TECHNICAL REPORT

ISO/TR 13387-2

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Fire safety engineering —

Part 2:
Design fire scenarios and design fires

Ingénierie de la sécurité contre l'incendie —

Partie 2: Conception des scénarios-incendie et des feux

Reference number
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Contents

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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.

The main task of ISO technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 13387-2, which is a Technical Report of type 2, was prepared by Technical Committee ISO/TC 92*, Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

It is one of eight parts which outlines important aspects which need to be considered in making a fundamental approach to the provision of fire safety in buildings. The approach ignores any constraints which might apply as a consequence of regulations or codes; following the approach will not, therefore, necessarily mean compliance with national regulations.

ISO/TR 13387 consists of the following parts, under the general title *Fire safety engineering:*

— *Part 1: Application of fire performance concepts to design objectives*

— *Part 2: Design fire scenarios and design fires*

— *Part 3: Assessment and verification of mathematical fire models*

— *Part 4: Initiation and development of fire and generation of fire effluents*

— *Part 5: Movement of fire effluents*

— *Part 6: Structural response and fire spread beyond the enclosure of origin*

— *Part 7: Detection, activation and suppression*

— *Part 8: Life safety — Occupant behaviour, location and condition*

Annex A of this part of ISO/TR 13387 is for information only.

Introduction

The specification of appropriate design fire scenarios and design fires are a crucial aspect of fire safety design. The assumptions made with regard to these factors have a major impact on all aspects of the design as they represent the input into most of the quantification processes.

A design fire scenario is the description of the course of a particular fire with respect to time and space. It includes the impact on the fire of building features, occupants, fire safety systems and all other factors. It would typically define the ignition source and process, the growth of fire on the first item ignited, the spread of fire, the interaction of the fire with its environment and its decay and extinction. It also includes the interaction of this fire with the building occupants and the interaction with the features and fire safety systems within the building.

ISO/TR 13387-1 provides a framework for the quantitative fire safety engineering assessment of buildings using time-dependent calculations. Fire scenario analysis forms the basis of the method described.

The basis of these calculations is the design fire. A design fire is an idealisation of real fires that may occur in the building. Design fires are described in terms of the variation with time of variables used in the quantitative analysis. These variables typically include heat release rate, fire size, yield of toxic species and yield of soot.

Where the calculation methods used are not able to predict fire growth and spread to other objects within the compartment of origin or beyond, such growth and spread needs to be specified by the analyst as part of the design fire, satisfying the functions of both SS2 and SS3.

Fire safety engineering —

Part 2:
Design fire scenarios and design fires

1 Scope

This part of ISO/TR 13387 provides guidance on the identification of appropriate design fire scenarios for consideration in fire safety design. It also provides guidance on the specification of design fires for quantitative analysis in fire safety design of buildings. This approach may be applied to other constructions. It is intended for use in conjunction with the methodology outlined in part 1 of this Technical Report.

The document describes a systematic approach to the identification of significant fire scenarios that need to be considered in fire safety design. Once significant fire scenarios have been identified, the document provides guidance on the selection of "design fire scenarios" for quantitative analysis.

The document provides guidance on the specification of "design fires" to reflect the design fire scenarios that have been identified for analysis. Design fires are specified in terms of important characteristics that form the input data into the quantitative analysis of various subsystems of the fire safety system as described in part 1.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO/TR 13387. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO/TR 13387 are encouraged to investigate the possibility of applying the most recent additions of the normative documents indicated below. For undated references, the latest addition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid international standards.

ISO/TR 13387-1, *Fire safety engineering — Part 1: Application of fire performance concepts to design objectives.*

ISO/TR 13387-3, *Fire safety engineering — Part 3: Assessment and verification of mathematical fire models.*

ISO/TR 13387-4, *Fire safety engineering — Part 4: Initiation and development of fire and generation of fire effluents.*

ISO/TR 13387-5, *Fire safety engineering — Part 5: Movement of fire effluents.*

ISO/TR 13387-6, *Fire safety engineering — Part 6: Structural response and fire spread beyond the enclosure of origin.*

ISO/TR 13387-7, *Fire safety engineering — Part 7: Detection, activation and suppression.*

ISO/TR 13387-8, *Fire safety engineering — Part 8: Life safety — Occupant behaviour, location and condition.*

ISO 13943, *Fire safety — Vocabulary.*

3 Terms and definitions

For the purposes of this part of ISO/TR 13387, the terms and definitions given in ISO 13943 and ISO/TR 13387-1 and the following apply:

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

Typically, it is an idealised description of the variation with time of important fire variables such as heat release rate, fire propagation, smoke and toxic species yield and temperature.

3.2
design fire scenario
a specific fire scenario on which an analysis will be conducted

3.3
engineering judgement
the process exercised by a professional who is qualified by way of education, experience and recognised skills to complement, supplement, accept or reject elements of a quantitative analysis

3.4
fire scenario
a qualitative description of the course of a fire with time, identifying key events that characterise the fire and differentiate it from other possible fires

It typically defines the ignition and fire growth process, the fully developed stage and the decay stage, together with the building environment and systems that will impact on the course of the fire.

3.5
relative risk
the relative potential for realisation of an unwanted event

It is the product of the probability of occurrence of a consequence and the magnitude of the consequence based on numbers that are only internally consistent within the set being compared and does not represent the actual risk in absolute values.

4 Symbols and abbreviated terms

A_w	Area of window opening, expressed in m^2
g	Acceleration due to gravity, expressed in m/s^2
h_w	Height of window, expressed in m
$\dot{Q}$	Heat release rate, expressed in MW
$\dot{m}_{air}$	Rate of inflow of air, expressed in kg/s
$\dot{m}_f$	Rate of volatilisation of fuel, expressed in kg/s
R	Burning rate (wood equivalent) , expressed in kg/s
r	Stoichiometric air/fuel ratio
ρ	Density, expressed in kg/m^3

t Time, expressed in s, min or h

T_a Ambient temperature, expressed in °C

T_g Fire gas temperature, expressed in °C

T_w Temperature of fire at window, expressed in °C

T_z Flame temperature along the vertical axis, expressed in °C

w Aggregate window width of enclosure, expressed in m

X Flame length along axis of flame, expressed in m

z Vertical distance, expressed in m

z_f Flame height, expressed in m

5 Design fire scenarios

5.1 Role of design fire scenarios in fire safety design

Design fire scenarios are at the core of the fire safety engineering methodology described in all parts of ISO/TR 13387. The methodology is based on analysing particular design fire scenarios and then drawing inferences from the results with regard to the adequacy of the proposed fire safety system to meet the performance criteria that have been set. Identification of the appropriate scenarios requiring analysis is crucial to the attainment of a building that fulfils the fire safety performance objectives.

In reality, the number of possible fire scenarios in most buildings approaches infinity. It would be impossible to analyse all scenarios even with the aid of the most sophisticated computing resources. This infinite set of possibilities needs to be reduced to a finite set of design fire scenarios that are amenable to analysis and the results of which represent an acceptable upper limit to the fire risk. That is to say that more onerous fire scenarios have an acceptable probability of occurring and that the consequences of those scenarios would need to be borne by society. The outcome of these extreme scenarios may be mitigated by additional factors that are often outside the scope of the analysis. Regulatory authority input into, and concurrence with, the selection of the design fire scenarios is most desirable.

The characterisation of a design fire scenario for analysis purposes should involve a description of such things as fire initiation, growth and extinction of fire, together with the likely smoke and fire spread routes under a defined set of conditions. This may include consideration of such conditions as different combinations of outcomes or events of each of the fire safety subsystems, different internal ventilation conditions and different external environmental conditions. The possible consequences of each design fire scenario need to be considered.

Important design fire scenarios need to be identified during the qualitative design review (QDR) stage. During this process, it is possible to eliminate scenarios that are of low consequence or have a very low probability of occurrence from further consideration (see 5.2.4). It is important to remember that smouldering fires may have the potential to cause a large number of fatalities in certain occupancies such as residential buildings.

Each design fire scenario is represented by a unique occurrence of events and is the result of a particular set of circumstances associated with the fire safety measures. Accordingly, a design fire scenario represents a particular combination of outcomes or events associated with factors such as:

— type of fire;

— internal ventilation conditions;

— external environmental conditions;

— performance of each of the fire safety measures;

— type, size and location of ignition source;
— distribution and type of fuel;
— fire load density;
— fire suppression;
— state of doors;
— breakage of windows;
— building air-handling system.

Design fires may be needed for a wide range of design fire scenarios. These may be internal or external fire scenarios. Examples of typical design fire scenarios include:

a) Internal

  — room fire (corner, ceiling, floor, wall);
  — fire in stairwells;
  — single burning item fire (furniture, wastepaper basket, fittings);
  — developing fire (smoke extraction);
  — cable tray or duct fire;
  — roof fires (under roof);
  — cavity fire (wall cavity, facade, plenum).

b) External

  — fire in neighbouring building;
  — fires in external fuel packages;
  — fires on roofs;
  — fires on facades.

Other design fire scenarios may be agreed upon during the QDR for special situations.

5.2 Identification of important design fire scenarios

5.2.1 General

A systematic approach to the identification of fire scenarios for analysis is desirable in order to identify all important scenarios and to provide a consistent approach by different analysts.

Generally, several design fire scenarios must be applied to the building under consideration to meet different requirements. At least one fire scenario should be considered for structural hazards and one for life safety hazards.

A risk-ranking process is recommended as the most appropriate basis for the selection of design fire scenarios. Such a process takes into account both the consequences and likelihood of the scenario.

Key aspects of the risk-ranking process, explained in the detailed steps below, are:

— identification of a comprehensive set of possible fire scenarios;

— estimation of the probability of occurrence of the scenario using available data and engineering judgement;

— estimation of the consequence of the scenario using engineering judgement;

— estimation of the relative risk of the scenarios (product of consequence and probability of occurrence);

— ranking of the fire scenarios according to the relative risk.

Design fire scenarios may need to consider not only the impact of all of the fire safety provisions on the chosen design fire but also the partial or complete failure of fire safety provisions.

Generally, fire scenarios involving simultaneous failure of a number of reliable fire safety systems properly maintained need not be considered as the combined probability of such scenarios are very low. However, if they are associated with very severe consequences, where the resultant risk is significant, then they need to be considered.

Fire incident statistics provide an appropriate basis for identification of the initial set of possible design fire scenarios. Fire statistics can be used to identify both the most common types of fire as well as the most hazardous type of fire for a particular occupancy.

The following systematic approach towards identifying possible design fire scenarios is recommended. It is recognised that alternative means of identifying design fire scenarios may be used.

5.2.2 Step 1 — Type of fire

From fire incident statistics appropriate for the building and occupancy under consideration, identify:

a) the most likely type of fire scenario;

b) the most likely severe-consequence fire scenario.

The most likely type of fire scenario can be determined from consideration of the items most commonly ignited, the ignition source and location of the fire from relevant fire incident statistics.

The most likely severe-consequence fire scenario can be determined by consideration of a subset of the fire incident statistics based upon an appropriate measure of the consequences, such as life loss or property loss. From this subset of severe-consequence incidents, appropriate for the building and occupancy under consideration, the most likely severe-consequence fire scenario can be identified.

If appropriate national statistics are not available, then information from other countries with similar fire experience may be utilised. Care needs to be exercised in applying fire incident statistics to ensure that the data is appropriate for the building under consideration.

5.2.3 Step 2 — Location of fire

For each of the scenarios identified in step 1, select a specific location or locations in the building that would produce the most adverse fire scenario(s).

5.2.4 Step 3 — Potential fire hazards

Consider the fire scenarios that could arise from the potential fire hazards identified during the qualitative design review phase.

Identify other critical severe-consequence scenarios for consideration. These scenarios typically involve:

— fires in assembly areas;

— fires within the egress system;

— fires blocking entry into the egress system;

— fires leading to structural collapse;

— fires involving high-hazard materials;

— fires exhibiting rapid growth.

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

5.2.5 Step 4 — Systems impacting on fire

Identify the building and fire safety system features which are likely to have a significant impact on the course of the fire or the development of untenable conditions. Typical factors for consideration and their states include:

— type of fire (smouldering or flaming);

— wind (calm or representative of the location);

— doors and other openings in the enclosure of fire origin (open or closed);

— active suppression system (successful or unsuccessful in controlling fire);

— smoke management system (performed as expected or reduced performance);

— windows (glass intact or glass breaks);

— fire detection system (functions as designed or reduced performance);

— materials control (effective in limiting fire growth or not);

— warning and communication system (functions as designed or reduced performance);

— compartmentation (functions as designed or reduced performance);

— egress system (capacity and facility as designed or reduced);

— structural members (perform as designed or reduced performance).

5.2.6 Step 5 — Occupant response

Identify occupant characteristic and response features which are likely to have a significant impact on the course of the fire. Typical factors for consideration are:

— occupant response to alarm system (normal or delayed response);

— occupant intervention (successful or unsuccessful intervention).

5.2.7 Step 6 — Event tree

Construct an event tree that represents the possible states of the factors that have been identified as significant. A path through this tree represents a fire scenario for consideration.

Event trees are constructed by starting with an initial state, such as ignition, and then a fork is constructed and branches added to reflect each possible state of the next factor. This process is repeated until all possible states have been linked. Each fork is constructed on the basis of occurrence of the preceding state. An example of an event tree is illustrated in Figure 1 (not all scenarios need to be quantified).

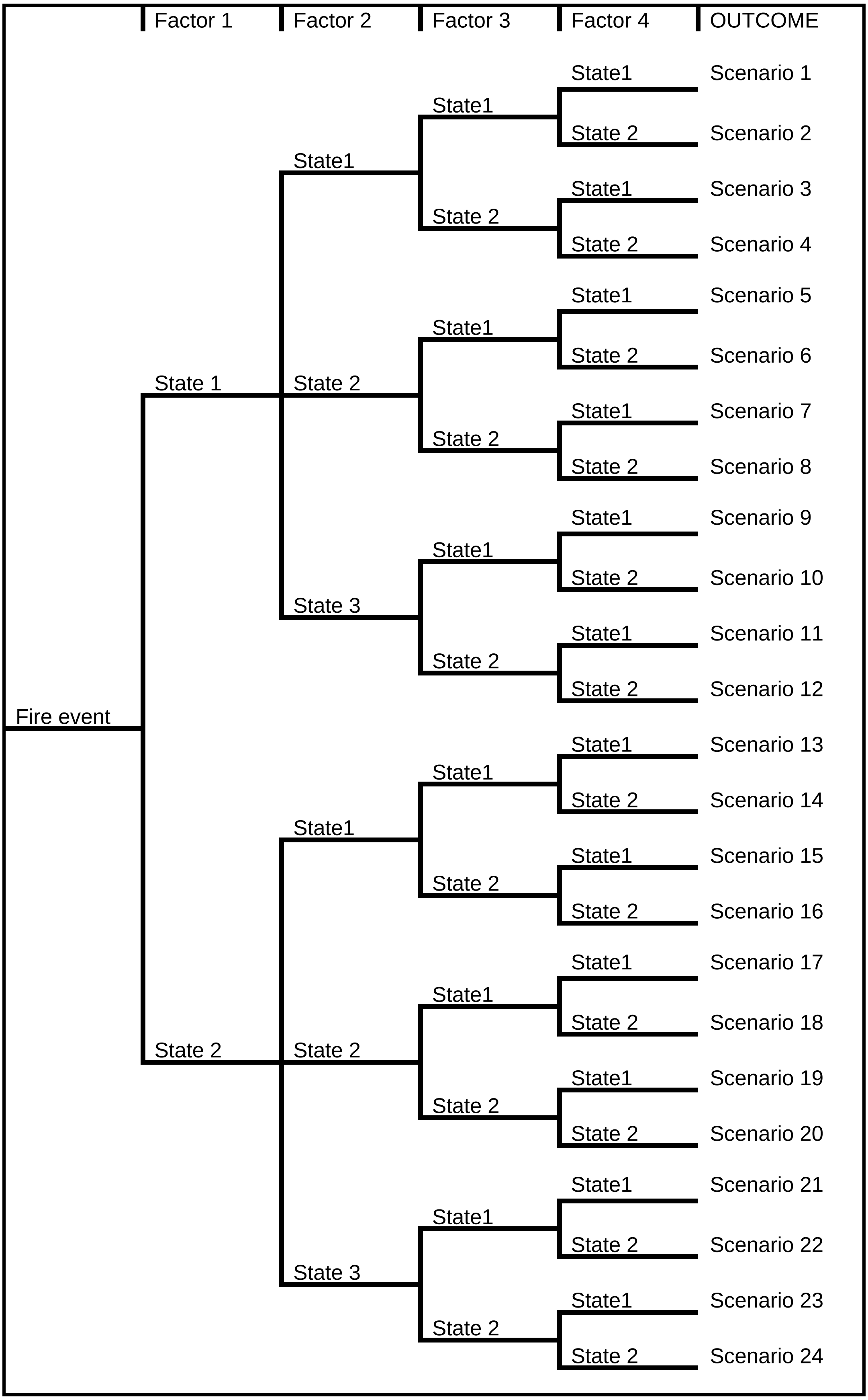

Figure 1 — Example of an event tree

5.2.8 Step 7 — Consideration of probability

Estimate the probability of occurrence of each state using available reliability data and/or engineering judgement. These can be marked on the event tree.

Evaluate the relative probability of each scenario by multiplying all the probabilities along the path leading to the scenario.

5.2.9 Step 8 — Consideration of consequences

Estimate the consequences of each scenario using engineering judgement. The consequences should be expressed in terms of an appropriate measure such as life loss, likely number of injuries or fire cost. The estimates should be conservative and may consider time-dependent effects.

5.2.10 Step 9 — Risk ranking

Rank the scenarios in order of relative risk. The relative risk is calculated by multiplying the measure of the consequences (step 8) by the probability of occurrence (step 7) of the scenario.

5.2.11 Step 10 — Final selection and documentation

Select the highest-ranked fire scenarios for quantitative analysis. The selected scenarios should represent the major portion of the cumulative risk (sum of the risk of all scenarios). Input from the regulatory authorities and the QDR team into this selection process is recommended. For a rigorous analysis, all scenarios in the event tree may need to be analysed.

Document the fire scenarios selected for analysis. These will become the “design fire scenarios”.

6 Design fires

6.1 Role of design fires in fire safety engineering

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 are referred to as “the design fire”.

The design fire needs to be appropriate to the objectives of the fire safety engineering task. For example, if the objective is to evaluate the smoke control system, a design fire should be selected that challenges the system. If the severity of the design fire is underestimated, then the application of engineering methods to predict the effects of the fire elsewhere may produce results which do not accurately reflect the true impact of the fire and may underestimate the hazard. Conversely, if the severity is overestimated, unnecessary expense may result.

It needs to be understood that the design fire is unlikely to occur in practice. Actual fires are likely to be less severe and will not necessary follow the specified design curve, such as a particular heat release rate curve. The design fire quantification process should thus result in a design profile that is conservative.

6.2 Characteristics of design fires

Design fires are usually characterised in terms of the following variables with respect to time (as needed by the analysis):

- heat release rate;
- toxic-species production rate;
- smoke production rate;
- fire size (including flame length);
- time to key events such as flashover.

Other variables such as temperature, emissivity and location may be required for particular types of numerical analysis.

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

Fire may grow from ignition through to a fully developed stage and finally decay and eventually burn out. The fire is described by the instantaneous value of the above variables over the life of the fire.

A full specification of a design fire (see Figure 2) may include the following phases:

— incipient phase — characterised by a variety of sources, which may be smouldering, flaming or radiant;

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

— fully developed phase — characterised 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.

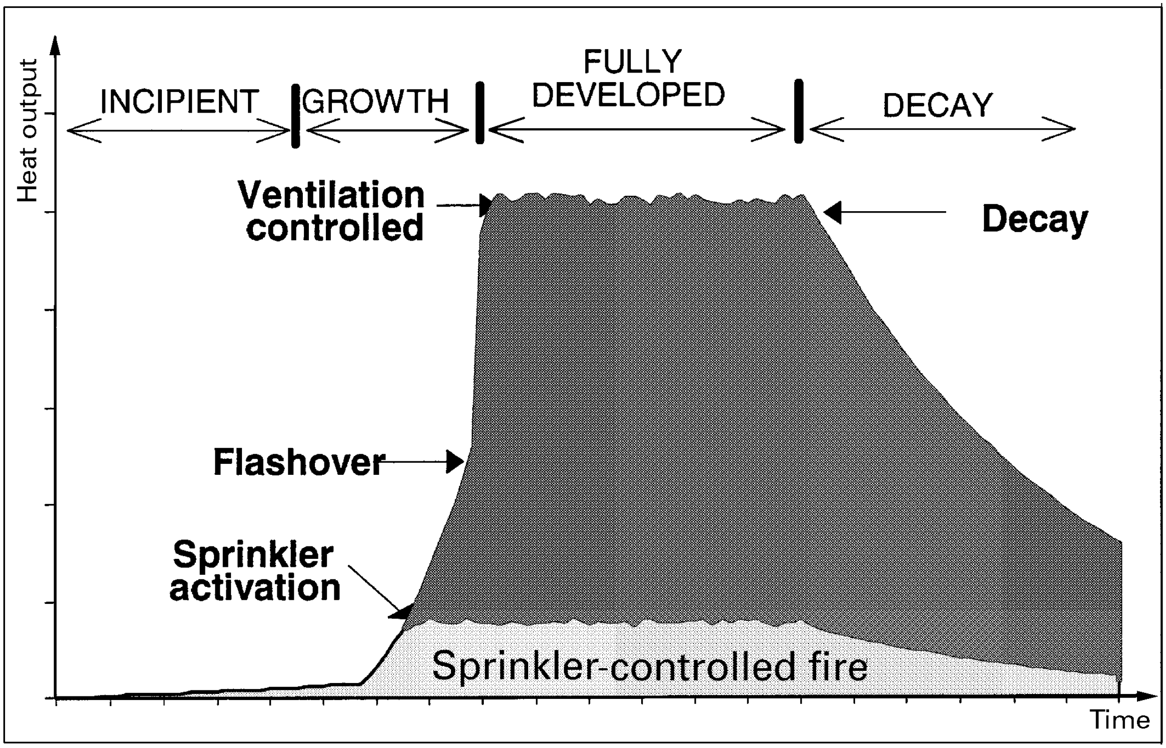

Figure 2 — Example of design fire

6.3 Characteristic fire growth

The factors determining the characteristic rate of fire growth for flaming fires are described in ISO/TR 13387-1 and in references [1] and [2]; they include:

— 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.

Determination of the rate of initial fire growth needs to consider these aspects. Fire models are available that can predict the rate of fire growth for simple fuel geometries under defined conditions. Experimental data is also available[2] to assist in the determination of the rate of fire growth of typical fuel packages.

NOTE The outcome of many design fire scenarios is sensitive to the choice of design fire, in particular the rate of fire growth.

6.4 Events modifying the design fire

6.4.1 General

The design fire is initially defined in terms of the design fire scenario being analysed. The design fire characteristics may be subsequently modified based upon the outcome of the analysis (SS1 and SS2). For example, when the fire has grown to an intensity when flashover in the enclosure is likely, the design fire is modified to reflect the characteristics of a ventilation-controlled or fuel-bed-controlled fire. Similarly, events such as sprinkler activation and window breakage impact on the design fire in a dynamic way.

6.4.2 Flashover

Flashover is characterised by the onset of a rapid transition from a localised fire to the combustion of all exposed surfaces within an enclosure. The effect of flashover on the design fire is to modify the heat release rate to that of a fully developed fire. The fully developed fire may be either ventilation or occasionally fuel-bed controlled.

The heat release rate and other characteristics following flashover should be based upon those applicable to a fuel-bed-controlled or ventilation-controlled fire.

6.4.3 Automatic suppression system activation

Automatic suppression systems may operate at any time during the fire but would normally be expected to operate in the pre-flashover stage of the fire. Modification of the heat release rate by the automatic suppression system is addressed in SS4.

For example, the heat release rate following activation of a sprinkler system may 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 may 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.

6.4.4 Intervention by fire services

The fire services may intervene at any time during the development of the fire, but it is likely that they will be able to control the fire only if it is within the capabilities of the appliances in attendance. Unless an appropriate model for fire brigade intervention and effectiveness is used, the intervention should not be considered to influence the design fire.

6.4.5 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.

In the absence of specific information, the heat release rate of the design fire may be taken to commence decay when 80 % of the available fuel has been consumed. The rate of decay may be taken as a linear decline over a time period such that the integral of the heat release rate over the decay period equals 20 % of the remaining energy in the available fuel.

6.5 Pre-flashover design fires

6.5.1 t^2 fires

Most fires that do not involve flammable liquids, gases or lightweight combustibles such as polymeric foams grow relatively slowly. As the fire increases in size, the rate of fire growth accelerates. This rate of fire growth is generally expressed in terms of an energy release rate. For design purposes, an exponential or power-law rate of energy release is often used. This represents an upper limit to the large range of possible actual fire growths in the scenario. The most commonly used relationship is what is commonly referred to as a t^2 fire. In such a fire, the rate of heat release is given by the expression:

$$\dot{Q} = \dot{Q}_o \left(\frac{t}{t_g} \right)^2 \qquad (1)$$

where the growth time t_g is the time to reach the reference heat release rate $\dot{Q}_o$.

t^2 fires may lead to $\dot{Q}$ values that exceed the maximum possible rate of heat release from the fuel under consideration. Furthermore, in large fuel beds the first ignited part may be burnt out before the last part is ignited. These factors should be considered.

The value of $\dot{Q}_o$ can be selected freely but is often taken to be 1 MW. 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:

— Flashover rapid acceleration to fully developed stage;
— Low hot layer acceleration;
— Sprinkler activation rate steady or declining;
— Manual fire suppression rate steady or declining;
— Fuel exhaustion decay;
— Changes in ventilation fire characteristics modified;
— Flaming debris subsequent ignition(s).

Figure 2 illustrates the heat release rate of a typical design fire used in the analysis of a fire hazard.

Four categories of fire growth rate are commonly used in fire safety engineering, as indicated in Table 1.

Table 1 — Categories of t^2 fire

Growth rate description	Characteristic time, t_g (s)
Slow	600
Medium	300
Fast	150
Ultra-fast	75

The selection of the appropriate category for a particular scenario needs to take into account the factors described above. Considerable engineering judgement is required in selecting the appropriate category of fire growth. Regulatory input into this selection is most desirable, and this issue should be discussed during the QDR stage.

For well defined design fire scenarios, where the geometric arrangement of the fuel is known, selection of category can be based on experimental data or numerical simulation using an appropriate flame spread model.

Guidance on the rate of fire growth in stored goods may be obtained from NFPA 204[3] and SFPE Handbook[2]. In the absence of more specific data, Table A.1 provides guidance.

6.5.2 Smouldering fires

A smouldering fire typically produces very little heat but can over a sufficiently long period fill an enclosure with unburned combustible gases, toxic products of combustion such as carbon monoxide and soot. Entrainment into these smouldering fires is low, resulting in high concentrations of smoke and toxic species within the enclosure.

The following factors affect the likelihood of onset of smouldering combustion:

— nature of the fuel;

— limitation on ventilation;

— strength of the ignition source.

Smouldering fires can readily transform into flaming fires, particularly when ventilation is increased.

The principal hazard associated with smouldering fires is the production of carbon monoxide as a result of incomplete combustion. The development of untenable conditions due to poor visibility is also a significant hazard that needs to be considered in the analysis, particularly in residential occupancies.

There are at present no quantitative methods available for the prediction of potential for smouldering. Consideration needs to be given to the presence of materials that are prone to smouldering such as upholstered furniture, bedding and cellulosic materials (particularly those treated with chemicals). Consideration also needs to be given to the presence of potential ignition sources capable of promoting smouldering such as cigarettes, hot objects and electrical sparks.

6.5.3 Burning objects

When the fuel package for the particular design fire scenario is well defined and unlikely to change over the design life of the building, then the actual burning characteristics of the fuel package may be used as the design fire. It is essential that sufficient conservatism is used, given the level of controls that may exist, so that the assumed design fire remains conservative over the life of the building or until a re-analysis of the fire safety system is undertaken.

The heat release characteristics of a range of common items have been determined by a number of laboratories using apparatus such as the furniture calorimeter or oxygen-consumption-based calorimetry[4],[5],[6]. These determinations are generally undertaken by burning the object under an instrumented hood under well ventilated conditions. It should be noted that the rate of fire growth for objects such as upholstered furniture in actual fires within an enclosure can readily exceed that determined under free-burning conditions in the open (such as under a hood). The preheating and radiation feedback from the hot layer can enhance the fire growth rate and possibly lead to underventilated fires with increased smoke and toxic-species production.

The burning characteristics of wall and ceiling lining materials may be determined using the ISO room fire test[7].

The design fire may be based on the actual burning characteristics of a reference fuel package if it can be demonstrated that:

— the fire characteristics are conservative and unlikely to be exceeded during the design life of the building by the actual fuel package;

— the conditions under which the characteristics have been determined are representative of the conditions likely to exist during the design fire scenario being analysed;

— fire is unlikely to spread to other fuel packages that have not been considered.

6.5.4 Prescribed fires

Regulatory authorities or the qualitative design review team may prescribe other design fire characteristics to be used in the analysis.

6.6 Fully developed fires

Following flashover, fires tend to rapidly reach a fully developed stage where the rate of combustion will be 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-controlled heat release rates. The transition from a fuel-controlled regime to a ventilation-controlled regime occurs approximately when:

$$\dot{m}_\mathrm{f} \approx \frac{\dot{m}_\mathrm{air}}{r} \quad \mathrm{kg/s} \tag{2}$$

More specific criteria have been developed for specific fuels such as burning timber cribs[8].

In determining the structural response, post-flashover fires are characterised 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 need to be carefully selected.

6.6.1 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[9] that the air flow into a fire compartment is proportional to the ventilation factor. 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[10] from consideration of the effective heat of combustion of the fuel.

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

6.6.2 Parametric fires

The temperatures resulting from ventilation-controlled fires have been shown[12] to depend upon the energy release rate (which in turn is dependent upon the ventilation), the thermal properties of the enclosure and the fire duration (dependent upon the fire load density). The family of fire gas temperature curves for different ventilation factors and fire load densities are commonly called "parametric fires". The research has been conducted on small compartments and cellulosic fuels, hence parametric fires are directly relevant to small compartments with cellulosic fuels. They are applicable when the flow of hot gases in and out of the enclosure is controlled by openings (vents) in the walls of the enclosure. Hence they are not applicable to enclosures with significant flow through horizontal openings in floors or ceilings.

The temperature-time curves of parametric fires are described in references [11] and [13]. Parametric time-temperature relationships may be used in SS3 to calculate thermal effects on the structure and fire spread following flashover. The pre-flashover temperatures and exposure duration are generally small in relation to their post-flashover values and may generally be neglected and the origin of the design fire taken as the time of flashover. Convective and radiative heat transfer coefficients reflecting the exposure conditions may be used to convert the temperature relationships to heat flux relationships.

6.6.3 Fuel-controlled fires

Fuel-bed-controlled fires occur less frequently than ventilation-controlled fires and would 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 geometric arrangement of the fuel. The rate of burning is dependent upon the 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[2].

6.6.4 Furnace fires

6.6.4.1 Standard temperature-time curve

Standard temperature-time curves are specified in national and ISO test methods for the determination of fire resistance ratings of structural elements. These curves have an empirical basis that do not reflect the variables that influence the post-flashover fire environment. Their application in fire safety engineering is limited to an approximation of post-flashover fire temperatures. They are useful when comparison needs to be made to experimentally determined performance.

The standard temperature-time curve is given by:

$$T_g = T_a + 345 \log_{10}(8t + 1) \tag{3}$$

Convective and radiative heat transfer coefficients reflecting the exposure conditions may be used to convert the temperature relationship to a heat flux relationship.

A number of relationships have been developed to relate actual fire temperature exposure to an equivalent standard temperature-time exposure. These find application in determining the equivalent performance in the fire resistance test.

6.6.4.2 Hydrocarbon curve

Fully developed fires involving flammable liquids may be represented by the hydrocarbon temperature-time curve. This curve is often used to represent such exposure in furnace tests.

The hydrocarbon temperature-time curve is given by:

$$T_g = 1080(1 - 0{,}325e^{-0{,}167t} - 0{,}675e^{-2{,}5t}) + T_a \tag{4}$$

Convective and radiative heat transfer coefficients reflecting the exposure conditions may be used to convert the temperature relationship to a heat flux relationship.

6.6.4.3 Other temperature-time curves

Other temperature-time curves are specified in national and ISO test methods for testing a range of products (e.g. those for intumescent passive fire protection) or specific applications (e.g. external structural members). These curves have an empirical basis and may not adequately consider the range of possible post-flashover fire environments. Their application in fire safety engineering is therefore limited. They may be useful when comparison needs to be made to performance determined during the test.

6.7 External design fires

6.7.1 Window fires

The jet of flame issuing from a window of a compartment fully involved in fire may be characterised by the flame length and the temperature along the jet. Expressions have been derived for both of these variables and are in use in some national codes[14]. For design purposes, the flame height may be taken to be:

$$z_\mathrm{f} = h_\mathrm{w}\left[16\left(\frac{R}{A_\mathrm{w}\rho(h_\mathrm{w}g)^{1/2}}\right)^{2/3} - 1\right] \quad (5)$$

where R is the rate of burning, expressed in kg/s.

The flame temperature along the vertical axis is given by:

$$T_z = \left(T_\mathrm{w} - T_\mathrm{a}\right)\left(1 - 0{,}027\frac{zw}{R}\right) + T_\mathrm{a} \quad \text{°C} \quad (6)$$

where

z is the distance from the window along the z-axis to the point where the calculation is made;

X is the distance from the window along the flame axis to the point where the calculation is made.

The flame temperature at the window T_w is given, in °C, by:

$$T_\mathrm{w} = T_\mathrm{a} + \frac{520}{1 - 0{,}027\left(\frac{Xw}{R}\right)} \quad (7)$$

For an external design fire, it is also important to consider the heat flux caused by the compartment fire.

Annex A
(informative)

Typical fire growth categories

Table A.1 — Typical fire growth categories of various design fire scenarios

Design fire scenario	Category
Upholstered furniture and stacked furniture near combustible linings	Ultra-fast
Lightweight furnishings	Ultra-fast
Packing material in rubbish pile	Ultra-fast
Non-fire-retarded plastic foam storage	Ultra-fast
Cardboard or plastic boxes in vertical storage arrangement	Ultra-fast
Office furniture — horizontally distributed	Medium
Displays and padded work-station partitioning	Fast
Bedding	Fast
Floor coverings	Slow
Shop counters	Medium

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