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Fire safety engineering — Selection of design fire scenarios and design fires —

Part 1: Selection of design fire scenarios

Ingénierie de la sécurité incendie — Sélection de scénarios d'incendie et de feux de dimensionnement —

Partie 1: Sélection de scénarios d'incendie de dimensionnement

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2. www.iso.org/directives

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The committee responsible for this document is ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

This first edition cancels and replaces ISO/TS 16733:2006, which has been technically revised.

ISO 16733 consists of the following parts, under the general title, *Fire safety engineering — Selection of design fire scenarios and design fires*:

— *Part 1: Selection of design fire scenarios*

Introduction

Selection of the fire scenarios requiring analysis is critical in fire safety engineering. The number of possible fire scenarios in any built environment (a building or other structure) can be very large and it is not possible to quantify them all. It is necessary to reduce this large set of possibilities to a small set of design fire scenarios that is amenable to analysis.

The characterization of a fire scenario involves a description of fire initiation, the growth phase, the fully-developed phase and extinction together with likely smoke and fire spread routes. This includes the interaction with the proposed fire protection features for the built environment. It is necessary to consider the possible consequences of each fire scenario.

This part of ISO 16733 introduces a methodology for the selection of design fire scenarios that is tailored to the fire-safety design objectives. There can be several fire safety objectives being addressed, including safety of life (for occupants and rescue personnel), conservation of property, protection of the environment and preservation of heritage. A different set of design fire scenarios can be required to assess the adequacy of a proposed design for each objective.

Following selection of the design fire scenarios, it is necessary to describe the assumed characteristics of the fire on which the scenario quantification are based. These assumed fire characteristics are referred to as “the design fire”. It is important that the design fire be appropriate to the objectives of the fire-safety engineering analysis and that they result in a design solution that is commensurate with credible worse case scenarios considered.

Users of this part of ISO 16733 should be appropriately qualified and competent in the fields of fire safety engineering and risk assessment. It is important that users understand the parameters within which specific methodologies may be used.

ISO 23932 provides a performance-based methodology for engineers to assess the level of fire safety for new or existing built environments. Fire safety is evaluated through an engineered approach based on the quantification of the behaviour of fire and based on knowledge of the consequences of such behaviour on life safety, property, heritage and the environment. ISO 23932 provides the process (necessary steps) and essential elements to design a robust performance-based fire safety programme.

ISO 23932 is supported by a set of ISO fire safety engineering standards available on the methods and data needed for the steps in a fire safety engineering design summarized in ISO 23932:2009, Clause 4 and shown in Figure 1. This system of standards provides an awareness of the interrelationships between fire evaluations when using the set of ISO fire safety engineering standards.

Each International Standard includes language in the introductory material of the standard to tie the standard to the steps in the fire safety engineering design process outlined in ISO 23932. Selection of design fire scenarios form part of compliance with ISO 23932, and all the requirements of ISO 23932 apply to any application of this part of ISO 16733. For example, ISO 23932:2009, 9.2 generally describes the procedure for identifying and selecting fire scenarios (see highlighted box in Figure 1). Clause 6 describes, in detail, the approaches for identifying and selecting design fire scenarios.

Fire safety engineering — Selection of design fire scenarios and design fires —

Part 1: Selection of design fire scenarios

1 Scope

This part of ISO 16733 describes a methodology for the selection of design fire scenarios that are credible but conservative for use in fire safety engineering analyses of any built environment, including buildings, structures or transportation systems. Following the procedures given in this part of ISO 16733, a manageable number of design fire scenarios is selected using a qualitative or semi-quantitative approach. For a full quantitative approach using risk assessment, the reader is directed to ISO 16732-1.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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*

ISO 16732-1, *Fire safety engineering — Fire risk assessment — Part 1: General*

ISO 23932:2009, *Fire safety engineering — General principles*

3 Terms and definitions

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

3.1
design fire
quantitative description of assumed fire characteristics within a design fire scenario

Note 1 to entry: Typically an idealized description of the variation with time of important fire variables, such as heat release rate and toxic species yields, along with other important input data for modelling such as the fire load density.

3.2
design fire scenario
specific fire scenario on which a deterministic fire safety engineering analysis will be conducted

Note 1 to entry: As the number of possible fire scenarios can be very large, it is necessary to select the most important scenarios (the design fire scenarios) for analysis. The selection of design fire scenarios is tailored to the fire-safety design objectives, and accounts for the likelihood and consequences of potential scenarios.

3.3
fire scenario
qualitative description of the course of a fire with respect to time, identifying key events that characterize the studied fire and differentiate it from other possible fires

Note 1 to entry: The fire scenario description typically includes the ignition and fire growth processes, the fully developed fire stage, the fire decay stage, and the environment and systems that will impact on the course of the fire. Unlike deterministic fire analysis, where fire scenarios are individually selected and used as design fire scenarios, in fire risk assessment, fire scenarios are used as *representative fire scenarios* (3.4) within *fire scenario clusters* (3.5).

3.4
fire scenario, representative
specific *fire scenario* (3.3) selected from a *fire scenario cluster* (3.5) such that the consequence of the representative fire scenario can be used as a reasonable estimate of the average consequence of scenarios in the fire scenario cluster

3.5
fire scenario cluster
subset of *fire scenarios* (3.3), usually defined as part of a complete partitioning of the universe of possible fire scenarios

Note 1 to entry: The subset is usually defined so that the calculation of fire risk as the sum over all fire scenario clusters of fire scenario cluster frequency multiplied by *representative fire scenario* (3.4) consequence does not impose an undue calculation burden.

3.6
target
person, object or environment intended to be protected from the effects of fire and its effluents (smoke, corrosive gas, etc.) and/or fire suppression effluents

4 Symbols and abbreviated terms

A	area of an opening, m^2
h	height of an opening, m
$\dot{m}_f$	rate of mass loss of fuel, kg/s
$\dot{m}_{air}$	rate of entry of air into the enclosure, kg/s
$\dot{Q}$	rate of heat release, kW
$\dot{Q}_0$	reference rate of heat release, kW
r	stoichiometric air requirement for complete combustion of fuel, expressed as the mass ratio of air to fuel
t	time, s
t_g	time required to reach the reference rate of heat release, $\dot{Q}_0$ s

5 Fire safety engineering applications

5.1 Fire safety engineering process

ISO 23932 provides a performance-based methodology for engineers to assess the level of fire safety for new or existing built environments. Fire safety is evaluated through an engineered approach based on the quantification of the behaviour of fire and based on knowledge of the consequences of such behaviour on life safety, property, heritage and the environment. ISO 23932 provides the process (necessary steps) and essential elements to design a robust performance-based fire safety programme.

This part of ISO 16733 provides guidance for developing design fire scenarios in ISO 23932:2009, 9.2. This step in the fire safety engineering process is shown as a highlighted box in Figure 1.

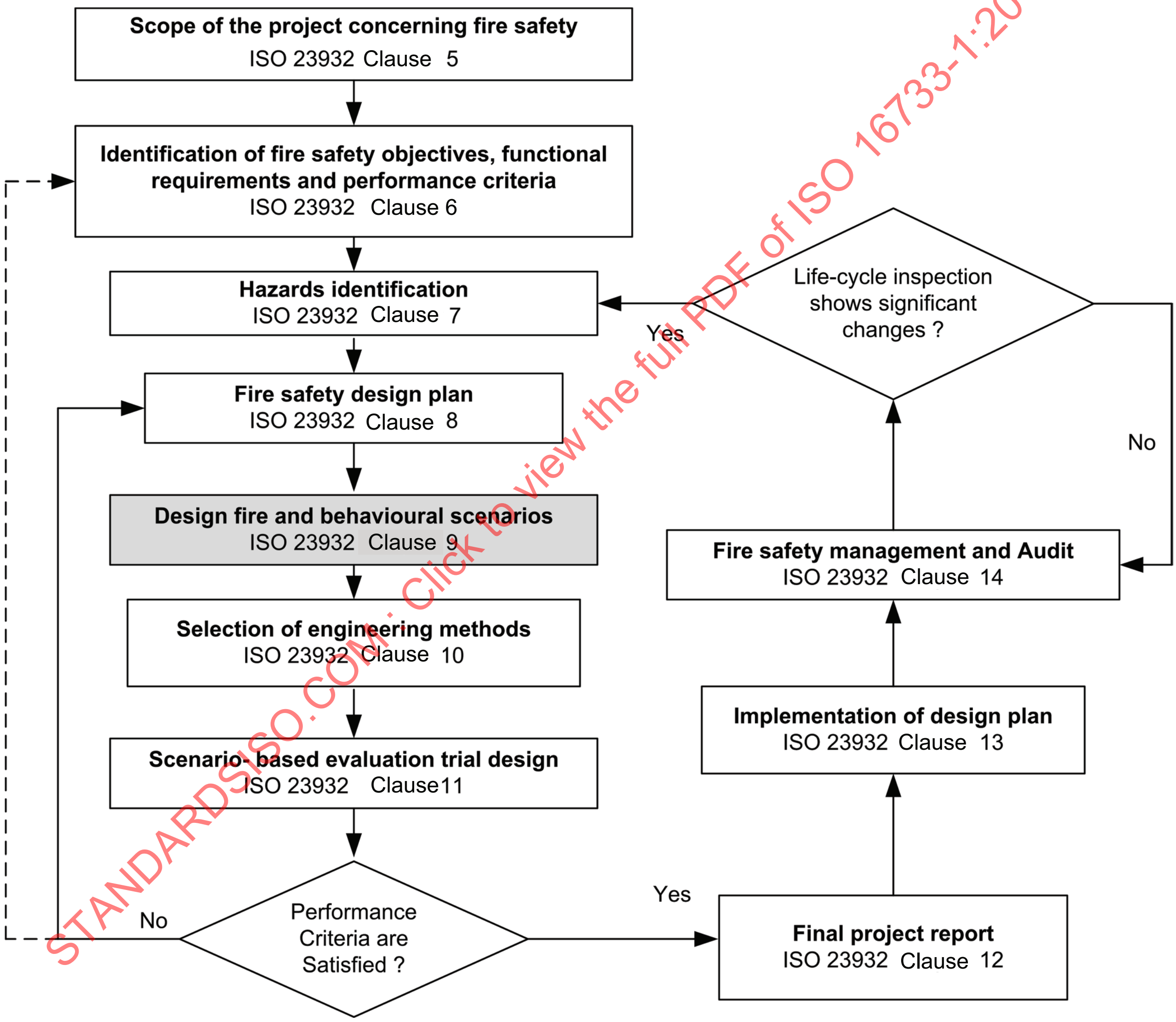


Figure 1 — Flow chart illustrating the fire safety design process and selection of design fire scenarios (Source: ISO 23932:2009)

5.1.1 Establish project scope

A preliminary plan shall contain information describing the purpose and function of each part of the design, and its intended fixtures, furnishings, decorations, equipment and combustible products that are planned to be installed, stored or used in the built environment. When this type of detailed information is not available, assumptions shall be made, the validity of which shall be checked and confirmed during and again at the end of the project. The contractual and organisational context of the design work must be clearly defined including the extent to which a FSE approach will be applied. See ISO 23932:2009, Clause 5.

5.1.2 Identify fire safety objectives

It shall be noted that there may be several fire safety objectives including safety of life (for occupants and rescue personnel), conservation of property, protection of the environment and preservation of heritage and that a different set of design fire scenarios can be required to assess the adequacy of the proposed design for each objective.

See ISO 23932:2009, 6.3 for a more detailed discussion.

5.1.3 Determine functional requirements

A functional requirement is a statement of a condition necessary to achieve the fire safety objective (e.g. harmful fire effects in spaces used for evacuation shall be avoided). It is necessary that these are identified and described in order that the potential of possible fire scenarios to threaten the fulfilment of the functional requirement can be assessed. If a fire scenario does not threaten the achievement of a functional requirement, then it is not relevant. An example of a functional requirement for life safety could be "avoid failure of the structure and protect the paths of egress from harmful fire effects until evacuation is completed".

See also ISO 23932:2009, 6.4.

5.1.4 Identify performance criteria

The level of analysis (deterministic, probabilistic) and the performance criteria shall be agreed. Performance criteria are the engineering metrics that are expressed in deterministic or probabilistic (e.g. measures of fire risk) form to determine if each functional requirement has been satisfied by the fire safety design. For a life safety functional requirement, performance criteria shall be developed. An example is setting the maximum concentration or dose of carbon monoxide that an occupant may be exposed to.

See ISO 23932:2009, 6.5.

5.1.5 Hazard identification

Hazard identification comprises both internal and external hazards that could have an impact on the built environment, hazards unique to the use of the property and hazards common to many properties, combustible materials or products, equipment and other heat sources, natural hazards and activities.

See ISO 23932:2009, Clause 7.

5.1.6 Fire safety design plan

The fire safety strategy shall be elaborated in a trial fire safety design plan and documented in a fire design report presenting enough detailed information to allow its evaluation in terms of meeting the fire safety objectives when assessed against the design fire scenarios. The fire safety design plan shall describe the functions of different parts of the built environment and their contribution to satisfying the fire safety strategy. Figure 1 illustrates the fire safety design process as described in ISO 23932.

5.2 The role of design fire scenarios in fire safety design

Design fire scenarios are the foundation of fire safety engineering assessments. Such assessments entail analysing design fire scenarios and drawing inferences from the results with regard to the adequacy of the proposed design to meet the performance criteria that have been set. Identification of the appropriate scenarios requiring analysis is crucial to the attainment of a built environment that fulfils the fire safety objectives.

In reality, the number of possible fire scenarios in most built environments approaches infinity. It is impossible to analyse all scenarios even with the aid of the most sophisticated computing resources. It is necessary to reduce this infinite set of possibilities to a manageable set of design fire scenarios that is amenable to analysis and that represents the range of fires that can challenge the engineering design that is the subject of the analysis.

Each design fire scenario is selected to represent a risk-significant cluster of fire scenarios. The risk associated with a cluster is characterized in terms of the combination of probability (or likelihood) of occurrence of the cluster and the resultant consequence. For the purposes of this International Standard, when a deterministic assessment is envisioned, a qualitative estimation of the likelihood and consequence suffices. For a full risk assessment, such as that outlined in ISO 16732-1, a quantitative estimation is undertaken.

Once design fire scenarios are selected, the design of the built environment is modified until the analysis demonstrates the performance criteria associated with the relevant fire safety objective(s) is met and the risk associated with the design is acceptably low.

It is necessary to identify relevant design fire scenarios in the preliminary qualitative report described in ISO 23932:2009, 10.2 and for them to be collectively reviewed by the stakeholders. During this process, it is possible to eliminate scenarios that are of such low risk that they cannot, individually or collectively, affect the overall evaluation of the design. It is important to remember that low consequence combined with high likelihood or high consequence combined with low likelihood can be high or low risk, depending on whether consequence or probability dominates. Neither probability nor consequence can be used completely in isolation for risk screening.

The characterization of a design fire scenario for analysis purposes involves a description of such things as the initiation, growth and extinction of fire, together with likely smoke and fire spread routes under a defined set of conditions. The impacts of smoke and fire on people, property, structure and environment are all part of potentially relevant consequences of a design fire scenario and are part of the characterization of that scenario when those consequences are relevant to the specified fire safety objectives. The characterization of fire growth, fire and smoke spread, fire extinction and fire and smoke impact involving temporal sequences of events belong to the "design fire". Some later events are predictable from earlier events through the use of fire safety science and it is important that the characterization of the event sequence in the scenario be consistent with such science.

5.3 The role of design fires in fire safety design

Following identification of the design fire scenarios, it is necessary to describe the assumed characteristics of the fire on which the scenario quantification will be based. These assumed fire characteristics and the further associated fire development are referred to as the "design fire".

A complete description of the design fire from ignition to decay is estimated using specified initial conditions and a series of simple calculations to estimate parameters such as the sprinkler activation time, transition to flashover and duration of fully developed burning. Alternatively, the design fire can be a combination of quantified initial conditions and subsequent fire development determined iteratively or by calculation using more complex models that account for phenomena such as transient effects of changing ventilation on smoke production or thermal feedback effects from a hot layer to the fuel surface.

As with the design fire scenario, it is important that the design fire be appropriate to the relevant fire-safety objectives. For example, if safety of life is an objective, a design fire could be selected that affects the means of escape. If the severity of the design fire is underestimated, then the application of engineering methods to predict the effects of the fire elsewhere can produce results that do not accurately reflect the true impact of fires and can underestimate the hazard. Conversely, if the severity is overestimated, unnecessary expense can result.

Guidance on characterizing design fires is given in Annex C.

6 Design fire scenarios

6.1 Characteristics of fire scenarios

Each fire scenario is represented by a unique occurrence of events and circumstances associated with the nature of the facility and the sources of fire, as well as a particular set of circumstances associated with the fire-safety measures. The latter are defined by the fire safety design, while the former is required to be specified to characterize the scenario. Accordingly, a fire scenario may be characterized with factors such as the following:

In relation to the nature of the facility or built environment:

— ventilation conditions including location and size of potential openings that could provide a source of air/oxygen during the course of the fire;

— ambient environmental conditions;

— interconnections between spaces or compartments providing potential routes of fire and smoke spread;

— materials and methods of construction and the size of the compartments;

— status and performance of each of the fire safety measures, including active systems and passive features;

— detection, alarm and suppression of fire by automatic or non-automatic (human) means;

— self-closing doors or other discretionary elements of compartmentalization;

— building air handling system or smoke management system;

— reliability of each of the fire safety measures.

In relation to the sources of fires:

— location of initial ignition (where the categories of location might be set to highlight occupied versus unoccupied spaces, spaces filled with valuable contents versus mostly empty spaces, or areas close enough to expose structural elements versus areas not so close. Each of these binary sorts could instead be made into a matter of degree, e.g. densely occupied, lightly occupied, occasionally occupied, inherently unoccupied);

— initial state is smouldering or flaming (which will be based firstly on the first item ignited and secondly on the igniting heat source);

— combustion environment of the initial ignition and availability of fuel is or is not sufficient to support fire growth to flashover (where the more detailed specifications of contents and furnishings, of room linings and such, or of fuel load per unit area, might be derived from field surveys that provide probabilities of high-density vs. low-density, high-combustibility vs. low-combustibility spaces directly. Alternatively, these might be set up as one of a few rooms designed and selected to represent all spaces that are or are not capable of going to flashover, where the probabilities are taken from fire statistics based on what percentage of fires in the design properties historically have gone to flashover or not).

6.2 Identification of fire scenarios

6.2.1 General

A systematic approach to the identification of design fire scenarios for analysis is required in order to identify important scenarios and to provide a consistent approach. The number of possible fire scenarios in any built environment can be very large and it is not possible to quantify them all. It is necessary to reduce this large set of possibilities to a manageable set of design fire scenarios that is amenable to analysis. When performance criteria are given in a deterministic form, the design fire scenarios shall be chosen so that a design shown to deliver acceptable safety for these scenarios can also be relied upon to deliver acceptable safety for all the scenarios that were not analysed. Alternatively, when performance criteria are in a probabilistic form, the design fire scenarios shall be chosen so that calculations based on them will produce an acceptably accurate estimate of the fire risk and in this case the reader is referred to ISO 16732-1 for probabilistic risk assessment procedures.

It is important that the design fire scenarios be appropriate to the objectives of the fire-safety engineering task. For example, for a life safety objective, the design fire scenarios should represent challenges to people who may be located within a building including fire service operations (see also ISO/TS 29761[1]), while for a structural objective, the design fire scenarios should represent challenges to the structural system of the building.

There are several possible approaches to identifying design fire scenarios that may be used, including the following.

a) Identifying a list of prescribed scenarios relevant to the particular built environment. These scenarios may be listed in a national code or standard with the regulator requiring they be considered as a minimum. While this approach, if available, is the simplest and easiest to apply there is a danger that some potentially important scenarios related to an individual built environment may be overlooked if only these scenarios are used. An example of prescribed scenarios is given in Annex B.

b) Applying a qualitative or semi-quantitative systematic approach to determine a set of credible design fire scenarios for deterministic analysis.

c) Selecting a comprehensive set of scenarios of known likelihood and consequence structured using such techniques as event trees to enable a quantitative fire risk assessment to be undertaken. This approach works best when historical fire incident or other statistical data relevant to the particular building environment is available with particular caution needed when assigning likelihoods based on statistics to rare events.

The remainder of this part of ISO 16733 will mainly be concerned with describing the second approach. For prescribed scenarios, the reader should consult the relevant regulatory document and for a fully quantitative risk assessment approach, the reader is referred to ISO 16732-1. Overall, the intent is to ensure that the design fire scenarios selected encompass all credible scenarios and those scenarios not selected are agreed to be an acceptable risk.

The following nine steps describe a systematic procedure for identifying design fire scenarios which are elaborated in the remainder of this Clause.

Step 1 — Identify the specific safety challenges

Step 2 — Location of fire

Step 3 — Type of fire

Step 4 — Potential complicating hazards leading to other fire scenarios

Step 5 — Systems and features impacting on fire

Step 6 — Occupant actions impacting on fire

Step 7 — Selection of design fire scenarios

Step 8 — Modify scenario selection based on system availability and reliability

Step 9 — Final selection and documentation

6.2.2 Step 1 — Identify the specific safety challenges

6.2.2.1 Identify the built environment use

Identify the use or uses of the built environment as might be relevant to the fire safety objective to ensure that all the different types of people in the building are accounted for. This is particularly important for buildings that are multi-functional, e.g. shopping malls, airports, transport terminals and conference centres.

EXAMPLE 1 An airport can accommodate functions such as check-in counters, parking garages, shops and air-side baggage handling. With a life safety objective in mind, each of these functions or uses might be associated with distinctly different users. Therefore, fire scenarios that challenge the evacuation strategies applying to different functional areas of the building will be of interest.

EXAMPLE 2 A manufacturing plant can accommodate functions such as receiving and processing of inwards goods, storage of combustible materials, office and administration support, and manufacturing processes. A safety objective to protect a piece of business-critical equipment will require fire scenarios that potentially expose that equipment to damaging concentrations of smoke or heat to be identified.

6.2.2.2 Identify the targets to be protected

The targets to be protected depend on the fire safety objective. For life safety, the occupants or users of the built environment are the relevant target. Depending on the building use or function, there may be different groups of users (e.g. staff, visitors, fire-fighters). For an environmental objective, it may be a nearby stream; or for a property protection objective, a valuable commodity stored in the built environment or the building structure itself. It is necessary to consider both the fire safety objectives and the relevant targets when selecting a design fire scenario.

6.2.2.3 Identify the important characteristics of the target

The important characteristics here are those that most influence the threat to the target posed by the fire. Where the target is the built environment users, characteristics of interest might include user tendencies in selecting an egress route, or their level of training related to undertaking manual fire-fighting or familiarisation with evacuation procedures and the layout of the built environment. They might also include the vulnerability of occupant groups within the built environment making them more susceptible to the effects of fire and smoke.

Similarly, the sensitivity of a piece of equipment to elevated temperature, smoke or combustion gases will assist in identifying those objects most vulnerable in the built environment and therefore which fire scenarios are more likely to challenge the specific characteristics of the target that makes it vulnerable.

6.2.2.4 Determine the safety challenges

Because the aim of the deterministic analysis is to test the fire safety design using a selection of severe but credible scenarios, it is imperative to identify what issues or conflicts that, in combination with fire, could potentially lead to the failure of the design. These issues and conflicts are referred to here as safety challenges.

For a life safety objective, these issues are often occupant characteristics that lead to non-optimal response or movement in emergency situations. Conflicts often involve a mismatch between built environment uses and users or between users and built environment layout.

A typical life safety challenge involving a conflict between built environment uses and users is people's tendency to use familiar exits. This tendency means that people will try to move towards the main entrance/exit, which is a potential major evacuation bottleneck in case of fire. A fire that quickly renders the main entrance unusable is therefore a scenario that severely challenges the fire safety design.

A property protection challenge is an item of machinery that is sensitive to exposure to elevated temperature or to contamination by specific types of combustion products.

6.2.3 Step 2 — Location of fire

Step 2 typically involves characterization of the space in which fire begins, as well as characterization of the specific location within the space. This shall be considered in the context of the specific safety challenges identified in the preceding step, and not treated in isolation without context.

Identification of most likely locations can be done using fire statistics. Alternatively, if statistics are not available, one can make an assessment based on the presence of heat sources, fuel packages and occupants. While the most likely locations are of interest, they may not necessarily represent challenging or credible worse case fire scenarios.

Identification of most adverse or challenging locations may be done using fire statistics for injury or monetary loss and may also require engineering judgment when statistical data are lacking. Challenging locations are those where special circumstances and events can adversely impact on achieving the applicable fire safety objectives.

Examples include the following:

— fires in assembly areas, clean rooms or other spaces with a high density of vulnerable people or highly vulnerable property close to the fire's point of origin or with access to exposed structural members, in each case such that there could be insufficient time and space for fire safety measures to act effectively;

— fires within or blocking entry to the egress system, which can delay or prevent safe evacuation;

— fires in rooms or spaces, including concealed spaces and exterior surfaces, that are outside the coverage areas of fire-safety systems.

Other examples of locations for which fire scenarios may be needed include the following:

a) internal:

- — fire in construction products (e.g. involving sandwich panels where sudden collapse could threaten firefighters);
- — room fires where the fire location potentially enhances flame spread and rate of fire growth (e.g. a room corner location leading to fire spread across combustible ceiling and wall materials will potentially challenge the egress design);
- — fire in stairwells required for to be used for evacuation;
- — cable tray or duct fire (e.g. a fire develops in a hidden or unoccupied area and spreads via the ducting to other parts of the built environment threatening occupant escape);
- — roof fires (under roof);
- — fire in cavity spaces (wall cavities, facades, plenums);

b) external:

- — fire originating in a neighbouring built environment or vegetation;
- — fires on roofs;
- — fires exposing surfaces of exterior cladding (e.g. if a combustible cladding is used, external vertical fire spread could lead to ignitions at various elevations in a building, challenging the design of any fire sprinkler system).

Design fire scenarios for other locations shall be agreed upon during the QDR for special situations. It may be necessary to consider possible changes that may occur over the life of the built environment, for example, where energy efficiency measures have resulted in changes to the materials within the external envelope leading to changes in their expected fire behaviour.

Also consider the location of the target to be protected. Fires that will not develop, spread into, or lead to damaging conditions where the targets of interest are located, are not likely to be design fire scenarios.

Annex A contains guidance relating to sourcing data for frequencies by fire location.

6.2.4 Step 3 — Type of fire

The type of fire is characterized by a series of stages including ignition, fire growth, full development, decay and extinction. Of particular importance in defining the type of fire that will challenge a design and the fire safety systems are the initial intensity and rate of growth of the fire, which can be associated with some combination of the initial heat source, the first item ignited, the first large item ignited, and any other items ignited prior to ignition of the first large item.

This means Step 2 typically involves two steps, characterization of the initial ignition and characterization of the early-stage fire when it is well established. If the first item ignited is also a large item, these two steps can be treated as the same. However, many fires begin with very small initial fuel items, such as spilled food on a stove, trash in a trash can, deposited soot in a chimney or accumulated lint in a clothes-dryer. For these fires, the initial ignition does not occur at the same time or closely resemble the early-stage well established fire.

Fire incident statistics provide an appropriate basis for identification of the initial ignition conditions for fire scenarios, together with frequencies for alternative initial ignition conditions. The goal of this systematic approach is to screen possible fire scenarios by relative risk. A practical way to do this using fire incident statistics and engineering judgment is to identify one set of fire scenarios with high likelihood and minimal consequence and another set of fire scenarios with high consequence and minimal likelihood. Identification of the initial ignition conditions could also be determined by risk analysis using, for example, fault tree methods, engineering judgement or tests.

From fire incident statistics appropriate for the built environment and occupancy under consideration, rank the combinations of the initial heat sources and the initial fuel items by some frequency and consequence-related criteria. Examples include the most likely fires or those with fire extent of a certain minimum size, flame extent beyond room of origin, fire size greater than a specific area, consequences of five or more deaths, or consequences of more than a defined monetary threshold indicating a large loss, such as the minimum loss associated with the costliest 1 % of fires. In the absence of sufficiently detailed fire incident data, fires accounting for the largest shares of fire injuries or fire fatalities, or fires accounting for the largest share of property damage, measured in monetary terms, could also be considered. It is also important to identify types of fires that will challenge the built environment and features bearing in mind the fire safety objectives.

Appropriate statistics can be available on a national basis, a state or provincial basis, or for like properties with the built environment being designed. If appropriate national statistics are not available, then information from other countries with similar fire experience may be utilized. It is necessary to exercise care in applying fire incident statistics to ensure that the data are appropriate for the built environment under consideration, particularly when using data from other countries since the differences may be in orders of magnitude.

Fire scenarios for other types of fires may be agreed upon during the development of the trial fire safety design plan for special situations.

It may be necessary to consider a smouldering phase of fire development for objectives such as life safety of sleeping occupants. However, it is less likely that relevant fire incident statistics will be readily available for smouldering fires compared to flaming fires, since some of these fires will transition to flaming fires before being included in fire incident databases. If any flaming fire scenarios involving very small initial fuel items ignited rank high on a consequence-weighted ranking, it is necessary that these fires have involved at least one additional fuel item of substantial size. Engineering judgement is usually sufficient to estimate what large fuel item(s) are close enough to a small fire of the defined type to be the subsequent item ignited that creates a well-established fire.

Annex A contains guidance relating to sourcing data for frequencies by fire type.

6.2.5 Step 4 — Potential complicating hazards leading to other fire scenarios

It is necessary to consider the fire scenarios that can arise from the potential hazards identified while developing the trial fire safety design plan as associated with the intended use of the property or the design. It is also necessary to identify other critical high-consequence scenarios excluding high-hazard locations, which were addressed in Step 2. Examples include the following:

— vulnerability to common-cause events, such as earthquakes or terrorism, with the potential to initiate multiple severe fires or to disable multiple fire-safety measures simultaneously;

— vulnerability to non-fire events that can weaken the built environment structure and lower the threshold of fire severity needed to produce structural collapse;

— use of high hazard materials that are susceptible to spontaneous ignition, rapid fire spread, explosion, unusually intense fire, unusually toxic smoke, unusual environmental hazard in products of combustion or contaminated fire-fighting media, embedded oxygen that can feed fire separately from ambient air, unusual difficulty or danger if fire is fought by conventional means (such as pool chemicals), or other unusually severe fire conditions;

— presence of high-hazard operations, including use of open flame near easily ignited materials;

— special hazards present during the construction phase or during maintenance operations.

If any of these scenarios are considered to be as likely as and more severe than those identified previously, it is necessary that they need to be included in the set for analysis. They may replace less hazardous scenarios that are similar in nature.

6.2.6 Step 5 — Systems and features impacting on fire

Identify the fire safety systems and features which, if they fail, are likely to influence the achievement of the fire safety objective. The impact of less than perfect system reliability will be considered separately in 6.4 (Step 8).

Typical systems and features for consideration include the following:

a) passive systems and features:

   — contents, furnishings or materials control (perhaps with fire retardant treatments, or otherwise subject to flammability control);

   — doors and other openings in the enclosure of fire origin and other relevant compartmentation; windows, wall and ceiling/floor assemblies and other elements of compartmentalization as well as any penetration systems, fire resistance ratings and flammability properties;

   — structural members including their means of protection and fire resistance ratings;

b) active systems and features:

— active suppression system (sprinklers, gas flooding, etc.);

— smoke management system (natural or mechanical ventilation);

— fire detection system (smoke, heat, etc.);

— warning and communication system;

— egress system (including hold-open devices on doors);

— fire safety management;

— fire fighter operations.

6.2.7 Step 6 — Occupant actions impacting on fire

The actions that people take can have significant impact, favourable or otherwise, on the course of the fire or the movement of smoke, and shall be identified in this step. Acts of carelessness or of arson that cause fires to start are likely to have been captured in the fire incident data employed in Step 3 and need not be considered here again. Rather, it is actions following ignition that it is necessary to consider.

Depending on the nature of the built environment, trained staff or an in-house fire brigade can have a profound influence on a fire in the early stages of development, for example if staff close doors upon detection of the fire. The favourable actions of municipal fire fighters can also be considered, particularly for objectives related to property protection or business continuity. On the other hand, poorly trained staff or casual visitors could leave key doors open, allowing rapid fire development and smoke transport. The characteristics of the fire and its effluent could also prevent people intervening in the fire.

6.3 Step 7 — Selection of design fire scenarios

6.3.1 General

In Steps 1 through 6, a large number of potential fire scenarios have been identified. From this large number, scenario clusters and a set of design fire scenarios is to be selected.

6.3.2 Combining scenarios into scenario clusters

The characterization of scenarios performed in 6.2 shall now be refined into a concise, parametric description of the universe of possible scenarios. Models and other calculation procedures may be used to evaluate the effect that the fire safety systems and features identified in Step 5 have on the course of the fire, by applying for example, ISO 16735 (smoke layers) or ISO 16737 (vent flows).[2] [3] The limits of application of the models and procedures used shall be recognized. See ISO 16730-1 and ISO/TS 13447 for further guidance.[4] [5]

The process of combining scenarios into scenario clusters involves identifying common parameters and fire characteristics. For example, one could identify five types of rooms or areas (e.g. normally occupied rooms, normally unoccupied rooms, means of egress, concealed spaces, exterior locations) or three ranges for the rate of increase in fire severity (e.g. linear growth, corresponding to smouldering and two ranges for the alpha parameter in a t-squared fire representation, corresponding to flaming and fast flaming). By selecting a type or range from each parameter, the user defines a specific scenario cluster, which combines more fully specified scenarios (e.g. each of the specific points of origin in each of the rooms that fit a particular room type). Each scenario cluster is represented by a single representative design fire scenario whose consequence will be used to characterize the consequence for all scenarios in the cluster.

With respect to both the location of the point of origin and the initial rate of fire growth (such as smouldering, flaming, fast flaming or explosion), it is likely that some locations or rates of fire growth will challenge some fire protection systems or features, while other locations or rates will challenge other fire protection systems. This may dictate the use of multiple representative scenarios for a single scenario cluster or it may be addressed by selecting representative scenario characteristics to challenge one design system or feature in one area, while selecting characteristics to challenge a different system or feature in another area.

6.3.3 Caution on exclusion of scenarios believed to have negligible risk

Because there are a very large number of possible fire scenarios, the process of combining scenarios into a collectively comprehensive set of scenario clusters will be simplified if some scenarios can be excluded at the outset based on negligible risk. This step shall be justified explicitly and quantitatively and shall be taken only when there is strong evidence that the facts support a judgment of negligible risk. It is particularly dangerous to use this step to exclude low-frequency, high-consequence scenarios. Scenarios that have low frequency individually may not be low frequency if considered as a group.

Scenarios that are considered unlikely may also have sufficient uncertainty in that estimate that they cannot be confidently treated as such.

6.3.4 Demonstrating that the scenario structure is complete

Provide a mapping of the universe of potential scenarios into scenario clusters either selected for analysis or specifically excluded, as specified in 6.3.2 and 6.3.3. This will establish that all scenarios have been considered and that their treatments were explicitly chosen, which means the scenario structure is complete.

If two or more candidate designs are to be compared relative to each other rather than to specified acceptability criteria, then in some cases, scenario clusters can be excluded even if they involve significant risk. For example, if the two designs can be expected to have similar or identical risk in those scenarios. In this case, "similar" means that the expected difference in risk for the scenarios proposed for exclusion is substantially less than the expected difference in risk for the scenarios proposed for explicit analysis. Set these expectations on the basis of engineering judgement, however, since consensus engineering judgment can reflect a shared misperception of the true risk, these kinds of exclusions should be few in number.

6.3.5 Scenario selection procedure based on level of analysis

There are two levels of analysis that may apply:

— qualitative based on engineering judgement and simple risk screening;

— semi-quantitative using generic data from similar built environments for scenario frequency assessment and deterministic calculations.

Where a full quantitative fire risk assessment procedure is envisaged using built environments specific data and determination of scenario probability and consequence, a risk-ranking process as described in ISO 16732-1 is an appropriate basis for the final selection of design fire scenarios, and readers are directed to ISO 16732-1 at this point.

Where a simplified approach (qualitative or semi-quantitative) to design fire scenario selection where less detailed scenario frequency data may be available, the procedures described in 6.3.6 shall be considered appropriate.

6.3.6 Selection of design fire scenarios for deterministic analysis

The process described in this subclause will focus on finding worst credible cases, i.e. design scenarios that challenge the achievement of the fire safety objectives. For this purpose, Steps 1 to 6 described in 6.2 can be simplified for different locations and types of fire, by identifying the following:

a) those aspects and characteristics of target/people/fire that are challenging because they increase the risk of unacceptable harm through characteristics of the targets and/or the occupants;

b) those aspects and characteristics of target/people/fire that are challenging because they increase the risk of unacceptable harm through characteristics of the fire;

c) those aspects and characteristics of the fire safety systems or features that are challenging because they reduce the operability or effectiveness of the system or feature.

Where the built environment has been compartmented to prevent fire spread, it will be necessary to consider location(s) within each compartment to ensure all parts of the built environment are evaluated. Compile a manageable set of design scenarios that are challenging based around the identified characteristics of the target/people, fire development, and fire safety systems or features.

For a qualitative or semi-quantitative selection process, the frequency of each design fire scenario does not require explicit evaluation since all representative scenarios shall be considered and not combined with other scenarios. Fire scenarios can be evaluated for use as representative or design fire scenarios by considering whether the scenario is capable of producing conditions that would exceed the performance criteria, or whether they can be replaced by other representative scenarios of greater severity.

For example, for semi-quantitative screening, separate risk matrices can be developed for each type of consequence. An example of a risk ranking matrix is shown in Figure 2. In this example, the scenario frequency appears in each column and the scenario consequence in each row. Therefore, the scenarios with the highest risk appear in the top right of the matrix (darker cells) while the lower risk scenarios appears in the bottom left of the matrix. See also ISO 31000 and References [7] and [8] for further guidance in using risk ranking matrices.

EXAMPLE 1 For a life safety objective, a high risk scenario could be when fatalities or life threatening injuries are expected (high consequence) as a result of a fire scenario that could occur several times over the life of the built environment (anticipated event).

EXAMPLE 2 For a business interruption objective, a low risk scenario could be when some downtime is expected with damage that is repairable (low consequence) as a result of a fire scenario that will probably not occur over the life of the built environment (unlikely event).

Where the fire safety objective is life safety, readers are also referred to ISO/TS 29761[1] for a more detailed discussion on the selection of design occupant behavioural scenarios and design behaviours and how they relate to the design fire scenario.

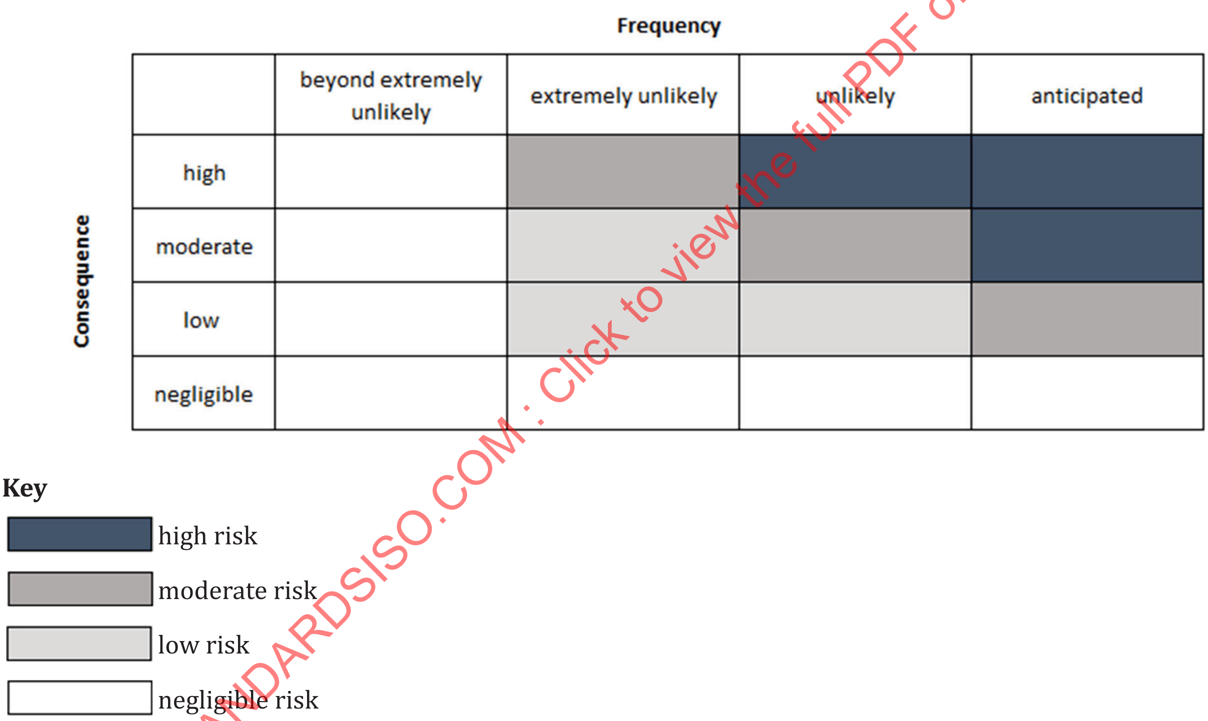


Figure 2 — Risk ranking matrix

6.4 Step 8 — Modify scenario selection based on system availability and reliability

When the ability of the fire to grow arises from less than perfect system reliability or a fire safety feature not performing as intended, it is not possible for any design, however redundant, to fully achieve the fire safety goals and objectives normally set for a project where systems are all fully functional and operating as designed.

For each system (as identified in Step 5), consider the possibility that it is not operational (due to routine maintenance, deterioration with age, or human action or inaction, etc.). In this case, it is acceptable to include the scenario for analysis but modify the design fire or the performance criteria to be achieved under a system failure condition, such that a greater hazard may be considered tolerable.

If the possibility of a system or feature not performing as intended has not been allowed for in the preceding identified design fire scenarios, then the probability of failure should be considered and either

— the stakeholders and design team agree that the probability of failure is sufficiently low that the risk is acceptable and the scenario is not a credible one for analysis or

— the stakeholders and design team agree to include the scenario as a design fire scenario and agree on what design fire characteristics and/or performance criteria will be applied in the analysis. These need not be the same as for other scenarios where the system or feature performs as intended. Justification of design fire size modifications shall be provided whenever limited performance of the system or feature is being considered.

EXAMPLE 1 Consider the design of a smoke extract system for a sprinklered building, for the scenario where the sprinklers fail to operate. Depending upon the acceptable resulting risk levels, the design of the smoke extraction system can be based on a fire size that is less than that expected to be reached when there are no sprinklers or when the sprinklers failure to operate. It would also be assumed that the designed smoke extraction system capacity is not adversely influenced in case of sprinkler failure.

EXAMPLE 2 Consider the design of a smoke extract system, for the scenario where a single smoke extract fan fails to operate. The design minimum smoke layer height above floor level might be reduced compared to the scenario where all smoke extract fans operate as intended.

6.5 Step 9 — Final selection and documentation

For each fire safety objective, select the highest ranked fire scenarios for analysis. The selected scenarios should represent the major portion of the cumulative risk (sum of the risk of all scenarios). Input from the stakeholders into this selection process is recommended. Document the fire scenarios selected for analysis. These become the "design fire scenarios". Also document the fire scenarios not selected for analysis and indicate reasons.

In making final selections, there are certain common errors or biases to be wary of, including the following.

— If multiple, high-consequence but unlikely scenarios are eliminated from consideration, it is important to be careful that the eliminated scenarios do not have a moderate or high collective likelihood. Where possible, it is better to combine like scenarios, so that more scenarios are directly represented and analysed, than to eliminate scenarios.

— It is not appropriate at this stage to eliminate a scenario, despite its substantial contribution to risk, because the only design choices capable of producing an acceptable outcome for that scenario are very expensive. A decision to accept the risk of a particular scenario because of the high cost of eliminating or reducing that risk should be made at a later stage, after more detailed analysis and only with the full involvement of the stakeholders.

— It can be appropriate to eliminate a scenario, despite its substantial contribution to risk, because no identifiable design choice can reduce or eliminate that risk. For example, unless design choices include selection of clothing and managing occupant activity, risks to persons who are intimate with the starting point of a fire or who are incapable of acts of self-preservation can be examples of the bases for scenarios that can legitimately be eliminated at this stage. Elimination of such scenarios, however, should be documented, stating why it is not possible to protect the person or eliminate the hazard by any means. It would not be appropriate to eliminate a scenario if the conditions of the occupants should be expected (for example, intoxicated customers in a nightclub). In such a case, additional protection would be an appropriate design decision.

Annex A
(informative)

Data for development of design fire scenarios

A.1 General

Table A.1 is intended to guide the user as to the type and source of data typically required in applying this part of ISO 16733. Sometimes, data required for a specific scenario is not available requiring users to apply engineering judgement. In this case, alternative sources of data could be from individuals with field observation knowledge based on lengthy work experience. Delphi panels comprising groups of experts are also sometimes used to try and eliminate bias in the grouping of opinions into an expert estimate. Also see ISO 16732-1 for further guidance on use of engineering judgment and in estimating frequency and probability.

A.2 Data for development of design fire scenarios

Table A.1 — Data for development of design fire scenarios

Data element	Value and/or Source	Reference
Frequencies by fire location	If fire statistics are available by area of origin, then use these. If not, separate areas into these groups: (a) normally occupied spaces, (b) occupiable but not normally occupied spaces (e.g. closets), (c) means of egress, (d) rooms and areas containing identified major hazards, (e) concealed spaces and exterior locations. Treat each of these area groups as a group to be represented by at least one of the areas chosen for a design fire scenario. Specific locations within a chosen space will also need to be selected, but these can be inferred by engineering judgment from the choice of first burning item. Also see ISO 16732-1 for further guidance on estimating frequency and probability. **Limitations** Fire incident data collected by Fire Departments may not be complete where only some Fire Departments contribute data to a wider jurisdiction. Many countries do not collect fire data systematically. International compatibility of fire statistics may be significantly limited in some cases, resulting in differences of orders of magnitude.	6.2.3

Table A.1 *(continued)*

Data element	Value and/or Source	Reference
Frequencies by fire type [with type defined by initial ignition conditions (or initial burning rate)]	First, create a typology of fires based on ranges of initial burning rates, with the contents of each type defined by lists of items first ignited, types of materials first ignited, and/or igniting heat sources (e.g. lighted tobacco product, open flame, radiant or convective heat). Based on the composition of this item, the arrangement of other (secondary) combustible items and availability of oxygen, one can use engineering judgment to infer an initial burning rate, which might be extended to initial smouldering, a generic free-burning rate or a flash fire or explosion initiation. Transition to multiple items burning may involve estimations of room layouts and ventilation conditions, and use of algebraic expressions to estimate when and whether a second item will ignite. Transition to full room involvement may involve estimations of room fuel loads and ventilation and use of algebraic expressions to estimate when and whether flashover will occur. Room linings may be relevant to flame spread past the first room to adjacent spaces. The existence, characteristics and status of barriers may be relevant to calculation of fire spread to sections of a floor or to additional floors. If the designations of items first ignited, first ignited materials, and heat sources match the structure of available fire incident databases, then fire statistics can be used directly to estimate the needed frequencies. If the match is not exact, it will be necessary to use engineering judgement in combination with fire statistics to produce the needed estimates. **Limitations** Fire incident data collected by Fire Departments may not be complete where only some Fire Departments contribute data to a wider jurisdiction.	6.2.4
Timing and frequencies of stage transitions by fire type	Fire statistics can be used to estimate the probability that a particular type of fire will spread from the object of origin (first item ignited) to the burning of multiple items in the first room or space, the probability that fire will spread from multiple items in the first room or space to burning outside the first room or space (which can be used as a proxy for the occurrence of flashover), and the probability that fire will spread from burning in more than one room on a single floor to burning on more than one floor, as well as the probability that fire will spread from burning in one building to burning of other buildings or outside objects. The timing of these transitions, if they occur, can be estimated from laboratory experiments or calculation, based on room dimensions, room linings, fuel load, ventilation, and other relevant factors. When enough data are available to track the spread of fire from the first item ignited to other nearby items prior to flashover, then new factors (such as the ignition characteristics and location of secondary items) may also need to be considered. Otherwise a representative heat release rate with time curve for the room of fire origin may be chosen. **Limitations** Data may be scarce in which case less complete data from other jurisdictions or sources might be considered. Otherwise it may be necessary to utilize engineering judgement to agree on the data to be used. It is desirable that this be a team effort involving individuals with the relevant areas of expertise and experience.	6.2.4

Annex B
(informative)

Example of a set of explicit fire scenarios

B.1 General

This example describes 10 general fire design scenario sets to be considered as part of a fire safety engineering analysis for a built environment. The example is based on the scenarios listed in several national regulatory documents.[9] [10] It is expected that each scenario set would be applied multiple times to different parts of the built environment as agreed amongst the project stakeholders, regulatory authority and peer reviewers. Analysis need not always involve quantitative calculations.

A set of design scenarios should apply given specific fire safety objectives. The fire safety objectives for this example include life safety, protection of neighbouring property and facilitating fire-fighting and rescue operations. The general set of scenarios described here serves to illustrate the range of scenario characteristics that might be included. It is expected that the scenarios would be further developed in detail and in scope to suit the particular requirements of a given jurisdiction.

The fire design scenarios sets are discussed in B.2 to B.11.

B.2 Fire blocks exit

This scenario set should require the engineer to evaluate the number and availability of escape routes within the built environment. It should allow the impact of fire location on the viability of escape routes to be assessed. It should consider the number of occupants potentially affected, their location within the built environment and the availability of alternative escape routes.

B.3 Fire in normally unoccupied room threatening occupants in other parts of the building

This scenario set requires the engineer to evaluate the potential for fire to develop undetected within a normally unoccupied area and then spread to other parts of the built environment, endangering occupants remote from the fire. The rate of fire and smoke spread and the extent to which the occupants receive early warning, and are protected from the effects of the developing fire should be considered.

B.4 Fire in a concealed space

This scenario set requires the engineer to evaluate the potential for fire to develop undetected within a concealed space (ceiling plenums, subfloor spaces, wall cavities, etc.) and then spread to other parts of the built environment, endangering occupants remote from the fire. The potential rate of fire and smoke spread and the extent to which it is restricted or confined should be considered.

B.5 Smouldering fire

This scenario set requires the engineer to evaluate the potential for a smouldering fire to incapacitate occupants taking into account the expected characteristics and activity of the occupants (sleeping, alert) and the extent to which early warning of fire and smoke is provided.

B.6 Horizontal fire spread

This scenario set requires the engineer to evaluate the potential for fully developed fire to spread or cause damage to horizontally offset built environments by breaching walls or roofs or due to flames emerging from openings within the walls and roofs. Where neighbouring built environments are separated by distance, heat transfer by mainly radiation and convection causing damage to the neighbouring built environment should be considered. Where neighbouring built environments are separated by construction, the level of fire resistance provided by the construction should be considered. It may also be appropriate to consider the presence of automatic suppression systems and the availability of external fire-fighting resources.

B.7 Vertical fire spread

This scenario set requires the engineer to evaluate the potential for fully developed fire spread to threaten occupants or fire services, or cause damage to vertically offset built environments typically located at different levels within the built environment. It is necessary to take into account the flammability and ignitability of materials and construction used in the external wall, the size and location of any openings in the wall, and the protection afforded by construction elements in reducing the hazard due to external fire plumes potentially allowing fire spread to other higher levels in the built environment. It may be necessary to consider initial fire locations both inside and external to the built environment.

B.8 Rapid fire spread involving interior surface linings

This scenario set requires the engineer to evaluate the flammability of materials used as interior surface linings (walls, ceilings, floors) for their potential contribution to the rate of fire growth, smoke and toxic gas generation causing incapacitation of occupants before evacuating. It is necessary to consider the number and locations of occupants, the time required to alert and evacuate occupants as well as the quantity and configuration of the surface linings. It may also be appropriate to consider the potential contribution to the fire hazard due to cables, ducts, pipe insulation materials or similar combustible components.

B.9 Challenging fire for fire-fighting and rescue operations

This scenario set requires the engineer to evaluate the potential for fire and smoke to endanger fire rescue personnel located within and around the built environment. These scenarios should challenge the structural stability of upper floors and stair shafts in multi-storey built environments intended to be used by fire services for rescue or fire-fighting operations. It may also be necessary to consider the means by which fire services and appliances can reach and access the building (vehicular facilities), receive information about the incident and fire location (fire control centres, alarm panels), access firefighting water supplies (hydrants) and so on.

B.10 Challenging fire for evacuation and life safety assessment

This scenario set requires the engineer to evaluate the potential for occupants to become incapacitated prior to safely evacuating the built environment. The fire locations and type need to be considered with respect to the number, location and characteristics of the occupants within the built environment such that it represents a credible worse case challenge to the safety of the occupants.

B.11 Robustness check

This scenario set requires the engineer to evaluate the potential for the fire safety features included within the built environment to be less than perfectly reliable or unavailable and the impact this would have on the evaluations carried out for the preceding scenarios (B.2 to B.10). For these scenarios, it may be acceptable to reassess previous scenario evaluations with either modified performance criteria or modified design fires under an assumed system failure condition, such that a greater hazard or reduced safety factor may be considered tolerable.

Annex C
(informative)

Design fires

C.1 General

Initially, the design fire is defined in terms of the design fire scenario. It can, for example, be defined in terms of the rate of heat release of a single item. However, design fire characteristics can be subsequently modified based upon the outcome of the analysis. For example, if the single-item fire grows sufficiently intense that flashover in an enclosure is likely, it is necessary to modify the design fire to reflect the characteristics of a ventilation-controlled post-flashover fire. Similarly, events such as sprinkler activation and window breakage impact on the design fire. It is necessary to ensure, however, that the design fire is appropriate to the objectives of the fire-safety engineering analysis and results in a design solution that is conservative.

It is possible to have more than one design fire for a particular design-fire scenario. For example, when fire spreads beyond the room of fire origin to another enclosure, a new design fire can be required to represent the fire in the second enclosure.

Fire can grow from ignition through to a fully developed stage and finally decay and eventual extinction. The design fire is described by the values of variables, such as the rate of heat release, over the life of the fire.

A full specification of a design fire (see Figure C.1) can include the following phases:

— incipient phase: characterized by a variety of sources, which can be smouldering, flaming or radiant;

— growth phase: covering the fire propagation period up to flashover or full fuel involvement;

— fully developed phase: characterized by a substantially steady burning rate as may occur in ventilation or fuel-bed-controlled fires;

— decay phase: covering the period of declining fire severity;

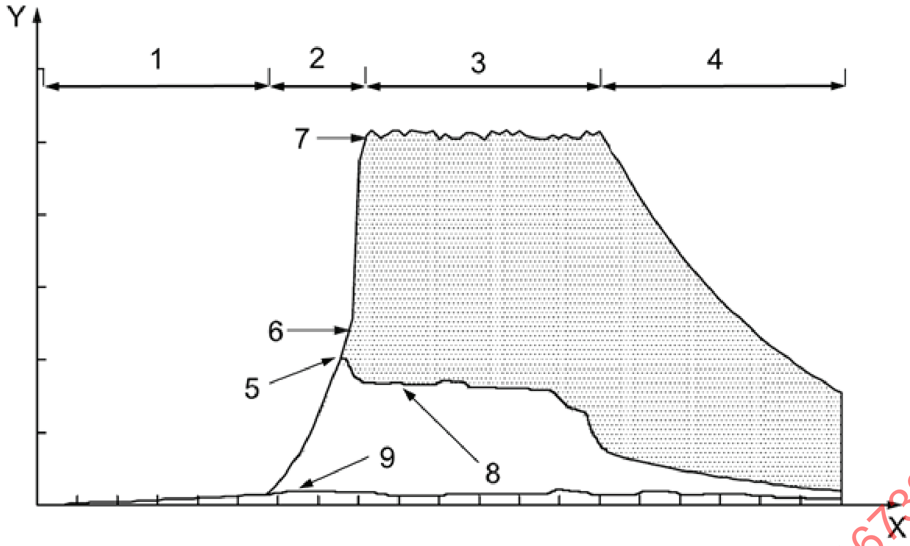
— extinction: when there is no more energy being produced.

Consequently, a design fire has to be understood as the description of the full duration of a fire. This description includes the following:

— parameters provided by the design-fire scenario (size of the room, location of the fire, combustible material under consideration, ...);

— parameters required to make the assessment of the fire development (rate of heat release and other parameters depending on the assessment model to be used);

— events that result in a change in any of the above parameters.



Key

1 incipient
2 growth
3 fully developed
4 decay
5 sprinkler activation
6 flashover
7 ventilation-controlled
8 sprinkler-controlled
9 smouldering
X time
Y heat output

Figure C.1 — Example of design fire

C.2 Basic characteristics

C.2.1 Design fires are usually characterized in terms of the following variables with respect to time [as needed by the fire safety objective(s) and consequently by the analysis]:

— heat release rate;

— toxic species production rate;

— smoke production rate;

— fire size (including its evolution versus time);

— temperature/heat flux evolution versus time.

C.2.2 The factors determining the characteristic rate of fire growth for flaming fires include the following:

— nature of combustibles;

— geometric arrangement of the fuel;

— geometry of the enclosure;

— ignitability of the fuel;

— rate of heat release characteristics;

— ventilation;

— external heat flux;

— exposed surface area.

C.2.3 The initial rate of fire growth is subsequently modified by events that occur during the design fire scenario. These events can modify the heat release rate of the fire either positively or negatively. Typical events and their effects are the following:

— flashover	transition to a state of total surface involvement;
— low interface (hot and cold) layers	acceleration;
— sprinkler activation	steady or declining;
— manual fire suppression	steady or declining;
— fuel exhaustion	decay;
— changes in ventilation	modify fire characteristics;
— flaming debris	subsequent ignition(s).

It is important that a determination of the rate of initial fire growth needs consider these aspects. Fire models are available that can predict rate of fire growth on simple fuel geometries under defined conditions. Experimental data are also available[11] to assist in the determination of rate of fire growth on typical fuel packages.

C.2.4 Flashover

Flashover is the rapid transition from a localized fire to the involvement of all exposed surfaces of combustible materials within an enclosure. It occurs somewhat commonly in small and medium enclosures.

The effect of flashover on the design fire is to modify the heat release rate and other characteristics to those appropriate to a fully developed fire. The fully developed fire can be either ventilation- or occasionally fuel-bed-controlled.

The general criteria for assuming the occurrence of flashover within an enclosure room are the following:[12]

— 500 °C to 600 °C in the upper layer of gases;

— 20 kW/m^2 for radiation from this upper layer to the floor.

C.2.5 Fully developed fires

Following flashover, fires tend to rapidly reach a fully developed stage where the rate of combustion is limited either by the fuel or the available ventilation. The peak heat release rate following flashover may be taken as the lesser of the ventilation-controlled and the fuel-bed controlled heat release rates. The transition from a fuel-bed controlled regime to a ventilation-controlled regime occurs approximately as given by Formula (C.1):

$$\dot{m}_\mathrm{f} \approx \frac{\dot{m}_\mathrm{air}}{r} f \quad \mathrm{kg/s} \qquad \text{(C.1)}$$

More specific criteria have been developed for particular fuels such as burning timber cribs.[13]

In determining structural response, post-flashover fires are characterized in terms of fire-gas temperatures. The convective and radiative heat transfer characteristics of the environment can also have a major impact on the heating of structural members and bounding elements of enclosures and it is important to select them carefully.

C.2.6 Ventilation-controlled fires

The ventilation-controlled rate of burning in a compartment can be determined from consideration of air flowing into the compartment. Research has indicated[12] that the rate of air flow into a fire compartment is proportional to the ventilation factor, $A\sqrt{h}$. The mass rate of fuel burning can then be estimated from the combustion reaction taking into account the fact that under ventilation-controlled conditions the fuel/air ratio is greater than the stoichiometric ratio. The energy release rate can be determined[13] from consideration of the effective heat of combustion of the fuel.

The above approach based on the ventilation factor underestimates fire severity in compartments with separate ventilation openings at floor and ceiling levels. It also might not be appropriate for large compartments.

C.2.7 Fuel-bed-controlled fires

Fuel-bed-controlled fires occur less frequently than ventilation-controlled fires and can be expected only in particular situations, such as storage-type occupancies with a high level of ventilation.

The burning rate of fuel-bed-controlled fires is dependent upon the nature and surface area of the fuel. In most practical applications, these factors are difficult to determine. For simple, well-defined geometries such as timber cribs, relationships have been developed relating fuel pyrolysis rate to initial fuel mass per unit area and the remaining fuel mass per unit area.[11]

C.2.8 Automatic suppression system activation

Automatic suppression systems can operate at any time during the fire but are normally expected to operate during the pre-flashover stage. The heat-release rate following activation of a sprinkler system can be taken as remaining constant, unless it can be demonstrated that the sprinkler system has been designed to suppress the fire within a specified period. In the latter case, the heat-release rate can be assumed to decrease in a linear manner over the specified period.

Similarly, activation of a total flooding gaseous fire suppression system designed in accordance with the relevant ISO or national standard can be assumed to suppress the fire soon after the design concentration of extinguishing agent has been reached.

C.2.9 Intervention by fire services

The fire services may intervene at any time during the development of the fire, but it is likely that they are able to control the fire only if it is within the capabilities of the appliances in attendance. The effect of the fire services on the fire will be dependent on factors such as the means of notification of the fire, the location and distance of the built environment from fire stations, the resources available to the fire services, site access conditions and adequacy of the water supplies. It is important that the design fire challenges the capability of fire services to carry out rescue and firefighting activities and therefore it may differ from other design fires intended to challenge other fire safety systems. For example, a longer fire growth stage can result in more challenging conditions at the time of fire service arrival compared to a fire that is in decline. It can also be necessary to consider the effect of the fire on fire services personnel to assess their effectiveness in carrying out rescue or fire-fighting activities.

Unless an appropriate model for fire brigade intervention and effectiveness is used (for example, see References [14] and [15]), the intervention should not be considered to influence the design fire.

C.2.10 Decay

When most of the fuel in an enclosure has been consumed, or the fire fails to spread to adjoining items, the rate of burning decreases generally due to the build-up of char. The onset of decay has not yet been defined and further research is needed for accurate prediction.

