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Grenfell Investigation into Potential Land Contamination Impacts

Technical Note 04: Fire Chemistry and Identification of COPC

Royal Borough of Kensington and Chelsea

Project number: 60595731

30 August 2019

Quality information

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Revision History

Revision	Revision date	Details	Authorized	Name	Position
Original	3 May 2019	Draft		Simon Cole	Technical Director
Final	16 July 2019	Final		Liz Philp	Technical Director
	30 Aug 2019	Minor typographical edits			

Distribution List

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Nil	PDF	MHCLG for distribution

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1. Introduction

This presents the methodology and findings of an evidence review into the contaminants that are likely to have been generated by the Grenfell Tower fire and which may potentially have been deposited on soils surrounding the site.

1.1 Review Question

The primary question to be answered by this review is:

- What potential contaminants arising from building fires may be present in surrounding soils as a result of the Grenfell Tower fire?

2. Methodology

Guidance on evidence reviews was published by Defra in 2015 in the form of two reports[1][2]. These describe four types of evidence review (ER), spanning from literature reviews (LR), quick scoping reviews (QSR), and rapid evidence assessments (REA), to systematic reviews (SR). The QSR approach has been used for this work for the following reasons:

- The intent of the work is to provide a general understanding of the evidence base; identifying the evidence available and summarising it;
- A critical appraisal of the robustness of individual studies is not required;
- Evidence bias is sufficiently mitigated by the review approach – focusing on common consensus in studies from independent sources;
- It involves the search and review of a selection of sources, which is compatible with the programme for this work. It does not require an extensive review of all possible sources of evidence.

Table TN04-01 below sets out the review protocol followed in this review.

TN04-01. Review Protocol – Fire Chemistry Quick Scoping Review

Protocol Element	Protocol Adopted
Background rationale:	Requirement to understand the range of chemicals that were emitted during the fire and what the potential long-term soil contamination and associated human health risk might be
Objective:	Identify the chemicals of potential concern (COPC) that were likely to have been emitted during the fire, from a public health perspective
Scope:	Focus on studies on building fires and building materials, and on identifying chemicals likely to remain in debris or in particulate or residue form No geographic restriction Limited to studies published after 2008 to avoid duplication of the review carried out by the Health Protection Agency in 2010 (Wakefield, 2010) Limited to English language only
Method: Search keywords	Generic search: Combustion, fire, emission, products, hazard, effluent, smoke, pyrolysis Specific search: World Trade Center collapse
Method: Search strategy	Regulatory agencies and international organisations, such as HPA/PHE, Environment Agency, EU JRC, WHO, ATSDR, US EPA, Health Canada, and UNEP Google Scholar search using Boolean search terms constructed from the keywords

[1] Collins, A.M., Coughlin, D., Miller, J., Kirk, S. 2015. The Production of Quick Scoping Reviews and Rapid Evidence Assessments: A How to Guide
[2] Defra. 2015. Emerging Tools and Techniques to Deliver Timely and Cost Effective Evidence Reviews. Final report WT1552

	above PubMed search as per Google Scholar search ResearchGate search as per above Cross reference to published documents referenced in existing Health Protection Agency reports and Professor Stec's papers
Method: Inclusion and exclusion criteria	Exclude studies on wildfires. Include polyvinyl chloride, insulation materials, flame retardants, cladding.
Method: Information extraction	Initial extraction from abstract only. Selection of full papers to be based on the results of the first phase screening. Information to be recorded in an evidence template
Information synthesis	To include: Descriptive characteristics of evidence identified A narrative synthesis of the evidence

2.1 Sources of Evidence

Sources of evidence were identified by:

- Web searches as presented in **Appendix TN04-A**.
- Correspondence with Professor Stec.

The sources of evidence used in this QSR are presented in **Appendix TN04-B**.

3. Summary of Evidence

The classes of contaminants that have been identified in the evidence as potential contaminants arising from building fires are listed below. For each class of contaminants, a summary of the available evidence is provided in **Appendix TN04-C**.

(British Standards Institution, 2017) provides a list of potential contaminants, (as listed below). The evidence review was not restricted to these contaminants, but also took into account other potential contaminants as identified in the literature.

3.1 General Guidance from BS ISO 26367‐2:2017

BS ISO 26367 – 2:2017 (British Standards Institution, 2017) provides guidance on the main contaminants which may be present in the environment following a fire, identifying the following categories of contaminants which can potentially cause long-term environmental effects:

- Metals.
- Polycyclic aromatic hydrocarbons (PAH).
- Polychlorinated dibenzodioxins and furans (PCDD/PCDF).
- Polybrominated dibenzodioxins and furans (PBDD/PBDF).
- Polychlorinated biphenyls (PCB).
- Perfluorinated compounds (PFC).
- Volatile organic compounds (VOC).

3.2 Metals

(Landrigan, et al., 2004) notes that metals were found in the inorganic fraction of settled dust samples collected at sites in lower Manhattan after the World Trade Center collapse.

Lead was selected as a Contaminant of Potential Concern (COPC) after the World Trade Centre collapse (World Trade Center Indoor Air Task Force Working Group, 2003), and was consistently detected across environmental media at concentrations above health-based screening values, from 101 to 625 ppm (Landrigan, et al., 2004).

Aluminium, antimony, arsenic, barium, chromium, manganese, nickel, mercury and thallium were found in dust to have maximum concentrations greater than the screening value but closer examination gave strong evidence that these contaminants were not likely present in indoor dusts at levels of health concern (Landrigan, et al., 2004). However, chromium in ambient air exceeded the health-based screening values and mercury in isolated samples of settled dust in Lower Manhattan was at levels greater than heath-based screening values. It was unclear whether the detected levels were associated with the World Trade Centre collapse (Landrigan, et al., 2004).

3.3 Polycyclic Aromatic Hydrocarbons (PAH)

Polycyclic aromatic hydrocarbons (PAHs) are a large group (over 100) of organic compounds containing a minimum of two fused benzene rings (Wakefield, 2010). PAHs may be evolved in the fire effluent from all combustion processes, with the largest quantities likely to be generated during the slow, incomplete combustion of organic materials, and likely to be present as complex mixtures rather than as single individual compounds (Wakefield, 2010).

PAHs were amongst a wide variety of volatile and semi-volatile organic compounds (VOC/SVOC) identified in the gaseous effluent from a series of house fire experiments reported in (Hewitt, et al., 2017). Anthracene, phenanthrene, fluoranthene and pyrene were the most commonly detected compounds, but (Hewitt, et al., 2017) noted that benzo(a)pyrene was detected in the majority of fires and that even if the quantities of benzo(a)pyrene released in a fire are significantly lower than quantities of other PAHs, there remained a cause for concern because it is known to have the highest toxicity of the 16 EPA PAHs.

(Stec, et al., 2019) identified elevated PAHs in the soil near Grenfell Tower when compared to background samples from Hyde Park, including benzo(a)pyrene, fluoranthene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, and benzo(ghi)perylene.

PAHs are identified as likely to be generated during the slow incomplete combustion of organic materials by (Purser, 2015). (Landrigan, et al., 2004) identified a complex mixture of PAHs including benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, benzo(e)pyrene, ideno(1,2,3-c,d)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene in air samples taken in the vicinity of the World Trade Centre site, and noted that consistently greater abundance of PAHs at Ground Zero collapse site than farther away indicated that burning debris at the site was a major source of airborne PAH pollution in lower Manhattan.

(Stec, et al., 2019) reference the study by Xu, et al, 2018 on metallurgical plants to suggest the potential presence of halogenated PAHs.

3.4 Dioxins and Furans

The term “dioxin” is most commonly used for a family of derivatives of dibenzo-1,4-dioxin, known as polychlorinated dibenzodioxins (PCDD) in which two benzene rings are connected by a 1,4-dioxin ring, and where one or more of the hydrogens atoms is substituted by chlorine. The term “furan” is used to refer to a family of derivatives of polychlorinated dibenzofurans (PCDF), a group of similar compounds, but where the benzene rings are joined by a furan rather than a dioxin ring.

In addition to the family of PCDD/PCDFs, hydrogen atoms can also be substituted by bromine atoms, to produce polybrominated dibenzodioxins (PBDD) and polybrominated dibenzofurans (PBDF), and there are a further class of mixed chloro- and bromo-substituted dioxins and furans. There are 75 dioxin PCDD congeners and PCDF congeners (Wakefield, 2010), and theoretically a further 4600 mixed bromochlorodibenzo-p-dioxin or dibenzofuran congeners (mixed PXDD/Fs), consisting of 3050 polybromochloro dibenzo-furans (PXDFs) and 1550 polybromochloro-dibenzo-p-dioxins(PXDDs) (Zhang, et al., 2016).

PCDD/Fs are widely reported to be products of building fires, with high concentrations found even when there are no inherently hazardous materials in the fuel supply (Amon, et al., 2014). PCDDs and PCDFs are formed mainly during the incomplete combustion of any materials containing carbon, oxygen and chlorine, and are therefore commonly found as emissions in most fire effluents (Wakefield, 2010). Chlorinated, brominated and mixed brominated-chlorinated dioxins and furans were also found in the organic fraction of the settled dust collected at sites in Lower Manhattan after the World Trade Center collapse (Landrigan, et al., 2004), and PCDD/F were found in the residue of samples of PVC carpet following combustion (Stec, et al., 2013).

(Stec, et al., 2019) found elevated concentrations of PCDD/Fs in the soil samples collected within 140 m of Grenfell tower. The PCDD/Fs found were:

PCDDs	PCDFs
2,3,7,8-TCDD	2,3,7,8-TCDF
1,2,3,7,8-PeCDD	1,2,3,7,8-PeCDF
1,2,3,4,7,8-HxCDD	2,3,4,7,8-PeCDF
1,2,3,6,7,8-HxCDD	1,2,3,4,7,8-HxCDF
1,2,3,7,8,9-HxCDD	1,2,3,6,7,8-HxCDF
1,2,3,4,6,7,8-HpCDD	2,3,4,6,7,8-HxCDF
OCDD	1,2,3,7,8,9-HxCDF
	1,2,3,4,6,7,8-HpCDF
	1,2,3,4,7,8,9-HpCDF
	OCDF

(Zhang, et al., 2016) reported that brominated fire retardants (BFR) are widely used in numerous commodities and products and identified three distinct pathways towards PBDD/Fs (and also mixed PXDD/Fs) formation starting from BFRs: precursor formation, de novo formation and incomplete destruction of PBDD/Fs contained in BFRs as impurities. (Stec, et al., 2019) noted that, although brominated flame retardants were not present in significant quantities on the exterior face of Grenfell Tower, furniture and other products in the Tower may have contained them, but it is less clear how much effluent would be released to the surrounding environment. (Stec, et al., 2019) went on to note that the presence of chlorinated PCDD/Fs in soil samples and the presence of brominated flame retardants in furniture etc. suggested that brominated and mixed brominated-chlorinated dioxins and furans were also likely to be present in soils.

3.5 Isocyanates

Isocyanates are a family of highly reactive and relatively low molecular weight aromatic and aliphatic compounds. The family is defined by the isocyanate functional group (−N= C = O), attached to an aliphatic or an aromatic moiety, and widely used in the manufacturing of flexible and rigid polyurethane (PU) foams, referred to as PUF and PUR respectively, as well as well as polyisocyanurate (PIR) foams (Bengtström, et al., 2016). A list of the most commercially important isocyanates is provided by (Bengtström, et al., 2016):

Compound	Abbreviation
Isocyanic acid	ICA
Methyl isocyanate	MIC
Ethyl isocyanate	EIC
Phenyl isocyanate	PHI
Hexamethylene di-isocyanate	HDI

Compound	Abbreviation
Toluene-2,4-diisocyanate	2,4-TDI
Toluene-2,6-diisocyanate	2,6-TDI
Methylene-bis-(phenylisocyanate)	MDI
Isophorone diisocyanate	IPDI

Isocyanates are reported to be generated during the thermal degradation of any PU based material, and (Bengtström, et al., 2016) references a large number of previous studies which have identified isocyanates as products of combustion of foams. The isocyanates that may be present as products of combustion will vary depending upon the composition of the material involved and the combustion conditions, but may include relatively simple compounds, such as methyl isocyanate, or more complex compounds such as toluene diisocyanate (Wakefield, 2010). (McKenna & Hull, 2016) noted that there is very little literature available regarding the yields of isocyanates produced by the combustion of polyurethane foams, and that around 10–15 % of the nitrogen in the polymer can be converted into hydrogen cyanide (HCN) with some being released in isocyanates, aminoisocyanates and amines in the fire effluent.

(Stec, et al., 2019) identified methyl isocyanate, isocyanic acid, ethyl isocyanate and propyl isocyanate in samples from close to Grenfell Tower.

3.6 Asbestos

Although (Landrigan, et al., 2004) found asbestos in settled dust samples within apartments and other buildings following the World Trade Centre collapse, according to (Wakefield, 2010) there is considerable evidence that, provided appropriate clean up procedures are followed, there is no significant public health risk due to asbestos from large-scale building fires. The release of asbestos is a function of a number of factors including the type, integrity, and location of the material, and in the event of a fire there is considerable potential for fibre release. Studies of fire events involving asbestos materials indicate that exposures during and in the immediate aftermath of the fire are expected to be minimal (Smith & Saunders, 2007).

3.7 Volatile Organic Compounds

(British Standards Institution, 2017) identified benzene, formaldehyde and perchloroethylene (PCE) as amongst the VOCs that have been found in surface water, groundwater and soil following fires.

Benzene is one of the principal components of fire effluent when polymers based on carbon, hydrogen and oxygen burn (Reisen, 2011), and is often used as an indicator compound for VOCs (Amon, et al., 2014)

Benzene levels in the soil around Grenfell Tower were reported in (Stec, et al., 2019) to be 40 times greater than the reference soil.

3.8 Phosphorus Compounds

Phosphorous is a common constituent of fire retardants, used on foams and electrical equipment (Wakefield, 2010).

Phosphorus compounds were identified in the condensed particulate soot samples in experiments reported in (Hewitt, et al., 2017), where the fuel load was a sofa or fully furnished room.

Several of the phosphorus-based compounds detected by (Hewitt, et al., 2017) in both the gaseous effluents and condensed particulate samples are reported to be used as fire retardants, namely:

Compound	Abbreviation
2-Propanol, 1-chloro-,2,2',2"-phosphate	TCIPP, previously known as TCPP
Phosphoric acid triphenyl ester	TPHP
Ethanol, 2-butoxy-,1,1',1"-phosphate	TBOEP, previously known as TBEP
Phosphoric acid tris(methylphenyl) ester	TMPP, previously known as TCP
Phosphoric acid triethyl ester	TEP

These compounds were only detected in fires where the fuel included a sofa and (Hewitt, et al., 2017) conclude that they are volatilised in their original form.

Tris(chloroisopropyl) phosphate (TCPP), tris(2-ethylhexyl) phosphate (TEHP) and tricresyl phosphate (TCP) were identified in samples, of soil, fire debris and char from Grenfell Tower by (Stec, et al., 2019).

3.9 Perfluorinated Compounds

Aqueous film forming foams (AFFF) are used in a variety of firefighting operations, particularly for flammable liquid pool fires and have the potential to cause contamination if they contain perfluorinated organic compounds (PFC) (Amon, et al., 2014). It is understood that PFC-containing AFFFs were not used to control the Grenfell Tower fire and hence PFCs are unlikely to be a contaminant of concern.

3.10 Polychlorinated Biphenyls (PCB)

(Amon, et al., 2014) notes that PCBs were found in debris from the World Trade Centre collapse and may be present in landfill fires, but (Wakefield, 2010) identifies PCBs as potential sources of PCDD/F formation rather than as contaminants in their own right. PCBs are therefore not identified as COPCs, although polybrominated biphenyls are considered separately under the section on brominated fire retardants below.

3.11 Hydrogen Cyanide

(Wakefield, 2010) reports that any material containing carbon and nitrogen, including polymers such as polyurethane, will generate hydrogen cyanide (HCN) during combustion under most conditions, and identified HCN is identified as an acutely toxic fire effluent by inhalation. (Stec, et al., 2019) reported the results of thermogravimetric analysis coupled to gas phase Fourier Transform Infrared Spectroscopy (TGA-FTIR) analysis, which showed the release of HCN from soils taken from around Grenfell Tower.

3.12 Brominated Fire Retardants

A wide range of brominated fire retardants (BFRs) are either currently or historically in use, and those with greatest application include: polybrominated biphenyls (PBB, no longer on the market), tetrabromobisphenol A (TBBP-A, still in use), polybrominated diphenyl ethers (PBDEs, including decaBDE, presently being voluntarily phased out by industry), and hexabromocyclododecane (HBCDD, still in use) (Amon, et al., 2014) (Zhang, et al., 2016). The presence of PBDE, as well as PBDD/Fs, is reported from accidental fires in residential buildings (Zhang, et al., 2016). BRFs were not found to be present in significant quantities on the exterior face of façade materials in the study of McKenna, et al., 2019 and how much BFR might have been released from products containing BFRs (such as furniture) during the fire is not clear (Stec, et al., 2019).

3.13 Bisphenol A

A study (Fu & Kawamura, 2010) of atmospheric bisphenol A concentrations concluded that open burning of plastics in domestic waste could be a significant emission source, although the study looked at atmospheric concentrations, and not soil concentrations. No other references to soil contamination as a result of accidental building fires were found in the literature.

3.14 Synthetic Vitreous Fibres

(Stec, et al., 2019) identified synthetic vitreous fibres (SVF) in soil and debris samples and attributed them to the presence of glass wool layers that formed part of the insulation foam panels. (Stec, et al., 2019) also comment that studies by Lippman (2014 and 2015) indicate that these fibres were one of the most significant health damaging contaminants after the World Trade Center collapse. The high airborne concentrations of coarse dust containing SVF and highly alkaline concrete and gypsum dust particles that were created by the collapse of the towers are identified as the more likely causal toxicants for acute and chronic adverse health effects observed after the WTC collapse (Lippmann, et al., 2015).

3.15 Adequacy of Evidence

The QSR process identified a number of recent papers and reports which directly address the primary review question, and a number of additional sources of evidence on the more general issue of the combustion products of fires in buildings. The majority of search results relate to gaseous products of combustion and acute toxic effects on fire victims and first responders, with only a relatively small number which focus on longer term environmental effects. AECOM considers that the QSR process has successfully identified the most recent and relevant information and provides an adequate basis for answering the primary review question.

4. Conclusions

Based on the results of this Quick Scoping Review, the following contaminants of potential concern (COPC) are identified as being possible fire effluents which may potentially have been generated and/or released by the Grenfell Tower fire and deposited on soils surrounding the site.

TN04-02. List of Contaminants of Potential Concern

Category	Specific compounds or elements
Metals	
	Lead
Polycyclic Aromatic Hydrocarbons	
	USEPA priority 16 PAH 7,12-dimethylbenzo(a)anthracene
Dioxins and Furans	
	PCDD
	PCDF
	PBDD
	PBDF
	PXDD
	PXDF
Isocyanates	
	Isocyanic acid
	Methyl isocyanate
	Ethyl isocyanate
	Propyl isocyanate

Category	Specific compounds or elements
	Phenyl isocyanate
	Hexamethylene di-isocyanate
	Toluene-2,4-diisocyanate
	Toluene-2,6-diisocyanate
	Methylene-bis-(phenylisocyanate)
	Isophorone diisocyanate
Volatile Organic Compounds	
	Benzene
Phosphorus Compounds	
	2-Propanol, 1-chloro-,2,2',2''-phosphate (TCIPP, previously known as TCPP)
	Phosphoric acid, triphenyl ester (TPHP)
	Ethanol, 2-butoxy-,1,1',1''-phosphate (TBOEP, previously known as TBEP)
	Phosphoric acid, triethyl ester (TEP)
	Phosphoric acid tris(methylphenyl) ester (TMPP, previously known as TCP)
	Tris(2-ethylhexyl) phosphate (TEHP)
Cyanides	
	Free cyanide
Brominated Fire Retardants	
	Polybrominated biphenyls (PBBs)
	Tetrabromobisphenol A
	Polybrominated diphenyl ethers (PBDEs)
	Polybrominated diphenyl ethanes
	Hexabromocyclododecane
Fibres	
	Asbestos
	Synthetic Vitreous Fibres

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Appendix TN04-A. Web Search

Search number	Keyword(s) / word string	Date of Search	Search tool/origin or other tracing information	Hyperlink to origin (URL)	Number of search hits	Number of hits screened	Number of hits taken forward to review (Appendix TN04-B)
1	combustion	08/04/2019	Google Scholar	https://scholar.google.co.uk/scholar...	3,430,000	20	0
2	combustion products	08/04/2019	Google Scholar	https://scholar.google.co.uk/scholar...	2,480,000	50	0
3	combustion products hazard	08/04/2019	Google Scholar	https://scholar.google.co.uk/scholar...	168,000	20	0
4	combustion products effluent	09/04/2019	Google Scholar	https://scholar.google.co.uk/scholar...	185,000	80	1
5	combustion products effluent world trade center	09/04/2019	Google Scholar	https://scholar.google.co.uk/scholar?start=0&q=combustion...	6,180	50	3
6	fire emission products	09/04/2019	Google Scholar	https://scholar.google.co.uk/scholar...	24,900	50	0
7	combustion emission products	09/04/2019	Google Scholar	https://scholar.google.co.uk/schola...	1,400,000	50	1
8	fire effluents	09/04/2019	Google Scholar	https://scholar.google.co.uk/scholar....	16,000	50	2
9	pyrolysis effluent	09/04/2019	Google Scholar	https://scholar.google.co.uk/scholar...	18,800	50	0
10	pyrolysis effluent world trade center	10/04/2019	Google Scholar	https://scholar.google.co.uk/scholar...	3,980	50	1

Search number	Keyword(s) / word string	Date of Search	Search tool/origin or other tracing information	Hyperlink to origin (URL)	Number of search hits	Number of hits screened	Number of hits taken forward to review (Appendix TN04-B)
11	fire products	10/04/2019	GOV.UK	https://www.gov.uk/search?q=fire+products	37,080	60	0
12	fire products hazard	10/04/2019	GOV.UK	https://www.gov.uk/search?q=fire+products+hazard	38,763	100	0
13	fire products hazard combustion effluent	10/04/2019	GOV.UK	https://www.gov.uk/search...	38,718	40	1
14	fire	10/04/2019	WHO	https://www.who.int/search?query=fire...	1,294	30	0
15	fire products	10/04/2019	WHO	https://www.who.int/search?query=fire...	563	50	0
16	combustion effluent	10/04/2019	WHO	https://www.who.int/search?query=combustion...	10	10	0
17	fire effluent	10/04/2019	WHO	https://www.who.int/search?query=fire...	29	29	0
18	products formed in combustion	10/04/2019	WHO	https://www.who.int/search?query=products...	84	50	1
19	combustion	10/04/2019	ATSDR	https://search.cdc.gov/search/?query=combustion	3,005	50	0
20	products of combustion	10/04/2019	ATSDR	https://search.cdc.gov/search/?query=products...	2,672	50	0
21	fire effluent	10/04/2019	ATSDR	https://search.cdc.gov/search/?query...	609	50	0
22	combustion products	10/04/2019	Health Canada	https://www.canada.ca/en/sr/...	45,530	50	0

Search number	Keyword(s) / word string	Date of Search	Search tool/origin or other tracing information	Hyperlink to origin (URL)	Number of search hits	Number of hits screened	Number of hits taken forward to review (Appendix TN04-B)
23	combustion products hazard smoke	10/04/2019	Health Canada	https://www.canada.ca/en/sr/srb....	1,535	50	0
24	fire effluent	10/04/2019	Health Canada	https://www.canada.ca/en/sr/...	2,565	50	0
25	fire products	10/04/2019	UNEP	https://www.unenvironment.org/search/node?keys=fire+products	12	12	0
26	hazardous fire products	10/04/2019	UNEP	https://www.unenvironment.org/search...	2	2	0
27	combustion products	10/04/2019	UNEP	https://www.unenvironment.org/search/node?keys=combustion...	13	13	0
28	fire products	10/04/2019	PubMed	https://www.ncbi.nlm.nih.gov/pubmed	981	50	1
29	combustion hazard products	10/04/2019	PubMed	https://www.ncbi.nlm.nih.gov/pubmed...	143	50	0
30	fire effluent	10/04/2019	PubMed	https://www.ncbi.nlm.nih.gov/pubmed/?term=fire+effluent	34	34	1
31	pyrolysis effluent	10/04/2019	PubMed	https://www.ncbi.nlm.nih.gov/pubmed	50	50	0
32	fire products	11/04/2019	ResearchGate	https://www.researchgate.net/search...	n/a	60	2
33	pyrolysis effluent	11/04/2019	ResearchGate	https://www.researchgate.net/search.....	n/a	50	0
34	world trade center dust screening method study	11/04/2019	Google	https://www.google.com/search...	5,270,000	30	1

Search number	Keyword(s) / word string	Date of Search	Search tool/origin or other tracing information	Hyperlink to origin (URL)	Number of search hits	Number of hits screened	Number of hits taken forward to review (Appendix TN04-B)
35	health risks world trade center	11/04/2019	Google	https://www.google.com/search...	50,100,000	30	0
36	fire retardant	11/04/2019	Google Scholar	https://scholar.google.co.uk/scholar...	229,000	50	0
37	foam combustion products	11/04/2019	Google Scholar	https://scholar.google.co.uk/scholar...	137,000	50	2
38	wtc combustion contaminants	11/04/2019	Google	https://www.google.com/search...	94,100	50	1
39	international standard environmental impact fire effluent	11/04/2019	Google	https://www.google.com/search...	3,540,000	50	1
40	Bisphenol A combustion product	29/04/2019	Google Scholar	https://scholar.google.co.uk/scholar...	24,000	30	1
41	products combustion health	01/05/2019	Google	https://www.google.com/search...	39,600,000	30	1

Appendix TN04-B. Summary of Evidence Identified

Evidence Number	Evidence Reference	Evidence hyperlink (if available)	Evidence Type	Corresponding search number	Brief summary of evidence available from source
1	Stec, A., Dickens, J., Barnes, J., & Bedford, C. (2019). Environmental contamination following the Grenfell Tower fire. Chemosphere, 226, 576-586		Journal Paper	Paper provided by author	Samples taken within 140 m of Grenfell Tower showed levels of contamination. Presence of pyrogenic contaminants including polychlorinated dibenzo-p-dioxin, benzene, PAHs, isocyanates and phosphorus flame retardants. Hydrogen cyanide and synthetic vitreous fibres were present in both soil and debris.
2	Bengtström, L., Salden, M., & Stec, A. (2016). The role of isocyanates in fire toxicity. Fire Science Reviews, 5(4)	https://firesciencereviews.springeropen.com/articles/10.1186/s40038-016-0013-2	Journal Paper	Referenced in Evidence 1	Discusses the reactivity and commercial applications of isocyanates and the generation of airborne isocyanates during thermal degradation, the human health effects as well as the environmental fate of some of the most commercially important isocyanates.
3	Hewitt, F., Christou, A., Dickens, K., R.Walker, & Stec, A. (2017). Release of volatile and semi-volatile toxicants during house fires. Chemosphere, 173, 580-593.	https://www.sciencedirect.com/science/article/pii/S0045653516318124	Journal Paper	Referenced in Evidence 1	Qualitative results are presented from analysis of volatile and semi-volatile organic compounds (VOCs/SVOCs) obtained through sampling of gaseous effluent and condensed particulates during a series of experimental house fires conducted in a real house.
4	Landrigan, P. J., Lioy, P. J., Thurston, G., Berkowitz, G., Chen, L., Chillrud, S. N., . . . Small, C. (2004). Health and Environmental Consequences of the World Trade Center Disaster. Environmental Health Perspectives, 112(6), 731-739	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1241968/pdf/ehp0112-000731.pdf	Journal Paper	Referenced in Evidence 1	Discusses compounds found in the aftermath of the World Trade Center disaster.
5	Stec A. (2017). Fire toxicity – The elephant in the room? Fire Safety Journal 91: 79-90;	https://core.ac.uk/download/pdf/157860168.pdf	Journal Paper	Referenced in Evidence 1	Summary of chemical compounds formed as a result of fire
7	Purser, D. (2015). Fire Types and Combustion Products. In D. A. Purser, R. L. Maynard, & J. C. Wakefield (Eds.), Toxicology, Survival and Health Hazards of Combustion Products (pp. 11-52). London: RSC	https://pubs.rsc.org/en/content/chapter/bk9781849735698-00011/978-1-84973-569-8	Book	4	Summary of fire types and combustion products.

Evidence Number	Evidence Reference	Evidence hyperlink (if available)	Evidence Type	Corresponding search number	Brief summary of evidence available from source
9	Zhang, M., Buekens, A., & Li, X. (2016). Brominated flame retardants and the formation of dioxins and furans in fires and combustion. Journal of Hazardous Materials, 304, 26–39	https://www.sciencedirect.com/science/article/pii/S0304389415301412?via%3Dihub	Journal Paper	5	Formation of both polybrominated dibenzo-p-dioxins and dibenzofurans (PBDD/Fs) and mixed polybromochloro-dibenzo-p-dioxins and dibenzofurans (PBCDD/Fs or PXDD/Fs) from brominated flame retardants.
10	Reisen, F. (2011). Inventory of major materials present in and around houses and their combustion emission products. Melbourne: Bushfire Cooperative Research Centre	http://www.bushfirecrc.com/sites/default/files/managed/resource/inventory.pdf	Report	7	Identifies and discusses likely combustion emission products from wildfires which affect residential properties.
11	Stec, A & Hull, R. (2011). Assessment of the fire toxicity of building insulation materials. Energy and Buildings 43(2-3):498-506	https://www.researchgate.net/publication/232397420_Assessment_of_the_fire_toxicity_of_building_insulation_materials	Journal Paper	8	Investigation of the fire toxicity of six insulation materials (glass wool, stone wool, expanded polystyrene foam, phenolic foam, polyurethane foam and polyisocyanurate foam) under a range of fire conditions.
12	Martin, D., Tomida, M., & Meacham, B. (2016). Environmental impact of fire. Fire Science Reviews, 5(5)	https://firesciencereviews.springeropen.com/articles/10.1186/s40038-016-0014-1	Journal Paper	8	General review of the adverse consequences of fires on the natural environment.
13	Amon, F., McNamee, M. S., & Blomqvist, P. (2014). Fire effluent contaminants, predictive models, and gap analysis. Stockholm: SP Technical Research Institute of Sweden	http://www.diva-portal.org/smash/get/diva2:962820/FULLTEXT01.pdf	Report	10	This report characterises effluent of specific type of fires including structure fires of residential buildings.
14	Schwela, D., Goldammer, J., Morawska, L. & Simpson, O. 1999. Health guidelines for vegetation fire events. United Nations Environment Programme, Nairobi	https://www.paho.org/hq/index.php?option=com_docman&view=download&category_slug=guidelines-9831&alias=44635-health-guidelines-for-vegetation-fire-events-1999-635&Itemid=270&lang=en	Report	18	Pollutants generated by combustion from the burning of vegetation fires.

Evidence Number	Evidence Reference	Evidence hyperlink (if available)	Evidence Type	Corresponding search number	Brief summary of evidence available from source
15	Fent K.W., Eisenberg, J., Snawder, J., Sammons, D., Pleil, J.D., Stiegel, M.A., Mueller, C., Horn, G.P., & Dalton, J. (2014). Systemic exposure to PAHs and benzene in firefighters suppressing controlled structure fires. The Annals of Occupational Hygiene, 58(7) 830–845,	https://www.ncbi.nlm.nih.gov/pubmed/24906357	Journal Paper	28	Explores the dermal contribution to the systemic dose of polycyclic aromatic hydrocarbons (PAHs) and other aromatic hydrocarbons in firefighters during suppression and overhaul of controlled structure burns.
16	Stec, A., Readman, J., Blomqvist, P., Gylestam, D., Karlsson, D., Wojtalewicz, D., & Dlugogorski, B. (2013). Analysis of toxic effluents released from PVC carpet under different fire conditions. Chemosphere, 90, 65–71.	https://www.ncbi.nlm.nih.gov/pubmed/22960058	Journal Paper	30	This study is an attempt to quantify acute and chronic toxicants including PAH and PCDD/F in conditions relating to unwanted fires. This paper investigates distribution patterns of fire effluents between gas and aerosol phase, and the different particle size-ranges produced under different fire conditions.
17	Khan, M & Chaos, M. (2016). Combustion Characteristics of Materials and Generation of Fire Products. SFPE handbook of fire protection engineering, fifth edition (pp.1143-1232) .	https://www.researchgate.net/publication/301658024_Combustion_Characteristics_of_Materials_and_Generation_of_Fire_Products	Chapter	32	Review of non-thermal hazards associated with fire products (smoke, toxic, corrosive, and odorous compounds).
18	Krüger, S, Berger, A., Krause, U., (2002). Chemical–analytical investigation of fire products in intermediate storages of recycling materials. Fire and Materials. 36(3) 165-175	https://onlinelibrary.wiley.com/doi/full/10.1002/fam.1098	Journal Paper	33	Report on experiments to evaluate the fire effluents from samples of materials likely to be involved in fires at recycling stores.
19	Rosati, J.A. Friedman, D. 2005. Report on the World Trade Center (WTC) Dust Screening Method Study	https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NHSRC&dirEntryId=137643	Report	34	Report on efforts to determine whether dust sampled as part of EPA’s planned sampling program contains residual contamination attributable to the collapse of the WTC towers.
20	Singh, H, & Jain, A. K. (2008). Ignition, combustion, toxicity, and fire retardancy of polyurethane foams: A comprehensive review. Journal of Applied Polymer Science. 111(2), 1115-1143	https://onlinelibrary.wiley.com/doi/full/10.1002/app.29131	Journal Paper	37	This review provides insight into the ignition, combustion, smoke, toxicity, and fire-retardant performance of flexible and rigid polyurethane foams.

Evidence Number	Evidence Reference	Evidence hyperlink (if available)	Evidence Type	Corresponding search number	Brief summary of evidence available from source
21	McKenna, S & Hull, T. (2016). The fire toxicity of polyurethane foams. Fire Science Reviews. 5(3).	https://firesciencereviews.springeropen.com/articles/10.1186/s40038-016-0012-3	Journal Paper	37	Review of the toxic product generation during flaming combustion of polyurethane foams, in order to relate the yields of toxic products and the overall fire toxicity to the fire condition.
22	World Trade Center Indoor Air Task Force Working Group, 2003. World Trade Center Indoor Environment Assessment: Selecting Contaminants of Potential Concern and Setting Health-Based Benchmarks, New York: US Environmental Protection Agency	https://archive.epa.gov/wtc/web/pdf/contaminants_of_concern_benchmark_study.pdf	Report	38	Report from a multi-agency task force formed to evaluate indoor environments for the presence of contaminants that might pose long-term health risks to local residents.
23	The British Standards Institution. (2017). BS ISO 26367 2:2017; Guidelines for assessing the adverse environmental impact of fire effluents Part 2: Methodology for compiling data on environmentally significant emissions from fires. London: BSI Standards Limited	https://www.iso.org/standard/50635.html	International Standard	39	Methodology for compiling the information needed to assess the environmental damage caused by a fire incident.
24	Fu, P & Kawamura, K. (2010). Ubiquity of bisphenol A in the atmosphere. Environmental Pollution, 158, 3138-43.	https://www.researchgate.net/publication/45460981_Ubiquity_of_bisphenol_A_in_the_atmosphere	Journal Paper	40	Concentrations of BPA in the atmospheric aerosols from urban, rural, marine, and the polar regions were measured: a positive correlation was found between BPA and 1,3,5-triphenylbenzene, a tracer for plastic burning, in urban regions, indicating that the open burning of plastics in domestic waste should be a significant emission source of atmospheric BPA.
25	Wakefield, J. C., 2010. A toxicological review of the products of combustion. Didcot: Health Protection Agency	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/458052/HPA-CHaPD-004_for_website.pdf	Report	13	Review of the common products of combustion and their toxicology.
26	Wakefield, J., 2016. Products of Combustion and Toxicity from Specific Types of Fires. In: D. A. Purser, R. L. Maynard & J. C. Wakefield, eds. Issues in Toxicology No. 23. London: Royal Society of Chemistry, pp. 79-107	https://pubs.rsc.org/en/content/chapter/bk9781849735698-00079/978-1-84973-569-8	Book chapter	41	This chapter reproduces the information presented in Evidence no. 25 (above).

Appendix TN04-C. Evidence Extraction

Evidence Number	Evidence Reference	Summary of Evidence
1	Stec, A., Dickens, J., Barnes, J., & Bedford, C. (2019). Environmental contamination following the Grenfell Tower fire. Chemosphere, 226, 576-586	Presents details of sampling and analysis undertaken around Grenfell Tower, including discussion of the types of contaminants likely to be found and their sources. Cited in this QSR.
2	Bengtström, L., Salden, M., & Stec, A. (2016). The role of isocyanates in fire toxicity. Fire Science Reviews, 5(4)	Discusses the reactivity and commercial applications of isocyanates and the generation of airborne isocyanates during thermal degradation, the human health effects as well as the environmental fate of some of the most commercially important isocyanates. This is followed by a review of the generation of isocyanates from large-scale fire testing and bench-scale test methods. Cited in this QSR.
3	Hewitt, F., Christou, A., Dickens, K., R.Walker, & Stec, A. (2017). Release of volatile and semi-volatile toxicants during house fires. Chemosphere, 173, 580-593.	Qualitative results are presented from analysis of volatile and semi-volatile organic compounds (VOCs/SVOCs) obtained through sampling of gaseous effluent and condensed particulates during a series of experimental house fires conducted in a real house. Particular emphasis is given to the 16 polycyclic aromatic hydrocarbons (PAHs) listed by the Environmental Protection Agency due to their potentially carcinogenic effects. A number of phosphorus fire retardants were detected, in both the gaseous effluent and particulates, from fires where the initial fuel source was a sofa. Cited in this QSR.
4	Landrigan, P. J., Lioy, P. J., Thurston, G., Berkowitz, G., Chen, L., Chillrud, S. N., Small, C. (2004). Health and Environmental Consequences of the World Trade Center Disaster. Environmental Health Perspectives, 112(6), 731-739	This study characterizes the environmental exposures resulting from destruction of the WTC and assesses their effects on health. Includes discussion of contaminants associated with the WTC collapse, but includes predominantly air contamination and dust associated with the structural collapse of the WTC – limited information is presented specifically on long-term contamination from combustion. Cited in this QSR
5	Stec A. (2017). Fire toxicity – The elephant in the room? Fire Safety Journal 91: 79-90;	Summary of the range of different toxic species that are potentially generated by fires and their toxicity, with the main focus on acute, atmospheric and particulate toxicity. Not cited in this QSR - contaminants discussed are similar to those analysed in Evidence No. 1
7	Purser, D. (2015). Fire Types and Combustion Products. In D. A. Purser, R. L. Maynard, & J. C. Wakefield (Eds.), Toxicology, Survival and Health Hazards of Combustion Products (pp. 11-52). London: RSC	Describes the different types of fire scenarios, how they vary in terms of burning rates, yields of toxic products, fire development and fire effluent dispersal. The effects of these parameters on the development of different fire hazard scenarios are described. Cited in this QSR

Evidence Number	Evidence Reference	Summary of Evidence
9	Zhang, M., Buekens, A., & Li, X. (2016). Brominated flame retardants and the formation of dioxins and furans in fires and combustion. Journal of Hazardous Materials, 304, 26–39	Summarises the formation mechanisms of both brominated (PBDD/Fs) and mixed dioxins (PXDD/Fs with X = Br or Cl) from Brominated Fire Retardants (BFRs), recaps available emissions data of PBDD/Fs and mixed PXDD/Fs from controlled waste incineration, uncontrolled combustion sources and accidental fires, and identifies and analyses the effects of several local factors of influence, affecting the formation of PBDD/Fs and mixed PXDD/Fs during BFRs combustion. Cited in this QSR.
10	Reisen, F. (2011). Inventory of major materials present in and around houses and their combustion emission products. Melbourne: Bushfire Cooperative Research Centre	A study to identify major objects or items that are typically found in and around a house and identify the major materials that these objects are made of. The focus is on house structure, house contents and house surroundings. The study also reviews available literature to determine the emission products released while materials identified in the first part are burning. Cited in this QSR
11	Stec, A & Hull, R. (2011). Assessment of the fire toxicity of building insulation materials. Energy and Buildings 43(2-3):498-506	Discusses yields of gaseous combustion products from different types of insulation. Not cited in this QSR – main focus is on gaseous contaminants, and types of contaminants are similar to those discussed in Evidence 1.
12	Martin, D., Tomida, M., & Meacham, B. (2016). Environmental impact of fire. Fire Science Reviews, 5(5)	Not cited in this QSR as the main focus is on the framework for assessing environmental impacts rather than details of combustion chemistry.
13	Amon, F., McNamee, M. S., & Blomqvist, P. (2014). Fire effluent contaminants, predictive models, and gap analysis. Stockholm: SP Technical Research Institute of Sweden	The “Eco-tox” project was funded by the Swedish Fire Research Board to investigate which chemical species should be included in an eco-toxicological evaluation of fires and to catalogue the existing models and measurement methods that are appropriate to characterize the identified species. This report is intended to provide information about the eco-toxicants (chemical compounds that are harmful to people and the environment) produced in fire effluent and the predictive models and measurement techniques that can be used for determining the presence and concentrations of eco-toxicants caused by a fire incident. Cited in this QSR.
14	Schwela, D., Goldammer, J., Morawska, L. & Simpson, O. 1999. Health guidelines for vegetation fire events. United Nations Environment Programme, Nairobi	Guidance on health effects from vegetation fires, including identification of gaseous pollutants from vegetation fires. Not cited in this QSR – focus is on vegetation, not building fires.
15	Fent K.W., Eisenberg, J., Snawder, .J, Sammons, D., Pleil, J.D., Stiegel, M.A., Mueller, C., Horn, G.P., & Dalton, J. (2014). Systemic exposure to PAHs and benzene in firefighters suppressing controlled structure fires. The Annals of Occupational Hygiene, 58(7) 830–845,	Results of experiments to assessment dermal contribution to the systemic dose of polycyclic aromatic hydrocarbons (PAHs) and other aromatic hydrocarbons in firefighters during suppression and overhaul of controlled structure burns. Not cited in this QSR – potential contaminants in this paper (PAHs) are already considered in other papers.

Evidence Number	Evidence Reference	Summary of Evidence
16	Stec, A., Readman, J., Blomqvist, P., Gylestam, D., Karlsson, D., Wojtalewicz, D., & Dlugogorski, B. (2013). Analysis of toxic effluents released from PVC carpet under different fire conditions. Chemosphere, 90, 65–71.	This study is an attempt to quantify acute and chronic toxicants including PAH and PCDD/F in conditions relating to unwanted fires. This paper investigates distribution patterns of fire effluents between gas and aerosol phase, and the different particle size-ranges produced under different fire conditions. PVC carpet was selected as the fuel as a precursor for both PAH and PCDD/F. Cited in this QSR.
17	Khan, M & Chaos, M. (2016). Combustion Characteristics of Materials and Generation of Fire Products. SFPE handbook of fire protection engineering, fifth edition (pp.1143-1232) .	Report on small scale experiments and how such testing can be used to determine the generation per unit of time of (1) the calorific energy, defined as the heat release rate, and (2) fire products. From these tests, measurements of so-called “fire properties” are made that can be used in models to predict, under a variety of conditions, (1) heat release rate, to assess thermal hazards; and (2) generation rates of fire products, to assess non-thermal hazards. Not cited in this QSR – emphasis is on detailed modelling of heat release and main combustion gases, rather than trace contaminants.
18	S. Krüge, S, Berger, A., Krause, U. (2002). Chemical–analytical investigation of fire products in intermediate storages of recycling materials. Fire and Materials. 36(3) 165-175	Study into the gaseous emissions from the combustion of different waste fractions. Not cited in this QSR – emphasis is on gaseous emissions from waste, rather than from buildings.
19	Rosati, J.A. Friedman, D. 2005. Report on the World Trade Center (WTC) Dust Screening Method Study	This report describes work performed to develop and validate a screening method for indoor dust that can be used to determine whether dust sampled is from the collapse of the World Trade Center towers. Not cited in this QSR – focus of the report is on dust from the structural collapse rather than from combustion and looks at slag wool, elements of concrete, and gypsum.
20	Singh, H, & Jain, A. K. (2008). Ignition, combustion, toxicity, and fire retardancy of polyurethane foams: A comprehensive review. 111(2), 1115-1143	Review of the ignition, combustion, smoke, toxicity, and fire-retardant performance of flexible and rigid polyurethane foams. Extensive detail presented on combustion products and types of fire retardants. Not cited in this QSR – main contaminants are covered in other Evidence.
21	McKenna, S & Hull, T. (2016). The fire toxicity of polyurethane foams. Fire Science Reviews. 5(3).	The chemistry of polyurethane foams and their thermal decomposition are discussed in order to assess the relationship between the chemical and physical composition of the foam and the toxic products generated during their decomposition. The toxic product generation during flaming combustion of polyurethane foams is reviewed, in order to relate the yields of toxic products and the overall fire toxicity to the fire conditions. Cited in this QSR.

Evidence Number	Evidence Reference	Summary of Evidence
22	World Trade Center Indoor Air Task Force Working Group, 2003. World Trade Center Indoor Environment Assessment: Selecting Contaminants of Potential Concern and Setting Health-Based Benchmarks, New York: US Environmental Protection Agency	The report describes the process of selecting contaminants of potential concern (COPC) and setting health-based benchmarks to determine which contaminants are likely associated with the WTC disaster for the purpose of setting health-based benchmarks for the indoor air and settled dust. Cited in this QSR
23	British Standards Institution. (2017). BS ISO 26367 2:2017; Guidelines for assessing the adverse environmental impact of fire effluents Part 2: Methodology for compiling data on environmentally significant emissions from fires. London: BSI Standards Limited	Provides a standard for assessing environmental impacts of fires and describes main categories of contaminants that may be produced and the environmental phases in which they may be present. Cited in this QSR.
24	Fu, P & Kawamura, K. (2010). Ubiquity of bisphenol A in the atmosphere. Environmental Pollution, 158, 3138-43.	Presents information about atmospheric concentrations of bisphenol A and postulates their production from combustion of plastics. Cited in this QSR.
25	Wakefield, J. C., 2010. A toxicological review of the products of combustion. Didcot: Health Protection Agency	Review of the main toxic combustion products, including complex molecules (e.g. PAH, isocyanates, dioxins), prepared for the Health Protection Agency to facilitate assessment of health effects from fires. Cited in this QSR.
26	Wakefield, J., 2016. Products of Combustion and Toxicity from Specific Types of Fires. In: D. A. Purser, R. L. Maynard & J. C. Wakefield, eds. Issues in Toxicology No. 23. London: Royal Society of Chemistry, pp. 79-107	Copy of evidence No. 25 (above) Not cited in this QSR.

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