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SPECIFICATION

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

*Ingénierie de la sécurité contre l'incendie — Sélection de scénarios d'incendie et de feux de calcul*

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ISO/TS 16733:2006(E)

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# Contents

# Foreword

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

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

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of normative document:

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— an ISO Technical Specification (ISO/TS) represents an agreement between the members of a technical committee and is accepted for publication if it is approved by 2/3 of the members of the committee casting a vote.

An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

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

ISO/TS 16733 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

## 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, structure or transportation vehicle) 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 manageably small set of fire scenarios that is amenable to analysis. In a deterministic assessment, which is implicitly envisioned in this Technical Specification, a manageable number of design fire scenarios is selected. For a full risk assessment, as described in ISO 16732, the large number of fire scenarios is combined into a set of scenario clusters.

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 Technical Specification introduces a methodology for the selection of design fire scenarios that is tailored to the fire-safety design objectives and accounts for the likelihood and consequences of potential scenarios.

There can be several fire safety objectives being addressed including life safety, property protection, continuity of operations and environmental protection. 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 conservative.

Design fires are usually characterized in terms of time-dependent variables, such as the heat-release rate and effluent production rate. Fire can grow from ignition through to a fully developed stage and finally decay and eventually burnout. The design fire is described by the above variables over the life of the fire.

**TECHNICAL SPECIFICATION** **ISO/TS 16733:2006(E)**

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

## 1 Scope

This Technical Specification describes a methodology for the selection of design fire scenarios and design fires that are credible but conservative for use in deterministic fire safety engineering analyses of any built environment including buildings, structures or transportation vehicles.

The selection of design fire scenarios is tailored to the fire-safety design objectives, and accounts for the likelihood and consequences of potential scenarios.

The selection of design fires is also tailored to the fire-safety objectives and to ensuring credible but severe fire exposure conditions.

While this Technical Specification provides more operational information on the selection of design fire scenarios and design fires than ISO/TR 13387-2[20], it is not intended to replace ISO/TR 13387-2 within the self-consistent set of parts making up ISO/TR 13387.

## 2 Normative references

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

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

ISO 13943, *Fire safety — Vocabulary*

## 3 Terms and definitions

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

NOTE Some of the definitions have been updated to reflect the current understanding of the terms as employed in fire safety engineering.

**3.1**
**built environment**
building, structure or transportation vehicle

EXAMPLE Examples of structures other than buildings include tunnels, bridges, off-shore platforms and mines.

**3.2**
**design fire**
quantitative description of assumed fire characteristics within a design fire scenario

NOTE 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.

**3.3**
**design fire scenario**
specific fire scenario on which a deterministic fire safety engineering analysis will be conducted

NOTE 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.

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

NOTE It typically defines the ignition and fire growth process, the fully developed stage, and decay stage as well as systems that impact the course of the fire and the nature of the local environment. Identification of potential fire scenarios is an important step whether a deterministic analysis or a risk assessment is envisioned.

# 4 Symbols

| | |
|---|---|
| $A$ | area of an opening, expressed in square metres |
| $h$ | height of an opening, expressed in metres |
| $\dot{m}_\mathrm{f}$ | rate of mass loss of fuel, expressed in kilograms per second |
| $\dot{m}_\mathrm{air}$ | rate of entry of air into the enclosure, expressed in kilograms per second |
| $\dot{Q}$ | rate of heat release, expressed in kilowatts |
| $\dot{Q}_\mathrm{o}$ | reference rate of heat release, expressed in kilowatts |
| $r$ | stoichiometric air requirement for complete combustion of fuel, expressed as the ratio kilograms of air to kilograms of fuel |
| $t$ | time, expressed in seconds |
| $t_\mathrm{g}$ | time required to reach the reference rate of heat release $\dot{Q}_\mathrm{o}$, expressed in seconds |

# 5 Fire safety engineering applications

## 5.1 The role of design fire scenarios in fire safety design

Design-fire scenarios are the foundation of deterministic 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.

It should be noted that there may be several fire safety objectives, including life safety, property protection, continuity of operations, and environmental protection, and that a different set of design fire scenarios can be required to assess the adequacy of the proposed design for each objective.

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 manageably small 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 high-risk cluster of fire scenarios. The risk associated with a cluster is characterized in terms of the probability (or likelihood) of occurrence of the cluster and the resultant consequence: most typically, in terms of the product of the probability and consequence. For the purposes of this Technical Specification, where a deterministic assessment is envisioned, a qualitative estimation of the probability and consequence suffices. For a full risk assessment, such as that outlined in ISO/TS 16732[19], a more quantitative estimation is undertaken.

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

It is important to demonstrate that the fire scenarios and associated scenario clusters NOT selected for direct analysis would not change the conclusions if they were included. First, a comparison is made between the total risk collectively represented by the selected scenarios and clusters vs. the total risk collectively represented by the scenarios and clusters not selected. If the latter is much lower than the former, that is evidence that the selected scenarios dominate the total risk and can be validly used to represent that risk. If the latter is lower but not much lower, then it is necessary that the combined risk for the selected scenarios be not only lower than an appropriate threshold for acceptable risk but also lower than a fraction of that threshold, where the fraction reflects the fraction of total risk that the selected scenarios constitute. A very rough calculation suffices to establish this point, and it is usually sufficient to concentrate on the size of the consequences, while allowing for the possibility that the probabilities are not low. Second, there can be unselected scenarios with significant consequences that can be shown to have acceptably low risk by virtue of acceptably low probability. It is necessary to take special care with these scenarios because the typically high consequences, if they occur despite the low probability, will be borne by society. Third, there can be unselected scenarios with significant risk that cannot be reduced by any choices available to the engineer. These scenarios can be mitigated by strategies outside the scope of the analysis, or it can be necessary to assure that the total risk, combining the selected scenarios with these unselected scenarios, is still acceptable.

It is necessary to identify important design-fire scenarios during the qualitative design review (QDR) stage. 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 probability or high consequence combined with low probability 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 (see 6.3).

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.

## 5.2 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 is based. These assumed fire characteristics and the further associated fire development are referred to as the “design fire”.

As with the design-fire scenario, it is important that the design fire be appropriate to the relevant fire-safety objectives. For example, if the objective is to evaluate the smoke-control system, a design fire should be selected that challenges that system. 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.

### 5.3 Selection of design fire scenarios and design fires

The methodology for selecting design fire scenarios and design fires described in this Technical Specification is summarized in Figure 1.

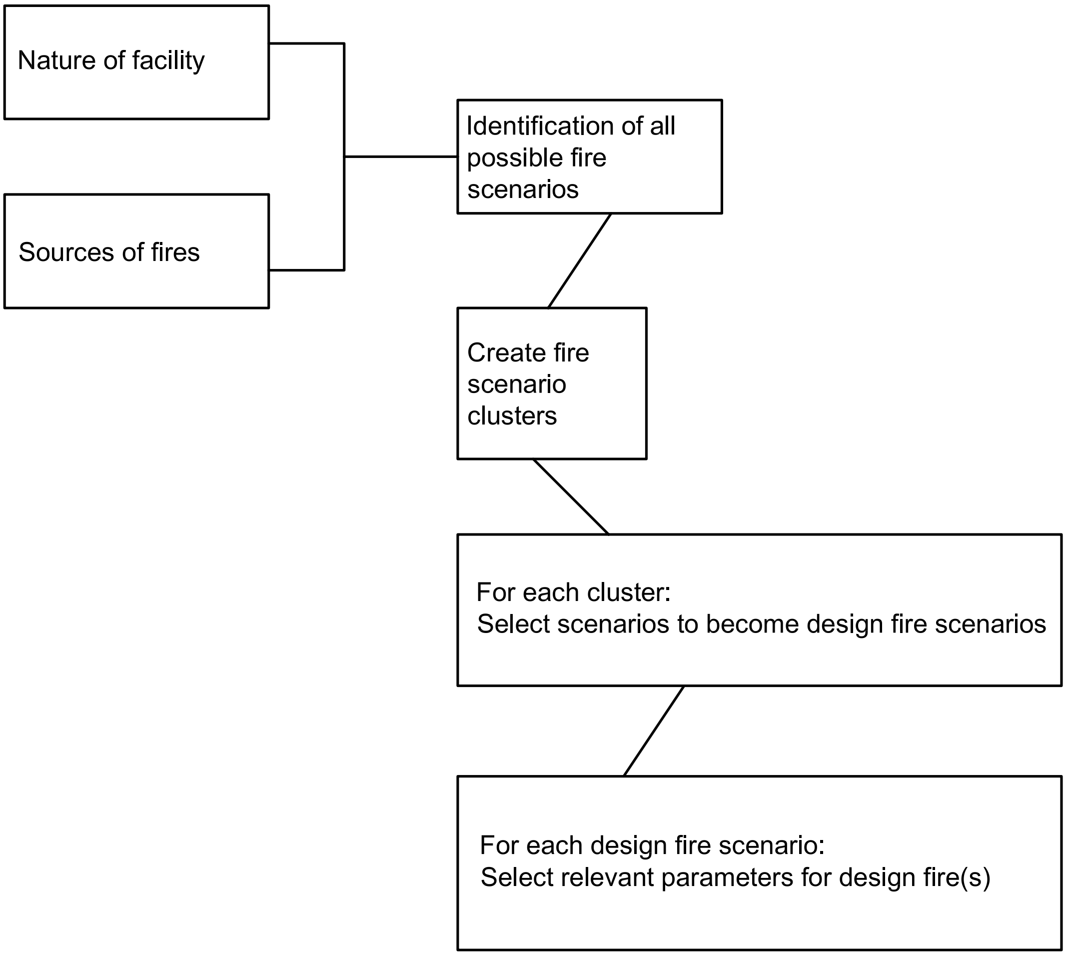


Figure 1 — Selection of design fire scenarios and design fires

## 6 Design fire scenarios

### 6.1 Characteristics of fire scenarios

Each fire scenario is represented by a unique occurrence of events and circumstances 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 what is required to be specified to characterize the scenario. Accordingly, a fire scenario represents a particular combination of events and circumstances associated with non-design factors such as the following:

- type of fire (smouldering, localized, post-flashover…);
- internal ventilation conditions;
- external environmental conditions;

- status of each of the fire safety measures, including active systems and passive features;
- type, size and location of ignition source;
- distribution and type of combustible materials;
- fire-load density;
- detection, alarm, and suppression of fire by non-automatic, human means;
- status of doors;
- breakage of windows, if not taken into account by the fire design calculation method.

Other factors that can be elements of some designs are treated as non-design factors if they are not considered choices for the design, such as the following:

- choices of contents and furnishings, structural materials and methods and interior and exterior finishes, affecting distribution and type of fuel or fire load density;
- automatic fire detection and alarm;
- fire suppression;
- self-closing doors or other discretionary elements of compartmentalization;
- building air-handling system or smoke-management system.

Other factors are always treated as elements of design, such as the following:

- performance of each of the fire-safety measures;
- reliability of each of the fire-safety measures.

## 6.2 Identification of fire scenarios

### 6.2.1 General

A systematic approach to the identification of fire scenarios for analysis is desirable in order to identify important scenarios and to provide a consistent approach by different analysts. 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 fire scenarios that is amenable to analysis. In a deterministic assessment, a manageable set of design fire scenarios is selected. For a full risk assessment, as described in ISO 16732, the large number of design fires is combined into a set of scenario clusters.

It is important that the design fire scenarios be appropriate to the objectives of the fire-safety engineering task.

A risk-ranking process provides a helpful basis for the selection of design-fire scenarios. Such a process takes into account both the consequence and likelihood of the scenario. This implies that fire-risk assessment techniques can be applied to the selection of design-fire scenarios for a deterministic analysis. Key aspects of the risk-ranking process, explained in the detailed steps below, are the following:

- identification of a comprehensive set of possible fire scenarios;
- estimation of probability of occurrence of the scenario;
- estimation of the consequence of the scenario;

- estimation of the risk of the scenarios (reflecting consequence and probability of occurrence);
- ranking of the fire scenarios according to their risk.

The ten steps outlined below provide a systematic approach towards identifying design-fire scenarios.

### 6.2.2 Step 1 — Location of fire

Step 1 typically involves characterization of the space in which fire begins, as well as characterization of the specific location within the space.

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.

Identification of most adverse or challenging locations involves engineering judgment. Challenging locations are those where special circumstances can adversely affect the performance of fire safety measures. 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; and
- 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 design fire scenarios may be needed include the following:

a) internal:
  - fire in construction products (sandwich panels, …),
  - room fire (corner, ceiling, floor, wall),
  - fire in stairwells,
  - cable tray or duct fire,
  - roof fires (under roof),
  - cavity fire (wall cavity, facade, plenum).

b) external:
  - fire in neighbouring building or vegetation,
  - fires on roofs.

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

### 6.2.3 Step 2 — Type of fire

The type of fire refers to 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 substeps: 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 substeps 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 design fire scenarios, together with probabilities for alternative initial ignition conditions. The goal of this systematic approach is to screen possible design 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 probability and minimal consequence and another set of fire scenarios with high consequence and minimal probability. From fire incident statistics appropriate for the building and occupancy under consideration, rank combinations of the initial heat sources and the initial fuel items by some frequency and consequence-related criteria, such as the following:

a) types of fires accounting for the largest shares of fire injuries or fire fatalities;

b) types of fires accounting for the largest share of property damage, measured in monetary terms;

c) most likely fires of those with fire extent of a certain minimum size, such as 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.

Other examples of types of fires for which design-fire scenarios can be necessary include the following:

a) internal:

  - single burning item fire (furniture, wastepaper basket, fittings),
  - developing fire (smoke extraction);

b) external:

  - fires in external fuel packages,
  - fires on facades.

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

Appropriate statistics can be available on a national basis, a state or provincial basis, or for like properties sharing ownership with the structure 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.

If any fire types 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.

### 6.2.4 Step 3 — Potential fire hazards

Consider the fire scenarios that can arise from the potential fire hazards identified during the QDR phase as associated with the intended use of the property or the design. Identify other critical high-consequence scenarios for consideration. 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 building 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 involve comparable likelihood and higher consequence than those identified previously, It is necessary that they be included in the set for analysis. They may replace less hazardous scenarios that are similar in nature.

### 6.2.5 Step 4 — Systems and features impacting on fire

Identify the fire-safety systems and features that are likely to have a significant impact on the course of the fire or the development of untenable conditions. For each system or feature, include in the characterization of each scenario the initial status of the system or feature. Typical systems and features for consideration and their associated statuses include the following:

a) Passive systems and features:

  - contents and furnishings (status: as new or degraded by age or vandalism),
  - doors and other openings in the enclosure of fire origin and other relevant compartmentation (status: open or closed), windows (status: as new or degraded),
  - materials control (status: as new or degraded by age or vandalism),
  - wall and ceiling/floor assemblies and other elements of compartmentalization (status: as designed or compromised by penetrations or in other ways),
  - structural members (status: as designed or compromised),
  - size of compartment;

b) Active systems and features:

  - active suppression system (status: fully operational or not, properly located or not),
  - smoke management system (status: fully operational or not, properly located or not),
  - fire detection system (status: fully operational or not, properly located or not),

- warning and communication system (status: fully operational or not, properly located or not),
- egress system (status: fully operational or not),
- fire safety management,
- fire fighter operations.

The status of systems and features are part of the characterization of a scenario. The events are parts of the timeline that is part of the scenario specification but that is likely to be inferred from engineering analysis (such as of predicted fire development and impact), rather than by external specification.

### 6.2.6 Step 5 — People response

The actions that people take can have significant impact, favourable or otherwise, on the course of the fire or the movement of smoke and should be considered in this step. (An assessment of the impact of fire on people is considered in Step 8 below.) 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 2 and should not be considered here again. Rather, it is the 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. 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 can leave key doors open, allowing for rapid fire development and smoke transport. Any of these effects can introduce new potential fire scenarios.

## 6.3 Selection of design fire scenarios

In Steps 1 through 5, a large number of potential fire scenario clusters have been identified. From this large number a set of design fire scenarios is selected. A risk-ranking process is the most appropriate basis for the selection of design fire scenarios. Such a process takes into account both the consequence and likelihood of the scenario.

One way of proceeding at this point is to construct an event tree, as outlined in Steps 6 through 10. However, often the risk-ranking process can be undertaken in an abbreviated fashion. For example, engineering judgement, readily available data and order-of-magnitude estimates of probabilities and consequences of the scenario clusters often suffice. Where this is the case, risk-ranking can be undertaken without resorting to an event tree. However, where an abbreviated approach is not possible, the event tree approach outlined in Steps 6 through 10 can be followed in order to construct the probability of a scenario from knowledge of the probabilities of individual events that make up the scenario.

### 6.3.1 Step 6 — Event tree

Construct an event tree that represents alternative event sequences from fire ignition to outcome associated with fire scenarios. Event trees are constructed by starting with an initial event, such as an ignition, in combination with initial states for all fire-safety systems and features and all occupants. Then a fork is constructed and branches added to reflect each possible successive event. This process is repeated until all possible initial states have been represented. Each fork is constructed on the basis of the occurrence of the preceding event. A path through this tree represents a fire scenario for consideration. Examples of the construction of an event tree are given in Annexes B and C.

Events define changes in the characteristics of the fire, the status of systems and features, the responses of occupants and other points in time that bear on the final outcome and consequences of the fire. Examples of events related to building systems and features include the following:

- secondary items are ignited by fire;
- fire is contained by doors or other barriers;

- system or feature performs as designed or with a reduced quality or degree of performance;
- glass breaks in windows.

Alternatively, a fault tree can be constructed. Fault trees are logic trees like event trees but in which each branch is based on a condition or state rather than an event in time. Because there is likely to be a number of factors, each with multiple possibilities for initial states, step 6 can be easier to execute if an initial fault tree is used to set up the alternative initial states and a commonly formatted event tree is then appended to each end-point of the fault tree, corresponding to a full specification of initial conditions. A scenario is then a single path through this hybrid tree.

### 6.3.2 Step 7 — Consideration of probability

Estimate the probability of occurrence of each event using available data and/or engineering judgement as recommended in ISO/TS 16732:2005, 6.3. For some branches, characteristics of the initial fire are the subject and fire incident data are the appropriate data source for the probabilities. For some branches, states of systems and features are the subject and reliability data are the appropriate data source. For some branches, characteristics and states of occupants or objects in the building are the subject and population or usage data are the appropriate data source. These all 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.

### 6.3.3 Step 8 — Consideration of consequence

Estimate the consequence of each scenario using available loss data and/or engineering judgement as recommended in ISO/TS 16732:2005, 6.4. The consequence should be expressed in terms of an appropriate measure such as the potentials for life loss or injury or the expected fire cost. The estimates may consider time-dependent effects.

When estimating life loss or injuries due to fire, care should be taken to ensure that data employed in the process are relevant to the built environment under consideration. Guidance on how occupant behaviour can depend upon the nature of the built environment can be found in ISO/TR 13387-8[22].

### 6.3.4 Step 9 — Risk ranking

Rank the scenarios in order of relative risk. The relative risk can be evaluated by multiplying the measure of the consequence (step 8) by the probability of occurrence (step 7) of the scenario.

### 6.3.5 Step 10 — Final selection and documentation

For each fire safety objective, 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 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, low-probability scenarios are eliminated from consideration, it is important to be careful that the eliminated scenarios do not have a moderate or high collective probability. 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 to eliminate a scenario, despite its substantial contribution to risk, because it makes a particular fire-safety system or feature or a particular design choice appear attractive or unattractive.

- 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. Risks to persons who are intimate with the starting point of a fire or who are incapable of acts of self-preservation (because of consumption of alcohol or drugs) can be examples of the bases for scenarios that can legitimately be eliminated at this stage.

## 7 Design fires

### 7.1 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 on 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 or fuel-bed-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 2) can include the following phases:

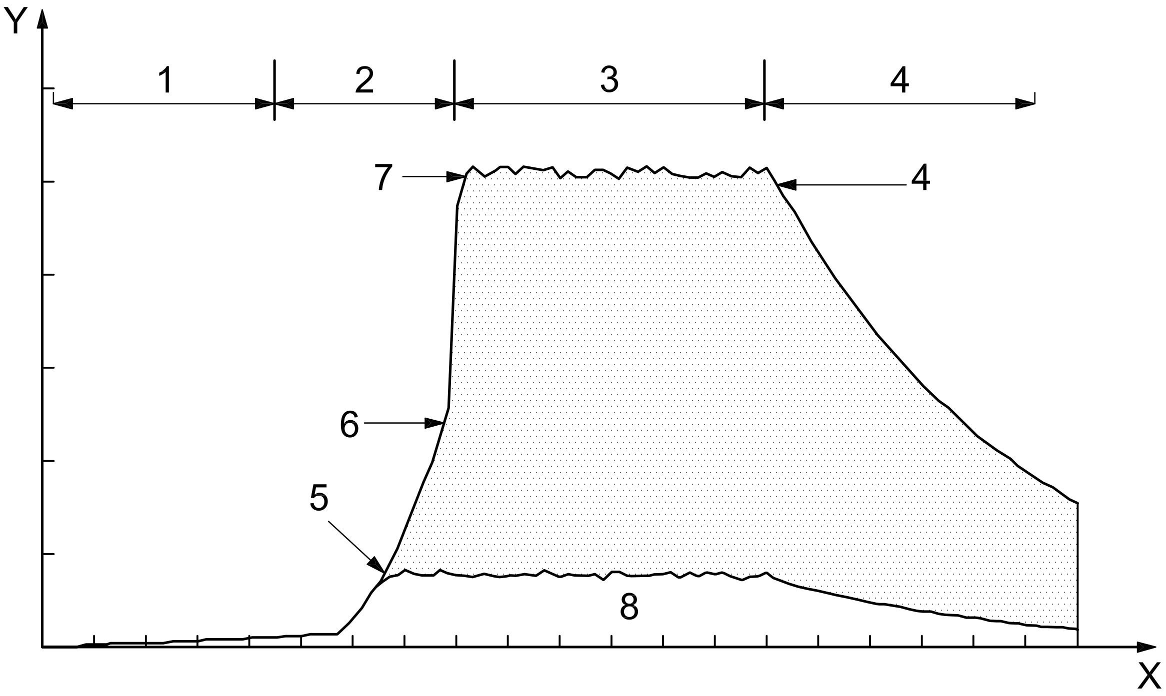
| | |
|---|---|
| — incipient phase: | characterized by a variety of sources, which can be smouldering, flaming or radiant; |
| — growth phase: | covering the fire propagation period up to flashover or full fuel involvement; |
| — fully developed phase: | characterized by a substantially steady burning rate as can 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 others parameters depending on the assessment model to be used);

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



**Key**

X time

Y heat output

1 incipient

2 growth

3 fully developed

4 decay

5 sprinkler activation

6 flashover

7 ventilation-controlled

8 sprinkler-controlled

**Figure 2 — Example of design fire**

## 7.2 Basic characteristics

**7.2.1** Design fires are usually characterized in terms of the following variables with respect to time (as required 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.

**7.2.2** 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.

**7.2.3** 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 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[1] to assist in the determination of rate of fire growth on typical fuel packages.

### 7.2.4 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[2]:

- 500 °C to 600 °C in the upper layer of gases;
- 20 kW/m$^2$ for radiation from this upper layer to the floor.

### 7.2.5 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 Equation (1):

$$\dot{m}_{\mathrm{f}} \approx \frac{\dot{m}_{\mathrm{air}}}{r} \qquad (1)$$

More specific criteria have been developed for particular fuels such as burning timber cribs[3].

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.

### 7.2.6 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[2] 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[3] 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.

### 7.2.7 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[1].

### 7.2.8 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. More guidance is provided in ISO/TR 13387-7[21].

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.

### 7.2.9 Intervention by fire services

The fire services can 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. Unless an appropriate model for fire brigade intervention and effectiveness is used (for example, see References [4] and [5]), the intervention should not be considered to influence the design fire.

### 7.2.10 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 required 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 the 20 % of remaining energy in the available fuel.

## 7.3 Parameters provided by the design fire scenario

For each of the scenarios, select specific location(s) in the room or major space identified for that scenario. The most likely location can be inferred by engineering judgment from the typical locations of the already-identified initial fuel items. The most challenging location are those where special circumstances adversely affect the performance of fire safety measures. Examples include the following:

- locations very close to room occupants (sometimes referred to as “intimate with ignition”), particularly vulnerable property, or exposed structural elements (for example, in a parking garage), such that there is insufficient time and space for fire safety measures to act effectively;
- locations in corners or other spaces where partial enclosure leads to unusually rapid fire build-up;
- locations that are shielded from fire-safety systems;
- locations near doorways or other openings connecting spaces that permit fires to spread to multiple spaces before compartmentalization provisions can effectively respond.

## 7.4 Parameters to be defined

### 7.4.1 Parameters that require definition for most applications

Some parameters are commonly employed in fire safety engineering assessments and it is important that they be estimated before quantification can commence. Examples follow.

### 7.4.1.1 Rate of heat release for growing fires

Most fires that do not involve flammable liquids, gases or light-weight 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 bound 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 Equation (2):

$$\dot{Q} = \dot{Q}_0 \left( \frac{t}{t_g} \right)^2 \qquad (2)$$

where $t_g$ is the growth time to reach the reference heat release rate, $\dot{Q}_0$.

$t^2$ fires can 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 can be burnt out before the last part is ignited. These factors should be considered.

The value of $\dot{Q}_0$ can be selected freely, but is often taken to be 1 MW. Four categories of fire growth rate are commonly used in fire-safety engineering, as indicated in Table 1.

**Table 1 — Categories of $t^2$ fires**

| Growth rate description | Characteristic time $t_g$ s |
|---|---|
| Slow | 600 |
| Medium | 300 |
| Fast | 150 |
| Ultra fast | 75 |

It is necessary that the selection of the appropriate category for a particular scenario take into account the factors described above. Considerable engineering judgement is required in selecting the appropriate category of fire growth.

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 can be obtained from NFPA 204[6] and SFPE Handbook[1]. In the absence of more specific data, Table A.1 provides guidance.

### 7.4.1.2 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 rates of release of smoke and toxic species per unit of mass burned[7].

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 it is important to consider in the analysis, particularly in residential occupancies.

There are at present no quantitative methods available for the prediction of potential for smouldering. It is important that consideration 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). It is also important that consideration be given to the presence of potential ignition sources capable of promoting smouldering, such as cigarettes, hot objects and electrical sparks.

### 7.4.1.3 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 can be used as the design fire.

The heat-release characteristics for 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[8], [9], [10]. 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 on 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 fire growth rate and possibly lead to under ventilated 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[11].

The design fire can 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.

### 7.4.2 Parameters that require definition when simplistic calculation models are employed

Whereas most advanced models require the rate of heat release of the fire as input to a calculation of the enclosure temperature or other fire properties, there is a class of models that is simpler in nature and requires less sophisticated input data. For example, the parametric fire curves for post-flashover fires discussed in 7.5.2.1 do not require estimates of the rate of heat release of the fire as input. Instead, the temperature is predicted directly, employing simpler information, such as the geometry of the enclosure and its ventilation openings, the thermal properties of room lining materials and the fuel load.

## 7.5 Assessment of fire development

For a given design fire scenario, the parameters determined in 7.3 and 7.4 can be employed to predict the temperature/heat flux evolution versus time and the associated effluents using simple calculation methods, advanced calculation methods or *ad hoc* test results. In addition, it should be recognized that there are some specific situations where it is necessary to use prescribed fires, not necessarily representative of the actual risk, in addition to the design scenarios identified.

### 7.5.1 Prescribed fires

Regulatory authorities or the qualitative design review team may prescribe other design fire characteristics to be used in the analysis. Typically the temperature/heat flux versus time is prescribed.

### 7.5.2 Simple calculation models

### 7.5.2.1 Parametric fires

The temperature resulting from ventilation-controlled fires has been shown[2] 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 [12] and [13]. Parametric time-temperature relationships may be used 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.

### 7.5.2.2 External design fires

There are two types of fires that can harm the external surface (or façade) of a built environment: fires originating within the built environment and those originating outside it. An example of the former is when flames from a developing or fully developed internal fire issue from an opening and thereafter transfer heat to an external surface (or façade). An example of the latter is when flames from a fire in miscellaneous storage or waste adjacent to the built environment transfer heat to the external surface. In both cases, flame heat transfer can lead to ignition of combustible content in the external surface and subsequent sustained flame spread. This can cause massive damage to the external surface or propagation of fire to the interior via openings in the external surface at locations and distances remote from the original source fire.

Generally, the highest imposed total heat transfer from flames to external surfaces, and, therefore, the greatest risk of damage or sustained flame spread, occurs as the result of fire sources outside and adjacent to the external surface. It is important to select an external design fire that accurately reproduces the maximum heat-flux exposure to be expected from the design fire scenario of concern.

### 7.5.2.2.1 Flames issuing from an opening

Flames issuing from an opening in the external surface of a built environment can be characterized by a heat-flux profile on the external surface along the length of the flame. The jet of flame issuing from a window of a compartment fully involved in fire may be characterized 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].

### 7.5.2.2.2 Fire from a burning object adjacent to an external surface

Flames from a burning object near the external surface of a built environment can be characterized by a heat-flux profile along the length of the flame.

### 7.5.3 Test

In some cases, engineering calculation methods are not available, e.g., for estimating fire growth in complex material systems or for estimating the response of a given fire to proposed protection systems, such as sprinklers, because of the complexity of the interactions involved. For such cases, the only way to predict the outcome of a given scenario is to make use of one or more reference-scale test methods or *ad hoc* test methods developed for the purpose. This type of test method is intended to represent a possible “real” fire situation by exhibiting a wide range of “real” fire phenomena in a full-scale geometry while maintaining a well defined, well documented and well controlled test environment.

Reference-scale test methods are used either directly, to evaluate specific trial design strategies, or indirectly, to evaluate the accuracy of a particular engineering calculation method that, if found to be suitable, are then used to evaluate a range of design strategies. In all cases, proper interpretation of results from reference-scale test methods is particularly important to ensure validity for the particular design application. For example, if a reference-scale test environment is used to evaluate a trial sprinkler protection strategy in a warehouse, it is important that the test results be analysed to verify that the success of fire protection is not influenced by factors, such as oxygen depletion, that might not be present during an actual fire.

In some particular cases, it is necessary to employ a combination of test results and calculations. Generally, the efficiency of the calculation method is determined by assessing the results of the test, and a calculation is performed for the real-case scenario, taking into account some safety factor to deal with the accuracy of the method obtained in the comparison with the test results.

# 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 or stacked furniture near combustible linings | Ultra fast |
| Light-weight 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 |
| Bedding | Fast |
| Displays and padded work-station partitioning | Fast |
| Office furniture | Medium |
| Shop counters | Medium |
| Floor coverings | Slow |

# Annex B
(informative)

# Selection of design fire scenarios — Fire in a multipurpose covered stadium

## B.1 Objective

The objective of this annex is to demonstrate, via an example, how design fire scenarios can be selected using the “ten step” methodology presented in this document. The example is a multipurpose covered stadium with smoke venting for which the fire safety objective is life safety.

## B.2 Description of the building and its use

The building is a covered stadium incorporating smoke venting over the arena and spectator areas open to the arena. Although the building is primarily used for sporting events, it can also be used for a variety of other events. For example, the stadium can be used for concerts, religious or secular ceremonies, conventions, trade fairs, even monster-truck shows. Lower-tier seating can be retracted to allow for these multipurpose events. There is also a fire risk associated with other areas in the facility, for example in the retail (concession) booths or in storage areas containing high fuel loads.

## B.3 The ten-step procedure

### Step 1 — Location of fire

Select locations in the building that produce the most adverse fire scenarios.

### Step 2 — Type of fire

From fire incident statistics appropriate for the building and occupancy under consideration identify: the most likely types of fire scenarios and the most likely high consequence fire scenarios.

In this example steps 1 and 2 are done together. Fire-incident statistics were not gathered; however, likely fire scenarios and locations were gained from consultation with designers and other fire safety practitioners. These are the following.

a) Scenario 1: Fire in the arena, while it is being used for a sporting event:

   In this scenario, there is a large number of people. Spectators are elevated in tiers relative to the fire origin and exposure to a smoke layer is enhanced. Retractable seating might or might not be in use. There might or might not be a dedicated fire watch. Typically, the fuel load, fire growth and peak heat release rate (HRR) are limited.

b) Scenario 2: Fire in the arena while it is being used for an event other than a sporting event, but where spectators are still seated in the tiers; for example, a rock concert or monster-truck show:

   Here, the spectator conditions are similar to scenario 1 but the fuel load and fire growth are significantly increased. Additionally, in the case of rock concerts where theatrical “smoke” is used, the automatic smoke detection system can be turned off. There might or might not be a dedicated fire watch.

c) Scenario 3: Fire in the spectator tiered seating area when occupied:

   For example, this could feasibly be the same occupancy as either scenario 1 or 2 but with the fire in a different location. The seating might or might not be of fire-retardant material, so the fuel properties might or might not include limited fuel load, fire growth and peak HRR. One could also consider fires involving rubbish under the seats.

d) Scenario 4: Fire in the arena while it is being used for an event, for example a trade show, other than a sporting event and spectators are not seated in the tiers:

   Here, the occupant load is lower. Typically, the occupants are at the same level as the fire, meaning a greater depth of acceptable smoke reservoir (assuming there is not a high heat flux). The occupants are more mobile than in the previous scenarios. Way-finding can be difficult. They might be engrossed in a display and it is possible that exit signs are not visible. Here, the fuel load, fire growth and peak HRR are higher than in scenario 1.

e) Scenario 5: Fire in an assembly area other than the arena and spectator area, for example in a merchandising area or hospitality area:

   Here, the design fire might or might not have a high fire growth but fuel loads and peak HRR are usually lower than the arena scenarios. However, depending on geometry and fire separations, in this scenario there is an increased chance of emergency-exit blockage from the arena area itself as the merchandising and hospitality areas are often in the tiered seating under croft adjacent to the spectator entrance/exit.

f) Scenario 6: Fire in storage area.

   This type of building typically has a large amount of combustible materials stored near the arena area. This fuel is capable of fast growth and high peak HRR resulting in a severe fire. The storage areas usually have a large door connecting them to the area for fork-lift access of large goods. This CAN prove more prone to barrier failure than a smaller portal would.

At this stage, some scenarios identified above can be superseded by others. If fire-retardant materials are used in the seating construction, as required by many national codes, the consequence of scenario 3 would be below those of scenarios 1 and 2. If the occupant load, the most important parameter driving life safety consequence, for a rock concert is similar to a sporting event, and yet the rock concert hazard is greater, it may be assumed that a design for scenario 2 can supersede scenario 1.

**Step 3 — Potential fire hazards**

Identify other critical high-consequence scenarios for consideration. If any of these scenarios are likely to be of a higher consequence than those identified previously, it is necessary to include them in the set for analysis. They may replace less hazardous scenarios that are similar in nature.

Typically such additional fires are not uncovered by review of statistical databases, but through discussion with experts. Since fire incident statistics are not employed in steps 1 and 2, but rather likely fire scenarios and locations are gained from consultation with designers and other fire safety practitioners, no further higher-consequence scenarios have been identified.

**Step 4 — Systems impacting on fire**

Identify the building and fire safety systems features which are likely to have a significant impact on the course of the fire or the development of untenable conditions.

A full range of active, passive and egress systems are assumed present. If any of these systems is not present, it is necessary to set the probabilities of success of these systems in the event tree (below) to zero.

a) Active systems:

   It is assumed that there is automatic fire sprinkler protection throughout, automatic smoke detection throughout (excluding kitchens, latrines) and automatic smoke-venting (natural or forced) with fire service override. The alarm system activates smoke-venting, self-closing doors, etc.

b) Passive systems:

Areas are assumed to be fire-separated as follows: the spectator area and arena is one primary fire compartment, the foyer/reception area another, mercantile and hospitality another, dedicated exit routes (horizontal and vertical) another and storage and “back-of-the-house” another.

c) Egress systems:

It is assumed that there appropriate signage, emergency lighting, evacuation wardens and a voice communication (EWIS emergency warning intercommunication system).

**Step 5 — Occupant response**

Identify occupant characteristic and response features that are likely to have a significant impact on the course of the fire.

Occupants can be able to suppress the fire in certain areas (first aid suppression in the event tree below). Fire wardens are assumed to be present to assist in evacuation. Of course, occupants can detect fire, leave doors open, etc.

**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 event tree is illustrated in Figure B.1 (it is not necessary to quantify all scenarios).

The first event considered is the ignition of a flaming fire. It has, therefore, been implicitly assumed that, in such facilities, smouldering fires are not of as much concern as flaming fires.

The fire can start in the arena and spectator’s area with probability, $P_1$, in a merchandising or hospitality area (retail) with probability, $P_2$, or in a storage area with probability, $P_3$. Assuming these are the only locations where fire can start $P_1 + P_2 + P_3 = 1$.

In its early stages, a fire can be suppressed by first aid responders. The conditional probability that this happens, given it started in the arena and spectators area, is $P_{1,1}$. The probability that it is not suppressed by first aid responders is $P_{1,2} = 1 - P_{1,1}$. Similar conditional probabilities are assigned to the effectiveness of first aid responders in the retail and storage areas. If the first aid response is effective, further elaboration of the scenario is not warranted (and the consequences are quite low as far as life safety is concerned).

If the fire is not suppressed by the first aid responders, it can be suppressed some time later by the sprinkler system. The conditional probability that it is suppressed by sprinklers, given that it was not suppressed by first aid responders in the arena and spectators area, is $P_{1,2,1}$. The probability that it is not suppressed by sprinklers is $P_{1,2,2} = 1 - P_{1,2,1}$. Similar conditional probabilities are assigned to the effectiveness of sprinklers in the retail and storage areas. If the sprinklers are effective, further elaboration of the scenario is not warranted (and the consequences are quite low as far as life safety is concerned).

In the arena and spectator area, if the fire is not suppressed by first aid responders or by the sprinkler system, tenable conditions can be assured by smoke venting. The conditional probability that smoke venting is effective, given the fire is not suppressed by first aid responders or the sprinkler system, is $P_{1,2,2,1}$. The probability that smoke venting is not effective is $P_{1,2,2,2} = 1 - P_{1,2,2,1}$. If smoke venting is effective, further elaboration of the scenario is not warranted (and the consequences are quite low as far as life safety is concerned). Smoke venting is not, however, likely to be attempted if the fire originates in either the retail or storage areas.

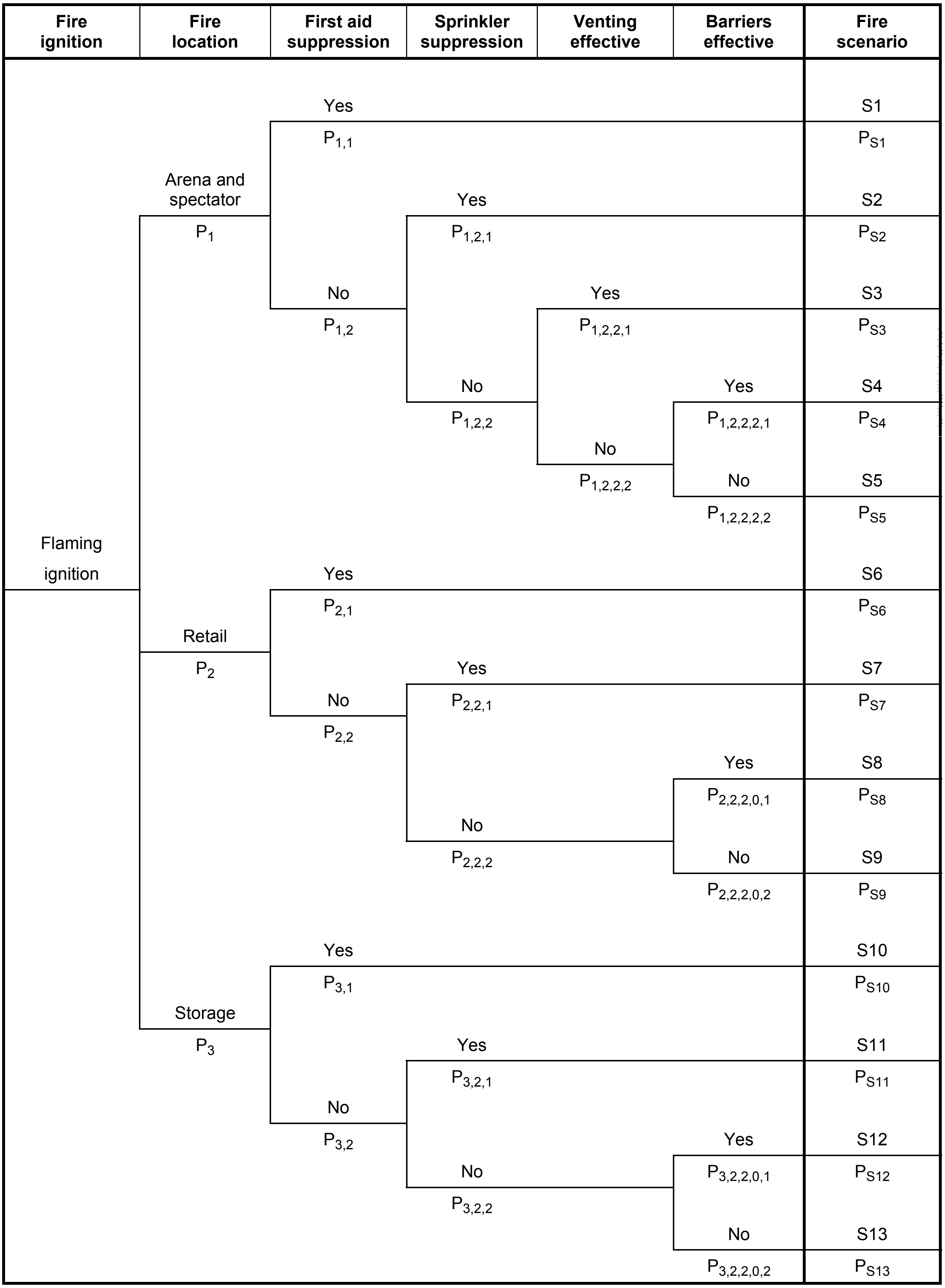


Figure B.1 — Event tree for fire in a multipurpose covered stadium

In the arena and spectator area, if a fire is not suppressed by first aid responders or the sprinkler system and if the smoke venting system is not effective, occupants in the arena and spectator area are threatened, but occupants in the retail area can still be safe if barriers prevent the movement of smoke into the retail area. The conditional probability that barriers are effective, given the fire is not suppressed by first aid responders or the sprinkler system and the smoke venting is ineffective, is $P_{1,2,2,2,1}$. The probability that these barriers are ineffective is $P_{1,2,2,2,2} = 1 - P_{1,2,2,2,1}$.

In the retail area, if the fire is not suppressed by the first aid responders or sprinkler system occupants in the retail area are threatened, but occupants in the arena and spectator can still be safe if they do not need to exit through the retail area and if barriers prevent the movement of smoke into the arena and spectator area from the retail area. The conditional probability that barriers are effective, given the fire is not suppressed by first aid responders or the sprinkler system is $P_{2,2,2,0,1}$. The probability that these barriers are ineffective is $P_{2,2,2,0,2} = 1 - P_{2,2,2,0,1}$.

In the storage area, if the fire is not suppressed by first aid responders or sprinklers, occupants in the storage area are threatened but occupants in the arena and spectator area or in the retail area can still be safe if barriers prevent the movement of smoke into these areas. The conditional probability that barriers are effective, given the fire is not suppressed by first aid responders or sprinklers is $P_{3,2,2,0,1}$. The probability that these barriers are ineffective is $P_{3,2,2,0,2} = 1 - P_{3,2,2,0,1}$.

**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.

In selecting design fire scenarios, an estimate of the probability of occurrence of each event is sufficient. Such estimates can be made using statistical data or engineering judgement (often informed by statistical data). The entries in this event tree are made on the basis of engineering judgement.

To illustrate the process, the following values for the conditional probabilities have been assumed.

The probabilities that the fire starts in each of the three locations are

— $P_1 = 0{,}20$ (arena and spectators area),

— $P_2 = 0{,}60$ (retail area),

— $P_3 = 0{,}20$ (storage area).

The selection of design fire scenarios is not dependent on the choice of these values because, in this example, design fire scenarios are chosen for each location independently.

The probabilities of successful suppression by first aid responders are

— $P_{1,1} = 0{,}5$ (moderate in the arena and spectators area),

— $P_{2,1} = 0{,}8$ (very good in the retail area where employees are close at hand),

— $P_{3,1} = 0{,}1$ (very poor in the storage area, which is typically unoccupied).

The probabilities that first area responders do not suppress the fire are $P_{1,2} = 0{,}5$, $P_{2,2} = 0{,}2$ and $P_{3,2} = 0{,}9$.

The sprinkler effectiveness is as follows:

— $P_{1,2,1} = 0{,}5$ (with the high ceilings in the arena and spectators area, there will be a number of potential fires that are not large enough to activate the sprinkler system);

- $P_{2,2,1} = 0,95$ (this is a typical value selected for sprinkler effectiveness in areas with low ceilings, such as the retail area);
- $P_{3,2,1} = 0,95$ (again, this is a typical value selected for sprinkler effectiveness in areas with low ceilings, such as the storage area).

The probabilities that the sprinklers do not suppress the fire are $P_{1,2,2} = 0,5$, $P_{2,2,2} = 0,05$ and $P_{3,2,2} = 0,05$.

The smoke venting effectiveness in the arena and spectators area is $P_{1,2,2,1} = 0,7$ (based on engineering judgement).

The probability that the smoke venting system is ineffective is $P_{1,2,2,2} = 0,3$.

Assuming there are automatically closing doors between the arena-and-spectator area and the retail area, the barrier effectiveness is $P_{1,2,2,2,1} = 0,9$ (the doors are assumed to prevent the movement of smoke but not fire as such a large space is unlikely to flash over).

The probability that these barriers are ineffective (do not prevent smoke flow into the retail area) is $P_{1,2,2,2,2} = 0,1$. (If there are no doors between the arena-and-spectator area and the retail area, the probabilities are $P_{1,2,2,2,1} = 0$ and $P_{1,2,2,2,2} = 1,0$.)

Assuming there are automatically closing doors between the arena-and-spectator area and the retail area, the barrier effectiveness is $P_{2,2,2,0,1} = 0,8$ (it is necessary that the doors prevent the spread of smoke and fire as a post-flashover fire within the retail area will challenge the door. Presumably, the doors will maintain their integrity for some time).

The probability that these barriers are ineffective is $P_{2,2,2,0,2} = 0,2$.

Assuming there are automatically closing doors between the storage area and the arena and spectator area and the retail area, the barrier effectiveness is $P_{3,2,2,0,1} = 0,8$.

The probability that these barriers are ineffective is $P_{3,2,2,0,2} = 0,2$.

The relative probability of each scenario is obtained by multiplying along the path leading to the scenario. For example, the conditional probability that, if there is a fire, the scenario will be S5 is as follows:

$$P_{S5} = P_1 \times P_{1,2} \times P_{1,2,2} \times P_{1,2,2,2} \times P_{1,2,2,2,2} = 0,2 \times 0,5 \times 0,5 \times 0,3 \times 0,1 = 0,001\,5.$$

**Step 8 — Consideration of consequence**

Estimate the consequence of each scenario using engineering judgement. The consequence 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.

In selecting design-fire scenarios, it is necessary to make an estimate of the consequence of each scenario using engineering judgement. In this example, the consequence has been expressed in terms of the number of people threatened. This number has not explicitly accounted for timelines, such as the relative time at which untenable conditions arise versus the time it takes occupants to evacuate a space. This level of assessment is done during the hazard assessment that follows the selection of design-fire scenarios.

For the purpose of these examples, it is assumed that the occupant load in the arena and spectator areas is 2 000 people; in the retail area, 400; and in the storage area, 10.

a) Fires originating in the arena and spectators area — Scenarios S1 to S5:

Consequence assigned to scenario S1. The fire is quickly suppressed by first aid responders so that there is little threat to anyone who is not intimate with the fire. The consequence of scenario 1 is minor, so set the consequences $C_{S1} = 0$, which really means the consequences are acceptable and almost unavoidable.

Consequence assigned to scenario S2. The fire is not suppressed by the first aid responders, but is suppressed at some time later by the sprinkler system. Once again, there is little threat to anyone who is not intimate with the fire. The consequence of scenario 2 is minor, so set $C_{S2} = 0$ (the consequences are acceptable and almost unavoidable).

Consequence assigned to scenario S3. The fire is not suppressed by the first aid responders or the sprinkler system. However, the smoke venting system operates properly, so there is little threat to anyone who is not intimate with the fire. Nonetheless, assume the consequence of scenario 3 is that 1 % of the people in the arena and spectator area are threatened, so $C_{S3} = 0{,}01 \times 2\,000 = 20$.

Consequence assigned to scenario S4. The fire is not suppressed by either the first aid responders or the sprinkler system and the smoke venting system does not operate properly. However, barriers prevent movement of smoke into the retail area. Assume 50 % of occupants originally in the arena-and-spectator area are threatened. The consequence of scenario 4 is $C_{S4} = 0{,}5 \times 2\,000 = 1\,000$.

Consequence assigned to scenario S5. The fire is not suppressed by either the first aid responders or the sprinkler system, the smoke venting system does not operate properly and barriers do not prevent movement of smoke into the retail area. Assume that 50 % of occupants originally in arena-and-spectator areas are threatened and that 10 % of occupants originally in the retail area are threatened. The consequence of scenario 5 is $C_{S5} = 0{,}5 \times 2\,000 + 0{,}10 \times 400 = 1\,040$.

b) Fires originating in the retail area — scenarios S6 to S9:

Consequence assigned to scenario S6. The fire is quickly suppressed by first aid responders so that there is little threat to anyone who is not intimate with the fire. The consequence of scenario 6 is minor, so set $C_{S6} = 0$ (the consequences are acceptable and almost unavoidable).

Consequence assigned to scenario S7. The fire is not suppressed by the first aid responders, but is suppressed some time later by the sprinkler system. Once again, there is little threat to anyone who is not intimate with the fire. Assume the consequence of scenario 7 is that 0,5 % of the people in the retail area are threatened so $C_{S7} = 0{,}005 \times 400 = 2$.

Consequence assigned to scenario S8. The fire is not suppressed by the first aid responders or sprinkler system. However, barriers prevent spread of fire and smoke from the retail area into the arena and spectator areas. If it is not necessary for the occupants in those areas to escape through the retail area, it can be assumed that 0 % of occupants originally in arena and spectator areas are threatened and that 50 % of occupants originally in the retail area are threatened. The consequence of scenario 8 is $C_{S8} = 0{,}50 \times 400 = 200$.

Consequence assigned to scenario S9. The fire is not suppressed by the first aid responders or sprinkler system and barriers do not prevent spread of fire and smoke from the retail area into the arena-and-spectator areas. Assume that 25 % of occupants originally in arena and spectator areas are threatened and that 50 % of occupants originally in the retail area are threatened. The consequence of scenario 9 is $C_{S9} = 0{,}25 \times 2\,000 + 0{,}50 \times 400 = 700$.

c) Fires originating in the storage area — Scenarios S10 to S13:

Consequence assigned to scenario S10. The fire is quickly suppressed by first aid responders so that there is no threat to anyone who is not intimate with the fire. The consequence of scenario 10 is minor so set $C_{S10} = 0$ (the consequences are acceptable and almost unavoidable).

Consequence assigned to scenario S11. The fire is not suppressed by the first aid responders, but is suppressed some time later by the sprinkler system. Once again, there is little threat to anyone who is not intimate with the fire. The consequence of scenario 11 is minor so set $C_{S11} = 0$ (the consequences are acceptable and almost unavoidable).

Consequence assigned to scenario S12. The fire is not suppressed by the first aid responders or sprinkler system. However, barriers prevent spread of fire and smoke from the storage area into the retail or arena-and-spectator areas. The consequence of scenario 12 is minor so set $C_{S12} = 0$ (the consequences are acceptable and almost unavoidable).

Consequence assigned to scenario S13. The fire is not suppressed by either the first aid responders or by sprinkler system and barriers do not prevent spread of fire and smoke from the storage area into the arena-and-spectator or retail areas. Assume that 25 % of occupants originally in arena and spectator areas are threatened, and 25 % of occupants originally in the retail area are threatened. The consequence of scenario 13 is $C_{S13} = 0{,}25 \times 2\,000 + 0{,}25 \times 400 = 600$.

**Step 9 — Risk ranking**

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

The risk associated with each scenario is computed as probability times consequence. In Table B.1, the risks of each scenario are estimated and an overall ranking provided.

**Table B.1 — Risk ranking of scenarios**

| Fire Scenario | Probability | Consequence | Risk | Rank |
|---|---|---|---|---|
| S1 | 0,10 | 0 (low) | 0 (low) | 4 |
| S2 | 0,05 | 0 (low) | 0 (low) | 4 |
| S3 | 0,035 | 20 | 0,70 | 3 |
| S4 | 0,013 5 | 1 000 | 13,5 | 1 |
| S5 | 0,001 5 | 1 040 | 1,56 | 2 |
| S6 | 0,48 | 0 (low) | 0 (low) | 3 |
| S7 | 0,114 | 2 | 0,228 | 2 |
| S8 | 0,004 8 | 200 | 0,96 | 1 |
| S9 | 0,001 2 | 700 | 0,84 | 1 |
| S10 | 0,02 | 0 (low) | 0 (low) | 2 |
| S11 | 0,171 | 0 (low) | 0 (low) | 2 |
| S12 | 0,007 2 | 0 (low) | 0 (low) | 2 |
| S13 | 0,001 8 | 600 | 1,08 | 1 |

**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). For a rigorous analysis, it can be necessary to analyse all scenarios in the event tree. Document the fire scenarios selected for analysis. These will become the “design-fire scenarios”.

a) For fires originating in the arena-and-spectators area:

Scenario S4 has the greatest risk and entails rather large consequences. The design should be undertaken to address such potentially large-loss fires. Perhaps two design-fire scenarios can be considered.

— One in which the fire grows until sprinklers activate. This would assure design of an adequate sprinkler system.

— One in which the fire grows without sprinkler activation (that is, the sprinklers fail to activate). This would assure design of an adequate smoke-venting system.

b) Fires originating in the retail area — Scenario S9:

Scenarios S8 and S9 have about the same risk and both entail rather large consequences. The design should be undertaken to address these potentially large-loss fires. Perhaps two design-fire scenarios can be considered.

- One in which the fire grows until sprinklers activate. This would assure design of an adequate sprinkler system.
- One in which the fire grows without sprinkler activation (that is, the sprinklers fail to activate) and flashover is achieved. This would assure design of adequate barriers.

c) Fires originating in the storage area — Scenario S13:

Scenario S13 has the largest risk and entails rather large consequences. The design should be undertaken to address this potentially large-loss fire. Perhaps two design fire scenarios can still be considered, particularly if one wished to ensure some redundancy.

- One in which the fire grows until sprinklers activate. This would assure design of an adequate sprinkler system.
- One in which the fire grows without sprinkler activation (that is, the sprinklers fail to activate) and flashover is achieved. This would assure design of adequate barriers.

## B.4 Observations

The event-tree approach presented in this annex is not only useful in selecting design-fire scenarios but also in allowing the designer to ensure that all fire-safety design features are consistent with the probabilities and consequences entered on the event tree. It is necessary that the designer ensure that the consequences, expressed as occupants threatened, are realistic by, for example, providing an adequate detection and alarm system, which is not explicitly entered on the tree. It is important that the probabilities, such as the probability of successful operation of sprinklers, be realistic.

The event tree is also useful for gauging where improvements can be made. For example, one can explore the impact of improving various fire-safety measures by taking actions that yield an increased probability and/or decreased consequence of a favourable measure.

# Annex C
(informative)

# Selection of design fire scenarios — Fire in a warehouse containing a single commodity

## C.1 Objective

The objective of this annex is to demonstrate, via an example, how design-fire scenarios can be selected using the “ten step” methodology presented in this document. The example is a warehouse containing a single commodity for which the fire safety objectives are property protection and continuity of operations.

## C.2 Description of the building and its use

A fire in a warehouse can lead to a devastating loss because of the high concentration of value in the occupancy and because an important link in the distribution chain is removed. Such losses can involve rapid fire-growth because the arrangement of combustibles in the occupancy is such that ventilation of each fuel element and confinement of heat in flue spaces is virtually optimized. For this reason, many warehouses depend on automatic sprinklers (at the ceiling and, often, within any rack structures used to hold the storage) for protection. In other cases, only manual fire fighting by a plant emergency organization using hose streams is relied upon. Hose streams can be very effective in storage occupancies if the fire is caught at a very early stage but not if fire propagation is well advanced.

For the present example, the following are assumed.

- The warehouse is of non-combustible construction.
- All storage is a single commodity type in a rack structure five tiers high.
- The commodity is accessed by manual lift trucks (i.e., the warehouse is not automated).
- Protection is by control-mode sprinklers (see ISO 13387-7).

## C.3 The ten-step procedure

In this example, steps 1 and 2 have been inverted to better suit the analysis.

**Step 1 — Type of fire**

The most likely types of fire scenarios and the most likely high-consequence fire scenarios have been identified from fire incident statistics appropriate for the building and occupancy under consideration.

- most likely fire types from 542 FM Global storage losses, 1991-2000: arson (32 %), electricity-related (18 %), exposure to fire external to warehouse (12 %), hot work, e.g, cutting or welding (8 %), careless use of smoking materials (8 %), chemical action, e.g. spontaneous ignition (7 %); spark (6 %) and hot surface (5 %);
- high-consequence fire type: flammable liquid spills (due to arson or process work) that can initiate fires at several locations.

**Step 2 — Location of fire**

Select locations in the building that produce the most adverse fire scenarios.

The most adverse locations are the following:

- at the bottom of storage rack, in a transverse or longitudinal rack flue space most remote from hose streams or from the sprinkler riser;
- at the bottom of one tier of "illegal" storage in an aisle;
- at the bottom of storage rack when there is an extra, "illegal" tier of storage.

**Step 3 — Potential fire hazards**

Identify other critical high-consequence scenarios for consideration. If any of these scenarios is likely to be of a higher consequence than those identified previously, it is necessary that they be included in the set for analysis. They may replace less hazardous scenarios that are similar in nature.

Potential fire hazards include the rack storage of the following generic types of commodities that the sprinkler system is not designed to protect:

- storage of commodities containing aerosol cans;
- storage of flammable-liquid containers;
- storage of commodities containing mostly polymers that melt and drip;
- storage of commodities containing uncartoned foam (expanded) plastics.

**Step 4 — Systems impacting on fire**

Identify the building and fire-safety systems features that are likely to have a significant impact on the course of the fire or the development of untenable conditions.

The most likely contributing factors from 527 FM Global storage losses, 1991-2000, include human element (see step 5, 31 %), storage arrangement (aisle storage or storage height, 28 %); protective devices not working (water flow alarm, interlocks, fire doors, 9 %), exterior exposure (8 %), sprinkler problems (hang-ups, improper spacing or temperature rating, spray pattern blocked by obstructions, 5 %), shut water-supply valve (5 %), building processing operations (4 %).

**Step 5 — Occupant response**

Identify occupant characteristic response features that are likely to have a significant impact on the course of the fire, such as plant emergency-organization actions (not calling fire service, shutting valves too soon or shutting valves inadvertently, shutting pumps, keeping fire/smoke doors open), or fire service response too slow or inadequate.

**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 event tree is illustrated in Figure C.1 (it is not necessary that all scenarios be quantified).

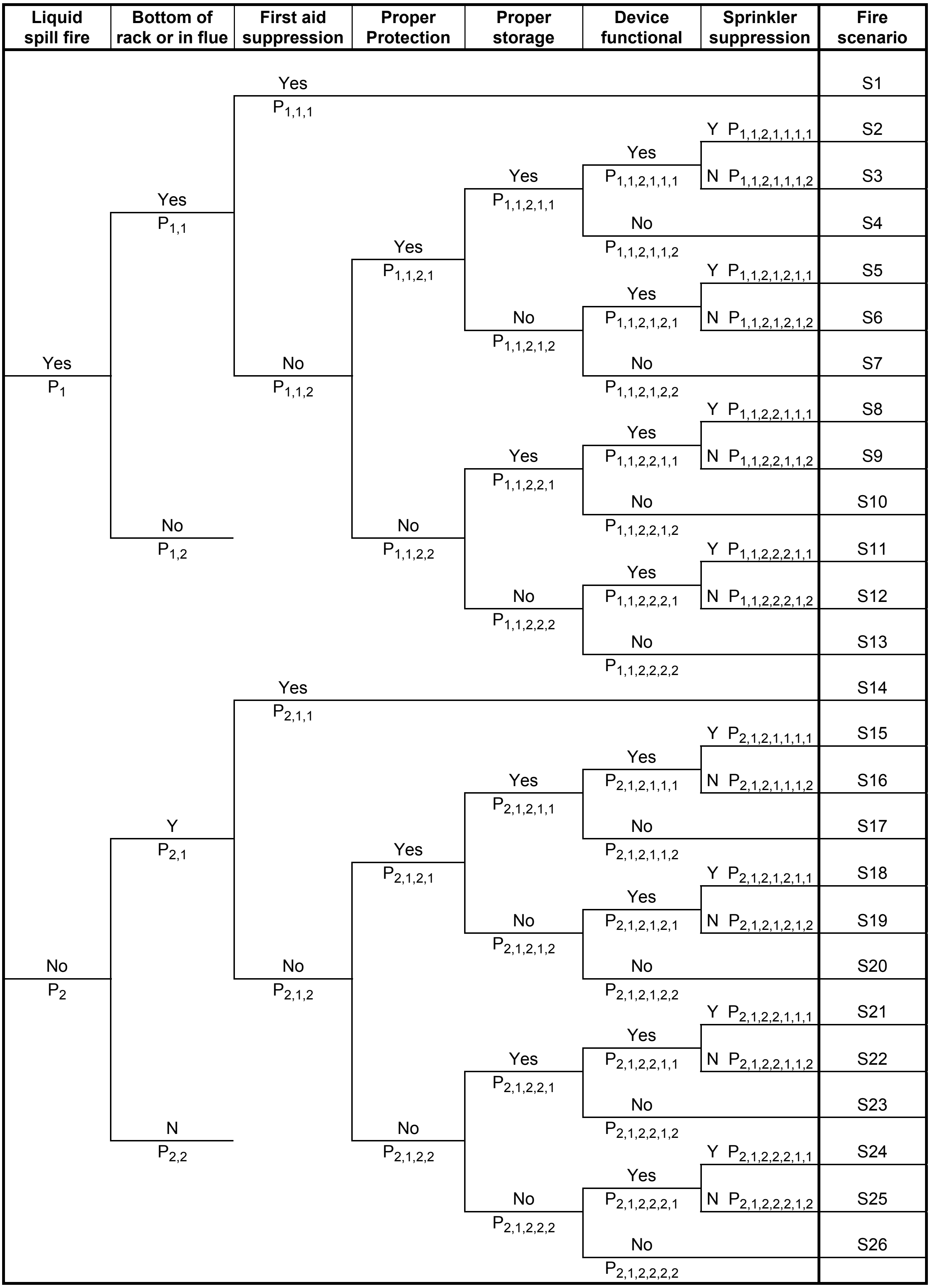


**Figure C.1 — Event tree for fire in a warehouse containing a single commodity**

The branches of the event tree are as follows:

Branch 1: The fire is either a flammable liquid spill fire or some other type. As mentioned above, liquid-spill fires are more challenging for sprinkler systems.

Branch 2: The fire starts either at the bottom of a rack or in a flue or it starts elsewhere. The two options have about the same probability, so only the option with the fire's starting at the bottom of a rack or in a flue is continued here because it yields greater consequences.

Branch 3: First aid suppression is either successful or not successful.

Branch 4: The sprinkler system design is appropriate for the stored commodity or it is not.

Branch 5: The commodity is stored an fashion appropriate to the sprinkler design or it is not.

Branch 6: The sprinkler system is operational or it is not. It can, for example, be shut off for maintenance.

Branch 7: The sprinkler system suppresses the fire or it does not.

**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.

Overall reliability of the sprinkler system is about 95 %, assuming a public water supply. This is substantially lower, however, when a flammable liquid spill ignites a large area of storage.

The various conditional probabilities have been estimated using statistics and engineering judgment as follows:

- $P_1 = 0{,}16$ (liquid spill fire);
- $P_2 = 0{,}84$ (other fire);
- $P_{1,1} = P_{2,1} = 0{,}5$ (fire starts either at the bottom of a rack or in a flue);
- $P_{1,2} = P_{2,2} = 0{,}5$ (fire starts elsewhere);
- $P_{1,1,1} = P_{2,1,1} = 0{,}7$ (first aid suppression is successful);
- $P_{1,1,2} = P_{2,1,2} = 0{,}3$ (first aid suppression is not successful);
- $P_{1,1,2,1} = P_{2,1,2,1} = 0{,}9$ (sprinkler system design is appropriate for the stored commodity);
- $P_{1,1,2,2} = P_{2,1,2,2} = 0{,}1$ (sprinkler system design is inappropriate for the stored commodity);
- $P_{1,1,2,1,1} = P_{1,1,2,2,1} = P_{2,1,2,1,1} = P_{2,1,2,2,1} = 0{,}8$ (commodity storage is appropriate to sprinkler design);
- $P_{1,1,2,1,2} = P_{1,1,2,2,2} = P_{2,1,2,1,2} = P_{2,1,2,2,2} = 0{,}2$ (commodity storage inappropriate to sprinkler design);
- $P_{1,1,2,1,1,1} = P_{1,1,2,1,2,1} = P_{1,1,2,2,1,1} = P_{1,1,2,2,2,1} = P_{2,1,2,1,1,1} = P_{2,1,2,1,2,1} = P_{2,1,2,2,1,1} = P_{2,1,2,2,2,1} = 0{,}9$ (sprinkler system is operational);
- $P_{1,1,2,1,1,2} = P_{1,1,2,1,2,2} = P_{1,1,2,2,1,2} = P_{1,1,2,2,2,2} = P_{2,1,2,1,1,2} = P_{2,1,2,1,2,2} = P_{2,1,2,2,1,2} = P_{2,1,2,2,2,2} = 0{,}1$ (sprinkler system is not operational);

- for flammable liquid fires:
  - $P_{1,1,2,1,1,1,1} = 0{,}5$ (sprinkler suppresses fire but probability is low because flammable liquid spills can ignite fire over a large area),
  - $P_{1,1,2,1,1,1,2} = 0{,}5$ (sprinkler does not suppress fire),
  - $P_{1,1,2,1,2,1,1} = 0{,}4$ (sprinkler suppresses fire but probability is even lower due to improper storage),
  - $P_{1,1,2,1,2,1,2} = 0{,}6$ (sprinkler does not suppress fire),
  - $P_{1,1,2,2,1,1,1} = P_{1,1,2,2,2,1,1} = 0{,}1$ (sprinkler suppresses fire but probability is very low because commodity is incompatible with sprinkler design),
  - $P_{1,1,2,2,1,1,2} = P_{1,1,2,2,2,1,2} = 0{,}9$ (sprinkler does not suppress fire);
- for other fires:
  - $P_{2,1,2,1,1,1,1} = 0{,}95$ (sprinkler suppresses fire with typical probability of success),
  - $P_{2,1,2,1,1,1,2} = 0{,}05$ (sprinkler does not suppress fire),
  - $P_{2,1,2,1,2,1,1} = 0{,}75$ (sprinkler suppresses fire but probability is lower due to improper storage),
  - $P_{2,1,2,1,2,1,2} = 0{,}25$ (sprinkler does not suppress fire),
  - $P_{2,1,2,2,1,1,1} = P_{2,1,2,2,2,1,1} = 0{,}5$ (sprinkler suppresses fire but probability is quite low because commodity is incompatible with sprinkler design),
  - $P_{2,1,2,2,1,1,2} = P_{2,1,2,2,2,1,2} = 0{,}5$ (sprinkler does not suppress fire).

**Step 8 — Consideration of consequence**

Estimate the consequence of each scenario using engineering judgement. The consequence 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.

In this example, the risk of people getting injured is low. The maximum consequence is direct physical damage ($50 M to $200 M) and business interruption ($10 M to $200 M, depending on the number of similar storage facilities in the enterprise).

Consequence assigned to scenarios S1 and S14: The fire is suppressed by first aid responders so damage is limited, although damage is more widespread for the flammable liquid fire. Assume $C_{S1} = \$500\,000$ and $C_{S14} = \$100\,000$.

For scenarios in which the sprinkler system suppresses a liquid spill fire assume the damage is still considerable: $C_{S2} = C_{S5} = C_{S8} = C_{S11} = \$10\,000\,000$.

For scenarios in which the sprinkler system suppresses another fire type, assume the damage is considerably less: $C_{S15} = C_{S18} = C_{S21} = C_{S24} = \$1\,000\,000$.

For scenarios in which the sprinkler system fails to suppress the fire, assume the maximum damage: $C_{S3} = C_{S4} = C_{S6} = C_{S7} = C_{S9} = C_{S10} = C_{S12} = C_{S13} = C_{S16} = C_{S17} = C_{S19} = C_{S20} = C_{S22} = C_{S23} = C_{S25} = C_{S26} = \$400\,000\,000$.

**Step 9 — Risk ranking**

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

**Table C.1 — Ranking of the relative risk of the fire scenarios**

| Fire Scenario | Probability | Consequence | Risk | Rank |
|---|---|---|---|---|
| S1 | 0,056 | $500 000 | $28 000 | — |
| S2 | 0,007 776 | $10 000 000 | $77 760 | — |
| S3 | 0,007 776 | $400 000 000 | $3 110 400 | 1 |
| S4 | 0,001 728 | $400 000 000 | $691 200 | 3 |
| S5 | 0,001 555 2 | $10 000 000 | $15 552 | — |
| S6 | 0,002 332 8 | $400 000 000 | $933 120 | 2 |
| S7 | 0,000 432 | $400 000 000 | $172 800 | 5 |
| S8 | 0,000 172 8 | $10 000 000 | $1 728 | — |
| S9 | 0,001 555 2 | $400 000 000 | $622 208 | 4 |
| S10 | 0,000 192 | $400 000 000 | $76 800 | — |
| S11 | 0,000 043 2 | $10 000 000 | $432 | — |
| S12 | 0,000 388 8 | $400 000 000 | $155 520 | 6 |
| S13 | 0,000 048 | $400 000 000 | $19 200 | — |
| S14 | 0,294 | $100 000 | $29 400 | — |
| S15 | 0,077 565 6 | $1 000 000 | $77 566 | — |
| S16 | 0,004 082 4 | $400 000 000 | $1 632 960 | 4 |
| S17 | 0,009 072 | $400 000 000 | $3 628 800 | 1 |
| S18 | 0,015 309 | $1 000 000 | $15 309 | — |
| S19 | 0,005 103 | $400 000 000 | $2 041 200 | 2 |
| S20 | 0,002 268 | $400 000 000 | $907 200 | 5 |
| S21 | 0,004 536 | $1 000 000 | $4 536 | — |
| S22 | 0,004 536 | $400 000 000 | $1 814 400 | 3 |
| S23 | 0,001 008 | $400 000 000 | $403 200 | — |
| S24 | 0,001 134 | $1 000 000 | $1 134 | — |
| S25 | 0,001 134 | $400 000 000 | $453 600 | 6 |
| S26 | 0,000 252 | $400 000 000 | $100 800 | — |

### 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). 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”.

Whether the fire starts with a flammable liquid spill or some other means, it is clear that the most severe scenarios are those in which the sprinkler system fails to suppress the fire. Sprinkler control is necessary.

Two design-fire scenarios can be envisioned:

- The fire starts with a flammable liquid spill and ignites fires in several flues and at the bottom of a rack. At least one rack that is ignited has one tier of commodity stored above what is to be permitted. (The design objective is to design a sprinkler system that can control the resultant fire.)
- The fire starts by some means other than by a flammable liquid spill and ignites a fire in one flue. At least one rack that is ignited has one tier of commodity stored above what is to be permitted. (The design objective is to design a sprinkler system that can control the resultant fire.)

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