PPE), fire hoods and fire gloves were sent less frequently by 63% and 19% of firefighters respectively.

Several barriers for sending PPE for professional cleaning were mentioned by firefighters as free text. The slow turn-around time of the professional cleaning service, in combination with a lack of PPE stock, was raised as a concern for firefighters who would otherwise be left without PPE while their sets were sent away. Firefighters also mentioned that PPE items would sometimes go missing after laundering, or that the wrong items were returned to them. However, the concern raised most often was that PPE tended to shrink after it was professionally cleaned, compromising fit e.g. "shrinks a great deal after cleaning so very often too small and have to get pool stock while waiting for suitably sized PPE".

These barriers may offer explanation for the significant association between sending/cleaning PPE after every incident and fire attendance frequency, whereby firefighters were less likely to send/clean PPE after every incident the more frequently they attend fires. These firefighters may not have enough time to decontaminate their PPE between incidents and cannot afford to be without PPE (or left with ill-fitting PPE) for extended periods.

Firefighters in more senior roles and those who had served the longest were also increasingly less likely to clean/send their PPE after every incident. These significant associations may plausibly be explained by senior firefighters attending incidents in supervisory (rather than active firefighting) roles, where PPE does not become visibly contaminated and is therefore not cleaned. Long-serving, or incident-active firefighters may also have become desensitized to the threat of contamination or may not have received up-to-date training concerning the latest scientific evidence regarding the health effects of contaminant exposure[23].

PPE storage and cross contamination. The survey uncovered several potential routes via which contaminants can travel back from fire incidents to firefighters' workplaces and their homes. Many of these routes are a result of cross contamination, and begin at the fire incident.

Most surveyed firefighters (84%) indicated that they would de-robe PPE worn during an incident after they had re-entered the appliance cab. This means that contaminants remaining on firefighters' PPE can be transferred to the surfaces of the appliance cab, and then to fire stations, offices etc. (or personal vehicles and homes). Only 5% of surveyed firefighters indicated that there was dedicated storage within appliances for dirty PPE, or that dirty PPE was bagged in disposable plastic bags during storage (reported by 9% of firefighters). Firefighters' free-text comments also revealed appliance interiors were rarely cleaned, allowing contaminants to build-up.

Significant proportions of firefighters (see Supplementary File S2, Tables S7,S8) indicated that they would remain in their PPE, or at least in their workwear, for an extended length of time after attending a fire incident, increasing opportunities for cross contamination.

Also of concern were the 14% of firefighters who indicated taking their PPE home to clean, storing contaminated PPE in a personal vehicle. This represents a direct route for contaminants to travel back to firefighters' homes and their families. Flexi-duty firefighters were significantly more likely than expected to indicate storing soiled PPE in personal vehicles, most likely due to the nature of their employment. Special attention to the PPE storage needs of these firefighters is required to ensure that contaminated PPE is appropriately contained.

Laundering PPE in domestic-style washing machines has been found to be a key source of cross contamination, where contaminants may be transferred to laundry water and/or components of washing machines and later to other items of laundry[15]. This is concerning given the prevalence of firefighters using washing machines for laundering fire hoods (35% of firefighters) and gloves (14% of firefighters) in the UK FRS. These practices should be reviewed in order to minimise cross contamination risks.

One of the strongest cross-contamination examples uncovered by the survey, was the storage of fire gloves. Around 57% of firefighters indicated that they would store their fire gloves in other items of PPE, potentially allowing contaminants to transfer to the inside of helmets, boots and tunic/trouser pockets, which may all make direct contact with the skin of the wearer. What's more, fire gloves are rarely sent for professional cleaning (19% surveyed firefighters).

Those who attended fires on more frequent bases, and who have served longer in the UK Fire and Rescue Service were increasingly likely to store fire gloves in other items of PPE. This is concerning given the greater number of direct exposure events these demographics have received, and indicates a lack of awareness and/or complacency over the comparatively subtle issue of cross contamination.

Less than half of firefighters (45%) indicated that clean and dirty PPE is not stored separately. Even if the clean and dirty PPE was stored separately, it was often kept in in the same room. Around 22% of firefighters indicated that there was no (or a poorly adhered to) system for separating clean/dirty areas within the station. In fact, a small proportion of firefighters (1%) indicated that PPE was stored in "clean" areas e.g. offices. This implies that, unless there are e.g. two PPE rooms, one dedicated for clean PPE and one for dirty PPE, the level of separation between clean and dirty PPE may not be sufficient to protect against cross contamination. For example, contaminants off-gassing from dirty PPE may diffuse to the area of the room in which clean PPE is stored. Similarly, removal of contaminants from the firefighter's workplace surfaces may be less challenging if the level of separation between clean/dirty PPE is greater (e.g. storing dirty PPE outside of the station).

Conclusions

The UK Firefighter Contamination Survey uncovered considerable variation in terms of PPE provision, cleaning and storage in UK Fire and Rescue Services. Several practices which increase the risk of direct contaminant exposure and/or cross-contamination were found to be prevalent amongst surveyed firefighters. As such, the survey identified several opportunities for immediate intervention:

- Policies concerning the use of RPE should be revised and better enforced. Firefighters should wear RPE at all fires, including during pre- and post-fire tasks. Different levels of protection may be required depending on the task/fire, thus adequate RPE should be available at all times.
- Firefighters in managerial roles should set an example to more junior colleagues in terms of adhering to PPE/workplace maintenance and decontamination practices.
- To prevent the passage of contaminants from fire incidents back to stations/homes, PPE and workwear should be de-robed on-site of the incident, before firefighters re-enter the appliance cab.
- Contaminated PPE/workwear should be:
    - Bagged in disposable plastic bags on-site before being placed in any (fire and rescue service) vehicle in order to contain off-gassing/surface contaminants and then stored in a designated area of the appliance/vehicle, or, preferably collected by professional cleaning services on-site.
    - All personnel who may have been contaminated at the incident, whether involved in firefighting activity or not, should undergo a process of personal decontamination before changing into clean workwear, such that only ever clean PPE/workwear makes contact with the interior of the appliance/vehicle cab.
- PPE storage and cleaning policies should prevent firefighters from cleaning PPE at home and/or transporting contaminated PPE in personal vehicles.
- Review of current policy for the decontamination of vehicles shows existing policy to be inadequate. FRSs should review their policy and develop suitable and sufficient decontamination procedures.
- The decontamination of appliance/vehicle interiors should be carried out in accordance with those improved procedures and should be conducted after every fire incident (however small) or other incidents where contamination is suspected.
- Storage of clean/ bagged dirty PPE also requires proper separation in order to prevent cross contamination, e.g. through enforcing clean/dirty zones in the station.
- Where PPE cannot or has not been collected on-site at an incident, dirty and bagged PPE should be sent for professional decontamination as soon as possible after every incident to ensure thorough removal of contaminants. This requires re-evaluating the policies and provisions concerning supplies of pooled PPE stock, PPE fit, and the length of the professional cleaning service.
- Regular training/ message-reinforcement on the health effects of contaminant exposure and/or best decontamination practices may raise firefighters' awareness of cross contamination and serve to reduce the prevalence of practices such as storing fire gloves within other items of PPE, laundering fire hoods in home washing machines etc.
- Finally, standardisation is required in order to ensure effective decontamination practices. Promoting high-quality, nationally consistent policy on minimising exposures to fire toxins will help to reduce the incidence of occupational diseases and cancers in UK firefighters.

Limitations

The UK Firefighter Contamination Survey was able to amass a sizeable sample of UK firefighters, potentially lending greater precision to the trends analysed in its results. However, the survey was unable to ask firefighters about all aspects of contaminant exposure or decontamination in specific detail. Thus, further trends in terms of PPE and workplace contamination may yet to be uncovered.

Additionally, the survey was cross-sectional in design; only able to assess firefighters' current practices and exposures. It does not consider whether this current practice/exposure is representative of past practices/exposures. Thus, the survey cannot accurately account for how decontamination practices have changed over time and/or the reasons for this change.

The survey is potentially subject to participation bias, whereby firefighters with grievances against the Fire and Rescue Service may have been more likely to participate. Conversely, the survey may also under-represent firefighters' personal experiences/adherence to decontamination practices as firefighters may plausibly have felt pressured to answer more "favourably" (for example indicating that they adhere to practices or station policies more frequently than they do in reality).

Data availability

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

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Author contributions

A.C. and A.S. devised the survey and distributed it to firefighters with the assistance of the Fire Brigades Union. A.S., A.C. and T.W. coded free text answers for analysis. A.S. and T.W. analysed trends in the data, with input from L.T. and A.R. A.S. and T.W. drafted the first iteration of the manuscript. A.S. and T.W. reviewed and edited the final version of the manuscript for publication.

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Competing interests
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Cancer incidence amongst UK firefighters

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Firefighters suffer an increased risk of cancer from exposures to chemicals released from fires. Our earlier research has found that fire toxicants not only remain on firefighters' PPE, but are also tracked back to fire stations. The UK Firefighter Contamination Survey assesses firefighters' risk of developing cancer due to occupational exposure to fire toxins. Over 4% of surveyed firefighters were found to have a cancer diagnosis, with the age-specific cancer rate up to 323% higher (35–39 year olds) than that of the general population. Firefighters who had served ≥ 15 years were 1.7 times more likely to develop cancer than those who had served less time. Firefighters were at least twice as likely to be diagnosed with cancer if they noticed soot in their nose/throat (odds ratio (OR) = 2.0, 1.1–3.5), or remained in their PPE for more than four hours after attending a fire incident (OR = 2.3, 1.1–5.2). Also associated with an increased likelihood of cancer was: eating while wearing PPE (OR = 1.8, 1.2–2.7); failing to store clean/dirty PPE separately (OR = 1.3, 1.0–1.7); working in a station that smells of fire (OR = 1.3, 1.0–1.8) or not having designated (separated) clean and dirty areas (OR = 1.4, 1.1–1.7); using an on-site washing machine to launder fire hoods (OR = 1.3, 1.0–1.7); feeling that cleaning is not taken seriously at work (OR = 1.5, 1.2–2.0).

Firefighters continue to suffer chronic illnesses as a result of occupational exposure to fire toxins[1–5]. Research has found that carcinogens from fire incidents not only remain on firefighters' personal protective equipment (PPE), but are also tracked back to fire stations[3,6–8]. These "contaminants" are receiving increasing attention from Fire and Rescue Services globally, and are the focus of decontamination procedures which aim to minimise firefighters' chronic exposure to toxic fire effluents[9,10].

To date, the majority of research concerning firefighters' chronic exposure to contaminants has focused on the context of US firefighters[6,7,11]. Comparatively little research characterises the occupational health of UK firefighters. This research gap has seen the UK's Industrial Injuries Advisory Council (IIAC) fail to recommend cancer (except mesothelioma) as a prescriptive disease in firefighters[12]. Thus, presumption cannot be assumed for firefighters suffering cancer in the UK, compromising their access to workplace compensation. This is in contrast to some states in the US and Canada, where presumptive legislation protects firefighters' right to compensation for a range of cancers and other chronic illnesses[13].

A lack of research concerning UK firefighters' occupational health also poses challenges for the effective implementation of preventative measures, i.e. measures which would limit chronic exposure to harmful contaminants in the first instance. Without an established baseline, it is difficult to implement or quantify the effectiveness of such preventative measures. Similarly, for UK Fire and Rescue Services (FRSs) required to operate under increasingly strained resources[14], a lack of current research makes it difficult to prioritise such measures in a resource-efficient manner.

The UK Firefighter Contamination Survey was conducted in order to provide an evidence base for understanding the risks and common sources of contaminant exposure, informing decontamination and future research recommendations. The survey probed UK firefighters' experiences and behaviours on a range of topics including their health, exposure to fire toxins (duration, frequency etc.), contamination and decontamination practices, PPE (provision, maintenance, cleaning, storage, fit etc.)[8], attitude/culture, awareness and training[15].

This manuscript presents links between firefighters' occupational exposure to fire toxins and their risk of developing cancer.

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Methods

Survey design. The methods used to conduct the survey and analyse its results are detailed in Wolffe et al., 2023 (i.e. "Contamination of UK Firefighters Personal Protective Equipment and Workplaces"[8]). Ethical approval for the survey was granted by the University of Central Lancashire Ethics Committee, and all analyses were conducted in accordance with relevant guidelines and regulations.

Briefly, all serving UK firefighters were eligible to take part in the survey and were recruited to participate via email with the aid of the UK's Fire Brigades Union. Informed consent was obtained from all participants.

The survey consisted of 64 questions covering five key topics: demographics, PPE, contamination, attitudes, awareness and training, and health (see Supplemental File S1). The responses of a total of 10,649 firefighters were included for analysis, representing approximately 24% of the UK's total firefighter workforce[8].

Cancer. Over 4% of serving firefighters (n = 441), who responded to the questionnaire, indicated that they had received a cancer diagnosis. 85% (n = 373) of those firefighters provided further details on their diagnosis. To determine whether diagnoses might be linked to occupational exposure, these firefighters were asked to indicate how many years they had served in the Fire and Rescue Service prior to diagnosis. Any firefighters who indicated their diagnosis was received before joining the Fire and Rescue Service (n = 17) were excluded from further analysis. Similarly, firefighters who did not wish to provide an answer to this question (n = 49) were also excluded from further analysis. Thus, any subsequent analyses on the relationship between cancer and exposure to fire toxins are based on the 307 firefighters who confirmed their cancer diagnosis was received after they joined the Fire and Rescue Service.

Analysis. Firefighters' cancer diagnosis status was cross tabulated with several proxies of contaminant exposure. The proportion of firefighters with a cancer diagnosis in each exposure category was then compared. For example, 17 flexi-duty firefighters were diagnosed with cancer out of a total of 335, thus the proportion of flexi-duty firefighters with cancer is reported as 5%. Odds ratios (OR), with 95% confidence intervals, were used to assess the statistical significance of differences between more/less exposed groups.

Multiple logistic regression was used to account for the confounding effects of other (i.e. non-contaminant) cancer risk factors for which there is evidence in the scientific literature (e.g. smoking[16], excessive alcohol consumption[17] etc.). Analyses were conducted using Statistical Package for Social Sciences (SPSS) version 28.0.1.1 and the statsmodels module for Python[18]. A step-wise backward variable selection method was used and is presented in Supplemental File S2. Initial modelling included all well-known, non-contaminant cancer risk factors assessed in the survey i.e. sunbathing, excessive drinking, smoking, diabetes, high blood pressure, problems sleeping, and age (Supplementary File S2). However, age was the only independent variable in the final analysis model found to have a significant positive relationship with cancer incidence in UK Fire and Rescue Services (Supplementary File S2). Therefore, all reported odds ratios are adjusted for age (unless otherwise stated).

Results and analysis

Participant demographics were analysed and presented in Wolffe et al. (2023)[8], and were not found to significantly differ from the English firefighter population[19] with respect to sex ($p > 0.05$), but appeared to under-represent younger age categories, retained firefighters, and those belonging to an ethnic minority ($p < 0.05$).

Around three percent of firefighters (n = 307) indicated that they had received a cancer diagnosis after joining the Fire and Rescue Service. The modal age of diagnosis was 45–49 (28% firefighters with cancer).

Twenty-eight different cancers were coded from the free-text responses of those diagnosed after joining the Fire and Rescue Service. Figure 1 displays the range and frequency of these cancers. Skin cancer was by far the most prevalent cancer reported (36% firefighters with cancer).

Demographics and cancer. Participant demographics were compared to English FRS statistics[20] in Wolffe et al. (2023)[8], and were in broad agreement.

The proportion of firefighters with a cancer diagnosis increased with age, length of service and seniority of role (Fig. 2). When adjusting for age, managerial firefighters (i.e. crew, watch, station, group, area, and principal managers combined) were not found to be any more likely to develop cancer than non-managerial firefighters (OR = 1.1, 0.8–1.3). However, firefighters who had served 15 years or longer were 1.7 times more likely to develop cancer than those who had served less than 15 years (OR = 1.7, 1.2–2.5).

Given the strong contribution of age to cancer diagnosis status[21], a crude age-specific cancer rate was used to better compare the prevalence of cancer among surveyed firefighters to that of the general UK population (Table 1). Crude age-specific rates are calculated by dividing the number of firefighters in each age bracket with a cancer diagnosis by the total number of surveyed firefighters and multiplying by 100,000. It is worth noting that the relatively small sample size for female firefighters may skew results.

Flexi-duty firefighters appeared to be nearly twice as likely to develop cancer than those on all other contract types combined (crude OR = 1.9, 1.1–3.1). However, many surveyed flexi-duty firefighters were over 50 years old (47%). Consequently, they were not found to have a significantly increased cancer odds ratio when adjusting for their age (OR = 1.2, 0.8–2.1).

The geographic distribution of cancer diagnoses is presented in Supplementary File S2 (Fig. S9).

Firefighters' health and lifestyle. Firefighters were asked to provide information on several lifestyle factors with known links to chronic health conditions such as cancer, i.e. exercise habits, alcohol consumption, smoking and sunbathing habits (see Supplemental Files S1-S2).

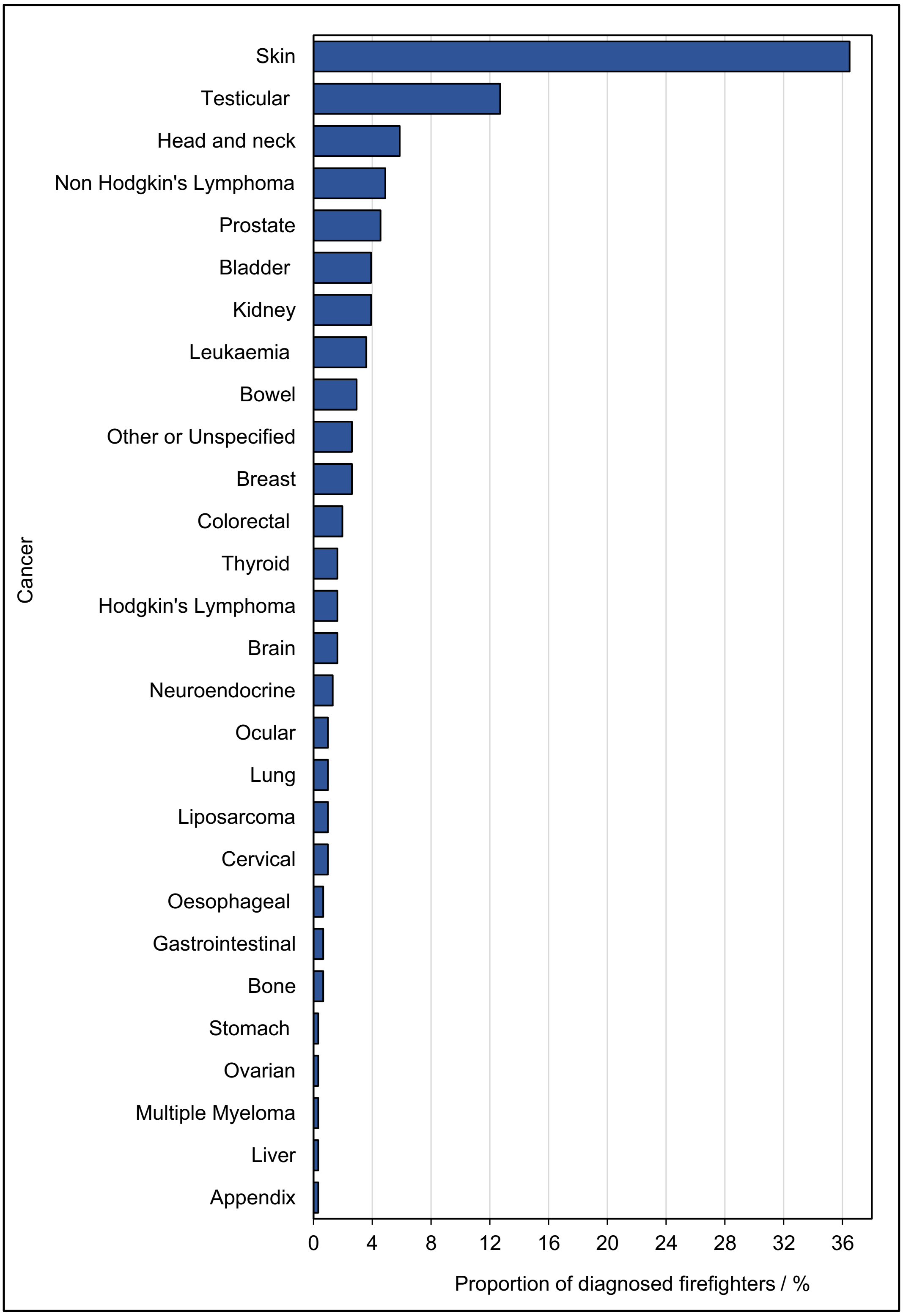

Figure 1. Range and frequency of cancers among diagnosed firefighters in the UK Fire and Rescue Service. Prevalence of specific cancers among firefighters who received a diagnosis after joining the Fire and Rescue Service (i.e. a % of 307). Cancers were reported as free text and manually coded for analysis.

Firefighters in several "higher risk" lifestyle categories did not have a statistically significant increased cancer odds ratio (i.e. those that exercise 2 h or less per week compared to those who exercise more frequently, those

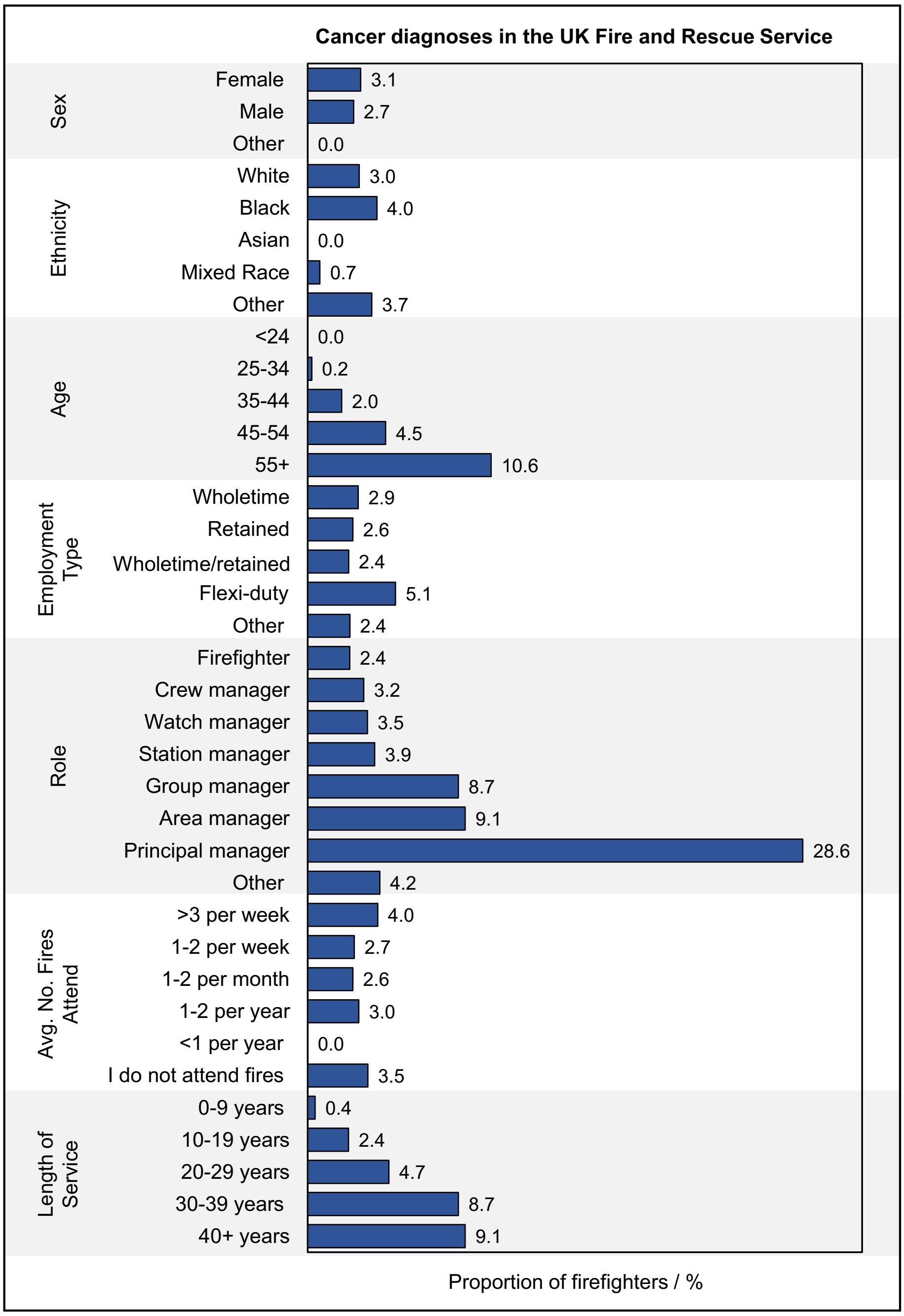

Figure 2. Demographics and Cancer Prevalence in the UK Fire and Rescue Service. The proportion of firefighters with a cancer diagnosis in each demographic category is presented (i.e. a percentage of the total number of female firefighters in the survey, male firefighters in the survey, etc.). Note that the relatively small sample size of certain demographic groups (e.g. female firefighters) mean the above results should be interpreted cautiously (see Wolffe et al., 2023 for demographic proportions). Also note that wholetime firefighters work full-time contracted hours/shift patterns. Retained firefighters do not have contracted hours, but are kept on a paid "retainer" contract, remaining on-call for emergencies. Wholetime/ retained firefighters represent wholetime firefighters who work a second retained contract outside of wholetime hours. Flexi-duty firefighters work full-time contracted hours in a more flexible shift pattern.

that sunbathe/use sunbeds compared to those who never sunbathe/use sunbeds, those that drink 15 units or more of alcohol per week compared to those who drink fewer than 15 units per week, and those who smoke compared to those who do not smoke).

Annual fitness tests were available for just over half (52%) of all surveyed firefighters, with the exception of breathing apparatus (BA) instructors, who indicated via free-text that these tests were available on a 6-monthly basis.

Age at cancer diagnosis	Crude age-specific rate of cancer diagnosis (per 100 000 people)		
	Male (M)/Female (F)	Surveyed firefighters	English population (for 2017)
20-24	M	37.6	29.7
	F	0	32.3
25-29	M	65.7	46.9
	F	9.4	70.8
30-34	M	262.9	66.1
	F	18.8	117.9
35-39	M	375.6	88.8
	F	18.8	168.6
40-44	M	441.4	119.5
	F	75.1	257.4
45-49	M	610.4	208.5
	F	65.7	410.0
50-54	M	394.4	384.0
	F	9.4	566.6
55-59	M	47.0	676.4
	F	0	724.4
60-64	M	37.6	1127.1
	F	0	959.3

Table 1. Crude, age-specific rate (per 100, 000 people) of cancer in surveyed firefighters compared to the population of England in 2017[22].

Around 69% of firefighters indicated that they had access to a regular, 3-yearly medical screening for their health. A smaller proportion of firefighters (13%) indicated access to an annual medical health screening (Fig. 3). An exception was for BA instructors, who were provided with a 6-monthly medical screening (data not presented).

Access to an Occupational Health Unit (OHU) was available to a majority of surveyed firefighters (72%), although 27% of firefighters said that this facility was not readily accessible. No clear trend was observed for FRS location/size and access to an OHU (Supplementary File S2, Fig. S7). A similar proportion of managerial (76%) and non-managerial (70%) firefighters had access to an OHU (Supplementary File S2, Fig. S8), although managers were 1.3 times more likely to have access to an OHU when compared to non-managerial firefighters (crude OR = 1.3, 1.2–1.5).

Figure 3 presents the most common health-related screening/tests firefighters had received over the past three years. These were: hearing tests (84%); blood pressure tests (83%); eye tests (82%); and lung function/spirometry (79%). Any type of screening for cancer (whether routine or diagnostic) was received by 14% of all surveyed firefighters. The majority of firefighters who selected the "other" option indicated that they had received none of the listed health screenings (equivalent to 1.2% of all surveyed firefighters).

Cancer screenings were generally positively correlated with age, with the proportion of firefighters receiving screening increasing for older age brackets (Fig. 3).

As well as cancer, firefighters were asked to indicate whether they have had other health conditions such as: problems sleeping, high blood pressure, or diabetes; all of which increase cancer risk. However, no significant association between these conditions and cancer incidence was found for surveyed firefighters after adjusting for age (Supplemental File S2).

Occupational exposure to toxins and cancer. *Exposure to fire contaminants at/during the fire incident.* A larger proportion of firefighters who indicated that they *often* attend incidents without wearing respiratory protective equipment (RPE) were diagnosed with cancer after joining the Service compared to those who *never* attend incidents without wearing RPE (3.4% versus 2.9%). However, the difference between these two groups was not found to be statistically significant (OR = 1.2, 0.8–1.7)). Similarly, no statistical significance was found for firefighters who only sometimes (versus never) attend fire incidents without RPE (OR = 0.9, 0.7–1.3).

Interestingly, a statistically significantly larger proportion ($p < 0.05$) of cancer diagnoses was found for those firefighters who preferred not to say if they attended fire incidents without wearing RPE (5.7%) when compared to firefighters who always wear RPE. In fact, those who preferred not to say were more than twice as likely to indicate they had been diagnosed with cancer compared to those who *never* attend without RPE (crude OR = 2.2, 1.0–4.9).

It should be noted that RPE covers a wide range of equipment, providing different levels of protection. For example, breathing apparatus is designed to protect the wearer from inhaling toxic gases/particulates, whereas disposable dust masks only offer protection from larger particles (i.e. not from inhalation of toxic gases). Thus, the frequency with which surveyed firefighters attend incidents with/without RPE may not accurately reflect potentially significant differences in exposure to contaminants.

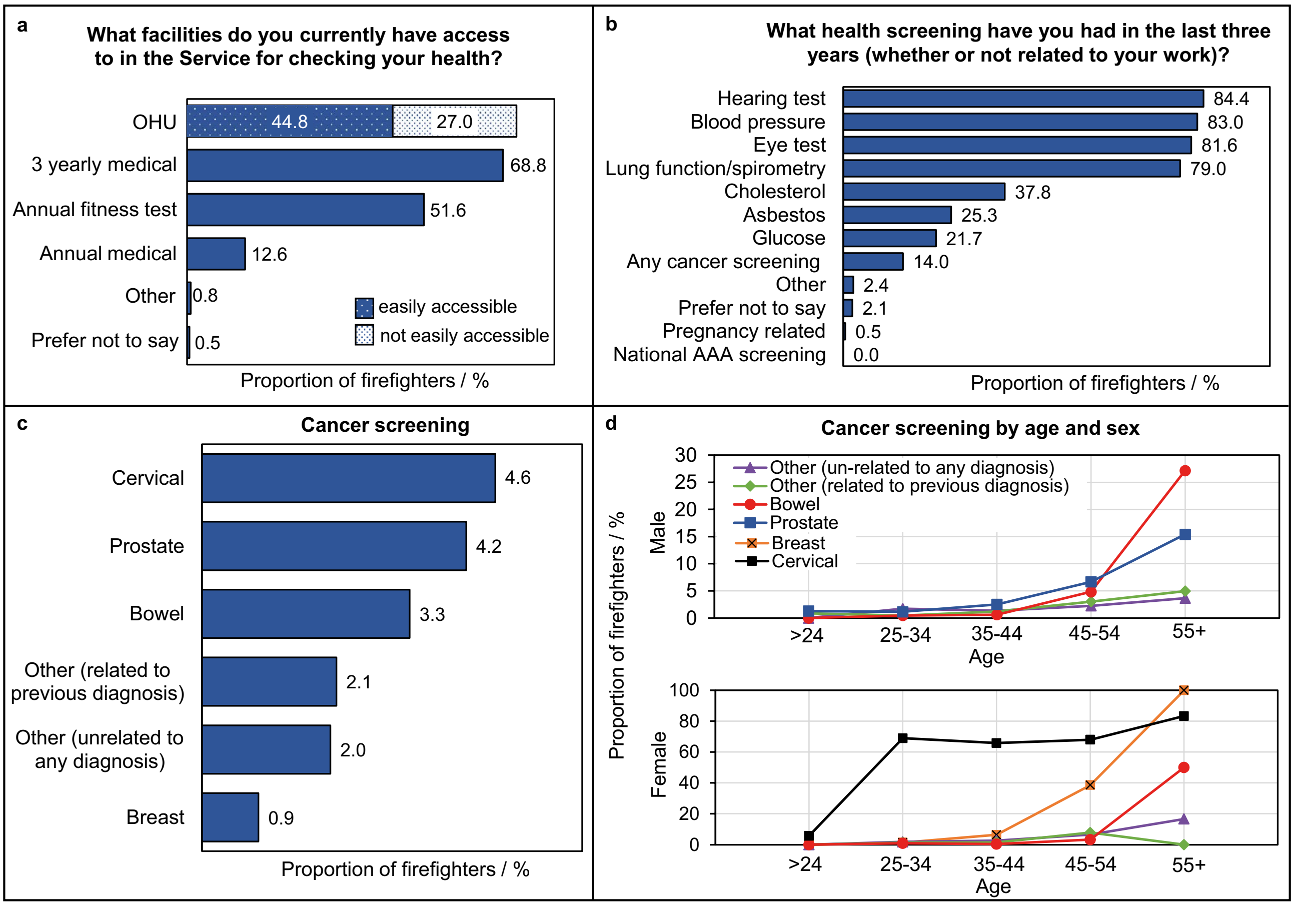

Figure 3. **Health Screening in UK Fire and Rescue Services.** The proportion of total surveyed firefighters who (**a**) have access to health screening facilities within their Service, (**b**) received specific health screening/tests over the last three years, and (**c**) received specific cancer screening over the last three years. Note firefighters can choose more than one type of screening and screening facility. (**d**) The proportion of male or female firefighters in each age bracket who received specific cancer screenings. AAA = Abdominal Aortic Aneurysm, OHU = Occupational Health Unit.

Personal contamination. Several measures of personal contamination were significantly associated with an increased cancer odds ratio, i.e. eating while wearing PPE (OR = 1.8, 1.2–2.7), noticing soot in the nose/throat for an extended time after attending an incident (OR = 2.0, 1.1–3.5), and staying in PPE for more than four hours after an incident (OR = 2.3, 1.1–5.2). ORs are presented in Fig. 4.

No clear association was found between cancer diagnosis and firefighters' subjective ratings of feeling contaminated (Supplementary File S2, Fig. S10). However, a clear trend in which areas firefighters felt were most contaminated after fire incidents was found. Face, neck, hands and hair were all consistently rated as feeling more highly contaminated than arms, legs, and trunk.

Contaminated PPE and cancer. Almost all proxies of contaminant exposure from PPE were associated with an increased odds ratio of developing cancer among surveyed firefighters (Fig. 5). However, this increase was only statistically significant for failing to store clean and dirty PPE separately (OR = 1.3, 1.0–1.7), and for using a washing machine to clean contaminated fire hoods (OR = 1.3, 1.0–1.7), with storing fire gloves within other items of PPE (i.e. within helmets, boots, and tunic/trouser pockets) near to the threshold of significance (OR = 1.3, 1.0–1.6).

PPE fit did not appear to significantly influence the proportion of firefighters with a cancer diagnosis (OR = 1.2, 0.8–1.7). Roughly equal proportions of firefighters (around 3%) in each PPE fit category received a cancer diagnosis (i.e. PPE fits—2.9%, PPE does not fit—3.1%, prefer not to say—2.9%). Similarly, a roughly equal proportion of firefighters were diagnosed with cancer among those issued with personal-use PPE (2.9%) and those issued with pooled-stock PPE (3.2%, OR = 1.2, 0.9–1.6 for pooled vs personal-use PPE).

Contamination at the workplace and cancer. Two survey questions asked firefighters about fire contamination at their station, assessing whether workplaces smelt of fire, and whether workplaces had a system for designating separate clean and dirty areas. For both questions, the proportion of firefighters with cancer was greater for those who indicated workplace contamination compared to those who did not (Fig. 6B, C). Both measures of workplace contamination were significantly associated with an increased odds ratio of developing

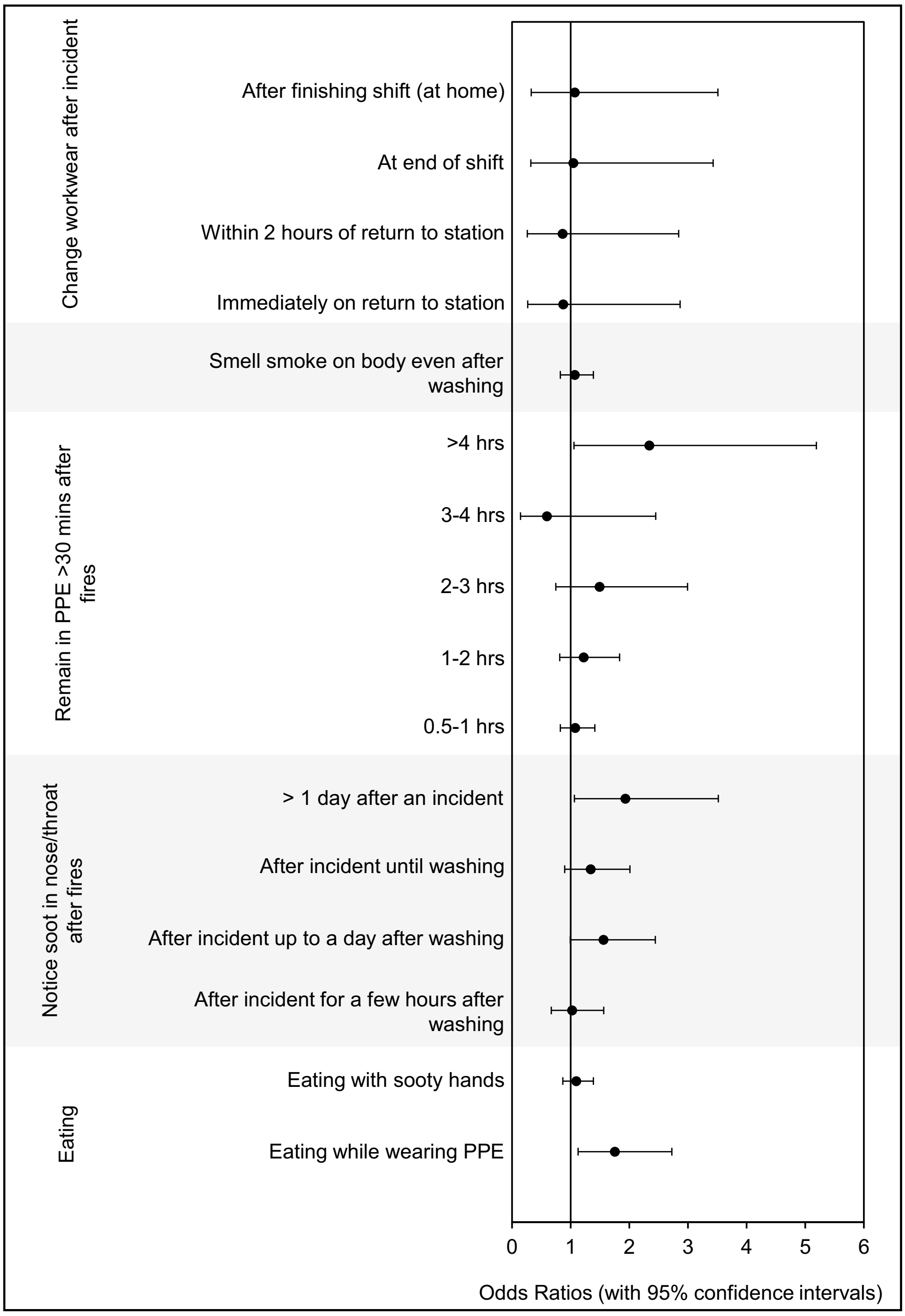

Figure 4. Personal contamination and cancer odds ratios for UK Firefighters. Odds ratios (with 95% confidence intervals) were adjusted for age.

cancer: OR = 1.3 (1.0–1.8) for fire smell in the workplace, and OR = 1.4 (1.1–1.7) for lack of (or unadhered to) clean/dirty areas (Fig. 6A).

Interestingly, smell of fire in the workplace was reported by a majority of surveyed firefighters (87%) regardless of whether those firefighters had designated clean/dirty areas within their workplaces. However, it was found that firefighters whose stations did not have designated clean/dirty areas were almost twice as likely to report a smell of fire in the workplace compared to those working in stations *with* designated clean/dirty areas (crude OR = 1.8, 1.5–2.0).

Attitudes, awareness and training. Firefighters who believed that cleaning was not taken seriously at their workplace had a significantly higher cancer odds ratio compared to those who felt that cleaning was taken seriously (OR = 1.5, 1.2–2.0), Fig. 7A. Figure 7D illustrates the larger proportion of firefighters diagnosed with cancer among those who believe that cleaning is not taken seriously. Not receiving training on fire toxins and

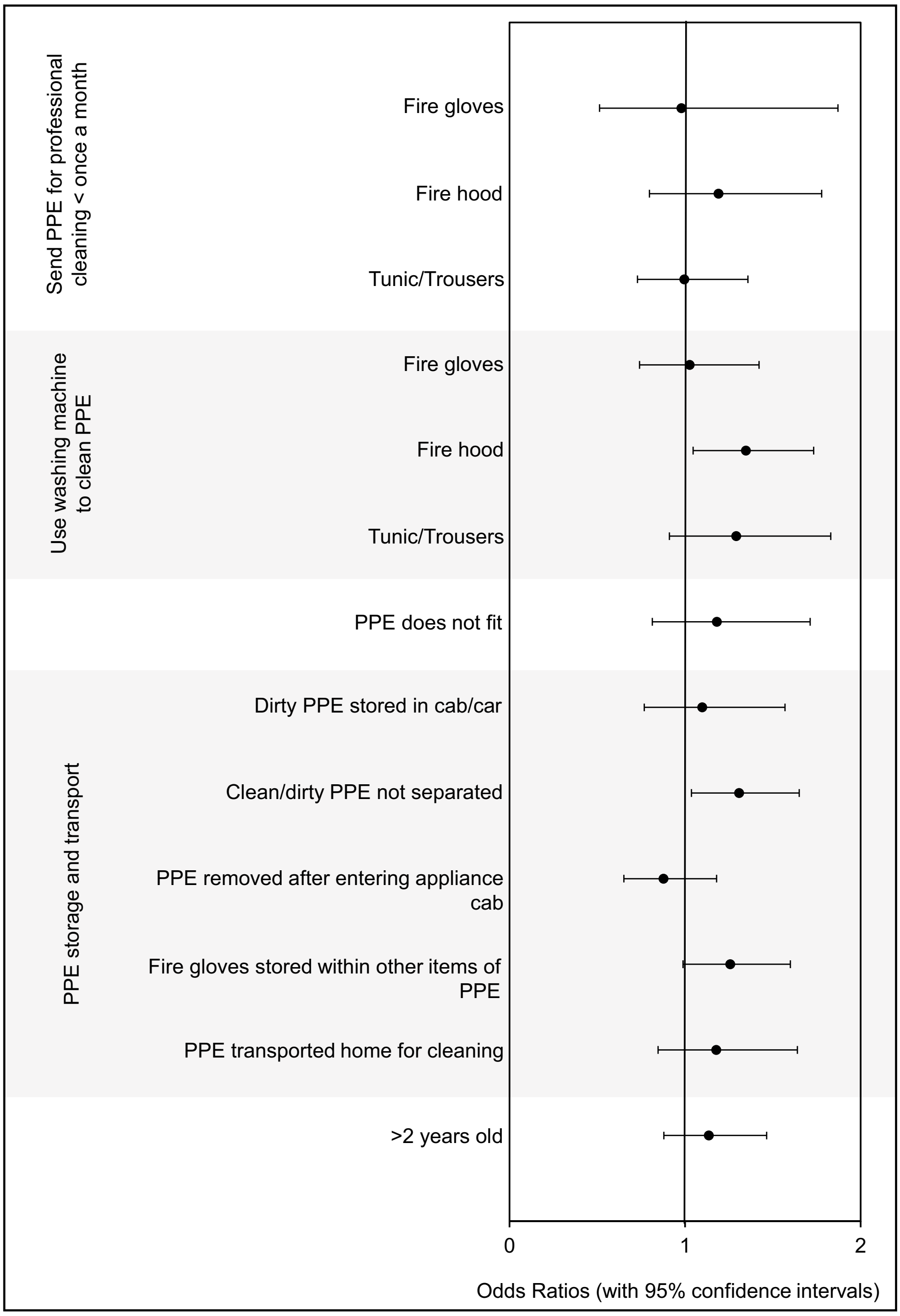

Figure 5. PPE contamination and cancer odds ratios for UK firefighters. Odds ratios (with 95% confidence intervals) were adjusted for age.

their health outcomes was also associated with an increased odds ratio of developing cancer, although this was not found to be statistically significant (OR = 1.2, 0.9–1.5), Fig. 7A (see similar proportions of cancer diagnoses among these two groups in Fig. 7B). Similarly, believing in the "badge of honour" was almost equivalent to not believing in the "badge of honour" in terms of reporting cancer diagnoses (OR = 1.0, 0.8–1.2, Fig. 7A, C).

Discussion

Prevalence of cancer in UK firefighters.

The survey found that only 14% of firefighters had received screening for cancer in the last three years, and that this was mostly the age-related screening offered through the National Health Service (NHS) to all UK citizens. Only 2% of firefighters had received cancer screening which was not a part of this NHS provision, and was also not related to a previous cancer diagnosis (Fig. 3).

Skin cancer was most prevalent amongst firefighters diagnosed with cancer after joining the Fire and Rescue Service (Fig. 1), mirroring international findings[23–26]. The most common cause of skin cancer is exposure to UV

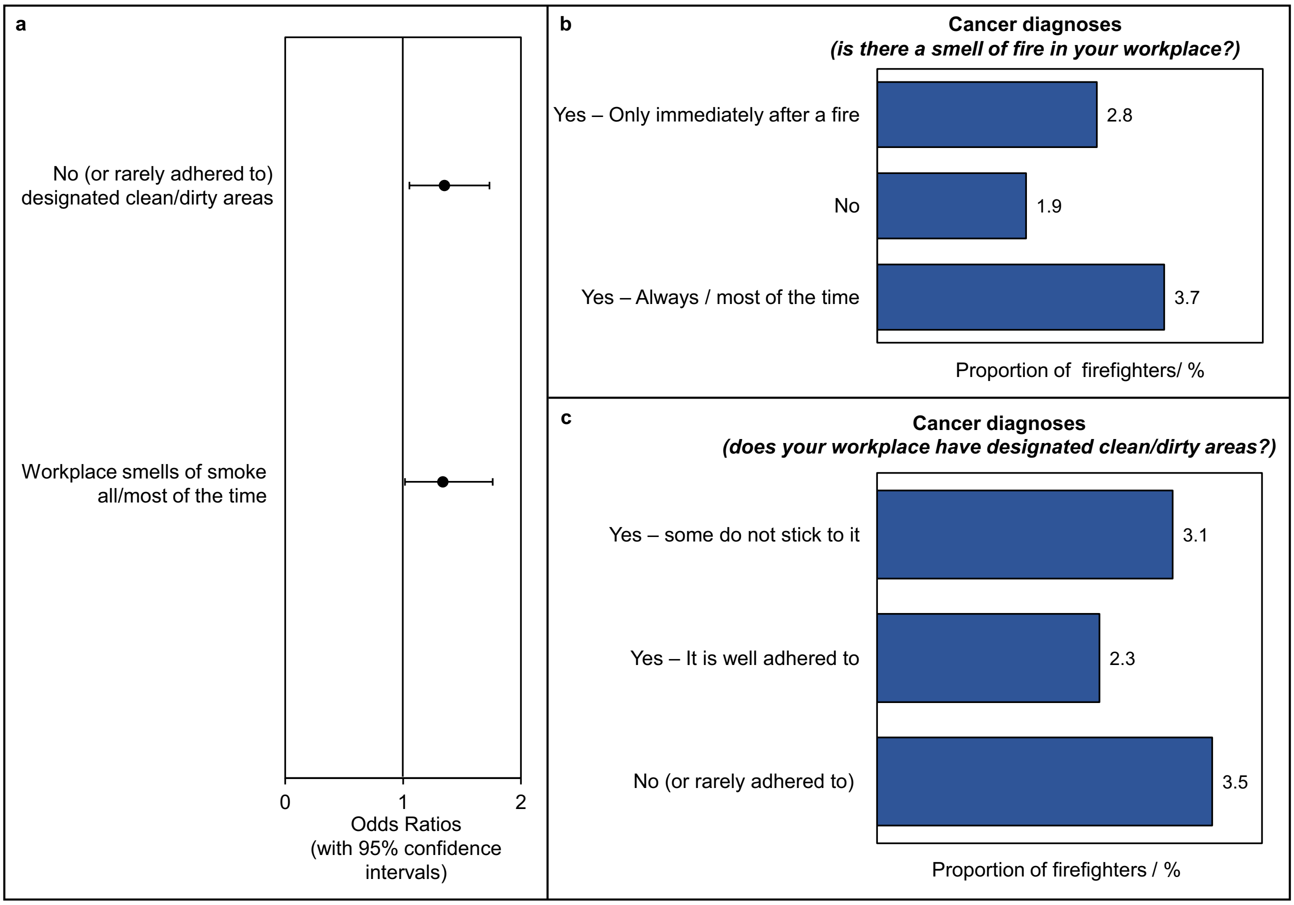

Figure 6. Workplace contamination and cancer diagnosis in the UK Fire and Rescue Service. (**a**) Cancer odds ratios for measures of workplace contamination. (**b**), (**c**) The proportion of firefighters in each workplace contamination category who received a cancer diagnosis. Odds ratios (with 95% confidence intervals) were adjusted for age.

radiation[27]. Although the survey did not account for time spent working outdoors without protective clothing, firefighters who actively sunbathe/use sunbeds were not found to be at a significantly increased risk of cancer compared to those that never sunbathe (OR = 0.8, 0.6–1.0). This suggests that firefighters' occupational exposures may plausibly account for the high incidence of skin cancer, likely due to dermal exposure to carcinogenic contaminants[3,4].

Skin cancers are not routinely screened as these cancers can usually be readily identified by patients at an early stage[28]. Given firefighters increased risk of skin cancers, training and/or awareness campaigns may be beneficial in helping them to identify the early signs of such cancers[29].

Firefighters were found to suffer cancer at a higher age-specific rate than the general UK population (Table 1). However, there is currently no formal provision for preventatively screening firefighters for cancer within the UK Fire and Rescue Service. The successful treatment of cancer, and subsequent cancer survival rates, are highly dependent on early detection[29]. Thus, given the higher rate of cancer in younger firefighters within the survey (Table 1), additional screening at earlier stages of life may be required to safeguard firefighters' health.

Firefighters exposure through contaminated PPE. Following fire incident attendance, firefighters' PPE may become heavily contaminated with components of fire smoke. This has significant implications for firefighters who remain in contaminated PPE for considerable lengths of time after attending an incident, as it increases the window of exposure to fire toxins, via both inhalation (while toxins continue to off-gas) and dermal (as toxins permeate through fabric to the skin[3,6]) routes.

In fact, the survey found that firefighters who remain in PPE for more than four hours after attending a fire are over twice as likely to develop cancer than those who remain in PPE for 30 min or less after an incident (OR = 2.3, 1.1–5.2). If not effectively removed, contaminants will remain on PPE where they can continue to accumulate, posing a long-term exposure risk. Removing contaminants from PPE and firefighters' skin (e.g. through washing after an incident) as soon as possible is therefore vital for reducing both acute and chronic dermal exposure.

Cross contamination. While decontamination plays a major part in reducing exposure to harmful contaminants, emerging research indicates that, without careful consideration of the techniques and procedures

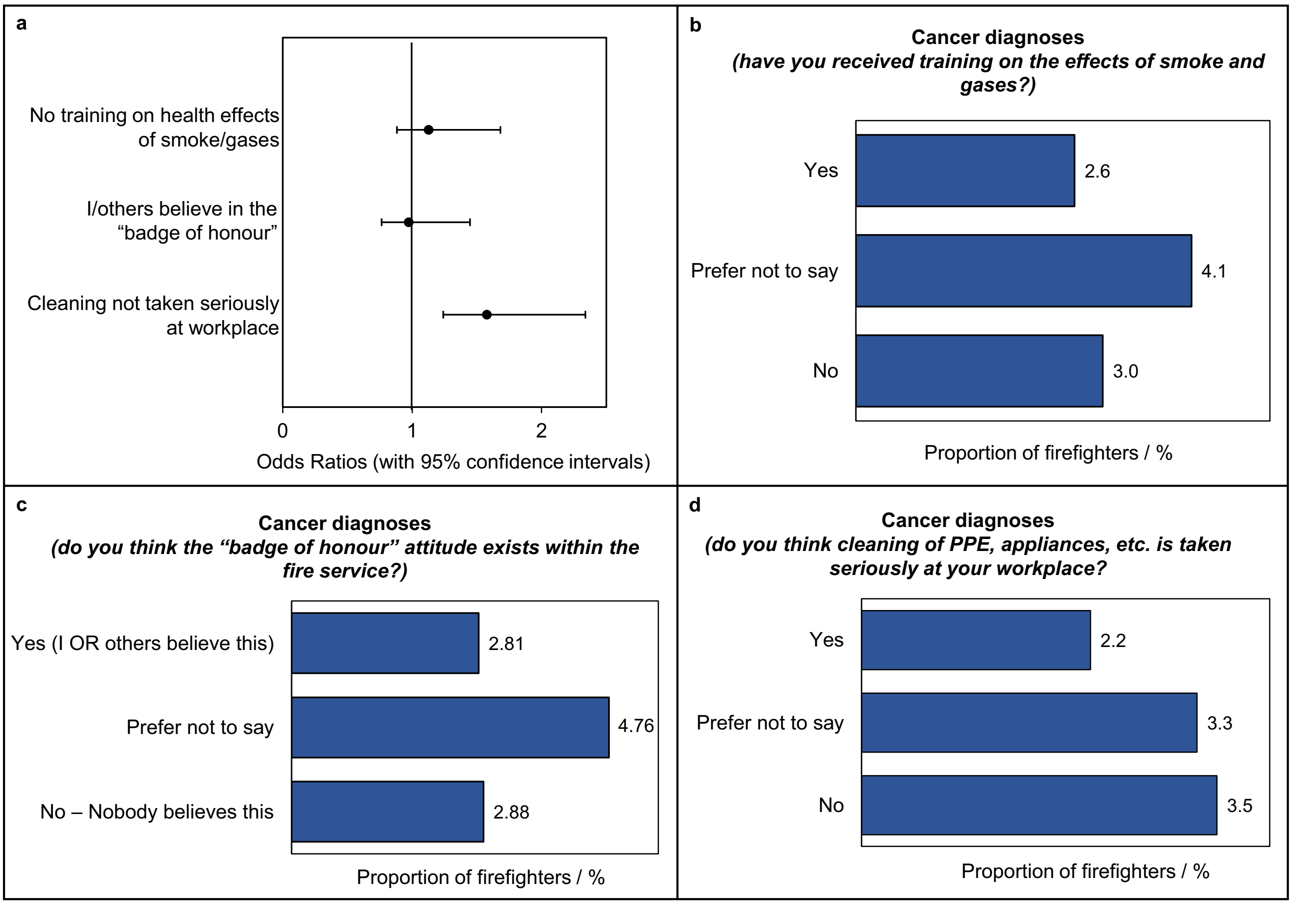

Figure 7. Attitudes, awareness and training and cancer diagnosis in the UK Fire and Rescue Service. (**a**) Cancer odds ratios for measures of contaminant exposure due to attitudes/training. (**b**), (**c**), (**d**) The proportion of firefighters in each training/attitude category who have received a cancer diagnosis. Odds ratios (with 95% confidence intervals) were adjusted for age.

used, cleaning/decontamination efforts can contribute to harmful cross-contamination[30]. Cross contamination occurs when otherwise clean items come into direct or indirect contact with dirty/contaminated items[30]. A key example of cross-contamination arising through poorly controlled cleaning procedures is the use of on-site washing machines to launder both contaminated and non-contaminated items[30–32]. Mayer et al. (2019) identified significant cross contamination when laundering fire hoods[30], supporting findings from the survey, which revealed that the use of washing machines to launder fire hoods was associated with a significantly increased odds ratio of developing cancer (OR = 1.3, 1.0–1.7). It should also be noted that 12% of surveyed firefighters indicated that they take their PPE home to launder. These findings are of concern to firefighters' family members, who may be exposed to contaminants through potential cross-contamination in home washing machines.

Other potential sources of cross contamination found to significantly increase cancer odds ratios were failing to store clean and dirty PPE separately (OR = 1.3, 1.0–1.7), and failing to designate separate clean and dirty "zones" within the fire station (OR = 1.4. 1.1–1.7).

Storing fire gloves within other items of PPE, e.g. within helmets and boots, was also associated with an increased cancer odds ratio (OR = 1.3, 1.0–1.6), although at the threshold of significance. This practice is of particular concern given that 71% of surveyed firefighters indicated that their fire gloves were *never* sent for professional cleaning, and that 20% indicated that their fire gloves were never cleaned at all[8].

Minimising exposures to fire toxins: regulations and accountability. As well as effective PPE decontamination and storage practices, UK Fire and Rescue Services should implement rigorous procedures which control and minimise firefighters' exposures to fire toxins, in order to reduce cancer risk. Survey results suggest a link between lack of such procedures (e.g. cleaning not taken seriously in the workplace, absence of designated clean/dirty areas) and increased cancer odds ratios (Fig. 6).

However, workplace decontamination procedures are only effective with full compliance, as just one non-compliant individual can cause cross contamination which adversely impacts compliant individuals. The survey found several measures of personal contamination were associated with an increased cancer odds ratio, e.g. noticing soot in the nose/throat (OR = 2.0, 1.1–3.5), eating while wearing PPE (OR = 1.8, 1.2–2.7), staying in PPE for an extended amount of time after an incident (OR = 2.3, 1.1–5.2). Holding firefighters accountable to personal decontamination procedures in the first instance (e.g. changing out of PPE as soon as possible after an incident, showering on return to the station, avoiding eating while wearing PPE etc.[9]) may help promote adherence to community-level decontamination measures, such as those implemented in the wider workplace.

Culture and awareness. Tackling the "badge of honour" attitude within the UK Fire and Rescue Service may also help to promote adherence to decontamination procedures. This attitude refers to the outdated belief that heavily soiled/contaminated PPE should be celebrated as a symbol of hard-work and dedication among firefighters[15]. The survey found that 16% of firefighters still hold this belief, while 46% believe that others do. Although not significantly associated with an increased risk of cancer, this attitude was positively associated with proxies of fire toxin exposure which were found to be significantly associated with cancer e.g. eating while wearing PPE and staying in PPE for an extended amount of time after an incident (explored further in Wolffe et al. 2023[15]).

Similarly, training on fire contaminants and their health outcomes may also help promote compliance with decontamination procedures. However, whether firefighters had received such training did not appear to significantly increase their odds ratio of developing cancer.

Additionally, finding that a significantly higher proportion of firefighters diagnosed with cancer preferred not to say if they attend fires without RPE (compared to those who always wore RPE) hints at a potential disconnect between firefighters' awareness and uptake of contaminant control measures. These firefighters may plausibly "prefer not to say" as a means of avoiding accountability for participating in a practice which they know to be a risk to their health and safety. Such disconnect has been found in a surveyed population of US firefighters, and in other occupational settings[33–35]. This may imply that, while potentially beneficial for improving compliance and awareness, one of the most effective measures for reducing cancer incidence in UK firefighters is simply to have and strictly enforce decontamination procedures/policy in the first instance (combined with regular training and inspection).

Limitations and future work

Analysis of the UK Firefighter Contamination survey revealed several significant associations between exposures to fire contaminants and cancer diagnosis in the UK Fire and Rescue Service. These findings are valuable for the development of effective decontamination procedures/policy, and/or for targeting interventions designed to reduce these exposures and the rate of cancer among firefighters.

Several of the survey's limitations are outlined in Wolffe et al. 2023[8] and include potential participation bias; whereby firefighters with cancer or grievances against the UK Fire and Rescue Service may have been more likely to complete the survey than those without cancer/grievances.

Participation bias may also be more pronounced in demographic groups with a relatively small sample size, e.g. female firefighters, and those in senior roles. Conversely, the small sample size of these groups may mean that their demographic-specific findings are underpowered.

Survey questions did not consider all exposures a firefighter has received throughout their career, only assessing firefighters' current practice/s. Given that repeat (chronic) exposures to carcinogenic contaminants increase the likelihood of developing cancer, results of the survey analysis may be weakened by its failure to account for firefighters' past exposures.

Cancer is a complex disease, with a variety of inherent risk factors and modes of progression. The survey was also limited in that it did not include all risk factors (e.g. family history, exposure to UV radiation etc.). Study of a wider variety of inherent cancer risk-factors may provide a more accurate view of cancer risk in the UK Fire and Rescue Service.

Conclusion

Serving UK firefighters were found to have much higher cancer incidence rates than the general population of the same age. Contaminated PPE is a potentially significant source of dermal exposure which increases the risk of developing cancer. Failing to implement procedures which control cross-contamination and/or firefighters' personal contamination were also associated with a significantly increased likelihood of developing cancer.

Survey results identified several areas for immediate intervention. These include procedures/policy which target cross-contamination e.g. keeping clean/dirty PPE separately, designating specific clean/dirty zones within the station etc. Interventions which target personal contamination (e.g. avoiding eating while wearing PPE, changing PPE/workwear as soon as possible after an incident etc.) should also be considered as both a means of reducing the incidence of cancer in firefighters, and of promoting compliance with less tangible, (community-level) workplace decontamination practices.

It should also be noted that the survey uncovered considerable variation among firefighters in the same demographic, fire exposure, and health outcome categories. For example, firefighters from the same geographic region indicated access to different decontamination facilities/procedures etc. Similarly, surveyed firefighters indicated (via free text) use of different respiratory protection equipment, from disposable dust masks to breathing apparatus[8].

Overall, these findings reflect the need for better standardisation of decontamination procedures/policies and facilities within the UK Fire and Rescue Services. Equally important and essential for safeguarding firefighters' health, is the provision of health screening, regularly, and preferably at earlier stages of life.

Data availability

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

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Author contributions

A.C. and A.S. devised the survey and distributed it to firefighters with the assistance of the Fire Brigades Union. T.W., A.S., K.D. and D.M.-T. coded free text answers for analysis. A.S. and T.W. analysed trends in the data. M.J. provided statistical expertise. A.R. and T.W. calculated crude odds ratios and ran logistic regression analyses, with input from L.T. and M.J. T.W. drafted the first iteration of the manuscript. A.S. and T.W. reviewed and edited the final version of the manuscript for publication.

Competing interests

The authors declare no competing interests.

Additional information

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Mental health of UK firefighters

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Exposure to trauma, high-stress situations, and disrupted sleep are well known risk factors affecting firefighters' mental health. Little is known about the association between firefighters' exposure to fire contaminants and mental health disorders. The UK Firefighter Contamination Survey assessed firefighters' health and capacity for occupational exposure to contaminants. Participants were invited to anonymously complete its 64 questions online. Logistic regression analyses assessed the associations between self-reported mental health disorders and proxies of contaminant exposure. Results found that firefighters who notice soot in their nose/throat for more than a day after attending fires (Odds Ratio (OR) = 1.8, 1.4–2.4), and those who remain in their personal protective equipment (PPE) for over 4 h after fires (OR = 1.9, 1.2–3.1), were nearly twice as likely to report mental health disorders. Significantly increased odds ratios for all three outcomes of interest (anxiety, depression and/or any mental health disorders) were also found among firefighters who take PPE home to clean. Sleeping problems were reported by 61% of firefighters. These firefighters were 4.2 times more likely to report any mental health disorder (OR = 4.2, 3.7–4.9), 2.9 times more likely to report anxiety (OR = 2.9, 2.4–3.5) and 2.3 times more likely to report depression (OR = 2.3, 1.9–2.8) when compared to firefighters who did not report sleep issues. Effective decontamination measures within UK Fire and Rescue Services, together with firefighters' wellness, may play a crucial role in protecting firefighters' mental health.

Mental health disorders can be caused by a combination of psychological, environmental, biological, and chemical factors. To date, research on firefighters' mental health has mainly focused on psychological factors such as direct exposure to trauma[1] or occupational stress[2], finding firefighters to have an increased risk of suicide[3], depression[1,2], and post-traumatic stress disorder (PTSD)[4]. Studies have also investigated the effects of other occupational exposures, e.g. abrupt fire incident call-outs, disrupted sleep[5], as well as physical and/or emotional fatigue on firefighters' mental health. However, little is known about the relationship between firefighters' exposure to fire effluent and mental health.

Fire smoke is a heterogenous cocktail of chemicals with varying toxicities and modes of action[6]. A growing body of research has identified a number of different fire effluents contaminating fire stations and firefighters' PPE. Elevated levels of polybrominated diphenyl ethers (PBDEs)[7,8], polychlorinated and polybrominated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs and PBDD/Fs)[9] or halogenated gas phase flame retardants[7] have also been reported in firefighters' blood and urine[10]– suggesting several routes for chronic exposure[11–16].

Several components of fire smoke have also been associated with mental health disorders. For example, the U.S. Environmental Protection Agency and the Agency for Toxic Substances and Disease Registry, found exposure to neurotoxic chemicals such as mercury and lead, or endocrine disruptors such as polychlorinated biphenyls, PBDEs or poly- and perfluoroalkyl substances (PFAS), can lead to hormone imbalances and/or neuroendocrine dysfunction, leading to conditions such as depression and anxiety[17]. Additionally, suffering life-altering, painful and/or chronic physical health conditions (e.g. cancer or other long-term diseases) from exposures to contaminants may also negatively impact firefighters' mental health.

The UK Firefighter Contamination Survey has uncovered several practices which would increase firefighters' risk of contaminant exposure and/or promote travel of contaminants back to workplaces/homes[18]. This manuscript explores one of potentially many health implications of such increased exposure, associating proxies of contamination with self-reported mental health disorders among UK firefighters (see also Wolffe et al.[18]). By assessing mental health risks for a broad range of contaminant control practices the survey provides an interim means of quickly identifying areas in which UK Fire and Rescue Services can optimally target resources for improving firefighters' occupational health.

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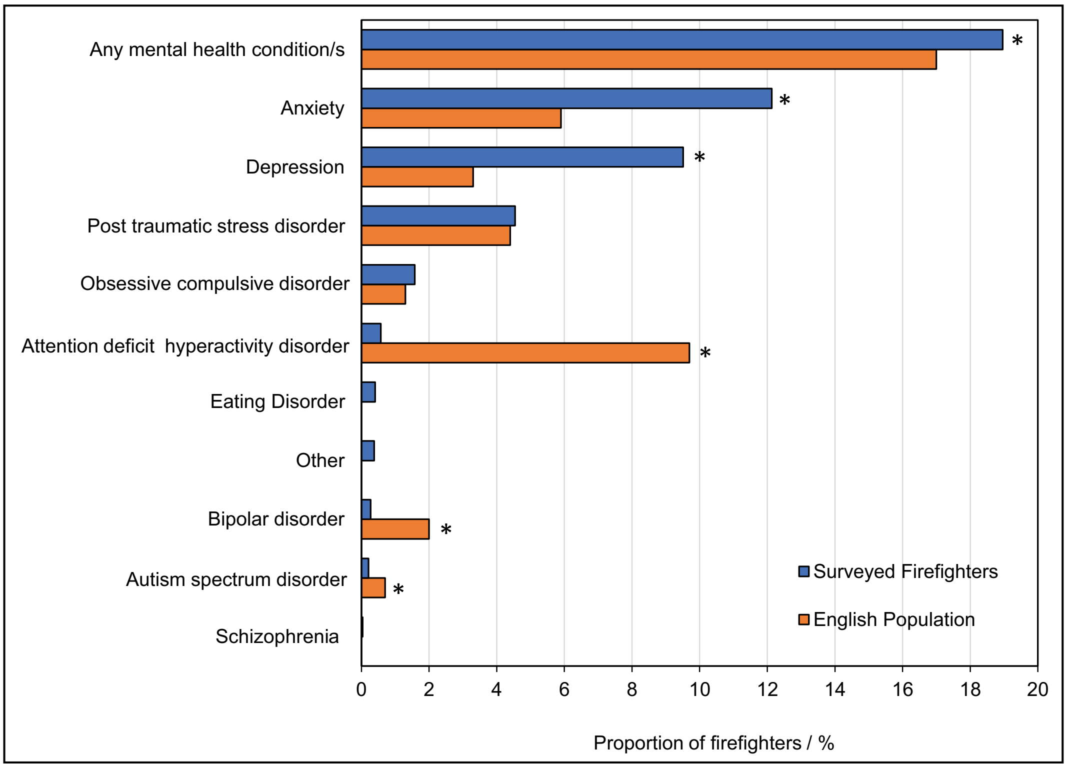

Figure 1. Firefighters' Mental Health Conditions. The proportion of total surveyed firefighters with any, or specific, mental health disorders (blue). The prevalence of mental health disorders in the general English population[39] is displayed for comparison (orange). "Any mental health condition", "anxiety" and "depression" among surveyed firefighters is compared to "any common mental disorder", "generalised anxiety disorder" and "depressive episode" in the general English population, respectively. * indicates a p-value of < 0.05 for differences in proportions between firefighters and English population.

Methods

Survey design. The methods used to conduct the survey and analyse its results are detailed in Wolffe et al.[18] and are summarised again in Supplemental File S2. Ethical approval for the survey was granted by the University of Central Lancashire Ethics Committee and all analyses were conducted in accordance with relevant guidelines and regulations.

Briefly, all currently serving (i.e. excluding retired) UK firefighters were eligible to take part in the survey and were recruited to participate via email through the Fire Brigades Union (whose members make up approximately 75% of the UK's total firefighting workforce[18,19]). Firefighters were invited to anonymously complete the survey online. Informed consent was obtained from all participants.

The survey, which took approximately 20 min to complete, consisted of 64 questions covering six key topics (Tables S1, S2, S3, S4, S5 and S6): demographics, PPE, workplace contamination, personal contamination, attitudes/awareness and training, and health (Supplemental File S1). Branching logic was used to route participants through the survey based on answers to previous questions.

Mental health conditions. Firefighters were able to choose multiple specific conditions from a list, as presented in Fig. 1 and Supplemental File S1. Analyses conducted in this manuscript specifically assess *any* mental health condition (i.e. those reporting at least one of the listed mental health conditions), anxiety, or depression.

Analysis. A complete case analysis was conducted for all firefighters who answered the questions about mental health and potential contaminant exposure.

Multiple logistic regression analyses were used to assess the association between mental health conditions and potential for exposure to fire contaminants, adjusting for plausible non-contaminant risk factors and confounders assessed in the survey (see Supplemental File S2) i.e. age, length of service, sleeping problems[20], excessive drinking[21,22], smoking[23], infrequently exercising[24], having a managerial role (as a measure of work-related stress[25]), attending fires on a more frequent basis (regular exposure to trauma[26]), having another physical health condition (i.e. diabetes[27,28], blood pressure problems[29,30], cancer[31,32], or fertility issues[33–35]), and having another mental health condition[36] (for analyses of depression and anxiety).

Analyses were conducted using the statsmodels module for Python 3[37], and Statistical Package for Social Sciences (SPSS) version 28.0.1.1. Note that firefighters reporting only attention deficit hyperactivity disorder

	Schizophrenia	ASD	Bipolar disorder	Other	Eating Disorder	ADHD	OCD	PTSD	Depression	Anxiety
Schizophrenia										
ASD	0.1									
Bipolar disorder	0.3	0.2								
Other										
Eating Disorder	0.1	0.1	0.2							
ADHD	0.2	0.7	0.3		0.2					
OCD	0.2	0.7	0.8	0.1	0.7	1.0				
PTSD	0.1	0.8	0.6		1.0	1.0	3.8			
Depression	0.2	1.1	1.9	0.3	2.7	1.9	6.7	23.6		
Anxiety	0.2	1.1	1.4	1.0	3.6	2.4	10.1	26.5	69.9	

Proportion of firefighters with more than one mental health disorder / %

Figure 2. Firefighters' Co-occurring Mental Health Conditions. Proportion of firefighters with more than one mental health condition (n = 878), who reported the co-occurrence of specific mental health conditions. Blank cells indicate that mental health conditions did not co-occur among surveyed firefighters.

(ADHD) or only autism spectrum disorder (ASD) were excluded from logistic regression analyses as these conditions represent developmental disorders, first appearing in childhood, and most commonly researched with regard to early life exposures to contaminants, rather than the later life exposures firefighters receive as adults during their careers.

Odds ratios (OR) with 95% confidence intervals are presented as a means of assessing the statistical significance of differences in the prevalence of mental health conditions between various demographic groups, or between groups at (potentially) greater versus lower risk of contaminant exposure.

Results and analysis

A total of 10, 649 firefighters responded to the questionnaire, representing approximately 24% of the UK's total firefighter workforce (Wolffe et al.[18]). Participant demographics were analysed in Wolffe et al. [18], and were not found to significantly differ from the English firefighter population[38] with respect to sex ($p > 0.05$), but appeared to under-represent younger age categories, retained firefighters, and those belonging to an ethnic minority ($p < 0.05$)[18].

Around 19% (n = 2019) of firefighters self-reported at least one mental health condition. Figure 1 displays the range and frequency of mental health disorders selected by firefighters, which is then compared to the prevalence of those conditions in the general English population (where possible[3]). Note that firefighters were able to select more than one mental health condition.

Self-reports of anxiety were most prevalent among surveyed firefighters (approximately 12%), followed by depression (around 10%) and post-traumatic stress disorder (PTSD) (around 5%), as presented in Fig. 1. The prevalence of self-reported anxiety and depression among surveyed firefighters was also significantly higher than that of the English population (Fig. 1, difference in proportions test $p < 0.05$).

Less than 2% of surveyed firefighters reported obsessive compulsive disorder (OCD) (1.6%), attention deficit hyperactivity disorder (ADHD) (0.6%), eating disorders (0.4%), bipolar disorder (0.3%), autism spectrum disorder (ASD) (0.2%), or schizophrenia (0.04%). The majority of firefighters who selected "other" (0.4%) listed "stress" associated with their work (40% of firefighters answering "other", or 0.2% of total surveyed firefighters).

Out of the 19% of surveyed firefighters suffering any mental health condition (n = 2019), around 44% reported having more than one condition (n = 878). The frequency with which mental health conditions co-occurred is displayed in Fig. 2. Anxiety and depression co-occurred most frequently.

From the logistic regression models (Supplemental File S2), having a co-occurring mental health condition had the most sizeable impact on reporting depression or anxiety. Firefighters with at least one co-occurring condition were nearly 16 times more likely to suffer depression (OR = 15.6, 13.3–18.4) and around 13 times more likely to suffer anxiety (OR = 13.3, 11.5–15.5) when compared to firefighters with no co-occurring mental health conditions (i.e. who only had depression, or only anxiety).

Demographics. Similar proportions of firefighters in each role, except for the most senior roles (such as area or principal manager), were found to suffer from any mental health condition, anxiety, or depression, Fig. 3. The proportion of surveyed firefighters with any mental health condition, anxiety, or depression generally increased with length of service, Fig. 3. Firefighters who had served longer (i.e. ≥ 15 years) were slightly more likely to report suffering any mental health condition compared to firefighters who had served less time (OR = 1.1, 1.0–1.3), although no significant differences were observed for anxiety (OR = 1.0, 0.9–1.2) or depression (OR = 1.0, 0.9–1.2).

Only wholetime firefighters, when compared to firefighters on all other contract types combined, were more (but not significantly more) likely to report any mental health condition (OR = 1.1, 1.0–1.3), and anxiety (OR = 1.2, 1.0–1.4).

Firefighters who attended fires on at least a weekly basis were more likely to report depression compared to firefighters who attended fires less frequently (OR = 1.2, 1.0–1.4). However, no significant differences between these groups were noted for any mental health condition (OR = 1.0, 0.9–1.1), or anxiety (OR = 1.0, 0.9–1.2).

Health and lifestyle. Firefighters were also asked questions related to their health and lifestyle, which could possibly be linked with mental health conditions such as anxiety, or depression (Supplemental File S1, Wolffe et al.[18]). These questions were subsequently included in logistic regression models (Supplemental File S2) and are explored further below.

Sleeping problems. Around 61% of all surveyed firefighters (n = 6490) said that they have sleeping problems, Fig. 4a. Those who reported sleeping problems were 4.2 times more likely to report any mental health condition (OR = 4.2, 3.7–4.9), 2.9 times more likely to report anxiety (OR = 2.9, 2.4–3.5) and 2.3 times more likely to report depression (OR = 2.3, 1.9–2.8) compared to firefighters who did not report it, Fig. 4c.

Firefighters were also asked to provide more details about their sleeping problems. They were able to select multiple answers, listed in Supplemental File S1. Over 65% of firefighters (out of 6490, n = 4228) indicated that shift work was a major sleep disturbance (Fig. 4b). Mental health (46%, n = 3010) and workload (36%, n = 2313) were also frequently selected. Home, personal or family-life related reasons (e.g. disturbed by children or split/divorce etc.) were the most common disturbances listed by firefighters selecting "other".

Multiple logistic regression analyses (Supplemental File S2) revealed a slightly increased likelihood of reporting sleeping problems for managerial firefighters (OR = 1.1, 1.0–1.2), wholetime firefighters (OR = 1.1, 1.0–1.2), firefighters attending fires on at least a weekly basis (OR = 1.2, 1.1–1.3), and firefighters with 15 + years of service (OR = 1.1, 0.9–1.2), Fig. 4d. However, this increase was only significant for firefighters attending incidents on a weekly basis. Retained firefighters were slightly, but significantly, less likely to report sleeping problems when compared to firefighters employed on all other contract types combined (OR = 0.9, 0.7–1.0).

Other health and lifestyle variables. Several other health and lifestyle variables were also found to be significantly associated with firefighters' mental health, and are presented in Table 1.

Firefighters with a cancer diagnosis were significantly more likely to report any mental health condition (OR = 1.5, 1.1–1.9), but were not found to be significantly more likely to report anxiety (OR = 1.2, 0.9–1.7), depression (OR = 0.9, 0.6–1.3) or sleeping problems (OR = 1.0, 0.8–1.3).

Aside from problems sleeping and having a co-occurring mental health condition, the only health/lifestyle variables found to be significantly associated with depression was infrequent exercising (OR = 1.4, 1.2–1.7). Excessive drinking, smoking, and problems with blood pressure were found to be significantly associated with both any mental health condition and sleeping problems (Table 1).

Fertility problems were significantly associated with any mental health condition (OR = 1.4, 1.1–1.9), anxiety (OR = 1.3, 1.0–1.7) and sleeping problems (OR = 1.3, 1.1–1.5).

Exposure to fire contaminants during/after fire incidents. Significantly increased odds ratios for any mental health condition were found for firefighters who noticed soot in their nose/throat for more than a day after attending a fire (OR = 1.8, 1.4–2.4), and for those that remained in PPE for more than 4 h after a fire (OR = 1.9, 1.2–3.1). Results are shown in Fig. 5. Firefighters were also significantly more likely to report any mental health condition if they reported still noticing the smell of fire smoke on the body after washing (OR = 1.3, 1.1–1.5), or eating with sooty hands (OR = 1.3, 1.1–1.4).

Similar results were found for anxiety. Significantly increased odds ratios were found for firefighters who eat with sooty hands (OR = 1.2, 1.1–1.4 for anxiety), and who noticed soot in the nose/throat for up to a day after washing (OR = 1.4, 1.0–1.8 for anxiety).

Those noticing the smell of fire smoke on the body after washing were significantly more likely to report depression (OR = 1.3, 1.0–1.5).

Fire contaminants on firefighters' PPE and at their workplace. Firefighters with ill-fitting PPE were significantly more likely to report any mental health disorder (OR = 1.4, 1.2–1.7), and anxiety (OR = 1.4,

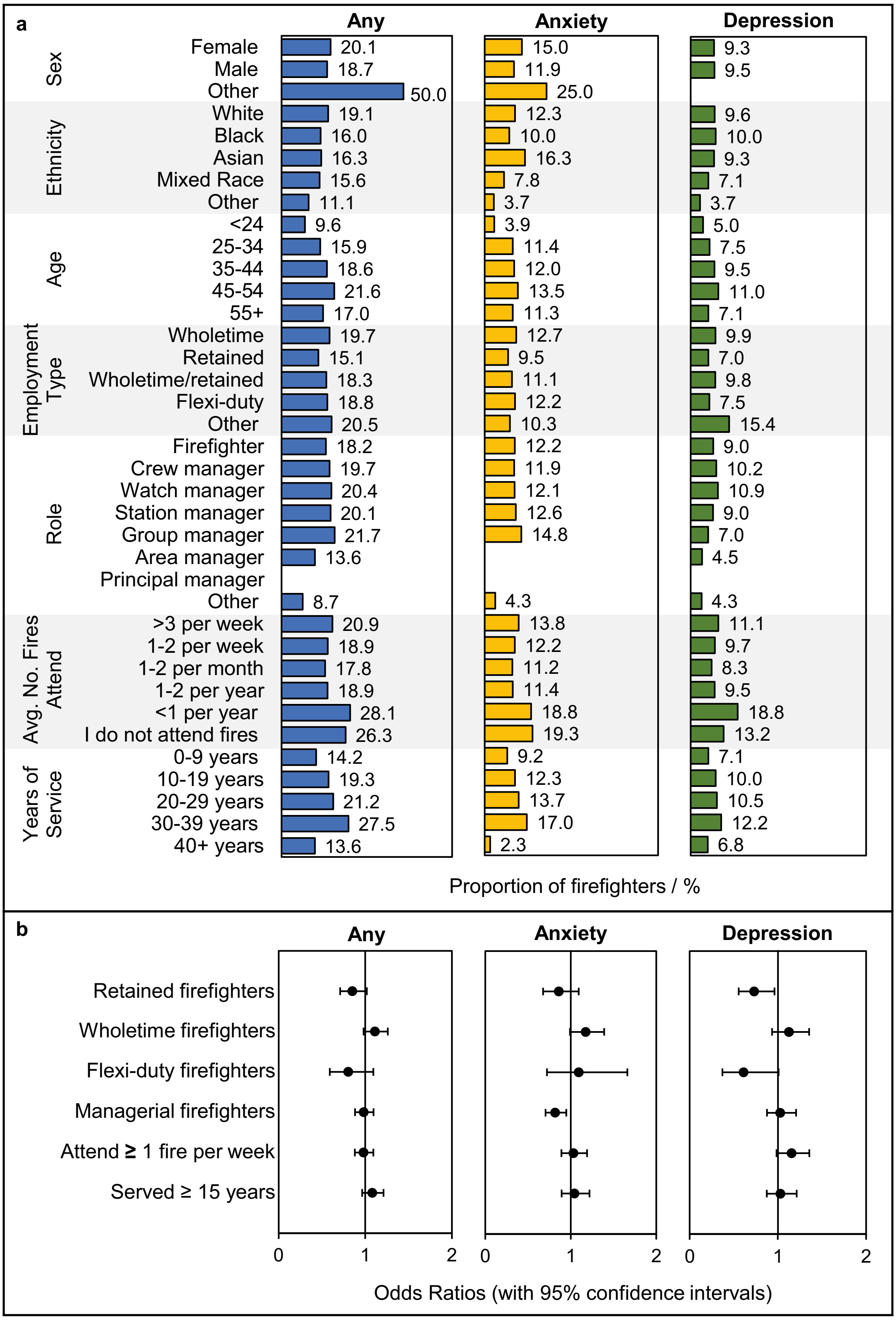

Figure 3. Firefighters' Mental Health Conditions by Demographics. (**a**) The proportion of firefighters with any mental health condition, anxiety, or depression in each demographic category. (**b**) Odds ratios (with 95% confidence intervals) for specific demographic groups having any mental health condition, anxiety, or depression. Note that the proportions of surveyed firefighters in each demographic category are presented in Wolffe et al., [18]. The results of underpowered demographic groups (e.g. sex = "Other" for which there was a total of 4 firefighters) should be interpreted cautiously. Odds ratios were adjusted for various mental health risk factors (Supplementary File S2).

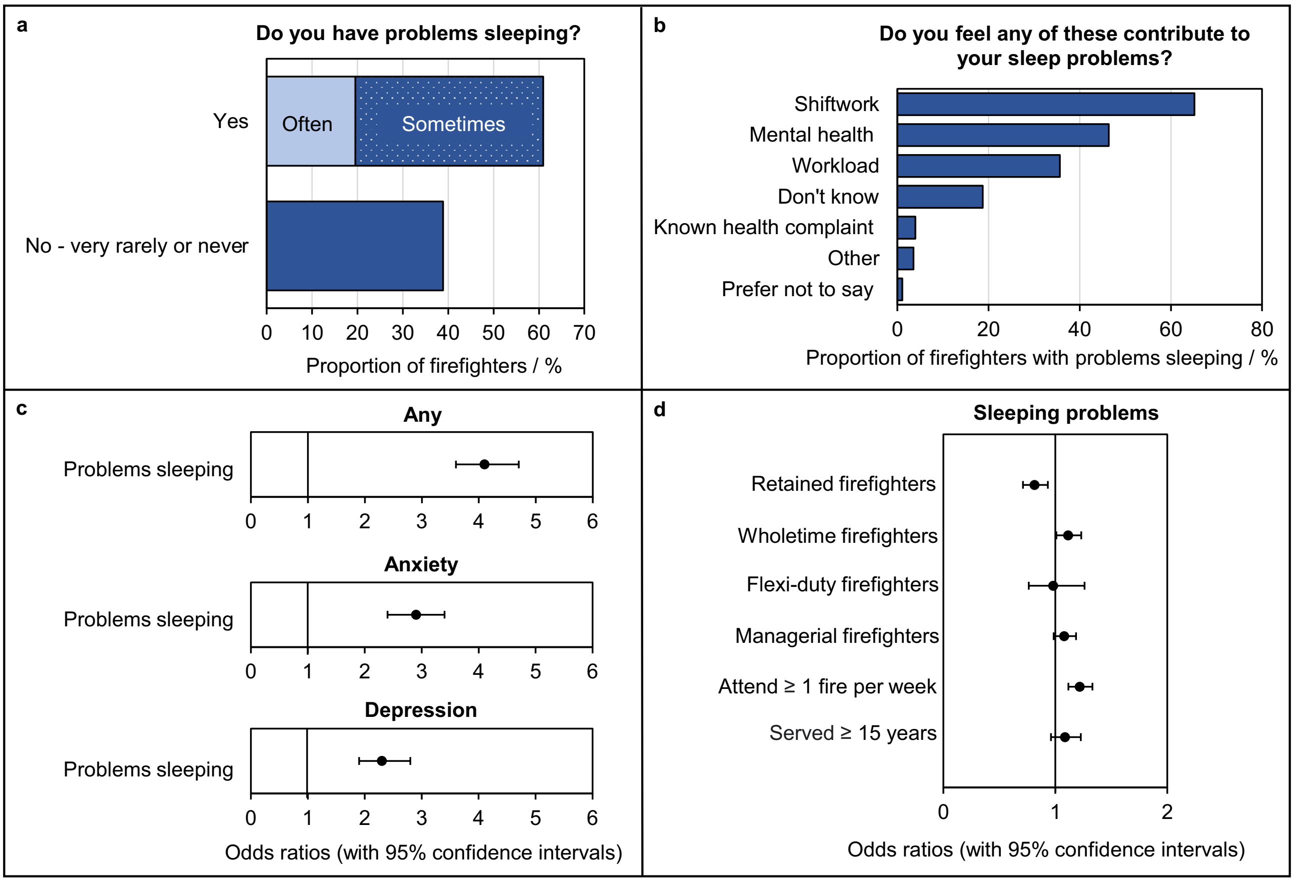

Figure 4. **Firefighters' Sleeping Problems.** (**a**) The proportion of total surveyed firefighters who indicated whether they had sleeping problems. (**b**) The proportion of firefighters with sleeping problems listing the reasons for their sleep disturbances. Note that firefighters were able to select more than one reason. (**c**) Adjusted odds ratios (with 95% confidence intervals) for firefighters' mental health conditions due to sleeping problems. (**d**) Adjusted odds ratios (with 95% confidence intervals) for firefighters sleeping problems due to demographic variables. Note that odds ratios presented in (**c**) and (**d**) were adjusted for a variety of disturbed sleep risk factors (Supplementary File S2).

	Lifestyle variables	Odds ratio (OR) with 95% confidence intervals
Any mental health condition	Blood pressure problems	1.5 (1.3–1.8)
	Cancer diagnosis	1.5 (1.1–1.9)
	Fertility problems	1.4 (1.2–1.7)
	Excessive drinking	1.2 (1.0–1.4)
	Smoking	1.3 (1.1–1.5)
Anxiety	Blood pressure problems	1.4 (1.1–1.7)
	Fertility problems	1.3 (1.0–1.7)
Depression	Exercising infrequently	1.4 (1.1–1.7)
Sleeping problems	Blood pressure problems	1.5 (1.2–1.7)
	Excessive drinking	(1.1–1.4)
	Smoking	1.2 (1.1–1.4)
	Fertility problems	1.3 (1.1–1.5)

Table 1. Firefighters' other health and lifestyle factors found to be significantly associated with their mental health. Odds ratios were adjusted for several mental health risk factors (e.g. sleeping problems) and/or sleep disturbances (e.g. age), detailed in Supplemental File S2, Tables S2, S3 and S4. Excessive drinking refers to the consumption of more than 15 units of alcohol per week (one unit equals 10 mL of pure alcohol).

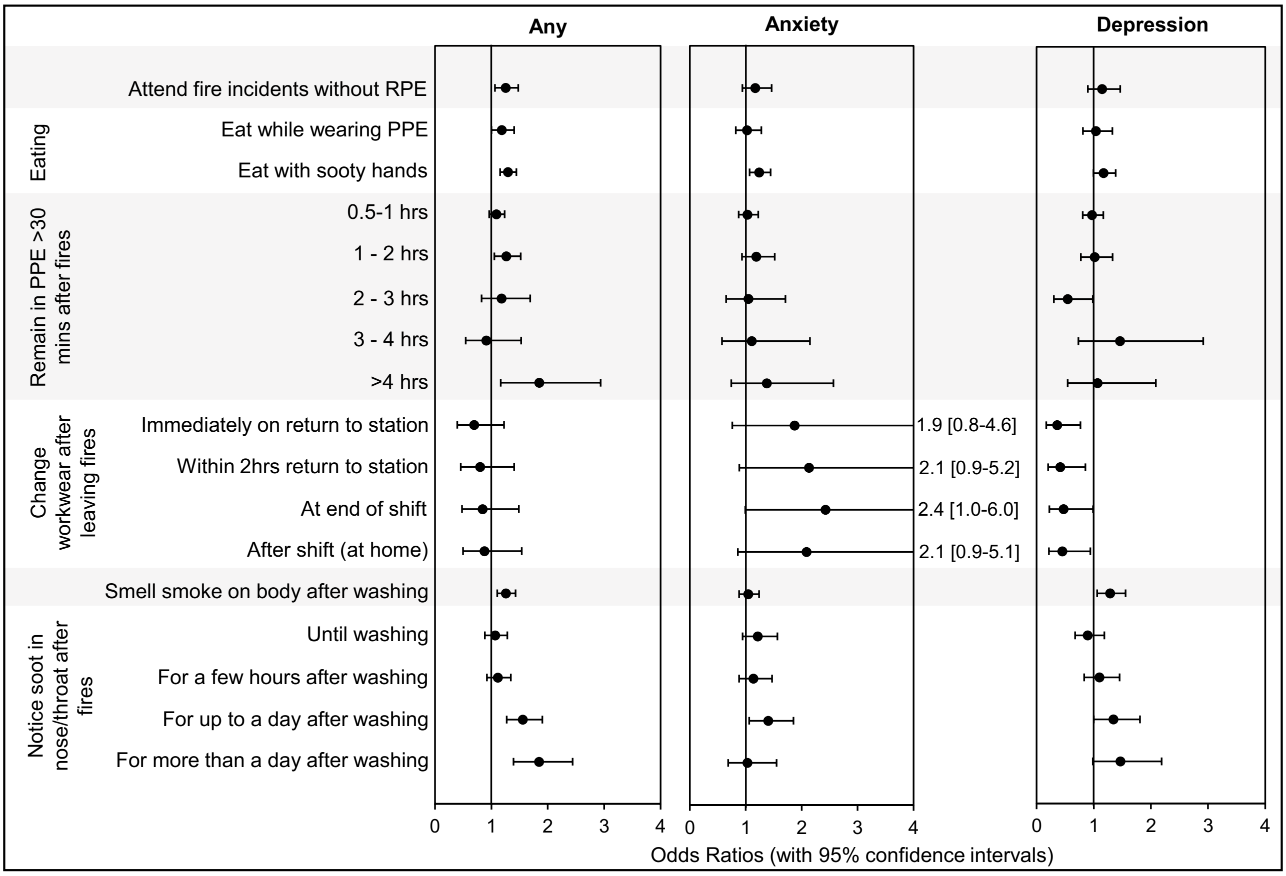

Figure 5. Firefighters' Exposure to Contaminants During/After Fires and Mental Health Odds Ratios. Odds ratios (with 95% Confidence Intervals) were adjusted for various mental health risk factors (Supplementary File S2).

1.1–1.7), presented in Fig. 6. Significantly increased odds ratios were also found for firefighters taking PPE home (OR = 1.4, 1.2–1.6 for any mental health condition, OR = 1.3, 1.1–1.6 for anxiety, and OR = 1.3, 1.0–1.6 for depression).

Additionally, significantly increased odds ratios were found, for those firefighters failing to store clean and dirty PPE separately (OR = 1.1, 1.0–1.3 for any mental health condition (Fig. 6)).

Infrequently sending fire gloves for professional decontamination was also associated with an increased anxiety odds ratio (OR = 1.5, 1.0–2.3).

Firefighters who worked in stations with no designated clean and dirty areas were also more likely to report any mental health condition (OR = 1.2, 1.1–0.4), and anxiety (OR = 1.2, 1.0–1.4), as were firefighters working in stations which smell of fire (OR = 1.2, 1.1–1.4 for any mental health condition and OR = 1.2, 1.0–1.4 for anxiety), Fig. 6.

Culture, fire contaminant awareness and training and culture.

Firefighters who personally believe that contaminated PPE should be celebrated as a "badge of honour" (explained in Wolffe et al.[18]) were significantly more likely to report any mental health condition (OR = 1.5, 1.2–1.7), or anxiety (OR = 1.2, 1.0–1.5) (Fig. 7). Feeling that colleagues uphold this belief was also associated with a slightly increased odds ratio for any mental health condition (OR = 1.2, 1.0–1.3).

The other variables significantly associated with any mental health disorder and anxiety were feeling that cleaning was not taken seriously at the workplace (OR = 1.4, 1.3–1.6 for any mental health condition, and OR = 1.2, 1.0–1.4 for anxiety). In addition, firefighters who had not received training on the health effects of fire contaminants were only slightly (but not significantly) more likely to indicate having any mental health condition (OR = 1.1, 1.0–1.2).

Discussion

Occupational exposure to contaminants and mental health disorders in firefighters.

UK firefighters were found to have significantly higher rates of (any) self-reported mental health conditions when compared to the general UK population (who were more reliably diagnosed against the UK revised Clinical Interview Schedule (CIS-R)). In particular, the rates of self-reported anxiety and depression in firefighters far

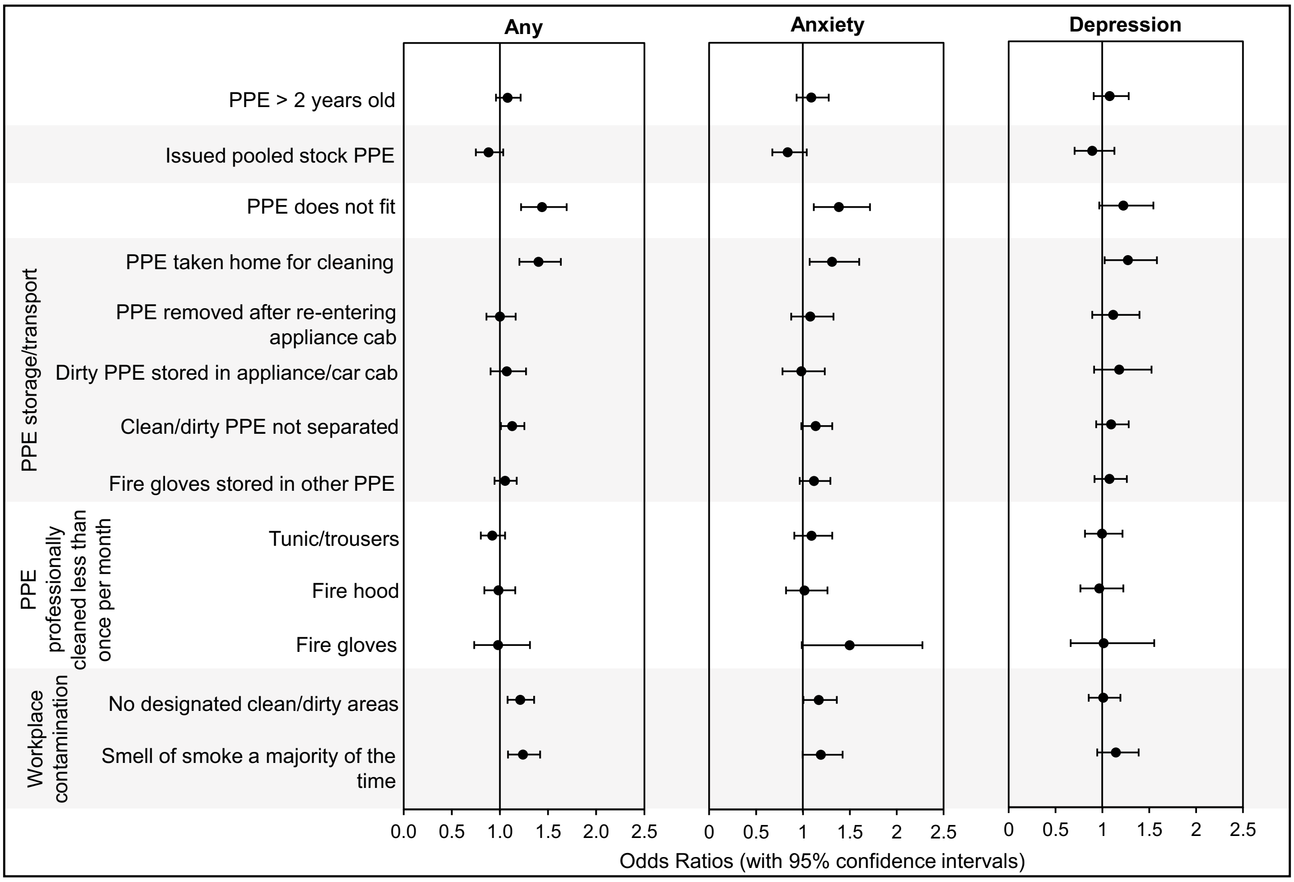

Figure 6. Firefighters' PPE/Workplace Contamination and Mental Health Odds Ratios. Odds ratios (with 95% confidence intervals) were adjusted for various mental health risk factors (Supplementary File S2).

exceeded those diagnosed in the general population. The rate of anxiety among surveyed firefighters was twice that of the general population, while the rate of depression was nearly three times that of the general population.

Several measures of potential contaminant exposure were associated with a significantly increased odds ratios for any mental health condition, anxiety, or depression. For example, firefighters noticing soot in the nose/throat for a day or more after washing, were nearly twice as likely to suffer any mental health condition.

Of the potential sources of contaminant exposure assessed in the survey, eating with sooty hands, taking PPE home to clean, wearing poorly fitting PPE, and noticing soot in the nose/throat were most consistently associated with increased odds ratios for mental health disorders, significantly increasing the likelihood of firefighters reporting any mental health condition, anxiety, and (in the case of taking PPE home) depression.

There is very little known about the association between firefighters' exposures to different contaminants and mental health disorders. Given that firefighters spend prolonged amounts of time attending fire incidents, their capacity for exposure is far greater when compared to the general population and other occupational groups. For example, exposure studies record concentrations of particulate matter (PM) orders of magnitude greater at fire incidents (e.g. wildfires[40]) when compared to ambient concentrations measured in studies of mental health in general populations[41]. This comparison is particularly concerning, given that 84% of surveyed firefighters often/sometimes attend fires without respiratory protective equipment (Wolffe et al.[18]).

Furthermore, recent biomonitoring data has revealed positive associations between urinary concentrations of several polycyclic aromatic hydrocarbons[42] (a class of chemicals commonly released in fires and found on firefighters' PPE, workplaces etc.) and mental health disorders (such as depression)[43–45].

However, most research on the association between mental health disorders and chemicals, particulates etc. found in fire smoke comes from studies focused on identifying genetic risk factors for mental health disorders[46,47] and exposure to chemicals in early-life (including pre-natal) leading to impeded neurodevelopment[48,49]. There are also epidemiological studies examining the occurrence of mental health disorders in general populations, e.g. associations between common air pollutants (PM_{10} and $PM_{2.5}$, benzene, nitrogen oxides, ozone etc.) and common mental health disorders[41,50], depression[41,51–53], and/or anxiety[52] have been documented[41].

Further, it is widely recognised that social (e.g. socioeconomic status), psychological (e.g. exposure to trauma), biological (e.g. enduring painful illness), and environmental (e.g. interactions with the physical environment) factors not only vary, but may also have synergistic effects on mental health outcomes. Thus, it is possible that the impact on firefighters may be amplified as firefighters are already occupationally predisposed to several other mental health risk factors (e.g. exposure to trauma/stress etc.).

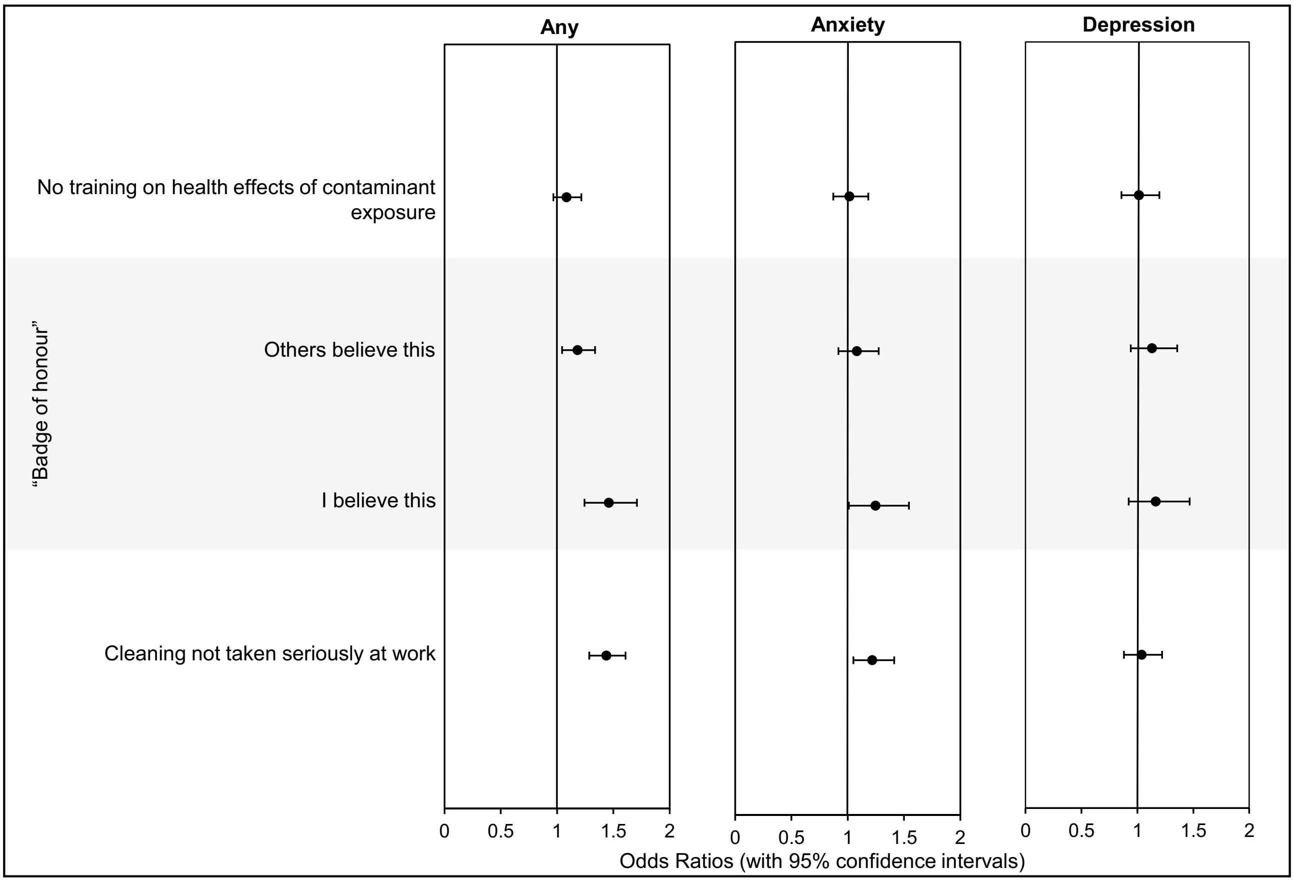

Figure 7. Firefighters Training/Culture and Mental Health Odds Ratios. Odds ratios (with 95% confidence intervals) were adjusted for various mental health risk factors (Supplementary File S2).

Mental health disorders in firefighters and sleeping problems. As well as mental health conditions, poor sleep is known to impact performance, e.g. compromising firefighters' safety by reducing reaction times[54]. In addition, chronic sleeping problems may also lead to poor immune, cardiovascular, and gastrointestinal health[55].

Over 60% of surveyed firefighters reported sleeping problems (with shift work pattern being the major reason). By contrast, an estimated 36% of UK adults have sleeping problems[56]. A strong link between sleeping problems and mental health was found among surveyed firefighters (Fig. 4), with firefighters reporting sleeping problems being at least twice as likely to suffer anxiety or depression compared to firefighters without sleeping issues, and over 4 times as likely to report any mental health condition (Fig. 4).

Research suggests that increasing awareness and screening firefighters for sleep disorders as well as revising their shift schedules (in order to minimise disruption to circadian rhythms) may help to maintain healthy sleep schedules[57].

Other occupational risk factors for mental health disorders in firefighters. Although the survey did not account for all mental health risk factors, the rate of self-reported PTSD (a condition associated with exposure to trauma) among surveyed firefighters was comparable to that of the UK population ($p > 0.05$). However, as explained earlier, caution needs to be taken when comparing self-reported cases with CIS-R diagnosed cases.

Scientific literature on firefighters' risk of PTSD is variable in terms of its findings and measures. Some authors have identified being younger, or beginning a career in the Fire and Rescue Service at a young age, as risk factors for developing PTSD[58]. Others have documented a higher prevalence of PTSD among retired when compared to serving firefighters[59]. Thus, given the relatively older modal age of surveyed firefighters (between 45 and 54 years old, Wolffe et al.[18]), and the exclusion of retired/ex-firefighters, it is possible that the prevalence of PTSD in UK firefighters is under-represented in the survey. Similarly, firefighters suffering from PTSD may have been less inclined to participate in the survey.

Other occupational risk factors for mental health disorders among firefighters may include cultural aspects of firefighting, and/or awareness of contaminant exposure and its health effects. Studies in populations who are knowingly exposed to contaminants (e.g. contaminated drinking water etc.) document increased rates of mental health conditions such as anxiety, as a result of concern over the effects of this exposure[60]. Similarly, if firefighters' awareness of the health effects of contaminant exposure outpaces decontamination policy changes/enforcement, this may cause anxiety among firefighters who feel that their health is not being prioritised.

Similarly, cultural aspects of firefighting (e.g. workplace bravado or the need to remain stoic in high stress or traumatic situations), may negatively impact firefighters' mental health e.g. by supressing trauma.

Limitations

Previous parts of the UK Firefighter Contamination Survey analysis already discussed some of the limitations of this survey (Wolffe et al.[18]) such as participation bias. Additionally, the self-reported mental health conditions, studied in this manuscript, were not verified against an official clinical diagnosis.

As the primary focus of the survey was on contaminant control measures, several confounders of mental health were also not accounted for e.g. family history and/or co-occurring diseases which may contribute to the development of mental health disorders[61].

Quantitation of contaminants in firefighters and/or PPE and workplaces, and how these may change with regards to the contaminant control practices assessed in this survey, would further strengthen suggested relationships between fire contaminant exposure and mental health outcomes.

The analyses conducted in this manuscript found several significant associations between potential contaminant exposure and mental health disorders. However, the manuscript does not assess interaction between these exposure variables. For example, eating while wearing PPE may be associated with eating with sooty hands. Refining a final logistic regression model, in which all relevant exposure variables assessed in the survey are included and interaction accounted for, represents an area for future work. Additionally, a complete case analysis is presented in this manuscript (whereby firefighters who did not answer the question about mental health were excluded from subsequent analyses). Thus, further model development will require imputation methods to account for missing data and reduce potential bias.

It should also be noted that mental health is a topic which continues to be associated with stigma, especially in males[62]. Thus, it is possible that the prevalence of mental health conditions in the survey has been under-represented.

Furthermore, sleeping problems and mental health conditions share mutual causality, whereby mental health conditions can arise from poor sleep, and vice versa. In fact, 46% of firefighters reporting sleeping problems indicated that mental health was the cause. As logistic regression analyses did not distinguish between firefighters who did and did not report mental health as a cause of their sleeping problems, further refinement of logistic regression models should be performed.

Finally, the survey did not ask firefighters about their access to mental health services/support within their workplaces, (a variable known to influence mental health outcomes in firefighters[63]), so cannot give a complete account of issues concerning mental health within the UK Fire and Rescue Service.

Conclusion

The rate of depression among UK firefighters is nearly three times that of the general population. Additionally, firefighters suffer anxiety at a rate over twice that of the general population, with a slightly higher proportion of firefighters reporting any mental health condition compared to the general population (20% versus 17%). Given the high rates of depression and anxiety, further support for mental health, and focus on mental health interventions, may be required in UK Fire and Rescue Services.

Several health and lifestyle factors were found to be significantly associated with mental health disorders among surveyed firefighters. The most significant among these was sleeping problems. However, adjusting for such risk factors through logistic regression analyses revealed significantly increased anxiety and any mental health condition odds ratios for several measures of contaminant exposure, including noticing soot in the nose/throat, taking PPE home to clean, wearing poorly fitting PPE, and eating with sooty hands. Further analysis on firefighters' capacity for exposure to fire contaminants is covered in Wolffe et al.[18].

Analyses conducted in this manuscript can be used to inform more comprehensive predictive models of mental health in the UK FRSs, outlining several contaminant control measures which should be considered in such modelling.

Further research is required in order to better understand the complex relationship between potential contaminant exposure and firefighters' mental health, including the potentially modifying effects of other risk factors such as psychological, biological, environmental, and genetic factors.

However, given the potentially synergistic effects of these risk factors, it is important to consider interventions which address not only contaminant exposure, but also firefighters' physical and mental well-being in order to improve the mental health of firefighters in the UK Fire and Rescue Service.

Data availability

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

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Author contributions
A.C. and A.S. devised the survey and distributed it to firefighters with the assistance of the Fire Brigades Union. T.W. calculated logistic regression analyses, with input from L.T. and A.R. T.W. drafted the first iteration of the manuscript. A.S. and T.W. reviewed and edited the final version of the manuscript for publication.

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Culture and awareness of occupational health risks amongst UK firefighters

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Firefighters are exposed to toxic chemicals not only from the fire incidents they attend, but also from their contaminated station and/or personal protective equipment (PPE). Little is currently known about firefighters' awareness, attitudes, and behaviours towards contaminants which was assessed in the UK firefighter contamination survey. Results revealed that lack of training on fire effluents and their health outcomes are strongly associated with increased fire smoke/contaminant exposure. Notably, untrained firefighters were at least twice as likely to: never clean personal protective equipment (PPE) (Crude Odds Ratio, OR 2.0, 1.5–2.7), infrequently send their PPE for professional cleaning (OR 2.0, 1.6–2.4), remain in the workwear (t-shirt etc.) worn while attending a fire incident (OR up to 3.6, 2.3–5.6), and indicate that cleaning at fire stations is not taken seriously (OR 2.4, 2.2–2.6). Firefighters personally viewing contamination as a "badge of honour" (BoH) were at least twice as likely to: remain in contaminated PPE after fire incidents (OR 2.3, 1.4–3.9), eat with sooty hands (OR 2.2, 1.9–2.5), notice soot in the nose/throat (OR 3.7, 2.7–5.2), and smell fire smoke on the body for more than a day after incidents (OR 2.0, 1.6–2.4). They were also more likely to indicate that cleaning at fire stations is not taken seriously (OR 2.5, 2.2–2.9) and that fire stations smell of smoke always/most of the time (OR 2.3, 2.0–2.6). Strong links were also found between belief in the BoH and never cleaning PPE (OR 1.9, 1.4–2.7), and eating while wearing contaminated PPE (OR 1.8, 1.5–2.2).

Many fire contaminants are associated with chronic health outcomes such as cancer[1–3]. Carcinogens have been identified on firefighters' PPE, equipment, fire station surfaces etc[1,4]. While research has begun to characterise firefighters' cancers and diseases in relation to their occupational exposures, little is currently known about firefighters' awareness, attitudes, and behaviours towards contaminants.

When firefighters are subjected to repeated similar experiences (such as fire attendances), over time, they may pay less attention or take less caution over their exposure to toxic substances[5–7]. This puts them at risk of gradually resuming bad habits and routines, leading to illness or accidents[6,8].

The "badge of honour" (BoH) is an attitude sometimes upheld by firefighters; whereby heavily contaminated personal protective equipment (PPE) is perceived as a mark of prestige[9]. Visibly contaminated PPE provides a performative means of earning the respect of esteemed colleagues, and/or meeting the public's expectations of firefighters as heroic. BoH and similar attitudes therefore have the propensity to not only increase the wearer's exposure to fire toxins, but also that of his/her colleagues/family.

This manuscript discusses the influence of cultural beliefs such as the BoH on firefighters' exposure to contaminants and engagement in decontamination practices. The prevalence of training provision, its potential relationship to BoH belief, and its success at promoting engagement in decontamination practices is also assessed and presented.

Methods

The methods used to conduct the survey and analyse its results are detailed in Wolffe et al.[10]. Ethical approval for the survey was granted by the University of Central Lancashire Ethics Committee, and all analyses were conducted in accordance with relevant guidelines and regulations. The survey consisted of 64 questions (Supplemental File S1) covering several key topics, including demographics, PPE (provision, maintenance, storage, fit, decontamination practices etc.)[10], health[11], and attitudes/awareness and training.

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All currently serving (i.e. excluding retired) UK firefighters were eligible to take part in the survey and were recruited to participate via email through the Fire Brigades Union (whose members make up approximately 75% of the UK's total firefighting workforce[10,12]). Firefighters were invited to anonymously complete the survey online. Informed consent was obtained from all participants.

Belief in the BoH was cross tabulated with several key variables that represented behaviour or practice linked to contaminant exposure (e.g. eating while wearing PPE is a practice/behaviour which acts as a proxy for contaminant ingestion). The training status of firefighters (i.e. whether firefighters had received training on fire contaminants and their health effects) was similarly cross tabulated with behaviour/practice variables. In both instances, BoH/training status was treated as the explanatory (independent) variable, and the practice/behaviour of interest treated as the response (dependent) variable. Thus, the proportion of firefighters in each BoH/training status category who engage in a particular behaviour/practice is presented. An exception is that of the demographics section, which explores the type of firefighter who believes in the BoH/has not received training (i.e. presents BoH/training status as the dependent variable and demographics as independent variables).

Crude Odds Ratio (OR) with 95% confidence intervals were used to assess the statistical significance of differences between the proportion of firefighters who believe in the BoH/have not received training and engage in behaviours/practice which proxy contaminant exposure. Explanatory and response variables were generally collapsed into two categories for each analysis (see Supplemental File S1). A lack of answer or answers of "prefer not to say" were excluded from analyses.

The chi-squared test for trend and z-score test for difference in proportions were also used to assess the statistical significance of apparent trends/findings.

Free-text responses were manually coded by a single author according to an iterative list of the most commonly occurring themes.

Results and analysis

The responses of a total of 10,649 firefighters were included for analysis, representing approximately 24% of the UK's total firefighter workforce[10]. Participant demographics were analysed in Wolffe et al.[10], and were not found to significantly differ from the English firefighter population[13] with respect to sex ($p > 0.05$), but appeared to under-represent younger age categories, retained firefighters, and those belonging to an ethnic minority ($p < 0.05$).

Approximately sixteen percent of firefighters indicated that they believe visible signs of contamination is a BoH, while a further 46% indicated that they believe others hold this attitude (Fig. 1A).

The majority of firefighters (62%) had not received any training on the health effects of contaminant exposure (Fig. 1B). Of those that had received training, 93% found this training to be useful. Those that had not received training were also receptive to the idea, with 98% indicating that they would find training valuable.

Lack of training only slightly increased the odds ratios for firefighters indicating that they or others believed in the BoH (ORs 1.1, 1.0–1.2, for personal belief in the BoH and 1.1, 1.0–1.2 for others belief). However, this increase was not statistically significant for personal belief in the badge of honour.

Demographics. The Fire and Rescue Services in the United Kingdom are divided into England, Wales, Scotland and Northern Ireland, and each operates under separate legislative and administrative arrangements[14]. Participant demographics were compared to English FRS statistics[13] and presented in Wolffe et al.[10]. Detailed analysis of the geographic distribution of belief in the BoH/lack of training can be found in Supplemental File S2.

The proportion of firefighters indicating personal belief in the BoH generally increased, and was significantly associated with age ($p < 0.05$), seniority of role ($p < 0.05$), and years of service ($p < 0.05$) (Fig. 2). Managerial firefighters (i.e. crew, watch, station, group, area, and principal managers) were 1.5 times more likely to indicate personal belief in the BoH compared to non-managerial firefighters (OR 1.5, 1.3–1.7). Older firefighters (i.e. those 45 or older) were slightly more likely to indicate personal belief in the BoH compared to younger firefighters (OR 1.2, 1.0–1.3).

Belief in the BoH was significantly more likely in firefighters who had served for more than 5, 10, or 15 years (OR 1.9, 1.6–2.3 for 5+, OR 1.5, 1.3–1.8 for 10+, and OR 1.4, 1.3–1.6 for 15+) when compared to firefighters who had served less than 5, 10 or 15 years respectively. In other words, the association between length of service and belief in the BoH was not diluted by regrouping firefighters into wider length of service categories; indicating that belief in the BoH is spread among firefighters who have served for shorter (5+/10+) and longer (15+) lengths of time. Supported by free text analysis, this indicates that belief in the BoH has only very recently begun to wane, i.e. within the last 0–4 years prior to the survey.

Interestingly, the proportion of firefighters personally believing in the BoH was greatest for those that attend fires on the most and least frequent bases, dipping for firefighters who fall between the two extremes (Fig. 2, although small sample sizes at either extreme warrant caution). Fire attendance frequency was found to be significantly associated with personal belief in the badge of honour ($p < 0.05$), with firefighters attending fires on at least a weekly basis being 1.2 times more likely to report belief in this attitude than those attending fires less frequently (OR 1.2, 1.1–1.4).

Trends in the number of firefighters who believed that others held the BoH attitude were less clear, with roughly equal proportions of each demographic category indicating that others held the attitude (Fig. 2), and no significant associations found for fire attendance frequency ($p > 0.05$), or years of service ($p > 0.05$). However age ($p < 0.05$) and seniority of role ($p < 0.05$) were still found to be significantly associated with others' belief in the badge of honour.

Fire attendance frequency was significantly ($p < 0.05$) and positively correlated with a lack of training (Fig. 2). Firefighters attending fires at least once a week were 1.2 times more likely to have had no training on fire contaminants compared to those attending fires less frequently (OR 1.2, 1.1–1.3).

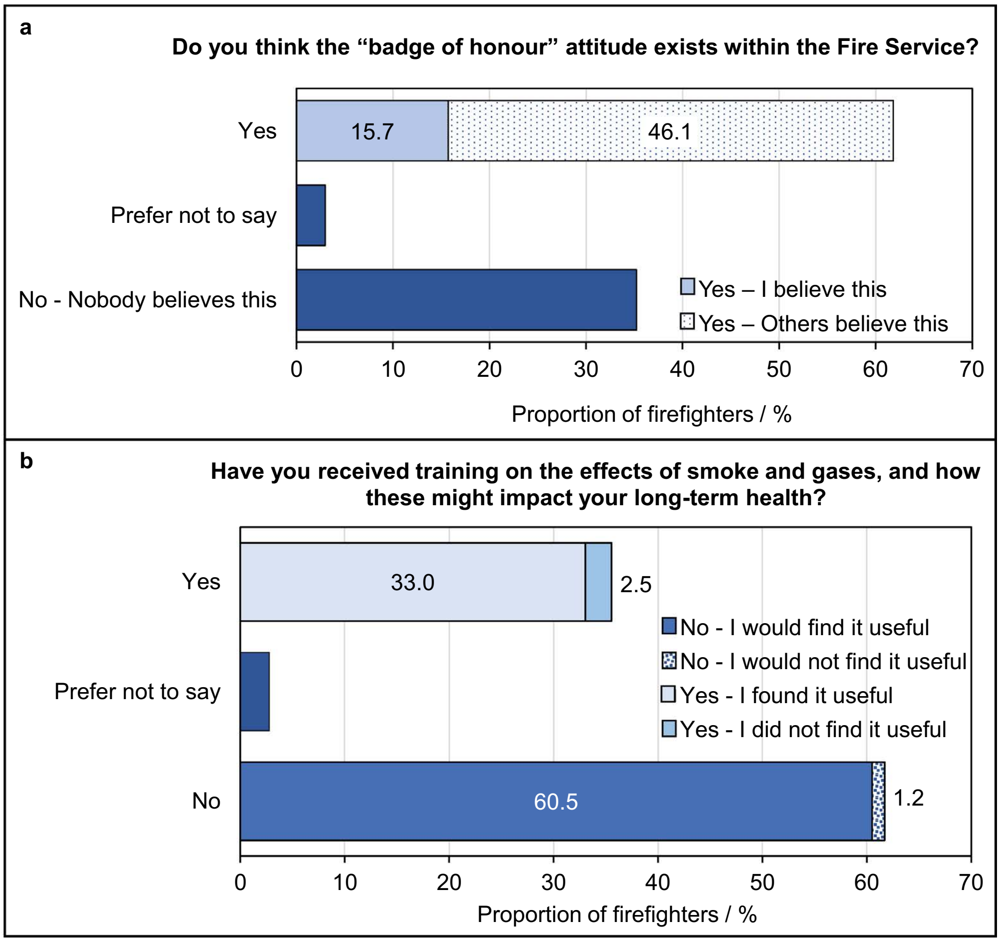

Figure 1. Training on fire contaminants and their associated health outcomes, and belief in the BoH attitude in the UK Fire and Rescue Service. Proportion of total surveyed firefighters who (**A**) hold/do not hold the BoH attitude, and (**B**) who have/have not received training on the health effects of fire contaminant exposure.

Years of service was also found to be significantly associated with lack of training ($p < 0.05$). Firefighters who had served 15 years or longer were found to be slightly but significantly more likely to indicate that they had not received training compared to those that had served less time (OR 1.3, 1.2–1.4). This was similarly found for firefighters who had served 5 + years (OR 2.1, 1.9–2.4) or 10+ years (OR 1.7, 1.5–1.9). Free text answers also indicated that training on contaminants may only have been introduced in the last 0–4 years before the survey.

A significant association was additionally found between lack of training and age ($p < 0.05$), but not between lack of training and seniority of role ($p > 0.05$).

Personal contamination during/after fire incidents. Crude odds ratios for firefighters attending incidents without respiratory protective equipment (RPE) were significantly increased for both belief in the BoH and lack of training on fire contaminants (Fig. 4). Firefighters who personally believed in the BoH, or who had not received training, were both 1.7 times more likely to attend incidents without RPE compared to those who felt nobody believed in the BoH, or who had received training (OR 1.7, 1.5–1.2 and OR 1.7, 1.5–1.9 respectively). Those who felt others believed in the BoH were still more likely to attend incidents without RPE, albeit to a lesser extent than those who personally believed the attitude (OR 1.4, 1.3–1.6).

Culture, awareness and training featured strongly among firefighters' reasons for attending fires without RPE. Free text responses revealed that firefighters were left to make their own judgements on the use of RPE (14% firefighters providing free text), or felt pressured by peers to attend fires without RPE (7% firefighters providing free text).

Around 4% of firefighters providing free text reasons for attending fire incidents without RPE specifically cited a lack of procedures or poorly enforced procedures concerning when to use RPE, or which RPE was most appropriate to use (Fig. 3). It should be noted that a lack of/poorly enforced procedures are likely to facilitate firefighters being left to make their own judgements on the use of RPE. Thus, while firefighters may not always have mentioned both issues in their free text responses, they are likely to be closely linked.

Firefighters who believe in the BoH were significantly more likely to eat while wearing PPE (OR 1.8, 1.5–2.2 for personal, and OR 1.4, 1.3–1.6 for others belief in the BoH), Fig. 4. Similarly, a significantly increased odds

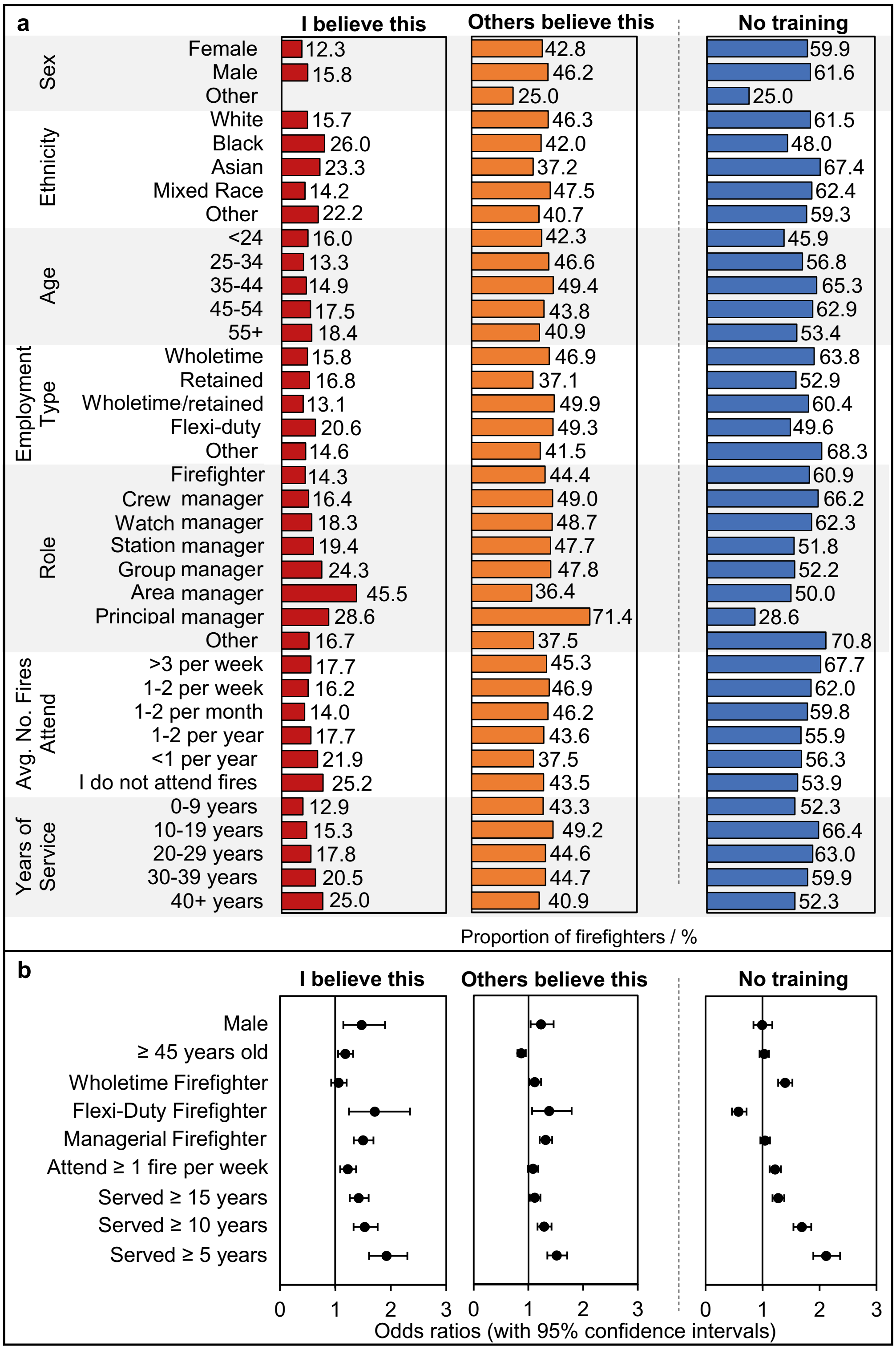

Figure 2. **Firefighter demographics and belief in the BoH, and training on fire contaminants and their associated health outcomes.** (**A**) The proportion of total surveyed firefighters in each demographic category who personally believe in the BoH, who feel others believe in the BoH, and who have not received any training on the health effects of smoke/contaminant exposure. (**B**) Crude odds ratios (with 95% confidence intervals) for belief in the BoH attitude/lack of training and demographics. Note that the small sample size for certain demographic groups (e.g. sex = Other, where n = 4), mean that the above proportions should be interpreted cautiously. Participant demographics are summarised in Wolffe et al.[10].

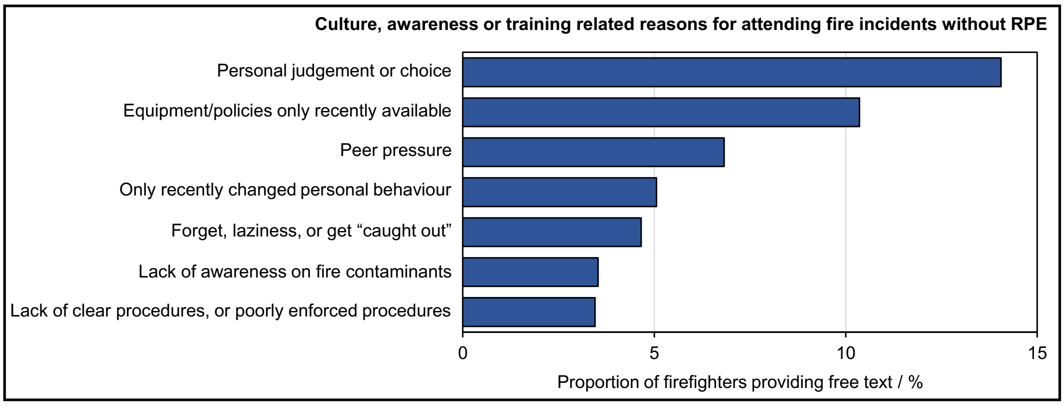

Figure 3. Culture, awareness and training and attending fires without RPE. Cultural/awareness related reasons for firefighters' attending fire incidents without respiratory protective equipment, coded from free text. Note that a single firefighter's free-text answer may have contained several sentiments belonging to several different themes.

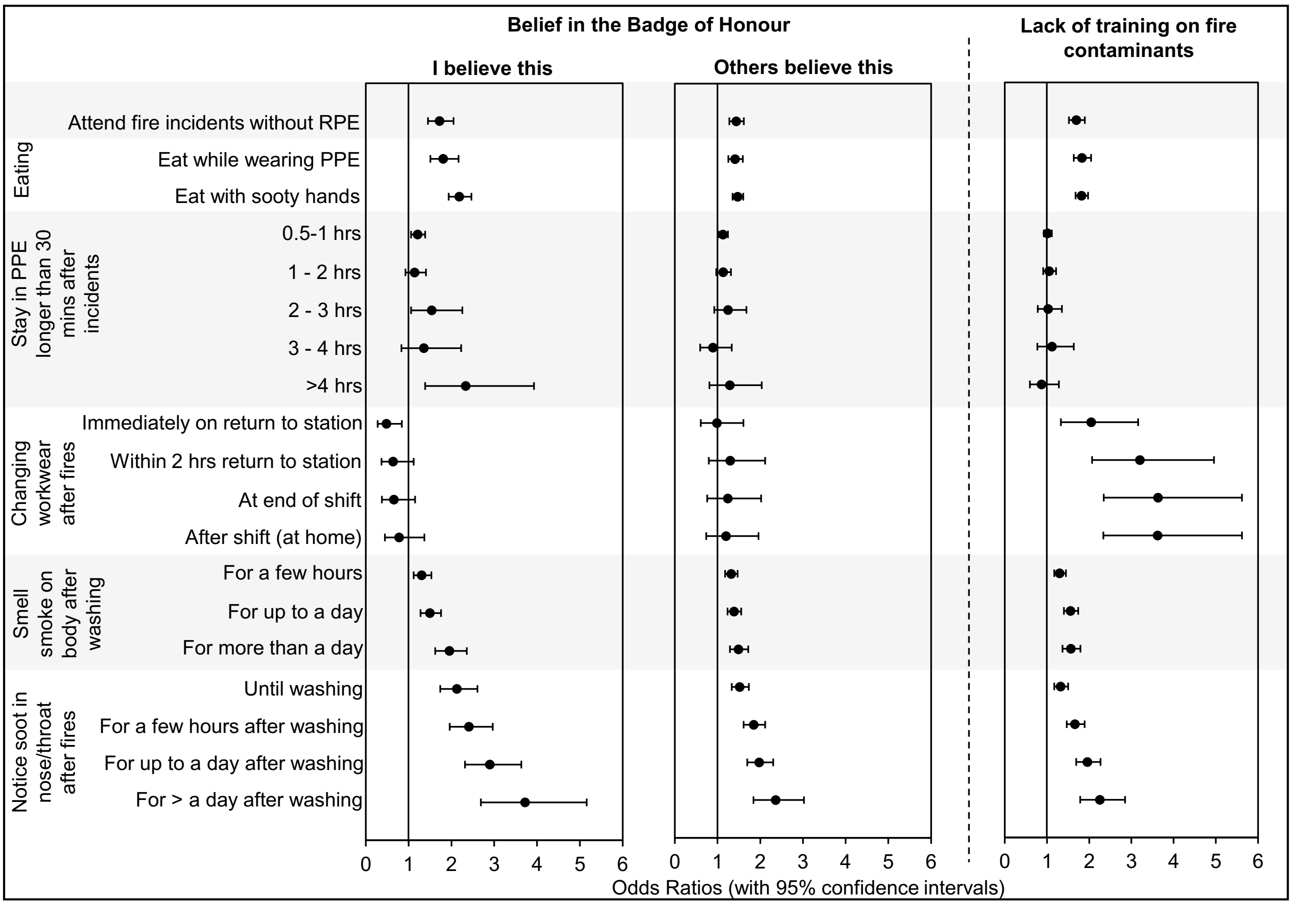

Figure 4. Crude odds ratios for engaging in behaviours/practices that lead to personal contamination during/after fire incidents for firefighters who believe in the BoH, or who have not received training on fire contaminants and their associated health outcomes.

ratio for eating with sooty hands was found for personal/others belief in the BoH (OR 2.2, 1.9–2.5 for personal, and OR 1.5, 1.4–1.6 for others' belief in the BoH, respectively). A statistically significant increased odds ratio was also found for staying in PPE for an extended amount of time after attending fire incidents among those who personally believed in the BoH (OR 2.3, 1.4–3.9 for > 4 h). This was not found for firefighters who claimed that others believed in the BoH (Fig. 4).

BoH attitude did not appear to influence the odds ratios for firefighters remaining in their workwear after attending a fire incident (Fig. 4).

Except for remaining in PPE for an extended amount of time after a fire incident, a lack of training was associated with a significantly increased odds ratio for every measure of personal contamination assessed in the survey, i.e. attending fire incidents without wearing RPE (OR 1.7, 1.5–1.9); consuming food with sooty hands (OR 1.8, 1.7–2.0), or while wearing PPE (OR 1.8, 1.6–2.0); smelling smoke on the body after fire incidents (OR 1.3, 1.2–1.4 for a few hours after washing, OR 1.6, 1.4–1.7 for up to a day after, OR 1.6, 1.4–1.8 for more than a day after); and noticing soot in the nose/throat after fire incidents (OR 1.3, 1.2–1.5 until washing, OR 1.7, 1.5–1.9 for a few hours after washing, OR 2.0, 1.7–2.3 for up to a day after, OR 2.3, 1.8–2.8 for more than a day after). Most notably, firefighters who did not receive training were up to 3.6 times more likely to remain in their workwear for an extended amount of time after attending an incident (OR 3.6, 2.3–5.6 for changing workwear at home after finishing a shift, Fig. 4).

For firefighters who believed in the BoH, the odds ratios for both continuing to smell smoke on the body, and for noticing soot in the nose/throat, increased as the length of time after washing on return from an incident increased (Fig. 4). When compared to those who felt nobody believed in the BoH, these firefighters were 2.0 times more likely to smell smoke on their bodies (OR 2.0, 1.6–2.4), and 3.7 times more likely to notice soot in their nose/throat, for more than a day after washing on return from a fire incident (OR 3.7, 2.7–5.2, Fig. 4).These trends were mirrored by firefighters who felt that others believed in the BoH.

Compared to those who felt nobody believed in the BoH, a consistently larger proportion of firefighters who believed in the BoH, or felt their colleagues did, rated face (49% and 38% vs. 36%), neck (32% and 26% vs. 23%), hair (40% and 36% vs. 32%), and hands (54% and 50% vs. 45%) as feeling highly contaminated after fire incidents (Supplemental File S2, Fig. S3).

As expected, a larger proportion of these firefighters also consistently rated hair (65% and 60% vs. 57%) and hands (49% and 43% vs. 38%) as smelling strongly of smoke (Supplemental File S2, Fig. S4). These trends were mirrored for firefighters who had not received training (Supplemental File S2, Figs. S3, S4).

Personal protective equipment. A lack of training and belief in the BoH, were both significantly associated with several negative behaviours/practices concerning the storage and cleaning of PPE (Fig. 5), i.e. those that would put firefighters at a potentially increased risk of contaminant exposure, or would lead to harmful cross contamination.

Personal belief in the BoH significantly increased the odds ratios for firefighters never cleaning their PPE (Fig. 5) by as much as 1.9 times (BA never cleaned, OR 1.9, 1.4–2.7). Similarly, belief in the BoH was associated with failing to send PPE for professional cleaning on a regular basis (i.e. sending PPE for professional cleaning less than once per month), although this was only found to be significant for tunics/trousers (OR 1.4, 1.2–1.7) and fire hoods (OR 1.4, 1.2–1.7). Firefighters were also significantly more likely to wear ill-fitting PPE (OR 1.4, 1.1–1.7), and to engage in PPE storage/transport practices known to contribute to cross-contamination if they believed in the BoH. This included taking PPE home to clean (OR 1.4, 1.1–1.6), storing fire gloves within other items of PPE e.g. helmets, boots, tunic pockets etc. (OR 1.2, 1.1–1.4), and failing to store clean/dirty PPE separately (OR 1.5, 1.3–1.7).

Statistical significance was also found for the increased odds ratio associated with firefighters who indicated that their colleagues believed in the BoH sending their PPE for cleaning on an infrequent basis (OR 1.4, 1.1–1.8 for fire gloves, OR 1.2, 1.1–1.0–1.3 for fire hoods, OR 1.2, 1.1–1.3 for tunic/trousers). In addition, a significantly increased odds ratio was found for these firefighters failing to store clean/dirty PPE separately (OR 1.2, 1.1–1.3) and storing used/dirty PPE in the appliance/car cab on return from an incident (OR 1.2, 1.1–1.4). Interestingly, there was no significant association between firefighters who indicated their colleagues believed in the BoH and never cleaning their PPE (Fig. 5).

Lack of training was also associated with a significantly increased odds ratios for all negative PPE storage/cleaning practices assessed in the survey. An exception was for failing to send breathing apparatus (BA) for regular professional cleaning. However, it is not standard practice to send this item for external, professional cleaning (Fig. 5). Notably, a lack of training doubled the odds ratio for firefighters *never* cleaning BA (professionally or otherwise, OR 2.0, 1.5–2.7), sending fire gloves for professional cleaning infrequently/never (OR 2.0, 1.6–2.4), storing dirty/used PPE in the appliance or vehicle cab on return from incidents (OR 1.8, 1.6–2.0), storing clean and dirty PPE together (i.e. not separately, OR 1.9, 1.8–2.1) and wearing PPE that does not fit well (OR 1.8, 1.5–2.0).

When asked what firefighters' main reasons for cleaning their PPE were, roughly equal proportions of those from each BoH belief category (i.e. I believe this, others believe this, nobody believes this) selected each of the answer options (Supplementary File S2, Fig. S2). The exceptions were for "I send it after every incident" and "It is damaged"—where a smaller proportion of those who believe in the BoH indicated that these were reasons they would send their PPE for cleaning compared to those who felt nobody believed in the BoH.

A similar trend was observed for training status—whereby a smaller proportion of those who had not received training indicated that they would send their PPE for cleaning after every incident compared to those who had received training (Supplementary File S2, Fig. S2).

Workplace contamination. A statistically significantly larger proportion of firefighters personally holding the BoH attitude indicated that their station had no separate clean/dirty areas (28%) for PPE compared to firefighters who felt others believed in the BoH attitude (22%) ($p < 0.05$), and compared to firefighters who felt that nobody believed in the BoH attitude (20%) ($p < 0.05$).

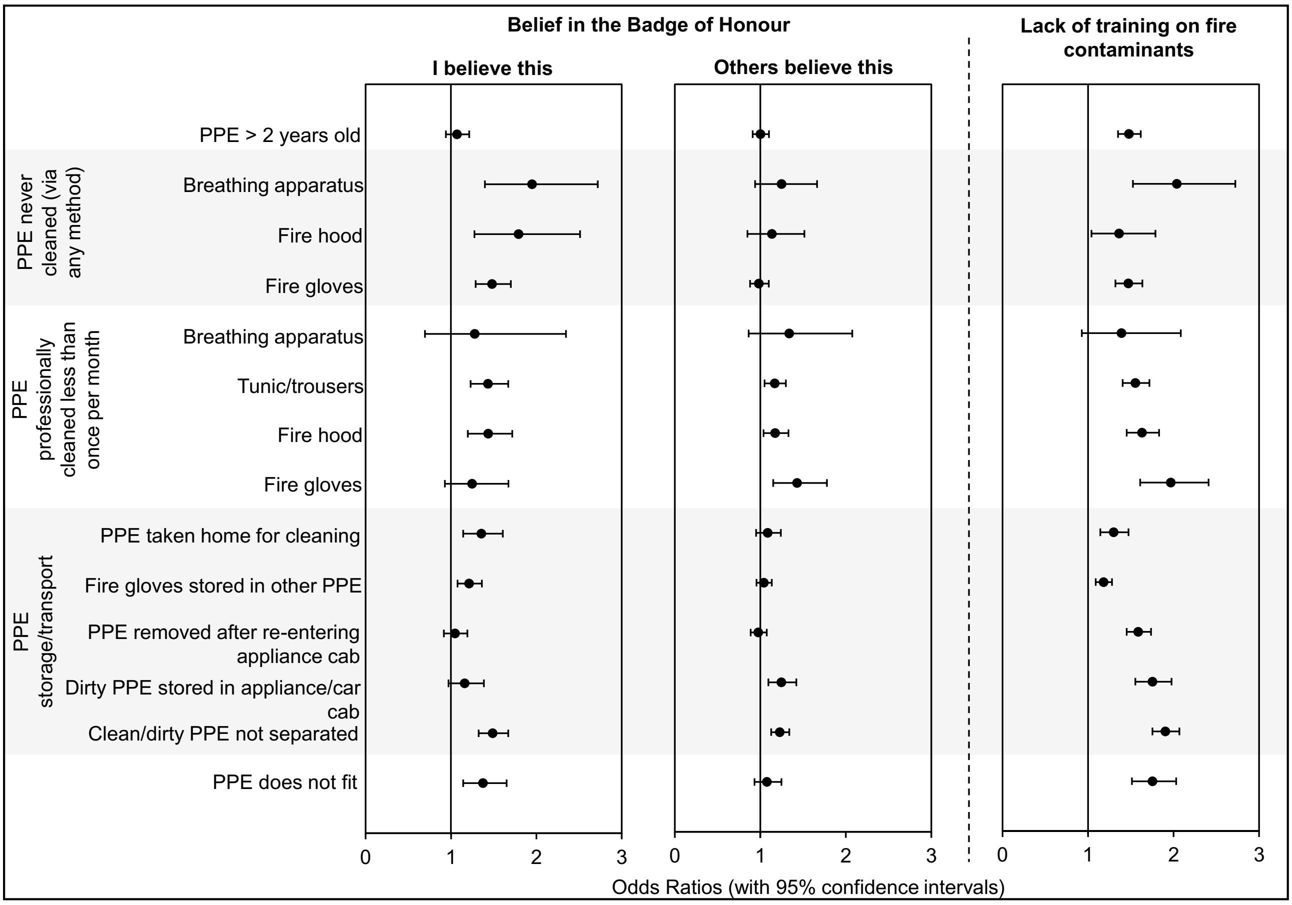

Figure 5. Belief in the BoH/lack of training and crude odds ratios for engaging in negative PPE storage or cleaning practices. Although the survey asked firefighters whether they sent breathing apparatus and fire gloves for professional cleaning—it should be noted that sending these items for external, professional cleaning is not (currently) standard practice[10].

Similarly, a significantly larger proportion of firefighters personally holding the BoH attitude indicated that their workplace smelt of fire/smoke always/most of the time (26%) compared to those who felt that others believed in the BoH (20%) ($p < 0.05$), and compared to those who felt nobody believed in the BoH (13%) ($p < 0.05$), Fig. 6.

These findings were mirrored for firefighters who had not received training (compared to firefighters who had received training, Fig. 6), i.e. $p < 0.05$ for the difference in proportions between trained and untrained firefighters whose workplace smells of fire always/most of the time, or whose workplaces have no designated clean/dirty areas.

Firefighters who personally believed in the BoH were found to have odds ratios for smelling fire in the station always/most of the time which were more than twice that of firefighters who felt that nobody believes in the BoH, Fig. 6 (OR 2.3, 2.0–2.6). Firefighters who did not receive any training on fire contaminants were 1.8 times more likely to work in a station without dedicated clean/dirty areas compared to those that had received such training (OR 1.8, 1.6–2.0).

It was also found that firefighters who personally believed in the BoH, or who had not received training on fire contaminants, were over twice as likely to indicate that cleaning was not taken seriously at their workplace compared to those who felt nobody believed in the BoH/had received training (OR 2.5, 2.2–2.9 and OR 2.4, 2.2–2.6, respectively). Firefighters who felt that their colleagues believed in the BoH were also significantly more likely to indicate that cleaning was not taken seriously at their workplace (OR 1.9, 1.7–2.0), albeit to a lesser extent than those who personally held the attitude.

Firefighters were also given the opportunity to provide their thoughts and feelings on the subject of fire contamination at their workplace, via free-text. Around 38% of all firefighters ($n = 4072$) provided free text responses to this prompt, covering a variety of issues including training provision and culture/awareness. Most notably, 13% of firefighters who answered the question indicated discrepant attitudes toward cleaning and contamination at their workplace, (e.g. “Some people take it seriously, but others don’t”). Approximately, 1% specifically mentioned the BoH, with similarly discrepant views on the demographic of firefighters who hold the attitude (e.g., “Cleaning is not taken seriously by some, mostly new personnel and some experienced personnel. I feel some think it’s a badge of honour to be covered in soot”).

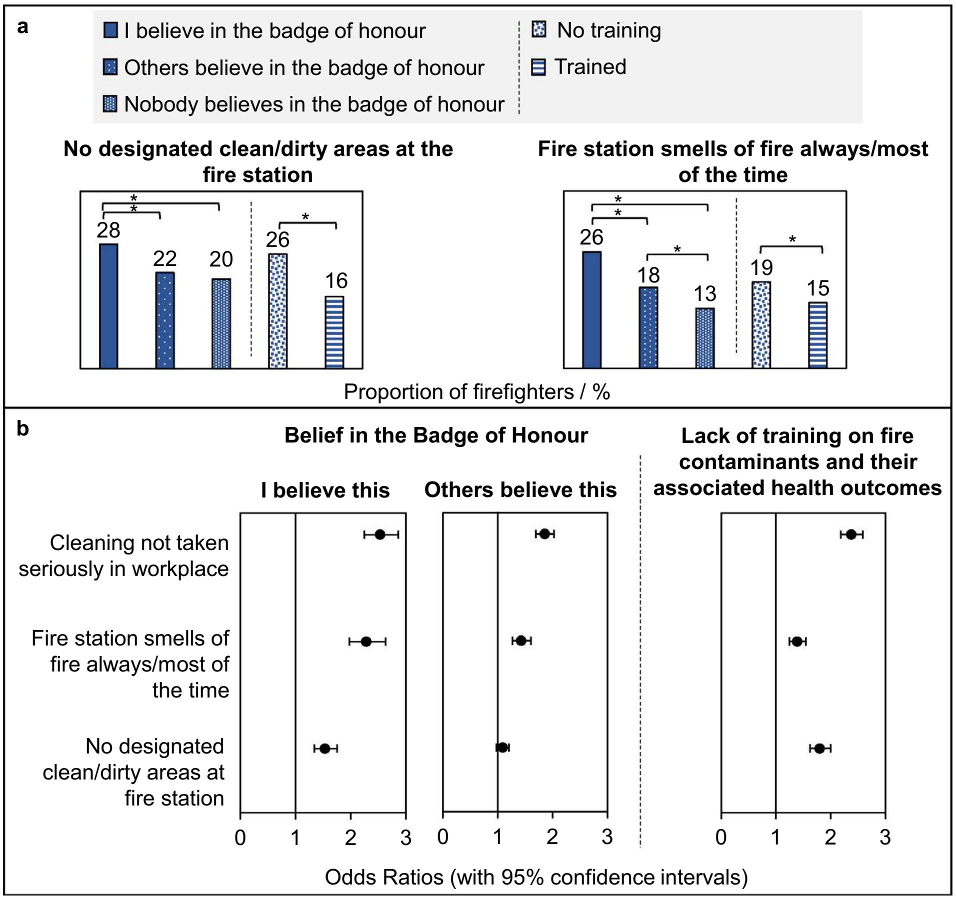

Figure 6. Belief in the BoH/lack of training and workplace contamination. (**A**) The proportion of firefighters, and (**B**) the crude odds ratios, for firefighters in each BoH belief/training status category whose workplaces have no designated clean/dirty areas or smell of fire always/most of the time. *Indicates a p-value of <0.05 for the z-score test for difference in proportions.

Training also received mention among free text responses. Just 0.2% of firefighters left positive sentiments towards training/awareness. By contrast, 2.4% of firefighters providing free text felt that training/awareness was inadequate, or that further training was required.

Encouragingly, around 9% of firefighters providing free text felt that attitudes/awareness were improving (e.g. "It is getting better with the more we learn"). Many of these firefighters indicated that training had very recently been introduced, or that awareness was only recently increasing. However, many indicated that there was still much work needed to protect firefighters from fire contaminant exposure, or that the pace of change was still slow, e.g. "I can see the new research and findings taking a positive effect on station but it's not as fast a change as perhaps it needs to be", "it is only within the last 6 months that it has reached the radar…still a long way to go").

Discussion

Procedures and regulations versus awareness and habits. The results of the survey uncovered considerable variation in the decontamination practices firefighters engage in. Firefighters from the same demographic or geographic region indicated different levels of compliance with decontamination procedures, and/or varied training provision. For example, firefighters within the same geographical regions indicated storing clean and dirty PPE separately or not, or that their workplaces have/have not designated clean/dirty areas (Supplemental File S2), suggesting a potential lack of standardisation of decontamination policies and/or a lack of compliance with such policies in the UK Fire and Rescue Services. This was similarly found in earlier work, when reviewing UK FRS decontamination policies[15], and was a sentiment which was echoed in firefighters' free text responses to the current survey, e.g. "My Watch Manager on my on-call station doesn't follow the policy all the time so is rarely cleaned and decontaminated after incidents", "I wrote an SOP [standard operating procedure] relating to decontamination and kit cleaning after attending a course. All agreed, but it was never followed or taken seriously by management", "cleaning is taken seriously by most but not all. Very little from headquarters to reiterate what must be done".

Without such standardisation, several firefighters indicated that they felt judgements on contaminants were left to personal choice, e.g. "PPE cleanliness is generally down to personal choice I find…", "There is no clear guidelines. It seems to be personal preference", "…I believe it should be enforced strictly as it is normally down to personal preference". As well as practicality and resources, firefighters indicated that these judgements were sometimes based on a personal assessment of risk, e.g. reasons given for attending fire incidents without RPE such as "own risk assessment", "I believe I risk assess the appropriateness for the need to wear PPE. Many occasions when I attend I am for example up wind out of smoke, if I decide to enter a smoke area or cold fire scene I may use the PPE or RPE", "Assess where the smoke is, and what it is, and if it affects me I will wear one [RPE]". This is particularly detrimental for firefighters who are not fully aware of the dangers of contaminant exposure and/or the routes via which firefighters are exposed to chronic, low doses of contaminants.

"Habit" was another reason commonly given for engaging in negative contaminant exposure practices e.g., attending incidents without RPE. While some firefighters left free text responses which implied they knew these habits may have negative effects on their health ("sometimes I don't think I need it [RPE], but probably should") several also indicated that they had changed their behaviour after gaining knowledge on fire contaminants and their health effects, e.g. "I have attended incidents for years without being aware of the risks especially post fire. Things are changing now but this needs to become embedded as normal practice", "never used to [wear RPE] but am more mindful now".

Thus, providing training as an intervention which increases awareness of the dangers of contaminant exposure, in combination with stricter regulations and better standardised decontamination practices, may be required in order to protect firefighters from exposure to harmful fire contaminants.

Provision of training on fire contaminants and their associated health outcomes. The majority (62%) of firefighters in the UK Fire and Rescue Service have not received any training on fire contaminants and their health effects. This is particularly concerning given that a lack of training increased the odds ratios for firefighters engaging in a variety of behaviours/practices which not only increase their exposure to harmful contaminants, but also increase their likelihood of developing cancer[11]. These behaviours/practices either expose firefighters directly (e.g. eating while wearing PPE, attending fires without RPE etc.)—or indirectly through cross contamination (e.g. failing to store clean and dirty PPE separately).

Also of concern is the finding that firefighters most at risk of exposure to contaminants are also most likely to have received no training on the health effects of the contaminants they are exposed to, i.e. those attending fires on at least a weekly basis were 1.2 times more likely to have received no training compared to those attending incidents less frequently (OR 1.2, 1.1–1.3). A significantly larger proportion of firefighters attending fires on a weekly basis were found to have served 15 years or longer compared to those attending fires less frequently ($p < 0.05$). Further breakdown of these trends finds firefighters who had served more than 5 years still had an increased odds ratio for having received no training (OR 2.1, 1.9–2.4). Thus, training may only have been introduced very recently (i.e. within 0–4 years before the survey was conducted), which is supported by free text responses, e.g. "we have only just recently started to adhere to a clean cab policy following on from evidence coming out about the risk of cancers to firefighters", "in the past year we understand the risks from contaminants so take greater care for cleaning equipment. For the previous two decades this was just a cursory clean, basically as long as soot didn't come off on your hands then the equipment was fine".

This also implies that there is a legacy group of firefighters who never received training on the health effects of contaminant exposure, and who continue to be overlooked in terms of training provision, even if new recruits have since received such training.

Compared to more obvious or direct indicators of contamination (e.g. workplace smelling of smoke, spending an extended amount of time in PPE after incidents etc.), a lack of training appeared to be most strongly associated with more subtle or indirect proxies of contamination (compared to belief in the BoH). For example, the greatest odds ratios for working in a fire station without designated clean/dirty areas was found for firefighters who had not received training (Fig. 6, OR 1.8, 1.6–2.0). Similarly, firefighters without training were most likely to stay in their workwear (i.e. the clothes worn underneath PPE) for an extended amount of time after attending fire incidents (OR 3.6, 2.3–5.6 for changing workwear at home after the end of a shift), or to engage in PPE transport/storage practices known to cause cross contamination, e.g. de-robing dirty PPE after re-entering the appliance cab (Fig. 4, OR 1.6, 1.5–1.7).

These more subtle measures of exposure to fire contaminants are perhaps easily overlooked, leading to chronic exposure. Exposure to (even very low doses of) contaminants which are carcinogenic or endocrine disrupting (e.g. polycyclic aromatic hydrocarbons, polybrominated diphenyl ethers, etc.) can illicit health conditions with long latent periods such as cancer. Further, chronic exposure to such chemicals makes these health outcomes increasingly likely. Given the above discussed results, it can be assumed that training increases awareness of the health effects associated with chronic, low-dose exposures—and promotes the uptake of policies/procedures which target such exposures.

Having said that, considerable proportions of firefighters who did receive training still indicated engagement in negative behaviours/practices regarding fire contamination. For example, 80% of trained firefighters indicated that they would attend fire incidents without RPE, while 81% indicated that they would eat while wearing PPE. In some instances, this may plausibly be due to discrepant training status among firefighters working in the same station. For example, new recruits who have received training may begin working in stations that are staffed by firefighters who have not received such training, and who may therefore unknowingly perpetuate negative contamination practices.

Firefighters who *have* received training may also be subject to "habitual blindness"[7]—where the frequency with which they have historically engaged in negative contamination practices desensitises them to the potential dangers of such practices, even if previously educated on the health implications. Thus, regular training updated with the latest scientific evidence on fire contaminants, their exposure routes and health outcomes may be required in order to tackle such habitual blindness.

Alternatively, continued engagement in such practices may be more significantly influenced by cultural factors such as the BoH attitude and similar bravado—reflected in several of the survey's free text responses. This was also found to be relevant for a surveyed population of US firefighters, where cultural influences such as peer pressure were found to be a major influence on firefighters' choice to use PPE[16].

In fact, several studies in non-firefighting occupational groups similarly find a disconnect between high levels of safety knowledge and the use of PPE in practice, demonstrating the importance of exploring cultural modifiers of safety behaviour[17,18].

Badge of honour. The BoH is an attitude which has historically been strongly associated with the Fire and Rescue Service[9], and celebrates visibly contaminated PPE as a mark of hard work. Firefighters who personally believe in the BoH had the greatest odds ratios for engaging in practices/behaviours which are linked to PPE contamination, e.g. never cleaning PPE (Fig. 3).

Interestingly, the survey found that those who felt others believed in the BoH (46% of all surveyed firefighters) were also more likely to partake in behaviours/practices that increase the risk of exposure to contaminants, although generally to a lesser extent than those who personally hold the attitude. These findings indicate the potentially considerable influence of peer pressure in the UK Fire and Rescue Service, and/or the need to conform to cultural expectations. Examples of peer pressure modifying firefighters' behaviour were found in the free text reasons given for attending fire incidents without RPE, e.g. "I do wear it occasionally but when I don't it's usually due to nobody else wearing it and an element of peer pressure", "peer pressure, Bravado from colleagues", "it is the attitude not to wear it and seen as weak", "pressure from others—would get some stick".

Unsurprisingly, firefighters who felt their colleagues believed in the BoH were also more likely to indicate that cleaning was not taken seriously at their workplace (OR 1.9, 1.7–2.0). This illustrates the far-reaching impacts of non-compliance to decontamination practices—as even a single non-compliant colleague has the potential to lead to cross contamination which increases the exposure of complaint colleagues[10]. This may in turn compromise overall compliance, as individuals following decontamination procedures feel their efforts are undone by noncompliant colleagues.

Some research suggests that the BoH is an outdated attitude which is becoming less common in Fire and Rescue Services globally[9], particularly as awareness of the harmful effects of fire contaminants grows. As such, firefighters personally believing in the BoH were in the minority (16%) in the UK Firefighter Contamination Survey (compared to 46% indicating others believe in the BoH, and 35% indicating nobody believes in it, Fig. 1). Consistent with this research, the proportion of firefighters personally believing in the BoH was positively and significantly correlated with age, years of service, fire attendance frequency, and seniority of role (Fig. 1). Those attending fires on the most and least frequent bases were the demographic categories with the largest proportions of firefighters personally believing in the BoH. This may result from a desensitisation to contaminant exposure for those frequently attending incidents, whereas those attending fires least frequently may feel extra pressure to prove their worth. Alternatively, the interconnected relationship between age, years of service and seniority of role may offer explanation for the latter finding, as more senior ranking managerial firefighters (who may still uphold the outdated BoH attitude) begin attending fewer incidents as their careers progress.

Consistent with the odds ratios calculated for firefighters serving 15+,10+ or 5+ years above, analysis of free text responses concerning PPE/workplace cleaning practices revealed an inconsistent picture of belief in the BoH within the UK Fire and Rescue Service. Some firefighters blamed new recruits for perpetuating the attitude, while others cited older firefighters/management as continuing to uphold the attitude e.g. "younger crew members see a dirty kit as a badge of honour…", "some new firefighters think it's cool and good that their kit smells of fire after having a working job and wearing BA. It's like it's a status", "I think among the people with more years in the job the smell after a fire is seen as a badge of honour…", "getting the old crew to clean is a problem", "old hands rarely if ever clean kit, let alone send it off to be cleaned professionally. I have routinely been told to take my gloves and flash hood home to clean in the washing machine which I have refused to do so. I am shocked with how some people are so stuck in older times and refuse to look at the evidence-based research…".

Limitations and future work

As discussed in previous parts of the UK Firefighter Contamination Survey analysis[10,11,19], the survey may be subject to participation bias.

In this manuscript, a lack of training on fire contaminants and belief in the BoH were treated as independent variables, and engagement in certain negative contamination behaviours/practices treated as dependent variables. Crude odds ratios were not adjusted for other factors associated with the outcome variables as in other analyses of the UK Firefighter Contamination Survey[11,19], due to the large variety of outcomes assessed in this manuscript. While it may have been possible to devise a list of plausible risk factors (e.g. access to changing facilities) for engaging in negative behaviours/practices, the survey did not ask firefighters for these details and therefore cannot account for these plausible justifications. Thus, the OR presented in this manuscript may be an oversimplification of the true relationship between lack of training on fire contaminants or belief in the BoH and engagement in practices which potentially increase contaminant exposure. These crude results may be used to inform future work, whereby a more comprehensive multi-variate model analysis may be used (in conjunction with additional survey questions) to account for the presented (and other) confounding variables.

Some of the negative behaviours/practices assessed in the survey may be beyond the control of firefighters. For example, frequency of sending PPE for professional cleaning may be determined by management, fire station layout may make it impossible to completely separate clean/dirty areas etc. In these circumstances, the contribution of training/BoH belief to firefighters' engagement in such practices may be overstated.

As previously reported[10], the negative contamination practices assessed in the survey only represent firefighters' current activities and do not account for past behaviour.

Similarly, the survey cannot verify the quality or content of the training received by firefighters, or when in their careers this training was received. Thus, training status may be an over-simplified representation of firefighters' awareness of the health risks associated with contaminant exposure, and the practices which lead to it.

Conclusions

This manuscript identified belief in the BoH and a lack of training on fire contaminants as risk factors for firefighters engaging in practices which increase their exposure to toxic fire contaminants. At the time the survey was conducted, only 36% of firefighters had received training on fire contaminants and their associated health outcomes. A lack of training increased the odds ratios for firefighters engaging in practices/behaviours which increase exposure to contaminants, particularly those leading to cross-contamination.

Culture also appeared to strongly influence firefighters' engagement in behaviours/practices which increase contaminant exposure. In particular, those who personally believed in the BoH were significantly more likely to indicate engaging in practices which lead to direct exposure. Those indicating their colleagues believed in the BoH were also more likely to engage in such practices.

Evidence from the UK Firefighter Contamination Survey suggests that awareness and training (and the effective decontamination practices that are associated with it), have very recently been introduced to the UK Fire and Rescue Service. However, given the weak association between training status and personal belief in the BoH, and firefighters' continued engagement in poor decontamination practices as a result of peer pressure—there is still a need for a more fundamental culture shift in the UK Fire and Rescue Service, in combination with increased training provision.

Data availability

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

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Author contributions
A.C. and A.S. devised the survey and distributed it to firefighters with the assistance of the Fire Brigades Union. T.W., K.D. and D.M.-T. coded free text answers for analysis. A.S., L.T., T.W. and K.D. analysed trends in the data. A.R., L.T. and T.W. calculated crude odds ratios. T.W. and L.T. drafted the first iteration of the manuscript. A.S. and T.W. reviewed and edited the final version of the manuscript for publication.

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