TECHNICAL REPORT

ISO/TR 13387-1

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Fire safety engineering —

Part 1: Application of fire performance concepts to design objectives

Ingénierie de la sécurité contre l'incendie —

Partie 1: Application des concepts de performance aux objectifs de conception

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Contents

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Foreword

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

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

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

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

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

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 Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 13387-1, which is a Technical Report of type 2, was prepared by Technical Committee ISO/TC 92*, Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

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

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

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

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

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

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

— *Part 5: Movement of fire effluents*

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

— *Part 7: Detection, activation and suppression*

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

Annex D forms a normative part of this part of ISO/TR 13387. Annexes A to C and annexes E and F are for information only.

Introduction

A fire safety engineering approach may have many benefits over prescriptive approaches (see annex A). It takes into account the totality of the fire safety package and provides a more fundamental and economic solution than traditional approaches to fire safety. It may be the only viable means of achieving a satisfactory level of fire safety in some large and complex buildings. For most buildings prescriptive recommendations may be found to be adequate but the use of a fire safety engineering approach enables the more precise design necessary for the assessment of new and complex projects.

This part of ISO/TR 13387 is intended to be applicable to both new and existing buildings and can be used either to justify minor deviations from traditional/prescriptive codes or to evaluate the building design as a whole.

The interaction of fire, buildings and people gives rise to a large number of possible scenarios. Together with the wide range of building designs and uses, this makes it impractical to establish a single set of calculations and procedures that can be applied directly to all buildings. There are still many gaps in the available knowledge and it is, therefore, not possible to set down simple step-by-step procedures that can be applied to all buildings. This part of ISO/TR 13387 is, therefore, intended to provide a framework for a flexible but formalised approach to fire safety design that can be readily assessed by the statutory authorities.

The current knowledge and ability to model fire processes and the response of people requires the use of engineering judgement to compensate for gaps in, or supplement, knowledge. The approaches and procedures detailed in this part of ISO/TR 13387 should, therefore, only be used by suitably qualified and experienced fire safety professionals. It is also important that account should be taken of statutory requirements, and the appropriate approvals bodies should, where necessary, be consulted before final decisions are made about the fire safety design.

Fire safety engineering —

Part 1:
Application of fire performance concepts to design objectives

1 Scope

This part of ISO/TR 13387 describes one framework for the provision of an engineered approach to the achievement of fire safety in buildings, based on the quantification of the behaviour of fire and people. The Technical Report is not intended as a detailed technical design guide, but could be used as the basis for development of such a guide. It indicates the interdependence and interactions between various components of the fire safety system and provides an indication of the totality of fire safety design. It is appropriate for various alternative single or multiple design objectives.

The basic principles given in this part of ISO/TR 13387, together with the guidance on detailed aspects of fire safety design given in other parts, may be applied to all types of building and their use. Principally this Part applies to common types of building such as dwellings, office buildings, department stores, schools, hotels, and public-assembly and industrial buildings, new and existing.

The principles, the methodology and many of the calculation tools may be applied to the safe design of many other structures, which may or may not accommodate people, such as tunnels, petrochemical plants, offshore oil/gas installations and transportation systems (railway carriages, aircraft cabins and passenger ships).

This part of ISO/TR 13387 takes into account many factors including building construction, means of escape, human factors, smoke management, detection, alarm and fire suppression and their contribution to the attainment of the fire safety objectives. It provides some alternative approaches to existing codes for fire safety and allows the effect of departures from more prescriptive codes and regulations to be evaluated.

Although the emphasis in this document is on safety of life, the fire safety engineering approach can also be used to assess property loss, business interruption, contamination of the environment and destruction of heritage. It is anticipated that, in the future, this part of ISO/TR 13387 will be broadened to cover, for example, property loss, business interruption, contamination of the environment and destruction of heritage.

2 Normative references

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

ISO 31-0:1992, *Quantities and units — Part 0: General principles.*

ISO 31-4 1992, *Quantities and units — Part 4: Heat.*

ISO/TR 13387-2, *Fire safety engineering — Part 2: Design fire scenarios and design fires.*

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

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

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

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

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

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

ISO 13943, *Fire safety — Vocabulary*.

3 Terms and definitions

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

3.1
acceptance criteria
qualitative and quantitative criteria which have been agreed with the building approval authority and hence form an acceptable basis for assessing the safety of a building design

3.2
alarm time
the time between ignition and alarm

3.3
characterisation
the process of determining design data which are in a form suitable for input to a subsystem

3.4
critical fire load
the fire load required in a compartment to produce a fire of sufficient severity to cause failure of fire-resisting barriers or structural elements

3.5
detection time
the time between ignition of a fire and its detection by an automatic or manual system

3.6
deterministic study
a methodology, based on physical relationships derived from scientific theories and empirical results, that for a given set of initial conditions will always produce the same outcome

3.7
engineering judgement
the process exercised by a professional who is qualified by way of education, experience and recognised skills to complement, supplement, accept or reject elements of a quantitative analysis

3.8
escape/evacuation time
the interval between the time of a warning of fire being transmitted to the occupants and the time at which the occupants of a specified part of a building or all of the building are able to enter a place of safety

3.9
estimated design parameter
a design parameter which involves a process of estimation (or characterisation)

It may describe the building, contents, occupants and environment. This is usually decided by the fire safety engineer.

3.10
exit
a doorway or other suitable opening giving direct access to a place of safety

Exits include exterior exit doors, exit passageways, horizontal exits, separated exit stairs and separated exit ramps.

3.11
fire safety engineering
the application of engineering principles, rules and expert judgement based on a scientific appreciation of the fire phenomena, of the effects of fire, and of the reaction and behaviour of people, in order to:

— save life, protect property and preserve the environment and heritage;

— quantify the hazards and risk of fire and its effects;

— evaluate analytically the optimum protective and preventative measures necessary to limit, within prescribed levels, the consequences of fire

3.12
fire safety manual
a document detailing the fire safety management procedures that should be implemented on a continuing basis

3.13
hazard
the potential for loss of life (or injury) and/or damage to property by fire

3.14
movement time
the time needed for all of the occupants of a specified part of a building to move to an exit and pass through it and into a place of safety

3.15
management or manager
the persons or person in overall control of the premises whilst people are present, exercising this responsibility either in their own right, e.g. as the owner, or by delegation

3.16
means of escape
structural means whereby safe routes are provided for persons to travel from any point in a building to a place of safety

3.17
phased evacuation
a process by which a limited number of floors (usually the fire floor and the level above and below) are evacuated initially and the remaining floors are evacuated as and when necessary

3.18
place of safety
a place in which persons are in no immediate danger from the effects of fire

3.19
prescribed design parameter
a design parameter which can be directly measured and requires no estimation or conversion of data

It may describe the building, contents, occupants and environment, and is usually decided by the fire safety engineer.

3.20
pre-movement time
the time interval between the warning of fire being given (by an alarm or by direct sight of smoke or fire) and the first move being made towards an exit

3.21
risk
the potential for realisation of an unwanted event, which is a function of the hazard, its probability and its consequences

3.22
system variables
those parameters which are functions of time and which are used in a fire safety engineering evaluation

They are listed under the category Simulation Dynamics in the global information.

3.23
travel distance
the actual distance that needs to be travelled by a person from any point within a building to the nearest exit, having regard to the layout of walls, partitions and fittings

3.24
trial design parameters
design parameters (prescribed and estimated) chosen for the purpose of making a fire safety engineering analysis on one (trial) design

3.25
validation (as applied to fire calculation models)
process of determining the correctness of the assumptions and governing equations implemented in a model when applied to the entire class of problems addressed by the model

3.26
verification (as applied to mathematical fire models)
process of checking a mathematical fire model for correct physical representation and mathematical accuracy for a specific application or range of applications

The process involves checking the theoretical basis, the appropriateness of the assumptions used in the model, and that the model contains no unacceptable mathematical errors and has been shown, by comparison with experimental data, to provide predictions of the course of events in similar fire situations with a known accuracy.

4 The global approach

4.1 General

Traditional approaches to achieving fire safety in buildings have involved the adoption of a number of complex and often disjointed requirements for different components of the fire safety system. The value of each to the overall design objective is unknown and the complementary or compensating nature of these provisions cannot be quantified.

As a result of the large and rapid increase in innovative and diversified building design, traditional regulations based on "prescription" rather than "performance" have proved to be restrictive and inflexible. Consequently, more fundamental approaches to the provision of fire safety in buildings have had to be pursued. A more detailed discussion of the background to the application of fire safety engineering and its benefits is given in annex A.

This part of ISO/TR 13387 looks at the provision of fire safety in buildings from a fundamental viewpoint, and it ignores the constraints that may be applied to building design as a consequence of various national regulations or codes. The fact that a building has been designed adopting the approach given in this document does not, therefore, mean that it will satisfy the requirements of national regulations. The document may help to discipline engineered approaches to fire safety design and to ensure that all the essential requirements and aspects of design have been properly considered and addressed, and that, having established the objectives of design, these are demonstrated as being satisfied in an acceptable and quantified manner.

The approach adopted in this part of ISO/TR 13387 is to consider the global objective of fire safety design and to give guidance on the nature of criteria which may be appropriate to demonstrating compliance with these objectives. The global design is sub-divided into what are called "subsystems" of the total design, and the document ensures that the inter-relationship and interdependence of the various subsystems are appreciated, and that the consequences of all the events in any one subsystem on all other subsystems are identified and addressed.

In addition to life safety, the principles and methodology in this document can also be used to determine property loss, business interruption, contamination of the environment and destruction of heritage. The Technical Report can be used, for instance, to predict a contents response-time profile which enables the amount of fire loss (direct, consequential, etc.) to be determined from a knowledge of the location, value, damageability and salvageability of the individual items of building contents and spatial distribution of smoke, heat, water and corrosive products.

4.2 Summary of the fire safety engineering assessment process

Fire safety engineering assessment involves the following steps (the basic process is illustrated in Figure 1):

a) Qualitative design review (QDR):

The review is qualitative because not all the values of the design parameters will be known and engineering judgement will need to be applied to obtain them. It is also qualitative because judgement will need to be used to decide on a limited number of important fire scenarios for later quantified analysis.

For a large project, it is preferable for the QDR to be undertaken by a team which includes the design team and the approval authorities.

More information on the QDR is given in annex B.

It is necessary to:

— define fire safety objectives and acceptance criteria — possibly in consultation with the approval authorities;

— establish the prescribed design parameters by reviewing the architectural design and the proposed fire safety features;

— characterise the building and its occupants, i.e. estimate design parameters not given by the architect;

— identify potential fire hazards and their possible consequences;

— select those fire scenarios which should form part of the quantified analysis;

— establish trial fire safety designs;

— indicate appropriate methods of analysis.

b) Quantitative analysis of design:

— carry out a time-based quantified analysis using the appropriate subsystems — or use another appropriate method of analysis as indicated in the QDR, making sure that, wherever possible, mathematical models are verified (see ISO/TR13387-3).

c) Assess the outcome of the analysis against the safety criteria:

— Repeat the analysis if the acceptance criteria not satisfied (e.g. in a life safety assessment) by controlling the fire process to increase the time available for safe escape (where appropriate) and/or reducing the time required to escape.

d) Report and present the results.

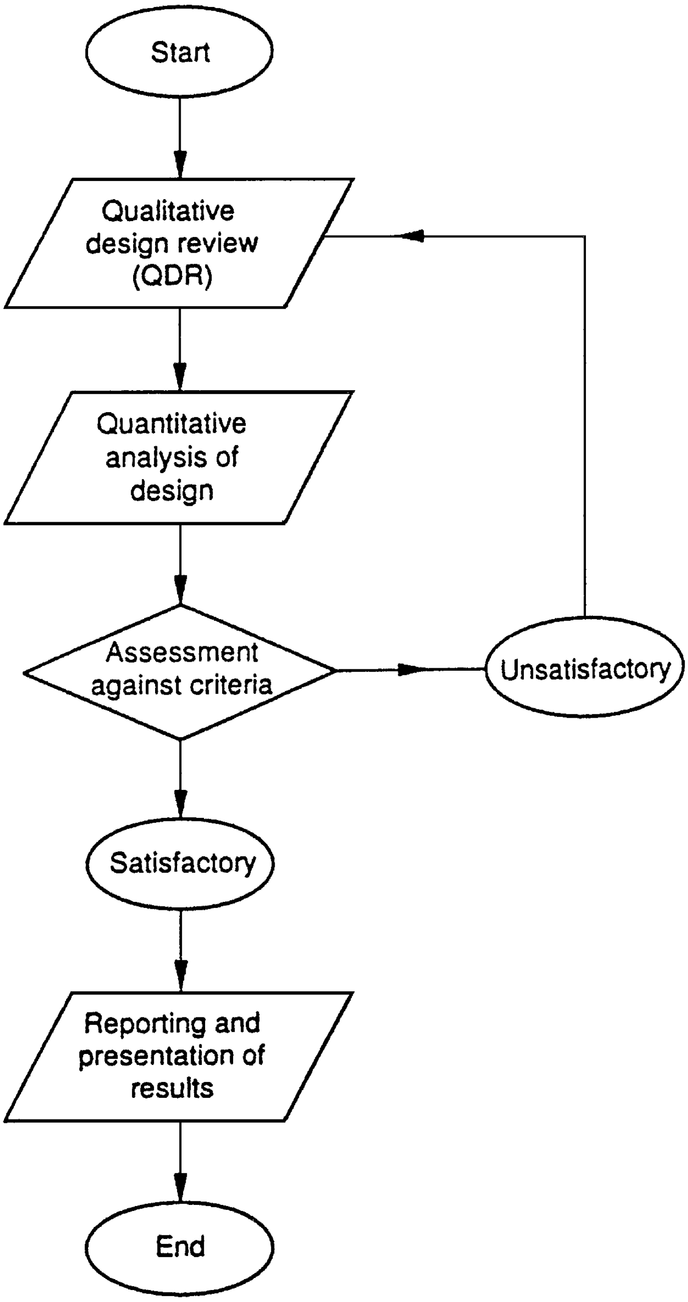


Figure 1 — Basic fire safety design process

4.3 The subsystems of the design

4.3.1 General

The evaluation of the fire safety design of a building is broken down, to simplify the process, into five separate components of the system (subsystems denoted by SS1 to SS5) as follows:

4.3.2 SS1 — Initiation and development of fire and generation of fire effluents

This subsystem provides a framework for critically reviewing the suitability of an engineering method for assessing the potential for the initiation and development of fire and generation of fire effluents. The subsystem may also provide means to assess the effectiveness of fire safety measures meant to reduce the probability of ignition, to control fire development, and to reduce accumulation of heat, smoke, and toxic products or products causing non-thermal damage. Methods for calculating the effects of the design fires for use in the design and assessment of fire safety of a building are also addressed.

4.3.3 SS2 — Movement of fire effluents

This subsystem provides a framework for critically reviewing the suitability of an engineering method for assessing the potential for movement of fire effluents during the course of a fire. The subsystem may also provide means to assess the effectiveness of fire safety measures meant to reduce the adverse effects of the movement of fire effluents. Methods for calculating the effects of the design fires for use in the design and assessment of fire safety of a building are also addressed.

The subsystem draws on other subsystems for a prescription or characterisation of the fire. The predictions of the fire development and the production of fire effluents is provided by subsystem 1. The prediction of the spread of smoke and flames through openings is addressed by subsystem 2 while the spread of fire through barriers is provided by subsystem 3.

4.3.4 SS3 — Structural response and fire spread beyond the enclosure of origin

This subsystem provides a framework for critically reviewing the suitability of an engineering method (hand calculation, computer method or fire test) for assessing the structural response and the potential for fire spread in a given situation (application). This entails an analysis of the unit physical and chemical processes involved in each of the modes of fire spread (e.g. room to room, building to building, room to external items). The availability (and reliability) of the relevant input data for each unit process is also addressed.

The subsystem draws on other subsystems for a prescription or characterisation of the fire. Subsystem 1, for example, provides predictions of the time to flashover and the temperature history in the room of fire origin. These data, along with the description of the building assemblies (trial design parameters) are employed by the subsystem to predict the likelihood (and time) of fire spread, and the likelihood (and time) of structural collapse.

Should fire spread from the room (compartment) of fire origin or should local structural collapse occur, not only will additional property damage be incurred, but the safety of building occupants and firefighters outside the room (compartment) of fire origin can be compromised. Hence data generated by subsystem 3 become inputs to subsystem 5.

Finally, guidance on interpreting the results of an analysis of the potential of fire spread is also provided. This includes guidance on the selection of criteria for assessing the effectiveness of fire safety measures meant to reduce the potential of fire spread. The latter is only possible if the objectives of fire safety design have been clearly specified.

4.3.5 SS4 — Detection, activation and suppression

This subsystem provides guidance on the use of engineering methods for the prediction of the time to detect smoke or flames by a wide range of commercial devices, including the time required for heat-sensitive elements in suppression or other control devices to respond to the gas flow generated by an incipient or growing fire. The subsystem also provides guidance on how to predict, once detection has occurred, the time required to activate the desired response to a fire, such as an alarm, a smoke damper or a specified flow of extinguishing agent from typical distribution devices. Methods of estimating the effectiveness of many common fire-suppression and control strategies are also addressed.

Subsystem 4 draws on subsystems 1 to 3 for characterising the size of the fire as well as the temperature, species concentration and gas velocity fields generated by the fire at any time after ignition/initiation of the design fire event. This information, along with a description of sensor locations from the building design parameters, is employed by subsystem 4 to predict detection times and the operation of elements, such as those in automatic sprinklers, that allow release of pressurised extinguishing agent (e.g. water) at a nozzle.

The effect of various suppression strategies on the fire heat release rate is estimated in subsystem 4 currently by reference to national codes and installation guidelines and the use of engineering judgement in the application of these guidelines to the design fire scenarios. Once an assumed suppression strategy (usually in terms of a required agent flow rate) takes effect, there is considerable feedback required between subsystem 4 and subsystem 2 so that the resultant fire environment (e.g. gas temperatures and species concentrations) can be determined. If the fire environment is unacceptable, alternative suppression strategies may have to be considered.

Activation times are also determined in subsystem 4, most often from a wealth of input information available from the vendors and manufacturers of the various detection and suppression systems to be installed in a building. The hydraulic design of sprinkler piping systems is considered to be part of this activation process since such piping design ensures that the required flow rate of water or other agent will be available when distribution nozzles are activated by the detection elements.

4.3.6 SS5 — Life safety: occupant behaviour, location and condition

This subsystem provides guidance to designers, regulators and fire safety professionals on the use of engineering methods of evaluating the condition and location of the occupants of a building exposed to fire with respect to time.

It covers assumptions that underlie the basic principles of designing for life safety and provides guidance on the processes, assessments and calculations necessary to determine the location and condition of occupants of the building, with respect to time. The subsystem also draws on other subsystems for matters that impact on the occupants. Temperature, smoke and toxicity profiles from SS2 are of particular importance.

This subsystem also provides a framework for reviewing the suitability of an engineering method for assessing the life safety potential of building occupants.

4.4 Design parameters

4.4.1 Prescribed design parameters

These represent all the parameters and data which are known and provided by the architect to the fire safety engineer. Prescribed design parameters fall into the following categories:

a) aspects of the building design, its contents and its use;

b) the fire safety system installations and facilities for fire brigade intervention;

c) the occupants;

d) the environment.

4.4.2 Estimated design parameters

These represent all the parameters and data needed to supplement the prescribed design parameters before a fire safety engineering assessment can begin. Here the fire safety engineer, based on engineering analysis, needs to make assumptions or estimates in the absence of data from the architect, hence the term estimated design parameters. Fire load density is an example of an estimated design parameter since it is unlikely that the architect will know the value (e.g. kg timber/m^2 or MJ/m^2) corresponding to the actual combustible contents of the building or room, and will therefore not be able to give this data as a prescribed design parameter.

The process of deriving the estimated design data is called "characterisation" in this Technical Report and concerns four main areas:

a) fire load;

b) design fire scenario/design fires;

c) occupant characteristics and number;

d) environmental effects.

Further information on how to derive characteristic data for design fires is given in ISO/TR 13387-2.

4.5 The global information, evaluation and process concept

The relationships and inter-dependence of the two kinds of design parameters and subsystems is illustrated in a simplified form in Figure 2 in which evaluations and processes are omitted for clarity.

Values of the prescribed design parameters (which are fixed for a particular trial design) are input to the global information, indicated in Figure 2 by an inward-pointing arrow. Some of the values of the estimated design parameters (which are also fixed for a particular trial design) require input from the prescribed design parameters and this is done via the global information; other values of the estimated design parameters come direct from other sources. The engineering analysis is done to convert the inputs to the estimated design parameters to outputs which are placed in the global information. All the values of the design parameters are now included in the global information ready for input to the various subsystems.

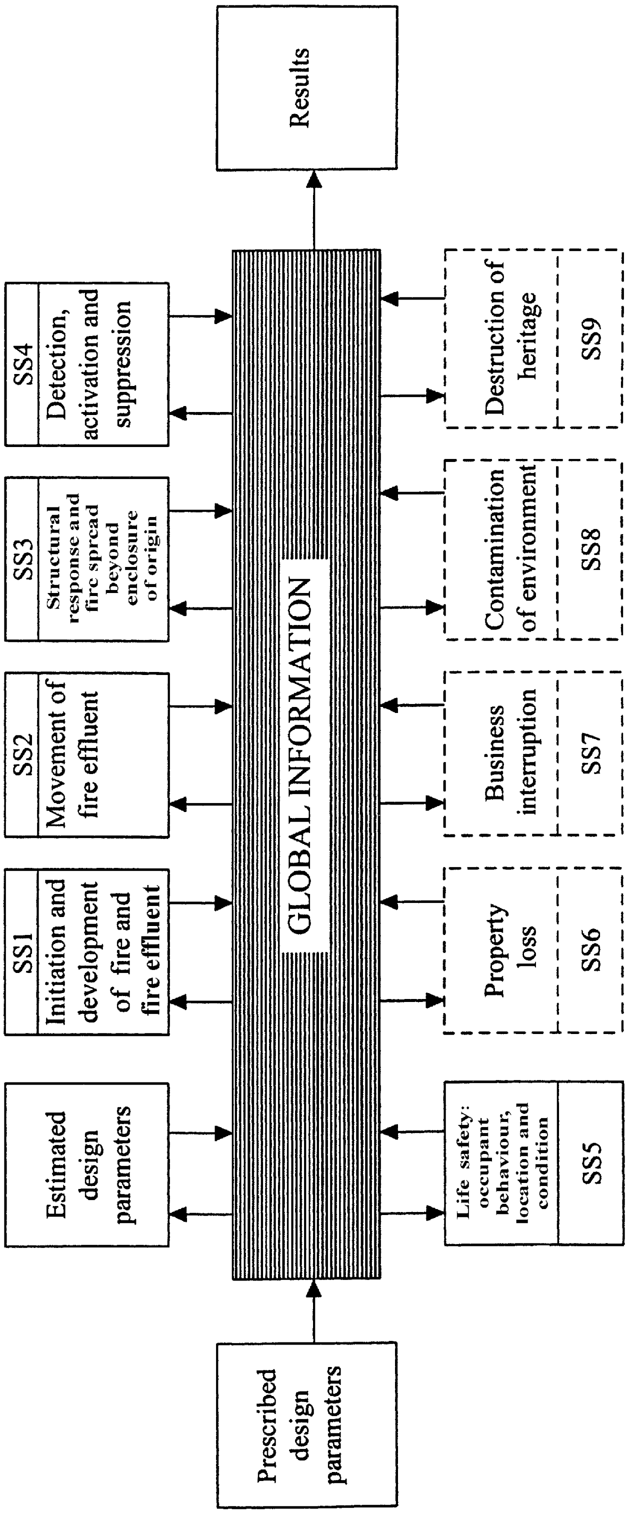
Each subsystem takes the values of design parameters it needs, makes the calculation and places the output in the global information. For example, subsystem 2 (SS2) takes information such as rate of heat release at the appropriate time (obtained as an output of SS1), time to activate smoke extract system and environmental effects, makes its calculations and outputs information such as smoke temperature and layer depth versus time at the target location(s) to the global information for possible use by another subsystem.

If a calculation is complex, the subsystem is more complex and subsystem evaluations and processes are then established in addition to the global information.

The relationship of these three (global information, evaluations and processes) and the activities involved is as follows. The global information contains only numbers representing information about each item in the information. The information can be a single number (e.g. room height in the building) or an array of numbers (such as temperature distribution at a particular location in a room). The evaluations represent a series of sub-routines executed in such a way that the overall job of a particular subsystem is accomplished. The evaluation sub-routines will accept all the information it or its processes need from the global information. Process algorithms accomplish specific jobs for an evaluation sub-routine (e.g. calculating radiative heat transfer from one object to another). When an evaluation sub-routine has finished its execution, it now contains updated information for output to the global information related to its specific tasks. When all the sub-routines in a given subsystem's evaluations have been executed, the whole subsystem's tasks are finished for a given time from ignition. When all the subsystems have executed all their sub-routines in logical order and looped through time in small increments, a fire safety engineering assessment for a defined scenario will have been made.

In a life safety assessment, the occupant location and condition data are returned to the global information system and these are compared against the life safety strategy to establish if the safety objective has been met.

The above-mentioned procedure is used in a deterministic design. A probabilistic risk assessment would require an overlay of the anticipated frequency that the events or sequence of events will occur in the way assumed.



NOTE The dash-outlined boxes indicate possible future work on design objectives.

Figure 2 — Schematic representation of the fire safety engineering system

4.6 Engineering methods

Having established one or more trial designs and the significant fire scenarios, the depth and scope of quantification required needs to be established.

The scope of quantification required and the type and complexity of analysis required to provide an adequate solution should be carefully considered. For instance, when considering the movement of a uniform crowd of occupants from a large, unobstructed building, simple hand calculations may be appropriate, whereas a more detailed model may be more appropriate in a case where the effect of smoke movement in the space or the presence of disabled people in the population need to be taken into account.

The types of analysis procedure to consider include:

a) simple calculation;

b) computer-based deterministic analysis;

c) probabilistic studies;

d) experimental methods.

In some circumstances where a quantitative analysis is not appropriate, a detailed qualitative study or results from evacuation trials may provide an effective means of arriving at a design solution.

A deterministic study using comparative criteria will generally require far fewer data and resources than a probabilistic approach and is likely to be the simplest method of achieving an acceptable solution.

The probabilistic approach is introduced in clause 8. Deterministic models are given in the documents dealing with the subsystems, i.e. ISO/TR 13387-4, 13387-5, 13387-6, and 13387-7.

5 Fire safety management

5.1 General

Fire safety management procedures have a vital role to play in the prevention and control of fires, the evacuation of the occupants and the maintenance of fire safety systems. A common element in multi-fatality fires is often the failure of the occupants of premises, whether they are staff or members of the public, to take the correct action when fire is discovered or when the alarm is raised. When a facility is effectively managed, the probability of fire starting can be reduced and the likelihood of successful evacuation can be enhanced.

For the purpose of this part of ISO/TR 13387, it has been assumed that the building will be managed in a manner that takes account of the need to implement effective evacuation procedures, maintain fire safety equipment and provide adequate staff training.

The possibility of failures in management procedures and fire protection systems should be considered. This is particularly important as it is often difficult to be certain that effective fire safety management procedures will be maintained over the lifetime of the building. However, in certain types of building, particularly those occupied by large numbers of the public, effective management procedures are crucial to a speedy and orderly evacuation. In such buildings, it is desirable for a regular audit, ideally third-party, to be carried out to ensure that effective fire safety management procedures are implemented on a continuing basis.

5.2 Independent audit

Where an independent audit of fire protection and management procedures is carried out regularly, e.g. at least once every six months, it is reasonable to assume that fire protection systems and evacuation procedures are more likely to work effectively than where there are no regular independent audits. Therefore, in buildings that are not subject to independent audit the results of the fire engineering study may show that additional fire protection measures are needed to achieve an acceptable level of safety.

Guidance on key aspects of fire safety management is given in annex C.

6 Objectives and criteria

6.1 General

Prior to proceeding with any design, the objectives must be clearly defined and appropriate criteria established. The procedures given in this part of ISO/TR 13387 may be used to develop a complete fire safety strategy or may simply be used to consider one aspect of the design. It is, therefore, important to establish that the objectives and associated acceptance criteria are appropriate to the particular design aspect under consideration.

6.2 Functional objectives

6.2.1 General

The main fire safety objectives that may need to be addressed in carrying out a fire engineering study are listed below. The list is not exhaustive, and not all items may be appropriate to a particular study.

6.2.2 Life safety objectives

The occupants of a building, as well as firefighters who may have entered that building together with members of the public, and firefighters who are in the vicinity of a building can, potentially, be put at risk by fire. The main life safety objectives are therefore to ensure that:

a) the occupants are able to remain in place, evacuate to another part of the building or totally evacuate the building without being subject to hazardous (e.g. causing injury or incapacitating) or untenable conditions;

b) firefighters are safely able

  1) to assist evacuation where necessary,

  2) to effect rescue where necessary,

  3) to prevent extensive spread of fire;

c) collapse of elements of structure does not endanger people (including firefighters) who are likely to be near the building.

Details of life safety strategies and evaluation techniques are given in annex D.

6.2.3 Loss prevention

The effects of a fire on the continuing viability of a business can be substantial and consideration should be given to the limitation of damage to:

a) the structure and fabric of the building;

b) the building's contents;

c) the ongoing viability of the business;

d) the public image of the business.

6.2.4 Environmental protection

A conflagration involving several buildings or the release of quantities of hazardous materials may have an environmental impact that is out of proportion to the size of the original fire. Consideration should, therefore, be given to the limitation of:

a) the effects of fire on adjacent buildings or facilities;

b) the release of hazardous materials into the environment.

6.3 Acceptance criteria

6.3.1 General

Whatever measures are taken to reduce the consequences of fire, the possibility of death or injury cannot be totally eliminated. It must be recognised that there is no such thing as zero risk. It is, therefore, an important first step to establish the criteria against which the adequacy of a design can be judged.

It is possible to establish the adequacy of a design using the following approaches:

a) deterministic (including, when appropriate, safety factors);

b) probabilistic (risk-based);

c) comparative (comparison of performance with accepted codes of practice).

Whilst the procedures outlined in this document may be used to estimate the probability and extent of damage caused by fire and fire effluent, it is not possible nor appropriate to propose any criteria of acceptability which relate to values attached to such losses. The information may, however, be used in a cost benefit study to assess the need for additional fire protection systems.

6.3.2 Deterministic criteria

6.3.2.1 General

Deterministic criteria are normally measures of hazard and are assessed in detail relative to selected fire scenarios. The addition of safety factors may be needed to take account of:

a) uncertainty in calculation procedures; and/or

b) the consequences of failure of the design.

Where there is doubt as to the reliability of input data or calculation procedures a conservative approach should be adopted.

6.3.3 Probabilistic criteria

Probabilistic criteria are measures of risk and so reflect the probability and severity of harm (e.g. injury, death, large loss of life or property) in fire scenarios that can occur. The criterion is normally expressed as either an acceptably small probability of unacceptable harm or an acceptably small expected value of harm, the latter normally expressed as a sum over scenarios of the probability of each scenario times the severity of harm for that scenario.

Society is far less tolerant of incidents, however infrequent, that can give rise to more than a small number of casualties (e.g. bus accidents compared with car accidents). The implications of a major accident are much wider than those of injury to a particular individual. Any large-scale accident raises questions of responsibility for safety and public accountability in a way that accidents to individuals generally do not.

6.3.4 Comparative criteria

The acceptability of a particular design may be evaluated by means of a comparison. The level of safety provided by alternative fire safety strategies can be compared with that achieved by the well established codes. This approach will generally involve deterministic and/or probabilistic techniques, and therefore there is no clause entitled "Comparative design". The objective of a comparative study is simply to demonstrate that the building, as designed, presents no greater risk to the occupants than a similar type of building that complies with a well established code.

For a comparative study it should not normally be necessary to include safety factors within the calculation procedures. Any inaccuracies in the assumptions made will generally have less effect upon the outcome than in a full probabilistic or deterministic study.

7 Deterministic design

7.1 Background

7.1.1 General

Deterministic procedures exist to quantify ignition, fire growth, flame spread, the movement of combustion products, the movement of people, the reaction to fire and effect on fire of building systems and features, and the consequences of fire for the building and its occupants.

These procedures are based on physical, chemical, thermodynamic, hydraulic, electrical or behavioural relationships derived from scientific theories and empirical methods, or from experimental research. A deterministic design analysis involves the use of these procedures to calculate the performance of a design in a form that can be compared to deterministic criteria.

7.1.2 Deterministic techniques

Several deterministic techniques are available. Many are described in part 2, and parts 4 to 8 of this Technical Report.

7.1.3 Fire scenarios

The interaction of fire, buildings and people can give rise to a very complex system, which means a nearly uncountable number of possible fire scenarios. Full analysis of all scenarios would be impossible, so it is necessary to identify a manageable group of scenarios for analysis. These selected scenarios should be chosen so that a building design shown to deliver acceptable safety for these scenarios can be depended upon to deliver acceptable safety for all the unanalysed scenarios as well.

A deterministic design will be evaluated using a hazard assessment, which will assess performance against deterministic criteria. Therefore, in selecting scenarios, the first consideration is the type and severity of hazard of each scenario. For many scenarios (e.g. a discarded cigarette on a concrete floor), it may be apparent without analysis that the scenario will not produce a level of hazard that would be unacceptable under the criteria. These scenarios can be ignored.

Some scenarios with an unacceptably large hazard may be excluded, either because of very low probability or because neither their probability nor their severity can be significantly affected by design decisions (e.g. a thermonuclear blast). Such exclusions should be made cautiously. To be excluded due to low probability, these scenarios must have very low probability not only individually but collectively. And for many severe scenarios (e.g. a bomb in a parking garage in a high-rise office building), loss can be significantly mitigated through design even if it cannot be entirely prevented.

The scenarios that remain — all having sufficient probability and severity to justify attention — should be grouped by similar type of hazard. A group should be defined so that a design feature that affects one scenario in the group will affect all the scenarios in that group in similar fashion. For example, fires originating in the same or similar locations will tend to respond to detection, suppression and compartmentation features in the same way, across a wide range of initial sizes and speeds of growth of the fires. The most severe fire in each group should be chosen, and those will be the "worst credible fire scenarios“. Each scenario will be sufficiently different from the other selected scenarios as to justify separate assessment, in order to make sure the design is acceptably safe overall. Each scenario will be sufficiently specific that it can be defined in enough detail for quantitative evaluation; this detailed specification is called a "design fire“.

In conducting the hazard assessment, it will be possible to ignore many factors and characteristics of fires that can be shown to have negligible effect on probability and severity. Some factors that cannot be ignored will be difficult to quantify, and for these it is important to use simplifying assumptions that are conservative. However, if too many conservative assumptions are used, the overall assessment will be too conservative and may, in fact, be incompatible with any practical design. An iterative process should be used in defining scenarios so that the degree of conservatism is diminished for each assumption as the number of conservative assumptions increases. Typical current designs that are acceptable to authorities under existing regulations should also be found acceptable under the hazard assessment. Therefore, the hazard assessment can be applied to such designs as a way of calibrating the necessary level of conservatism in the assessment.

Fire scenarios and design fire specifications are described in ISO/TR 13387-2.

7.1.4 Limits of application

Often the experimental work used to develop empirical relationships is carried out in scaled-down facilities in research establishments. It is important to appreciate that the application of the models resulting from such work may be limited by the degree of extrapolation that can be made, e.g. in terms of the size of the room or the range of factors that have been examined. This must be carefully considered if extrapolation of test data is unavoidable.

Deterministic techniques provide a useful indication of the development and effects of a fire, but the nature of fire is such that the results are unlikely to be precise. Normally, well formulated models would be expected to provide conservative predictions within their range of application.

However, in some cases there may be no factor of safety inherent within the model, and the technique should be used with care. In all situations, where there is any doubt as to the validity of a model (see ISO/TR 13387-3), the user should establish from the literature how the experimental work was carried out and decide whether the design situation is markedly different. If so, factors of safety should be applied.

7.1.5 Sensitivity analysis

Deterministic design may involve uncertainties. Usually, these can be dealt with by taking a conservative approach, e.g. selecting a fire growth rate that is faster than would normally be expected. However, if this approach is not suitable then the primary sources of uncertainty should be addressed. These are associated with:

a) the input parameters, i.e. uncertainties associated with the initial qualitative interpretation of the problem;

b) the simplification needed to develop the deterministic techniques and hence make the analysis more tractable.

An indication of sensitivity may be gained by investigating the response of the output parameters to changes in the individual input parameters. This will act as a guide to the level of accuracy required of the input data.

The objective of a sensitivity study should be not simply to check the accuracy of the results but also to investigate the criticality of individual parameters. For example, it may be important to establish how critical a sprinkler system is to the final consequences. If a single system or assumption is shown to be critical to the overall level of safety achieved, consideration should be given to providing a degree of redundancy in the design or to carrying out a probabilistic study.

The simplifications and assumptions made in the input data to aid the full analysis should be tested for their criticality to the fire safety design. For example, it may have been assumed for a comparative study with existing codes that a compartment remains a compartment, and that the possibility of an open door may be ignored. However, an alternative scenario would include the open-door assumption. Thus, a sensitivity test on the qualitative components of fire safety design is possible.

More detailed information is given in ISO/TR 13387-3.

7.1.6 Common mode failures

In some instances, the failure of one part of the system can have an adverse effect on the efficiency of another fire protection measure: e.g. an open fire door will not only be an ineffective barrier to fire spread but may also lead to failure of a gaseous extinguishing system due to loss of agent. Particular care must be taken by the QDR team to ensure that any such common mode failures are identified and accounted for in the analysis.

7.1.7 Property protection

Property protection objectives may be stated in terms of monetary losses or spatial extent of damage from fire and its effects. Monetary-loss measures are easier to use in combination with information on the costs of design alternatives, but calculation methods and fire tests can only produce estimates of spatial damage. Data on the monetary value of property damage per area or space damaged, by type of damage (e.g. char, smoke deposition), are not generally available but will need to be developed if calculations of spatial damage are to be translated into predictions of monetary loss.

The extent of acceptable damage is defined by the QDR team for specific objects or zones, and the calculated deterministic values for heat and smoke spread should not exceed these.

Predicting damage caused by firefighting water from either fire suppression systems (e.g. sprinklers) or the activities of the fire brigade, in either spatial or monetary terms, is much more difficult than predicting or calculating damage from fire and its effects. It is recommended that the analysis not attempt to include such damage, as the associated uncertainty is likely to be so large as to render the analysis results unusable.

7.1.8 Environmental protection

The amount of damage done to the atmosphere local to the building on fire may be calculated using a large fire plume model capable of predicting the trajectory and dispersion of the fire gases. Contamination of the land and ground water however is not easy to calculate.

The extent of acceptable contamination of the air, land and water will have been set for the project during the QDR. Calculated contamination values should not exceed the environmental limits.

8 Probabilistic design

8.1 Background

8.1.1 General

Probabilistic procedures exist to quantify ignition, fire growth, flame spread, the movement of combustion products, the movement of people, the reaction to fire and effect on fire of building systems and features, and the consequences of fire for the building and its occupants.

These procedures are based on fire incident and field survey data, as well as a variety of techniques for producing best subjective estimates. More often, "probabilistic“ procedures use a combination of probabilistic methods for such phenomena as ignition and system reliability with deterministic methods for such phenomena as fire growth and development and effects on people and property. A probabilistic design analysis involves the use of these procedures to calculate the performance of a design in a form that can be compared to probabilistic criteria.

There are some advantages and disadvantages of probabilistic procedures vs. deterministic procedures. At a fundamental level, probabilistic procedures provide a basis for addressing and considering all types of fire scenario. Deterministic procedures may mislead if a design is unusually vulnerable to a scenario that is (1) slightly less probable but much more severe than any considered in the analysis, (2) slightly less severe but much more probable than any considered in the analysis or (3) more probable and/or more severe but more unusual (e.g. in location) than any considered in the analysis. By their extensive use of fire incident and field survey data, probabilistic procedures are better able to reflect all the aspects of real fires, including the often complex interactions among factors. Probabilistic procedures are also better adapted to quantify uncertainties.

Disadvantages of probabilistic procedures include gaps in needed data that require either expensive data collection procedures or extensive use of subjective estimates, with associated large uncertainties. Also, probabilistic procedures often lack the technical detail and the full use of fire science fundamentals found in deterministic procedures. This can make them difficult to use for design.

8.1.2 Probabilistic techniques

Basic probabilistic techniques of fault trees and event trees are briefly described later in this section. More detailed descriptions may be found in a number of references, including the SFPE Handbook for Fire Protection Engineering.

8.1.3 Fire scenarios

As already pointed out, the interaction of fire, buildings and people can give rise to a very complex system, which means a nearly uncountable number of possible fire scenarios. Full analysis of all scenarios would be impossible, so it is necessary to identify a manageable group of scenarios for analysis. In probabilistic techniques, these selected scenarios must be chosen so that collectively they represent all the possible fire scenarios. Each detailed scenario is specific enough to permit calculation of its consequences, or anticipated loss, but each detailed scenario is also associated with the other scenarios that resemble it, and probability is estimated for the larger set of scenarios.

The scenarios should be grouped by similar type of hazard. A group should be defined so that a design feature that affects one scenario in the group will affect all the scenarios in that group in similar fashion. For example, fires originating in the same or similar locations will tend to respond to detection, suppression and compartmentation features in the same way, across a wide range of initial sizes and speeds of growth of the fires. Choose the most representative or typical fire scenario in each group, and those will be the fire scenarios selected for analysis, with the probabilities calculated for the associated groups. Each scenario will be sufficiently different from the other selected scenarios as to justify separate assessment. Each scenario will be specific enough that it can be defined in sufficient detail for quantitative evaluation; this detailed specification is called a "design fire“.

In conducting the risk assessment, it will be possible to ignore many factors and characteristics of fires that can be shown to have negligible effect on probability and severity. Some factors that cannot be ignored will be difficult to quantify, and for these it is important to use assumptions that are neither conservative nor typical of all buildings and occupants but rather that are typical of buildings and occupants involved in fires. Only in this way will the resulting risk assessment properly reflect patterns of fire development.

8.1.4 Limits of application and sensitivity analysis

Probabilistic techniques are subject to the same limits due to experimental-scale effects, uncertainties of data extrapolation and uncertainties of model validity and applicability as described for deterministic techniques in 7.1.4.

The probabilistic models themselves can be adapted to quantify uncertainty by the use of probability distributions for the probabilities in the models. This approach, often called Bayesian analysis, is described in greater detail in any reference on probabilistic modelling.

Fire scenarios and design fire specifications are described in ISO/TR 13387-2.

8.2 Basic probabilistic techniques

8.2.1 General

Probabilistic risk analysis begins with a definition of the risk as a function of the probabilities and consequences of scenarios:

Risk = Σf(probability, consequence of a given scenario), for all scenarios.

There are two commonly used functions defining risk. One is the "expected value“ or average-consequence definition of risk:

Risk = Σ(probability $\times$ consequence of a given scenario), for all scenarios.

The other is the probability that consequences will exceed a specified safety threshold:

Risk = Σ (probability of a given scenario), for all scenarios where the consequences exceed the specified safety threshold.

The complementary definition of safety is the inverse of risk, i.e.

Safety = $Risk^{-1}$

A probabilistic risk assessment, using a particular definition of risk, will include the following steps:

a) determining what fire scenarios can occur;

b) dividing the fire scenarios that can occur into groups and selecting specific fire scenarios for analysis from each group;

c) estimating or calculating the probability of each scenario group;

d) estimating or calculating the effects and consequences of each fire scenario selected for analysis;

e) calculating the total risk associated with fire;

f) if step (e) identifies unacceptable risks, identifying the extra measures required to reduce that risk.

Items (a), (d) and (f) should be considered in detail during the QDR (see 4.3), just as in a deterministic calculation. Items (b), (c) and (e) are unique to probabilistic risk assessment but have analogous steps in deterministic approaches, as described in clause 7.

8.2.2 Fault trees

Fault trees are logic diagrams showing the logical dependence of events on one another. Fault trees are most suitable for PRA when risk is defined as the probability that the consequences will exceed a certain threshold, including cases like the example where risk is defined as the probability of an unacceptable event (e.g. structural collapse). The unacceptable event or, more generally, the event of the consequences exceeding the threshold is shown as a "top event" — defined as failure, hence the name "fault tree" — and the fault tree is constructed to show what combinations of events would lead to failure.

If two or more lower-level events must all occur in order for a higher-level event to occur, the fault tree uses an AND gate (see Figure 3). If the lower-level events are "independent" (i.e. the probability that one will occur is unaffected by knowledge of whether the other lower-level event(s) has(ve) occurred), then the probability of the higher-level event is equal to the product of the probabilities of the lower-level events.

If any one of two or more lower-level events will lead to a higher-level event, the fault tree uses an OR gate (see Figure 4). If the lower-level events are independent, then the probability of the higher-level event is equal to the sum of the probabilities of the lower-level events.

The methodology may be illustrated by a compartment fire example, in which risk is defined as the probability of an unacceptable consequence and the unacceptable consequence is defined as structural failure.

Suppose further that the only factors capable of preventing structural failure are prevention of ignition, restriction of fuel load, fire resistance of the structure and fire sprinklers. Suppose that the first two are not treated as design elements but as uncontrollable random factors:

a) Did a fire start which was capable of reaching room burn-out?

— If no, then structural failure is avoided.

— If yes, continue.

b) Were sprinklers present?

— If no, go to (e).

— If yes, continue.

c) Were the sprinklers operational (a reliability question)?

— If no, go to (e).

— If yes, continue.

d) Was the fire scenario one that would render sprinklers ineffective (e.g. a large initial explosion)?

— If no, then structural failure is avoided.

— If yes, continue.

e) Was the structural fire resistance intact (both a reliability and a scenario question)?

— If no or yes, continue.

f) Based on the answers to the above questions, what was the critical fuel load such that a room burn-out would result in a fire of sufficient intensity and duration as to cause structural failure, and was that critical fuel load present?

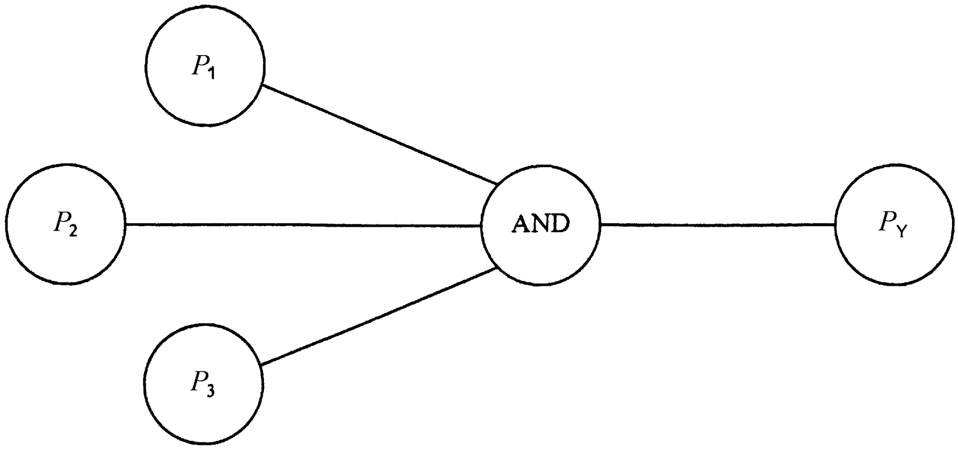
— If no, then structural failure is avoided.

— If yes, then structural failure occurs.

Quantification of the analysis can be illustrated by going through the branching. The probability of a fire capable of reaching room burn-out can be estimated from fire incident data (e.g. as the probability of a fire in an unsprinklered building having flame spread beyond the room of origin). The question of whether sprinklers are present or not is a design question, and the analysis should be run both ways, with yes and no answers to the question. Reliability data will answer question (c), but it is important to include the human errors that can render sprinklers non-operational (e.g. the fact that the sprinkler valve had been turned off), as they are more common than mechanical failures. Question (d) can also be answered using an estimate from fire incident data. Some of the scenarios that disable sprinklers can also damage the structure or its fire resistance, but question (e) will mostly be a reliability question, depending upon workmanship and maintenance. Like question (c), it can be answered by field surveys. Question (f) requires a deterministic calculation or use of fire tests to determine the critical fuel loads in each situation (e.g. the critical fuel load with damaged fire resistance would be less than with intact fire resistance). Then a field survey is needed to determine the probability of that critical fuel load being present. The answer to each question is a probability, and the risk for that scenario group is the product of the probabilities for the respective questions.

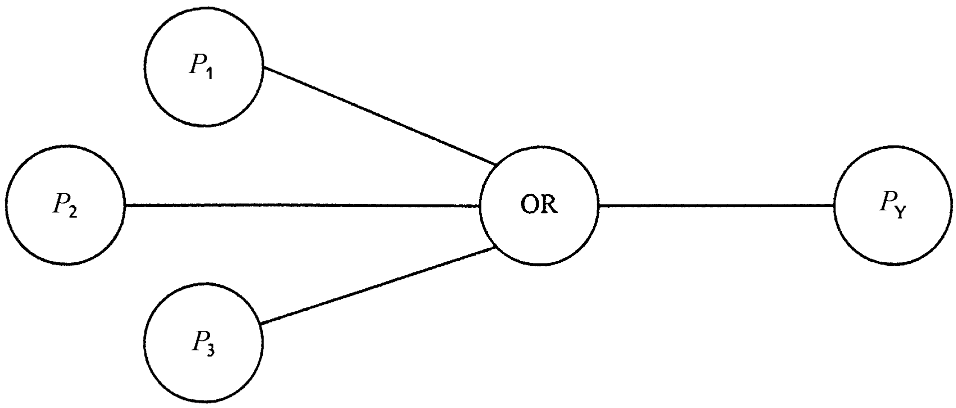
8.2.3 Event trees

Event trees (see Figure 5) are diagrams showing events in time in fire development, movement of people, response of systems, etc. Event trees are most suitable for PRA when risk is defined as an expected value.



$$P_Y = P_1 \times P_2 \times P_3$$

Figure 3 — Fault tree and gate for case when lower-level events are dependent



$$P_Y = P_1 + P_2 + P_3$$

Figure 4 — Fault tree and gate for case when lower-level events are independent

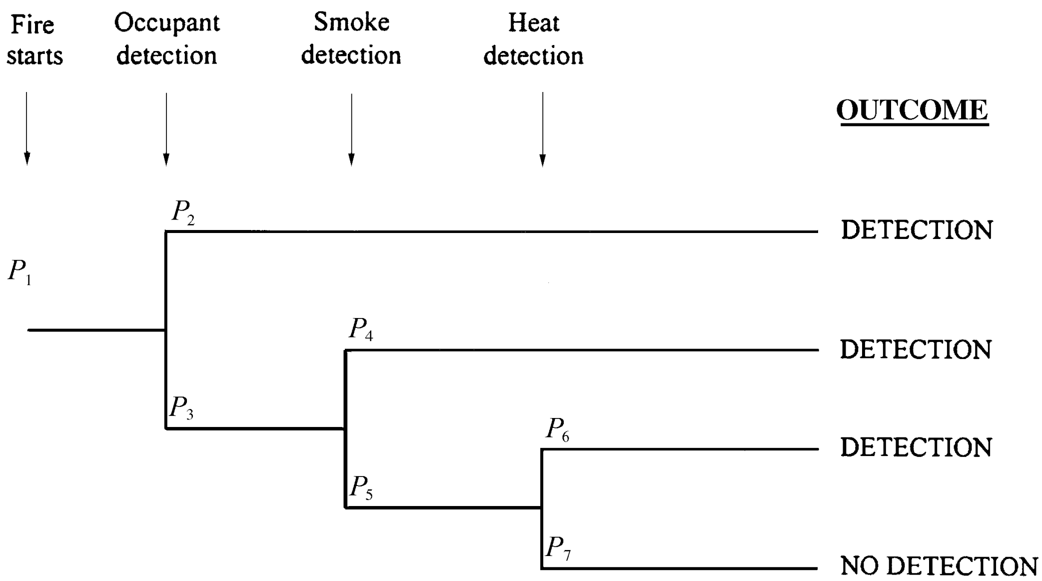


Figure 5 — An event tree

8.3 Data required

8.3.1 General

The acquisition of reliable data can be one of the most important tasks in performing any risk assessment.

The type of information required for a PRA can broadly be classified into four main groups:

a) deterministic data;

b) fire statistics;

c) building data;

d) system reliability data.

8.3.2 Deterministic data

Deterministic information regarding the development and possible consequences of fire may be evaluated on the basis of the deterministic procedures (see clause 7) and the subsystems.

8.3.3 Fire statistics

The likelihood of a fire occurring within a particular type of building should be established on the basis of statistical data from buildings of similar use and location.

8.3.4 Building data

Survey data are available to quantify key items of the PRA such as fractile fire loads and occupancy levels. The continued development of a fire and the potential consequences will depend upon a number of factors such as:

a) the availability of combustibles and the fractile fire load;

b) the imposed structural loads;

c) the number of occupants present and their condition at any given time.

Where data are lacking, it is possible to make assumptions regarding occupancy, fire load, etc.; however, the use of reliable statistical data will assist in the performance of a realistic risk assessment.

8.3.5 System reliability data

All fire protection systems may on occasions fail for reasons such as lack of maintenance, random mechanical failures or inability to cope with an unusually high fire severity.

Manufacturers may be able to provide data on frequencies of mechanical or electrical failure and on severity of fire conditions required to overpower the system. Fire incident data or other published field survey statistics may be able to provide data on the frequency of fire conditions with the severity specified by the manufacturers and the frequency of failure due to human error (e.g. the fact that the sprinkler valve had been closed).

Examples of aspects of automatic fire detection and control systems for which reliability data may be required are:

a) detection system response;

b) smoke control system operation;

c) extinguishing system operation;

d) breaches of compartmentation (e.g. insufficient fire stopping, doors being propped open at time of fire, etc.).

8.4 Common mode failures

In some instances, the failure of one part of the system can have an adverse effect on the efficiency of another fire protection measure: e.g. an open fire door will not only be an ineffective barrier to fire spread but may also lead to failure of a gaseous extinguishing system due to loss of agent. Particular care must be taken by the QDR team and those responsible for the PRA to ensure that any such common mode failures are identified and accounted for in the analysis.

9 Safety factors and uncertainty

In developing the solution to a fire safety engineering problem, as with any engineering design, there are many sources of uncertainty. These may include uncertainties associated with:

a) the choice and definition of the scenario(s);

b) the formulation of an appropriate conceptual model for a chosen scenario;

c) the formulation of the associated computational model;

d) the input data and other chosen parameters.

In principle, the magnitude of uncertainty associated with each stage and component of a solution should be quantified and then combined to establish an overall level of uncertainty. This overall level may then provide the basis for the choice of the safety factor to be used.

Unfortunately, it is not yet possible to quantify levels of uncertainty for all stages of the design process, nor is there yet a generally accepted methodology for combining them. These problems are being addressed, as described in annex E but, until further progress has been made, any safety factors incorporated in a proposed solution will involve a degree of professional judgement by the design engineer and, consequently, also by those responsible for assessing and approving the solution. Wherever possible, this judgement should be informed by an understanding of the basis and limitations of the chosen scenarios, models and data, and should be made explicit in the reporting and presentation of the final design.

For the important practical case where a design is based on a single analytical expression, methods have been developed in structural and other engineering areas to derive safety factors (partial coefficients) corresponding to a pre-determined level of risk or failure. The method is usually termed "reliability-based design" and assumes that relevant uncertainties are quantified in statistical terms. A general description of the methodology is given in annex E.

10 Summary of the fire safety design process

10.1 Overview

The complexity of the problem being addressed means that no single set of calculations and procedures can be prescribed which will be applicable to all buildings in all circumstances. However, it is possible to identify the important steps in the process and set them down in a logical sequence (see Figure 1). Having established the design safety objectives and acceptance criteria and assembled known data (prescribed design parameters) about the building, contents, fire safety systems, occupants and environment, and having estimated other important inputs to the design (estimated design parameters), it is necessary to undertake the qualitative design review. The purpose of the qualitative design review is to identify the fire hazards and their possible consequences, and specify fire scenarios for analysis. During the assessment, the impact that high standards of fire safety management may have on mitigation of the hazard should be identified. Having simplified the problem to manageable proportions, the scope and type of quantification which is appropriate can be decided.

A quantitative assessment is then made using the calculation methods contained in the five subsystems. The comparison to check that the design satisfies all the design safety objectives and acceptance criteria must be carried out. If the objectives and criteria are not met, the design should be changed and the calculations repeated. Finally, a report is prepared which clearly describes what has been done. The procedure is described below.

10.2 Define the safety objectives and scope of the study

Statutory requirements are generally intended to protect life; however, in a particular project it may also be desirable to take measures to reduce the potential for large financial losses. The objectives of the fire safety strategy need to be clearly established, taking account of statutory requirements and the level of protection required.

The main design objectives can be identified in terms of:

a) life safety, safety of occupants, safety of firefighters and safety of people in the vicinity of the building who may be at risk from falling debris (see annex D);

b) loss prevention (loss of the structure and fabric of the building, loss of building contents, loss of business and potential damage to public image);

c) environmental protection (e.g. preventing the release of hazardous materials into the environment).

A fire engineering study may be used to assess all fire safety aspects of a building design or to consider one section of a building and justify a small departure from existing prescriptive requirements. The scope of the study should be clearly identified and if considering only a partial study it should be ascertained that there is no cascade effect on other aspects of the design that would necessitate a more extensive study.

10.3 Set acceptance criteria

10.3.1 General

In the light of the fire safety objectives, acceptance criteria must be established against which the success of the trial design(s) can be judged. Guidance on the selection of acceptance criteria for use in fire safety analyses is given in 6.3.

Existing knowledge, time constraints and project requirements will all have an influence on establishing the most appropriate basis for setting the acceptance criteria. It is important to ensure that the regulatory enforcement authorities are fully consulted to ensure they agree to the proposed approaches and associated acceptance criteria.

10.3.2 Codes of practice

In many projects, it is likely that the provisions of existing codes of practice and other guidance will be largely followed and that fire engineering techniques will not be necessary (or may be used only to justify limited departures from the codes). One of the simplest measures of acceptance, therefore, may be to define the acceptance criteria in terms of compliance with existing code specifications.

10.3.3 Comparative criteria

Another possibility is to make a comparative analysis between the new design and a design complying with existing codes of practice. In such cases, the level of safety in the trial design should be shown (qualitatively or quantitatively) to be at least equal to that in a similar building satisfying traditional guidance (see also 6.3).

10.3.4 Deterministic criteria

The criteria for deterministic design should be specified in terms of single values of the relevant parameter(s) at the location of interest, e.g. the maximum acceptable smoke concentration and temperature for tenability. Because of the uncertainty inherent in the calculation procedures and initial assumptions, deterministic criteria should be used in conjunction with appropriate safety factors. The safety factors may be expressed explicitly or may be implicit within the analysis approach adopted. If it is necessary to include explicit safety factors (see clause 9) within the analysis, these should also be identified and agreed in light of the chosen methods of analysis and the acceptance criteria (see also 6.3).

10.3.5 Probabilistic criteria

Probabilistic criteria provide the most rational means of assessing the overall level of safety of a design. However, they do require a judgement to be made regarding the acceptable level of risk. Guidance on the current levels of risk of death associated with fire and recommendations regarding appropriate acceptance criteria are given in 6.3.

10.3.6 Assembly of trial design parameters

The known factual data on the design or the building, contents, fire safety systems, environment and occupants is obtained from the building designer. These data may be varied for the purpose of conducting assessments of alternative designs to arrive at a better or more economic fire safety strategy, but are kept constant during a single design process.

The designer must fully describe the project by reference to schematic drawings, models, etc., and highlight any architectural or special requirements that may have an important bearing on the hazard analysis.

It is helpful to have a checklist of items which can be referred to when deciding the range of information needed for the trial design parameters and the characteristic parameters. The following checklists, which are not exhaustive, are provided:

Table 1 — information on the building and its rooms;

Table 2 — information on the fire safety systems;

Table 3 — information on the occupants.

If the designer does not know this information, it will have to be assumed by the fire safety engineer and this then forms part of the characterisation process described in 4.5, leading to the estimated design parameters.

In a large building with many rooms, it may not be necessary or economically feasible to provide all the information identified in Tables 1, 2 and 3 for every room. From an examination of the plans of the building it will often be clear that some rooms can be considered to be safe from fire and therefore do not need such information to be provided.

Table 1 — Checklist for choice of trial design/estimated parameters for the building

Area of review	Items to be considered
Building design	Location and orientation relative to other buildings or site boundary Overall size and shape of building and storey heights Position and sizes of windows and other areas of low fire resistance in the external/internal fabric Location of fire-separating elements (e.g. walls, doors, shutters, floors and roofs) and their fire resistance Nature of construction (e.g. materials forming the frame, walls, partitions, floors, suspended ceilings and roof) Normal circulation routes Location of main entrances/exits Provision for dispersal of people from vicinity of building Escape routes Access for fire appliances Firefighting access within the building (e.g. location of firefighting stairways, firefighting lifts and protected lobbies) Fixed firefighting appliances Compartmentation (fire and smoke spread routes) Location and dimensions of vertical and horizontal ducts and their fire resistance Configuration of hidden voids Design constraints Expected level of continuing fire safety management Any other factor that may influence the fire safety design
Each room or compartment	Size and shape of rooms Activity in room Potential ignition sources Combustible contents Fire load density Wall lining Ceiling linings Location of load-bearing elements (e.g. beams, columns) Ambient noise levels Ventilation systems Possible fire and smoke spread routes Escape routes Proposed fire protection systems Any other factor that may influence the fire safety design

Table 2 — Checklist for choice of trial design/estimated parameters for the fire safety systems

Fire safety system	Items to be considered
Automatic suppression	Availability of water for firefighting Extinguishing medium Delivery rate Nozzle spacing Zoning Reliability
Detection	Detector types Locations Zoning Response characteristics
Compartmentation	Fire resistance Location Boundaries
Automatic systems	Dampers Shutters Magnetic door catches Fans Vents Reliability
Smoke ventilation	System type, extraction, pressurisation Extraction rate/pressurisation level Zoning
Alarm and warning systems	Sounder or public address Zoning
Evacuation strategy	Phased or simultaneous Management procedures
Escape routes	Exit widths Travel distances Stairways Lifts — protected Refuges for disabled
First-aid firefighting	Call points Extinguishers/hose reels Availability of trained staff
Fire service facilities	Equipment carried on fire appliances Attendance time External fire hydrants Access routes Rising mains Firefighting lifts Firefighting stairs Protected lobbies Smoke extraction
Fire safety management	Numbers and locations of fire wardens Level of staff training Management plan Staff availability Third-party audit of procedures Maintenance schedules

Table 3 — Checklist for choice of trial design/estimated parameters for the occupants

	Items to be considered
Occupants	Number Distribution Mobility State of wakefulness Familiarity with the building Any other factor that may influence the fire safety design

10.4 Characterise the building, occupants and environment

The known factual data available from the building designer may not be sufficient to allow the fire safety design process to proceed, and the data may need to be supplemented by assumptions (estimated design data). Like the trial design parameters, these data may be varied for the purpose of conducting assessments of alternative designs to arrive at a better or more economic fire safety strategy, but are kept constant during a single design process. Tables 1, 2 and 3 represent checklists that can be used to identify the kind of information needed. To provide a basis for consistent assumptions, additional guidance may be found in ISO/TR 13387-2, 13387-3 and 13387-8 for five main areas:

a) building and fire safety system installations and facilities for fire brigade intervention;

b) contents;

c) occupants;

d) environment;

e) design fires.

10.5 Undertake the qualitative design review

10.5.1 Hazard identification

A systematic review of the project should be conducted to establish the potential fire hazards within the building. The review should take account of factors such as:

a) general layout;

b) potential ignition sources;

c) nature of the activities;

d) anticipated occupancy;

e) construction materials;

f) combustible contents;

g) any unusual factors.

The above list is not exhaustive and all significant fire hazards should be identified. In evaluating the significance of a fire hazard, particular account should be taken of the influence of each hazardous event on the achievement of the fire safety objectives under consideration.

During the hazard identification stage, possible consequences of failures in the fire protection systems and management procedures should be considered, e.g. fire doors left open or the smoke detection system being inoperative. In a probabilistic risk assessment (PRA), the likelihood and consequences of such failures will generally be quantified; however, in a deterministic study a judgement has to be made as to what represents a credible scenario for the purposes of detailed analysis. Where a comprehensive fire safety management plan is implemented and subject to third-party review, the benefits of this can be taken into account when assessing the likely efficiency of the evacuation process or the reliability of installed fire protection systems.

10.5.2 Fire scenarios for analysis

The number of possible fire scenarios in a complex building can become very large and often there are neither the data nor the resources available to attempt to quantify them all. The detailed analysis and quantification should, therefore, be limited to the most significant fire scenarios.

The characterisation of a fire scenario for analysis purposes should involve a description of such things as the initiation, growth and extinction of the fire together with the likely smoke and fire spread routes such as ventilation/exhaust ducts. The possible consequences of each fire scenario should also be considered.

Where alternative fire safety design options are being compared against a reference case (i.e. in a comparative study), the quantification can often be considerably simplified. In such instances, it may only be necessary to consider a single fire scenario if this will provide sufficient information to evaluate the relative levels of safety of the trial design and the reference (i.e. code-compliant) case.

It is important to establish the important fire scenarios and those that can be neglected (e.g. whether a very rare fire with the potential to cause a large loss is more or less important than small fires having a higher probability of occurrence but with the potential to produce a similar loss over time). More information is given in ISO/TR 13387-2.

The possibility of failures of protection systems and fire safety management procedures should be taken into account when establishing the sequences of events to be considered. In a deterministic or comparative study, it would be useful to identify a number of worst-case scenarios for further evaluation. However, care and judgement should be used to avoid analysing events with a very low probability of occurrence.

The purpose of the qualitative hazard identification analysis is to identify the important fire development scenarios and describe them in a manner suitable for the quantification process.

10.6 Conduct quantified analysis

10.6.1 General

Having established one or more trial designs and established the significant fire scenarios, the justifiable depth and scope of quantification needs to be determined.

To establish the required scope of the quantification, it is necessary to identify the extent to which each fire scenario requires quantification, together with the type and complexity of analysis required to provide an adequate solution. For instance, when considering smoke movement, simple hand calculations may be appropriate in relation to one fire scenario whereas a computational fluid-dynamics model may be more appropriate to another.

The types of analysis procedure that should be considered include:

a) simple calculations;

b) a computer-based deterministic analysis;

c) a simple probabilistic study, e.g. comparative PRA;

d) a full probabilistic study.

In some circumstances where a quantitative analysis is not appropriate, a detailed qualitative study or fire tests may provide an effective means of arriving at a design solution.

A deterministic study using comparative criteria will generally require far fewer data and resources than a probabilistic approach and is likely to be the simplest method of achieving an acceptable design. A full probabilistic study is only likely to be justified when a substantially new approach to building design or fire protection practice is being adopted, or when the consequences of failure are very large.

At the conclusion of the qualitative hazard identification analysis, if not before, the type of approach to the quantified analysis must be decided on. The choices are:

e) deterministic;

f) probabilistic;

g) comparative.

The advantages/disadvantages of these approaches have been outlined in clauses 7 and 8.

10.6.2 Undertaking the quantified analysis

The design information, i.e. design parameters and characteristic parameters, are input to the relevant subsystems via the global information flow system. It may have been possible to utilise a design fire which bypasses subsystem 1 and directly enters the other subsystems. Where an appropriate design fire is not available in ISO/TR 13387-2 or cannot be specified, the design information enters subsystem 1, the calculations are made and the results (e.g. data on size of fire/smoke, pressure/velocity and building condition) are output to the global information so that they can be input to the other subsystems.

Subsystem 1 provides outputs from time of ignition (time zero) and receives information on time of activation of fixed fire suppression systems from subsystem 4 and time of fire brigade intervention from subsystem 5. The effects of these fire suppression activities are calculated within subsystem 1 for the room of origin.

An important output from subsystem 1 is the rate of heat release, and this is used as an input to subsystem 2 to enable calculations of smoke mass with time to be made using appropriate air entrainment factors as the smoke spreads through the building. The outputs of subsystem 2 are, for example, smoke temperature, smoke density and CO concentration at all points in the building as time proceeds. Inputs to subsystem 2, which affect the production of smoke and how it spreads, come from the global information flow system and include parameters such as the rate of heat release, environmental factors, rate of smoke production (expressed as a mass) and time of activation of smoke control devices.

The same process of subsystem interaction operates in the other subsystems and is shown in Figure 2. The values of the parameters on the global information bus may be time-dependent, such as rate of heat release, or time-independent, such as a single activation time. The global information bus and, when used, the evaluation and process buses, are continuously carrying data as the fire safety assessment proceeds.

The assessments stops when, in the case of a life safety assessment involving evacuation, it is shown that people have or have not been evacuated safely from the building. The check on tenability conditions for every location in the building where there are occupants is carried out in subsystem 5. Subsystem 5 outputs data on occupant condition and location to the global information and this is compared with the life safety strategy.

If the design has failed, i.e. if an unacceptable number of people are killed by a fire or the fire has done too much property damage, the design has to be changed and the assessment repeated until the safety objective has been reached.

10.6.3 Reporting the results

The building owner, building control and fire authorities, insurer and building maintenance personnel will require a clear record of the fire safety strategy for the building, the layout and contents of the building, and the details of fire safety management provisions. The report should typically contain the information given in 11.2.

11 Reporting and presentation

11.1 General

When checking that a design complies with traditional codes and guidance documents, it is relatively straightforward to establish whether the various provisions of these have been correctly implemented. This document, however, provides a flexible approach to design using performance-related objectives rather than prescriptive solutions. It is, therefore, not possible for an approval body simply to compare the proposed design against a set of well defined recommendations. Because of this, the results of a fire engineering assessment should be fully documented in a way that can be readily assessed by a third party. The report should set out clearly the basis of the design, the calculation procedures used and any assumptions made during the study, and pertinent aspects of the design which require on-going supervision, inspection or maintenance should be included in the fire safety manual.

11.2 Contents

The format of the report will depend on the nature and scope of the fire engineering assessment but it should typically contain the following information:

a) objectives and scope of the assessment;

b) description of the building and its fire safety installations;

c) description and characteristics of the occupants;

d) fire safety objectives;

e) results of the qualitative design review;

f) basis for selecting fire scenarios for analysis;

g) acceptance criteria;

h) trial designs;

i) any influences of fire safety management;

j) analysis of results, detailing:

   1) assumptions,

   2) description of models used and their limitations,

   3) input and output data for each subsystem,

   4) engineering judgements,

   5) calculation procedures,

   6) validation of methodologies,

   7) sensitivity analyses;

k) comparison of results of analysis with acceptance criteria;

l) fire protection installations;

m) management requirements, including a fire safety manual;

n) conclusions, giving explicitly:

1) requirements for fire protection,

2) any limitations on use;

o) references:

1) drawings,

2) design documentation,

3) technical literature.

For the purposes of clarity, it is desirable that the main body of the text provides an overview of the study and that calculations, computer outputs, detailed analysis, etc., be included in annexes.

Annex A
(informative)

The emergence of fire safety engineering

A.1 The challenge

Each year, fires in buildings throughout the world kill thousands of people and injure many thousands more. For example, in the European Community approximately 5 000 people are killed each year with 10 to 15 times as many people injured.

Fire causes major property loss (the overall property loss within the European Community has been estimated at between 0,5 % and 1,0 % of the gross domestic product (GDP), and also destroys our heritage and pollutes the environment via contaminated firefighting water and the emission into the atmosphere of particulates and toxic fumes.

The challenge is to reduce these losses.

The challenge can be partly met by keeping people aware of the disastrous effects of fire by continuously educating people on common causes of fires, speed of fire spread, life-threatening fire scenarios, the part played by passive and active fire precautions, the need for prompt evacuation, and so on. At the same time, buildings have to be designed which are fit and convenient for normal use, pleasant to be in and, above all, safe for the occupants. The burden of providing fire-safe buildings is carried in part by the fire legislator via the drafting application and, where appropriate, policing and enforcement of regulations and technical guidance.

Over the past two decades, the building regulations in a number of countries have moved from comprehensive prescriptive regulations to brief functional regulations supported by non-mandatory detailed technical guidance. While present combinations of regulations and guidance may have served each country well, they do not, except in few circumstances, provide a basis for calculation of fire safety based explicitly on engineering principles. As buildings become larger, less compartmented and more complex, more people are placed at risk from fire than before. There is very little technical guidance which uses time-based calculations to address the important relationship between the time required for escape and the time available for escape.

Prescriptive guidance is often weakest in occupant evacuation because of inadequate information on the behaviour of people in a fire. The challenge here is to gain further information on the time it takes for people to get away from danger, particularly in shops and in public-assembly and institutional buildings where large numbers of people, including the disabled, may be present.

In the longer term, there is a need to introduce the probabilistic element so that functional requirements may be set in explicit terms. Analytical methods should be developed which integrate deterministic and probabilistic parts of the design so that the life risk can be assessed.

The next decade will be a period of major change as prescriptive approaches lead to more performance or "engineered" means of addressing fire safety in buildings in many countries. It is essential that all countries promote research into fire safety engineering so that freedoms which regulations may already provide are exploited. In the meantime, the fire safety design of buildings will proceed using a mixture of fire safety engineering and prescriptive methods.

There are, of course, many imponderables in the field of fire. What will be the item first ignited? Will the door be open or closed? Will sprinklers operate and will they control the fire? These kinds of question cannot be resolved in deterministic design but can be accounted for in probabilistic design if appropriate statistical data are available, e.g. data on the frequency of occurrence of certain events.

The fire safety design of a building can be established from a deterministic and/or a probabilistic approach. For most buildings, i.e. houses, offices, shops, factories, schools, hospitals and public-assembly buildings, design is deterministic because deterministic design is easier, faster and less expensive than probabilistic design. Probabilistic design is used where the building is of strategic importance and the consequences of an error in the design, construction or operation of the building or facility are major — nuclear power stations, petrochemical plants and underground mass transport systems are examples.

The task of predicting the growth and severity of a fire and the behaviour of people exposed to the fire is great, for both are prone to capricious behaviour. We are at the beginning of this task. Lives are lost when people, whether they be members of the general public or professional firefighters, are exposed to untenable conditions arising from heat, smoke and toxic products of combustion. It is therefore vital that ways be found to predict with reasonable accuracy:

— the spread of heat, smoke and toxic products of combustion throughout the building;

— the locations and condition of people within the building.

A.2 The goal

The goal should be to enable the achievement of a scientifically based and fully developed fire safety engineering package (methodology furnished with appropriate calculation methods and data) that can be applied in a cost-effective way to the design and management of buildings so that world-class design is encouraged, safety of occupants is assured, fire losses and pollution of the environment are minimised and our international heritage is preserved.

The fire safety engineering package should be strongly influenced by the needs of those involved in the design, construction, occupancy, management and policing of buildings. Thus the package would need to address and resolve the sometimes conflicting needs of the regulation drafters, building control authorities, fire brigades, building designer, building material producer, building constructor, building user, building manager and building insurer.

Research strategies have been prepared which indicate that a considerable amount of further research is needed to support a fully quantified approach to the fire safety engineering design of buildings.

A.3 Meaning of fire safety engineering

Fire safety engineering can mean many things to many people. At one level, it can mean the calculation of pipe sizes for sprinkler systems or the calculation of the structural response of a building element, such as a beam or a column, from a knowledge of the material properties at elevated temperatures, the temperatures they achieve, the loads acting, and so on.

At another level, requiring the use of integrated computer programmes, it can mean evaluating the life safety consequences of a specified fire, which involves defining the context, defining the scenario and calculating the hazard.

At a more strategic level, fire safety engineering can mean a package of measures (methodology, calculation tools and data) which has the objective of reducing the potential for injury, single deaths and multiple deaths in and nearby the building to an acceptable level.

This part of ISO/TR 13387 defines fire safety engineering (see 3.11), and this can be considered under several headings:

The process of fire safety engineering, which is about measurements and relationships, backed by scientific study, for engineering application to the required problems, but where experience and judgement can contribute, as in other engineering disciplines.

The context of fire safety engineering, which is the need to evaluate the fire hazard and risk, and to offer fire safety strategies and designs based on performance not prescription.

The tools supporting fire safety engineering, which are the calculation methods (sometimes called models) which describe the measurements, relationships and interactions.

The inputs, which are the physical data for the calculation methods, derived from measurement methods (testing, etc.).

The framework of fire safety engineering basically comprises the essential core and, in addition, the transfer of knowledge which permits an engineering approach, the education and training of users, and the professional recognition of the discipline.

A.4 The benefits of fire safety engineering

Fire safety engineering can have many benefits. It can:

- form the basis of design, especially of major projects such as airport terminals, stadiums, convention centres and large atrium buildings which are of such a magnitude that they cannot be designed using present technical guidance;
- discipline the designer to follow a structured approach to fire safety design;
- determine how safe buildings are by allowing a comparison of safety levels for alternative building designs;
- enable drafters of regulations and codes to improve the consistency of information, and justify the removal of outdated traditional measures;
- enable rules for construction modifications providing an equivalent level of protection of active and passive fire precautions to be made;
- overcome the restraints on design imposed by prescriptive regulations/codes;
- facilitate more cost-effective design of complex buildings while maintaining safety levels;
- enable insurance underwriting to be rationalised;
- identify topics of fire research which have a major bearing on life safety or property loss;
- remove obstacles to innovation for construction products and building design;
- enable consultants to acquire and maintain leading-edge expertise in fire-safe design;
- assist in the development of fire tests;
- assist the management of change from prescription to performance;
- assist the management of fire safety for the building during its whole life cycle, including the construction phase, taking account of changes of building use.

At a more detailed level, there are many benefits of fire safety engineering. It can for example reduce the number of fire starts and improve the efficacy of evacuation if good fire safety management and training is implemented. Again, fire protection measures can be identified which have greatest impact on life safety and fire loss reduction, but these benefits must be attainable preferably without extra cost.

A.5 International developments in fire safety engineering

There is much activity within the world to bring about fire regulation reform and move towards fire safety strategies which are based on fire performance codes as opposed to prescriptive codes.

The pressure for these moves is generated by the need for more flexible ways of designing buildings and the need to facilitate more cost-effective designs, particularly for complex or large buildings, without prejudicing safety levels.

Several international organisations such as the International Association for Fire Safety Science (IAFSS), the Conseil International du Batiment (CIB), the FORUM and ISO are committed to, and deeply involved in, developing fire safety and its application to the science of fire safety engineering. A number of countries are committed to the development of fire safety engineering codes based on engineering principles.

Since design is an interactive process, normally requiring repeated modification of the initial design to reach the final design, and since this requires certain kinds of calculation to be repeated, it has been found convenient to break down the system of fire safety design into a number of clearly identifiable and separate parts, called subsystems. This approach is not new; it has been proposed as a basis for fire safety engineering design codes in a number of countries, notably Australia, the United Kingdom, Japan, Sweden and New Zealand.

Annex B
(informative)

The qualitative design review

B.1 General

For large and complex projects, it is recommended that the QDR should be carried out by a study team involving fire safety engineers, other members of the design team and a member of operational management. It may also be appropriate to include representatives of approval bodies or insurers in the QDR team.

For smaller projects, the qualitative procedure may be carried out by a less extensive study group but the same basic review process should be followed.

The make-up of the QDR team will depend upon the nature and size of the project, but it should include an experienced fire safety engineer and preferably the person who will ultimately be responsible for carrying out the quantified analysis.

The QDR provides a technique that allows a group to think of the possible ways in which a fire hazard might arise and establish a range of strategies to maintain the risk at an acceptable level. The fire safety design can then be evaluated quantitatively against the objectives and criteria set by the team. The QDR should be conducted in a systematic way to reduce the chance of a relevant item being missed.

The QDR is essentially a qualitative process that draws upon the experience, knowledge and engineering judgement of the team members; however, it may often be useful to carry out quick calculations to resolve a difference of opinion between team members or to establish the most significant scenarios for detailed quantification.

The QDR cannot be completed until a full architectural design is available; however, a preliminary study at the outline design stage may obviate the need for significant changes to the scheme at a later stage.

It is important that the findings of the QDR be recorded and that ultimately the main findings be clearly documented for reference by the design team or a third party.

B.2 Review of architectural design

The first stage in the QDR is for the architect/designer to describe the project by reference to schematic drawings, models, etc., and to highlight any architectural or client requirements that may be significant in the development of a fire safety strategy.

All the relevant information about the building, including its anticipated contents, should be obtained. The team should be provided with information on building location, internal layout, contents, combustible materials, ventilation, etc. It is important that the team also establish at this stage the number of people likely to be present at any time, their distribution within the building and their general characteristics, such as mobility.

Information on any proposed fire safety systems such as automatic fire suppression should also be provided to the QDR team at this stage.

B.3 Objectives and scope of study

Statutory requirements are generally intended to protect life; however, in a particular scheme it may also be desirable to take measures to reduce the potential for large financial losses. The QDR team should identify clearly the objectives of the fire safety strategy, taking account of statutory requirements and the level of property protection required by the client.

The main design objectives can be identified in terms of:

a) life safety;

b) loss prevention;

c) environmental protection.

A more detailed consideration of possible design objectives is given in 6.2.

A fire engineering study may be used to assess all fire safety aspects of a building design or to consider one section of a building and justify a small departure from existing codes of practice. The scope of the study should be clearly identified by the QDR team. When considering only a partial study, the QDR team should satisfy themselves that there is no knock-on effect on other aspects of the design that would necessitate a more extensive study.

B.4 Fire hazard identification

A systematic review of the scheme should be conducted to establish the potential fire hazards within the building. The review should take account of factors such as:

a) general layout;

b) potential ignition sources;

c) nature of the activities;

d) anticipated occupancy;

e) construction materials;

f) combustible contents;

g) any unusual factors.

The above list is not exhaustive, and the QDR team should identify all significant fire hazards. In evaluating the significance of a fire hazard, the QDR team should take particular account of the influence of each hazardous event on the achievement of the fire safety objectives under consideration.

During the hazard identification stage, the QDR team should consider the possible consequences of failures in the fire protection systems and management procedures, e.g. fire doors left open or the smoke detection system being inoperative. In a probabilistic risk assessment (PRA) the likelihood and consequences of such failures will generally be quantified; however, in a deterministic study the team should make a judgement as to what represents a credible scenario for the purposes of detailed analysis. Where a comprehensive fire safety management plan is implemented and subject to third-party review, the benefits of this should be taken into account when assessing the likely efficiency of the evacuation process or the reliability of installed fire protection systems.

B.5 Trial fire safety design

In many cases, it will be necessary to amend the architectural design or provide additional fire protection measures to achieve an acceptable level of safety. To enable the quantification study to be carried out, the QDR team should establish one or more trial fire safety designs (fire protection strategies) for the purposes of more detailed analysis and quantification.

There can be no hard and fast rules laid down for the specification of alternative fire protection strategies. The members of the study team should use their knowledge and expertise to make sensible judgements on the suitability of various alternatives. It is desirable that the QDR team be able to identify cost-effective strategies that are likely to satisfy the fire safety objectives and criteria.

The alternative design strategies should be compared with each other in terms of cost and practicality. The QDR team should be able broadly to estimate the various costs of the different strategies. Also, certain fire protection strategies may present design, constructional or operational difficulties. If the fire protection requirements compromise the speed of construction or the day-to-day operation of the building, it is, in practice, likely that they will be negated at some stage. Therefore, care should be taken to ensure that any trial designs presenting significant practical difficulties are eliminated if at all possible.

It is possible for the QDR team to lose sight of practicalities and specify expensive measures to guard against unlikely hazards. Sometimes a full quantified analysis will be required, but more often a problem can be brought into perspective by a logical comparison or a few simple calculations.

The QDR team will inevitably consist mainly of engineers, who tend to favour hardware solutions; however, the team should recognise that in certain types of building the implementation of a well defined and maintained management system can often provide a more effective means of reducing the overall fire risk.

B.6 Fire scenarios

The number of possible fire scenarios in a complex building can become very large and often there are neither the data nor the resources available to attempt to quantify them all. The detailed analysis and quantification should therefore be limited to the most important fire scenarios. Engineering judgement becomes very important in the process of deciding the important fire scenarios.

The characterisation of a fire scenario for analysis purposes should involve a description of such things as the initiation, growth and extinction of a fire together with the likely smoke and fire spread routes. The possible consequences of each fire scenario should also be considered.

Where alternative fire safety design options are being compared against a reference case (i.e. in a comparative study), the quantification can often be considerably simplified. In such instances, it may only be necessary to consider a single fire scenario if this will provide sufficient information to evaluate the relative levels of safety of the trial design and the reference case.

The QDR team should establish the important fire scenarios and those that can be ignored (e.g. whether a very rare fire with the potential to cause a large loss is more or less important than small fires having a higher probability of occurrence but with the potential to produce a similar loss over time).

The QDR team should take account of the possibility of failures of protection systems and management procedures when establishing the sequences of events to be considered. In a deterministic or comparative study, it would be usual to identify a number of worst-case scenarios for further evaluation. However, care and judgement should be used to avoid analysing events with a very low probability of occurrence. Also, the QDR team should not request detailed analysis and quantification where the outcome is obvious.

B.7 Acceptance criteria

Once the safety objectives of the study have been established, the team should establish acceptance criteria against which the success of the trial design(s) can be judged.

It should be the responsibility of the QDR team to take account of existing knowledge, time constraints and project requirements and to establish the most appropriate basis for setting the acceptance criteria for the scheme.

In many projects, it is likely that the provisions of existing codes of practice and other guidance will be largely followed and that fire engineering techniques will not be necessary (or may be used only to justify limited departures from the codes). At its simplest, the QDR team may, therefore, define the acceptance criteria in terms of compliance with existing code specifications.

Criteria may be deterministic, probabilistic or comparative.

B.8 Methods of analysis

Having established one or more trial designs and the significant fire scenarios, the QDR team should provide guidance on the depth and scope of quantification required. Indeed, the QDR study may remove the need for further detailed analysis where, for instance, the qualitative study has shown a level of safety which is equal to that in prescriptive codes and guidance documents.

To establish the required scope of the quantification, the QDR team should identify the extent to which each fire scenario requires quantification. Where possible, guidance should also be provided on the type and complexity of analysis required to provide an adequate solution. For instance, when considering smoke movement simple hand calculations may be appropriate in relation to one fire scenario whereas a computational fluid-dynamics model may be more appropriate to another.

The types of analysis procedure that the QDR team may consider include:

a) simple calculations;

b) a computer-based deterministic analysis;

c) a simple probabilistic study, e.g. comparative PRA;

d) a full probabilistic study.

In some circumstances where a quantitative analysis is not appropriate, a detailed qualitative study or fire tests may provide an effective means of arriving at a design solution.

A deterministic study using comparative criteria will generally require far fewer data and resources than a probabilistic approach and is likely to be the simplest method of achieving an acceptable design. A full probabilistic study is only likely to be justified when a substantially new approach to building design or fire protection practice is being adopted.

B.9 Outputs

The QDR provides a largely qualitative set of outputs which will form the basis for the quantified analysis. The QDR study should typically provide the following information:

a) a clear statement of the fire safety objectives;

b) the significant hazards and their possible consequences;

c) one or more trial fire safety designs;

d) specifications of the fire scenarios for analysis;

e) a statement of key design parameters;

f) acceptance criteria;

g) suggested methods of analysis.

Annex C
(informative)

Fire safety management

C.1 Fire safety manual

The basis on which the fire safety design of a large or complex building has been achieved should be documented in a fire safety manual. The manual should set out the basis on which the means of escape were planned, as well as giving the management structure, staff responsibilities and other factors relevant to the continuing operation of the building. The documentation should provide guidance on the fire protection systems (active and passive) and the requirements for routine testing and maintenance of such systems. The purpose of the fire safety manual is to provide a clear and concise guide to the procedures to be adopted by management and staff so that they can maintain a high standard of fire safety.

Detailed fire safety management procedures should be developed by, or in conjunction with, building management. Guidance on the information that should be incorporated into the fire safety manual is given below.

The fire safety manual will inevitably be different in character for different types of facility and should take account of the general management and operational procedures of the organisation(s) concerned. The fire safety manual should be drafted, and its requirements implemented and monitored, in a professional manner. The manual should include the following main components: safety management structure, actions to be taken in a fire emergency, fire drills, housekeeping, planned maintenance procedures, staff training, continuing control and audit procedures, and security.

The following points are intended to highlight the main items that should be considered when developing management procedures.

C.2 Safety management structure

The safety management structure should provide clear lines of responsibility, authority and accountability, replacements during the absence of persons with specific responsibilities, and an emergency services liaison officer to call, and provide information to, the fire service.

C.3 Actions to be taken in a fire emergency

C.3.1 Evacuation procedures

The evacuation procedures should ensure that staff encourage and assist non-staff members to respond to an alarm, designated members of staff check that no one is left behind, provision is made for people with disabilities, and persons are deterred from re-entering the building until it is safe to do so.

C.3.2 Other procedures

Procedures should be developed for calling the fire service and providing information, shutting down equipment and (where appropriate) protecting the building contents, and first-aid firefighting.

C.4 Housekeeping

Particular attention should be paid to housekeeping measures in order to reduce the chances of fire and smoke spreading and escape routes being blocked.

Housekeeping measures should include keeping combustible materials separate from possible ignition sources, storing flammable liquids, paints and polishes in appropriate containers, recognition of potential hazards, ensuring that escape routes are kept clear, ensuring that fire doors are kept closed, and waste control.

C.5 Maintenance

Planned maintenance procedures should be established and used to ensure that all fire protection systems can operate effectively when required. Maintenance, testing and inspection of these systems should be carried out by competent persons. Maintenance and testing procedures should cover the following systems: fire warning, fire detection, fixed extinguishing systems, emergency lighting, operation of fire doors and closing mechanisms, and smoke ventilation systems.

Potential sources of ignition such as gas, oil and electrical heating installations should also be examined by competent persons on a regular basis.

When repairs or alterations are made to the building structure, it should be ensured that compartment walls or other passive fire protection systems are reinstated if damaged.

A record of all tests and checks should be maintained in a log book.

C.6 Staff training

Fire safety training should be provided to staff. All staff should be trained in the following matters: action to be taken on discovering a fire, action to be taken on hearing the fire alarm, procedure for calling the fire service, evacuation procedures, process shutdown, and good housekeeping.

Staff with special fire safety responsibilities should be provided with additional training appropriate to their role and duties.

C.7 Continuing control and audit procedures

Periodically, an audit should be carried out to review current fire safety management procedures, the effect of changes in personnel and usage of the building, etc., and the effectiveness of automatic fire safety systems, i.e. to ensure that they are suitable even after a change in compartment usage.

An audit by an independent third party may be required if the fire safety design requires a continuing high standard of fire safety management.

C.8 Security

It should be ensured that measures intended to prevent unauthorised access do not hinder the escape of the occupants or the entry of the fire service to rescue people who may be trapped by a fire.

C.9 Precautions against arson

In many countries, arson in buildings has increased greatly over the last two decades. In commercial and industrial buildings, arson causes large direct losses and serious interruptions in business operations. Arson can also be a threat to life, especially if the fire is started with a rapid-burning material such as gasoline or if the arsonist starts fires in several places simultaneously so that the alternative escape routes normally provided in a building are blocked.

The principal motives for arson are spite, revenge, jealousy, juvenile fire-setting, pyromania; profit-making (including insurance fraud following bankruptcy), the need to damage competition, fraud related to slum clearance, gaining possession of a building, and the desire of criminals to conceal their crime.

Inadequate building management can lead to serious fires by arson. However, a number of management methods can be used to reduce the likelihood of arson occurring and reducing the effects if it does occur. These include the following:

— Management awareness of vulnerability to arson:

  Management should be alert to the possibility of arson attacks by employee and outsiders. Careful selection of staff is necessary and good labour relations should be maintained. The provision of extra security staff should be considered if a short period of vulnerability seems likely, e.g. during a period of staff redundancies.

— Security against intruders:

  Intruders should be deterred by a suitable boundary fence and by a building which does not have obvious points of weakness where forced entry is possible.

  A vulnerability survey should be made, followed up by improvements in the facilities if necessary.

— Intruder detection:

  A number of techniques may need to be considered, for example security patrols, closed-circuit television and combined intruder alarm and fire alarm systems linked to a central control centre.

— Control of ignition sources/ easily ignitable materials:

  Inherent ignition sources should be removed wherever possible, and procedures should be installed and monitored to ensure that quantities of easily ignitable materials are not allowed to accumulate inside or outside the building.

— Early fire detection:

  Management should consider the possibility of an arson attack occurring in every space in or near the building and consider how the fire can be detected at an early stage at any time during the day or night.

— Early fire suppression:

  The ability of existing fire suppression systems to respond to and control a rapidly growing fire should be considered. Additional fire suppression systems may be needed to control fires started deliberately where accidental fires are unlikely to occur.

— Segregation of risks:

  Management should review the different risks (sleeping versus non-sleeping, high-value versus low-value stock) to see if, in the event of arson, the risks are acceptable or need to be reduced. Additional compartmentation may be required.

— Effective staff training:

  Staff should be made aware of the risks of arson and the remedial measures they can take. Reporting of unusual happenings should be encouraged.

Annex D
(normative)

Life safety

D.1 Life safety objectives

The occupants of a building, and firefighters who may have entered that building together with members of the public, and firefighters who are in the vicinity of a building can, potentially, be put at risk by a fire. The main life safety objectives are therefore to ensure that:

a) the occupants are able to remain in place, evacuate to another part of the building or totally evacuate the building without being subject to hazardous conditions that impede their progress or affect their health;

b) firefighters are safely able:

    1) to assist evacuation where necessary,

    2) to effect rescue where necessary,

    3) to prevent extensive spread of fire,

c) collapse of structural elements does not endanger people (including firefighters) who are likely to be near the building.

D.2 Life safety strategies

Basic life safety strategies comprise:

a) total evacuation of the occupants, by either simultaneous or phased procedures;

b) evacuation of the occupants to a place of safety within the building, where people can remain and, if necessary, complete the evacuation in safety as part of a managed system;

c) occupants in places from which evacuation could not normally be contemplated for functional reasons remaining in place, with the design ensuring that the location of the occupants remains a place of safety throughout;

d) rescue by the fire brigade, rescue teams or another appropriate organisation.

The life safety strategy may rely on direct assistance to the occupants by other occupants, staff or fire brigade personnel. The choice of strategy must be carefully matched to the nature of the building and its occupants, with some strategies being inapplicable to certain types of buildings. For example, in hospitals or premises providing residential care, appropriate evacuation strategies might include those where occupants evacuate to a place of safety within the building or are afforded protection while remaining inside. Similarly, it may not be appropriate to adopt a strategy of total evacuation from an air traffic control tower. Also in buildings such as hospitals where progressive horizontal evacuation or phased evacuation is adopted, some of the occupants may remain in the building for an extended period while firefighting operations take place elsewhere in the building.

D.3 Evacuation and life safety criteria

D.3.1 Evacuation and escape

The time necessary for evacuation of the occupants to a place of safety will depend on a number of factors relating to the occupants, the building and the fire dynamics (the last-mentioned can be assessed by simulation techniques). It is useful to consider the sequence of events within the evacuation process. Evacuation time is the summation of two discrete times, namely the time taken for occupants to become aware of the need for evacuation and to carry out a range of preliminary activities (the pre-movement time) and the time to actually travel the distance to the place of safety (the movement time).

Where evacuation is necessary (see clause D.2), escape times should be based on the maximum anticipated occupancy and should take account of physiological, psychological, pre-movement and movement factors for the occupants which affect the condition and location of occupants (see SS5).

D.3.2 Life safety criteria

The ability of people to escape will be impaired by their exposure to conditions which include loss of visibility, exposure to toxic and irritant products and exposure to heat. Ultimately, one or more of these conditions will lead to conditions which are untenable. Tenability limits may therefore be established based on each of these factors.

Whilst heat and the inhalation of smoke and toxic/irritant gases can impair movement, they may not cause total incapacitation which would prevent escape. In principle, it would be possible to take account of the effect of inhalation of toxic gases on the speed of escape; however, in most circumstances, if the design is sufficiently conservative, their effects on evacuation may be ignored, and for the purpose of design it may generally be assumed that the physiological response of the occupants (i.e. their condition) is unchanged until untenable conditions are achieved, at which time movement ceases.

D.4 Comparison of results with design criteria

D.4.1 Deterministic design

When considering life safety objectives, a deterministic design should be based upon the prevention of fatal and non-fatal casualties. Guidance on choosing appropriate criteria for life safety (for occupants, bystanders and rescue teams) is given in clause D.2.

In a deterministic study, the task is to demonstrate that none of the people within a building will be subjected to untenable conditions. This may be achieved by safe evacuation of occupants to the outside of the building or by providing a safe place within the building (see Figure 2).

a) **Conditions for safe escape:** Exposure to toxic gases, exposure to heat and loss of visibility represent a threat to life and health and affect the ability of people to escape safely. Failure of structural elements before the evacuation is complete can also present a threat to life. The study should, therefore, address all likely causes of death or incapacitation in a fire such as:

   1) loss of visibility,

   2) exposure to toxic, irritant and asphyxiant products,

   3) exposure to heat,

   4) structural failure.

   The hazard analysis should attempt to establish which potential threats are significant and require quantification. However, in most circumstances it will be loss of visibility due to the spread of smoke that determines the initial threat to life and consequently the time available for escape, where escape is necessary.

Essentially, when designing for life safety in situations where evacuation rather than remaining in place is the strategy, the aim is to ensure that the time available for escape t_{avail} is greater than the time needed for escape t_{needed}:

$$t_{avail} > t_{needed} \quad (D.1)$$

with

$$t_{needed} = t_{alarm} + \Delta t_{pre} + \Delta t_{move} \quad (D.2)$$

where

t_{alarm} is the alarm time;

Δt_{pre} is the pre-movement time;

Δt_{move} is the movement time.

b) **Safety factor (evacuation):** In many design procedures, safety factors are applied to ensure that the adequacy of design is commensurate with the hazard. Uncertainties in the design arise as a consequence of uncertainties, variabilities and inaccuracies in the various parameters, actual or assumed, or in the design methodology. Advice is given in annex E, and the calculation procedures and design assumptions presented in the subsystems include appropriate safety factors which contribute to the overall safety margin inherent in the design.

However, if a fire may put a large number of people at risk, it may also be appropriate to include an additional factor when establishing the design criteria.

For example, it may be possible to calculate the minimum time (i.e. the movement time) required for people to travel to and pass through a particular exit. However, it is known that people tend to leave a building by the routes with which they are familiar and it is often difficult to determine how many people will use each of the available exits. It should not be necessary to include such additional factors where the occupants are generally familiar with their surroundings and are likely to use all of the available exits (e.g. in offices). However, in buildings where large numbers of the public are likely to be present who may be unfamiliar with all of the available exit routes (e.g. in shopping complexes), it is considered appropriate to include an explicit design factor to take account of uncertainties in the distribution of the occupants using the available exits.

c) **Safety factor (structural failure):** In tall buildings subject to phased evacuation, for example hospitals, the occupants may need to remain in the building for an extended period while firefighting operations take place. It is therefore recommended that, where the failure of the structure will threaten the life of the occupants, who may have to remain in the building for a prolonged period, the structure should be capable of resisting structural failure.

In other buildings, consideration should be given to the introduction of an additional safety factor into the design where the consequences of failure are likely to be particularly significant.

d) **Comparative study:** An alternate method of analysis is to ensure that the design will provide a level of safety at least equivalent to that achieved by traditional codes of practice. In a comparative study, there is generally no need to introduce explicit safety factors, as any uncertainties in the calculation procedures are likely to apply to both the base case (design complying with traditional code) and the new design. For instance, when considering an assembly building that complies with traditional codes in all respects other than travel distance, there should be no need to consider explicitly detection time or pre-movement time, as these are likely to be unaffected by an increase in travel distance.

e) **Traditional criteria:** Traditionally, some fire safety recommendations have been arbitrarily based. One example is the allowable size of a compartment in a building. For life safety purposes, once adequate means of escape have been provided and provision has been made for their protection, there is no reason (in terms of safety of the occupant) for dividing a space into smaller compartments to control the size of a fire.

There may, however, be advantages in compartmentation for facilitating firefighting, reducing fire spread and limiting the area radiating on to adjacent buildings. These objectives can often be achieved by other methods such as sub-compartmentation, installing sprinklers and smoke control.

D.4.2 Probabilistic design

The life risk analysis in a probabilistic design involves considering the probability of a fire starting and heat and smoke spreading to produce untenable conditions in an occupied space. This assessment may be based either on statistical data (e.g. regarding the probability of death in a house fire) or, if this is not available, on the probability and potential consequences of a range of possible deterministic fire scenarios. Factors for assessing untenable conditions are given in clause D.2.

The overall risk associated with a particular building design is the sum of the risks for all the potential fires of interest within that building. The basic steps in the life risk calculation procedure are shown in Figure D.1.

The number and probability of deaths or injuries, for a given fire scenario, is calculated from the following equation:

$$N(\mathrm{C}) = N(\mathrm{O})_{\mathrm{INIT}} - N(\mathrm{O})_{\mathrm{EXIT}} \quad \text{(D.3)}$$

where

$N(\mathrm{C})$ is the number of deaths or injuries for the assumed occupancy;

$N(\mathrm{O})_{\mathrm{INIT}}$ is the initial number of occupants expected to be in the threatened area;

$N(\mathrm{O})_{\mathrm{EXIT}}$ is the number of occupants able to escape to safety in the available safe-escape time.

The risk to life may be estimated from the following equation:

$$P_{\mathrm{d}} = P_{\mathrm{esc}} \times P_{\mathrm{scen}} \times P_{\mathrm{i}} \quad \text{(D.4)}$$

where

P_{d} is the risk to life from the scenario;

P_{esc} is the probability that the escape time will exceed the time available for escape (a function of the number of occupants present at the time of the fire, the pre-movement time and the movement time);

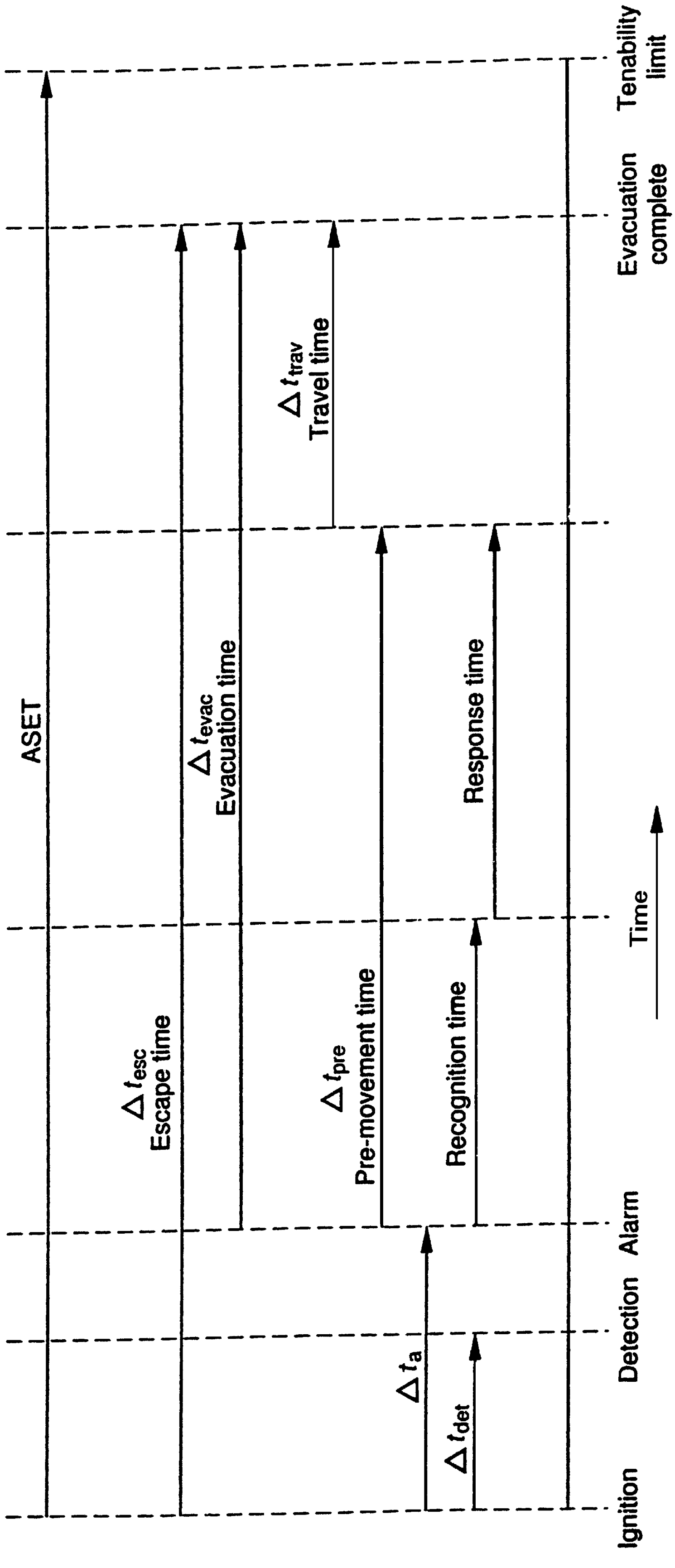
P_{scen} is the probability of the specified fire scenario developing following ignition;

P_{i} is the probability of a fire starting.

There will generally be more than one way in which a fire at a specified location may provide a hazard to the occupants. The characteristic risk associated with a particular fire location (source) is, therefore, the sum of the risks over all fire scenarios and all potentially threatened (target) locations.

The characteristic risk associated with a particular building is the sum of the risks for all the potential fire sources within that building.

To produce a definitive measure of the risk to life, it would be necessary to consider every combination of fire source, fire scenario and target location within the building. However, the computational effort required increases with the number of sources, scenarios and targets considered. The simplification of the problem by the QDR team (see 4.3) is therefore an essential precursor to carrying out a comprehensive PRA.



ASET = Available safe egress time

Figure D.1 — Example of a time line comparison of fire development and evacuation

Annex E
(informative)

Safety factors

E.1 Background

The term "reliability-based design" in this document refers to design based on the probability that a specified limit state will not be attained during the lifetime of the building (or another specified reference period).

Reliability methods can have two basic objectives: analysis on the one hand and design and safety checking on the other.

Reliability methods that only employ one "characteristic" value of each uncertain parameter are called level 1 methods. Methods that employ two values of each uncertain parameter (usually mean and standard deviation) are called level 2 methods. Reliability methods which require a joint distribution of all uncertain parameters are called level 3 methods.

Both level 2 and 3 methods can be used for checking the safety of a design or directly in the design process, provided a target safety index (reliability index) β or target reliability has been specified. This is an unrealistic safety format for a code, however, as such a format would require the designer to perform a level 2 or level 3 analysis in each individual case — level 1 design and safety checking is the most appropriate for a code format. In a level 1 design method the appropriate degree of reliability is provided by the use of a number of partial safety factors (partial coefficients) related to predefined values (characteristic values) of the major random variables.

A level 1 design method does not require a reliability analysis by the designer. On the other hand, code parameters must be specified with a view to achieving a desired level of reliability. The term "code parameters" means all numerical quantities specified in the code except physical constants. Calibration is the process of assigning values to the code parameters. A code may be calibrated by judgement, fitting, optimisation or a combination of these approaches.

Calibration by judgement and fitting has been the traditional approach and until recently the only one available. The background to calibration by optimisation is a level 2 reliability analysis — see below.

E.2 Procedure for deriving code parameters in a level 1 design method

A general procedure may be outlined for deriving partial coefficients and other code parameters:

— set limits on the range of scenarios for which the individual deterministic equation in the code will be applicable;

— specify the deterministic functional relationships to be used as a basis for each design sub-procedure;

— characterise the major sources of uncertainty in models and input parameters;

— select a suitable safety format, i.e. the number of partial coefficients and their position in the design equation;

— select appropriate characteristic values to be used as fixed deterministic quantities in the code;

— determine the magnitude of the partial coefficients to be used, together with corresponding characteristic values, to achieve the required reliability (by judgement, fitting, optimisation, etc.).

E.3 Calibration of level 1 design procedure by judgement and fitting

On the whole, the traditional prescriptive approach has proved to provide socially acceptable safety levels, and if possible the accumulated practical experience using the traditional approach should be utilised in design based on performance. One approach could be to apply the level 1 code to design solutions approved according to the traditional code and adjust code parameters accordingly. The main problem is that no systematic procedure has been derived for this, nor is there likely to be one, as safety levels within the prescriptive format are known to vary within a wide range even for an individual scenario.

E.4 Calibration of a level 1 design procedure by optimisation

E.4.1 Relationship of partial coefficients to level 2 design point

The design value of a specific design parameter is found by multiplying the characteristic value by the corresponding partial coefficient. In a level 2 reliability analysis and for a specified scenario and a specified building, the design point is given directly as the most probable point of failure. Having defined the characteristic value (mean value, 80% or 90% fractile, etc.), the corresponding partial coefficient is obtained directly.

E.4.2 General method for the determination of partial coefficients

In practice, design equations in a code must cover a whole class of buildings. Consider evacuation from a public-assembly room as an example. Let A = floor area and H = room height. A level 2 analysis will result in design points which will differ from one combination of A and H to another combination. The code, to be practicable, should cover ranges of A and H. A general method for the determination of a set of partial coefficients to cover these ranges may be defined as follows:

- define the target failure probability or target safety index β [see equation (E.7)];
- define the smallest number of partial coefficients that is consistent with a reasonably uniform standard of reliability;
- Calculate by an optimisation procedure a set of partial coefficients minimising the difference between the target failure probabilities and the calculated failure probabilities, taken over ranges of A and H given in practice.

The general aim of this procedure is to minimise deviations from the target failure probability while maintaining the average failure probability at the target level. The appropriate number of partial coefficients, the formulation of target functions, the definition of a class of suitable scenarios, etc., are factors that will have to be defined iteratively during the course of the process.

E.5 Limit state functions and checking the equations

It is assumed that a scenario has been defined and the appropriate variables (quantities and parameters) have been selected in the form of a random variable $X = (X_1, ... X_n)$. For a given scenario, each value x_i (where $i = 1, ... n$) is considered to represent the random variable X_i. In other words, the value of x is a point in the n-dimensional basic-variable space. Assume that the general condition for a limit state not to be exceeded can be written as:

$$g(X_i, ... X_n) = g(X) > 0 \quad \text{(E.1)}$$

where

$X_i, ... X_n$ are the n basic random variables which influence the limit state;

g is the limit state function (failure function);

and

$$P[g(X_1, \ldots X_n) < 0] < P_{\text{target}} \quad \text{(E.2)}$$

where P denotes probability.

The equivalent deterministic criterion for safety checking (i.e. checking the sufficiency of a fire safety system whose design properties are given) is:

$$g(x_{1,\text{d}}, x_{2,\text{d}}, \ldots x_{n,\text{d}}) > 0 \quad \text{(E.3)}$$

where

g is the same limit state function as above, involving the n quantities x_d;

$x_{i\text{d}}$ is the deterministic design value of the random variable X_i.

E.6 Methods of safety checking

A classification system for different methods of safety checking was developed by the Joint Committee on Structural Safety during the late 1970s, dividing the methods into three broad classes or levels. This classification is still used.

— Level 1: Design methods in which the appropriate degree of safety is provided by the use of a number of partial safety factors or partial coefficients, related to pre-defined characteristic or nominal values of the major variables.

— Level 2: Methods involving certain approximate iterative calculation procedures to obtain an approximate failure probability.

— Level 3: Methods in which calculations are made to determine the "exact" probability of failure, utilising the full stochastic description of the random variables X_i and of their joint occurrence and taking into account the true description of the failure domain. In practice, use of Monte Carlo simulation techniques is necessary.

A level 1 code is a conventional deterministic code where the appropriate, and in most practical cases unknown, degree of safety is provided by a two-step procedure. In the first step, the characteristic value x_k of a basic random variable X is determined, this value being defined as the p^{th} fractile of X, given by:

$$x_\text{k} = F_x^{-1}(p) \quad \text{(E.4)}$$

where F_x^{-1} is the inverse distribution function of X.

The selection of the probability P is to a large extent arbitrary but influenced by the following considerations:

— Characteristic values should rarely be exceeded in practice.

— The value of P should not be so large that values of x_k are not occasional encounters.

— For practical reasons, it is generally necessary when applying a level 1 code to work with specified values of the design variables rather than with actual characteristic values because the statistical information is insufficient. A specified value will be denoted $x_{i,\text{sp}}$.

In the second step, the components of the design value vector $x_\text{d} = (x_{1,\text{d}}, \ldots x_{n,\text{d}})$ are then given by:

$$x_{i,\text{d}} = \gamma_i \, x_{i,\text{sp}} \quad \text{(E.5)}$$

where γ_i denotes the relevant partial coefficient.

In a level 1 code, the partial coefficients are to be seen as a set of control parameters to be selected by a procedure using optimisation, fitting or judgement in such a way that the outcome of all designs undertaken to the code is in some sense optimal over a class of buildings.

Design according to level 2 in an individual case involves the mapping of the set of n random variables X to a set of independent standard normal variables Z with the limit state failure surface given by:

$$f(z_1, ..., z_n) = 0 \quad \text{(E.6)}$$

The safety index β is defined in Z-space as the shortest distance from the origin to the failure surface. The corresponding point on the failure surface is referred to as the design point z and is obtained by an approximate iterative calculation procedure. If the failure surface is linear and the basic variables X_i (i = 1 to n) are normally distributed, the probability of failure P_f is related to the safety index β by the equation:

$$\beta = \Phi^{-1}(P_f) \quad \text{(E.7)}$$

where Φ is the standardised normal distribution function.

For this special case, no iteration is necessary. In the general case, we obtain the set of values $X_{i,d}$ for the original basic variables X corresponding to the design point z by use of inverse mapping.

If the values $X_{i,d}$ are to be used as the design values in a deterministic level 1 design calculation, the resulting fire safety subsystem would have a safety index β and a corresponding value of P_f The corresponding set of partial coefficients would be:

$$\gamma_i = X_{i,sp}/X_{i,d} \quad \text{(E.8)}$$

However, the use of this relationship must be based on a level 2 probabilistic analysis and if this is undertaken there is little point in following it with a level 1 safety check. Furthermore, this leads to a partial coefficient for every basic variable, which is too many in practical design. For a class of buildings, the general method described in E.4.2 has to be employed.

Annex F
(informative)

Firefighting and rescue facilities

It is important that consideration is given to the potential of the local fire brigade for firefighting and rescue, taking into account the occupant and building parameters and the fire spread and development scenarios. An analysis, where necessary in liaison with the fire brigade, should be carried out of the fire brigade response times and of the procedures, equipment, facilities and water supplies available, before considering what additional facilities are necessary in the building design to assist the fire brigade.

Firefighting and rescue operations are extremely difficult to quantify because of the wide range of variables involved. The factors that have to be taken into account include:

a) whether the firefighters are full-time or volunteers;

b) the availability of specialist appliances and equipment;

c) the precise nature and location of the fire incident;

d) the position and condition of persons requiring assistance during the evacuation (or rescue if the life safety design system has failed).

The design of the building, and the facilities provided, can now be reviewed to ensure that:

a) there is sufficient means of external access to enable fire appliances to be brought near to the building for effective use;

b) there is sufficient means of access into, and within, the building for firefighters to assist in the evacuation, to effect rescue (where necessary) and to fight the fire;

c) the building is provided with sufficient fire mains and other facilities to assist firefighters in their tasks;

d) the building is provided with adequate means of venting heat and smoke from basement areas.

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