BS 7974:2019

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Application of fire safety engineering principles to the design of buildings – Code of practice

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Contents

Summary of pages

This document comprises a front cover, and inside front cover, pages i to iv, pages 1 to 61, an inside back cover and a back cover.

Foreword

Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 31 March 2019. It was prepared by Technical Committee FSH/24, *Fire safety engineering*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

This British Standard supersedes BS 7974:2001, PD 7974-0:2002 and PD 7974-8:2012, which are withdrawn.

Relationship with other publications

BS 7974 is intended to provide a framework for the application of fire safety engineering principles to the design of buildings. It is supported by the PD 7974 series of Published Documents, *Application of fire safety principles to the design of buildings,* that contain guidance and information on how to undertake detailed analysis of specific aspects of fire safety engineering in buildings. PD 7974-1 to PD 7974-7 provide a summary of the state of the art and it is intended that they are updated as new theories, calculation methods and/or data become available. The parts of PD 7974 are structured as follows:

- PD 7974-1, *Initiation and development of fire within the enclosure of origin (Sub-system 1)*;
- PD 7974-2, *Spread of smoke and toxic gases within and beyond the enclosure of origin (Sub-system 2)*;
- PD 7974-3, *Structural response and fire spread beyond the enclosure of origin (Sub-system 3)*;
- PD 7974-4, *Detection of fire and activation of fire protection systems (Sub-system 4)*;
- PD 7974-5, *Fire and rescue service intervention (Sub-system 5)*;
- PD 7974-6, *Occupant evacuation, behaviour and condition (Sub-system 6);* and
- PD 7974-7, *Probabilistic risk assessment*.

PD 7974-4 has now been withdrawn; it provided guidance on the detection of fire and activation of fire protection systems. This guidance is now included in the various parts of the PD 7974 series and other standards covering the subject. PD 7974-4 is referred to as part of the PD 7974 series for the sake of completeness but is no longer maintained as a current document.

Information about this document

This British Standard can be used to identify and define one or more fire safety design issues to be addressed using fire safety engineering. The appropriate part(s) of PD 7974 can then be used to set specific acceptance criteria and undertake detailed analysis.

This is a full revision of the standard, and introduces the following principal changes:

a) the incorporation of recommendations previously contained in PD 7974-0:2002 and PD 7974-8:2012;

b) a greater emphasis on the competence of the fire safety engineer;

c) additional recommendations for the quality assurance and verification of fire safety engineering reports; and

d) the terminology used has been simplified and consolidated.

The underlying process of fire safety engineering based on the qualitative design review has not changed, but every effort has been made to ensure that the terms used to describe that process are consistent throughout the standard.

Use of this document

As a code of practice, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

Any user claiming compliance with this British Standard is expected to be able to justify any course of action that deviates from its recommendations.

It has been assumed in the preparation of this British Standard that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

Presentational conventions

The provisions of this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is “should”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Where words have alternative spellings, the preferred spelling of The Shorter Oxford English Dictionary is used (e.g. “organization” rather than “organisation”).

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

Attention is drawn to the following statutory regulations: the Building Regulations [1], [2], [3], [4], [5], and Regulatory Reform (Fire Safety) Order 2005 [6] and Fire (Scotland) Act 2005 [7].

0 Introduction

0.1 General

For most buildings, the recommendations in existing design codes such as BS 9991 and BS 9999 are generally adequate. Where they are not, this British Standard can be used for developing and assessing fire safety engineered proposals.

A fire safety engineering (FSE) approach that takes into account the total fire risk management package specific to the building can often provide a more fundamental and economical solution than design codes. It might in some cases be the only viable means of achieving a satisfactory standard of fire safety in some large and complex buildings.

FSE can have many benefits. The use of this British Standard is intended to facilitate the practice of FSE and, in particular, to:

a) provide the designer with a disciplined approach to fire safety design;

b) allow the safety levels for alternative designs to be compared;

c) provide a basis for selection of appropriate fire protection systems;

d) provide opportunities for innovative design; and

e) provide information and assessment methods to support the design, construction, management and operation of buildings.

Fire is an extremely complex phenomenon and gaps exist in the available knowledge and technology. This British Standard is intended to provide a framework for a flexible but formalized approach to fire safety design by which an adequately fire safe building can be constructed while allowing for inevitable uncertainties in the development of a fire and the response of the building and occupants to it. It also sets out a reporting methodology which allows for the design to be readily assessed by approvals bodies.

This British Standard is supported by a series of Published Documents that contain guidance and information on how to undertake detailed analysis of specific aspects of FSE. This does not preclude the use of appropriate methods and data from other sources. Figure 1 shows the structure of this British Standard and the Published Documents.

This British Standard:

1) provides a framework for and describes the philosophy that underpins FSE;

2) outlines the principles involved in the application of the philosophy to the FSE of particular buildings;

3) provides means of establishing acceptable levels of fire safety without imposing disproportionate constraints on aspects of building design;

4) provides guidance on the design and assessment of fire safety measures in buildings;

5) gives a structured approach to assessing the effectiveness of the fire safety strategy in achieving the functional objectives;

6) can be used to identify and define one or more fire safety design issues to be addressed using FSE;

NOTE The appropriate part(s) of PD 7974 can then be used to set specific acceptance criteria and undertake detailed analysis.

7) provides alternative approaches to existing standards for fire safety and also allows the effect of departures from design codes to be evaluated;

8) recognizes that the functional objectives can be achieved by a range of alternative and complementary fire protection strategies;

9) aims to facilitate innovation in design without compromising safety;

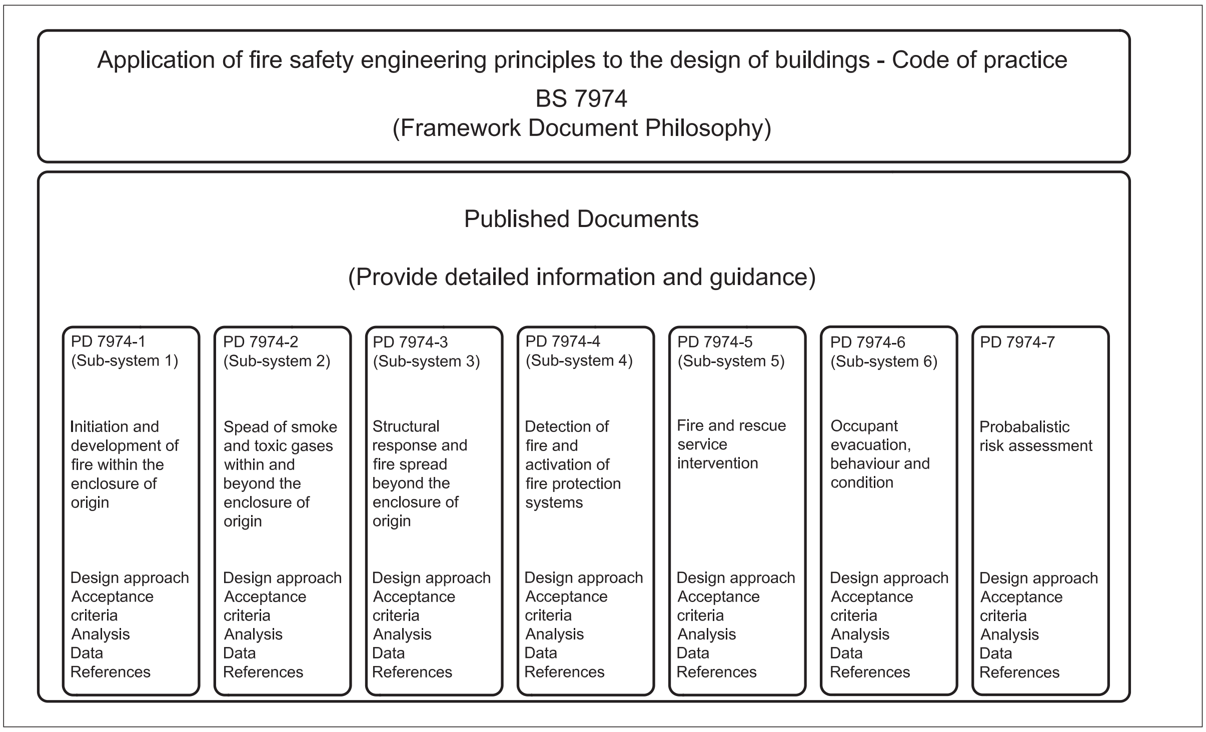
10) provides guidance to ensure that the building is constructed such that: it can withstand fire actions that are reasonably foreseeable; its layout and configuration does not prejudice its integrity; and foreseeable life-cycle fabrication, construction, commissioning, operation, modification, maintenance and repair can proceed without prejudicing its integrity; and

11) provides a flexible framework that can be used for simple aspects of fire safety design (e.g. a minor variation from prescriptive guidance) using perhaps only part of a single sub-system of this standard, to complex fire safety challenges (e.g. a major departure from prescriptive guidance) that require use of all sub-systems.

This British Standard provides a performance-based approach to design in which the specific fire hazards and their potential consequences can be identified and fire safety measures can be introduced, as necessary, to ensure that the functional objectives are met. It also enables the results of research into fire and human response to be translated directly into the building design process.

There are some frequently cited misconceptions about FSE and its applicability. These are discussed in Annex A.

Figure 1 — *The structure of the British Standard and the Published Documents*



The framework for an engineering approach to fire safety described in this code of practice is applied using the following three main stages.

- Qualitative design review (QDR): The scope and objectives of the fire safety design are defined, performance criteria established and one or more potential design solutions proposed. Key information is also gathered to enable evaluation of the design solutions in the quantitative analysis.

- Quantitative analysis: Engineering methods are used to evaluate the potential solutions identified in the QDR. Quantitative analysis can be time-based analysis using appropriate sub-systems (see **0.2**) to reflect the impact of the fire on people and property at different stages of its development. Steady state and limit state analysis can also be used.
- Assessment against criteria: The output of the quantitative analysis is compared to the acceptance criteria identified in the QDR to test the acceptability of the proposals.

In order to substantiate a FSE design, these three distinct stages are worked through, with each of the stages being fully documented so that they are readily accessible to a third party, e.g. approvals bodies, insurers, owner occupiers of buildings.

0.2 The sub-systems

0.2.1 General

To simplify the evaluation of the fire safety design, the FSE process can be further broken down into six sub-systems. The sub-systems can be used individually to address specific issues or together to address all of the main aspects of fire safety.

The sub-systems can be used as follows.

a) Sub-system 1: initiation and development of fire within the enclosure of origin (see PD 7974-1). Sub-system 1 provides guidance on evaluating fire growth and/or size within the enclosure taking into account the four main stages of fire development:

  1) pre-flashover (including early growth and development);

  2) flashover;

  3) fully developed fire (where all the fuel is burning); and

  4) decay.

b) Sub-system 2: spread of smoke and toxic gases within and beyond the enclosure of origin (see PD 7974-2). Sub-system 2 provides guidance by which the following can be evaluated:

  1) the spread of smoke and toxic gases within and beyond the enclosure of fire origin; and

  2) the characteristics of the smoke and the toxic gases at the location of interest.

c) Sub-system 3: structural response and fire spread beyond the enclosure of origin (see PD 7974-3). Sub-system 3 provides guidance so that the following can be evaluated:

  1) the fire size, in terms of temperature and heat flux within the enclosure; and

  2) the ability of the elements forming the enclosure, directly or in part, to withstand exposure to the prevailing fire size.

d) Sub-system 4: detection of fire and activation of fire protection systems (see PD 7974-4). Sub-system 4 gives guidance on the calculation of the following with respect to time:

  1) detection of the fire;

  2) activation of the alarm and fire protection systems, e.g. sprinklers, smoke management systems, roller shutters, etc.; and

  3) fire service notification.

e) Sub-system 5: fire and rescue service intervention (see PD 7974-5). Sub-system 5 provides guidance on the evaluation of the rate of build-up of fire extinguishing resources of the fire service, including the activities of in-house or private fire brigades and in particular:

   1) the time interval between the call to the fire and rescue service and the arrival of the fire and rescue service's pre-determined attendance;

   2) the time interval between the arrival of the fire and rescue service and the initiation of attack on the fire by the fire and rescue service;

   3) the time intervals related to the build-up of any necessary additional fire and rescue service resources;

   4) the extent of fire-fighting resources and extinguishing capability available at various times; and

   5) the provision of additional access and facilities for fire-fighters to improve the likelihood of successful fire-fighting.

f) Sub-system 6: occupant evacuation, behaviour and condition (see PD 7974-6). Sub-system 6 provides guidance on how to assess the response of people to fire, including their evacuation time from any space inside a building and time to loss of tenability in any occupied space. Once the evacuation time has been established it can be compared with the outputs from sub-systems 1 to 4 and the calculated available safe escape time from system 6, within the quantitative analysis. Acceptance criteria are contained in this sub-system.

NOTE The various parts of PD 7974 (PD 7974-1 to PD 7974-6 respectively) give selected data and engineering relationships (including information on their applicability) that may be used for design. However, this British Standard recognizes the use of alternative information.

All six sub-systems together can be used to produce a time-based analysis of fire safety.

0.2.2 Relationship between sub-systems

A FSE solution might make reference to only one or two sub-systems or there might be a complex series of interactions involving all of the sub-systems. For instance, the activation of sprinklers (sub-system 4) and fire service intervention (sub-system 5) can influence the rate of fire growth (sub-system 1). The flow chart in Figure 2 is an example of the order in which the sub-systems are normally evaluated. The solid lines indicate the order of calculation and the links that are normally required from other sub-systems. The dotted lines indicate the links that can be included depending upon the complexity of the analysis being undertaken.

Analysis adheres to a formal framework following a preliminary review, the QDR, which sets out functional objectives. Achieving the functional objectives set by the QDR can involve using one or all of the six sub-systems whereas to achieve a specific design objective, such as structural failure, it might only be necessary to consider sub-systems 1 and 3. The ways in which sub-systems can be linked together in typical life safety and structural analyses (where the development of fire is not controlled by active suppression systems) are illustrated in Figure 3 and Figure 4. However, these examples do not represent the only acceptable method and the fire safety engineer is expected to establish the most appropriate approach.

Figure 2 — *Example of the complexity of the linkages between the sub-systems that can arise if the analysis is not simplified*

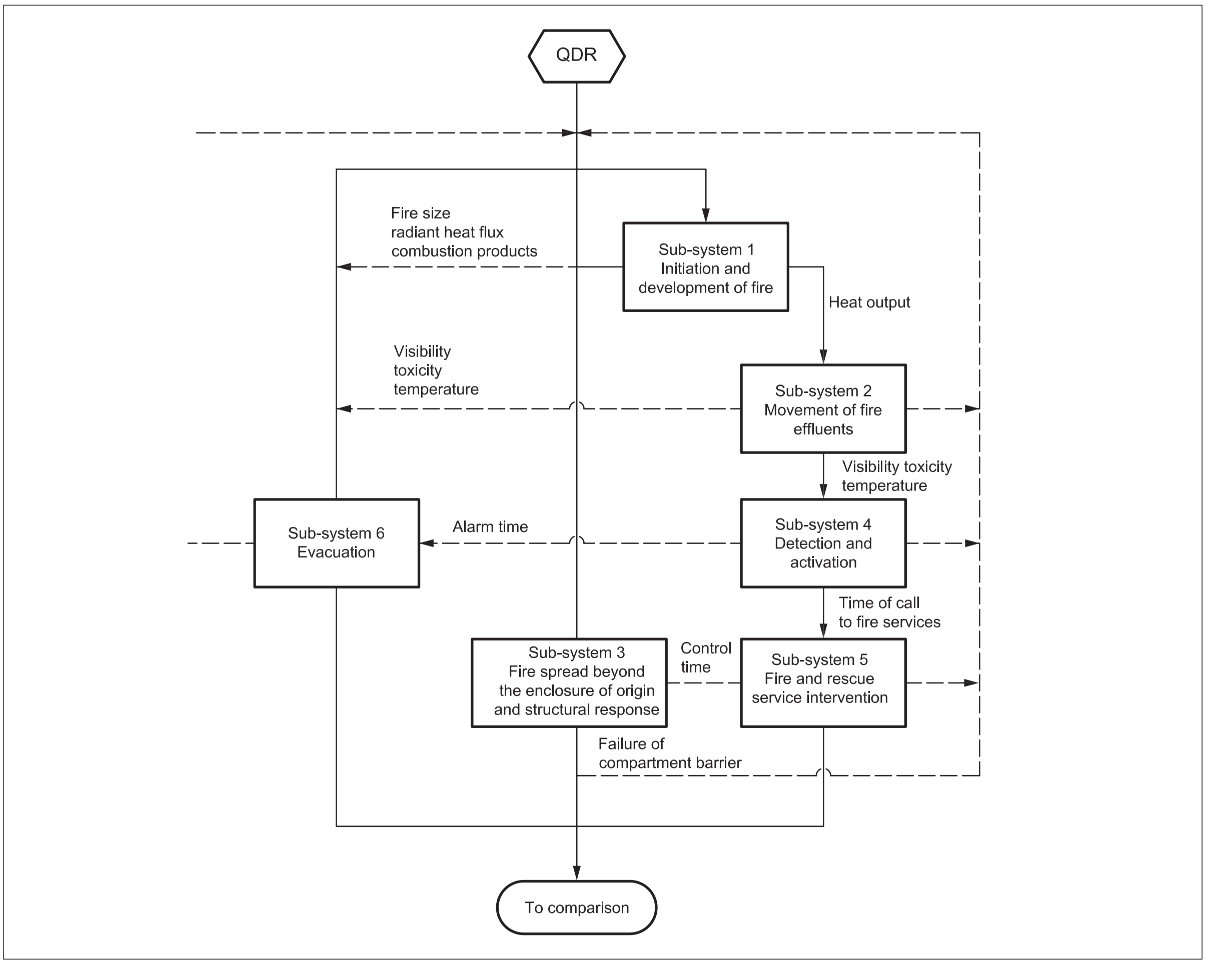
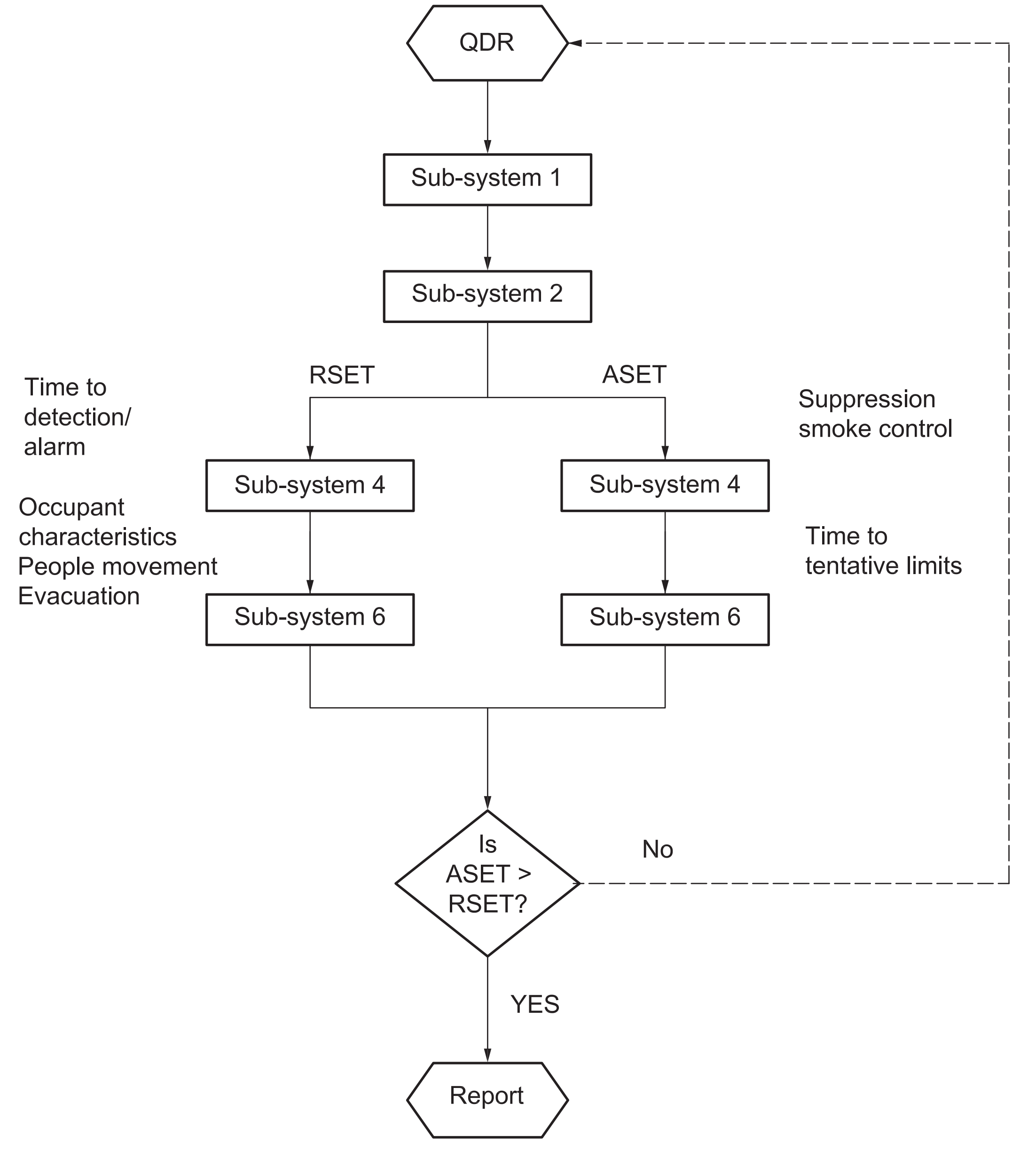
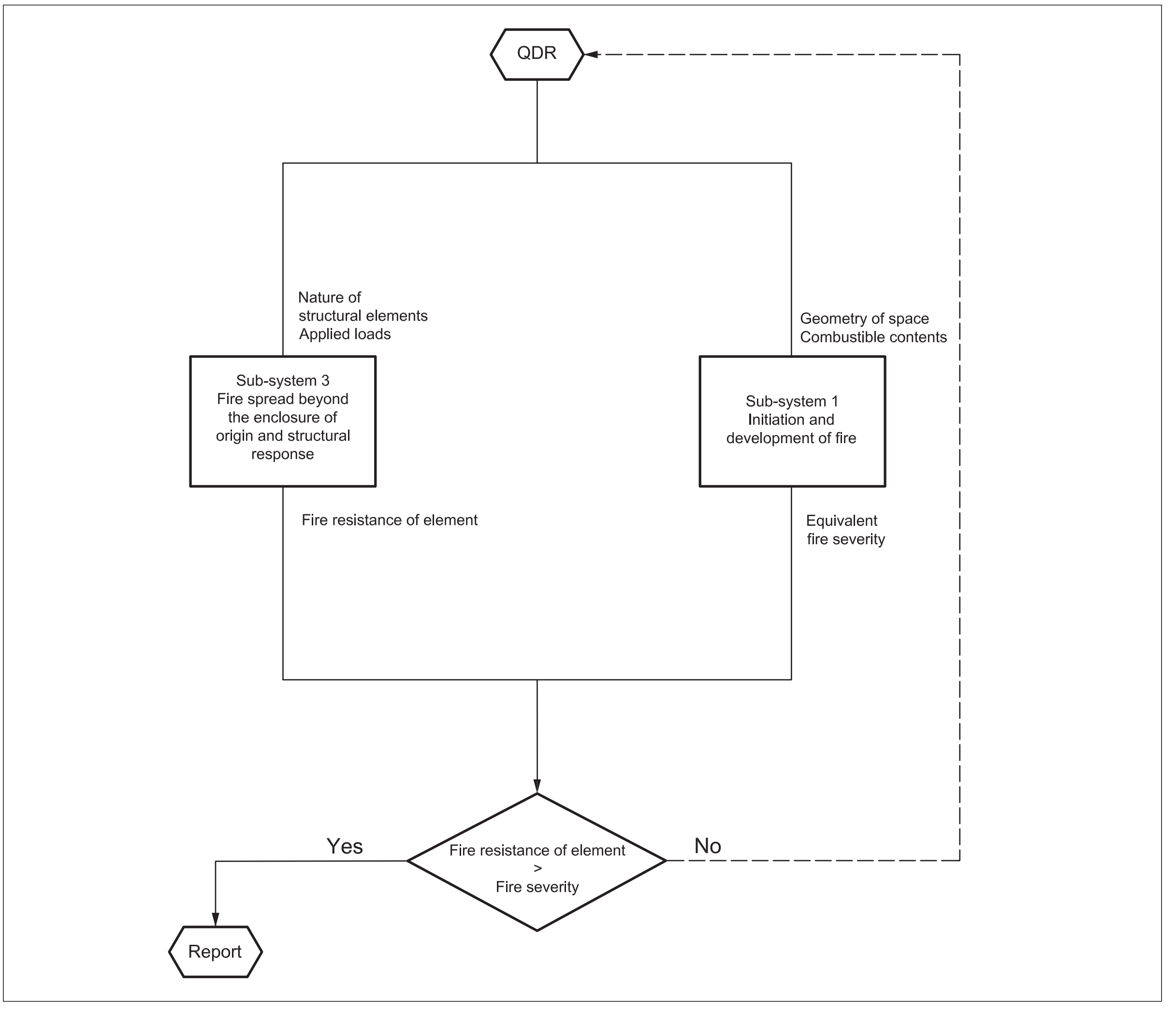


Figure 3 — *Example of how the sub-system procedures can be simplified to assess the adequacy of means of escape from the room of fire origin*



NOTE For further information on ASET (available safe escape time) and RSET (required safe escape time), see 7.4.1.

Figure 4 — *Example of how the sub-system procedures can be utilized to assess the ability of a building structure to resist a compartment burnout*



0.3 PD 7974-7 — Probabilistic risk assessment

In addition to PD 7974-1 to PD 7974-6 that cover the sub-systems, PD 7974-7 addresses another aspect of FSE, that of probabilistic risk assessment.

PD 7974-7 provides guidance on how to analyse the risk to a building and its contents, occupants and fire control systems with the intention of determining the frequency and consequences of certain fire scenarios and the possible need for extra measures required to reduce any unacceptable risks.

0.4 Background

0.4.1 General

Historically, fire safety measures have been specified by reference to design codes that provide solutions for a given set of building parameters. For many buildings of straightforward construction, layout and use, design codes provide the designer and fire safety engineer with an acceptable solution.

However, these codes have to account for a wide range of buildings and often do not provide the optimum solution in terms of:

a) life safety;

b) property protection;

c) protection of the environment;

d) cost-effective fire protection; and

e) operational requirements.

The design code approach often does not meet the needs of building owners, designers or approvals bodies, particularly for more complex buildings or processes or where there is a potential for substantial financial loss arising from a relatively small fire.

Similarly, design codes for fire protection systems such as sprinklers, detectors and smoke control do not always take account of all significant design factors (e.g. the effect of height on the speed of sprinkler activation and consequential extinguishing effectiveness).

Some of the advantages and disadvantages of the traditional design codes are summarized in Table 1.

Table 1 — *Examples of advantages and disadvantages of design codes*

Advantages	**Disadvantages**
Simple to use	Often not flexible
Embody past experience	Unable to anticipate all eventualities
Provide a consensus view	Do not necessarily provide optimum solution
Familiarity to stakeholders and authorities having jurisdiction	Unresponsive to changes in construction methods, technology and materials
	Might result in compliance taking precedence over wider safety considerations

0.4.2 Benefits of fire safety engineering

A fire safety engineering (FSE) approach that takes into account the total fire safety package can provide a more fundamental and economic solution than traditional approaches to fire safety. It might be the only viable means of achieving a satisfactory standard of fire safety in some large and complex buildings.

A FSE approach might initially result in higher design costs due to the increased engineering effort, but the potential improvement in safety and the construction and operational savings can far exceed the increased design cost.

The main benefits and disadvantages of FSE compared to the more traditional design code approach are summarized below in Table 2.

Table 2 — *Examples of advantages and disadvantages of FSE approach*

Advantages	Disadvantages
Fire safety measures tailored to risk and specified functional objectives.	Suitably qualified and experienced personnel are required to carry out and assess FSE studies.
Facilitates innovation in building design without compromising safety.	Might involve increased design time and costs.
Fire protection costs can be reduced without compromising safety.	Lack of data in some fields.
Provides a framework to translate research into practice.	Might be restrictive unless future flexibility of use is explicitly considered as a functional objective.
Enables alternative fire safety strategies to be compared on cost and operational grounds.	Potentially unfamiliar to stakeholders and authorities having jurisdiction.
Enables cost and benefits of loss control measures to be assessed.	Might require additional analyses/fire testing as part of verification of the design package.
Increased opportunity to use modern and innovative technology.	
Requires design team and operator to explicitly consider fire safety.	

1 Scope

This British Standard provides a framework for an engineering approach to fire safety in buildings by giving recommendations and guidance on the application of scientific and engineering principles to the protection of people, property and the environment from fire. It is applicable to the design of new buildings and the appraisal of existing buildings.

The general approach to fire safety engineering (FSE) described in this British Standard can be applied to all types and uses of buildings or to facilities such as tunnels and process plants. However, the risks associated with installations used for the bulk processing of explosives or flammable liquids and gases necessitate special consideration which is beyond the scope of BS 7974 and its supporting documents.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purpose of this British Standard, the following terms and definitions apply.

3.1 approvals body

organization responsible for approving the fire safety aspects of a building

NOTE Examples of approvals bodies are the local authority building control, approved inspectors, and the fire authority.

3.2 authority having jurisdiction

organization, office or individual responsible for enforcing the requirements of legislation or standards, or for approving equipment, materials, an installation, or a procedure

3.3 available safe escape time (ASET)

calculated time available between the time of ignition and the estimated time at which conditions become untenable

3.4 common mode failure

failure that is the result of an event(s) that, because of dependencies, causes a coincidence of failure states of components in two or more separate channels of a redundancy system, leads to the defined system failing to perform its required function

3.5 compartment

enclosed space, which can be subdivided, separated from adjoining spaces within the building by elements of construction having a specified fire resistance

3.6 design code

design guidance which provides accepted solutions appropriate for the more common building situations and specific building types

NOTE Examples include Approved Document B (Fire Safety) to English Building Regulations [8], Scottish Government Technical Handbooks [9], [10] and BS 9999 and BS 9991.

3.7 design objective

specific condition(s) that FSE analysis is expected to demonstrate in order to indicate that a broader functional objective has been met

3.8 deterministic analysis

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

3.9 enclosure

volume defined by bounding surfaces, which can have one or more openings

3.10 escape time

interval between ignition and the time at which all occupants are able to reach place of safety

3.11 evacuation time

interval between the time at which a warning of a fire is transmitted to the occupants and the time at which all of the occupants are able to reach a place of safety

3.12 exit

doorway or other suitable opening giving access towards a place of safety

3.13 fire hazard

source of possible injury or damage from fire

3.14 fire load

calorific energy of all of the contents within a compartment and structure that can be involved in a fire

3.15 fire load density

fire load per unit area

3.16 fire safety engineer

person suitably qualified and experienced in fire safety engineering

3.17 fire safety engineering (FSE)

application of scientific and engineering principles to the protection of people, property and the environment from fire

3.18 fire safety manual

document providing all necessary information for the effective management of fire safety in the building

3.19 fire safety strategy

combination of fire safety measures that has been shown by reference to design codes or FSE analysis to be capable of satisfying the specified functional objectives

3.20 fire scenario

set of circumstances (taking account of the building, its contents and occupants), chosen as an example, that defines the development of fire and the spread of combustion products throughout a building or part of a building

3.21 flashover

sudden transition from a localized fire to the ignition of all exposed flammable surfaces within an enclosure

3.22 functional objective

high level purpose of a fire safety engineering project

NOTE For example, a functional objective could be "to provide an appropriate level of safety from fire" or "to protect the environment from harmful products of combustion".

3.23 management (noun)

person or persons 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 (of statutory duty)

NOTE This could be the owner.

3.24 means of escape

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

3.25 place of safety

predetermined place in which persons are in no immediate danger from the effects of fire

NOTE The place of safety can be inside or outside the building depending upon the evacuation strategy.

3.26 pre-travel time

interval between the time at which a warning of a fire is given and the time at which movement towards an exit begins

NOTE 1 Pre-travel time consists of two components: recognition time and response time.

NOTE 2 For groups of occupants, two phases can be recognized: the pre-travel time of the first occupants to move; and the pre-travel time distribution between the first and last occupants to move.

NOTE 3 Although occupants might engage in activities involving movement during the pre-travel time, these do not include movement towards an exit.

3.27 probabilistic analysis

methodology to estimate statistically the probability and outcome of events

3.28 qualitative analysis

non-numerical examination of a fire safety engineering proposal using experience, knowledge and engineering judgement alone

3.29 quantitative analysis

examination of a fire safety engineering proposal using generic data and case-specific data as inputs into calculations that generate numerical results

3.30 reasonable worst case scenario

set of credible conditions that, when taking account of the building, its contents and occupants, gives rise to the highest level of fire risk

3.31 risk

probability of occurrence of a hazard causing harm and the degree of the severity of the harm

3.32 tenability limit

maximum exposure to fire hazards that can be tolerated without causing incapacitation

3.33 travel distance

actual distance travelled by a person, having regard for obstructions between two points

3.34 trial design

group of fire safety measures which, in the context of the building parameters, might meet the specified functional objectives

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4 Overview of the design approach

4.1 Competence

*COMMENTARY ON **4.1***

The complexity of the interactions between people, buildings and fire is such that no single set of calculation procedures can be applied to all types of buildings in all circumstances. Therefore, FSE requires a greater degree of care and responsibility by the designer than does the application of design codes.

The application of FSE should be entrusted to suitably qualified and experienced people at all stages. This includes the fire safety engineer and anyone carrying out quality assurance, peer review and approval, who should be able to demonstrate that they have relevant experience of successfully working on similar schemes, that they are appropriately qualified and have the appropriate professional status for the scope of the work being undertaken.

Adequate and relevant competence should be demonstrated.

a) Competence: As a minimum, competence requires adequate qualifications, knowledge, skill and experience.

b) Adequacy: The level of competence should be commensurate with the reliance being placed on that competence. For example, for a "simple" problem (e.g. a minor deviation from prescriptive guidance), reliance on competency might be lower than for a more complex problem (e.g. a detailed numerical analysis across many sub-systems). For the former, a non-specialist might be adequately competent, but for the latter a specialist fire safety engineer with specific qualifications and training might be required.

c) Relevance: The competence should be specific and relevant to the problem at hand (i.e. a high degree of competence in one field does not mean adequate competence across all fields).

All users of this British Standard (designers, approvers, peer reviewers, etc.) should determine whether they have adequate and relevant competence for the application in question.

NOTE For example, Chartered Engineer status through a relevant profession institution, such as the Institution of Fire Engineers, would provide a good indication of competency in that a process of education, training, and experience is required in order to achieve this. The engineer undertaking the work might not have to meet the description above as long as they are mentored/supervised and their work is quality assured by someone who does.

The fire safety engineer should be able to, when questioned, provide sufficient information to demonstrate their competence. This is especially important where specialist FSE, e.g. structural FSE, is being undertaken.

4.2 Framework

This British Standard provides a performance-based framework for an engineering approach to fire safety which may be applied to both the design of new buildings and the appraisal of existing buildings, to show that regulatory and/or financial requirements and/or environmental considerations can be satisfied. The use of this framework is not a guarantee that the resulting design would be adequate. Approvals bodies should be consulted before final decisions are taken about the fire safety design. It can also be used as part of a cost-benefit analysis to establish the value of property protection measures or to evaluate the environmental impact of fire.

The engineering approach may be used in conjunction with other standards (e.g. BS 9999). It may also be used to justify alternative approaches to those in other standards.

Whilst FSE procedures can be used to evaluate the entire set of fire, people and building interactions, in many practical applications their most common use is to evaluate specific departures from design codes (e.g. the evaluation of extended travel distances in a building which otherwise conforms to design codes).

The basic design process comprises the following main stages, as illustrated in Figure 5:

a) Qualitative Design Review (QDR) (see Figure 6 and Clause **5**);

b) performing the analysis (see Clause **6** and Clause **7**);

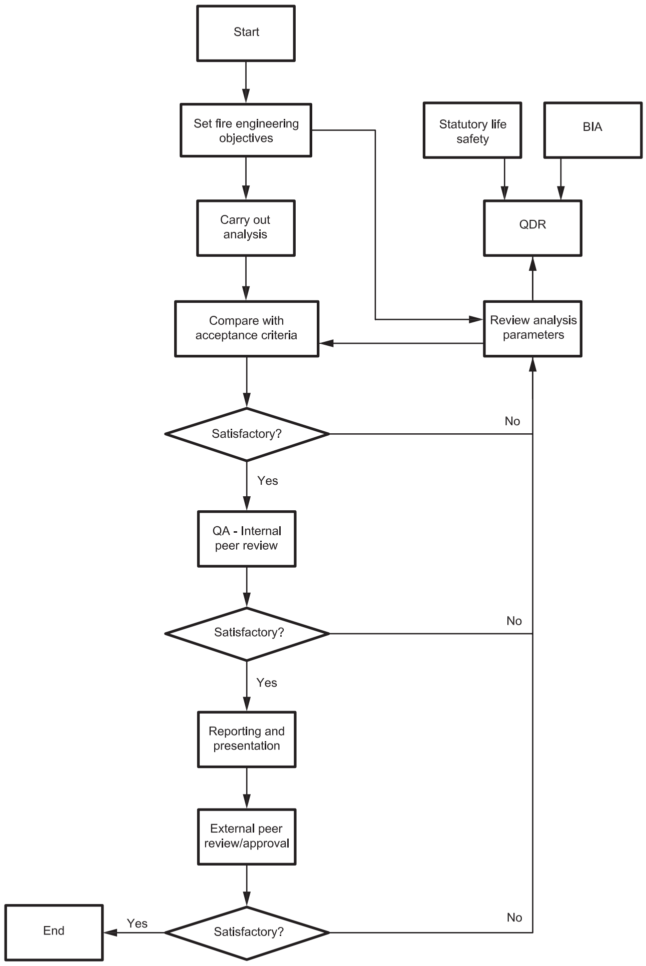
c) assessment against acceptance criteria (see Clause **8**);

d) internal peer review, quality assurance (see Clause **9**);

e) reporting and presentation of results (see Clause **10**); and

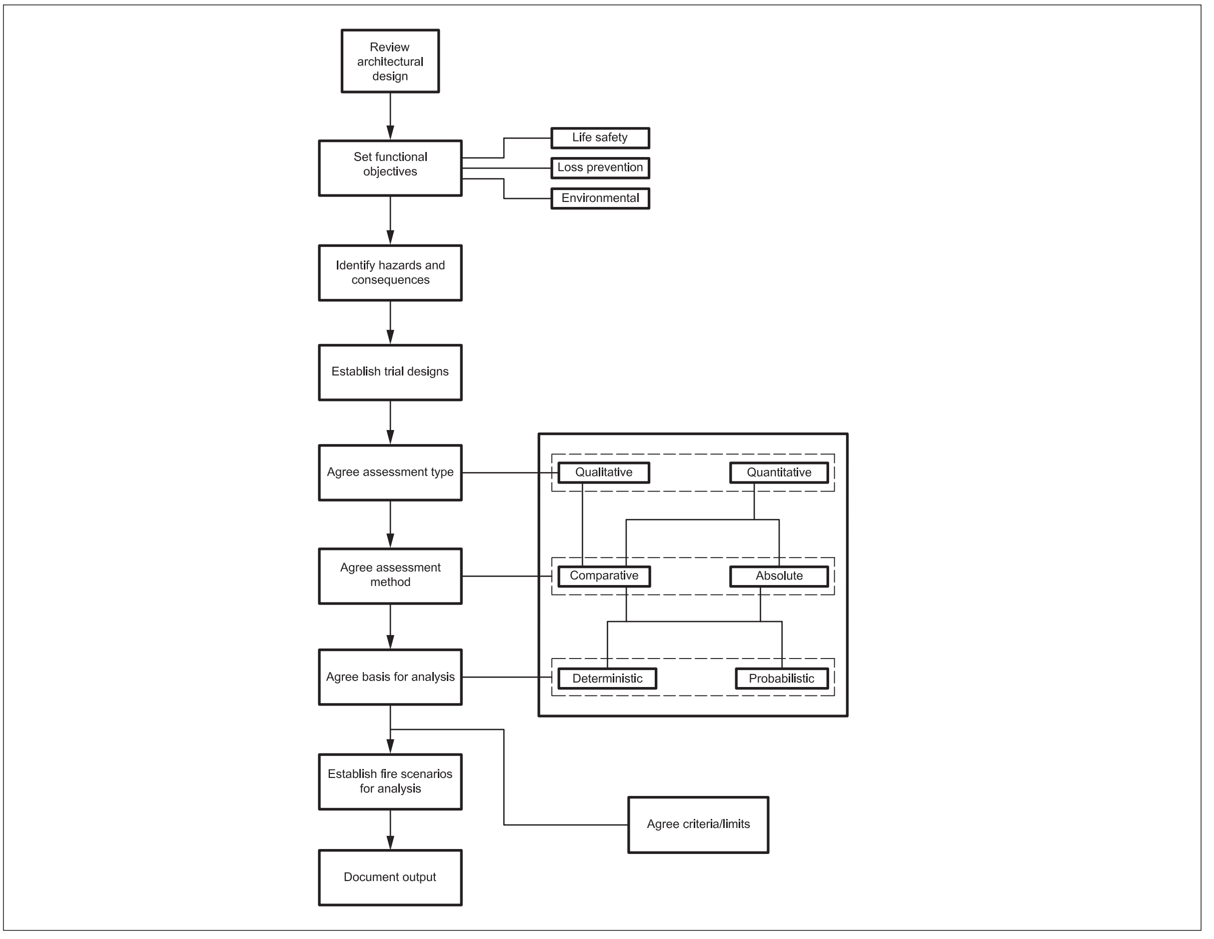
f) external peer review/approval.

Figure 5 — *Basic fire safety design process*



NOTE For further guidance on BIA (business impact analysis), see Annex B, B.2.

Figure 6 — *The QDR process*



4.3 Qualitative Design Review (QDR)

*COMMENTARY ON **4.3***

The first stage in any engineering design is to establish the basic parameters of the project. This includes a review of the scheme, identification of any overriding constraints and definition of the functional objectives. This initial stage draws on the expertise and experience of the engineer, the design team and other relevant stakeholders. Quantification normally only follows when the design parameters have been established. This preliminary stage is described as the QDR.

The main stages in the QDR are to:

a) review architectural design and selection of materials including their suitability and fire properties, occupant characteristics and client requirements;

b) establish functional objectives for fire;

c) identify fire hazards and possible consequences;

d) establish trial FSE designs;

e) set acceptance criteria;

f) identify method of analysis;

g) establish fire scenarios for analysis; and

h) document outputs of QDR.

4.3.1 Functional objectives

During the QDR process, the scope and the functional objectives of the fire safety design should be defined, acceptance criteria established and one or more potential design solutions (trial designs) proposed, and the design process milestones and the quality assurance process should be defined. Key information should also be gathered to enable detailed evaluation of the design solutions in any following quantitative analysis.

Functional objectives may be one or more of the following:

a) life safety (see **5.3.2**);

b) loss control and organizational resilience (see **5.3.3**); and

c) environmental impact/protection (see **5.3.4**).

4.3.2 Acceptance criteria

Once functional objectives have been set, it is then usually necessary to refine these to produce more detailed design objectives setting engineering criteria to be met. The design objectives should be tailored to meet the functional objectives and the circumstances of the particular project. The purpose of the FSE design is then to meet these design objectives, i.e. acceptance criteria should be set that reflect the design objectives.

4.3.3 Method of analysis

There are three basic methods of analysis that should be taken into account by the QDR team to demonstrate that a FSE solution meets the design objectives:

a) deterministic analysis;

b) probabilistic analysis; and

c) qualitative analysis.

Deterministic analysis is a quantitative approach that calculates fire conditions and other parameters in absolute terms.

Probabilistic analysis is a quantitative approach that assesses the probability of certain events or outcomes.

Qualitative analysis is a non-numerical examination of a FSE proposal using experience, knowledge and engineering judgement alone (see Clause **6**).

For any given functional requirements, the method of quantitative analysis can be either deterministic or probabilistic, and the acceptance criteria can be either absolute or comparative.

EXAMPLE

Method of analysis	Functional objectives > Design objectives > **Acceptance criteria**
Deterministic	
Calculate the smoke layer height in the means of escape.	**Absolute:** Smoke layer is to be >2.5 m above floor.
Calculate the smoke layer height in the means of escape in a similar building that conforms to ADB [8].	**Comparative:** Smoke layer is to be as high or higher than the smoke layer in the building that conforms to ADB [8].
Probabilistic	
Assess the probability of being injured by smoke inhalation in the event of a fire during escape.	**Absolute:** Probability of being injured by smoke inhalation in the event of a fire during escape is to be < 1:10 000.

Assess the probability of being injured by smoke inhalation in the event of a fire during escape in a similar building that conforms to ADB [8].	**Comparative:** Probability of being injured by smoke inhalation in the event of a fire during escape is to be the same as or less than in the building that conforms to ADB [8].
Qualitative	
With only minor deviations from a design code solution, logical argument alone can establish that a sprinkler system is sufficient compensation to deliver the acceptance criteria.	**Absolute:** Occupants reach a place of ultimate safety before available safe escape time (ASET) has elapsed. **Comparative:** Those escaping from a fire are at no greater risk than they would be if the building conformed to ADB [8].

4.4 Quantitative or qualitative analysis

4.4.1 Quantitative analysis

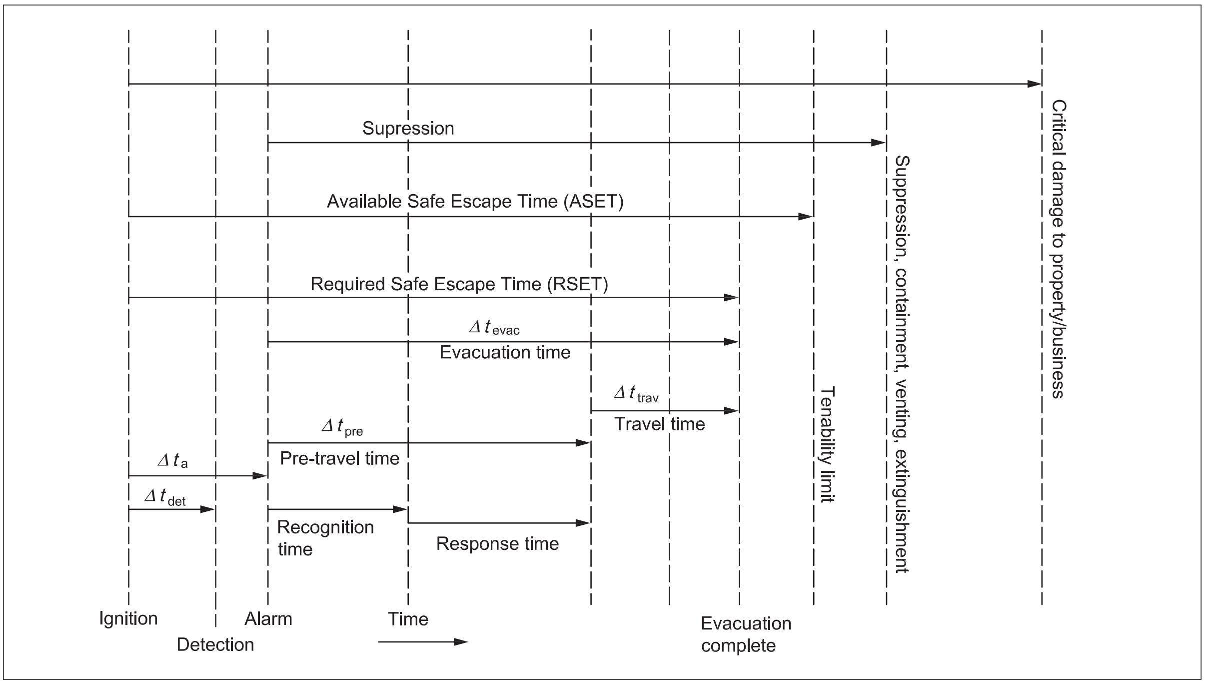
Following the QDR, quantitative analysis should be carried out, if necessary.

NOTE 1 PD 7974, parts 1 to 7, provide selected guidance on the underlying principles and the type of calculations that may form part of FSE analysis. However, the use of data and calculation procedures from other sources is not precluded and can often be essential to reach a solution.

A quantitative analysis may involve probabilistic or deterministic calculation procedures or a combination of both. It is frequently time-based, but steady state and limit state analysis can also be used.

NOTE 2 Figure 7 shows an example of a time line comparison between fire development and evacuation/damage to property that could be the subject of quantitative analysis.

Figure 7 — *Example of time line comparison between fire development and evacuation/damage to property*



4.4.2 Qualitative analysis

Generally, qualitative analysis should only be used for simple projects; the acceptability of an alternative solution might be so obvious that it can be demonstrated by non-quantitative argument alone during the QDR process.

Qualitative analysis may be used for complex problems provided the uncertainty is sufficiently low or mitigated through sufficient conservatism.

NOTE Even with some less simple projects, the fire safety engineer might be able to take information from the QDR and construct a non-quantitative argument to demonstrate that acceptance criteria have been met.

4.5 Assessment against acceptance criteria

Following the analysis, the results should be compared with the acceptance criteria identified during the QDR. All relevant uncertainties (see **9.4**) should be identified, documented and adequately mitigated.

If none of the trial designs satisfy the specified acceptance criteria, the QDR and assessment process should be repeated until a fire safety strategy is found that does.

The acceptance criteria should, in general, meet client requirements depending on the defined functional objectives.

4.6 Peer review

All FSE studies, especially those that are complex in nature and those that are particularly safety critical, should undergo an appropriate internal and/or external peer review process by a suitably competent person or organization before they are submitted to clients or to authorities having jurisdiction (see Clause **9**). The scale of the peer review should be a function of the complexity of the problem and the magnitude of the risk.

4.7 Reporting and presentation of results

In order to substantiate a FSE design, the process should be fully documented in a clear, concise and complete report so that it is readily accessible to a third party, e.g. approvals bodies, insurers, owner occupiers of buildings (see Clause **10**). Any assumptions made should be clearly stated within the report and should be substantiated as necessary.

NOTE This British Standard does not recommend a fixed format for the report but does make recommendations regarding the minimum information that is to be documented.

5 Qualitative Design Review (QDR)

5.1 Overview

5.1.1 General

The interaction of fire, buildings and people gives rise to an almost infinite number of possible scenarios; therefore, before attempting to carry out detailed quantified analysis, the significant fire hazards should be identified, the problem simplified and the required extent of quantification established. This process is described as the Qualitative Design Review (QDR).

The QDR is a qualitative process that draws upon the experience and knowledge of the fire safety engineer(s) and a team of others involved in the design, construction and operation of the building. The QDR should be used to identify the inputs to the quantitative analysis and acceptance criteria.

5.1.2 QDR team

For large and complex projects, the QDR should be carried out by a study team involving:

a) one or more fire safety engineers (chair);

b) members of the design team; and

c) operational management.

The QDR team might also include the following:

1) architect;
2) services engineer;
3) structural engineer;
4) other member of operational management: a manager with sufficient seniority to understand the organization’s priorities in a holistic way, plus a manager with responsibility for business continuity management, such as the risk manager who might have undertaken a business impact analysis of the organization (see Annex B);
5) relevant fire authority;
6) approvals body and/or authority having jurisdiction;
7) insurer;
8) those developing the security strategy;
9) building contractor; and
10) any other stakeholder who might impact the project.

Where possible, the fire safety engineer should be provided with as complete a brief as possible from all stakeholders including the end-user client. This might need facilitation by the architect or "design and build" contractor.

For smaller projects or where FSE is being applied to a limited and well-defined aspect of a project, the QDR may be carried out by a smaller team. However, the same basic review process should be followed to ensure that no significant factors are missed.

The membership of the QDR team should be reviewed as the QDR process proceeds.

5.1.3 QDR process

*COMMENTARY ON **5.1.3***

The QDR is a structured technique that allows the team 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 or qualitatively against the acceptance criteria set by the team.

The QDR should be conducted in a systematic way to ensure that no relevant item is omitted.

NOTE Whilst the QDR is essentially a qualitative process, it can 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.

Ideally, the QDR should be carried out early in the design process so that any substantial findings can be incorporated into the design of the building before the working drawings are developed. However, in practice, the QDR process is likely to involve some iteration as the design process moves from broad concept to greater detail.

The main stages in the QDR are to:

a) review architectural design and selection of materials, including their suitability and fire properties, occupant characteristics and client requirements (see **5.2**);
b) establish functional objectives for fire (see **5.3**);
c) identify fire hazards and possible consequences (see **5.4**);
d) establish trial FSE designs (see **5.5**);

e) set acceptance criteria (see **5.6**);

f) identify method of analysis (see **5.7**);

g) establish fire scenarios for analysis (see **5.8**); and

h) document outputs of QDR (see **5.9**).

This list suggests the general order in which each aspect of the QDR might be carried out but, in practice, the order of events are likely to change to suit the circumstances. However, whichever order is adopted, it should be ensured that each stage is adequately completed and that no important factors are missed.

Finally, all findings should be clearly recorded so that the philosophy and assumptions that underpin the FSE design are explicit.

5.2 Review architectural design and selection of materials, including their suitability and fire properties, occupant characteristics and client requirements

The architectural design should be reviewed at the early outline stage of scheme development to ensure that the fire safety measures and architectural design are developed in harmony.

The first stage in the QDR should be for the architect/designer to describe the project by reference to schematic drawings, models, etc., and to highlight any architectural or client requirements that might be significant in the development of the fire safety strategy. In an existing building, the fire safety design is often constrained by the location of existing stairs and walls and the type of construction materials used. However, in a new building, there is potentially much greater flexibility and the team should identify any aspects of the design that can be readily amended and which can enable fire safety measures to be simplified.

All the relevant information about the building, its occupants and uses and its anticipated contents, should be provided to and reviewed by the QDR team, including information on:

a) building characterization, i.e. the layout and geometry of the building, details of the construction, the nature and extent of the loads acting on the structure (e.g. dead loads and imposed loads), planning constraints, and historical merit;

b) fire hazards, the degree of fire loading present and its flammability, and unusual fire hazards (e.g. flammable liquids);

c) environmental influences, such as wind and snow, which influence fire safety design through their effect on structural load levels, smoke ventilation systems and the nature of external flame envelopes issuing from the windows of the building;

d) occupant characterization, i.e. the type of occupancy, the building population and its distribution, and the likelihood of the fire alarm being raised manually;

e) management of fire safety, i.e. the likely extent and nature of management in the building;

NOTE For further information regarding fire safety management, see BS 9999.

f) fire-fighting, including proposed active fire protection systems, fire service access, safety and safe egress, response times and availability, and, where relevant, in-house fire team resources; and

g) other client requirements, including the requirement for future flexibility in use and the need for organizational resilience.

Table 3 provides a list of the typical items that should be taken into account when reviewing the architectural design. The list is not exhaustive but provides a guide to the range of factors to be considered. In a limited FSE analysis, many of these items do not have a direct bearing on the outcome, but it is still useful to have a full understanding of the building and the way in which it is to work before embarking on an FSE analysis.

Table 3 — *Typical items to be taken into account during review of architectural design*

Area of review	Items
Building characterization	Number of storeys (above and below ground)
	General dimensions
	Nature of construction
	Geometry and interconnection of spaces
	Internal subdivision of building
	Normal circulation routes
	Escape routes
	Wall and ceiling linings
	Provision for dispersal of people from vicinity of building
	Possible fire and smoke spread routes
	Proposed fire detection and fire alarm system
	Location relative to other buildings or site boundary
	Planning constraints (e.g. listed building of historical interest)
	Any other factor that might influence the fire safety design
Fire hazards	Unusual fire hazards (e.g. flammable liquids stored in offices)
	Potential ignition sources
	Combustible contents and structure
	Fire load density
	Any other factor that might influence the fire safety design
Environmental influences	Ambient noise levels
	Any other factor that might influence the fire safety design
Occupants characterization	Number and distribution
	Single or multiple tenancy of use
	Mobility, vulnerability and need for assistance
	State of wakefulness
	Familiarity with the building
	Social groupings
	Roles and responsibilities of key individuals
	Commitment to an activity (e.g. eating in a restaurant)
	Presence of a focal point (e.g. stage)
	Any other factor that might influence the FSE design (see PD 7974-6 for guidance on the influence of these factors on human response)

Table 3 *(continued)*

Area of review	Items
Management of fire safety	Quality and extent of continuing management control Number of people on site responsible for the fire safety management Staff to occupant ratio Level of fire safety training Security arrangements which might conflict with evacuation strategy Level of control over work on site (e.g. hot works) Level of planning and adaptability for changes to risk on site Level of knowledge and understanding to implement the fire safety strategy developed Contacts for provision of additional information Any other factor that might influence the fire safety design
Fire-fighting	Fire and rescue service response time Access for fire appliances Fire-fighting access to, safety within and safe egress from the building Water supplies Any other factor that might influence the fire safety design
Other client requirements	Future changes of layout or changes that might be anticipated Any commercialization of the space (e.g. mall areas) Fire protection systems specified by client (e.g. sprinklers for loss control) Any other factor that might influence the fire safety design Impact of fire on business continuity as set out in a business impact analysis (BIA) if available

5.3 Establish functional objectives for fire

5.3.1 General

*COMMENTARY ON **5.3.1***

Whilst the protection of life is the main functional objective of FSE, the financial impact of fire on a business as a result of direct property damage or lost production might also be an important consideration. Environmental factors might also be important. Some businesses (e.g. an international hotel chain) might also be susceptible to intangible losses if their reputation is damaged as a result of a major and well-publicized fire.

In some cases, it can be relatively straightforward to comply with the statutory provisions for life safety (e.g. a warehouse) by reference to design codes, but FSE analysis can be particularly useful in assessing the costs and benefits of fire protection for loss control purposes.

A fire in a building used for the processing or storage of quantities of toxic or radioactive materials can have an adverse impact on the local environment. FSE techniques can assist in an environmental impact assessment.

At an early stage of the design process, the functional objectives of the fire safety design should be clearly defined.

The functional objectives should be established during the QDR. The FSE analysis may be used to develop a total fire safety strategy or could simply be used to consider one aspect of the design (e.g. extending travel distances in a design which otherwise conforms to design codes). It is, therefore, essential that the functional objectives for an FSE analysis are established and agreed with interested parties at an early stage during the QDR.

The functional objectives that might typically be addressed in an FSE analysis are:

a) life safety;

b) loss control and organizational resilience; and

c) environmental impact/protection.

This list is not exhaustive and not all items need to be addressed.

NOTE In most situations, economic and financial factors are also important, and in many cases the chosen fire safety strategy is the one that satisfies the functional objectives for the least cost. In a minority of cases financial factors are the primary driver behind FSE analysis (see 7.7).

5.3.2 Life safety

*COMMENTARY ON **5.3.2***

The occupants of a building, fire-fighters and members of the public who are in the vicinity of a building can be put at risk by fire. The main life safety functional objective can be refined into design objectives such as:

a) the occupants are ultimately able to leave the building in reasonable safety or the risk to occupants is acceptably low;

b) fire-fighters can operate without undue risk to:

- *assist evacuation when necessary;*
- *effect rescue when necessary;*
- *prevent conflagration;*

c) collapse does not endanger people (including fire-fighters) who are likely to be in or near the building.

Most FSE studies involve analysis to demonstrate that life safety objectives are being achieved. Even when property or environmental protection is the key factor in initiating an FSE study, life safety objectives should still be taken into account and should be of paramount importance.

5.3.3 Loss control and organizational resilience

The effects of a fire on the continuing viability of a business can be substantial and, depending on the client's wishes, methods to minimize the damage to the following should be assessed:

- the structure and fabric of the building;
- the building contents;
- the ongoing business viability; and
- the corporate image.

NOTE Statutory requirements and associated design codes are generally intended to protect life and to prevent conflagration, so FSE is particularly suited to analysing these further aspects, which could be largely ignored in a design which conforms to design codes.

Where the end-user client is able to submit a business impact analysis (BIA), this information should be added to the fire safety objectives suite to inform the QDR process. Where the client is unaware of the role that FSE can play in meeting their business resilience requirements, an additional stage should be incorporated into the QDR process to determine and document the impact of a disruption from a fire event in order to provide input into business resilience design objectives.

5.3.4 Environmental impact

A conflagration involving several buildings or the release of quantities of hazardous materials can have a significant impact on the environment. Methods should be determined to limit:

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

b) the release of hazardous materials into the environment; and

c) the unintended effects of methods of fire-fighting (e.g. avoidance of river pollution).

5.4 Identify fire hazards and possible consequences

5.4.1 Hazards

A systematic review should be conducted to establish the potential fire-related hazards within the building and their potential consequences. The review should take into account factors such as:

a) ignition sources;

b) combustible contents;

c) construction materials;

d) nature of the activities in the building;

e) general building layout; and

f) any unusual factors.

The list of factors in a) to f) is not exhaustive and all significant fire hazards for the individual building 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 possible consequences and the achievement of the functional objectives under consideration.

NOTE 1 Table 4 summarizes some of the main items that might be considered in carrying out the hazard assessment.

Table 4 — *Typical items to be considered during hazard identification*

Ignition sources	Combustible materials
Smokers' materials	Flammable liquid products (paints, adhesive, thinners, etc.)
Naked flames	Flammable liquids (petrol, diesel, paraffin)
Electric, gas or oil heaters	Flammable chemicals
Hot work processes	Wood
Cooking	Paper products
Engines or boilers	Plastic and rubber (particularly as foam)
Machinery or office equipment	Flammable gases
Lighting equipment	Furniture
Friction from moving parts	Textiles
Reactive dusts	Packaging materials
Static electricity	Combustible waste materials
Metal impact	MDF, hardboard, timber plastic, etc. linings
Deliberate ignition	GRP and other plastics cladding materials
	Combustible insulation and linings
	Combustible structure

The list in Table 4 is not exhaustive and the QDR team should attempt to identify all the significant hazards. In evaluating the significance of a fire hazard, the QDR team should take particular account of the influence of each hazardous item on the achievement of specified design objectives. Even an unlikely event can result in the greatest loss and so should not be discounted without careful consideration.

The determination of hazards should not only be restricted to the ignition and spread of fire but should include hazards that can impede evacuation (e.g. tripping hazards in plant room escape routes or a disorientating layout).

NOTE 2 When carrying out a deterministic analysis, it might be sufficient to record that the hazards are generally typical of the generic building type (e.g. office) and note in detail only those hazards that are unrepresentative of the main use (e.g. the storage of flammable fluids in part of an office building).

5.4.2 Consequences

The potential consequences arising from the realization of the hazards should be reviewed qualitatively by the QDR team to identify events that are likely to give rise to a significant risk.

The consequences of a particular fire hazard (e.g. cooking) varies significantly depending upon the contents and construction of a building, and the QDR team should identify the chain of events that is likely to give rise to significant consequences, for example:

a) unattended cooking activity leads to ignition;

b) ignites material adjacent to cooker;

c) fire spreads rapidly across combustible wall lining;

d) fire penetrates ceiling to floor above;

e) fire spreads to other rooms via open doors; and

f) building and contents written off.

NOTE This review of the hazards and consequences might immediately suggest possible solutions (trial designs) which in this case could be replacing a cooker with a microwave oven, or installing a cooker fire protection system.

5.5 Establish trial FSE designs

5.5.1 General

*COMMENTARY ON **5.5.1***

In many cases, it is necessary to amend the architectural design or provide various fire safety measures to achieve the functional objectives. A trial design is simply a group of fire safety measures that, in the context of the building parameters, might meet the specified functional objectives.

To meet the more specific design objectives, it is more than likely that several trial designs can be identified that could provide an acceptable solution; the members of the study team should use their knowledge and expertise to make sensible judgements on the suitability of various alternatives.

NOTE In many cases, a good first step is to base a trial design on the recommendations of an established design code. Knowledge and experience of previous fire safety designs in similar buildings are also often helpful in arriving at possible trial designs. Such "proven" designs could be compared with more innovative designs incorporating new FSE technology, for example.

In developing trial designs, the QDR team should not just look at adding additional fire protection systems, but should also review the potential for reducing or eliminating some of the hazards by amending the construction or layout of the building. When practical, reducing any hazards inherent in the design of a building is often preferable to adding additional fire protection measures.

Whilst under (or over) specifications can be identified in the quantification process following the QDR, this can be time consuming and the QDR team should identify cost-effective trial designs that are likely to satisfy the acceptance criteria. There are other factors apart from fire safety that determine whether a particular design is acceptable, and trial designs that are impractical or that conflict with design or operational requirements should be ruled out unless there is no other practical alternative. The alternative trial designs should be compared with each other in terms of cost and practicality. To limit the number of evaluations required to find an acceptable solution, the first trial design evaluated might be the one that is likely to meet the functional objectives and optimally meet other building criteria in terms of operability, ease of construction and cost.

5.5.2 Fire safety systems

Table 5 provides a list of items that should be taken into account when developing the trial designs. This list is not exhaustive but provides a guide both to the types of systems that can be considered and to the basic information required to enable quantified analysis to be carried out.

FSE techniques may be used to justify deviations from design codes for fire safety systems (e.g. the BS 5839 series for fire detection systems or BS EN 12845 for automatic sprinkler systems). However:

a) in many cases, it is sufficient to specify fire protection systems in terms of such design codes; and

b) as with any system, the recommendations of design codes for fire safety systems are often interrelated with other parts of the codes and with other matters beyond them, so deviation from such codes should only be undertaken with caution.

Table 5 — *Checklist for development of trial design*

Fire protection system	Possible QDR considerations/Examples of information to be provided by QDR
Control on materials	Use of non-combustible materials in: – construction – linings Use of flame retardant materials in: – furniture – furnishings
Automatic suppression	Localized or extensive Extinguishing medium Design standard
Detection	Detector types Locations Zoning Response characteristics
Structural protection and compartmentation	Fire resistance Compartment size Location boundaries Passive fire protection systems
Automatic systems	Dampers Shutters and curtains Automatic door hold open devices Fans Vents
Smoke control	Extraction Pressurization De-pressurization Containment Reservoir volume
Alarm and warning systems	Sounder or public address Zoning Investigation delay periods
Evacuation strategy	Phased Simultaneous Progressive horizontal Management procedures

Table 5 *(continued)*

Fire protection system	Possible QDR considerations/Examples of information to be provided by QDR
Escape routes	Escape routes and number Exit widths Travel distances Stairways Occupant capacity Lifts – protected Refuges for disabled Escape lighting
First aid fire-fighting	Extinguishers/hose reels Availability of trained staff
Fire service facilities	Access routes Rising mains Fire-fighting shafts Smoke extraction
Fire safety management	Management plan Staff availability Staff training Third party audit of procedures Maintenance schedules

5.5.3 "What if" study

As part of the hazard assessment process, an assessment of "what if" events should be made to identify system failures or foreseeable events that might have a significant influence on the outcome of the study.

NOTE An example would be "what if" a fire resisting roller shutter between compartments fails to operate? The answer could be that it has no impact on life safety but it would lead to increased property damage. Some examples of typical "what if" events are:

a) fire door propped open;

b) combustible displays introduced into sterile areas;

c) compartment walls penetrated and not made good;

d) materials of poorer than specified reaction-to-fire properties are present;

e) power supply to smoke vents fails;

f) sprinklers ineffective due to poor maintenance;

g) sensitive detection systems adversely affected by movement of ventilation air;

h) the fire is located where it blocks an exit; and

i) management fails to implement fire safety procedures.

In a probabilistic analysis, the likelihood and consequences of failures are generally quantified. However, in a deterministic analysis, the team should make a judgement as to whether the "what if" event is likely to significantly affect the overall fire risk. In this respect, it should be determined whether:

a) the event is credible;

b) the consequences of the event are tolerable or no worse than in a design which conforms to design codes; and

c) additional fire protection measures are needed to provide a degree of redundancy.

5.5.4 Common mode failures

*COMMENTARY ON **5.5.4***

In some instances, the failure of one system has an adverse effect on the efficiency of another fire protection measure. For instance, an open fire door is not only an ineffective barrier to fire spread but also undermines the performance of a gaseous extinguishing system due to escape of the extinguishing agent.

Similarly, unless provided with suitable backup protection, failure of the power supply could lead to the failure of a number of fire safety systems.

Particular care should be taken by the QDR team to ensure that potential common mode failures are identified and accounted for in the analysis.

NOTE Guidance on the assessment of common mode failures is given in PD 7974-7.

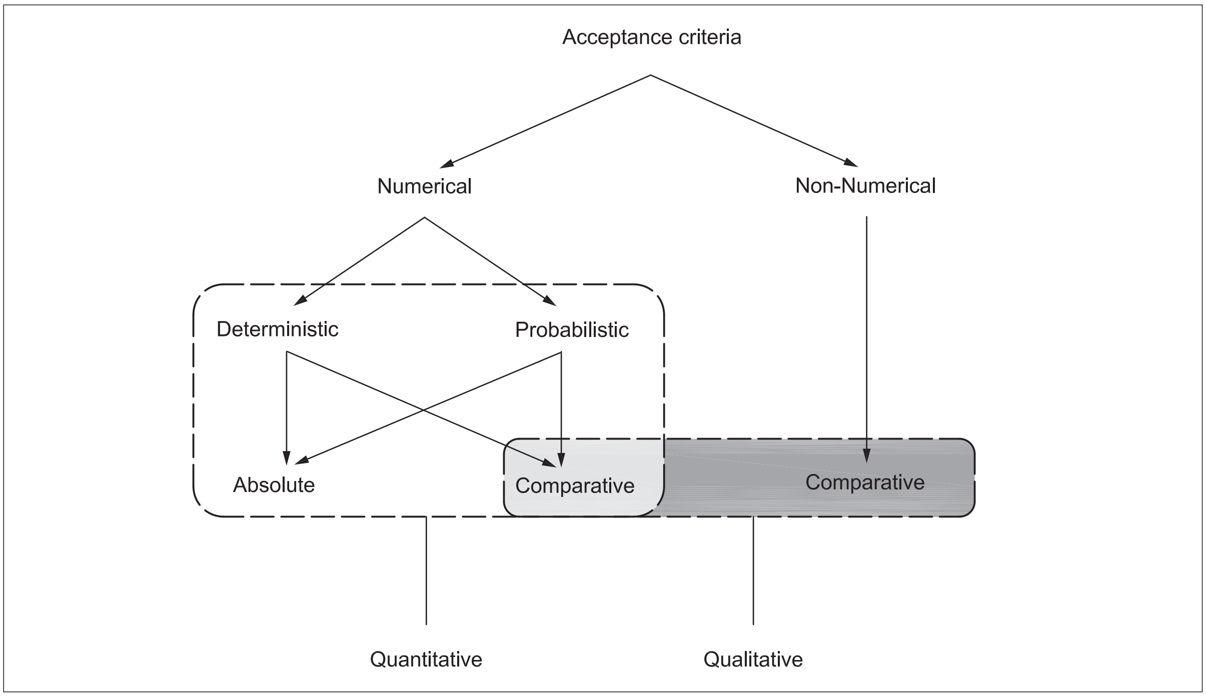
5.6 Set acceptance criteria

5.6.1 General

Acceptance that the functional objectives (see **4.3.1**) have been met requires a set of criteria against which as assessment can be measured. The acceptance criteria should be set as appropriate to the specific scenario under consideration and it should be recognized that elimination of all risk from the effects of a fire is an unrealistic expectation.

Dependent upon the type of assessment undertaken acceptance criteria may be an absolute or comparative numerical value. They may also be a qualitative descriptor as part of a narrative assessment (see Figure 8).

Figure 8 — *Relationship for setting quantitative and qualitative acceptance criteria*



5.6.2 Absolute acceptance criteria

Absolute acceptance criteria are numerical values set to show that a particular condition has been met, a specific limit has not exceeded or a threshold value has been reached. The value should reflect a particular aspect of the analysis undertaken with the purpose of demonstrating that the specific functional objective has been met.

EXAMPLE

For a quantitative analysis, where the functional objective for life safety is that all occupants are able to escape, it is necessary to show that tenable conditions will be maintained throughout the escape period. Acceptance criteria might then be set to ensure a smoke layer remains at a minimum height above floor level and that the temperature of the smoke layer does not exceed an agreed value. Alternatively, the criteria might be that occupants are not exposed to an agreed heat flux from the smoke layer.

5.6.3 Comparative acceptance criteria

Specific criteria that indicate the functional objectives are likely to be met might already be established in a published guidance document such as ADB [8] or BS 9999. A comparison between the proposals under investigation and a similar code-compliant case may therefore be used to establish acceptability.

The comparison may be numerical, in which case an analysis of both cases should be undertaken with acceptance being agrees where the result for the proposal is not less favourable than the code solution. As part of the QDR the team should examine and agree all aspects of the feature under test, as there might be other unrelated implications that need to be addressed.

EXAMPLE

For a single-stair residential block standard guidance recommends limits on the travel distance along a naturally vented corridor. Where a design is proposed with an extended escape distance, compensated for by using a mechanical smoke extract system, the acceptance criteria could be set by stipulating that a numerical analysis of the conditions for smoke temperature and visibility in the design proposal do not exceed the values of a similar analysis on the code-compliant design.

5.6.4 Non-numerical criteria

Where the condition in question has no numerical basis or where insufficient data are available to make a reliable calculation a non-numerical qualitative comparison may be used. Acceptance criteria for this is explanatory and is therefore likely to rely on agreement of purpose and the criticality of omission for a particular feature or system.

5.7 Identify method of analysis

5.7.1 General

*COMMENTARY ON **5.7.1***

*Analysis can be either deterministic, probabilistic or qualitative. Qualitative analysis is dealt with in Clause **6**. In deterministic analysis, numerical values are calculated for fire conditions and other relevant matters. In probabilistic analysis, the likelihood of critical events is calculated.*

At QDR stage, the method of analysis should be agreed. All parties should be made aware of the advantages and disadvantages of each method so that an informed decision can be made. They should also be made aware that many assumptions made in the analysis might not always be valid in every circumstance.

5.7.2 Deterministic analysis

A deterministic analysis should:

- be framed to err on the side of caution to account for uncertainties; and
- be based on a reasonable worst-case scenario.

NOTE This means that the results of the deterministic analysis have probabilistic elements. For example, the fire safety engineer might present the results of deterministic analysis showing a ceiling temperature to the nearest degree, but the QDR team needs to know that this result does not come with a guarantee, just because it was derived by deterministic analysis.

The main advantages and disadvantages of deterministic analysis are summarized in Table 6.

Table 6 — *Advantages and disadvantages of deterministic analysis*

Advantages	Disadvantages
Considerable data available	Very dependent on initial assumptions
Wide range of well-validated calculation procedures available	Provides no measure of costs and benefits
	Limited benefit for loss control purposes
Provides a simple yes/no result	

5.7.3 Probabilistic analysis

Given the limitations of deterministic analysis, a probabilistic analysis might be more attractive to the QDR team. However, they should be made aware that in many areas there are only limited statistical data (e.g. in terms of currency and sources) on which to base calculations.

NOTE Available data might suggest than an event has a 5% probability of occurring, but the data might be only 50% complete and 50% accurate. Calculating an accurate probability of occurrence is therefore not possible.

The main advantages and disadvantages of probabilistic analysis are summarized in Table 7.

Table 7 — *Advantages and disadvantages of probabilistic analysis*

Advantages	Disadvantages
Provide comparison between dissimilar fire protection systems	Availability of directly applicable data can be difficult to source
Provides a numerical value of risk	Data are often out of date
Can quantify the probability of unlikely events with severe consequences	Time-consuming analysis
Can quantify the risk associated with failure of one or more fire-protection systems	
Provides data for cost-benefit analysis	

5.8 Establish fire scenarios for analysis

The number of possible fire scenarios in even a relatively simple building can become very large and it is not feasible (or necessary) to assess the effects of them all. Therefore, when carrying out an FSE analysis, the QDR team should discuss and agree one or more reasonable worst case scenarios for detailed evaluation.

NOTE 1 In a complex building, it might be necessary to establish a number of fire scenarios for detailed assessment. In some cases (e.g. a single compartment building), it is often feasible to identify one fire scenario that clearly represents the reasonable worst case but even then, the fire that produces the worst conditions in terms of smoke obscuration might not also produce the worst conditions in terms of radiated heat.

Depending upon the functional and design objectives of the FSE analysis the definition of a fire scenario should take into account some or all of the following factors:

a) design fire;

b) fire location; and

c) occupant characteristics.

The detailed analysis and quantification of fire scenarios for a specific building should be limited to the most significant fire scenarios.

The characterization of a fire scenario for analysis purposes should include a description of the following, where appropriate:

1) type of fire;

2) natural ventilation conditions;

3) performance of each of the safety measures;

4) type, size and location of the ignition source;

5) distribution and type of fuel;

6) fire load density;

7) fire suppression;

8) state of doors (i.e. are the doors open or closed);

9) breakage of windows; and

10) mechanical building ventilation system.

The possible consequences of each fire scenario should also be determined.

NOTE 2 Where comparative acceptance criteria are to be used, alternative fire safety design options are compared against a reference case, e.g. a design code solution, and the quantification can often be simplified. In such instances *it might only be necessary to consider a single fire scenario if this provides 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 to analyse and those that do not require analysis.

The QDR team should take into account the possibility of failures of protection systems and management procedures when establishing the sequences of events to be considered. In an FSE analysis it is usual to identify a number of reasonable worst-case scenarios for further evaluation. However, events with a very low probability of occurrence should not be analysed unless their outcome is potentially catastrophic and a reasonably practicable remedy is available.

The analysis and identification of significant fire scenarios should identify the important fire development scenarios and describe them in a manner suitable for the quantification process.

5.9 Document outputs of QDR

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

a) results of the architectural review;

b) a clear statement of the functional objectives;

c) the significant hazards and their possible consequences;

d) one or more trial designs;

e) acceptance criteria and suggested methods of analysis; and

f) specifications of the fire scenarios for analysis.

Following the QDR, the team should decide which trial design(s) is likely to be optimum. The team should then decide whether quantitative analysis is necessary to demonstrate that the design meets the functional objective(s).

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6 Qualitative analysis

*COMMENTARY ON CLAUSE **6***

Although relatively limited in scope, for some fire safety design problems it might be appropriate to investigate and develop a solution using qualitative analysis only. For example, it could be possible to qualitatively assess and compare a case-specific fire safety design solution against a design scenario that conforms to design codes, with it being demonstrated that an equivalent level of safety is achieved by ways of a logical FSE judgement. Where qualitative analysis is applied, it is important to ensure that it is clearly identified what benchmark design guidance or design code scenarios are being used as the comparison.

The merits and appropriateness of using qualitative analysis to support a FSE design scheme should be discussed and agreed by the relevant stakeholders as part of the QDR process.

NOTE In some cases the qualitative analysis might be relatively straightforward, whereas in other cases the fire safety engineer might need to develop, present, and justify the approach being adopted through several iterations of QDR meetings. It could be that a specific design problem and potential solution is initially investigated in detail qualitatively, with it then determined by this qualitative analysis that additional quantitative analysis is required.

As per the recommended process for quantitative analysis (see Clause 7), any qualitative analysis should still go through the processes of quality assurance and suitable reporting and presentation of results.

7 Quantitative analysis

*COMMENTARY ON CLAUSE **7***

A quantified analysis can be carried out, if necessary, to verify the adequacy of the trial design(s) established during the QDR. It has been found convenient to split the analysis procedures into a number of segments, each covering a specific aspect of fire safety design. Basic design data, example calculation procedures and the general principles associated with each sub-system are given in the associated PD 7974 series.

This clause provides outline guidance on how the sub-systems can be used as part of a deterministic or probabilistic analysis. PD 7974-7 provides guidance on the application of probabilistic risk assessment techniques.

7.1 Use of sub-systems

Each of the sub-systems can be used in isolation but, for most practical design purposes, two or more sub-systems should be used to carry out an FSE analysis.

NOTE The design data and calculation procedures in the PD 7974 series for sub-systems 1 to 6 are intended, when used together, to provide a satisfactory engineering solution without the need for additional explicit factors of safety. However, in some circumstances, it might be appropriate to provide an additional factor of safety where the consequences of failure are potentially catastrophic (e.g. the structural collapse of a high-rise city centre building, the total failure of a critical IT centre or radiological release in a nuclear industry building).

During the QDR, the main input data for quantified analysis should be established (e.g. building parameters, trial designs, fire scenarios). The basic analysis approach (i.e. deterministic or probabilistic) should also be identified.

Different types of FSE analysis require different calculation approaches and before embarking on a series of calculations the following should be established:

a) the required numerical outputs;

b) the relationship between sub-systems; and

c) appropriate calculation procedures.

7.2 Deterministic and probabilistic analysis

7.2.1 Deterministic analysis

*COMMENTARY ON **7.2.1***

Deterministic analysis quantifies fire growth, fire spread, smoke movement and the consequences of these for the building and its occupants. These consequences are based on physical, chemical and thermodynamic relationships derived from scientific theories and empirical methods. A deterministic analysis involves the evaluation of a set of circumstances (usually reasonable worst case scenario) that provides a single outcome, i.e. a decision whether the design is either successful or not.

Several numerical methods are available for evaluating the development and effects of fire and the movement of people, some of which are described in PD 7974, parts 1 to 6.

The sub-system calculations can be used to provide a time-based analysis where the inputs and outputs of each sub-system vary as a function of time. This approach should incorporate either:

a) a computer-based analysis with repeated loops through each set of sub-systems at defined time intervals; or

b) a limit state method to determine the conditions under which a given event can occur (e.g. flashover).

NOTE 1 Hand calculations or intermediate computer models might provide adequate accuracy. This type of model can provide results quickly and simply and can be extremely useful.

Intermediate models generally assume a uniform (average) distribution of conditions (e.g. temperature) throughout a zone. This simplified approach might be acceptable but care should be taken to ensure that localized variations do not have a significant effect on the design (e.g. despite an average low temperature, localized high temperatures can cause an extract fan to burn out).

Models and correlations should be chosen to ensure that they are suitable for the particular scenario under consideration. For instance, hand calculations or simple or intermediate computer models might be suitable for assessing the movement of smoke where the flow path is straightforward [see Figure 9a)] but, where the smoke cascades past several overhanging balconies [see Figure 9b)], the only viable way of reaching a solution might be to utilize a computational fluid dynamics (CFD) model.

A detailed description of the various modelling techniques and their suitability for particular applications is given in PD 7974, parts 1 to 6, but, in adopting any modelling technique, the user should ensure that:

1) it has adequate predictive capability;

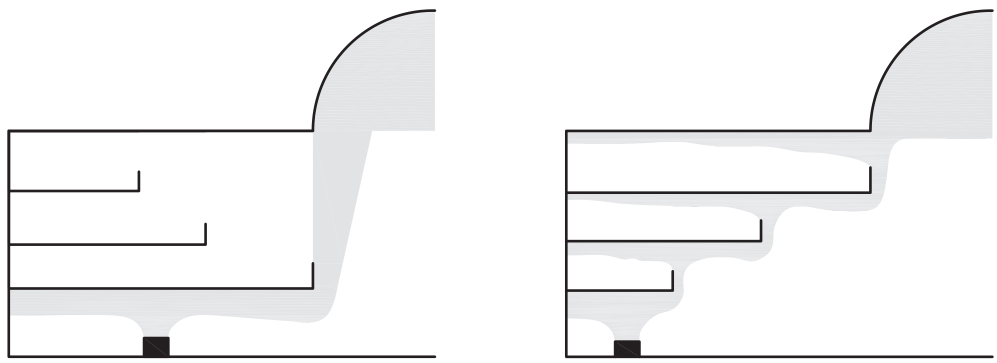
2) it is appropriate to the scenario under consideration; and

3) computer models have been adequately assessed and verified.

NOTE 2 Guidance on the assessment and verification of computer-based fire models is given in BS ISO 16730-1.

NOTE 3 There might be occasions when the computer simulation using CFD modelling suggests unexpected behaviour. If a physical simulation were to produce something unexpected, the engineer would use their knowledge and experience to explain the event. However, with a numerical simulation, it can have two explanations: (a) it is genuine and would have been observed in a physical simulation, or (b) it is some sort of modelling error caused by either incorrect input or software. The possibility of a modelling error cannot be completely discounted with such complex numerical simulations as those involved in CFD. It is therefore good practice to "shadow" the numerical solution, where possible, with known simple calculation methods or, in cases where the results are heavily relied upon to validate the design, with physical modelling.

Figure 9 — *Straightforward and complex smoke spill plumes*



a) Simple flow geometry capable of being modelled using zone modelling

b) Flow geometry with multiple spills likely to require evaluation using complex modelling techniques (e.g. CFD)

7.2.2 Probabilistic analysis

*COMMENTARY ON **7.2.2***

The purpose of this clause is to illustrate how some of the techniques of probabilistic analysis can be applied to FSE problems. Although a detailed description of the procedures and techniques involved in *probabilistic analysis is beyond the scope of this British Standard, a variety of accepted text books are available on this topic (see PD 7974-7 for further information).*

Probabilistic analysis can be an important decision-making tool provided that its limitations are recognized. Even if only limited data are available, meaningful calculations might be possible using numerical estimates based on experience and judgement. Because the judgements required to generate these estimates relate to specific items, they are likely to lead to a more accurate assessment than a judgement relating to the overall problem.

By assigning probabilities of failure to fire-protection measures and frequencies of occurrence to unwanted events, it is possible to assess the likelihood of a particular set of consequences. Probabilistic analysis can be used as a basis to:

a) estimate the frequency of high-consequence events (e.g. multiple fatalities, probable proportion of occupants injured while escaping);

b) establish the most cost-effective design;

c) compare the effectiveness of dissimilar fire-protection systems (e.g. sprinklers versus compartmentation);

d) evaluate the likelihood of failure of one or more fire-protection systems; and

e) estimate the risk of injury or death (e.g. probable proportion of occupants injured while escaping).

In practice, there are many factors that can influence the development of a building fire and the escape of occupants. These factors vary according to the circumstances at the time of the fire (e.g. whether first-aid fire-fighting has been unsuccessful or fire doors are propped open).

Probabilistic analysis should be used to estimate the likelihood of a particular unwanted event occurring. This can be achieved by the use of statistical data regarding the frequency of a fire starting and the reliability of fire protection systems combined with a deterministic analysis of the consequences of the range of possible fire scenarios. This type of approach should, to some degree, take account of the uncertainties that characterize real fires and the complex interactions between the factors involved. Probabilistic analysis can be used to evaluate the effect of variable factors such as fire growth rate, pre-travel time, the number of occupants.

Using probabilistic analysis, it is possible to estimate the probability of death or injury or the potential for extensive property damage that can result from fire. This information should then be used to estimate potential financial losses and enable a cost-benefit analysis to be carried out to establish the value of installing additional fire protection measures.

The probabilistic analysis process should involve determining:

a) what fire scenarios can occur;

b) the likely frequency of each scenario;

c) the potential consequences of each scenario;

d) the total risk associated with fire; and

e) the measures needed to reduce the risk to acceptable levels.

Potentially, probabilistic analysis provides a powerful means of assessing the fire risk and the benefits of various fire protection measures. However, for a comprehensive assessment of fire hazards, considerable statistical data are often required to obtain a meaningful result. Because of the lack of a comprehensive statistical database and the engineering design effort required, probabilistic techniques should only be used in very specialist applications. However, a simplified probabilistic approach can be useful in assessing the relative costs and benefits of various fire protection measures provided for property protection purposes or for assessment using comparative acceptance criteria. This is discussed in more detail in PD 7974-7.

7.3 Fire analysis

7.3.1 Fire scenarios

The interaction of fire, buildings and people can give rise to a very complex system. In order to evaluate fire safety in large complex buildings by deterministic analysis, some conservative simplifications should be made.

NOTE 1 In theory, several factors can contribute to the fire scenarios, but in practice the contribution of many factors is insignificant. By carefully selecting when and where to apply calculations, and then adopting the calculation technique appropriate to the particular problem being considered, a more flexible, pragmatic and equally safe solution can be reached.

When considering fire scenarios in isolation, the reasonable worst case conditions for assigning values to the variables should be chosen. However, it should be taken into account that, when considering several fire scenarios, using a series of unlikely events can lead to an over-conservative design. On the other hand, using average values for the variables does not lead to a design that is likely to provide an acceptable level of safety.

NOTE 2 The key to a successful analysis relies upon rationalizing the problem qualitatively, in the context of the particular fire safety requirements, during the QDR. Attention can then be focused on the quantitative interpretation of the design and in particular the uncertainties that the quantification might involve.

7.3.2 Design fire

7.3.2.1 General

To evaluate the effects of a developing fire, one or more design fires on which to base the analysis should be defined. A design fire can be characterized in terms of:

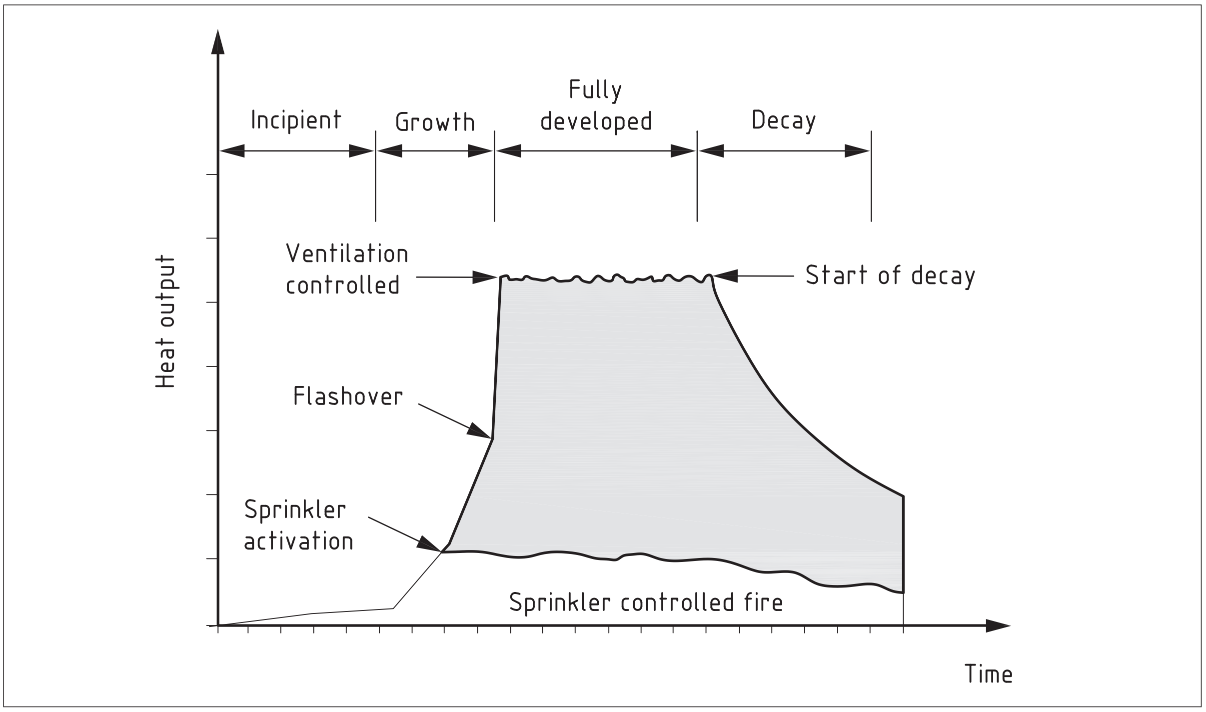
- heat release rate;
- toxic species production rate;
- smoke production rate;
- fire size (including flame length); and
- time to key events, such as flashover.

As shown in Figure 10, fires can be characterized by the following phases:

- incipient phase: slow initial growth phase characterized by smouldering, or limited flaming;
- growth phase: the fire propagation period as the fire grows prior to flashover or full fuel involvement;
- fully developed phase: characterized by a substantially steady (maximum) burning rate in either ventilation or fuel bed controlled fires;
- decay phase: covering the period of declining fire size; and
- extinction: where there is no more energy being released.

PD 7974-1 gives guidance on how to establish the characteristics of a fire but the QDR team should seek to establish the basic parameters.

Figure 10 — *Typical stages in the development and decay of a fire*



7.3.2.2 Growing fire

*COMMENTARY ON **7.3.2.2***

Where it is possible to establish the item likely to be first ignited, the initial rate of fire growth can be determined from test data. The fire development is defined in terms of the actual heat release rate versus time. However, in most circumstances, only the general nature of the combustible materials is known and the first item to be ignited is indeterminate.

Most fires that do not involve flammable liquids or gases initially grow relatively slowly. As the fire increases in size, the rate of growth accelerates. This can be dependent on many factors including:

a) nature of combustibles;

b) geometric arrangement of the fuel;

c) ignitability of the fuel;

d) rate of heat release characteristics of the fuel;

e) ventilation;

f) external heat flux; and

g) exposed surface area.

For design purposes, fires are often assumed to grow proportionately to a growth rate constant multiplied by the square or other exponent of the time. Guidance on the use of characteristic fire growth curves is provided in the PD 7974-1 but, when carrying out the QDR, the team should take into account the expected rate of fire growth in each fire scenario.

The growth rate constant is an indication of the rate at which fire spreads in a given fuel, the exponent of time is a function of the distribution of the fuel.

The speed of fire development can be assessed qualitatively in terms of five main categories:

a) smouldering;

b) slow;

c) medium;

d) fast; and

e) ultra-fast.

NOTE 1 The characteristic fire growth rates are necessarily idealized but are based upon research involving both tests and analysis of real fires and are considered to represent a reasonable basis for design.

If a fire spreads through the fuel load in a two-dimensional circular way the exponent of time used should be time squared. If a fire spreads through the fuel load in a three dimensional way such as in a high bay warehouse, the exponent of time used should be time cubed. If a fire spreads is a one-dimensional linear way, the exponent of time used should be time to the power one. Fractional exponents may be used where appropriate.

NOTE 2 The conditions in and beyond the enclosure of origin, in terms of heat, smoke and toxic gas concentrations, depend upon the mass rate of effluent production and their dispersal volume, which in turn depend on the pyrolysis rate of the fuel, the fuel composition, the combustion conditions and air entrainment.

7.3.2.3 Fully developed fire

To simplify calculations, particularly for smoke control design, it might be possible to assume a fully developed fire with constant heat output from the time of ignition. The value of the rate of heat output should correspond to the largest size to which the fire is expected to grow within the appropriate period.

Fire load data should be obtained in order to evaluate the duration and size of a fully developed fire.

Information on fire load densities in different generic occupancies is given in PD 7974-1. Often the 80% fractile value is used in deterministic analysis (e.g. the fire load that is not exceeded in 80% of rooms). Alternatively, when a design for a specific building (such as an industrial plant) is being produced where good initial information is available on likely contents, actual contents can be used to determine fire load. (In such cases, it is also usual to include an additional percentage of fire load to account for transient combustibles.) Guidance on fire spread beyond the enclosure of origin and the response of structures is given in PD 7974-3.

In either case, the QDR team should be cognisant that the implication of this is that any subsequent deterministic analysis of the fire is based on a probabilistic assessment of fire load density.

NOTE Combustible materials stored within containers that have a degree of resistance to fire (e.g. steel filing cabinets) are protected to some degree and are rarely fully consumed in a fire. These materials are known as a "protected fire load". The effective fire load might, therefore, be less than that of the total quantity of combustible materials present.

7.3.2.4 Factors affecting fire growth and size

The following factors affecting fire growth and size should be taken into account.

a) Ventilation: The ventilation conditions can have a significant influence on the development and ultimate size of a fire. The potential ventilation paths that should be evaluated within the QDR might include:

   1) open doors and windows;

   2) mechanical ventilation systems;

   3) windows (after breakage); and

   4) failed enclosing elements (e.g. roof collapse).

   Automatic closure of fire resisting roller shutters or dampers in ducts, etc., can substantially reduce the ventilation available and should be identified in the QDR.

b) Suppression systems: The activation of automatic suppression systems are expected to extinguish or at least control the growth of a fire. The impact of suppression systems on fire development is described in detail in PD 7974-1 and PD 7974-4.

c) Fire location: The location of the design fire should be specified and the QDR should identify the geometry of the enclosure and, where necessary, the location of fire origin within the enclosure, i.e. whether a fire in the centre, beside a wall or in a corner, should be taken into account.

The location of the fire within the building also influences the time required by the fire service to begin to fight the fire once they have arrived on site. For example, the fire service set-up time might be much longer for a fire on the upper floors of a high-rise building than for a single-storey building.

7.4 Life safety analysis

7.4.1 General

To establish an acceptable standard of life safety, a comparison should be made between a calculated time for all occupants to reach a place of safety and the time taken for conditions to reach agreed tenability limits. This is expressed in engineering terms as:

$$ASET > RSET$$

where:

ASET is the available safe escape time (before untenable conditions occur) and can be defined in terms of:

a) the smoke layer height;

b) the smoke layer temperature;

c) the temperature and radiant flux at head height;

d) the visibility distance; and/or

e) the concentrations of asphyxiant gases (CO, CO_2 and HCN).

The time dependent values of each of these items would be outputs from sub-system 1 and sub-system 2 used as inputs to tenability limits or calculations in sub-system 6.

RSET is the required safe escape time and represents the time taken (from ignition) for all of the occupants to reach a place of safety. This information can be obtained from sub-system 4 (PD 7974-4) and sub-system 6 (PD 7974-6).

7.4.2 Tenability limit

Untenable conditions can be caused by a number of factors and in a life safety analysis the following hazards should be taken into account:

a) loss of visibility;

b) exposure to toxic and irritant products;

c) exposure to heat; and

d) structural failure.

NOTE PD 7974-6 provides limiting conditions for the human tolerance of toxic gases, irritants, smoke obscuration, radiant heat flux and smoke temperature. Detailed guidance on structural performance in fire is given in PD 7974-3.

The QDR team should establish which potential threats and occupant behaviours are significant and require quantification but, in most circumstances, it is loss of visibility due to the spread of smoke that determines the initial threat to life and consequently the available safe escape time (ASET).

7.4.3 Occupant characteristics

7.4.3.1 General

Variations in evacuation response time are related to the type of occupancy, population and physical setting. For this reason, the occupancies should be reviewed in relation to the factors that are most likely to influence human behaviour and movement.

Research into escape behaviour in fires and evacuations suggests that, in addition to means of escape design parameters (such as travel distance, number and position of exits and exit widths), factors that influence the response of occupants in a fire emergency can include:

a) warning system;

b) fire safety emergency management strategy;

c) familiarity with the building;

d) alertness;

e) mobility;

f) social affiliation;

g) role and responsibility;

h) any fire safety training received;

i) location within building;

j) staff/occupant ratio; and

k) building complexity.

Guidance regarding the impact of these and other factors is given in PD 7974-6 but the QDR team should, when appropriate, make an assessment of these factors.

7.4.3.2 Occupant numbers

The number of occupants in a space often has a direct impact on the time required to evacuate via the available exits. For the purposes of probabilistic or deterministic analysis of life safety, the reasonable worst case scenario should include an assessment of the maximum likely number of occupants present in the building or part of a building.

7.4.4 Probabilistic life safety analysis

*COMMENTARY ON **7.4.4***

When carrying out a probabilistic analysis, the aim is usually to show that the frequency of a given event occurring (e.g. injury, death or large life loss) is acceptably small.

The use of probabilistic techniques to assess life safety objectives should be assessed carefully.

NOTE Guidance on the selection of suitable acceptance criteria for probabilistic purposes is given in PD 7974-7.

7.5 Loss control and organizational resilience analysis

7.5.1 Deterministic analysis

*COMMENTARY ON **7.5.1***

Minimum provisions for life safety usually arise from statutory requirements but the benefits of additional provisions for property protection ought to be judged in the context of the impact of fire on a business and the cost of additional fire protection measures.

However, it is feasible to apply deterministic analysis to property protection. For instance, the client might set a functional objective of maintaining continuity of operations by limiting production down-time to a maximum of one week. In some circumstances, this might be most easily achieved by transferring operations to another location. If the business is dependent upon a unique piece of electronic equipment which can be damaged by corrosive combustion products such as hydrogen chloride (HCl) gas, one of the design objectives can be set in terms of maintaining concentrations of the gas below a specified level.

The QDR team should define the extent of acceptable damage. (Some examples of how the various property protection functional objectives might be refined into absolute acceptance criteria are indicated in Table 8.)

Table 8 — *Examples of setting property protection design objectives and acceptance criteria*

Functional objective	Design objective	Acceptance criteria
Protect the building structure	Ensure that structural collapse does not occur as a result of a complete burn out	$L_{crit} \geq L$ [A)]
Limit the loss of the building contents	Ensure that not more than 33% of stock is destroyed by fire and smoke damage	plan area of the fire < 3 000 m^2
Maintain ongoing business viability	Ensure that not more than 50% of operational facilities are affected by a fire	Fire in production line A to have nil effect on production line B
Maintain the corporate image	Ensure that any fire does not cause multiple fatalities	Fire confined to room of origin and A_f < 100 m^2 and means of escape conforms to design codes

A) L_{crit} is the fire load required to cause structural failure; L is the design fire load.

The value of a fire-damaged object should be assessed not only as a direct financial replacement cost, but also as a loss of an asset and productive time.

NOTE *All objects are part of the complete property package and are integral to the purpose of a building. Time lost replacing key fire damaged objects can be considerable, resulting in business interruption.*

Irrespective of the fire damage to a building or its contents, the disruption of services caused by a fire, for example when evacuation is necessary, can cause large financial loss. Examples include financial trading operations, and any retailing operation in which custom is lost to competitors.

Methods that can be employed to alleviate losses due to fire include:

a) selecting materials with resistance to fire;

b) providing fire protection systems (see **7.5.2**, Table 9); and

c) contingency planning.

7.5.2 Probabilistic analysis

Design objectives for property protection should be set by the QDR team in conjunction with the client, who could have specific views regarding the acceptable level of risk.

Where a fire is not likely to have a catastrophic effect on the continuing operation of a business, i.e. if the facilities are duplicated at several locations or can be quickly reinstated, acceptance criteria could be set on the basis of ensuring that the cost of fire protection is balanced by the potential reductions in losses.

A decision to provide additional fire protection measures for property protection purposes might be taken on the grounds that the cost of fire protection measures for loss control purposes would be less than the potential savings over the lifetime of the building. The main factors that might be taken into account in this type of analysis are summarized in Table 9.

Table 9 — *Benefits and costs of fire protection measures for property protection*

Fire protection benefits	Fire protection costs
Reduction in direct fire losses	Installation costs
Reduction in business interruption	Maintenance costs
Maintenance of corporate image	Operational impact (e.g. reduced efficiency resulting from split location of stocks)

To estimate the potential financial losses and compare them with the benefits of installing various fire protection systems, the concept of average potential loss (APL) may be used. The APL is simply a means of expressing the fire risk in monetary terms over the expected lifetime of the building.

If a total loss of the building and its contents can result in closure of the business, the cost to the business should reflect the potential future loss of profits as well as the direct cost of the building and contents.

For a large organization, spreading the operations between several locations might be more cost-effective than operating at one location that is protected with a comprehensive set of fire protection measures. However, where the number of locations is such that fires are likely to occur regularly, it might be desirable to provide additional fire protection measures to minimise the potential for regular bad publicity.

NOTE More detailed guidance on the application of probabilistic analysis to FSE design is given in PD 7974-7.

7.6 Analysis of environmental impact/protection

COMMENTARY ON ***7.6***

A fire in a building containing large quantities of toxic material could have a significant impact on the environment in terms of contamination of the air, land and water.

Ground and water contamination can be difficult to evaluate and, where this is likely to be a significant issue, specialist expertise should be sought. Groundwater source zones might be protected from contamination by law. This could impact on the FSE not only through direct fire products but on fire-fighting water run-off.

7.7 Economic/financial analysis

Although the overriding consideration when undertaking FSE is to ensure adequate safety, in most instances economic and financial considerations should also be taken into account. For example, if two trial designs are both shown to be adequately safe, it is reasonable for the less expensive of these two designs to be chosen.

NOTE 1 There are also cases where the primary reason for undertaking a FSE study is to review costs. A common example is when design codes require a degree of passive fire protection that is not in proportion to the fire load of the building. Modelling potential fire size together with analysis of the inherent fire resistance of the structure could indicate that a lesser, or no, passive fire protection would still produce an adequately safe building, with subsequent cost savings.

NOTE 2 Probabilistic FSE analysis coupled with cost-benefit analysis can be used to assess the most cost-effective of two or more differing strategies when deciding on what methods are used and to what degree additional fire protection measures are provided to give property protection. For instance, a choice might need to be made between providing sprinkler protection or additional compartmentation, both of which limit potential fire damage to an acceptable maximum foreseeable loss as agreed with insurers. Probabilistic analysis to determine the probability of achieving this objective with each method, coupled with information on the cost of each different approach (including ongoing costs), can indicate which method offers the best return on the investment made.

Even when financial considerations are the main focus of an FSE study, it should still be demonstrated that an acceptable level of life safety is being provided.

8 Assessment against acceptance criteria

Following deterministic or probabilistic analysis, the results should be compared with the acceptance criteria identified during the QDR.

If none of the trial designs satisfies the specified acceptance criteria, the QDR and quantification process should be repeated to establish the available options. The options might include:

a) development of additional trial designs;

b) adoption of a more discriminating design approach; and

c) re-evaluation of design objectives (e.g. if cost of fire protection measures for property outweigh the potential benefits).

When a satisfactory solution has been identified, the resulting fire safety strategy and the FSE process that produced it should be fully documented as described in Clause **10**.

9 Quality assurance

9.1 General

FSE studies should undergo a quality assurance process before they are submitted to clients or to authorities having jurisdiction.

NOTE 1 Many aspects of FSE are based on quantitative numerical calculation whilst other aspects are based on qualitative assumptions, opinions and margins. There are, therefore, many opportunities for numerical error, as well as many opportunities for selecting inappropriate inputs, estimates and approximations.

If the FSE analysis is for the purpose of addressing a minor issue in a building which otherwise conforms to design codes, quality assurance can take the form of an internal peer review by another engineer. Where a project is particularly large (and therefore the opportunities for error are increased) and where a project is particularly safety critical (and therefore the consequences of error could be great), the quality assurance process should be more rigorous and can include an internal and external peer review process.

Where an FSE analysis is submitted to an authority having jurisdiction, this should not be considered to be part of the quality assurance process, as it should be fully checked before it is submitted to an authority having jurisdiction. The liability for any errors in the FSE remains with the fire safety engineer, even if the authority having jurisdiction has reviewed the analysis and has issued an approval.

Quality assurance should check matters such as, but not limited to:

a) the suitability of analysis and its inputs;

b) the accuracy of analysis, including any typographical, numerical and transposition errors; and

c) the credibility of conclusions.

NOTE 2 9.2 to 9.4 describe some approaches and techniques that can be applied as part of a quality assurance process.

9.2 Limits of application

9.2.1 General

Often the experimental work used to develop empirical relationships is carried out in scaled-down facilities in research establishments. It should be taken into account that the accuracy of models resulting from such work might be limited when they are extrapolated from scaled-down test facilities to full scale situations, e.g. in terms of the size of the room or the range of factors that have been examined.

Where extrapolation of test or experimental data is used it should be justified.

NOTE Deterministic analysis provides a useful indication of the development and effects of fire, but the nature of fire is such that the results are unlikely to be precise.

In all situations, where there is any doubt as to the validity of a model, the user should establish how the experimental work was carried out and justify the solution, for example by a sensitivity analysis (see 9.3).

9.2.2 Predictive ability

*COMMENTARY ON **9.2.2***

The empirical relationships presented in the parts of the PD 7974 series (and other established published works that have been subject to independent peer review) may be assumed to have adequate predictive ability for most FSE design purposes, provided that the relationships are used within the stated limits of applicability.

Where a model or correlation has not been subject to independent validation or is used outside its limits of applicability, its ability to accurately predict outcomes should be assessed in terms of its theoretical basis and an empirical comparison with data gathered experimentally or from real fires. Where some doubt remains regarding the predictive ability of a model, its use might still be reasonable provided that suitable safety factors are included in the analysis.

NOTE It is important to understand how variation between predicted and measured values is likely to affect the outcome. For instance, a model or correlation that over-predicts the volume rate of smoke production would generally be conservative and provide an intrinsic safety factor in the design of natural smoke vents. However, this same correlation would tend to under-predict smoke temperature which could lead to an under specification of the temperature rating of a mechanical extraction fan.

9.3 Sensitivity analysis

Any analysis involves uncertainties. In most cases, this is adequately accounted for by the use of reasonable worst case initial assumptions (e.g. selecting a fire growth rate that is at the upper bound of expectations). Where there is doubt that this is the case, then the primary sources of uncertainty should be assessed using sensitivity analysis; these are associated with:

a) input parameters;

b) necessary simplifications in the modelling techniques; and

c) limitations of empirical relationships.

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

EXAMPLE

Radiant heat flux from a flame is given by:

$$\dot{q}_{\mathrm{R}} = \phi \varepsilon_{\mathrm{f}} \sigma \overline{T}_{f}^{4}$$

where:

$\overline{T}$ is the mean flame temperature.

If the mean flame temperature is assumed to be 1 100 K instead of 1 000 K, the error is 10%.

Because the mean flame temperature is raised to the power four in the equation, the radiant heat flux is in error by 46%. The result is said to be very sensitive to the average flame temperature.

On the other hand:

Flame length for an axi-symmetric fire source is given by:

$$z_{\mathrm{f}} = 0.2\dot{Q}^{2/5}$$

where:

$\dot{Q}$ is the total rate of heat release.

If the total rate of heat release is assumed to be 1 100 kW instead of 1 000 kW, the error is 10%.

Because the total rate of heat release is raised to the power 2/5 in the equation, the flame length is only in error by 4%. The result is NOT very sensitive to the total rate of heat release.

The aim of a sensitivity analysis is to check the robustness of the results and to investigate the criticality of individual input parameters.

If a single system or assumption is shown to be critical to the outcome of the FSE analysis, the possibility of providing a degree of redundancy in the design or carrying out a probabilistic analysis should be evaluated.

9.4 Uncertainties

*COMMENTARY ON **9.4***

The complexity of the interactions between people, buildings and fire coupled with gaps in knowledge means that there is a degree of uncertainty associated with any fire safety design. Uncertainties can exist in underlying science and research, theoretical models, experiments and tests, design, systems and component performance and reliability, and construction and operational quality.

Part of the designer's role is to identify uncertainties and adequately mitigate any associated risk. The greater the risk, the greater the mitigation required. Mitigation can include increased conservatism, *redundancy, robustness and/or reliability. Assessing the adequacy of mitigation is likely to involve sensitivities studies. The objective of a sensitivity study is to establish the impact on the output parameter(s) caused by variation in the input parameter(s); it is not intended to check the accuracy of the results. The greater the sensitivity, the greater the mitigation required.*

9.4.1 Uncertainties owing to QDR simplifications

The simplifications and assumptions made in the QDR to aid the full analysis should be assessed for their criticality to the fire safety design.

For example, it might have been assumed that an enclosure remains an enclosure, and that the possibility of an open door may be ignored. However, an alternative scenario would assume the door is open and the effect of confinement can be assessed. This type of issue should be dealt with by the QDR team in the "what if" study (see **5.5.3**).

9.4.2 Uncertainties owing to input parameters

*COMMENTARY ON **9.4.2***

Provided that the modelling techniques are appropriately chosen, it is probable that uncertainties in the initial assumptions would be the most significant.

If using absolute acceptance criteria, particular care should be taken to establish the adequacy of input parameters and assumptions. However, if using comparative acceptance criteria, impact on the ranking of the outcomes between a solution that conforms to design codes and the FSE solution might be less sensitive to the effects of any minor errors in these assumptions, which might cancel out.

9.4.3 Uncertainties owing to modelling or empirical relationships

Where there is doubt about the applicability of a particular calculation technique, further confidence in the results can be gained by comparing the outcome of one model with another which is based upon different empirical relationships or calculation approaches.

Any significant discrepancies should be accounted for by choosing the most onerous of the results or by introducing an appropriate safety factor.

10 Reporting and presentation of results

10.1 General

*COMMENTARY ON **10.1***

The format of the report depends on the nature and scope of the FSE analysis and the house style of the fire safety engineer. However, most buildings designed in accordance with this British Standard would be subject to review and approval. It is therefore important that the findings of the FSE analysis and any assumptions made are presented in a form that can be clearly and readily understood by a third party. It is also important that the necessary fire safety systems are adequately specified.

When checking that a design conforms to design codes, it is relatively straightforward to establish whether the various provisions of these have been correctly implemented. However, this standard provides for a flexible approach to design using performance-related functional and design objectives rather than design code solutions. It is not, therefore, possible for an authority having jurisdiction simply to compare the proposed design against a set of well-defined requirements. It is essential that the results of FSE analysis are fully documented.

The results of FSE analysis should be fully documented so that they can be readily assessed by a third party, e.g. approvals bodies. The report should set out clearly the basis of the design, the calculation procedures used and any assumptions made during the analysis.

The presentation of results should particularly take into account the following.

a) Some third parties who need to understand the design might not have a high degree of expertise in FSE. The underlying principles of the fire safety strategy should therefore be explained in simple terms so that they can be easily understood.

b) Computer software can produce a "black box solution" where inputs and outputs are visible, but the manipulation process that has led from one to the other is hidden. In such cases the report should provide supporting information including the name of the software used, its release version and evidence that it is being used within its limitations.

The format of the report should contain some or all of the information in **10.2** to **10.8**, depending on the nature and scope of the FSE analysis.

10.2 Functional objectives of the FSE analysis

This section of the report should set out the overall functional objectives of the FSE analysis.

10.3 Building description

The report should provide a general overview of the layout, construction and proposed use of the building. A more detailed description should be given of those aspects of the scheme that relate to the reasons for, and the outcome of, the FSE analysis (e.g. travel distances in excess of the recommendations of design codes).

10.4 Results of the QDR

A detailed statement of the main factors considered in the QDR should be provided together with the reasons for proposing and rejecting the various fire scenarios and trial designs. It should include:

a) membership of the QDR team;

b) clear statement of functional objectives;

c) specification of the fire scenarios for analysis;

d) acceptance criteria;

e) results of the hazard analysis and possible consequences; and

f) trial designs.

10.5 Quantified analysis

The basis for choosing the adopted quantification techniques should be given and any assumptions or engineering judgements made in their application should be clearly stated.

Full details of the calculation procedures should be provided. Sufficient detail of the data inputs and boundary conditions should be provided to ensure that a third party can review or repeat the calculations without the need for reference to the author of the report.

All empirical relationships and computer models used in the analysis should be fully referenced. Where independent validation of a model or calculation procedure is not available, or it is being used outside the suggested limits of applicability, clear justification for its use should be provided in the context of the FSE analysis.

NOTE To improve the comprehension of a report, it is often advisable to provide an overview of the calculation procedures in the main body of the report and to relegate full details of any calculations to appendices, such as:

a) assumptions;

b) engineering judgements;

c) calculation procedures;

d) validation of methodologies; and

e) sensitivity analyses.

10.6 Comparison of design with acceptance criteria

The outcome of the quantified analysis should be compared with the acceptance criteria and this should be described for each of the specified design objectives.

10.7 Fire safety strategy

The fire safety strategy should include:

a) a description of fire scenarios and response;

b) the fire protection requirements;

c) the management requirements; and

d) any limitations on use.

The fire safety strategy should be written such that it can be understood by authorities having jurisdiction so that they can grant approval, and by the subsequent building occupants who are to manage the fire systems when it is occupied.

To assist with this, the fire safety strategy should include a prose description of the reasonable fire scenarios, an explanation of how inbuilt systems would respond to these fires, and an explanation of the expected response of occupants. This should set the scene for the more technical aspects of the fire safety strategy.

The fire safety strategy for the building should be based on the successful trial design and is likely to comprise a range of physical fire safety measures and management procedures. A description of these measures should be provided, together with performance specifications and any recommended deviations from the relevant design codes.

NOTE 1 For example, "The sprinkler system should conform to BS EN 12845, except that sprinkler heads are not required above the swimming pool".

The role of fire risk management is both critical and integral to successful fire safety, whether the design is based upon design codes or FSE design. Therefore, this British Standard assumes that all aspects of the fire safety strategy are capable of being maintained and deployed over the lifetime of the building. If there are any specific aspects of the design that are particularly dependent upon a high standard of fire safety management, this should be clearly highlighted to inform the fire risk manual and the associated fire risk assessment. The basis on which the fire safety design of a large or complex building has been achieved should also be recorded in the fire safety manual, which should be kept on the premises concerned, for the benefit of the management of the premises.

NOTE 2 Further information regarding the documentation of fire safety management procedures is provided in the BS 999X series.

10.8 Conclusions

The report should draw together the main findings of the FSE analysis and should highlight any aspects of the proposed design that are likely to impact on the use of the building in terms of:

a) fire protection requirements;

b) limitations on likely future use; and

c) specific management requirements.

The fire safety strategy, whilst being authored in a manner for authorities to understand, should also be written for the person ordering the works who might not have full competence in the subject matter. A clear and unambiguous set of recommendation(s) or actions should be presented for the end user and responsible persons.

10.9 References

To ensure that the report can be fully checked by a third party, detailed references should be given for all documents and procedures used in the report. These should include details of:

a) drawings;

b) design documentation; and

c) technical literature.

10.10 Qualifications and experience of the fire safety engineer(s)

In most FSE analysis, it is necessary to make some engineering judgements and the expertise of the fire safety engineer often plays a major part in defining the initial design assumptions. To enable a third party to establish that the FSE analysis has been carried out by a person with appropriate expertise, the name, qualifications and experience of the individual fire safety engineer(s) responsible for the analysis should be provided.

NOTE It is important that the report draws a clear distinction between life safety, property protection and environmental protection so that building owner, manager and authority having jurisdiction can clearly identify the purpose of the proposed measures.

Annex A (informative) Possible misconceptions

A.1 General

There are a number of possible misconceptions regarding the use of FSE rather than traditional prescriptive approaches and some of these are discussed in this annex.

A.2 "An FSE design is always more dependent upon management controls"

Whether designed in accordance with design codes or FSE principles, good fire safety management is essential to the safe operation of any building. FSE can be used to deliver a solution which is heavily dependent on management controls or a solution which requires few management controls. In either case, the FSE approach presented in this standard recommends that management issues are taken into account and any specific management requirements are addressed explicitly.

A.3 "FSE should not be applied to just one aspect of the design"

The most common use of FSE is to justify one or two specific departures from design codes. There is generally no need to apply FSE to all aspects of a project if it otherwise conforms. However, it is necessary to consider, as part of the FSE process and the justifications presented, whether these departures in some way undermine other aspects of the fire safety strategy and whether it works holistically.

A.4 "An FSE design provides less flexibility for future use"

During the QDR, the team identifies potential future changes of use and, where practical, ensures that the design accommodates these. If this is not feasible, any potential restrictions are to be highlighted. A lack of flexibility is a function of poor engineering design rather than an inherent function of FSE.

A.5 "An FSE design is always more dependent upon the correct performance of fire protection systems"

There is no reason why a wedged-open fire door or poorly maintained sprinkler system would be any less of a problem in a conforming building than in a building designed on the basis of FSE principles.

Where an FSE design is heavily dependent on a single fire protection system, this standard recommends that a "what if" study is carried out to assess the potential impact of system failures.

A.6 "The accuracy of many FSE calculations is unknown"

The accuracy of the calculation procedures presented in the PD 7974 series supporting this standard (and other appropriate publications which have been subject to peer review) are generally sufficiently accurate for engineering design purposes if they are used within their limits of applicability and with appropriate safety factors as necessary.

However, the old adage of "garbage in – garbage out" applies and, in most cases, uncertainties in the calculation procedures are outweighed by any errors in the initial assumptions (e.g. the rate of fire growth).

A.7 "An FSE solution always requires calculations and a numerical solution"

This standard provides a design framework and does not necessarily require a quantified analysis.

Very often, it is possible to reach a solution without recourse to numerical calculations. During the QDR process, it might be possible to establish simply by logical deduction that a trial design is at least as safe as the solution that conforms to design codes without the need for any calculations (see Clause 7).

Annex B (informative) Property protection and mission resilience

B.1 General

An important use of FSE is to design a building with an optimum level of fire protection features which together cost-effectively provide a level of protection against fire, appropriate to the financial consequences of fire and related fire-fighting caused by:

a) damage to or destruction of the building;

b) damage to or destruction of building contents, including both plant and stock;

c) loss of productive capacity; and

d) loss of reputation.

Insurance can be used to mitigate these losses, but an appropriately FSE-engineered building can reduce ongoing insurance premiums. Moreover, insurance cannot properly mitigate where business continuity is essential, such as in some data processing operations or medical facilities. Property protection FSE is also appropriate where fire can result in catastrophic consequences such as in chemical and nuclear plants.

The correct choice of FSE design can be arrived at using engineering judgement based on experience on similar building types or a more rigorous analysis can be applied, possibly using probabilistic analysis allayed with cost-benefit analysis. Business impact analysis (BIA) can be used to assist with assessing the effect of fire.

B.2 Business impact analysis (BIA)

B.2.1 Understanding an organization

The fire safety engineer, architectural design team and insurer endeavour to fully understand the end-user client's organization in terms of its objectives, stakeholder obligations, statutory duties and the environment in which the organization operates. The data gathered is used to inform the organization's continuity and recovery strategy, identify mission-critical activities, their dependent resources, and the timeframe within which they need to be recovered (the maximum tolerable outage, or recovery time objective), and as a means to establish dependencies and relationships between business processes and supporting infrastructures.

B.2.2 BIA process

B.2.2.1 Precursors

The approach outlined within this British Standard might not be applicable to all building or plant design projects involving elements of FSE. There is little purpose in undertaking a BIA unless the management of the end-user client's organization understand the requirement for undertaking such an activity and are willing to act on the findings. For a BIA to be undertaken successfully, its purpose needs to be appreciated and supported by senior management in advance of the process commencing. Before a BIA is undertaken, a clearly stated commitment to the wider goals and objectives of business continuity management is sought from senior management within the end-user client's organization. This commitment includes the organization's willingness to invest in the solutions that evolve following use of a BIA to help define the requirement.

B.2.2.2 Definition of scope

The next step in the BIA process is to address the scope of the analysis. This is largely influenced by the scope of the building or plant being designed. However, a new facility being constructed within an existing site might require a BIA which analyses the entire site, in order to fully understand the influences and dependencies within the new facility, and indeed any other sites out of which the organization operates.

As a FSE tool, and within the scope of this British Standard, the BIA may be restricted to fire-related disruptions. However, the end-user client might wish to conduct a holistic BIA which includes the consideration of non-fire-related disruptions at the same time. Therefore, the fire safety engineer and architectural design team need to be aware of their individual contribution to the process and be cognisant of the data they require to inform the subsequent steps in the QDR.

B.2.2.3 Data collection

The next step involves data collection and requires a collaborative approach to be taken, but it is essential that the end-user client is responsible for undertaking the analysis. The client's insurer, or insurance broker, often has a good understanding of the organization, the hazards, and business interruption consequences; however, it is only the end-user client who can convey the full picture. The senior management team is asked to assess the organization as a whole, and to provide a ranking for key products or services and the point at which the maximum tolerable period of disruption (MTPD) occurs. This team also sets the timescale for resumption within the MTPD, which is called the recovery time objective (RTO). The outcome of this data collection is to determine the critical activities across the organization that are needed to deliver these products and services.

B.2.2.4 Moderation

The next element of the BIA is to subject the findings to a moderation process, rather than simply accepting the findings at face value. Moderation is best conducted by senior managers within the client's organization so they can give the global perspective, but other methods to moderate the BIA data include:

a) comparison of output with findings of earlier reviews, or across other divisions, or with internal expectations;

b) use of peer review with other business continuity management experts; and

c) use of a senior figure within the end-user client organization (or panel) to assess the initial findings.

B.2.2.5 Report

Once the BIA process has been completed, the findings are documented in such a way that it:

a) provides a meaningful input into the FSE objective setting within the QDR;

b) feeds back into the wider client organization's business continuity management plan; and

c) provides sufficient evidence of the process to satisfy a later audit.

The incorporation of a BIA, or the interpretation of the end-user client organization's BIA, into the QDR and objective setting process allows the fire safety engineer to establish scenarios for quantitative analysis utilizing appropriate fire protection tactics, resulting in resilient building designs.

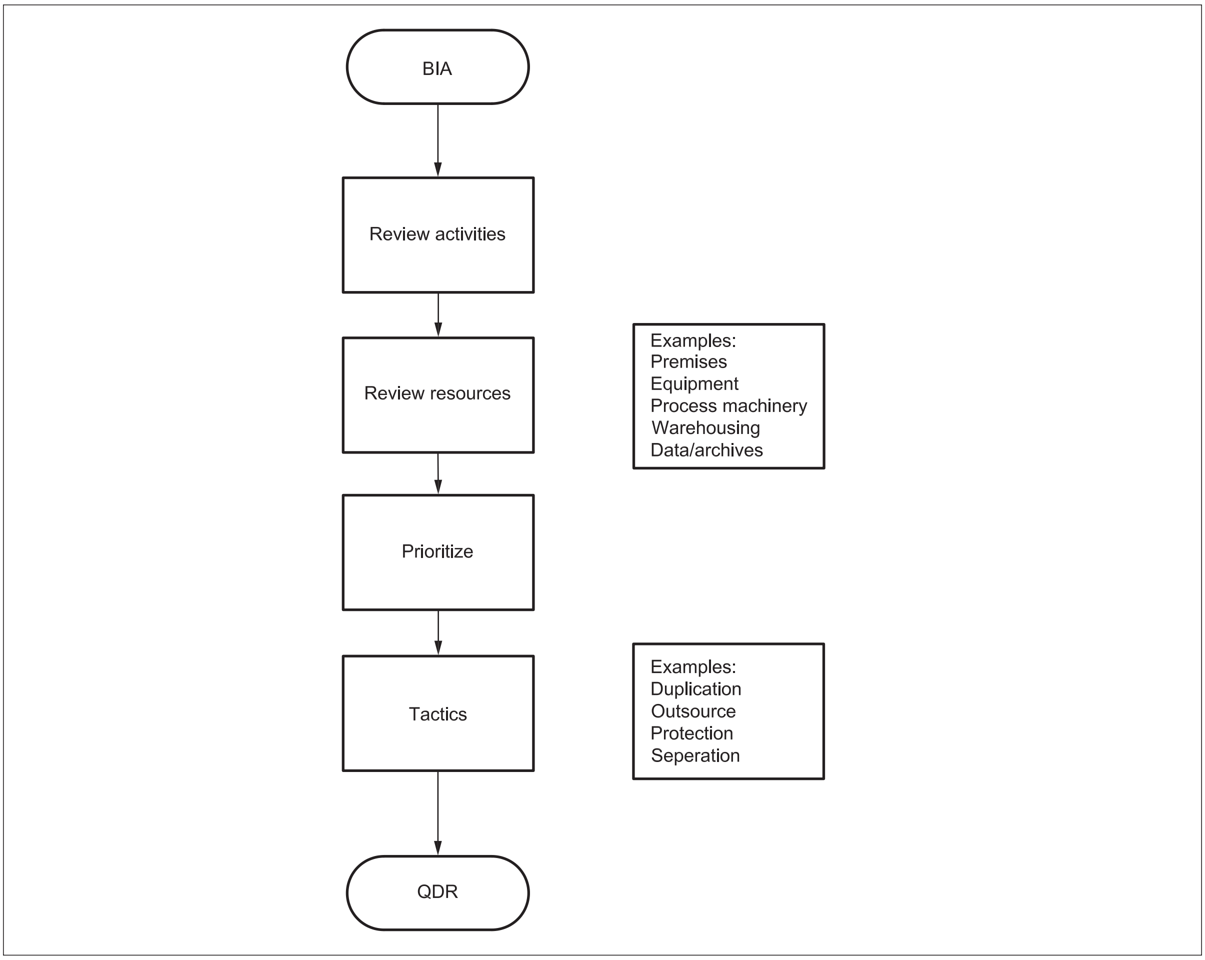
B.3 Interpreting BIA for FSE

B.3.1 Understanding the BIA report

Numerous templates and organization-specific formats have been developed and are used to record the output of a BIA.

The BIA report reviews all activities undertaken within the end-user client's organization. As shown in Figure B.1, the resources required to complete these critical activities are also identified. By undertaking the moderation exercise, the prioritization of these activities and supporting resources are documented. This then allows the building design team and the fire safety engineer to analyse and identify which resources would benefit from protection from fire and combustion products, and select the appropriate tactics for further analysis.

Figure B.1 — *BIA to QDR process*



B.3.2 Establishing FSE objectives

*COMMENTARY ON **B.3.2***

Property and business protection objectives are dealt with separately. The guidance in these subclauses is based on guidance given in PAS 911.

B.3.2.1 Property protection objectives

The building might or might not be seen as a crucial part of the resources supporting critical activities. Conceivably, if all persons have been safely evacuated from the building, then the consequential collapse of the building might be acceptable. However, in many cases, controlling a fire to prevent the destruction of the building is seen as an objective. In such cases, in order to define fire safety objectives, the BIA can be used to ascertain answers to such questions as the following.

a) What parts of the building are most vulnerable to a fire incident?

b) What parts of the building need special consideration to support the business continuity plan?

c) How big would a fire need to be to constitute a threat to the building?

d) What aspects of the building might cause a fire to spread throughout the building?

e) What parts of the building are most critical for protection and what parts are secondary?

The loss of the building fabric, i.e. the walls, doors, floors, ceilings and divisions, and their decorations and fittings, might be acceptable, as the rebuild costs might not be of primary importance when weighed against the cost of their protection. For buildings of historical importance or where special building materials and fabrics have been introduced, the fabric might be viewed as important as the building itself. Considerations might include the following.

1) What parts of the building fabric are most vulnerable to a fire incident?
2) What forms of damage are unacceptable (e.g. damage from toxic gases, smoke, from convected heat from a fire, water, etc.)?
3) How much of the building fabric is seen as an “acceptable loss”?
4) What parts of the building fabric are most critical for protection and what parts are secondary?

Fixtures and fittings might be furnishings, equipment, machinery and plant within the building that cannot be easily moved, especially in the event of a fire incident. IT equipment and data might be of particular importance. The importance of the fixtures and fittings in terms of value is often a subjective decision, and might be determined by the insurers, management or special interest parties. Considerations might include the following.

- What fixtures and fittings are deemed to be a priority for protection and what are secondary?
- What forms of damage are unacceptable (e.g. damage from toxic gases, smoke, from heat from a fire, water)?
- How easily can the fixtures or fittings be replaced?
- What forms of protection are most appropriate?
- What parts of the building are most critical for protection and what parts are secondary?
- What special requirements are there for fire-fighters (e.g. providing specific facilities and/or equipment other than those suggested by building regulations)?
- What salvage processes are appropriate to full equipment reinstatement and/or replacement?

Moveable items might be small furnishings, computer equipment, works of art, tools and test equipment, which are housed within the building but can be moved out of the building in the event of a fire incident. The importance of the moveable items, as with fixtures and fittings, in terms of value, is often a subjective decision and might be determined by the insurers, management or special interest parties. Considerations might include the following.

- What moveable items are deemed as a priority for protection and what are secondary?
- What forms of damage are unacceptable (e.g. damage from toxic gases, smoke, from heat from a fire)?
- What areas can be designated as places of safety for moveable items?
- What procedures are required to move the items to a place of safety?
- What fire and security protection is required for the designated location of the moveable items?
- How easily can the moveable items be replaced?
- What forms of protection are most appropriate?
- What salvage processes are appropriate for full item reinstatement/replacement?

B.3.2.2 Business/mission continuity objectives

When dealing with issues relating to the direct and indirect consequences of a fire, there are four main objectives to be separately reviewed.

a) **Short-term operations**. This is the assessment of how a fire would have an immediate and near immediate impact on the business. Considerations might include:
   - In what ways would a fire affect the running of the business on a day-to-day basis?

- What are the most critical short-term aspects of the business that require special attention?
- What are the short-term contingency arrangements that can be put into place following a partial and/or total fire?
- What would be the acceptable downtime following a fire?

b) **Long-term operations**. This is the assessment of how a fire would have a longer-term impact on the business. Considerations might include:

- In what ways would a fire affect the running of the business in the long term?
- What are the most critical long-term issues of the business that require special attention?
- What long-term contingency arrangements can be put into place?
- What changes to the business processes can be implemented if the business cannot continue in its present form following a fire?

c) **Confidence**. This is the assessment of how a fire would have an impact on the confidence of stakeholders. Considerations might include:

- How would a fire affect the confidence of employees?
- What changes in working arrangements would need to be implemented as a consequence of a fire?
- How would a fire impact on the confidence of customers, suppliers and shareholders in the business and its ability to continue to operate?
- How would a fire affect its relationship with the local community and/or the wider society?

d) **Mission**. This is the assessment of how a fire would have an impact on the ability of the organization to follow its objectives. Considerations might include:

- How would the fire impact on the core mission and values of the organization?
- What impact would a fire have on the viability of the organization?
- How would the organization be perceived over the longer term?
- What are the legal, commercial and logistical implications of a fire and how would they manifest themselves?

B.4 Fire protection tactics for improving resilience

Once the required objectives have been determined, all available fire protection tactics are assessed, to develop an appropriate fire safety strategy to provide the required degree of resilience of a building or plant in fire. Possibilities include the following.

a) **Minimizing ignition sources** – Wherever possible, all processes conducted within a building or plant are designed to reduce the likelihood of ignition. It is appreciated that frequently little can be done in this area at the design stage, but often some improvement can be made. For example, water-based central heating is far less likely to provide an ignition source than electric heaters.

b) **Minimizing combustibles** – Using non-combustible materials both in the structure of the building and in its contents would reduce the likelihood of a serious fire and hamper fire spread. Wherever practicable, flammable and combustible substances and materials used in a business are substituted by non-combustibles. Although the design process might have little influence on the contents of a building, some improvements can be made. For example, fire-resisting hydraulic oils can be substituted for mineral oil, and air-cooled switchgear substituted for oil-filled switchgear. Water-based solvents can be substituted for flammable solvents. Even when no practical non-combustible materials are available or their use is constrained by cost or other considerations, fire size can be reduced by selecting materials with improved reaction-to-fire properties. Examples include the use of composite structural panels using materials with improved fire performance, the use of flame retardant as opposed to standard cables, and the use of silicone-based transformer fluids instead of oil-based.

c) **Fire detection** – Early detection can give time to allow a fire to be tackled in its early stages before it is too large to be effectively dealt with. High-sensitivity detection can allow incipient fire to be spotted before flaming combustion occurs, and can allow for fire to be effectively eliminated (e.g. by powering down equipment) before it can develop.

   For detection to be effective, it would raise an alarm in a manned area from which early fire attack can be organized.

d) **Manual fire-fighting** – There is evidence that approximately two-thirds of fires are extinguished by the use of manual fire extinguishers. Availability of ample and appropriate fire extinguishers provides the means for this to occur. However, for this to be most effective, employees need to be given practical, hands-on training in the use of extinguishers.

   The provision of an on-site fire team or fire and rescue service would further enhance the capability to tackle fires in the early stages and to minimize loss.

   The provision of enhanced facilities for the fire and rescue service, such as hydrant systems, risers, fire-fighting shafts and improved vehicular and pedestrian access can also help to improve the chance of successful early fire-fighting to minimize losses. Fire ventilation can also be provided to allow safe fire attack.

   When designing measures to assist the fire and rescue service, discussions are held with the appropriate service to ensure that expectations are likely to be met in practice.

e) **Fire suppression** – Both manual and automatic fire suppression systems can be used. Further advice is given in BS 5306-0. Some fire suppression systems are designed to support life safety objectives and others for business and property protection. Sometimes the most effective life safety and property protection/business continuity fire strategies are able to harness the life safety and property protection/business continuity benefits from a single sprinkler system.

f) **Ventilation** – Smoke ventilation can limit damage from smoke and hot gases. It can also improve the fire and rescue service’s ability to successfully tackle a fire, by providing a safe clear layer for fire and rescue service operations or safe access routes (pressurization techniques). Ventilation systems can also hamper the effectiveness of sprinkler systems performance, so coherent design is required.

g) **Passive fire protection and compartmentation** – Reducing fire size by effective fire-resisting compartmentation can limit fire spread and potential loss. Compartmentation can also be used to protect particularly vulnerable equipment. Periods of fire resistance given in guidance to building regulations (e.g. Approved Document B [8]) might not necessarily provide a level of protection to survive a burn-out of contents; if not, a higher level of structural fire resistance can be used if structural integrity to survive a worst case fire is required or desirable.

h) **Back-up and redundancy** – Business and mission continuity can be assured by having back-up equipment available (or a contingency plan in place to ensure that the equipment can be quickly obtained). Backing up computer data to a remote server can be especially effective in protecting valuable records.

i) **Training and management** – Both the likelihood of a fire incident and the size of an incident can be minimized by good training of employees in fire prevention and in what to do in the event of fire. Effective management to ensure good housekeeping and regular maintenance of possible ignition sources and fire protection equipment is also key to preventing losses, in accordance with good practice guidance such as BS 9999. However, since people cause fires, passive, installed and automatic protection is preferred to complex management procedures in most instances.

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