
**Guidelines for assessing the adverse
environmental impact of fire effluents —**

**Part 1:
General**

*Lignes directrices pour déterminer l'impact environnemental des
effluents du feu —*

Partie 1: Généralités



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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 26367-1 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 3, *Fire threat to people and environment*.

ISO 26367 consists of the following parts, under the general title *Guidelines for assessing the adverse environmental impact of fire effluents*:

— *Part 1: General*

Components from fires in the built environment, open storage and transport is to form the subject of a future Part 2.

Introduction

In view of the fact that relevant quantitative data on environmentally hazardous components of fire effluents cannot routinely be obtained from accidental fires, appropriate data may also have to be obtained from real scale fire tests and simulations involving physical fire models.

General awareness of the fact that large fires present dramatic and persistent adverse effects on the environment has been accentuated by a number of high-impact incidents over the past half-century. Annex A contains a list of major fire incidents in recent years.

The serious consequences of such events have confirmed that the environmental impact of fires is a pressing international issue that urgently needs to be dealt with globally and systematically. This part of ISO 26367 provides a framework for a common treatment of the environmental impact of fires in answer to this pressing need.

It is principally intended for use by the following parties:

- fire-fighters and investigators;
- building owners and managers;
- storage facility operators;
- materials and product manufacturers;
- insurance providers;
- environmental regulatory authorities;
- civil defence organizations;
- public health authorities.

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Guidelines for assessing the adverse environmental impact of fire effluents —

Part 1: General

1 Scope

This part of ISO 26367 gives guidelines whose primary focus is the assessment of the adverse environmental impact of fire effluents, including those from fires occurring in commercial and domestic premises, unenclosed commercial sites, industrial and agricultural sites, as well as those involving road, rail and maritime transport systems. Its scope does not extend to direct acute toxicity issues, which are covered by other existing International Standards.

It is intended to serve as a tool for the development of standard protocols for

- a) the assessment of local and remote adverse environmental impacts of fires, and the definition of appropriate preventive measures,
- b) post-fire analyses to identify the nature and extent of the adverse environmental impacts of fires, and
- c) the collection of relevant data for use in environmental fire hazard assessments.

This part of ISO 26367 is intended as an umbrella document to set the scene concerning *what* should be considered when determining the environmental impact of fires. It is not a comprehensive catalogue of methods and models defining *how* to determine the environmental impact of fires, intended to be addressed by other parts of ISO 26367.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13943, *Fire safety — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943 and the following apply.

3.1 environment
surroundings within which a fire occurs, including air, water, land, natural resources, flora, fauna and humans, and their interrelation

NOTE 1 Adapted from ISO 14001[2].

NOTE 2 For the purposes of this part of ISO 26367, "the environment" includes the following:

- *local*: within the perimeter of a burning enclosure (this part of ISO 26367 is not applicable to burning enclosures);
- *immediate*: vicinity within a short distance of, e.g. 1 km from the fire and excluding the local area of an enclosure fire.
- *external*: area outside the immediate vicinity of a fire; the extent of this depends on weather conditions and types of emission, i.e. to air, water or land, with short-term or long-term consequences.

3.2 environmental impact
any change to the environment, whether adverse or beneficial, wholly or partially resulting from a fire

NOTE 1 Adapted from ISO 14001[2].

NOTE 2 In this part of ISO 26367 it is used to signify an *adverse* change to the environment.

3.3 major accident
significant 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 environmentally hazardous materials

3.4 fire effluent
all gases and aerosols, including suspended particles, created by combustion or pyrolysis

NOTE It also refers to run-off water generated during fire-fighting activities.

3.5 primary fire effluent
effluent released directly from the fire source

3.6 receptors
segments of the environment on which fire effluents can have an impact, including air, water, and soil environments, plus flora and fauna associated with these environments, including humans

3.7 secondary fire effluent
effluent created through interaction between a primary fire effluent and the environment

3.8 run-off
fluid effluent created through the interaction between a fire and a liquid extinguishing agent and hazardous materials stored or generated on site

3.9**enclosed fires**

fires which have been ignited and which take place inside an enclosure

NOTE This term is particularly important when defining the ventilation conditions in the fire.

3.10**fires in ruptured enclosures**

fires in enclosures that have been breached and that allow unrestricted emission of the fire smoke plume for environmental distribution

NOTE Fire-fighting tactics in this type of fire are, in some cases, similar to those for an enclosure fire, even though emissions and environmental effects are similar to those for a fire in the open.

3.11**unenclosed fires**

fires which initiate and propagate in the open air and those which initiate and propagate within an enclosure that subsequently ruptures and transforms the fire in terms of ventilation conditions and effluent transport mechanisms

4 Fire effluents**4.1 Overview**

The interaction between a fire and its surroundings or environment is illustrated in Figure 1, which shows how fires cause harm to the environment through

- direct gaseous and particulate emissions to the atmosphere,
- spread of atmospheric emissions,
- deposition of atmospheric emissions,
- soil contamination, and
- ground and surface water contamination.

NOTE The contamination can be due to emissions from the fire itself or those associated with the fire-fighting activities, which was the cause of the greatest environmental impact at the fire in the chemical facility in Basel, Switzerland in 1986 (see Annex A).

Interaction through thermal radiation is not included in Figure 1. In the case of sensitive environments, this effect should also be taken into account.

The effect of these various emissions depends in part on the transfer mechanism — for example, the emission of gaseous species and the effect of weather or the emission of contaminated fire-fighting water and its interaction with the drainage system — and on the specific species, i.e. small gaseous compounds, large particles and the range of species in between. It should also be noted that emissions can undergo chemical changes after emission, e.g. chemical modification of nitrogen oxides (NO_x) in the atmosphere due to ultraviolet (UV) light.

A wide variety of toxic effluents (both primary and secondary) are emitted in fires. These effluents can follow a number of pathways to impact on human, animal or plant receptors. Even for industrial sites, risk assessments cannot take into account all potential impacts, but contingency planning should take account of appropriate “worst-case” scenarios.

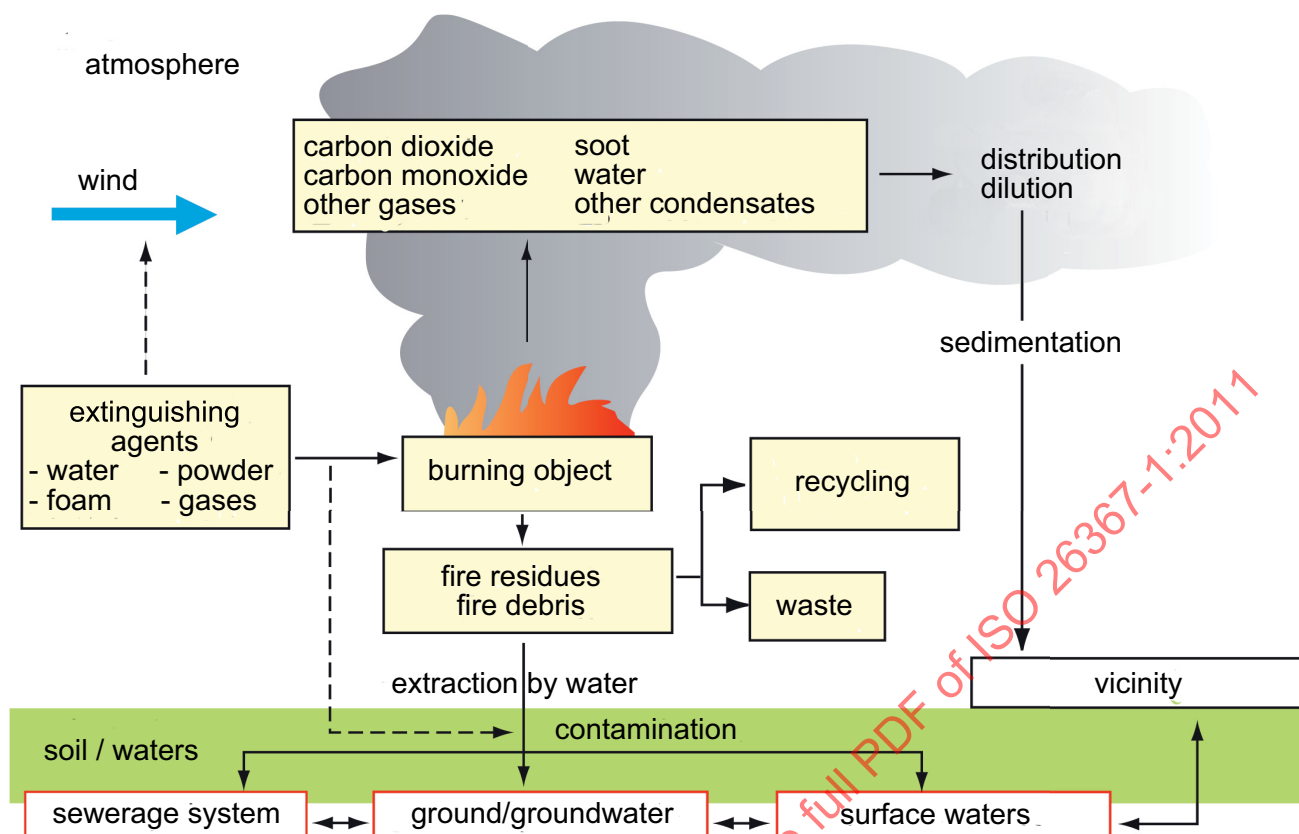


Figure 1 — Emission pathways from fires

4.2 Effluent generation

Initial decomposition is generally through pyrolysis, by which materials are broken down by heat to yield a range of organic by-products that provide the volatile fuel for combustion.

The elemental composition of materials provides guidance when predicting the combustion or decomposition products that can be generated during a fire. The molecular composition or structure of a polymer can affect combustion efficiency and the mix of organic and inorganic combustion products generated in a fire.

NOTE 1 BS 7982^[8] gives guidance on the environmental impact of large fires with polymers.

The relative yields of the various combustion and pyrolysis compounds depend mainly upon the combustion conditions. 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, having a high air/fuel ratio, provide more efficient combustion conditions than vitiated fires. In the context of potential impacts to the environment, large, ventilation-controlled flaming fires are potentially the most environmentally harmful. In an event it is important to consider what is being produced at any given stage in the fire and how this can be emitted to the environment. For example, species produced under low-temperature conditions in the later stages of a fire combined with a reduced plume height can represent a greater local hazard than those produced under high temperature conditions during the early stages, despite the fact that the yield of species could be higher during those early stages. A possible response to this could therefore be to allow a fire to initially burn and commence fire-fighting once the fire begins to die down. The advantage of such an approach is that it would allow less fire-fighting water to be used, thereby making containment easier.

NOTE 2 Guidance on these issues is intended to be provided in subsequent parts of ISO 26367.

Recent investigations of emissions from fires indicate that, whereas gases such as CO, CO₂, HCN, NO_x and other irritants are most important from an acute toxicological point of view, organic species of high molecular weight and aerosols, e.g. particulate matter, polycyclic aromatic hydrocarbons (PAHs) and dioxins, are most significant from an environmental point of view.

NOTE 3 The absolute and relative concentrations of species will depend on the ventilation conditions and chemical make-up of the fuel.

NOTE 4 Molecules adsorbed on particles can be environmentally significant even when distant from the fire. Examples include HCl or dioxins adsorbed on particles.

NOTE 5 Water containment issues are to be dealt with in a document under preparation.

The products of combustion interact with the environment through direct emission to the air or through contamination of surface or groundwater and soil. These three emission pathways are discussed in more detail in 4.4 to 4.6.

It needs to be noted that the contamination of the surface or groundwater and soil is potentially compounded by the presence of physical fire debris, unburned products, and fire-fighting agents.

4.3 Fire stages

4.3.1 Background

Large-scale fires are complex events whose behaviour depends on many parameters, including the level of ventilation, fire load, the presence or absence of an enclosure and the burning properties of the combustible materials.

Emissions to the environment are generally more restricted in an enclosure fire than in the case of a fire in the open, owing to the potential for natural containment of fire effluents and fire fighting agent within the structure.

4.3.2 Enclosed fire

There are four main stages of fire development within an enclosure, as shown in Figure 2 which represents a fire development that assumes no intervention by fire-fighters or active fire protection systems such as sprinklers. *Flashover* (see Figure 2) refers to the stage in the fire when rapid growth occurs from a small, well-ventilated fire to a fully developed fire. Flashover in an enclosure can be described based on the temperature of the hot gases, the heat release rate relative to the size of the room or some other parameter.

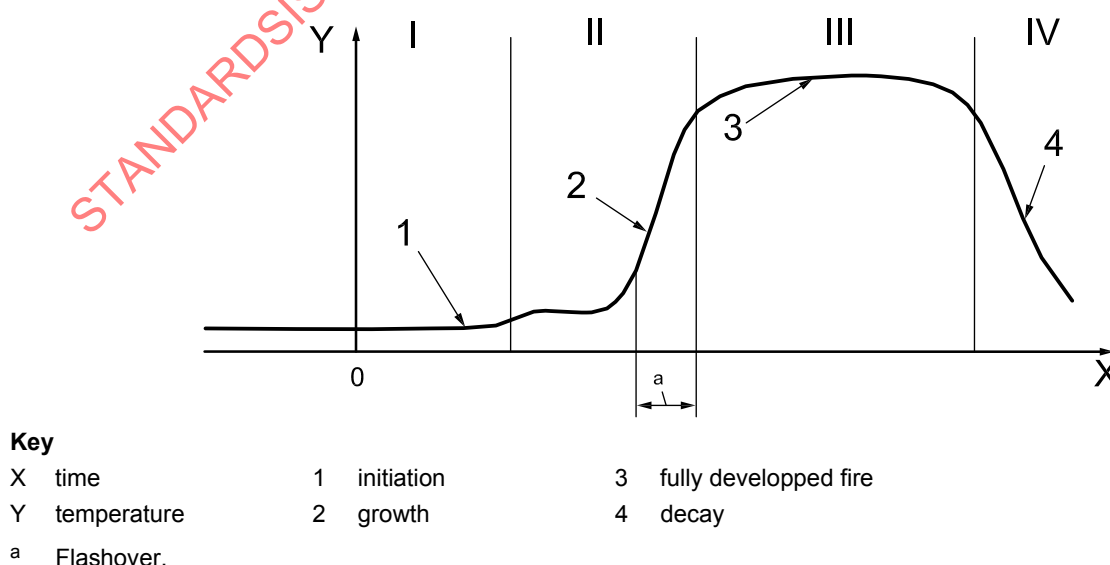


Figure 2 — Potential fire development in an enclosure

4.3.3 Effect of intervention

The environmental impact of fire-fighting intervention is linked to the stage in the fire during which this intervention takes place: I, II, III or IV. Table 1 gives a summary of the types of emissions that could be expected from intervention in the various stages shown in Figure 2.

Table 1 — Description of the impact of intervention depending on the stage of the fire episode

Stage	Emissions	Impact of intervention
I	Simple molecules, low concentrations.	Local impact only (rapid intervention).
II	Increasingly complex organic species, produced in higher concentrations than in Stage I. Simple molecules still produced, high concentrations.	Immediate and local impact.
III	Large amounts of high molecular weight organic species, high concentrations. Simple molecules still produced, high concentrations.	Greatest impact, i.e. local, immediate and external environmental impact (3.1). Care must be taken not to exacerbate the environmental impact through the intervention.
IV	Large amounts of effluents have been produced. Fire has begun to self-extinguish if intervention has not been made before this point.	Potential for major impact if effluents are largely enclosed and fire has begun to decrease, and the intervention risks large scale (and/or more toxic) emissions and distribution of effluents.

4.4 Emissions to the air

4.4.1 Background

The dispersion of the fire plume within the atmosphere causes

- elevated concentrations of airborne pollutants,
- increased risk from exposure to airborne pollutants, and
- reduced visibility.

Apart from reducing visibility and obstructing fire-fighting operations, particulate atmospheric emission results in a pervasive reduction in the environmental quality and in potential long-term toxicity. So-called PM₁₀, airborne particles with a mass median aerodynamic diameter of 10 µm or less, present an important potential environmental problem due to their direct effect on the respiratory system and to their transport of carcinogenic organic species such as PAHs, dioxins and furans.

NOTE 1 PAHs are a complex group of chemicals that are comprised of two or more joined aromatic rings.

NOTE 2 Dioxins and furans are abbreviated terms commonly used to generically refer to polychlorinated and polybrominated dibenzo-p-dioxins (PCDD/PBDD) and dibenzofurans (PCDF/PBDF).

4.4.2 Fire zone

The area within the fire zone (inside a burning building, in a waste deposit, outdoor storage of biofuels, etc.) relates primarily to the actual fire and the corresponding emergency response. If people (inhabitants, workers, etc.) are at risk within the fire zone, the priority in the response shall be their health and safety. In such cases, while the environmental impacts should be a secondary consideration, they are still considered during the incident management, but with a lower priority.

4.4.3 Fire plume zone

The fire plume zone is the area over which the smoke or vapour plume from the fire disperses.

Both local topography and meteorological conditions, such as wind speed and air stability characteristics, have an influence on the characteristics of dispersion and the extent of the fire plume zone. Furthermore, the fire-fighting strategy also impacts on the levels of pollutants in the plume: a controlled burn, for example, can reduce air pollution in some cases due to the better combustion and dispersion of pollutants.

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 other conditions that promote rapid plume grounding also hinder plume dispersion. The combined effects of topographical features and meteorological conditions that lead to restricted dispersion are generally additive and result in higher air pollutant concentrations within the fire plume.

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; nevertheless, it results in a pervasive reduction in environmental quality. "Urban particles", formed by gas-to-particle conversions, such as condensation of volatiles from combustion smoke, or photochemical formation of ammonium sulfate from ammonia and sulfur dioxide (SO₂), are in the size range which accumulates in the environment and also scatters light effectively.

Important species to consider when quantifying the environmental impact from the fire plume include large organic species such as certain aerosols, PAHs and dioxins.

4.4.4 Plume deposition zone

The plume deposition zone encompasses the area under the fire plume zone. Therefore, in a similar way to the fire plume zone, the plume deposition zone is also influenced by topographical features and meteorological conditions. Most particulate deposition occurs close to the fire source.

Air temperature normally decreases with increasing altitude. Reversal of this gradation in which a layer of warmer air lies above a cooler layer is known as temperature inversion. As the cooler layer of air is denser than the warmer layer, it cannot rise, and this results in any pollutants emitted below the "warm" inversion layer becoming trapped.

Atmospheric releases also affect terrestrial and aquatic environments through deposition of pollutants. Many thermal degradation products can condense on, or be adsorbed by, the soot particles and be transported with the smoke.

There is also deposition on structures leading to corrosion, particularly from acidic decomposition products.

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

Important species in this zone include high-molecular-weight organic compounds, such as PAHs and dioxins. In order to obtain an accurate measure of the environmental impact of a particular fire, full knowledge of weather conditions is essential for the determination of deposition patterns.

4.5 Emission to the terrestrial environment

Contamination of the terrestrial environment occurs both from direct emissions from the fire and emissions prompted either by fire-fighting or post-fire clean-up activities, or through interaction with weather (e.g. wind and rain). When assessing the effect of a fire on the terrestrial environment, it is important to include all potential sources of contamination.

Atmospheric releases (discussed in detail in 4.4) also affect the terrestrial environment through deposition of pollutants, which can be exacerbated through the effect of weather.

4.6 Emission to water environment

4.6.1 Background

The major threat to the water environment posed by fires arises from the direct run-off of contaminated fire-fighting water, foam and chemical agents into rivers, streams, lakes, coastal water, groundwater or sewage treatment works (STW), although some threat to such water bodies is posed by the deposition of airborne pollutants directly into the water environment or via run-off from the terrestrial environment.

The impact that any discharge of fire run-off has on the water environment is dependent on a wide variety of factors, including:

- a) the volume of run-off produced, the time of travel from the site of the fire to the receptor and the dilution afforded in the receiving water body, the temperature, chemistry and type of the receiving water body;
- b) the chemical composition of the run-off, influenced to a great extent by the source of the fire, which, for example, in the case of fires at sites storing chemicals, involves a complex mix that includes
 - soot, ash and other suspended solids,
 - the decomposition products of combustion of the building, storage vessels and of substances stored on site,
 - the stored chemicals and their thermal decomposition products washed off the site by the run-off, and
 - if used as a fire-fighting agent, the fire-fighting foam;
- c) the sensitivity and the distance (time of travel from the site) of the receiving receptors, such as public drinking-water abstraction points, fisheries and valuable aquatic ecosystems.

4.6.2 Surface water

The effects of a discharge of run-off to surface water are usually short term, although often very serious, and can include the contamination of public drinking-water supplies during or immediately following the fire. The effects are usually greatest within the immediate vicinity of the site, where the levels of pollutants are at their highest.

NOTE 1 This is not always the case. For example, oxygen sags sometimes form somewhere downstream of the discharge point, as can more toxic breakdown products, e.g. ammonia from the breakdown of protein-based foams. Perhaps most important is whether sensitive receptors are found somewhere downstream of the discharge point.

As well as short-term impacts, there is also the possibility of long-term impacts arising from direct ingestion of toxic/carcinogenic/exotic organic compounds in watercourses contaminated by fire-water run-off and/or plume deposition, as well as chronic effects on flora and fauna.

One should note that it is important that run-off water does not reach water treatment plants as these can be rendered non-functional by the inclusion of large volumes of pollutants or surfactants (e.g. fire-fighting foams).

NOTE 2 This issue is intended to be dealt with in a document under preparation.

4.6.3 Groundwater

In the case of the pollution of groundwater, the effects can sometimes last for decades and lead to long-term or permanent closure of public/commercial water supplies. The pollution of groundwater can also involve the pollution of groundwater-dependent surface water.

4.6.4 Fire-water run-off

The polluting effects of fire-water run-off, related to both surface water and groundwater, are due to one or more of the following:

- direct toxicity;
- oxygen depletion (i.e. caused by the breakdown of organic molecules in the fire-fighting water);
- physical, i.e. suspended solids covering the river bed, effecting the gills of fish, etc.

NOTE The New Zealand Institute of Environmental Science and Research (ESR) Limited has published a series of reports for the New Zealand Fire Service on the issue of ecotoxicity of fire-water run-off.^{[10][11][12]}

5 Adverse environmental impacts of fire effluents

5.1 Short-term impacts

Short-term environmental impacts from exposure to fires, i.e. impacts occurring after the fire over the period of a few minutes to a few days, pertain mostly to the local environment, within the fire plume zone and water run-off zone.

NOTE 1 Prediction of acute toxicity of the combination of exposure to asphyxiants and irritant gases on humans is outside the scope of this part of ISO 26367. For more details, refer to ISO 13571^[4].

Short-term environmental impacts from exposure arising from atmospheric releases are principally associated with asphyxiant gases and irritant gases/aerosols. Most toxic releases are unlikely to be produced in sufficiently high concentrations (apart from in the local environment) so as to result in immediate incapacitation. For many of these species, toxicity only occurs through long-term exposure (see 5.2).

High concentrations of substances of acute toxicity in run-off water, draining within a local catchment area, represent worst-case impacts on natural water courses and associated aquatic habitats and species.

NOTE 2 It is intended to discuss this issue in more detail in a document under preparation.

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

5.2 Long-term impacts

Long-term environmental impacts from exposures to large fires, i.e. impacts occurring after the fire over a period of years, are experienced largely within the local environment, within the fire deposition zone and along impacted surface and groundwater.

Long-term environmental impacts from emissions within the local environment and within the fire deposition zone are principally associated with persistent organic pollutants and other long-lived toxicants.

NOTE It is intended to give specific information concerning these species in a future part of ISO 26367.

Long-term environmental impacts on surface waters are rare, provided there is a rapid exchange of water. Environmental impact to surface water is typically short-term.

Long-term environmental impacts on groundwater can be due to persistent organic pollutants and metals that are able to percolate into the groundwater system.

6 Intervention

6.1 Background

During the planning of a site where there is a risk of pollution from fire-fighting, site operators, in liaison with fire and rescue services, other stakeholders and users, need to consider ways of reducing the risk.

There are four main ways to reduce risk which can be implemented at any given site.

a) Prevention

By giving the highest priority to preventing the fire in the first place: for example, segregating or controlling sources of ignition such as by segregation of flammable materials.

b) Detection

By ensuring that, if a fire does start, it is detected and tackled as quickly as possible. The fitting of automatic detection and protection systems such as sprinklers is one way of doing this. Site operators should seek advice on such systems from the fire and rescue service and their insurers.

c) Containment

By installing facilities for containing fire-fighting water, such as storage lagoons or chambers, shut-off valves and isolation tanks or areas.

NOTE It is intended that this issue be dealt with specifically in a document under preparation.

d) Mitigation

By planning with the fire and rescue service suitable fire-fighting strategies, such as

- reducing the amount of fire-fighting water generated, by using sprays instead of jets,
- recycling fire-fighting water where this is not hazardous, and
- controlled burning.

In cases where action is required to prevent the fire spreading, such as the application of cooling water to the area around storage tanks, care should be taken to ensure that this water does not become a pollutant.

The nature and place of any intervention that occurs have a major effect on the environmental impact of that intervention. Some guidance is given in Clause 7 as to what should be monitored when determining the environmental impact of a particular intervention and whether controlled burning, for example, could sometimes be preferable to traditional extinguishment.

6.2 Sensitivity of receptors

The sensitivity of the receiving environment/receptors for any fire effluent is highlighted as one of the factors that should be considered when assessing the environmental impact of fire effluents.

This sensitivity is generally divided into high, medium and low and depends both on the type of receptor and type of effluent. National environmental agencies can generally provide guidance concerning classification of the various receptors.

7 Assessment of environmental impact

7.1 Establishing sampling requirements

The size of the fire and the distribution or spread of fire effluents into the environment determine the need for, and location of, sampling and analysis in the post-fire assessment of the environmental impact. The flow chart shown in Figure 3 facilitates the determination of which samples should be made and which analysis of the samples is to be preferred.

NOTE It is intended that specific information concerning potential fire effluents and the evaluation of their environmental impact be given in a future part of ISO 26367.

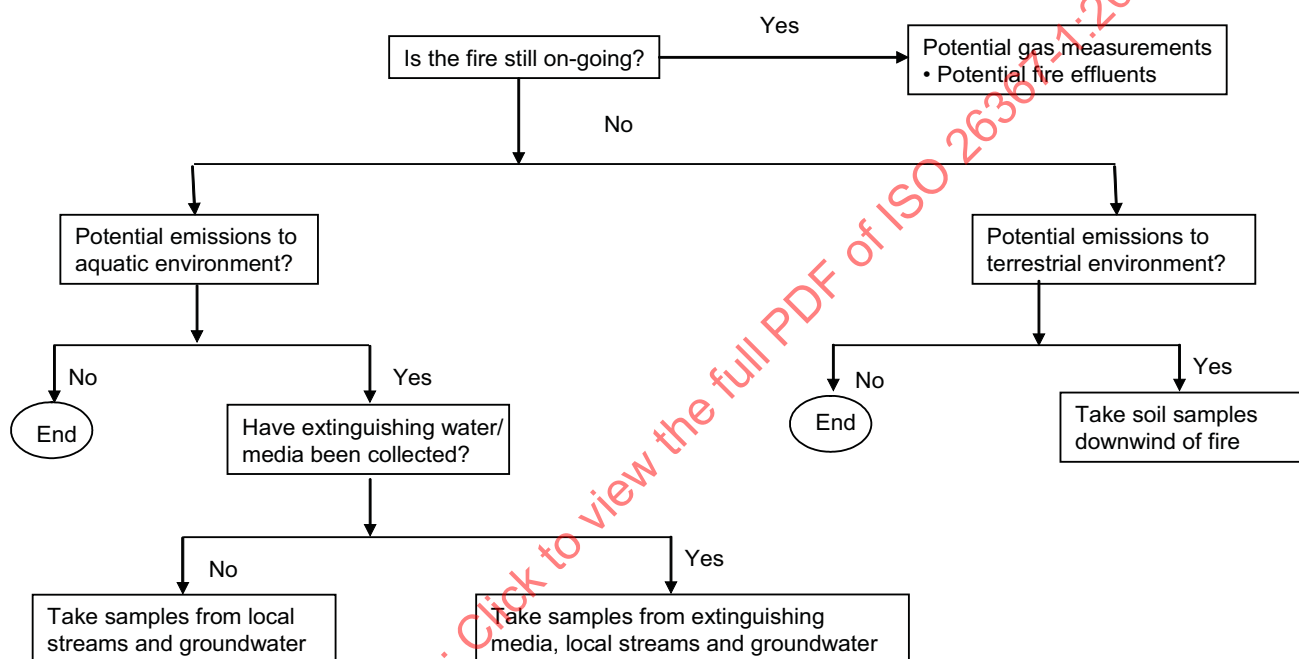


Figure 3 — Decision flow chart for environmental impact sampling

7.2 Sampling options

7.2.1 Emissions to the air

Sampling of emissions to the air can only be made when the fire is on-going. Sampling from the fire plume is extremely difficult. While attempted at times through airborne sampling from a variety of aircraft, it is unclear how such point samples can be related to deposition. Ground-based sampling below the plume can provide more direct input concerning potential deposition.

NOTE A variety of sampling methods are available. For more information, see ISO 19701^[5], ISO 19702^[6] and ISO 29904^[7].

Grab sampling and post-analysis in the laboratory could provide more data on the emissions of toxic and ecotoxic species, including inorganic gases, PAHs and dioxins. This data would not, however, be time-resolved.

7.2.2 Emissions to the water environment

If extinguishing media have been collected, samples should be taken for analysis.

Samples of groundwater and surrounding flowing water or lakes should also be taken.

The location and nature of sampling should be informed by the knowledge of the pathway by which run-off could be spread into the environment. A detailed post-incident analysis of pathways should be carried out to reveal all potential or actual routes to receptors.

The exact analysis of the samples should be determined on the basis of the products stored on site and their likely breakdown products, as well as on the fire-fighting agent used. Examples of the determinants that can be analysed for include PAHs, volatile organic compounds (VOCs), hydrocarbons, dioxins, metals, ammonia (NH_3), pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD) and suspended solids (SSs). In some cases, toxicity tests and biological monitoring can also be useful.

7.2.3 Emissions to the terrestrial environment

Samples of soil in the downwind direction from the fire and in the path of the fire plume should be taken.

The exact analysis of the samples should be determined on the basis of the products stored on site and their likely breakdown products, as well as on the basis of the fire-fighting agent used. Examples of the determinants that can be analysed for include PAHs, dioxins, metals and pH. In some cases, toxicity tests can also be useful.

Annex A (informative)

Examples of significant fire incidents

Historically, a large number of major fires have occurred which have had a significant effect on the environment. Table 1 lists a representative selection of such fires to illustrate the international nature of this issue and the ubiquitous nature of the environmental effects. (See the Bibliography for more information on the specific environmental impact of each incident.)

Table A.1 — Selection of significant fire incidents with environmental impacts

Date	Place	Description
1962 to the present day	Centralia, USA	Coal mine fire that has been burning continuously since 1962, when the local population was some 1 100; all but a few have relocated. See Reference [13].
November 1986	Basle, Switzerland	This chemical warehouse fire, referred to worldwide, initiated debate on the environmental issues of fires and served as a source of progress in the area. Ten years after, eels restocked in the Rhine were still not consumable. See Reference [14].
October 1987	Nantes, France	A chemical warehouse storing inorganic fertilizers suffered a major blaze due to self-sustained decomposition of 20 t of N-P-K products, releasing a massive toxic plume that eventually dispersed over the ocean. Some 15 000 people were evacuated as a precaution. Afterwards, an experimental assessment of the plume toxicity confirmed the toxicity of the effluents.
June 1987	Ohio, USA	Paint warehouse fire in an environmentally sensitive area. See Reference [15].
June 1988	Tours, France	Known as the "Protex" fire, this chemical fire spread vigorously due to the close proximity of flammable and toxic products. The plume zone was some 30 km long and 12 km large (fire plume zone) and provoked major pollution of the river Brenne.
February 1990	Hagersville, Canada	Two of the numerous large-scale tyre waste fires that have taken place in North America. Tyre fires last several days to several months, lead to massive air, soil and water pollution, and present to extreme difficulties in fire-fighting. Evacuation of people is required in some cases, and fresh water sometimes disrupted for long periods. Lessons learned led to the production of useful guidelines in North America and Europe. See References [16] and [17].
May 1990	Saint-Amable, Canada	
1991	Kuwait	As a result of the Iraqi invasion of Kuwait, oil wells were systematically damaged through the use of explosives, resulting in uncontrolled gas and oil blowout fires in some 700 wells. The environmental contamination by both oil leakage and fire gases was severe, in relation with the tremendously important and long-lasting releases of pollutants (equivalent to some 7 400 000 bbls/day) that have affected air and soil, according to a NIST evaluation report of 1994. See Reference [18].
July 1992	South Bradford, UK	A major pollution of the aquatic environment resulted from the run-off of some 16 000 m ³ of contaminated water used to fight a fire in the plant of a chemical manufacturer: the UK reference in matters of pollution by contaminated water run-off in fresh water streams. The origin was the proximity of storage of incompatible chemicals. See Reference [19].
October 1995	Wilton, UK	Polypropylene warehouse fire on a chemical complex, which raged for 12 h, due to fault in the lighting system. See Reference [20].
December 1995	Somerset West, South Africa	Massive fire of a sulfur stockpile used by three different companies in industrial applications. A unique proof that fire toxicity is a lethal threat, even in the open environment. See Reference [21].

Table A.1 (continued)

Date	Place	Description
June 2001	Venizel, France	A fire accident in a paper mill containing polychlorinated biphenyl (PCB) transformers. presented considerable difficulties for emergency response management, and required the medical survey over a year of some 100 people (including journalists), liable to have suffered some exposure to dioxins and PAHs. A case study which reveals that, until the phase-out of a banned product is fully effective, the threat remains. An instructive report was produced on the aftermath of the fire and made public by the French authorities. See Reference [22].
January 2002	Murcia, Spain	Large release of toxic effluents arising from a warehouse storing inorganic fertilizers (NPK) in a scenario quite similar to that which occurred in Nantes in 1987. See Reference [23].
1990s to the present day	Various, worldwide	Massive wildfires lasting for weeks, inducing multiple fire deaths and large property losses in urbanized areas, or causing sanitary problems or temporary closures of airports due to high levels of pollutants emitted for long periods (USA, Australia, Indonesia, Southern Europe, Russia, etc.).
December 2005	Buncefield, UK	A major fire occurring in an oil storage depot which contained 35 000 000 l of various types of fuel. The fire burned for several days, emitting massive plumes of dense smoke which, due to the prevailing meteorological conditions, were transported and dispersed in the upper atmosphere. The groundwater under and up to 2 km to the North, East and South-East of the site was contaminated with hydrocarbons and fire-fighting foams from the incident. After two years, the extent of the contamination appeared to be confined to within the immediate vicinity of the depot. Approx. 22 000 000 l of contaminated fire-fighting water has been treated and safely disposed of. See Reference [24].