Guidance on the environmental impact of large-scale fires involving plastics materials

ICS 13.020.30

Committees responsible for this British Standard

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Building Research Establishment
Electrical and Electronic Insulation Association (BEAMA Ltd.)
Electricity Association
ERA Technology Ltd.
GAMBICA
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Contents

Foreword

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 37 and a back cover.

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Introduction

A number of incidents at plastics storage sites involving hundreds of tonnes of plastics have focused the attention of the public on the consequences and the safety issues resulting from storing plastics materials and products. This British Standard aims to complement the Home Office document on the fire safety of tyre storage sites [1]; much of this guidance may also be applicable to certain plastics storage sites.

In addition to providing information and guidance on the burning of plastics and the environmental impact zones following a major fire, this standard lists and briefly reviews the relevant legislation, regulations and guidelines that apply to such situations. An important and far-reaching example of such legislation is the EU Directive 96/82/EC [2], commonly referred to as the "Seveso II" Directive.

Directive 96/82/EC [2] was implemented in the United Kingdom as The Control of Major Accident Hazards Regulations 1999 (COMAH) [3]. It aims to minimize the consequences to people and the environment where accidents have occurred. COMAH applies to a wide range of activities including the storage, use and manufacture of large quantities of dangerous substances. It should be noted that these regulations do not apply directly to plastics since plastics are not considered to be dangerous substances per se. It is possible, however, that burning plastics might release potentially dangerous substances and the application of COMAH represents a cautious approach in such cases. Most importantly, COMAH emphasizes the need for site operators to assess the risks of incidents and also their consequences for people and the environment. The competent Government authority for COMAH lies jointly with the Department of Environment, Food and Rural Affairs (DEFRA) and the Health and Safety Executive (HSE).

1 Scope

This British Standard gives guidance to site operators, emergency planners and local authorities on the likely environmental impact of large-scale fires involving significant quantities of stored plastics. This includes:

a) stocks of plastics raw materials stored prior to or during manufacture;

b) stocks of fabricated articles stored after manufacture;

c) stocks of articles for sale, e.g. in warehouses;

d) stocks of articles awaiting recycling.

The environmental impact of effluents from incinerators and power stations is not included.

Rubber tyres are not within the scope of this standard as they are the subject of separate guidance issued by the Home Office [1].

NOTE 1 Stocks of finished plastics and rubber articles at point of sale (e.g. garden centres) that contain very large quantities of plastics form a further category. This category is different from the four cited in 1a) to 1d) because large numbers of people can often be involved. A major plastics fire in a confined area, such as on a ship, forms yet another category.

NOTE 2 Whilst rubbers and rubber products are not covered in this standard, much of the guidance may be applied to them as well as to plastics. There are many similarities in chemical composition between thermoplastic elastomers and more rigid thermoplastics and the fire effluents from the two families of products are similar. Much of the guidance issued by the Home Office [1] for the storage of rubber tyres may be used as a example of how to manage large stocks of plastic products.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this British Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the publication referred to applies.

BS EN 2:1992*, Classification of fires.*

BS ISO 472*, Plastics — Vocabulary.*

BS EN ISO 13943*, Fire safety — Vocabulary.*

BS 5839-1:1988*, Fire detection and alarm systems for buildings — Part 1: Code of Practice for system design, installation and servicing.*

BS 5306-2:1990, *Fire extinguishing installations and equipment on premises — Part 2: Specification for sprinkler systems.*

BS EN ISO 1043-1, *Plastics — Symbols and abbreviated terms — Basic polymers and their special characteristics.*

3 Terms, definitions, symbols and abbreviations

For the purposes of this British Standard, the terms and definitions given in BS EN ISO 1043-1 and the following apply.

3.1
additive
substance added to polymers to improve or modify one or more properties
[BS ISO 472]

3.2
asphyxiant gas
gas that incapacitates victims by starving the body of oxygen, resulting in impairment of the nervous and cardiovascular systems causing loss of consciousness and ultimately death

3.3
environment
surroundings in which an organization operates, including air, water, land, natural resources, flora, fauna, humans, and their interrelation

3.4
environmental impact
any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization’s activities, products or services

3.5
establishment
building or premises under the control of an operator where plastic or rubber materials are present in one or more installations, including common or related infrastructure or activities

NOTE This definition has been adapted from that of “establishment” in EU Council Directive 96/82/EC [2].

3.6
“exotic” organic compounds
organic compounds that may be toxic at very low concentrations, such as certain polychloro- and polybromo-dibenzodioxins/furans and organophosphates

3.7
filler
relatively inert solid material added to a plastic to modify its strength, permanence, working properties or other qualities, or to lower costs
[BS ISO 472]

3.8
fire effluent
totality of gases and/or aerosols (including suspended particles) created by combustion or pyrolysis
[BS EN ISO 13943]

3.9
foamed plastic
cellular plastic

plastic in which the density is reduced by the presence of numerous small cavities (cells), interconnecting or not, dispersed throughout the mass

NOTE A foamed plastic often is called simply a foam. Rigid foams normally have a closed-cell structure whilst flexible foams have an open-cell (interconnecting) structure.

3.10
hazard
intrinsic property of a plastic or rubber material or physical situation, with a potential for creating damage to human health and/or the environment

NOTE This definition has been adapted from that of "hazard" in EU Council Directive 96/82/EC.

3.11
installation
technical unit within an establishment, in which plastic or rubber materials are produced, used, handled or stored

NOTE 1 This includes all the equipment, structures, pipe work, machinery, tools, private railway sidings, docks, unloading quays serving the installation, jetties, warehouses or similar structures, floating or otherwise, necessary for the operation of the installation.

NOTE 2 This definition has been adapted from that of "installation" in EU Council Directive 96/82/EC.

3.12
irritant
effluent that causes immediate painful sensory stimulation of the eyes, nose, throat and lungs, resulting in behavioural incapacitation and impairment of breathing

NOTE Irritants can cause inflammatory lung reactions and oedema which also result in impairment of respiration and may ultimately prove fatal several hours, or even days, after removal from a fire atmosphere.

3.13
major accident
major emission, fire, or explosion resulting from uncontrolled developments in the course of the operation of any establishment, and leading to serious danger to human health and/or the environment, immediate or delayed, inside or outside the establishment, and involving dangerous material

NOTE This definition is taken from that of "major accident" in EU Council Directive 96/82/EC.

3.14
MEL
maximum exposure limit

3.15
operator
individual or corporate body who owns or operates an establishment or installation or, if provided for by national legislation, has been given decisive economic power in the technical operation thereof

NOTE This definition is taken from that of "operator" in EU Council Directive 96/82/EC.

3.16
OES
occupational exposure standard

3.17
plastic
material which contains as an essential ingredient a polymer of high molecular weight and which at some stage in its processing into finished products can be shaped by flow

NOTE Thermoplastic elastomeric materials, flexible polyurethane foams and coated fabrics are included for the purposes of this document.

3.18
PM_{10}
a mass median aerodynamic diameter of 10 micrometres or less

3.19
pyrolysis
that part of the irreversible chemical decomposition caused solely by a rise in temperature
[BS EN ISO 13943]

3.20
risk
likelihood of a specific effect occurring within a specified period or in specified circumstances

NOTE This definition is taken from that of “risk” in EU Council Directive 96/82/EC.

3.21
storage
presence of a quantity of plastic or rubber materials for the purposes of warehousing, depositing in safe custody or keeping in stock

NOTE This definition has been adapted from that of “storage” in EU Council Directive 96/82/EC.

3.22
thermoplastic, noun
plastics material capable of being softened repeatedly by heating and hardened by cooling through a temperature range characteristic of the plastic and, in the softened state, of being shaped by flow repeatedly into articles by moulding, extrusion or forming
[BS ISO 472]

3.23
thermoset plastic
plastics material that has been cured by heat or by other means such as radiation, catalysts, into a substantially infusible and insoluble state
[BS ISO 472]

3.24
LC_{50}
term used to denote the concentration of material or fire effluent that causes death in 50 % of an exposed animal population in a given time

3.25
dioxins/furans
abbreviated terms for certain polychloro- and polybromo-dibenzodioxins and dibenzofurans

4 Plastics and fire

The use of plastics in our modern society increased over thirty-fold between 1970 and 2000. Plastics, or synthetic polymers, are chemically similar to natural polymers such as wood, paper, cotton and wool. These are all composed largely of carbon, hydrogen and oxygen, and so can burn. Although their combustibility characteristics are similar, special precautions are required where large concentrations of plastics products become involved in a fire.

The thirteen types of plastics covered in this British Standard are the materials most likely to be encountered. All plastics can be divided into two categories: melting, or thermoplastic, and non-melting, or thermoset.

As heat is applied to thermoplastic products there is deformation followed by shrinkage, melting and finally combustion of vaporized material. The melting point for most thermoplastics is in the range 75 °C to 250 °C. Cooling of the molten masses can result in the formation of a bridge or shell covering a hot pool of molten, smouldering and/or flaming plastic. Thorough and prolonged cooling with a water fog is recommended. In the case of cellular plastics (e.g. those used in insulation and packaging) breaking up clumps and using hoselines is recommended.

As heat is applied to thermoset materials there is no deformation, shrinking or melting but decomposition of the plastic takes place and the material once ignited burns.

Plastics require higher temperatures than natural polymers before they will ignite. Flash ignition temperatures of natural polymers are in the range 250 °C to 270 °C, whereas those for synthetic polymers are normally in the range 310 °C to 540 °C. However, once ignited, plastics can burn fiercely and can generate large quantities of smoke. The amount of smoke depends not only on the material but also on its shape, the ventilation, size of fire, and the presence of other materials.

Since most burning plastics generate toxic gases during combustion, wearing self-contained breathing apparatus before entering the scene of a fire is strongly recommended. Smouldering materials generate carbon monoxide, an odourless, colourless and tasteless gas, and this may present a hazard in premises even after the major part of the fire has been extinguished.

In this guide the major products of combustion are not listed in order of significance and there will be many other products of combustion in minor quantities. Those listed are known to be generated in quantities and/or concentrations that may be harmful.

Pre-planning to determine where large stocks of plastics are stored is recommended, since it can help ensure that any action taken in the event of a fire minimizes negative environmental impact.

Although this British Standard deals principally with the effects of plastics fires, such fires often involve the collateral burning of building elements. This can result, in particular, in the release of fibrous materials used in roofing and insulation products. In the case of older buildings, asbestos can be released and both individual fibres and larger lumps can be deposited over a wide area.

5 Overview of relevant legislation and guidance documents

The many detailed regulations and directives together with guidance documents from Government departments and agencies are summarized in Annex A.

6 Introduction to fires

6.1 Classification of fires according to BS EN 2:1992

BS EN 2:1992 classifies fires into four categories defined in terms of the nature of the fuel:

Class A	fires involving solid materials, usually of an organic nature, in which combustion normally takes place with the formation of glowing embers;
Class B	fires involving liquids or liquefiable solids;
Class C	fires involving gases;
Class D	fires involving metals.

NOTE Fires involving plastic materials are typically Class A fires, though if the fire results in runoff of melted plastics, these fires may be classified as Class B.

6.2 Flammability principles

The science of fire protection [4] rests upon the following principle: an *oxidizing agent,* a *combustible material* and an *ignition source* are essential for combustion. In the context of this British Standard:

— the combustible material is a plastics material and the oxidizing agent is the oxygen of the air;

— the combustible material has to be heated to its ignition temperature before it can be ignited or support flame spread;

— subsequent burning of a combustible material is governed by the heat feedback from the flames to the pyrolysing or vaporizing material.

The burning rate of large fires is principally governed by the radiant heat transfer from the flames to the pyrolysing fuel surface. Burning will continue until any of the following occurs:

a) the combustible material is consumed;

b) the oxidizing agent concentration is lowered to below that necessary to support combustion;

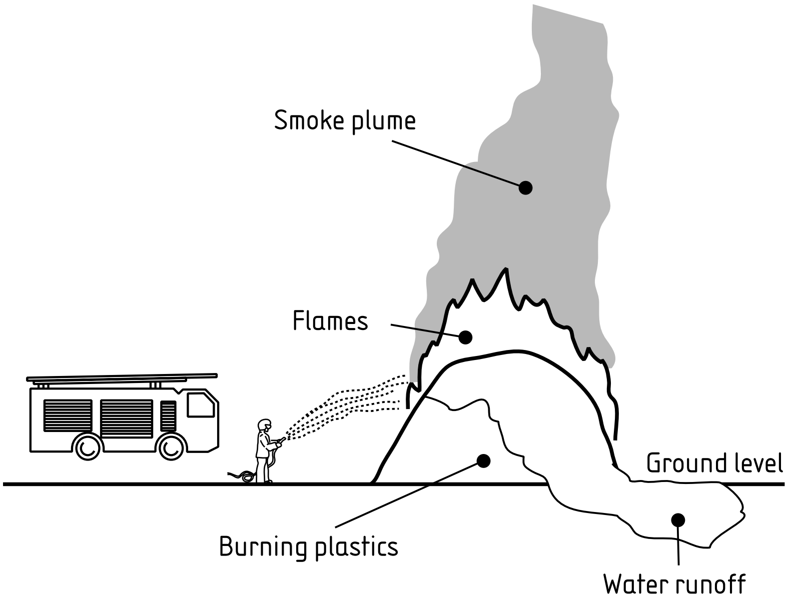
c) sufficient heat is removed or prevented from reaching combustible material to prevent further fuel pyrolysis; and

d) the flames are chemically inhibited or sufficiently cooled to prevent further reaction.

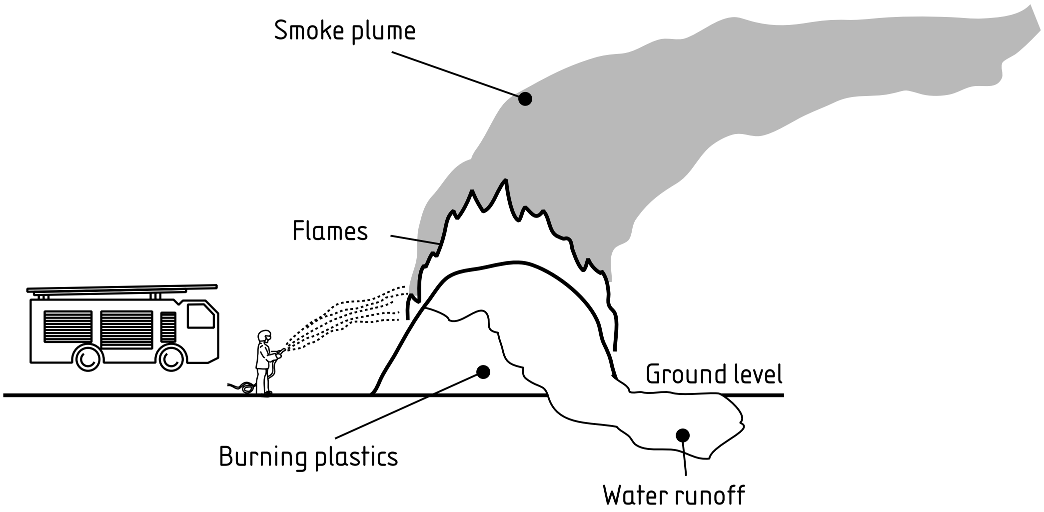
6.3 Possible environmental impacts

Figure 1 and Figure 2 are schematic representations of possible environmental effects in the open and in enclosures.

The fire-water from fire-fighters' hoses can threaten natural waterways as well as drains and sewers.

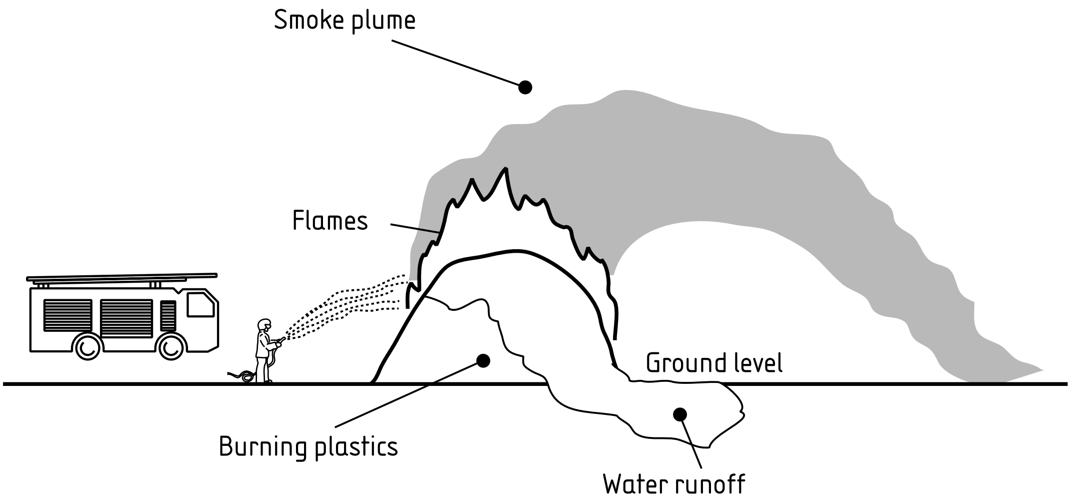


a) No wind: smoke travels mainly vertically, unaffected by wind.



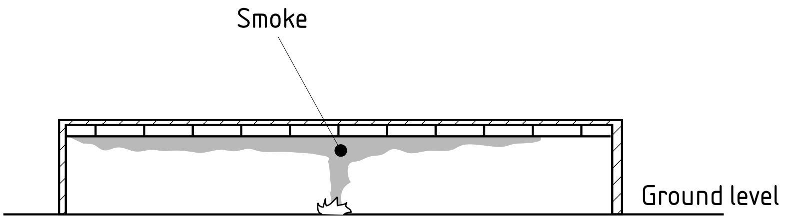
b) Windy day, scenario 1: smoke blown by wind downstream with little settling near fire (wind blowing from left).

Figure 1 — Fires in the open

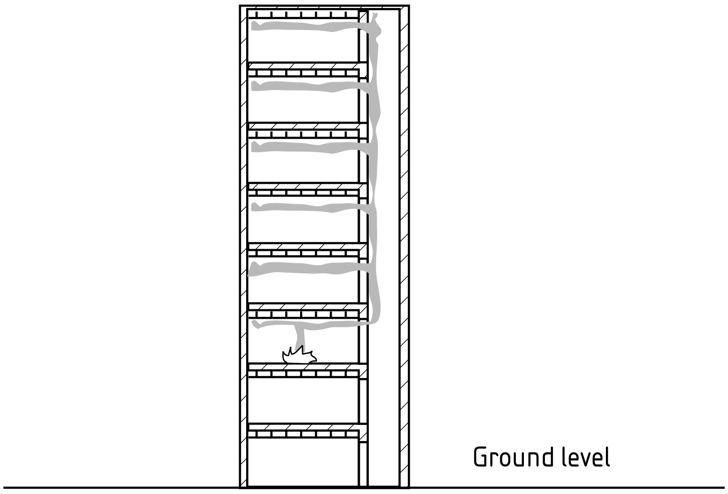


c) Windy day, scenario 2: smoke blown downwind and quickly falls to ground level (wind blowing from left).

Figure 1 — Fires in the open (*continued*)

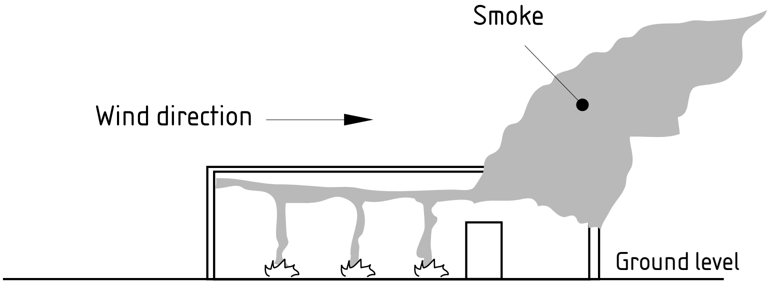


i) Single storey building: fast travel of smoke under ceiling dispersed by obstacles such as lintels.



ii) Multi-storey building: fast spread of smoke to upper storeys via stairwells and lift shafts.

a) Fires at the developing stage.



b) Fires at the developed stage.

Figure 2 — Fires in enclosures

Figure 2 depicts structures such as large buildings, tunnels, ships, shopping malls and sports stadiums. A fully developed fire in a building with the smoke plume escaping to the atmosphere [Figure 2b)] will result in a scenario as shown in Figure 1b). Smoke scenarios as shown in Figure 1a) or Figure 1c) are also possible, with decomposition of the combustible material.

6.4 Fire development in enclosures

6.4.1 *General*

Large-scale fires are complex events and are the focus of current fire research. Their behaviour depends on many parameters, which include the level of ventilation, fire load, structure of the building and the burning properties of the combustible materials.

The various phases of a fire are summarized in Figure 3. This figure depicts a fire development that assumes no involvement of fire-fighters or the presence of active fire protection systems such as sprinklers.

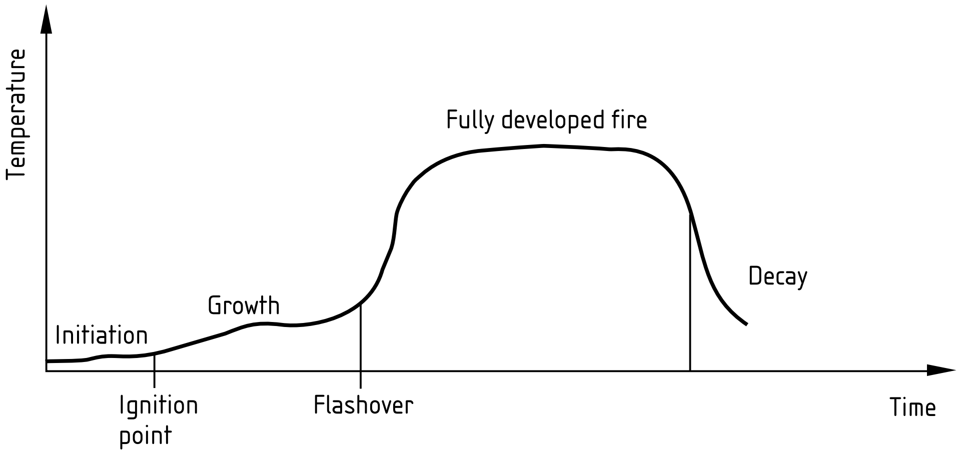


Figure 3 — The various phases of a fire

6.4.2 *Phase 1 — Initiation and early growth*

The combustible plastics material is heated by an ignition source (e.g. cigarette, burning paper in a waste basket). The ignition source is able to generate enough heat to start the decomposition of the adjacent combustible materials.

NOTE The critical parameter for this phase is the ease of ignition.

6.4.3 *Phase 2 — Fire growth*

As adjacent material is ignited, flames spread and the temperature rises. The surrounding combustible materials (e.g. stacks of plastics materials) become hot enough to decompose and give off flammable gases. If these ignite, there can be a "flashover" and the rate of flame spread can increase dramatically. The fire in the original compartment is then out of control.

NOTE The important parameters for this phase are the rate of heat release, rate of smoke generation and flame spread.

6.4.4 *Phase 3 — Fully developed fire*

During this phase, all of the combustible materials within the fire compartment are burning. In addition, this is the stage at which the fire can spread to adjacent rooms or other buildings.

The important parameters for this phase are the fire resistance and structural characteristics of the fire compartment, the heat released and the smoke and toxic gases generated.

6.4.5 *Phase 4 — Decay*

During the decay stage, the fire is exhausting its supply of combustible materials and/or oxygen. In the case of oxygen depletion, the fire may appear to have burnt out. However, smouldering combustion can continue and, if the full oxygen concentration is restored, combustion may be restored in an explosive manner. This is known as "back draught". The time-scales of events during the various phases of a fire are shown in Table 1.

Table 1 — Time-scales of events during the various phases of a fire

Event	Time-scale
Fire alarm	On discovery
Evacuation time	Minutes
Firefighting time	Hours
Post-fire clear up time	Days
Environmental monitoring	Months

6.5 Fire hazards of materials

6.5.1 *Fire initiation*

The ease with which plastics can be ignited when exposed to various ignition sources depends on the chemical composition of the polymer and concentration of fire retardants as well as on the intensity and duration of exposure to the ignition source. Physical conditions such as thickness of product, ventilation, presence of air-gaps, relative humidity and ambient temperature will also significantly affect ignitability and early fire growth. Direct contact with ignition sources is not the only threat of fire initiation since radiant heat from flames at the seat of the fire may be sufficiently intense (e.g. >35 kW/m^2) for plastics stored too closely to be raised to temperatures above their ignition threshold.

6.5.2 *Fire growth*

The heat released from ignited materials is generally regarded as the most important characteristic governing the eventual size of a fire. The rate of heat release and the heat of combustion of plastics vary widely; for example, polyolefins will give significantly higher rates of heat release than aromatic or halogen-containing polymers. Plastics with high rates of heat release can cause a flashover in small enclosures relatively quickly.

Fire growth may also be manifest in flame spread. Vertical flame spread (e.g. up high stacks of storage containers) can be particularly fast. Lateral flame spread rates depend more on geometric conditions (e.g. influence of ceilings on rooms and corridors). A further flame spread mechanism which occurs with thermoplastics is downward spread due to flaming drops, which effectively can move a fire at ceiling height to floor level with the risk of involving other materials positioned on the floor. Thermal properties such as melting and slumping may contribute to fire spread if the material is already sustaining a flame; in some fires, these same properties in materials which have not ignited can delay fire growth by effectively removing combustible material from the seat of the fire.

Flame spread is limited in its rate and extent if plastics and rubbers form chars or intumesce when they burn; both these mechanisms help to protect combustible material below the charred or intumesced layer. Similarly, plastics laminates or composites which have non-combustible facings or facings of limited combustibility (such as steel sheet, plasterboard or cementitious coatings) will show less tendency to spread flame than unfaced plastics.

6.5.3 *Smoke generation and spread*

Some plastics generate significant quantities of hot smoke which is often black and which spreads quickly away from the seat of the fire. This type of fire presents a major hazard to people nearby, since the smoke rapidly reduces visibility and induces disorientation. This can increase escape times for the occupants of the premises, which can result in them becoming trapped and inhibit rescue. Some plastics produce sooty smoke which can lead to significant and widespread deposits, resulting in high clean-up costs.

Most smoke is buoyant and in open locations smoke plumes do not generally present a hazard to life. However, cold smoke is often generated (e.g. owing to pyrolysis behind non-combustible layers) and this smoke can spread at ground level.

If people are trapped in smoke, the survival times can be short depending on the concentration of noxious fumes and on the irritancy of fumes and particles present in the smoke.

7 Decomposition products from burning plastics

The initial decomposition is generally through pyrolysis by which plastics are broken down by heat to yield a range of organic fragments. These fragments vary in size and chemical structure and provide the volatile fuel for combustion, ultimately generating oxides of carbon and water.

The elemental composition of a material can provide some guidance when predicting the combustion or decomposition products that can be generated during a plastics fire. The molecular composition or structure of a polymer can affect combustion efficiency and the mix of organic combustion products generated in a fire. Within a fire atmosphere the polymer backbone may be broken down by pyrolysis into its original structural units (monomers). For example, styrene may be produced from polystyrene and similarly PMMA can give rise to the methyl methacrylate monomer.

For almost all combustible materials, including plastics, the main compositional elements are carbon, hydrogen and oxygen and the majority of combustion products will consist of releases derived from these elements. Initial pyrolysis of plastics, however, yields a series of aliphatic hydrocarbons (e.g. alkanes, alkenes) from methane upwards. Ring cyclization reactions can result in the formation of alicyclic products (e.g. cyclohexane, cyclopentene) and aromatic compounds (e.g. benzene). If a plastic contains oxygen, or if decomposition occurs in air, oxygen can be incorporated into pyrolysis products to yield carbonyl compounds (e.g. aldehydes, ketones) and other oxygenated species (e.g. aliphatic alcohols, phenols).

The presence of other elements, arising either from the polymer structure (e.g. nitrogen in polyamides and chlorine in PVC) or from the inclusion of additives, will give rise to additional decomposition/combustion products. Examples of potential decomposition products for some of the common plastics and their additives according to elemental composition are shown in Table 2.

The relative yields of the various combustion/pyrolysis compounds depends mainly upon the conditions of thermal decomposition.

Smouldering fires involve slow thermal decomposition under oxidative non-flaming conditions. These conditions give rise to fire emissions that are rich in organic compounds.

Well-ventilated flaming fires provide efficient combustion conditions (e.g. a high air/fuel ratio) and the major products are carbon dioxide, water and heat.

Ventilation-controlled flaming fires result in high yields of carbon monoxide, carbon dioxide, hydrogen cyanide, smoke, inorganic acid gases and organic products. In the context of potential impacts to the environment, beyond the burning building itself, large ventilation-controlled flaming fires are deemed to be potentially the more environmentally significant.

Table 2 — Types of plastics and their decomposition products

Material		Major decomposition products
Thermoplastics	**Polyolefins** Polyethylene (PE-HD, PE-LD) Polypropylene (PP) Polyethylene-vinyl acetate (EVAC) copolymer	Partially oxidized organics including aldehydes (acrolein, formaldehyde), alcohols (methanol), acids (formic, acetic) and lower molecular weight hydrocarbons including aromatics like benzene and toluene.
	Polyvinylchloride compounds (PVC)	Hydrogen chloride, aliphatic and aromatic hydrocarbons (alkanes, benzene), acrolein, formaldehyde, acetone. Depending on combustion conditions, very low concentrations of vinyl chloride monomer may be detectable, as well as phosgene and chlorinated dibenzodioxins and furans.
	Polystyrene (PS)	Aldehydes such as formaldehyde and benzaldehyde and aromatic hydrocarbons (benzene, styrene, naphthalene).
		Most PS products generate heavy black smoke when they burn.
	Polyesters Polycarbonates (PC) Polyethylene terephthalate (PET) Polybutylene terephthalate (PBT)	Aldehydes, ketones, alcohols and acidic species including benzoic and terephthalic acids; low molecular weight hydrocarbons.

Table 2 — Types of plastics and their decomposition products (*continued*)

Material		Major decomposition products
	Acrylics Polymethyl methacrylate (PMMA) Polyacrylonitrile (PAN)	PMMA: MMA monomer, oxidized organics (esters, acids, alcohols etc.), hydrocarbons. PAN: Nitrogen-containing species including nitrogen oxides, hydrogen cyanide, ammonia, organic nitriles including AN monomer.
	Polyamides (PA, nylon)	Nitrogen-containing species including ammonia, hydrogen cyanide, nitrogen oxides, formaldehyde, acetaldehyde, ketones, organic acids, hydrocarbons including benzene.
	Polyphenylenes Ethers (PPE, PPO) Etherketones (PEK, PEEK) Sulfides (PPS) Sulfones (PES, PSU)	PPE, PPO: phenol, acetone PPS, PES, PSU: Sulfur-containing species such as SO_2 and, generally at lower concentrations, hydrogen sulfide, carbon disulfide; hydrocarbons such as styrene and methane, phenol.
	Polyoxymethylene	Formaldehyde.
	Fluoropolymers Tetrafluoroethylene polymers (PTFE) and copolymers (FEP, PFA, ETFE) Polyvinylidene fluoride (PVDF) Polyvinyl fluoride (PVF) Polychlorotrifluoroethylene (PCTFE) Ethylene chlorotrifluoroethylene copolymer (ECTFE)	Hydrogen fluoride (HF) and trace quantities of low molecular weight fluoro-organic compounds such as monomers, oligomers and carbonyl fluoride. In the case of PCTFE and ECTFE, some chlorinated species including HCl. See Purser, D.A., P.J. Fardell, and G.E. Scott [5].
Thermosetting resins	**Formaldehyde resins** Phenol-formaldehyde (PF) Urea-formaldehyde (UF) Melamine-formaldehyde (MF)	Formaldehyde, phenol, methane, acetone, acetaldehyde, propanol, formic acid, and, in the case of UF and MF, nitrogen-containing species such as nitrogen itself, ammonia, hydrogen cyanide, oxides of nitrogen and amines.
	Polyurethanes (PU)	Hydrogen cyanide, ammonia, nitrogen, NO_x, amines, isocyanates, nitriles, hydrocarbons, alcohols and aldehydes.
	Unsaturated polyesters	Oxidized organic species such as alcohols, aldehydes and acids (e.g. phthalic acid), hydrocarbons such as styrene and benzene.
	Epoxy resins	Phenol, formaldehyde, formic acid, acetone, hydrocarbons.
	Polyimides	Ammonia, benzene, phenol, aniline.

NOTE This information is taken from *Assessment of Plastics Fires* (Beurteilung von Kunststoffbränden), Bavarian Environmental Protection Agency Report [6].

Most commercial plastics contain additives such as those listed in Table 3. The presence of additives should be taken into account when assessing the hazard posed by the decomposition products produced by plastics raw materials and products when they burn. In the case of flame-retardant compounds, for example, decomposition products that may be of significance include heavy metal derivatives and chlorinated or brominated organic species.

Table 3 — Additives in plastics compounds

Fillers	Mostly inorganic substances such as calcium carbonate, silicate, aluminium hydroxide
Plasticizers	Organic acid esters (phthalates etc.) or phosphoric acid esters (e.g. triphenyl phosphate)
Flame retardants	Inorganic: antimony trioxide, hydrated alumina, zinc borate Organic: organo-phosphorus and organo-tin compounds; chloro-, bromo- and non-halogenated phosphoric acid esters; brominated organics: various aliphatic, alicyclic and aromatic compounds and combinations; chlorinated organics: chlorinated aliphatic and cyclo-aliphatic compounds and phthalates
Miscellaneous additives	Pigments, lubricants, stabilizers, antioxidants

Information on the environmental pathways and impacts of these decomposition products within the wider local environment of a plastics fire are provided by toxicity data, usually expressed as an LC_{50} (Lethal Toxic Potency) value over a time period and obtained from exposing animals to mixed test emissions from burning materials or from observing the effects of individual fire gases on animals and humans. Large-scale tests are the most valuable source of information as they mimic “real” fires most closely. Data from small-scale tests are difficult to validate with respect to real fire conditions as the tests are far removed from a full-scale fire.

MEL (**3.14**) and OES (**3.16**) are guidance levels for a range of substances, and have been defined for workplaces under The Control of Substances Hazardous to Health Regulations 1994 [7]. EAL (Environment Assessment Levels) are those set by the Environment Agency in relation to the control of emissions under the Environmental Protection Act, 1990 [8]. They tend to be stricter than MEL and OES guidance levels, reflecting the potentially greater sensitivity of individuals in the wider environment, and potentially longer exposures.

WHO (World Health Organization) guidelines [9] provide air quality standards for a range of air pollutants largely for the protection of human health.

NAQS (the UK National Air Quality Strategy) has identified a range of air quality objectives, including seven standards which are specified in the Air Quality Regulations, 1997 [10], and which are to be achieved by 2005.

8 Potential environmental impact of fires

8.1 General

A wide variety of pollutants can be emitted in plastics fires. This pollution may follow a number of pathways to impact on human and ecological receptors. A risk assessment might not be possible for all potential impacts but contingency planning should take account of selected “worst-case” scenarios.

8.2 Impact zones

8.2.1 *General*

In assessing the potential environmental impacts of toxic releases from plastics fires, four major zones of impact have been considered. This guide does not attempt to repeat the extensive and comprehensive works of others on fire zones but concentrates on impacts to the environment within fire plume, plume deposition and surface water runoff zones.

8.2.2 *Fire zone*

The major interest within the fire zone (generally the burning building) is in the actual fire and the corresponding emergency response. Within the fire zone the priority response should relate solely to the health and safety of individuals who might be within the burning building. The environmental impacts should be a secondary consideration. These will be considered after the incident and will relate primarily to ash disposal and fire-water runoff outside the immediate fire zone.

8.2.3 *Fire plume zone*

The fire plume zone is an area over which the emissions plume from the fire disperses. Both local topography and meteorological conditions (wind speed and air stability characteristics) have an influence on the characteristics of dispersion and the extent of the fire plume zone. Short-term environmental impacts are most significant in this zone. Valleys, basins, high buildings and street canyons adjacent to or surrounding the fire constrain dispersion of the plume. Low wind speed, temperature inversion and conditions that promote rapid plume grounding all limit plume dispersion. The combined effects of topographical features and meteorological conditions that result in restricted dispersion are generally additive and result in higher air pollutant concentrations within the fire plume.

8.2.4 *Plume deposition zone*

The plume deposition zone encompasses the area under the fire plume zone and therefore, in a similar way to the fire plume zone, is influenced by topographical features and meteorological conditions. Most particulate deposition will tend to occur closer to the fire source.

Air temperature normally decreases with increasing height, the reversal of this trend causes a layer of warmer air to overlie a cooler layer: this meteorological condition is known as temperature inversion. As cool air is heavier than warm air it cannot rise; this results in any pollutants emitted below the “warm” inversion layer becoming trapped.

8.2.5 *Surface water runoff zone*

The surface water runoff zone may include free-standing natural waterways and sewerage, generally ending at either a drain, watercourse or confined soak-away area. This zone is particularly influenced by surface topography, and affects lower-lying areas. Certain regions (e.g. Thames Water region) are served by combined sewerage systems. In running to the combined sewerage system contaminated fire-water could have an adverse effect on biological sewerage treatment works, resulting in significant pollution to the receiving watercourse as well as accelerating the time of travel of pollutants in the fire-fighting water to downstream water intakes.

The chemical nature of fire-fighting liquors should be taken into account before consideration is given to the acceptability of their discharge to the public sewerage system. In most cases dilution of fire-water is likely to be sufficient to minimize the risk but in some cases specialist clean-up and removal techniques may be required.

Pollution Prevention Guidelines 18 published by the Environment Agency [11] assist in the identification of the equipment and techniques available to prevent or mitigate damage to the water environment caused by fires and major spillage. This can be limited by the use of PODS, equipment specially designed for diverting the waste into dedicated containment systems.

8.3 Release pathways and affected receptors

8.3.1 *General*

The main types of emission releases and potential release pathways are summarized below, together with the various environmental impacts that might arise.

8.3.2 *Releases to atmosphere*

The dispersion of the fire plume within the atmosphere causes:

a) elevated concentrations of airborne pollutants;

b) increased risk from exposure to airborne pollutants;

c) reduced visibility.

Visual impairment occurs during fires as a result of atmospheric particles reducing visibility by scattering and absorbing light. This issue tends to get lower priority than other environmental aspects because there is no associated biological toxicity or clearly definable cost; however, it results in a pervasive reduction in environmental quality. "Urban particles", formed by gas-to-particle conversions (condensation of volatiles from combustion smoke, or photochemical formation of ammonium sulfate from ammonia and sulfur dioxide, for example) are in the size range which accumulates in the environment and also scatters light effectively. Visual impacts of airborne plumes from plastics fires will be temporary, and similar to those of other types of fire. They are not assessed further in this document.

Risk from atmospheric pollutants is attributable to:

a) direct inhalation by humans and animals;

b) contact with flora and fauna.

There are potential effects on indoor air quality of both naturally ventilated and forced-ventilated buildings in the vicinity/downwind of a plastics fire.

8.3.3 *Deposition to land and water*

Health and ecological damage can arise from exposure to deposited pollutants through a variety of pathways such as:

a) aerial deposition to water and land;

b) accumulation in the food-chain (e.g. fish, crops) and subsequent consumption, either directly or indirectly, of contaminated food.

Many thermal degradation products can condense on, or be adsorbed by, the soot particles and be transported with the smoke.

There may also be deposition on structures, leading to corrosion, particularly from acidic decomposition products such as SO_2 and HCl. Damage (erosion) to stone buildings from SO_2 is mainly due to rapid deposition of gaseous SO_2 to wet stone surfaces rather than the effects of acid rain itself. Regions of stone protected from acid rain tend to have a blackened appearance resulting from the deposition of particles. The particles, together with dry-deposited gases, such as SO_2, produce a crystalline gypsum lattice within the stonework interstices. Pressure from the crystal growth breaks off small areas of stone, exposing a more vulnerable surface. SO_2 also reacts with other materials such as zinc on galvanized steel (corrugated iron, electricity pylons) and can react with paint, paper and leather. Similarly, hydrochloric acid can attack metal materials, machines, electrotechnical and electronic equipment not directly affected by fire. This can cause considerable corrosive damage.

8.3.4 *Releases through surface water runoff*

The use of fire-fighting water can release contaminated surface water runoff to the sewerage system, to storm drains or to surface waters. Such water runoff can also drain to groundwater and can contain contaminated ash. Potential local visual impacts can arise from this runoff, but these are not considered significant. Exposure to contaminated water runoff releases can occur through various pathways:

a) the drinking of contaminated surface waters or groundwater;

b) releases to watercourses of water-borne contaminants that have direct impacts on aquatic species;

c) the consumption of contaminated food (e.g. fish) in which water-borne contaminants have accumulated.

8.3.5 *Ash disposal*

The disposal of ash following a fire can also release contaminants to the environment if the disposal process is not properly managed. Ash dust can be released following a fire as it dries, and the process of collecting and disposing of the ash can also produce dust. Exposure to pollutants within the ash can occur through:

a) direct inhalation of fugitive dust emissions produced following a fire, particularly during ash storage and removal;

b) improper disposal of ash at a landfill where contaminants are subsequently released.

8.3.6 *Affected receptors*

For those pollutant pathways where exposure to products decomposition is the primary concern, the potential affected receptors are as follows.

a) *Humans*

Some members of the population will be more susceptible to the effect of airborne irritants/axphyxiant gases through inhalation. Examples include children, the elderly, individuals with respiratory and other diseases and pregnant women. Clearly, where a fire occurs under conditions of restricted dispersion, the location of such groups (for example, schools and hospitals) relative to the course of the fire plume needs to be taken into account.

b) *Soils and crops*

Soil might be contaminated to some extent from primary deposition, which may only become apparent over the longer term. Contaminated soils potentially represent a hazard through the various pathways of:

1) direct ingestion;

2) take-up by crops, and accumulation within the food-chain.

c) *Terrestrial habitats and species*

Certain plant species will be more sensitive to air pollutant emissions (particularly HCl) and deposition products than others. Taking into account the vast variety of responses, and the lack of detailed data for more than a few such plants, it is not considered useful to identify individual sensitive species or crops. The component of the terrestrial environment which receives the higher load from atmospheric deposition tends to be the flora, rather than the soil [12] [13] as plant surfaces are extensive and exposed to the atmosphere.

d) *Freshwater and marine habitats and species*

Species found in streams and watercourses are variously susceptible to different pollutants.

e) *Property and equipment*

Some effluents from plastics fires are corrosive.

8.4 Effects of short-term exposure

8.4.1 *General*

The effects of short-term exposure (i.e. the effects occurring within minutes to a few hours of a fire) will pertain mostly to the local environment, within the fire plume zone and surface water runoff zone. A summary of potential short-term exposure effects of plastics fires is given in Table 4.

Table 4 — Possible short-term exposure effects

Potential exposure pathways	Asphyxiants	Irritants	Toxins/carcinogens	"Exotic" organics
Air exposure — effects on human health	Potential effects in the fire zone only	Potential impacts in the fire zone and in the fire plume zone	No short-term effects	No short-term effects
Air exposure — effects on terrestrial habitats/species	No short-term effects	Potential impacts in fire plume zone	No short-term effects	No short-term effects
Deposition on land effects on crops and vegetation	No short-term effects	No short-term effects	No short-term effects	No short-term effects
Deposition/runoff water — effects on human health (via drinking)	No short-term effects	Potential impacts from local runoff to surface waters	Potential impacts from local runoff to surface waters	No short-term effects
Deposition on water — effects on freshwater/marine habitats and species	No short-term effects	Potential impacts from runoff to surface waters	Potential impacts from runoff to surface waters	No short-term effects

The impacts from short-term exposure arising from atmospheric releases are principally associated with asphyxiant gases, irritant gases and smoke. Most toxic, carcinogenic and "exotic" organic releases are unlikely to be produced in sufficiently high concentrations to result in short-term impacts and for many (such as dioxins) toxicity only occurs through long-term exposures and acute toxicity through dioxins is reportedly unknown.

Short-term impacts on water, from highly soluble toxins, carcinogens and irritants in fire-water runoff, draining within a local catchment, will represent the worst case for natural watercourses and associated aquatic habitats and species.

Impacts to land, through deposition, from plastics fires are unlikely to result in short-term impacts.

8.4.2 *Impacts to air*

8.4.2.1 *Impact of asphyxiant gases on human health*

Plastics fires inside buildings produce asphyxiant gases, particularly carbon monoxide and hydrogen cyanide, which represent a major hazard. Within the fire zone the emitted gases and smoke from the fire may accumulate and concentrate. Narcotic effects, caused by the common asphyxiant gases, result in impairment of the nervous and cardiovascular systems causing loss of consciousness followed ultimately by death from suffocation.

Smoke will continue to cause intoxication until it is released and dispersed into the atmosphere where concentrations of the gases will be rapidly reduced through dispersion.

Key pollutants of concern are CO and HCN. Measured levels within the fire zone [14] [15] [16] lead to LC_{50} and STEL levels given in Table 5.

Table 5 — Acute toxic potency values for asphyxiant gases

Key pollutants	LC_{50} 30 min[a] µl	STEL[b] mg/m^3
CO	2 000–4 000	232
HCN	170–230	11

[a] The lower the LC_{50} value, the higher the toxic potency.

[b] STEL: 50 minutes short-term exposure period.

Unless dispersion of asphyxiant gases is extremely constrained, such as when the fire plume is effectively trapped, the reduction in concentrations once air is released means there is not likely to be a significant impact outside the fire zone itself.

8.4.2.2 *Impact of irritant gases on human health*

Irritant gases cause immediate sensory irritation of the eyes, nose, throat and irritation of the lungs. Higher exposure levels result in lung oedema and inflammation, impairment of respiration and behavioural incapacitation. Effects are observed directly upon exposure and are related to the exposure concentration rather than an accumulated dose.

As the severity of immediate irritant effects varies over such a wide range of concentrations, irritants can be identified as major potential causes of adverse human health effects both inside a burning building and within the fire plume zone.

Key pollutants of concern are acrolein and hydrogen chloride. Potential levels within the fire zone are summarized in ISO 13314, which incorporates guidelines for the rank-ordering of the major fire gases according to their acute toxic potency. ISO 13314 indicates that acrolein, HCN, NO_2 and SO_2 are reportedly 10–30 times more toxic than CO and HCl (see Table 5 and Table 6). Additionally, HCl has been shown to be a much weaker respiratory tract irritant than acrolein and other partially oxidized combustion products which are present in all fires [13]. Data show that although the mechanisms of action of HCl and CO are totally different, their lethal doses are very similar

Table 6 — Acute toxic potency values and short-term exposure limits for some irritant gases

Key pollutants	**Impacts** **LC_{50} 30 min** µl	**Significance** **STEL**[a] g/m^3
Hydrogen chloride (HCl)	3 800	8
Hydrogen bromide (HBr)	3 800	10
Hydrogen fluoride (HF)	2 042–3 500	2.5
Nitrogen dioxide (NO_2)	127–200	9.6
Sulfur dioxide (SO_2)	400	13
Acrolein	150	0.7
Formaldehyde	750	2.5

NOTE The lower the LC_{50} value, the higher the toxic potency.

[a] STEL: 50 minutes short-term exposure period.

The data suggest that various irritant gases can cause potentially significant impacts within the fire plume zone.

Worst-case circumstances are likely to arise within the fire plume zone resulting from irritant gases released under conditions of low dispersion (low wind speed), temperature inversion and rapid plume grounding. Such effects can be amplified in valleys and basins and in urban areas where air flow is restricted (such as street canyons and emission sources surrounded by high buildings). This can be aggravated where the fire plume is emitted from a low-lying source.

8.4.2.3 *Impact of irritant gases on habitats/species*

The irritant gas hydrogen chloride is both corrosive and reactive. On entering leaf stomata the gas reacts immediately with intercellular tissue creating characteristic foliage-burning symptoms.

Although chronic exposure to HCl gas can result in plant mortality, short-term (acute) injury to plants ceases once the source has dissipated and plants usually recover. Potential damage to vegetation is likely to be restricted to the fire plume zone.

As a result of its corrosive nature HCl is unique among common fire gases in that its concentration in the gas phase decays by reacting rapidly with most construction surfaces, which limits its transportation. If HCl comes into contact with water or humidity, hydrochloric acid forms, which, when released into the atmosphere, is immediately diluted to such an extent that large-scale or long-term environmental damage does not occur.

The data suggest that HCl is unlikely to have significant impacts on vegetation within the fire plume zone, though a few sensitive species (particularly lichens) might die as a result of a fire event.

Worst-case circumstances are likely to arise within the fire plume zone under conditions of low dispersion (low wind speed), temperature inversion and rapid plume grounding. Such effects can be amplified in valleys and basins.

8.4.3 *Impacts on water*

Fire-fighting water runoff presents the major potential threat to the aquatic environment from toxic releases from plastics fires in the short term. This threat is strongest where runoff waters directly enter aquatic habitats in surface waters (e.g. rivers, streams, ditches), within the immediate vicinity of the site, and where levels of toxic releases are particularly high.

8.4.3.1 *Impact of toxins and irritants on human health*

Short-term impacts may arise where fire-water runoff infiltrates drinking-water supplies during or immediately following a fire. The effects are very local to the fire, where the runoff water is potentially most highly contaminated with ash, soot and decomposition products, and relatively undiluted. The likelihood of such water being directly ingested is small, but such surface water bodies do represent a potential hazard.

The key pollutants of concern are those defined in **8.4.3.2**. Their impact on the aquatic environment will be exacerbated where the contours of the land are such that runoff is conducted directly to non-contained surface waters and where dilution effects are limited (low flow rates, small water volumes within the receptor and a short source to receptor pathway).

This exposure risk is probably best addressed as a potential, temporary, health and safety hazard associated with affected watercourses.

8.4.3.2 *Impact of toxins and irritants on freshwater/marine habitats and species*

There may also be short-term effects associated with high pollutant loads (toxins and irritants) from fire-water runoff suddenly released into streams and watercourses. In worst cases, there is the potential for mortality of fish and other aquatic fauna and flora. Key pollutants of concern are summarized in Table 7.

Table 7 — Summary of toxic and irritant impacts on freshwater/marine species

Key pollutants	**Impacts** **Measured concentrations**[a] µg/l	**Significance** **EU: MAC**[b] µg/l
Ammonia	—	500
Hydrogen cyanide	—	5
Phenol	5 630	—
Toluene	370	—
Aluminium	11 320	500
Antimony	—	10
Cadmium	336	5
Chromium	111	50
Copper	8 180	3 000 (guide level)
Iron	35 500	200
Lead	5 810	50
Manganese	2 779	50
Nickel	180	50
Zinc	70 500	5 000 (guide level)

[a] Maximum concentration measured in the fire-water runoff during the Ontario fire.

[b] MAC: Maximum Admissible Concentration — where no MAC value is available the EC guideline value has been given. (EC Drinking-water Directive [17]).

Aquatic bioassays, carried out following the Ontario plastics fire [16] demonstrated that water in the storm sewer (to which the fire-water runoff was discharged) was lethal to aquatic life, although the toxic effects were not found to extend to larger receiving waters.

The irritants phenol, toluene, cyanides and ammonia are also harmful to the aquatic environment when released in large concentrations, and before they are substantially diluted. The information available suggests that this pollutant pathway is potentially significant and might present a real risk of environmental damage to local aquatic ecosystems.

Impacts on aquatic life will be exacerbated where the contours of the land are such that runoff is conducted directly to natural surface waters (non-contained) and where dilution effects are limited (low flow rates, small water volumes within the receptor and a short source to receptor pathway).

In some cases impacts can be minimized and mitigated by dilution, for example, where releases are discharged to large/fast-flowing water bodies. In other cases releases can be contained and treated, or drained through the foul sewer system.

8.5 Impacts from long-term exposures

Long-term environmental impacts from exposures to plastic fire decomposition products will be experienced largely within the local environment, within the fire deposition zone and along affected streams and watercourses. A summary of potential long-term exposure effects of plastics fire emissions is given in Table 8.

Table 8 — Possible long-term exposure effects of plastics fire emissions

Potential exposure pathways	Asphyxiates	Irritants	Toxins/carcinogens	"Exotic" organics
Air exposure — effects on human health	No long-term effects	No long-term effects	No long-term effects	No long-term effects
Air exposure — effects on terrestrial habitats/species	No long-term effects	No long-term effects	No long-term effects	No long-term effects
Deposition on land — effects on crops, vegetation and through food-chain	No long-term effects	No long-term effects	Potential impacts	Potential impacts
Deposition/runoff water – effects on human health (via drinking)	No long-term effects	No long-term effects	Potential impacts	Potential impacts
Deposition on water — effects on freshwater/marine habitats and species, and through food-chain	No long-term effects	No long-term effects	Potential impacts	Potential impacts

8.5.1 *Impacts to land*

8.5.1.1 *Impact of general pollutants on crops and through food-chains*

The key pollutants of concern are summarized in Table 9.

Table 9 — Summary impacts of general pollutants on crops

Key pollutants	**Impact levels** Measured concentrations[a] mg/kg	**Significance** **UK: ICRCL**[b] mg/kg
Metals	—	—
Antimony	—	—
Cadmium	3.7	3
Chromium	32	600 (total Cr) 25 [Cr (VI)]
Lead	220	500
Polycyclic aromatic hydrocarbons (PAH)	6 466 (total, in soot)	500
Benzo[α]pyrene	262 (in soot)	—

[a] Maximum concentration measured in the soils during/after the Ontario fire [16].

[b] Interdepartmental Committee on the Redevelopment of Contaminated Land “action” concentrations for soil (where a range of ICRCL values exists the most stringent criteria have been listed in this table) [29].

In every plastics fire polycyclic aromatic hydrocarbons PAH are produced; these are known to be cancer-causing compounds. However, PAH are reported to adsorb strongly to soot particles, which results in low bio-availability. Analysis of soot from the fire at Dusseldorf airport found total PAH levels of 6 466 mg/kg soot, with benzo[α]pyrene concentrations of 262 mg/kg [19].

A study [19] was undertaken to investigate PAH dispersion and deposition to vegetation and soil, following a large-scale polypropylene fire. PAH concentrations under the plume deposition area were found to be elevated in grass shoots (by up to 70 fold) and in soil (by up to 370 fold). Lighter PAHs were found to disperse into the environment at greater distances (up to 4.5 km) than the heavier, more hydrophobic PAHs. Particulate deposition of PAHs occurred closer to the fire source compared with vapour phase deposition. For all PAHs, the fire was shown to result in greater contamination of soils compared with grasses, and the ratio of plant/soil contamination decreased as hydrophobicity increased.

Metals reportedly used in high concentrations in plastics are: cadmium (Cd), antimony (Sb), lead (Pb), zinc (Zn), chromium (Cr) and copper (Cu) [20]. (Although the use of cadmium has been restricted since 1991 it may still be present in older plastics, particularly those found at recycling facilities.) Studies to identify toxic heavy metals emitted to the atmosphere, or remaining in the ash phase during laboratory-scale combustion of plastics have shown that the main areas of concern relate to the presence of lead, cadmium, antimony and chromium. Cd, Pb, Sb and Cr were found as major, minor and trace components in the smoke and/or ash phases of almost all sampled plastic materials [21] [22] [23] with concentrations of Pb, Sb and Cr ranging from 0.1 µl/l up to, and including, percentage levels. Both Cd and Pb can enter the body through the food-chain.

During the fire in Ontario [16], elevated concentrations of Ni, Cr and Pb were detected within the smoke plume in the vicinity of the fire. Several metals (including Ni, Cr, Zn, Cu, Mn, V, Fe and Pb) were detected in soot samples taken from areas both near to and far from the fire. Heavy metals that reach the soil can also contaminate groundwater and enter the food-chain.

Following a fire at a recycling plant in a Scots pine region, Meharg *et al.* [24] reported food-chain transfer of cadmium within the ecosystem. The study indicated that cadmium released into the environment from the chemical accident was bioavailable and entering the food-chain at all the trophic levels investigated. Bioaccumulation was observed in all organisms investigated and bioconcentration was observed in invertebrates (woodlice and earthworms). Cadmium was also found to be present at elevated concentrations in wood mice and bank voles, showing that cadmium is mobile throughout the food-chain. However, no evidence was found for biomagnification occurring through the bank vole food-chain or through the omnivorous wood mouse food-chain [of which seeds (particularly), invertebrates and vegetation constitute a large part]. Both higher and lower plant tissue can reportedly accumulate moderate amounts of Cd with relatively little damage.

Owing to low solubility and relative freedom from microbial degradation, lead has a long residence time when released into the environment compared with most other pollutants and its compounds tend to accumulate in soils and sediments [22]. The populations most likely to be affected would be the very young, the very old, and the sick, since their accumulation of heavy metals is likely to be more pronounced because of underdeveloped or damaged excretory systems. There has also been growing concern for the effects that low concentrations of lead may have in the development of mental function in young children [23].

Information available on metal and PAH accumulation through the food-chain and the potential threat posed to human health is contradictory. The study [24] considers that a prudent approach is justified and that pollutant pathways through the soil could be significant, though the critical sources, pathways and ultimate receptors will all be important considerations.

The worst case is likely to be represented by a situation where crops are grown within the plume deposition zone and relatively close to the source, where highest deposition is likely to occur.

8.5.1.2 *The impact of "exotic" organics on crops and through food-chains*

The key pollutants of concern are halogenated dibenzodioxins and dibenzofurans, some of which are persistent organic pollutants and carcinogenic.

Dioxins and furans deposited in the environment can be consumed by domestic animals. Investigation of dioxin and furan accumulation in wood mice following a factory PVC fire revealed that TEQs were 9 fold higher in mice 10 m from the factory boundary than those caught at 200 m [25] and suggested that the dispersion of dioxins and furans from large-scale fires could be considerable. Dioxins and furans at the site were taken into the wood mouse food-chain, resulting in high liver residues. The residues appeared to cause increased liver weight compared with animals from a non-contaminated site, indicating that the dioxin and furan levels in the livers may have resulted in physiological damage. In this instance dioxins and furans were found to be bioavailable to terrestrial animals following releases from fires.

Conversely, reviews of the results from investigations in Germany, with regard to PVC fires, showed that dioxin and furan emissions were much lower than expected and in most cases levels were within normal background measurements [18]. All investigations concluded that dioxins and furans are most likely to be found adsorbed to soot (which is already hazardous) and as such are not likely to be bioavailable. Following a PVC fire in 1992, dioxin testing was carried out on soil, water, plants and crops; the results revealed negligible levels of dioxins to be present.

In another investigation of 200 fires involving chlorinated plastics, increased dioxin concentrations were found at 90% of the sites [26].

Research (R Weber *et al.* [27]) at the University of Tübingen, Germany, has addressed the question of whether polyfluorinated dibenzodioxins (PFDDs) and polyfluorinated dibenzofurans (PFDFs) can be formed during thermal decomposition of fluorinated polymers by mechanisms similar to those occurring in the case of chlorinated and brominated organic materials. Published work indicates the following differences between fluorine-containing and other halogenated materials:

a) no PFDD or PFDF was detected under conditions known to produce PCDD and PCDF;

b) no formation of PFDDs or PFDFs was detected during the thermal decomposition of polytetrafluoroethylene (PTFE).

Organophosphates represent a further class of "exotic" organics that can present a risk through accumulation within the food-chain.

Overall, these results show that "exotic" organic pollutants may represent a potential environmental impact, though insufficient information is presently available on likely risks of significant accumulation levels, or the likely critical sources, pathways and receptors. The worst case is likely to be represented by a situation where crops are grown within the plume deposition zone, and relatively closer to the source. Potential risks of contamination of soils, and therefore crops, can be checked through monitoring.

8.5.2 *Impacts on water*

8.5.2.1 *Impact of toxins, carcinogens and "exotic" organics on human health*

There is the possibility of long-term impacts arising from direct ingestion of toxic, carcinogenic and "exotic" organic compounds in watercourses contaminated by fire-water runoff, and/or by plume deposition.

The concentrations involved are likely to have been subject to dilution through their contact with fire-water and runoff into watercourses.

The pollutants of concern are summarized in Table 10.

Table 10 — Summary of the key toxins, carcinogens and "exotic" organic compounds monitored during the Ontario fire

Key pollutants	**Impacts** **Measured concentrations**[a] µg/l	**Significance** **EU: MAC**[b] µg/l
Aluminium	11 320	500
Cadmium	336	5
Lead	5 810	50
Nickel	180	50
Zinc	70 500	5 000 (guide level)
Dioxins/furans	210 PG/l TEQ	—
Organophosphates	—	—
PAH	172	200

[a] Maximum concentration measured in the fire-water runoff during the Ontario fire.

[b] MAC: Maximum Admissible Concentration, where no EC [28] MAC value is available the EC guideline value will be given.

Data from the Ontario fire showed that levels of metals were high in the fire-water runoff although these levels decreased with dilution into surface waters and with time. Surface water exceeded local objectives for several metals: Al, Cd, Cu, Pb, Ag, Zn.

Monitoring data from the plastics fire in Ontario revealed very high concentrations of six PAHs in fire-water runoff (including naphthalene, fluorene, phenanthrene and anthracene). As PAHs have low solubility and are formed during incomplete combustion their presence in fire-water runoff was not surprising. Levels of PAHs were observed to be lower in the storm sewer outfalls/surface waters and concentrations declined further with time.

The information available suggests that various pollutants are potentially significant where long-term contamination of drinking-water has occurred. The worst case is likely to be represented by a situation where fire-water runoff transports significant quantities of ash into natural watercourses that are subsequently used for drinking water abstraction.

8.5.2.2 *Impact of toxins, carcinogens and "exotic" organics on freshwater and marine habitats and species and on human populations through the food-chain*

Toxic, carcinogenic, and "exotic" organic compounds in surface waters can directly affect freshwater habitats and species. Marine habitats and species may also be affected, though owing to dilution, the impacts are likely to be diminished.

Key pollutants of concern are summarized in Table 11.

Table 11 — Summary of the impacts of toxins, carcinogens and "exotic" organics on freshwater/marine habitats and species and on human populations through the food-chain as a result of the Ontario fire

Key pollutants	Impacts Measured concentrations[a] µg/l	Significance EU: MAC[b] µg/l
Aluminium	11 320	500
Cadmium	336	5
Lead	5 810	50
Antimony	—	10
Chromium	111	50
Zinc	70 500	5 000 (guide level)
Dioxins/furans	210 pg/l TEQ	—
Organophosphates	—	—
PAH	172	200

[a] Maximum concentration measured in the fire-water runoff during the Ontario fire.

[b] MAC: Maximum Admissible Concentration, where no EC [28] MAC value is available the EC guideline value will be given.

Aluminium accumulates on specialized cells on fish gills that are responsible for maintaining sodium balance. All freshwater animals have a higher salt concentration than the water they live in — if they excrete more salt than they absorb they will die.

On the third day of the Ontario fire [16], elevated dioxin concentrations (up to 5.5 pg/l TEQ) were measured at the outfall to the harbour. Dioxins pose an indirect threat to aquatic life as they can accumulate slowly through the food-chain. One of the main sources of dioxin for humans is consumption of contaminated fish, as well as dairy and beef products.

These results show that some toxins, carcinogens or "exotic" organic compounds can accumulate significantly within aquatic based food-chains. However, insufficient information is presently available to determine the risks of environmental damage, since this depends on the critical sources, pathways and receptors concerned. The worst case is likely to be represented by a situation where simple aquatic based food-chains arise, e.g. fish to man.

9 Experience of large-scale fires involving plastics

9.1 Locations

Plastics materials are used in a large range of applications and fires involving plastics can occur under a range of circumstances and across the "life cycle" of the plastics as listed below.

a) *Manufacturing sites*

The quantities of plastics stored at manufacturing facilities can exceed 20 000 t. Storage is either in stacks or silos (ranging from 25 t to 300 t each).

Usually, only one type of material is stored at these sites and the operators know the composition of the material stored.

b) *Distribution sites*

Distribution sites typically have up to 2 000 t material stored. Some sites store only one type of material. Others offer a range of materials. Storage is mainly in stacks.

As with the manufacturing sites, site operators are aware of the exact composition of the materials stored.

c) *Converters*

Converters typically use plastics materials that contain additives (e.g. flame retardant, colourant, plasticizer). Their storage facilities rarely exceed 1 000 t. All types of materials are found: plastics, additives and finished products, and packaging materials such as paper, cardboard or wood (pallets). Site operators do not necessarily know the exact composition of their materials.

d) *Retailer, commercial outlets*

Commercial outlets and retailers store all types of plastics. As thousands of different types of material can be stored on the same site, operators do not generally know the composition or the exact quantity of each type of material.

e) *Recyclers*

Plastic products are increasingly being recycled and recycling centres have responded by increasing their storage facilities. Presently, storage capacity at these sites is not more than 1 000 t. The materials most often found at a recycling site are the recyclable plastics and rubber products, i.e. mainly the polyolefins (PE, PP), polyvinyl chloride (PVC), polyethylene terephthalate (PET), acrylonitrile–butadiene–styrene (ABS), and polycarbonate (PC).

9.2 Examples

9.2.1 *Manufacturing site*

On 9 October 1995, a fire occurred in a warehouse of a polypropylene producer at the Wilton site in Cleveland (UK). It occurred in a large building with dimensions 100 m × 200 m, which contained approximately 10 000 t of materials, stored on pallets. Some products were also stored in an open storage area next to the building.

The building comprised a steel frame, brick walls and a concrete floor. Plastic light diffusers made of poly(methyl methacrylate) (PMMA) were used in the lighting system. Rooms were separated by sliding doors. The building was part of a chemical production site, which contained various storage and production facilities, including an organic peroxide store.

The cause of the accident appeared to be a malfunction in the electrical lighting system leading to overheating of a PMMA light diffuser. This ignited, and the flaming droplets ignited polypropylene that had been stacked underneath the light. The fire detectors on the sliding doors failed to operate and so the fire was not detected until it was well established. When fire brigades arrived at the scene, the fire was already well developed.

With a strong wind and open loading-bay door, oxygen supply was unlimited. As the polypropylene melted, it dripped and ran whilst burning; this contributed to the spread of the fire. Roof lights also ignited, and this assisted in spreading the fire further via flaming droplets. Burning debris was carried by the wind toward the outside storage area, which easily ignited and burned.

The fire was finally brought under control and extinguished, and did not burn itself out. The fire-fighting operations lasted eight hours and involved 200 fire-fighters. A strong wind was the main factor in hampering fire-fighting efforts.

The predominant materials involved in the blaze were polypropylene and building and construction materials.

Polypropylene is an olefin plastic (i.e. composed of hydrogen and carbon). It burns very easily and with a high temperature. In some places of the building, steel frames disappeared suggesting that the temperature at these locations was higher than 1 500 °C.

9.2.1.1 *Air*

Despite the occurrence of a large, black plume of smoke, there was no evidence of any environmental impacts resulting from air-borne emissions, immediately after the fire. The weather conditions of that day allowed slow vertical and moderate horizontal dispersion. There were no sensitive natural areas (pasture, lake etc.) in the surroundings.

9.2.1.2 *Water*

The water runoff entered the drainage system of the Wilton complex. The effects of the fire were, most likely, diluted in the site drainage system by the large volume of water used to extinguish the fire.

9.2.1.3 *Soil*

No information was found concerning the possibility of soil contamination from the smoke plume and soot deposition. As the fire occurred in a large industrial area, it is assumed that any local soot deposition was washed toward the drainage system.

9.2.1.4 *Conclusion*

It would appear from the evidence available that this incident had no measurable impact on the environment, nor on the health of locals. This was due to the elemental composition of polypropylene and the weather conditions at that time, which allowed for good atmospheric dispersion of the pollutants.

9.2.2 ***Storage sites (converters)***

Following a fire at a polyethylene storage facility in Harlow, Essex on 25 February 1994, the Institute of Terrestrial Ecology [20] analysed the heavy metal contamination (lead, cadmium and zinc) of a grassland site adjacent to the fire. The analysis was based on samples collected one day after the fire. In total, 1 000 t of materials were destroyed during the blaze. Levels of contamination measured were up to 4.5 times higher than normal background levels.

Soil and water runoff analysis was performed following a fire at a warehouse in Langer, Nottinghamshire on 3 April 1994, containing 1 000 t of cling film (plasticized PVC [20]). Samples were collected both from the drainage ditch and the stream along side it. The results showed levels of contamination with antimony (Sb) downstream of the site. Soil analysis of samples collected under the direction of the plume after it had dispersed did not reveal significant contamination with antimony.

9.2.3 ***Recycler site — Example 1***

9.2.3.1 *General*

On 9 July 1997, a fire occurred at a plastics recycling facility in the urban area of Hamilton, Ontario, Canada. The fire began about 7.45 p.m. on 9 July and ended in the morning of 12 July.

The Ontario Ministry of Environment and Energy (MOEE) has produced a detailed report on the environmental impact of the fire as a result of contaminants released. The complete report can be downloaded free of charge from their Web site [30].

A minimum of 400 t of poly(vinyl chloride) and polyurethane foam was destroyed in the blaze. Initially the fire resulted in a dense black cloud of smoke rising hundreds of metres into the air before the wind transported the plume over the centre of the city. A strong night-time temperature inversion resulted in reduced rise of the plume from the fire, which increased the impacts around the fire site.

A number of hazardous substances were emitted during the fire. These included emissions directly to air, and indirectly to water (runoff from the site) and land (soot and other atmospheric deposition to soil, surfaces and vegetation). However, no long-term or environmental health effects are expected to occur as a result of the fire. The emission of HCl caused metal corrosion reported in the area close to the fire. Owing to an atmospheric thermal inversion during the incident, the plume height was low, causing local inhabitants to report to the Emergency Departments of the nearby hospital complaining of respiratory difficulties. It also led to the evacuation of 4 000 people.

9.2.3.2 *Releases to air*

During the course of the fire, concentrations of several volatile organic compounds (VOCs) in air in the vicinity were above normal, including benzene, vinyl buta-1,3-diene, chlorobenzene, styrene, toluene and naphthalene. Only naphthalene exceeded the Provincial air standard guideline [30] for VOCs during the fire. After the fire was extinguished, VOC concentrations dropped back to normal urban levels, except for xylene near the site, which was detected at a level well below the Provincial standard.

The concentration of hydrogen chloride in the smoke during the fire was elevated, frequently in excess of the MOEE's guideline [30] in the adjacent area. Elevated instantaneous readings were measured as far away as the mountain brow. Levels returned to normal soon after the fire was out.

The concentrations of nickel, lead and chromium in the smoke in the vicinity of the fire were above normal during the fire, with some samples exceeding Provincial ambient air quality criteria [30]. Samples taken at locations further downwind showed normal concentrations of these metals, although these latter samples contained only brief downwind exposures.

Levels of dioxins in air were higher than normal during the fire, exceeding the MOEE ambient air quality criteria on the first day of the fire, but rapidly declined to normal Hamilton background levels after the fire was extinguished. Polynuclear aromatic hydrocarbon (PAH) levels in the fire plume itself were quite high compared with the levels normally found in Hamilton air [30]; however, PAH levels further downwind at regular monitoring stations were normal [30] and below the ambient air quality criteria (for benzo[α]pyrene). PAHs in air near the fire site declined to normal levels after the fire was extinguished.

Polychlorinated biphenyls (PCBs) were detected in air immediately adjacent to the fire (but within the plume), however these were at levels below the MOEE's 24-hour ambient air quality criteria.

Because of the short duration of exposure, no long-term adverse health effects are anticipated as a consequence of exposure to contaminants from the fire in the air. Many acute short-term symptoms were reported from those exposed, e.g. skin irritation, eye irritation and sore throat. In addition, incidents of metal corrosion are attributable to hydrogen chloride released during the fire.

Air contaminant levels during the fire were below the occupational health limits [30], which are often used in emergency response situations to determine the risk of immediate adverse health effects

9.2.3.3 *Soot deposition*

Soot deposited on surfaces was analysed for dioxins and metals. Dioxin levels in soot were far below established clean-up guidelines and posed no health threat to residents. Several metals were detected in soot samples taken from areas both near to and distant from the fire, including nickel, chromium, zinc, copper, manganese, vanadium, iron and lead. The lead, which was of greatest concern in terms of toxicity, was in fact not detected in soot sampled at the location that had the greatest amount of soot deposited by the fire. Conversely, the highest lead level was found in soot at an industrial site over two kilometres away.

9.2.3.4 *Releases to water*

Analyses were done on water from site runoff, storm sewers, sewer outfalls to Hamilton Harbour and in the harbour's Wellington Street slip. Levels of some metals, volatile organic chemicals and PAHs were high at times in the site runoff (fire-fighting water). The levels were lower in the storm sewer outfalls and still lower in Hamilton Harbour surface water, and they declined with time. Where detected in surface waters, most of these substances were present at low concentrations. The Provincial Water Quality Objective (PWQO [30]) for the PAH phenanthrene was exceeded in Hamilton Harbour. Dioxins were also found, but at very low levels. Surface water in the Wellington Street slip also exceeded PWQOs for several metals after the fire, namely, aluminium, cadmium, copper, lead, silver and zinc. By 15 July, concentrations of most of the 65 chemicals were within reported ranges for Hamilton Harbour [30] and most were below their PWQO. PWQOs aim to provide protection to aquatic life over long-term exposure; short-term exposures resulting from the fire should not pose any long-term threat to aquatic life in the harbour. Hamilton's drinking-water, which is drawn from some distance out in Lake Ontario, was not affected.

Aquatic bioassays demonstrated that the storm sewer water was lethal to aquatic life (rainbow trout and *D. magna*). However, there was no evidence of fish being killed in Hamilton Harbour. Furthermore, storm sewer water sampled upstream of the fire site was lethal to both test species, indicating that the toxicity was due to substances in the sewer unrelated to the fire. Lasting impacts from runoff from the fire are unlikely since most measured chemical concentrations are now back within reported normal ranges [30], and most are lower than the Provincial Water Quality Objective [30].

9.2.3.5 *Releases to land*

The fire did not have a measurable impact on soil dioxin levels. All soil dioxin levels were within a range typical of an urban environment [30] and substantially below the MOEE's health-based soil clean-up guideline [30]. Soil PAH contamination at one particular site was found to be too high to be related to the fire, and was most likely due to historical contamination at that site. Marginally elevated soil PAH levels at two other sites near the fire site may have arisen as a consequence of the fire. Marginally elevated levels of one PAH, phenanthrene, in street tree foliage at three sites was also likely to have arisen as a consequence of the fire.

The fire had no measurable impact on metal concentrations in soil and on vegetation. The fire resulted in dioxin levels on street tree foliage that were between two and three times higher than normal [30] for an Ontario urban community to a distance of about three residential blocks from the fire site. The dioxins were present mostly as a surface deposit and were readily washed off by rain. After one week the highest foliage dioxin levels had been reduced to within the range typical of an urban environment [30]. Dioxin levels on street tree foliage fell by more than 80 % in the two weeks following the fire, confirming that most of the dioxins that landed on all types of vegetation were in the form of surface-deposited dust and soot, which readily washed off or rapidly photodegraded.

Sampling of residential gardens revealed no detectable dioxin (detection limit 1 pg/g) in vegetable produce in the areas of highest soil and tree foliage dioxin concentrations and in areas where soot fallout was documented. There was no relationship between dioxin levels in lawn grass and distance from the fire site or areas of substantial soot fallout.

The community response sampling of 20 residential properties conducted in August confirmed that one month after the fire there was no measurable residual dioxin contamination of soil and vegetation, including home garden produce. A health assessment by MOEE toxicologists concluded residential garden vegetables were safe to eat and that there was no health risk to children playing in backyards and parks. Normal use of property has not been affected.

9.2.4 *Recycler site — Example 2*

A fire occurred in a plastics recycling plant in Thetford, Norfolk, UK on 11 October 1991. The burning lasted four days and released toxic gases. Plastics stored on the site included 600 t of PVC and 400 t of non-chlorinated plastics (PE, PET, PP, PS and ABS). Almost five years after the incident, Institute of Terrestrial Ecology staff measured an elevated range of dioxins and furans (by up to four fold) on soil adjacent to the factory compared with a site 200 m from the factory perimeter. These residues were absorbed into the wood-mouse food-chain, and appeared to cause a relative increase in liver weight compared with similar animals caught on a relatively uncontaminated site. In addition, Chang *et al*. [31] observed a transfer of a range of dioxin and furan congeners from soil to farm animals (chicken and beef), following atmospheric deposition after a chemical fire.

It has been revealed that cadmium released from the fire was bioavailable to all trophic levels within the ecosystem studied (woodland). Cadmium was also found at elevated concentrations in wood mice and bank voles, showing its mobility through the food-chain. The effect of cadmium at the higher trophic levels (small mammals) is thought to have been minimal, but at lower trophic levels (invertebrates, i.e. earthworms), it has been observed to have had measurable effects.

Evidence was found to support the theory that persistent residues of dioxins and furans generated as a consequence of the fire, entered the food-chain, resulting in physiological damage to the wood-mouse population some five years after the original fire occurrence. Evidence has also been found illustrating the bioavailability of cadmium to local fauna. Cadmium was found through the food-chain with measurable effects being observed at lower trophic levels.

10 Mitigation measures

10.1 General

The potential for environmental impact from a large-scale plastics fire is dependent on a variety of factors, such as:

a) the plastics involved in the fire;

b) the likelihood of fire initiation and development;

c) the conditions under which the fire develops;

d) meteorological conditions affecting the fire plume and the dispersion of fire decomposition products;

e) site location/topography affecting the fire plume dispersion and the fire-water runoff;

f) the potential pathways by which fire decomposition products can transfer and accumulate within the environment; and

g) potential human or natural ecosystem receptors.

Four main zones of impact have been identified that allow the effects of both topographical and meteorological effects to be accounted for:

1) the fire zone, within the burning building itself;

2) the fire plume zone, the area around the burning building within which the emissions plume is dispersing;

3) the plume deposition zone, the area under the fire plume where significant pollutant deposition has occurred;

4) the surface water runoff zone, where water potentially carrying breakdown products from the fire (including ash/soot) drains and/or accumulates.

10.2 Ignition scenarios

The first and most important mitigation technique is prevention. A way of preventing incidents is to identify ignition scenarios. The following are the most common sources of ignition.

a) *Deliberate ignition — arson*

Warehouses are often targets of deliberate ignition. Some reasons for arson may include burglary, vandalism, insurance frauds or revenge. Arsons occur mainly at night, during the weekends and in the early hours of the morning. Those responsible vary in age and in many instances are former or even current employees unhappy with management decisions. In some cases, political groups are the cause of arson, motivated by the political stance of activities pursued by the owner of the premises. The Loss Prevention Council's *Design Guide for the Fire Protection of Buildings* [32] presents a methodology for assessing the risks of arson.

b) *Naked flames*

Open flames should not be permitted in a storage area and, wherever possible, should be replaced by alternative processes (e.g. indirect heating). Manufacturing processes, such as flame bonding, should be properly controlled and best practice would be to relocate these activities to another building away from the storage area.

c) *Hot surfaces*

Fixed or portable solid fuel, gas, or oil-fired heater units should not be located within a storage building. Electric heaters, unprotected light bulbs and any electrical devices producing heat (e.g. electric motors) should be located a safe distance from material stacks.

d) *Hot works, cutting and welding*

Maintenance work, such as welding and disc-cutting, should be strictly controlled. It is generally recommended that all flammable materials, such as plastic stacks or packaging, be removed from the vicinity in which such work is being carried out. Fire extinguishers should also be placed close to hand during any such work. Special attention should be paid to the possibility of sparks produced by cutting or grinding equipment.

e) *Electrical equipment*

This should be adequately protected, kept clean and maintained regularly.

f) *Internal transport vehicles*

Road vehicles should not be allowed in the storage area. Where possible, it is recommended that electrical vehicles be used within the vicinity of premises where quantities of plastics and rubbers are stored. In such cases, the charging-stations of these vehicles should be outside the building.

g) *Smoking*

The storage area should be a non-smoking area with provisions in place to ensure that non-smoking is strictly enforced. A specific smoking area with ashtrays should be provided for smokers, to discourage the flouting of the smoking ban.

h) *Housekeeping*

Premises should be kept clean. Waste should be removed frequently and kept in closed metal containers. These containers should be situated away from possible ignition sources and should be emptied frequently.

i) *Incoming goods*

Cardboard and fibre bales, which could support smouldering combustion, should be inspected before being allowed onto the premises.

10.3 Storage technique

10.3.1 *General*

Storage layout and management is a key factor in reducing fire growth and in controlling the spread of a fire. More detailed information on basic precautions for indoor and outdoor storage can be found in the leaflets published by The Fire Prevention Association (FPA) [33].

10.3.2 *Outdoor storage*

The following general rules should apply at any storage facility.

a) The premises should be fenced to prevent intrusion. Large access gates should be kept clear at all times to allow fast and easy access to the premises.

b) Rubbish and recycling containers with papers, cardboard, wood, plastics or any other flammable materials should be kept away from the fence and from the material stacks.

c) Stacks of plastics should not be more than 6 m high and should be located at least 9 m away from buildings in which hazardous processes are performed, 9 m from other buildings and 2 m from the fence. There should be a minimum of 3 m around stacks to allow easy access for inspection or fire-fighting.

d) Smoking should not be allowed within the premises or should be kept in a designated area, away from the stacks.

e) The use of flame-producing appliances or appliances which are heat producers should not be allowed in the storage area. When their use is necessary, the stacks of plastics should be moved as far as possible from the place of use and adequate precautions should be implemented to protect them.

10.3.3 *Indoor storage*

The following recommendations are made for indoor storage areas.

a) Automatic fire detection systems should be installed and comply with BS 5839-1:1988.

b) Automatic sprinkler systems are particularly effective in detecting, and reacting instantaneously to a fire. Their fitting should comply with BS 5306-2:1990.

c) Gangways between stacks and racks should be at least 1 m wide and be kept free of obstacles (e.g. waste-bins).

d) The height of stacks should not exceed the recommended stack height limit, particularly within premises with sprinkler systems.

e) Electrical apparatus (space heating, lighting, alarm bells etc.) should be kept away from materials in storage.

10.4 Training

Staff training is a key element in the event of an incident occurring. It is essential not only for their safety but also because their action could help to reduce the likelihood of a fire spreading. Staff training should at least cover the following issues.

a) What to do when a fire is discovered.

b) Where and how the alarm should be raised.

c) What to do on hearing the alarm.

d) How to call the fire brigade.

e) How to use the fire-fighting equipment and where to find it.

f) How to evacuate the premises.

g) The location of the muster stations.

h) How to switch off industrial machines and power supplies correctly.

10.5 Assessing the risks

To assess the fire hazards from solid materials refer to the guidance document published by the Home Office [1].

10.6 Mitigation measures during and following a fire

A summary is given in Table 12 of the key impacts and mitigation and monitoring measures recommended.

Table 12 — Summary of key impacts and mitigation measures

Potential impacts	Mitigation and monitoring measures
Plastics fires can produce releases to air within the fire plume zone, which are very toxic to human health through air exposure.	All people should be moved out of the fire plume zone, or if this is not possible, kept indoors where ventilation to the outside is minimized. Appropriate and methodical sampling regimes should be used to assess the risk.
High irritant levels (e.g. acrolein and hydrogen chloride) in the fire plume zone affecting human health through air exposure.	Move sensitive people (particularly children and the elderly) out of the fire plume zone or keep them indoors and ventilation to the outside has been minimized.
Local fire-water runoff contaminated by various pollutants is potentially hazardous to human health (via direct ingestion, though this remains unlikely).	Fire-water runoff produced directly from a fire site that has not been subject to dilution should be treated as hazardous and contained if possible.
Fire-water runoff into local watercourses may affect aquatic species in the receiving surface waters.	Precautions should be taken to divert fire-water runoff away from natural watercourses.
Contamination of soils through deposition of toxins or carcinogens (largely by heavy metals and PAHs) and long-term accumulation within food crops and dairy/beef products.	The potential risks of soil contamination following a fire can be determined through monitoring. If levels are found to be high, then remedial action is recommended.
Contamination of soils through deposition (dioxins/furans and organophosphates) and long-term accumulation within food crops and dairy/beef products.	The potential risks of soil contamination following a fire can be determined through monitoring. If levels are found to be high, then remedial action is recommended.
Abstraction of drinking-water from remote contaminated watercourses over longer time frames (potentially contaminated by heavy metals, dioxins/furans, organophosphates and PAHs).	Precautions should be taken to check and monitor abstraction points along affected watercourses.
Contamination of aquatic ecosystems over longer time frames (by heavy metals, dioxins/furans, organophosphates and PAHs) which may accumulate within aquatic based food-chains.	The potential risks of longer term water contamination following a fire can be determined through monitoring. If levels are found to be high, then remedial action is recommended.
Fugitive emissions during ash handling and disposal.	Precautions should be taken to minimize fugitive emissions from ash during handling and disposal. Plans should be made for the evacuation of surrounding areas.

Annex A (informative) Overview of relevant regulations and guidance documents

A.1 The Fire Precautions Act 1971

The Fire Precautions Act 1971 [34] requires the owner or occupier of premises such as factories, offices, shops and railway premises to obtain a fire certificate. A fire certificate is required if there are:

a) more than twenty people working in the same building at the same time; or

b) more than ten people working in the same building at the same time, excluding those employees working on the ground floor; or

c) factory premises where flammable or explosive substances are stored in or under the factory.

In cases of low fire risk, it is possible to be exempt from this requirement (see The Fire Safety and Safety of Places of Sport Act 1987 [35]).

The Framework Directive (89/391/EEC) [36] and the Workplace Directive [37] assign responsibility to the employer for ensuring health and safety in the workplace, making reference to the role to be played by fire risk assessments. Employers' health and safety responsibilities include the need to assess the possible risks resulting from a fire.

The EU Directives dealing with fire safety have been implemented in the UK through the Fire Precautions (Workplace) Regulations 1998, as amended 1999 [38]. These are supported by the Home Office Guidance on Workplace Regulations, 1999 [39].

A.2 The Building Regulations 1991

These regulations apply to new and altered buildings in England and Wales and have been made under the Building Act 1984 [40]. They specify procedures, including fire safety requirements, concerning health and safety of people in buildings. Guidance on how to meet the requirements of the Building Regulations 1991 [55] is given in Approved Document B: Fire Safety, 2000 [41].

A.3 Health and Safety at Work

The Health and Safety at Work Act 1999 [42] places an obligation upon employers to provide and maintain working conditions that are safe and without risk to the health of employees, so far as is reasonably practicable. The scope of the Health and Safety at Work Act 1999 [42] extends to the storage of highly flammable materials, the control of flammable vapours and dusts, standards of housekeeping, safe systems of work and the control of sources of ignition.

The obligations of employers concerning the implementation of the Health and Safety at Work Act 1999 [42] are stipulated in The Management of Health and Safety at Work Regulations 1992 [43] (the Management Regulations). These Regulations apply to all work activities, as does the Health and Safety at Work Act 1999 [42] itself.

The Management of Health and Safety at Work Regulations 1992 [43] (the Management Regulations) place a requirement upon employers to undertake a risk assessment. For those companies with five or more employees, significant risks must be recorded in the risk assessment. Undertaking a risk assessment for an office is relatively straightforward. However, for activities such as those that occur at a nuclear power station or chemical plant, the risk assessment procedures are much more onerous.

The Control of Substances Hazardous to Health Regulations 1994 [7] (COSHH) requires employers to prevent exposure of workers to hazardous substances or, in those cases where this is not possible (e.g. a laboratory), to ensure that adequate procedures are in place to maintain control. COSHH [7] requires employees to comply with control measures and, where appropriate, to record any weaknesses in the systems in place to their employer.

A.4 Seveso II Directive

The Control of Major Accident Hazards Regulations 1999 (COMAH) [3] have been issued to implement the Seveso II Directive (96/082/EC) [2] which aims to minimize the consequences to people and the environment where accidents have occurred. COMAH [3] replaces the Control of Industrial Major Accident Hazards (CIMAH) Regulations 1984 [44], implemented following the first Seveso Directive.

Responsibility for implementing the Seveso II Directive [2] lies jointly with the Department of the Environment, Food and Rural Affairs (DEFRA) and the Health and Safety Executive (HSE). The Seveso II Directive applies to a wide range of activities including the storage, use and manufacture of large quantities of dangerous chemicals. It places additional responsibility on operators of establishments to document their major-accident prevention policy and to ensure that it is properly implemented (article 7). Operators are also required to produce a safety report to document those procedures put in place to prevent major accidents or, in those instances where accidents have occurred, to limit their consequence for man and the environment. Such safety reports shall be made publicly available.

A.5 DETR guidance on Seveso II Directive

A guidance document on the Seveso II Directive has been written by the Institute of Terrestrial Ecology for the DETR [45]. This will assist users in interpreting and implementing the Directive. It is expected that the revised guidance will help operators and regulators to:

a) clarify what constitutes a major accident to the environment;

b) indicate what constitutes a long-term or significant consequence for the environment of a potential or actual accident;

c) identify sources of information about the environment that can be gathered at a scale appropriate to a site-based regulatory regime; and

d) understand the relationship between the Seveso II Directive and the provisions of other pieces of legislation concerned with protecting or enhancing environmental quality.

A.6 HSE guidance documents

The Health & Safety Executive publishes a number of documents aimed at assisting site operators to fulfil their obligations. These include the following.

Guidance Note EH 70, *The control of fire-water runoff from CIMAH sites to prevent environmental damage* [46]. This document provides guidance to help operators of CIMAH sites with putting arrangements in place to deal with water used to fight fires on their sites. It outlines the basic fire precautions, the emergency planning (risk assessment) and the control measures to be taken if the risk assessment indicates that the fire-water runoff might cause damage to the environment.

Guidance Book HSG 92, *Safe use and storage of cellular plastics* [47]. This document provides guidance on the control of fire hazards arising from cellular plastics. It is aimed at manufacturers, converters, users and occupiers of storage premises.

A.7 Other guidance documents

Fire Safety — An Employer's Guide [48].

Chemical Industries Association (CIA): *Guidance on chemical warehouse fire safety — Key questions for managers concerned with the protection of warehouses against fire* [49]. This document is a questionnaire intended to prompt managers to review their own arrangements in key areas of warehouse fire safety.

Loss Prevention Council: Report SHE 14 1997, *Assessment of pollution risks* [50]. The procedure outlined in this report provides a framework for developing cost effective systems for assessing pollution risks: 1) occurring on a particular site; and 2) having off-site consequences which are always location-specific and often related to geographical features.

The Fire Protection Association: *Guide to Building Fire Protection* [33]. This document provides an overview of the key factors affecting fire safety in industry and commerce for those responsible for buildings.

The Fire Protection Association: *Fire Risk Management in the Workplace* [51]. This document provides guidance on methods of fire risk assessment, and analysis of such assessment to reduce the risks and improve fire safety.

The Fire Protection Association: *Fire Safety Data: Housekeeping and General Fire Precautions* (GP6) [52].

The following documents give guidance on good practices for storage management.

DETR, *Environmental sampling after a chemical accident* [53].

Chemical incident response service, Guy's & St Thomas' NHS Trust, *Chemical incident management for local authority environmental health practitioners* [54].

Environment Agency. *Managing fire water and major spillages*. Pollution Prevention Guidelines 18 [11].

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Standards Publications

ISO/TR 9122-1:1989, *Toxicity testing of fire effluents — Part 1: General.*

ISO/TR 9122-2:1990, *Toxicity testing of fire effluents — Part 2: Guidelines for biological assays to determine the acute inhalation toxicity of fire effluents (basic principles, criteria and methodology).*

ISO/TR 9122-3:1993, *Toxicity testing of fire effluents — Part 3: Methods for the analysis of gases and vapours in fire effluents.*

ISO/TR 9122-4:1993, *Toxicity testing of fire effluents — Part 4: The fire model (furnaces and combustion apparatus used in small-scale testing).*

ISO/TR 9122-5:1993, *Toxicity testing of fire effluents — Part 5: Prediction of toxic effects of fire effluents.*

ISO/TR 9122-6:1994, *Toxicity testing of fire effluents — Part 6: Guidance for regulators and specifiers on the assessment of toxic hazard in fires in buildings and transport.*

Other Publications

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