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**BSI Standards Publication**

# **Application of fire safety engineering principles to the design of buildings**

Part 7: Probabilistic risk assessment

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# Foreword

## Publishing information

This Published Document 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 committee manager.

## Supersession

PD 7974-7:2019 superseded PD 7974-7:2003, which has been withdrawn.

PD 7974-7:2019+A1:2021 supersedes PD 7974-7:2019, which is withdrawn.

## Relationship to other publications

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 service intervention (Sub-system 5)*;
- PD 7974-6, *Occupant evacuation, behaviour and condition (Sub-system 6)*; and
- PD 7974-7, *Probabilistic fire risk assessment*.

This series of Published Documents are intended to be used in support of BS 7974, but do not represent the only means of satisfying the recommendations of the code of practice.

Where appropriate, references to relevant standards are provided in order to assist the reader in understanding the design methodologies presented and to compare different approaches or sources of data. It is therefore important that PD 7974-7 is not used in isolation and reference is made to the relevant standards, particularly in relation to additional notes and subclauses describing its application.

## Information about this document

Text introduced or altered by Amendment No. 1 is indicated in the text by tags  . Minor editorial changes are not tagged.

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Where websites and webpages have been cited, they are provided for ease of reference and are correct at the time of publication. The location of a webpage or website, or its contents, cannot be guaranteed.

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This publication is not to be regarded as a British Standard.

As a guide, this Published Document takes the form of guidance and recommendations. It should not be quoted as if it were a specification or a code of practice and claims of compliance cannot be made to it.

It has been assumed in the preparation of this Published Document 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 guidance in this Published Document is presented in roman (i.e. upright) type. Any 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.**



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## 1 Scope

This Published Document provides guidance on probabilistic risk analysis in support of [BS 7974](#). It sets out the situations in which a probabilistic risk assessment can add value to traditional deterministic analyses and outlines acceptance criteria for the assessment. Furthermore, common analysis techniques of probabilistic risk assessment are summarily discussed.

This Published Document also includes data for probabilistic risk assessment based on fire statistics, building characteristics and reliability of fire protection systems.

This Published Document does not contain guidance on techniques for hazard identification or qualitative risk analysis.

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## 2 Normative references

There are no normative references in this document.

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## 3 Terms and definitions

For the purposes of this Published Document, the following terms and definitions apply.

### 3.1 As Low As Reasonably Practicable (ALARP)

where all reasonable measures are taken in respect of risks to reduce them further until the cost of further risk reduction is grossly disproportionate to the benefit

### 3.2 assessment

undertaking of an investigation in order to arrive at a judgement based on evidence

### 3.3 availability

ability of a system to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided

### 3.4 conditional probability

probability of an event given the occurrence of a preceding event

### 3.5 consequences

severity of the outcome of an event

### 3.6 deterministic

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

### 3.7 event

something happening or that has happened that can be made up of several but mutually exclusive occurrences

### 3.8 failure mode

predicted or observed results of a failure cause on a stated item in relation to the operating conditions at the time of the failure

**3.9 frequency**

probability that an event will happen over a period of time

**3.10 hazard**

situation with a potential for undesirable consequences

**3.11 individual risk**

frequency at which an individual can be expected to sustain a given level of harm from the realization of specified hazards

**3.12 initiating event**

event that leads to other events and one or more outcomes

**3.13 maintenance**

combination of all technical and administrative actions including supervision actions intended to retain a product in, or restore it to, a state in which it can perform a required function

**3.14 outcome**

result of a chain of events

**3.15 probabilistic model**

methodology to determine statistically the probability and outcome of events

**3.16 probability distribution**

mathematical function expressing the probability attached to any value of a random variable

**3.17 reliability**

ability of an item to perform a required function under stated conditions for a stated period of time

**3.18 risk**

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

**3.19 safety**

freedom from an unacceptable risk of harm

**3.20 scenario**

set of circumstances and/or an order of events in a fire incident that are feasible and reasonably foreseeable

**3.21 societal risk**

relationship between frequency of occurrence and the number of people in a given population suffering from a specified level of harm from the realization of specified hazards

**3.22 stochastic**

uncertain

*NOTE the value of a stochastic variable could be analysed statistically but might not be predicted precisely.*

## 4 Design approach

### 4.1 Objective and use of probabilistic risk assessment or analysis (PRA) in fire safety engineering

#### 4.1.1 General

The fire safety design aims to satisfy the fire safety objectives derived from the stakeholders' fire safety goals.

The acceptability of the design can often be demonstrated using deterministic design methods described in other published documents. However, there are situations where explicit calculation of risk by a PRA is necessary to demonstrate acceptability or where it would be of benefit to use a PRA, e.g. a PRA can be used to rank the performance of design alternatives (whereas, potentially, no safety preference could be identified through a deterministic analysis), which enables a better-informed options appraisal.

These aspects are discussed in more detail in [4.1.2](#) to [4.1.4](#).

*NOTE "Safety" is used as a generic term and applies to all fire safety objectives. An "adequately safe" design has both an adequately low risk level and a range of possible consequences which are all either considered acceptable or have negligible probability.*

#### 4.1.2 Safety basis of deterministic design methods

Most buildings constructed can be considered common in the context of typical fire safety engineering design, with the design basis deterministic (i.e. absent of an explicit safety target). The attainment of adequate safety is assumed to arise from the application of the method and tools, either through the following of specific guidance, or through the satisfaction of performance criteria adopted by the designer. Necessarily, the assumption of attainment of adequate safety for deterministic designs can only be based on one or both of two fundamental "safety foundations":

- a) collective experience of the profession, i.e. continuous application of longstanding design approaches has not resulted in observations of unacceptable performance in multiple fire events. In this case, the absence of experiences of not fulfilling fire safety objectives is adopted as a proxy for meeting fire safety objectives. Achieving adequate safety is through precedent and is assumed to emerge from "corrective measures" when observed examples of performance are deemed unacceptable by society; and/or
- b) a large level of conservatism, i.e. conservatisms are introduced into one or more of the inputs, scenarios and/or performance criteria, and the demonstration of performance under such inputs/ conditions is considered to result in an adequate design. This safety foundation requires that the physics of the fire and the basis of the performance criteria are understood. Due to the highly nonlinear behaviour and complexity of many fire phenomena this is not always the case. Consequently, a design based on a "large level of conservativeness" is considered as a special case of a design based on the "collective experience of the profession" (i.e. relying upon engineering judgement, either at an individual or collective level).

*NOTE For further information, see Certain Uncertainty – Demonstrating safety in fire engineering and the need for safety targets [1] and The need for hierarchies of acceptance criteria for probabilistic risk assessments in fire engineering [2].*

Large levels of conservativeness should be quantified or at least specified further.

As no explicit evaluation of the probability of each scenario is made, the actual risk or level of safety remains unknown.

When multiple design options are being considered (where all options achieve the deterministic acceptance criteria), no risk-based preference exists. Any preference between the designs is then solely determined by considering criteria, e.g. ease of maintenance, aesthetics, without understanding the relative level of risk associated with each option.

#### **4.1.3 Objective and use of PRA**

##### **4.1.3.1 General**

There are two main objectives for using PRA:

- a) to demonstrate adequate safety; and
- b) to rank design alternatives with respect to safety performance.

##### **4.1.3.2 Use of PRA to demonstrate adequate safety**

In specific cases it might not be possible to assume adequate safety through a deterministic evaluation. For example, the uniqueness of the proposed design or the use of a new building material might make it impossible to rely on the experience of the profession, or application of a large level of conservativeness in the scenario assumptions might impose undue restrictions or cost. In those situations, PRA can be used to explicitly demonstrate adequate safety, by taking into account the uncertainties associated with the design and fire scenarios.

It is possible to combine deterministic approaches and PRA in the overall fire safety strategy, i.e. probabilistic fire risk assessment can be used as part of the analysis of any or all of the sub-systems. This is clarified further in [4.2](#).

##### **4.1.3.3 Use of PRA to rank design alternatives**

A second (optional) object of PRA is the comparison of design alternatives with respect to their safety performance and reliability. Whilst a deterministic evaluation could result in two candidate designs achieving the acceptance criterion, a PRA can enhance the assessment by taking into account the associated probabilities. In these cases it is possible that two designs with the same deterministic performance level are found to have a very different reliability; the safety level of the more reliable design is higher.

In a more extensive PRA the full range of possible consequences of a fire event and their associated probabilities can be assessed. This gives the stakeholders a much better understanding of the fire safety performance of the design and could highlight trade-offs between low-probability high-consequence events and low-consequence higher-probability events.

#### **4.1.4 Note on deterministic – PRA hybrid approaches**

PRA can be used to select input data for further deterministic analysis. It is important to emphasize that the achievement of adequate safety in these cases is, at least partially, founded on the explicit probability evaluation; therefore all (apparently) hybrid methods should be classified as PRA.

### **4.2 Steps in a PRA and layout of this published document**

#### **4.2.1 General**

PRA can be used to demonstrate adequate fire safety of a design with respect to specific or all identified fire safety design objectives. In this case, PRA fits into the overall design strategy as indicated in [4.2.2](#), based on the *SFPE Engineering Guide to Performance-Based Fire Protection* [3]. The steps in the specific analysis for the design objective with PRA methods are indicated in [4.2.3](#).

Where PRA is used to rank the performance of different acceptable design alternatives, the analysis steps discussed in [4.2.3](#) directly apply.

### 4.2.2 Flowchart for demonstrating adequate safety of a design

Figure 1 gives a flowchart illustrating how PRA fits in the design process. The need to apply PRA follows directly from the observation that either:

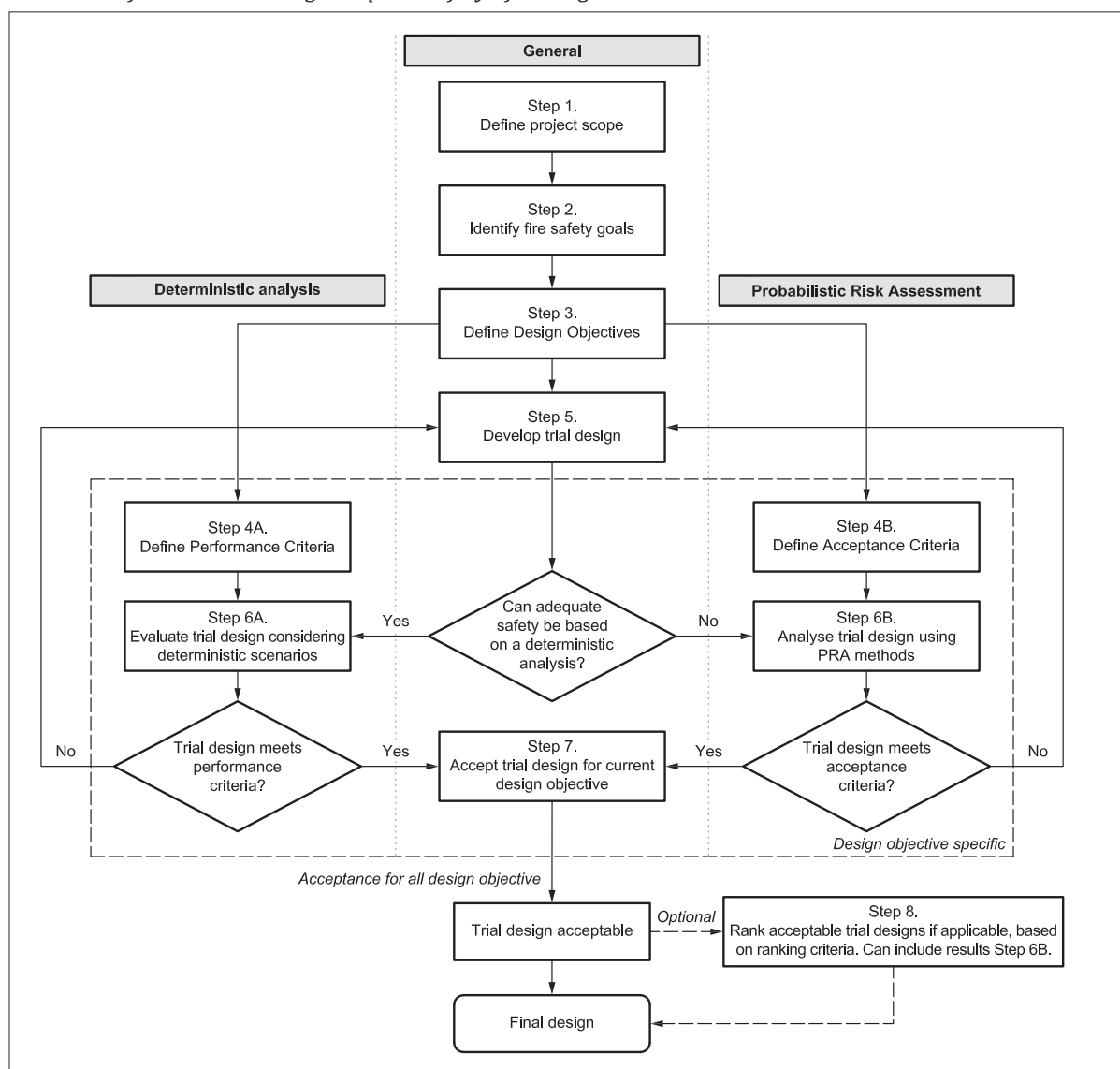
- the acceptability of the proposed trial design cannot be based on the experience of the profession, or
- use of a large level of conservativeness results in an undue design.

The designer can choose to use a PRA in situations where the acceptability of the design is sufficiently demonstrated with deterministic methods. The PRA generates additional information regarding the performance of the design that could be useful, e.g. ranking of design alternatives, stakeholder information.

Detailed discussion on the different steps relating to PRA is included in this Published Document.

*NOTE* See 4.2.4 for the layout of this published document and its relation to the flowchart in Figure 1.

**Figure 1** — Flowchart for demonstrating adequate safety of a design

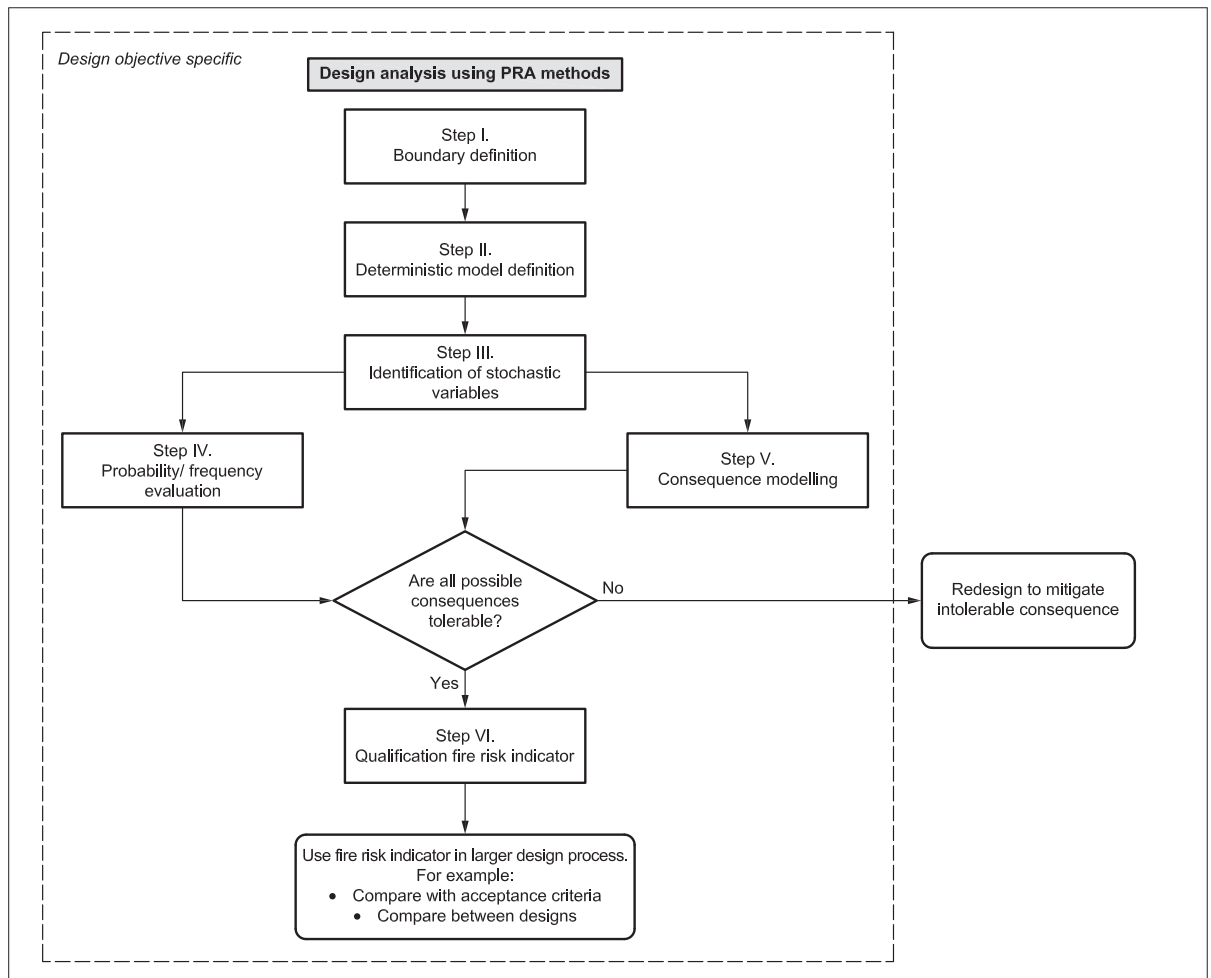


### 4.2.3 Flowchart for analysis of trial design using PRA methods

The general sub-steps in the analysis of a trial design with PRA methods, i.e. sub-steps to Step 6B in the general flowchart of [Figure 1](#), are listed in [Figure 2](#). The specifics depend on the analysis methodology used.

*NOTE The comparison of the calculated risk indicator with the PRA acceptance criteria is part of the larger design process given in [Figure 1](#).*

**Figure 2** — General flowchart for design assessment using PRA methods



### 4.2.4 Layout of this Published Document

[Figure 3](#) applies for a design fully assessed by PRA, and identifies the specific aspects within the scope of this Published Document.

*NOTE 1 A hybrid deterministic and PRA-based design is possible.*

[Clause 5](#) provides guidance on acceptance criteria for PRA. The definition of acceptance criteria is especially important and care should be taken to ensure that the concepts listed in [Clause 5](#) are critically applied.

[Clause 6](#) provides guidance on the following steps in the PRA analysis:

- common methods for calculating probabilities, see [6.2](#);
- specific aspects regarding consequence modelling, see [6.3](#);

*NOTE 2 [6.3](#) includes the relationship between probabilities and consequences. The models used for the evaluation of specific consequences are outside the scope of this Published Document.*

- c) specifics on the quantification of the risk indicator, see [6.4](#);
- d) uncertainty and sensitivity analysis, see [6.5](#); and
- e) special topics, including a discussion on the identification of variables featuring uncertainty, see [6.5](#).

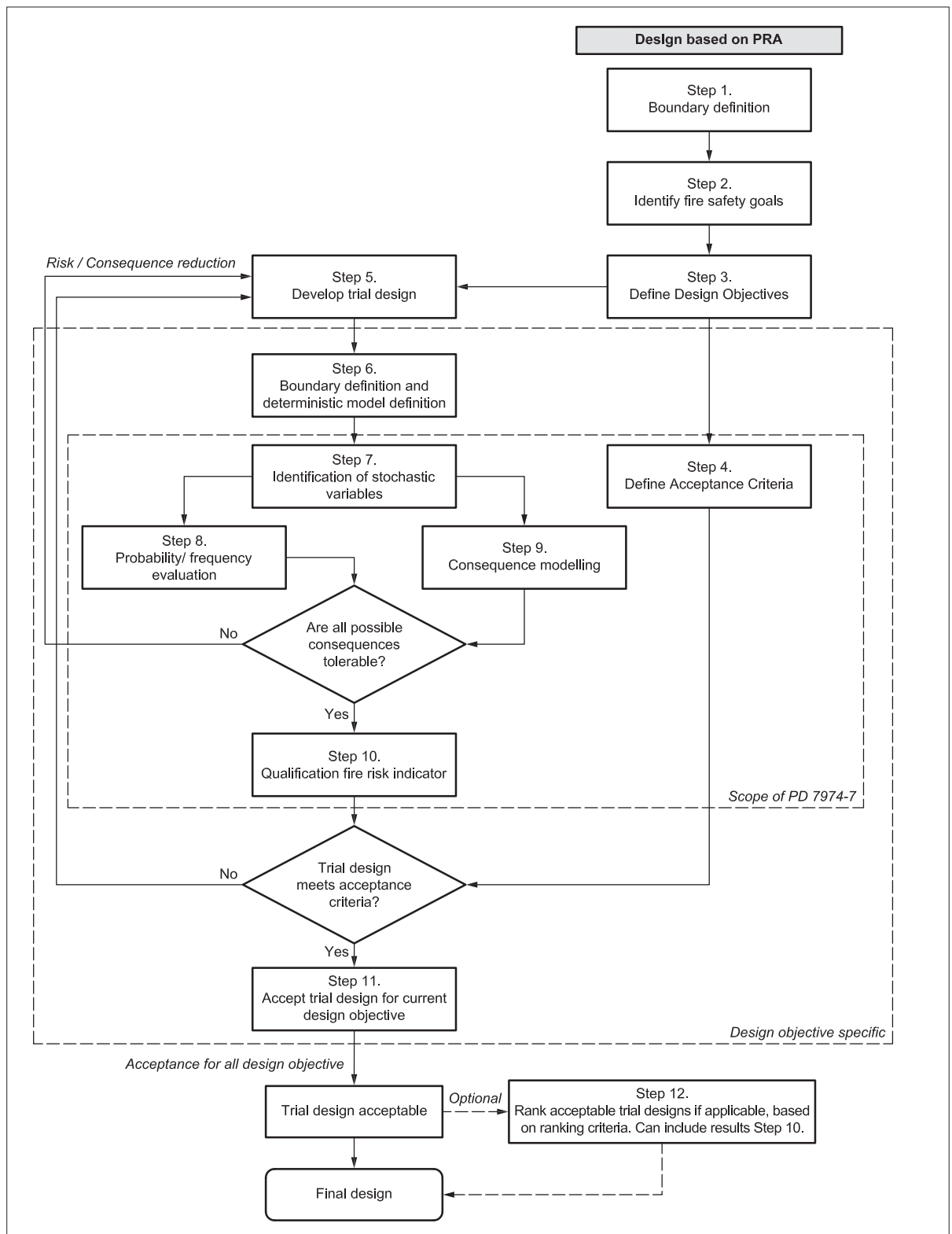
Although denoted as special topics, the issues highlighted in [6.5](#) should be clearly understood by the engineer applying PRA as they can have significant influence on the acceptance criteria, and on the PRA modelling.

[Clause 7](#) details special attention for the collection of data, considering its importance for PRA.

[Annex A](#) provides acceptance and tolerability criteria.

[Annex B](#) provides statistical reference data.

[Annex C](#) provides further commentary on the acceptance criteria (see also [Clause 5](#)).

**Figure 3** — Consolidated flowchart for a design through PRA

## 5 Acceptance criteria

### 5.1 General

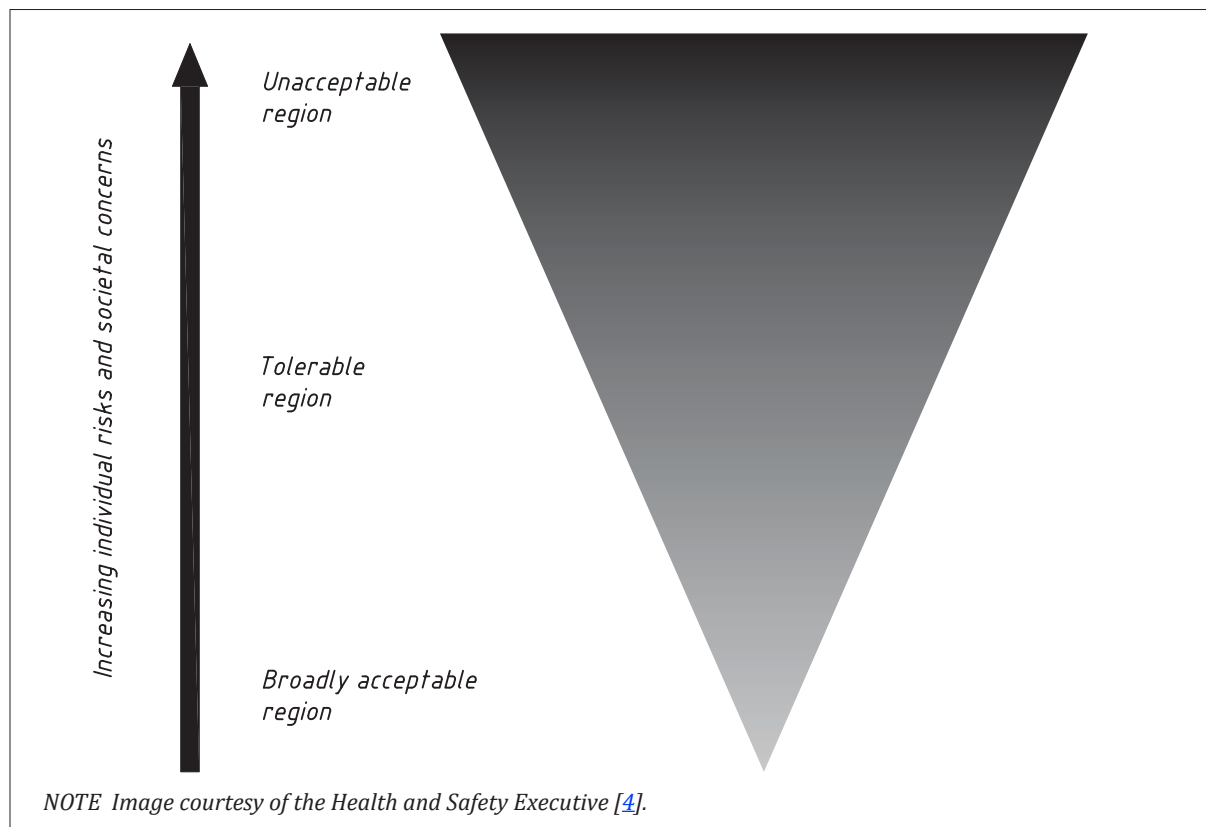
#### 5.1.1 Introduction and background to the definition of acceptance criteria

Acceptance criteria should be defined for each of the fire safety objectives considered in the PRA (see [Figure 3](#)). The acceptance criteria are set such that the risk is acceptably low and an adequate safety level is obtained (see [Figure 4](#), which illustrates the principle of risk and different levels of acceptability).

The acceptance criteria depend on the specific fire safety objectives, and should, in principle, be defined through a consultation with the stakeholders.

- a) The fire safety objectives can relate to purely private considerations, e.g. to limit the downtime in a production facility after a fire. In these cases the acceptance criteria are freely determined through discussion with the private stakeholders.
- b) Most fire safety objectives relate to societal requirements, e.g. the fire safety objectives of life safety, environmental protection, heritage protection.
- c) The fire safety objective of property protection often has a societal dimension, resulting from indirect damages, as well as a private consideration.

**Figure 4** — One-dimensional representation of generalized consequence-frequency (FC)



#### 5.1.2 Societal requirements and private decision-making

For a given fire safety objective, private stakeholders are in principle free in their subjective evaluation and preferred safety investments. Societal requirements impose a lower bound (i.e. minimum requirement) to the investment level. In all situations the private safety investment is

allowed to exceed the societal requirement, as long as the increased investments do not infringe on other societal requirements.

### 5.1.3 Risk perception and societal risk acceptance

Risk perception is fundamentally subjective.

A vision zero strategy, where safety investments are made irrespective of costs and efficiency, is not tenable as it puts undue strain on limited societal and private resources. Requiring inefficient safety investments results in a net loss of life when more efficient safety investments are available. Therefore every building or facility has a residual risk level even after all required fire safety measures have been implemented.

This residual risk level cannot be expected to satisfy the subjective expectations of all individual members of society.

*NOTE 1 For further information, see Reducing risks, protecting people [5].*

The acceptance criteria are defined to provide an adequate safety level for societal acceptance.

*NOTE 2 For further information, see Laws of Fear. Beyond the Precautionary Principle [6].*

### 5.1.4 Fundamental basis underlying the definition of acceptance criteria for fire safety

The acceptance criteria aim to maximize societal welfare through a balancing of risks across domains, whilst acknowledging societal risk preferences. Applied to the fire safety objective of life safety, the acceptance criteria aim to maximize the number of lives saved across domains, under a constraint of societal tolerability.

## 5.2 General framework for the definition of acceptance criteria

### 5.2.1 Introduction and hierarchy of acceptance criteria

A risk that exceeds the tolerability limit (see [Figure 5](#)) cannot be justified irrespective of the associated benefits. Adequate safety necessarily implies that the risk is not intolerable.

Designs which are tolerable are only acceptable if the risk is “As Low As Reasonably Practicable” (ALARP), unless the risk is “negligible”.

- a) A design is acceptable in accordance with the ALARP criterion when all reasonably practicable risk reduction measures have been implemented. A risk reduction measure can be considered not to be reasonably practicable if the factors in terms of time, difficulty of implementation or other would be grossly disproportionate to the risk reduction (or safety benefit).

When the risk is negligible, no further justification is required.

*NOTE 1 The HSE refers to these risks as being “broadly acceptable” [4].*

- b) Additional measures could be implemented, e.g. by following ALARP principles.

Formally the ALARP requirement still applies, implying that known reasonably practical measures which are available should be implemented.

*NOTE 2 Whilst this might seem anomalous, some approaches can be implicitly assumed to be ALARP (without a need for an explicit ALARP analysis).*

*NOTE 3 A flowchart indicating possible acceptance criteria is given in [Figure 6](#). An overview of the acceptance criteria AC1-AC5 is given in [Annex C](#). Application to the fire safety objective of life safety is given in [5.4](#).*

This clause assumes that the design’s performance with respect to different fire safety objectives can be assessed for each fire safety objective independently. If stakeholder consultation indicates that this assumption cannot be maintained, a multi-dimensional assessment is required (although the concepts in this clause can still be applied).

The necessary parameters, e.g. tolerability limits, absolute (approximate) ALARP thresholds, are dependent on the fire safety objective and should be determined through discussion with the stakeholders. For some safety objectives, e.g. environmental emissions, commonly accepted thresholds might exist. For others, e.g. heritage protection, an elaborate elicitation is required.

**Figure 5** — Generalized consequence-frequency (FC) diagram with indication of tolerability limit and negligible limit

