PD 7974-5:2014

BSI Standards Publication

PUBLISHED DOCUMENT

Application of fire safety engineering principles to the design of buildings

Part 5: Fire and rescue service intervention (Sub-system 5)

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This document comprises a front cover, an inside front cover, pages i to ii, pages 1 to 56, an inside back cover and a back cover.

Foreword

Publishing information

This Published Document is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 30 November 2014. It was prepared by Panel FSH/24/-/3, *Revision of PD 7974-5*, under the authority of 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This Published Document supersedes PD 7974-5:2002, which is withdrawn.

Relationship with other publications

This Published Document takes information on building characteristics and the design fire from the qualitative design review (QDR) together with the time of fire service notification from sub-system 4 (PD 7974-4) and the time of evacuation from sub-system 6 (PD 7974-6). It provides information on the effect of fire service activities on the growth of the fire, which is used by sub-system 1 (PD 7974-1).

PD 7974-5 is a new part of the PD 7974 series. The series comprises:

- Part 0: *Guide to design framework and fire safety engineering procedures*;
- Part 1: *Initiation and development of fire within the enclosure of origin (Sub-system 1)*;
- Part 2: *Spread of smoke and toxic gases within and beyond the enclosure of origin (Sub-system 2)*;
- Part 3: *Structural response and fire spread beyond the enclosure of origin (Sub-system 3)*;
- Part 4: *Detection of fire and activation of fire protection systems (Sub-system 4)*;
- Part 5: *Fire and rescue service intervention (Sub-system 5)*;
- Part 6: *Human factors – Life safety strategies – Occupant evacuation, behaviour and condition (Sub-system 6)*;
- Part 7: *Probabilistic risk assessment*;
- Part 8: *Property protection, business and mission continuity, and resilience*.

These Published Documents are intended to be used in support of BS 7974.

Information about this document

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

- the standard has been rewritten to accommodate changes resulting from the National standards of fire cover having been withdrawn and replaced by locally determined standards of fire cover developed through a process called "integrated risk management planning";
- guidance is provided on the relationship between building design and fire and rescue service operating procedures.

Use of this document

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.

Presentational conventions

The guidance in this standard 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.

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 Published Document cannot confer immunity from legal obligations.

Introduction

This Published Document is one of a series of documents intended to support BS 7974. BS 7974 provides a framework for developing a rational methodology for design using a fire safety engineering approach through the application of scientific and engineering principles to the protection of people, property and the environment from fire. The Published Documents (PDs) contain guidance and information on how to undertake quantitative and detailed analysis of specific aspects of the design. They are a summary of current practice and it is intended that they be updated as new theories, calculation methods and/or data become available. They do not preclude the use of appropriate methods and data from other sources. BS 7974 can be used to define one or more fire safety design issues to be addressed using fire safety engineering. The appropriate PD(s) can then be used to set specific acceptance criteria and/or to undertake detailed analysis. A fire safety engineering (FSE) approach that takes into account the total fire safety package can often provide a more fundamental and economical solution than more prescriptive approaches to fire safety. It might in some cases be the only viable means of achieving a satisfactory standard of fire safety in some large or complex buildings. Fire safety engineering can have many benefits. The use of BS 7974 can facilitate the practice of fire safety engineering and in particular it can:

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 on the management of fire safety for a building.

Fire is an extremely complex phenomenon and there are still gaps in the available knowledge. When used by suitably qualified persons, experienced in fire safety engineering, the series of documents can provide a means of establishing acceptable levels of fire safety economically and without imposing unnecessary constraints on aspects of building design.

1 Scope

This part of PD 7974 provides guidance on fire safety engineering and the necessary interaction with fire service intervention activities. This Published Document applies irrespective of whether the design objective, or fire service activities, are intended to support life safety, property, business, mission, or heritage protection objectives, as defined in the qualitative design review (QDR) process described in BS 7974 and PD 7974-0. The guidance provides an understanding of both the capabilities and limitations of fire service intervention, and takes into account the physiological demands on fire-fighters, the fire-fighting procedures that are used and the limitations of fire-fighting equipment.

This part of PD 7974 is intended to be applied to the design of new and, where appropriate, the appraisal of existing, buildings and plant.

It also contains analytical tools that allow an analysis of fire and rescue service intervention and offers a range of approaches that could improve the efficiency and effectiveness of fire and rescue service intervention if analysis indicates that design objectives might not be achieved.

The fire and rescue service can request access and facilities to assist them with emergencies other than fire. The recommendations contained in this document could be of value when considering such requests but the primary purpose of this document is concerned with fire.

2 Normative references

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

Standards publications

BS 7974:2001, *Application of fire safety engineering principles to the design of buildings – Code of practice*

BS 9990, *Code of practice for non-automatic fire-fighting systems in buildings*

BS 9999:2008, *Code of practice for fire safety in the design, management and use of buildings*

BS EN 81-72, *Safety rules for the construction and installation of lifts – Particular applications for passenger and goods passenger lifts – Part 72: Firefighters lifts*

PD 7974-1, *Application of fire safety engineering principles to the design of buildings – Part 1: Initiation and development of fire within the enclosure of origin (Sub-system 1)*

PD 7974-3, *Application of fire safety engineering principles to the design of buildings – Part 3: Structural response and fire spread beyond the enclosure of origin (Sub-system 3)*

PD 7974-4, *Application of fire safety engineering principles to the design of buildings – Part 4: Detection of fire and activation of fire protection systems (Sub-system 4)*

PD 7974-6, *Application of fire safety engineering principles to the design of buildings – Part 6: Human factors – Life safety strategies – Occupant evacuation, behaviour and condition (Sub-system 6)*

PD 7974-8:2012, *Application of fire safety engineering principles to the design of buildings – Part 8: Property protection, business and mission continuity, and resilience*

3 Terms and definitions

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

3.1 attendance

a) fire appliances that are at the incident or are on their way to the incident;

b) act or process of a fire appliance being mobilized and travelling to an incident

NOTE For the fire and rescue service, the word "attendance" has a slightly different meaning depending on the context in which it is used. Since this Published Document aims to achieve effective interaction between the fire engineer and the fire and rescue service, the fire and rescue service terminology is used within the text.

3.2 attendance time (Δt_{attend})

duration of time that passes between the fire and rescue service control room being notified that a fire appliance is required and the arrival of the fire appliance at the site

3.3 bridgehead

part of a building, usually the floor below the fire (floor above in the case of basements), from which fire-fighting teams can be safely committed to attack a fire

3.4 intervention (fire and rescue service)

all the activities of the fire and rescue service from the receipt of an emergency call right through to the end of their involvement with an incident

3.5 in attendance

being present at the scene of the incident

3.6 place of relative safety

place in which there is no immediate danger, but in which there could be future danger, from the effects of fire

[SOURCE: BS 9999:2008, **3.83**]

3.7 preparation time

time that the fire and rescue service spend, after arrival at the scene of a fire, gathering information, preparing an operational plan and ensuring that operational resources are in place

3.8 safe areas or refuge floors

rooms or floors or areas set aside to provide places of temporary refuge within buildings; such locations are provided with a very high degree of fire protection and can be provided with their own independent air supply

NOTE A safe area or refuge floor is a special case of a place of relative safety in that it is expected that people remain there for a period of time rather than be in transit to a place of ultimate safety.

3.9 tactical operations

implementation of an operational plan by the fire and rescue service; typically leading to and including fire-fighting and/or rescue; tactical operations begin following the end of preparation time

4 General guidance

4.1 The qualitative design review

This Published Document provides guidance on the capabilities of the fire service to:

- contribute to life safety by rescue (under exceptional circumstances – see **5.2**); and
- reduce the effect of a fire on the structure, contents and overall operation of the building.

Information on fire safety engineering (FSE) design objectives and the acceptance criteria are provided by the qualitative design review (QDR). Where achieving design objectives relies upon fire and rescue service intervention, the nature of that intervention and the provision of necessary access and facilities for the fire and rescue service should be included in the QDR.

For large and complex projects, the QDR should be carried out by a study team involving one or more fire safety engineers, other members of the design team and a member of operational management. For smaller projects however, the QDR may be carried out by a smaller study group but the same basic review process should be followed.

The make-up of the QDR team should be based on the nature and size of the project and on the extent of the analysis conducted. When the analysis being conducted relates to fire and rescue service intervention, the QDR team should comprise the fire safety engineer and a representative from the fire and rescue service as a minimum.

4.2 Overview of fire and rescue service intervention

COMMENTARY ON ***4.2***

Fire-fighters take calculated risks to carry out their job. However, the amount of risk that they are prepared to take depends on the potential outcome. For example, in order to attempt to save life, fire-fighters might take more risk than they would in order to attempt to save property.

If property protection, loss control and/or environmental protection are FSE design objectives, the provisions of this Published Document may be followed to assess the potential fire and rescue service response to an incident, and to consider whether additional fire protection measures could be appropriate to fulfil the aforementioned objectives.

If only life safety facilities are provided in a fire engineered building, the fire and rescue service might see fire-fighting as being high risk and not intervene to save property. If improved facilities for the fire and rescue service are engineered into the building, the fire and rescue service might see fire-fighting as being lower risk and be more likely to intervene to save property.

Fire and rescue service intervention can be divided into a number of stages: the receipt of an emergency call and driving to the scene, gaining access to the site, gathering information, setting up equipment, gaining access to the building, movement within the building and finally rescue or fire-fighting. If improved facilities for the fire and rescue service are engineered into the building, the duration of these activities can be reduced, and the likelihood of achieving design objectives might be increased.

Figure 1 shows the potential inputs that could impact upon fire and rescue service intervention.

4.3 Analysis

The factors to be taken into account when analyzing the effectiveness of fire and rescue service intervention derive from both the fire and rescue service and the building design and are identified as inputs.

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 code compliant solution without the need for any calculations.

When analysis of fire and rescue service intervention has been completed, the outputs should be compared against the design objectives and the acceptance criteria.

If the comparison is satisfactory, the results may be reported. If the comparison is unsatisfactory, the process should return to the QDR where alternative fire and rescue service information and/or building design approaches should be identified or the design objectives should be reviewed.

NOTE See Figure 2 and Figure 3, which outline the processes.

Figure 1 **Potential inputs into sub-system 5**

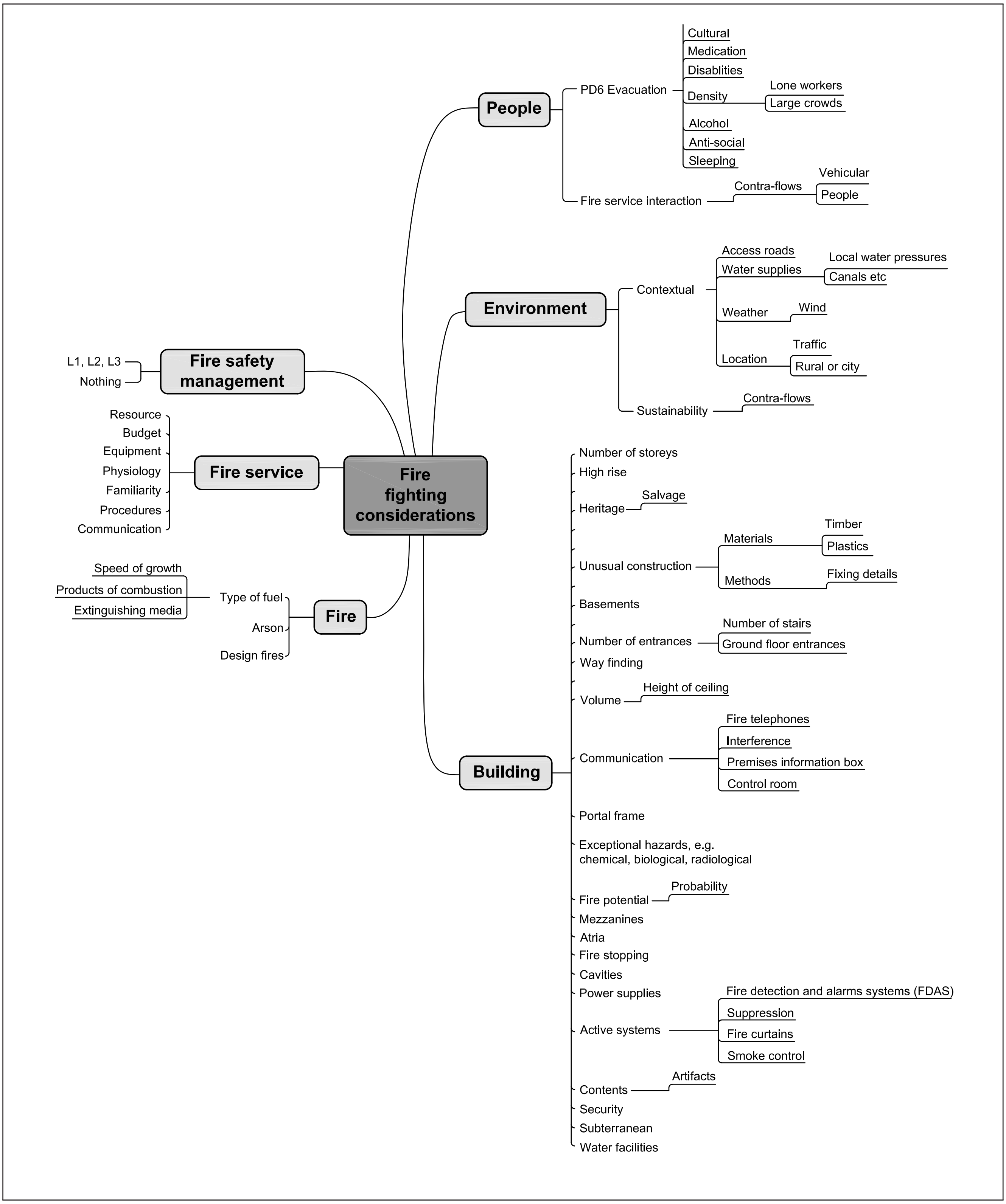
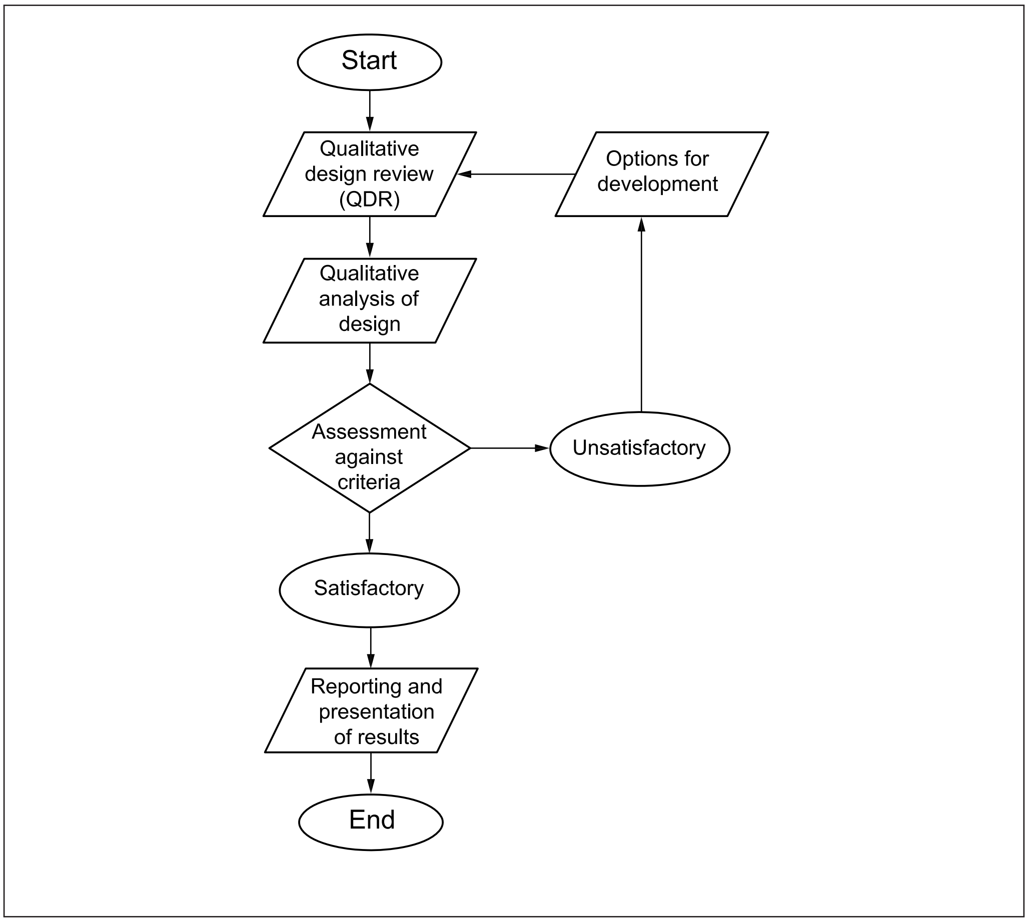


Figure 2 **Basic fire safety design process**



A statement should be produced regarding the capacity of the fire and rescue service to rescue casualties (in exceptional circumstances) and/or their capacity to contribute to loss control or the control of environmental damage. This can be quantified, for example, in terms of:

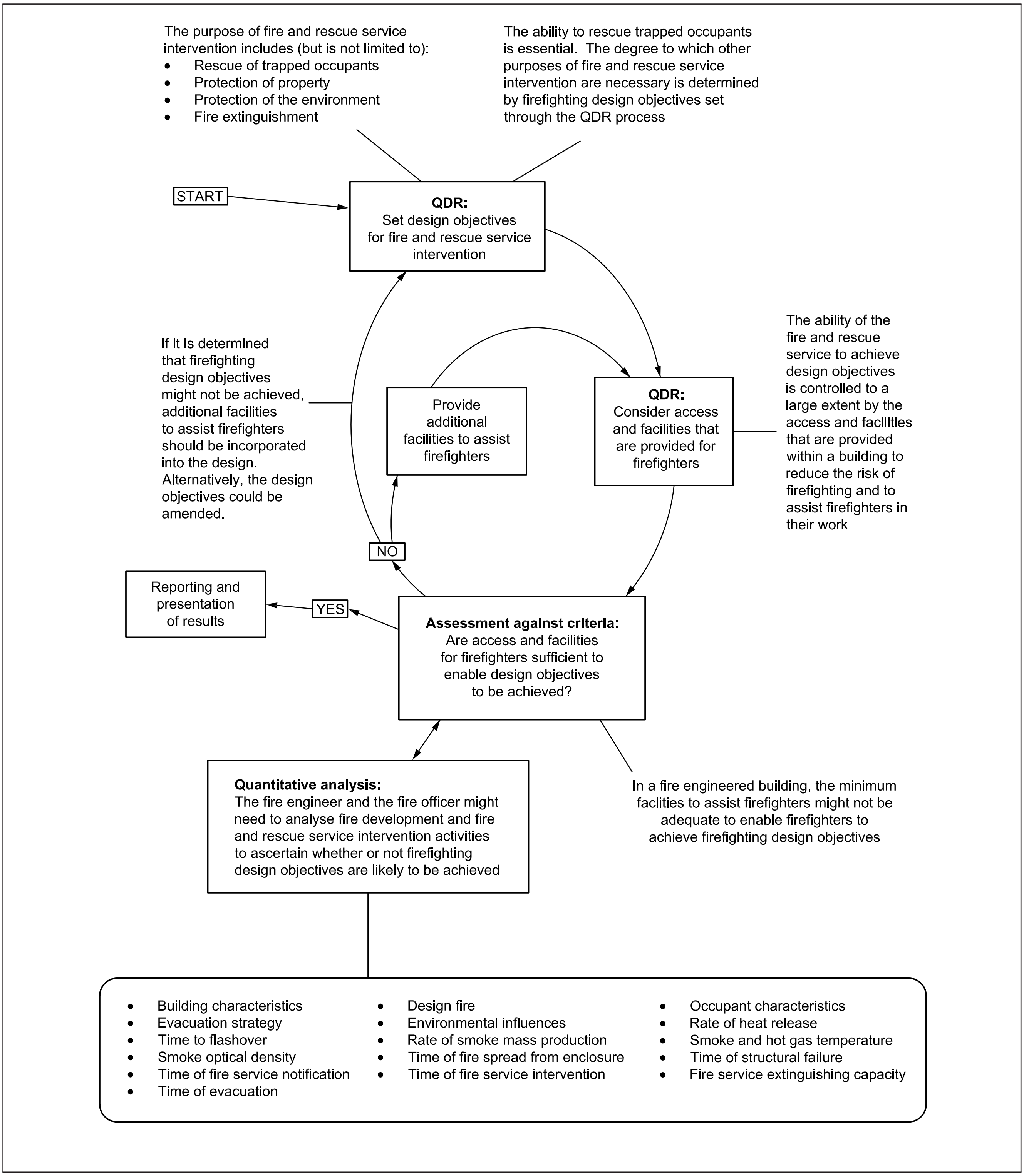
- the amount of property that is expected to be lost/saved by fire and rescue service intervention; or
- the amount of pollutants expected to be produced by a fire (airborne and waterborne pollutants and also fire damaged materials that cannot be recycled).

The first time that fire and rescue service (FRS) intervention is modelled, the desired outcomes might not be achieved. If this is the case, the QDR team should identify the fire and rescue service information (Clause **6**) and the design and building information (Clause **7**) (and any other measures identified by the QDR) that could be improved to increase the effectiveness of intervention.

If analysis suggests that fire and rescue service intervention might not achieve the design objectives, the distribution of fire and rescue service resources and fire-fighting procedures are overriding constraints that can only be altered at the discretion of the fire and rescue service.

The fire and rescue service’s influence on, or response to, building design factors varies depending on the fire and rescue service concerned. It is therefore essential that the fire and rescue service are involved throughout the QDR process, as any element of the QDR can have an impact on fire and rescue service intervention.

Figure 3 **Fire and rescue service intervention design process**



5 Design objectives

5.1 Selection of design objectives

At an early stage of the design process, the objectives of the fire safety design should be clearly defined and the acceptance criteria established. The protection of life is the main objective of fire safety legislation; however, the effects of fire and its products on the on-going operations of a business and direct property losses should also be taken into account.

The objectives and criteria for the particular study should be established during the QDR. The main fire safety objectives that are addressed when carrying out a fire engineering study are:

a) life safety;

b) loss control;

c) property protection; and

d) environmental protection.

NOTE 1 This list is not exhaustive; not all items are appropriate to a particular study.

NOTE 2 See BS 7974:2001, ***6.4.3****.*

Whatever the FSE design objectives, the provisions of this Published Document should be followed in an FSE design approach to ensure that those objectives can be supported by fire and rescue service intervention.

5.2 Life safety

The FSE design of a building should enable occupants of the building to be protected from fire, or to evacuate, without external assistance. However, there might be exceptional circumstances where the fire and rescue service have to assist with evacuation or even rescue occupants, for example:

- occupants being injured prior to their escape;
- unforeseeable fire growth overwhelming protection systems; or
- the failure of fire protection systems despite planned preventative maintenance and servicing.

In addition, the response of the fire and rescue service should take into account other factors affecting safety of the building occupants. For example:

- If evacuation is not completed by the time the fire and rescue service attend, fire-fighters might choose to assist with evacuation before they begin fire-fighting.
- In buildings with a “defend in place”, progressive horizontal evacuation or a phased evacuation strategy, the fire and rescue service might choose to initiate a wider evacuation if the circumstances of the fire are unfavourable.

5.3 Loss control and environmental protection

Fire safety engineering design objectives such as loss control and environmental protection should also be taken into account (see BS 7974 and PD 7974-8). These include:

a) damage to the structure and fabric of the building;

b) the loss of building contents;

c) risk to the on-going business viability;

d) damage to the corporate image;

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

f) the release of hazardous materials into the environment including stored hazardous materials, building materials damaged by fire, combustion products and fire-fighting water run-off;

g) the effect of fire and smoke on the viability of the surrounding transport infrastructure; and

h) loss of heritage buildings and valuable/historic artefacts.

NOTE See PD 7974-8 for guidance on property protection, business and mission continuity and resilience.

6 Fire and rescue service information

6.1 Fire and rescue service characteristics

Inputs from the fire and rescue service include:

- the pre-determined attendance;
- additional fire appliances;
- attendance time;
- preparation time;
- tactical operations;
- physiology of fire-fighters; and
- building management/FRS interface.

6.2 Fire and rescue service intervention

Figure 4 illustrates a typical process of fire service activity from the time of call to the fire and rescue service. It assumes that no other intervention by other systems has occurred which might impact upon the development of the fire.

6.3 The pre-determined attendance

*COMMENTARY ON **6.3***

On receipt of a report of fire in a building, a fire and rescue service mobilizes fire appliances. The fire appliances that are mobilized initially are a fixed number that has been found to be adequate to deal with “typical case” fires dependent upon the type and use of the building and local fire and rescue service policy. These fire appliances are known collectively as the pre-determined attendance or PDA.

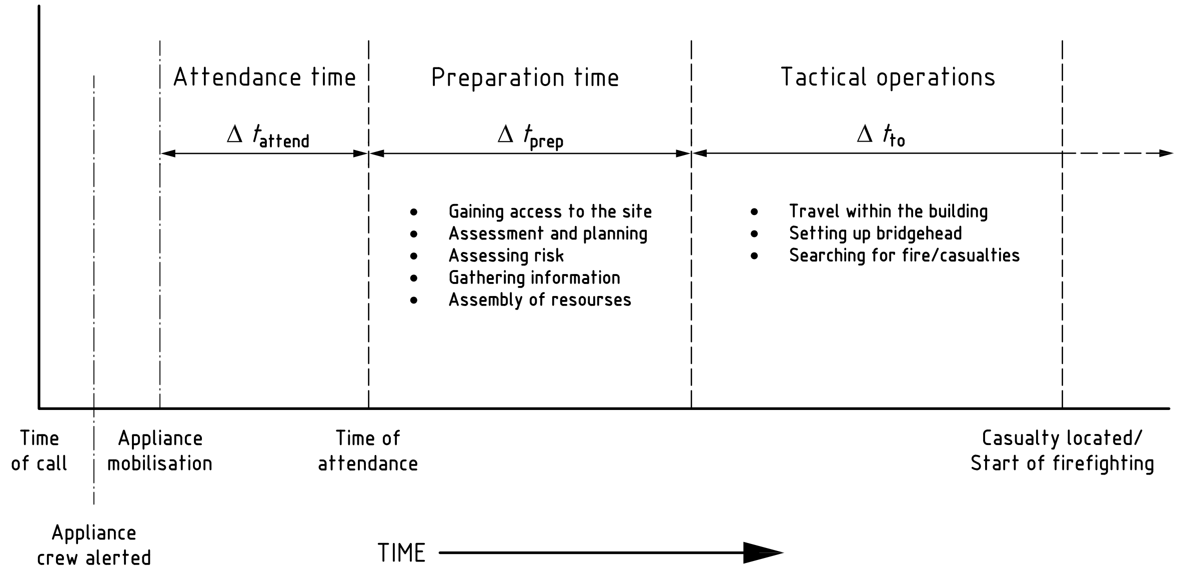
An FSE design solution is based on a “reasonable worst case” fire rather than a “typical case” fire so it is possible that the number of fire appliances in the PDA might be inadequate to deal with the FSE design fire.

Fire and rescue services do not mobilize a PDA that is large enough to deal with a reasonable worst case fire because the majority of fires in buildings are far less serious than this and mobilizing fire appliances creates risk to fire-fighters and other road users. Mobilizing a larger PDA on every occasion would create an excessive risk on the roads without an equivalent return of reduced risk at fires.

A fire and rescue service might mobilize additional fire appliances to a report of a fire in a building if reliable detailed information is passed to them at the time of the call indicating that the incident requires increased resources.

Once fire appliances have attended at the scene, the senior fire officer present may request additional fire appliances according to the perceived need.

Figure 4 **Fire and rescue service intervention**



NOTE 1 This figure is illustrative and some aspects might change or not be relevant dependent upon the fire being considered. For example, fire-fighting could take place entirely from the outside of the building, in which case, preparation time does not include travel time within the building. The precise nature of fire and rescue service intervention and the steps that comprise it form part of the QDR.

NOTE 2 The figure shows a simple linear process. At any reasonably large fire, intervention is not a linear process. Tactical operations take place at the same time as other fire-fighters elsewhere are preparing and other fire appliances are still travelling to the scene.

NOTE 3 The figure shows a demarcation line between preparation time and tactical operations, but in practice there is often no such clear demarcation. For example, connecting a fire hydrant to a fire appliance with a length of hose could equally be described as preparation or tactical operations. The demarcation is put in place here to break the process of intervention down into stages that can be analyzed to identify opportunities for improvement. The precise placement of fire-fighter activities in the timeline is not critical, as long as all activities are placed somewhere and are taken into account.

The following aspects of fire and rescue service attendance are required for an analysis of fire and rescue service intervention:

- the number and type of appliances (including the equipment carried) sent to an initial report of a fire in the building (PDA);

  NOTE 1 This could vary depending on whether the call is made in person by an occupant of the building or by an automatic system via a fire alarm monitoring organization.

- the predicted attendance times of the fire appliances that make up the PDA based on the location of fire stations and the distance to the building;

  NOTE 2 This could vary according to unpredictable parameters such as road and weather conditions, but it could also vary according to predictable parameters such as differences in day and night crewing systems.

- the nature and capability of the fire appliances; and
- the number of fire-fighters who are likely to attend on each fire appliance.

The local fire and rescue service should be involved throughout the QDR in order to establish the likely fire and rescue service response to a fire. Based on detailed knowledge of an FSE building, a fire and rescue service might choose to set a PDA specifically for that building, although the FSE design cannot be based on this assumption.

6.4 Additional fire appliances

If analysis suggests that the fire officer in charge who arrives with the appliances of the PDA might request additional fire appliances, aspects of their attendance are required for an analysis of fire and rescue service intervention:

- the attendance time of subsequent appliances that might be required if the initial pre-determined attendance is not adequate to deal with the fire;
- the attendance time of specialist appliances such as aerial appliances, control units and high volume pumps.

6.5 Attendance time

6.5.1 General

*COMMENTARY ON **6.5.1***

There are aspects of the attendance time of the fire and rescue service that are overriding constraints that cannot be altered by FSE.

The "pre-determined attendance" describes the number of fire appliances mobilized to an initial report of a fire. The "attendance time" describes the time that it takes for fire appliances to attend after the fire and rescue service has been called.

There is no national standard attendance time in the UK. Each fire and rescue service sets its own standard as part of their integrated risk management plan. Individual fire and rescue services publish the maximum attendance time that they aim to achieve on the majority of occasions.

The fire and rescue service should be involved in the QDR so that fire officers can provide a more detailed explanation of the attendance time that can be expected in a given situation.

6.5.2 Fire and rescue service policies

*COMMENTARY ON **6.5.2***

Different fire and rescue services have different policies for responding to automatically generated signals passed via fire alarm monitoring organizations. Fire control operators always mobilize fire appliances if an emergency telephone call is received which states that there are signs of fire, but they might challenge the caller if the only information passed is that the fire alarm has actuated.

Different fire and rescue services set different attendance time standards and they are expressed in different ways. One fire and rescue service might describe their standard as "one appliance in an average of eight minutes", while another could describe their standard as "one appliance in ten minutes on 80% of occasions".

One appliance in an average of eight minutes does not give any information about the expected maximum or minimum attendance time for any given location. One appliance in ten minutes on 80% of occasions does not give any information about the expected maximum attendance time for the other 20% of occasions. Advice should therefore be sought from the fire and rescue service as to the meaning of their attendance standard and, where intervention modelling is critical, the reasonably foreseeable range of attendance times that can be expected for the area in which the building is situated.

To reduce attendance time, the policies of the local fire and rescue service should be clearly understood, and the systems and procedures in the building for calling the fire and rescue service should be fully integrated with those policies. For example, the fire and rescue service might request detailed information to verify the call (call challenging). If there are systems and procedures in place for providing this verification, attendance time could be reduced.

6.6 Preparation time

*COMMENTARY ON **6.6***

Once a fire appliance arrives at the scene of an incident (t_{attend}), a number of activities are undertaken before the commencement of rescue or fire-fighting operations.

Activities could include gaining access to the site of a building through security gates, assessing the incident and gathering information about the building and the fire, gaining access to the building, removing equipment from the fire appliance, running out hose from a water supply to the fire appliance and from the fire appliance to the building.

All of these activities take time, and together they are described as preparation time (Δt_{prep}).

The safety of fire-fighters and the effectiveness of intervention could be improved by engineering measures into the fire safety strategy that reduce preparation time. Such measures therefore increase the likelihood that design objectives are achieved.

For any given fire scenario, analysis of fire and rescue service intervention should predict an appropriate time interval between fire and rescue service attendance and the start of tactical operations (Δt_{prep}). During this time, the fire and rescue service are carrying out preparatory tasks prior to the start of tactical operations.

Δt_{prep} is variable. It can be evaluated for any given set of circumstances by intervention modelling techniques (see Clause **8**).

The fire situation might be such that the PDA is not sufficient to begin tactical operations. In such a case, Δt_{prep} might include the attendance time of additional fire appliances.

6.7 Tactical operations

*COMMENTARY ON **6.7***

Once fire-fighters have completed their preparations (Δt_{prep}) they might need to undertake a number of activities before intervention is completed; successfully or otherwise. These activities include travelling within the building to find casualties and bringing them to safety, searching for the seat of the fire, applying water to a fire.

All of these activities take time and together are described as tactical operations.

The safety of fire-fighters and the effectiveness of tactical operations could be improved by engineering measures into the fire safety strategy that reduce the time it takes to carry out tactical operations (Δt_{to}). Such measures increase the likelihood that design objectives are achieved.

The time it takes to carry out tactical operations can increase as conditions for fire-fighters (such as temperature, humidity and visibility) become worse and as the time they need to spend in such conditions increases.

The time it takes to carry out tactical operations can be reduced by the provision of measures that reduce temperature and humidity, reduce the quantity and/or density of smoke, and that reduce the distance that fire-fighters need to travel through such conditions to search for casualties or locate a fire.

Once tactical operations begin, there is likely to be a time interval before the design objectives are achieved. The duration of tactical operations (Δt_{to}) is variable. It can be evaluated for any given set of circumstances by intervention modelling techniques.

If the design objective is life safety, tactical operations (Δt_{to}) end when casualties are outside the building. If the design objective is to control a fire before it reaches a certain size, Δt_{to} ends when the fire is below that critical size and under the control of fire-fighters.

6.8 Physiology of fire-fighters

6.8.1 General

Performance-based designs should not result in buildings that create conditions beyond the physiological capabilities of fire-fighters. The physiology of fire-fighters should be input into this sub-system such that the capacity of fire-fighters to undertake certain activities in a given time is modelled realistically in fire-fighting task analysis.

NOTE Fire Research Technical Report 2/2005 *[1] describes research which examined fire-fighter's physiology while undertaking defined tasks in a specific set of circumstances. However, difficulty exists with the analysis and quantification of fire-fighter activity, both in the field and in experimental conditions. All fires present their own individual conditions so there can be no standardization of tasks, performance or work rate. Data gathering is further complicated because there is anecdotal evidence that fire-fighter activity in the field is different from fire-fighter behaviour in training environments. In the field, it is driven by psychological factors such as uncertainty, anxiety and apprehension (see* Fire Research Technical Report 1/2005 *[2]).*

The temperatures to which fire-fighters are exposed during actual fire-fighting and related activities such as search and rescue are unknown. Some guidance can be provided from studies of training environments and experimental work, but there is strong anecdotal evidence that fire-fighters behave differently in an actual incident and might therefore be subject to higher temperatures than those documented during training.

6.8.2 Fire-fighter's body temperature

Fire Research Technical Report 2/2005 [1] describes the development and use of a breathing apparatus harness instrument with various environmental measuring sensors including air temperature. The sensors on the fire-fighter recorded temperatures at waist, chest and shoulder height throughout. Temperatures above 120 °C were experienced for up to 2 min at any one time and, on two occasions, temperatures briefly exceeded 180 °C.

Air usage from breathing apparatus sets might be in the range of 40% to 72% above that indicated on some breathing apparatus tables. This should be taken into account when considering the capacity of fire-fighters to undertake tasks.

Research results outlined below should be seen as indicative only (see *Fire Research Technical Report 1/2005* [2] for further details). Their application to fire-fighter task analysis should be interpreted in conjunction with the fire officer through the QDR process.

SCENARIO 1

The rescue of a 75 kg manikin positioned 45 m horizontal distance into a compartment.

The scenario was undertaken a number of times on different floors of the test building. Vertical distance from the entry point of the building to the manikin was between –5 m (basement) and +18 m (4th floor).

No fire or heat was used, but fire-fighters wore breathing apparatus with face masks covered to simulate zero visibility.

SCENARIO 2

Identical to Scenario 1, except that crib fires were used to increase heat and to provide real smoke to reduce visibility.

Mean ambient temperatures throughout the live fire scenarios, by floor, as measured by the body-borne probes, were between 27 °C and 53 °C, while mean peak temperatures ranged from 65 °C to 103 °C.

SCENARIO 3

This scenario investigated the physiological demands associated with the vertical component of fire-fighting and rescue operations in tall buildings.

Fire-fighters were instructed to climb stairs in a high rise building both carrying equipment and without equipment.

In all three scenarios, the physiological responses of the fire-fighters were measured. In particular, core body temperature was measured. Normal human body temperature is in the region of 37 °C. The starting temperature of fire-fighters was typically 37.5 °C, probably as a result of wearing protective fire clothing prior to the tests and the effort of donning breathing apparatus sets. Body temperature rises with work. 39 °C is considered to be a safe upper limit for live fire training in fire-fighters (see *Fire Research Technical Report 1/2005* [2]).

- In Scenario 1 (no heat), fire-fighter core body temperature increased at a rate of 0.05 °C per min. 39 °C was therefore reached after 30 min.
- In Scenario 2 (crib fires), fire-fighter core body temperature increased at a rate of 0.054 °C per min. 39 °C was therefore reached after 28 min.

The similarity in the results demonstrates that effective protective clothing insulates fire-fighters against moderate external high temperatures and that increases in core body temperature are caused by the fire-fighter's own activity and the inability of heat generated to escape.

As a conservative measure, fire and rescue service task analysis should be based on ensuring that the fire-fighter's body temperature does not exceed 39 °C.

In Scenario 3 (climbing stairs), core body temperature was found to increase by 0.02 °C per floor when carrying equipment and by 0.01 °C per floor without equipment. This means that after climbing stairs, a fire-fighter's starting core body temperature is elevated and the period of time for which they should be fire-fighting is shortened.

The research shows that 34 m is the maximum distance fire-fighters should penetrate into a fire compartment to rescue a casualty, where no stair climbing is required to access the point of entry (see *Fire Research Technical Report 2/2005* [1]). Having to climb stairs beforehand should be assumed to reduce the maximum penetration distance proportionally. Climbing 10 floors, for example, reduces the penetration distances to around 25 m. Climbing 20 and 30 floors allows penetration distances of approximately 20 m and 12 m, respectively.

6.9 Building management/FRS interface

6.9.1 General

In smaller buildings that do not warrant the provision of a fire control centre (see **7.4.3**), it is still possible to reduce fire and rescue service preparation time and speed up fire and rescue service intervention by introducing procedures for passing on information to fire officers when they attend.

Information may be passed on verbally by a person identified within the emergency plan for the building. Information may be made available in written form.

At building design stage, the key aspects of the fire safety design that are relevant to fire and rescue service officers who attend the building in the event of a fire should be recorded.

If information is to be passed on to fire officers verbally, a checklist of relevant information should be available, and passing on that information should be practised regularly, e.g. at fire drills.

Written information, such as plan drawings of the building for fire and rescue service use, may be handed over in person or, if the building is unoccupied, documents should be made available in a suitably located secure box agreed with the local fire and rescue service. See also BS 9999:2008, Clause **27**.

In the event of a fire, written information and plans for the fire and rescue service might be needed to be used in the dark and in wet conditions. Written information should therefore be written clearly and laminated.

6.9.2 Fire and rescue service familiarization with the building

*COMMENTARY ON **6.9.2***

Fire control centres and drawings for fire and rescue service use can contribute to reducing fire and rescue service preparation time and support efficient and effective fire-fighting that leads to the design objectives being met.

However, systems and written documents can be applied much more effectively if the fire-fighters and fire officers who use them already have a good knowledge of the building, the site, the contents, hazardous materials, the occupants and the process risks.

The fire and rescue service should be invited and should carry out regular familiarization visits and operational exercises to the building to improve the effectiveness of intervention. This is especially true where FSE systems in the building are innovative or unusual.

To reduce preparation time and to improve the effectiveness of intervention, the fire and rescue service should request, where needed, that plans and other information gathered at fire and rescue service familiarization visits be recorded by them for storage and retrieval, e.g. from mobile data terminals on fire appliances.

7 Design and building information

7.1 Building characteristics

The design and building information needed for an analysis of fire and rescue service intervention includes:

- building structure;
- building layout and geometry;
- fire protection systems;
- evacuation routes and muster points;
- occupant characteristics;
- fire and rescue service access;
- facilities for the fire and rescue service;

- fire and rescue service equipment; and
- operation of fire systems.

7.2 Building structure

Building structure information should be provided by the QDR. Primary structures have the greatest influence on a building's ability to remain standing during fire. A recognition of the primary structure of the building and the appraisal of its fire performance is an important factor which influences the nature and extent of the fire and rescue service intervention.

7.3 Building layout and geometry

7.3.1 General

Fire service personnel access routes in and around a building/site should be clearly identified as part of the QDR process, with the suitability of these routes being discussed and agreed with the local fire and rescue service.

7.3.2 Floor signage

In buildings that have split level floors, mezzanine floors and multiple access points, it can be difficult for fire-fighters who are unfamiliar with the building to identify the floor that they are on. In conditions of dense smoke experienced by fire-fighters, signage at eye level and above doors that is provided to identify rooms and for means of escape might not be seen.

In order to assist fire-fighters in locating the scene of a fire quickly, signage should be provided to:

a) indicate flat numbers and emergency exits at a low level to improve visibility in smoke conditions;

b) indicate floor levels both in stairwells and lift lobbies in high rise premises; and

c) identify all staircases uniquely as, for example, staircase 1, staircase 2 and so on. This avoids confusion when fire-fighters are navigating their way through a building or attempting to describe their location.

NOTE The recommendations above could also improve the safety and the speed of fire and rescue service intervention in any high rise building or any other building where "way finding" could be a challenge for fire-fighters.

Detailed measures should be discussed and agreed with the fire and rescue service during the QDR.

7.3.3 Safe areas or refuge floors

The primary concern of fire-fighters is the safety of occupants. In most cases, fire-fighting does not commence until either all occupants have left the building or, in a building subject to phased evacuation, they can safely remain in the building, in a place of relative safety. In very tall buildings, this has the potential to delay fire-fighting by a considerable amount of time.

If safe areas are provided so that occupants can reach them quickly, it can free the fire and rescue service to intervene with fire-fighting more quickly. The provision of safe areas should be agreed with the local fire and rescue service before they are incorporated into a FSE design. If the fire and rescue service procedures, policies and equipment are not compatible with the concept of safe areas, they should not be incorporated into the design.

7.4 Fire protection systems

7.4.1 Smoke control

7.4.1.1 General

Smoke control systems are typically provided in buildings to secure escape routes for occupants, to reduce smoke and heat damage to property and/or to reduce fire spread.

If a smoke control system is designed purely with evacuation in mind, the safety of occupants can be achieved. But if fire continues to grow after evacuation is complete, the limits of the smoke control system could be exceeded and conditions might have deteriorated by the time fire-fighters enter the building to carry out fire-fighting and rescue.

The provision of smoke control in a building can improve the environment for fire-fighters, but this should be confirmed by fire engineering analysis combined with fire and rescue service task analysis (see **8.4**).

7.4.1.2 Smoke control in extended corridors

Smoke control in extended corridors is a matter that requires particular attention.

Guidance for the design and construction of apartment buildings, flats and maisonettes encourages the principles of compartmentation and ventilation to protect occupants and assist the fire-fighting operation, particularly where a "stay put policy" is in place.

These design principles are based on occupants not affected by fire or smoke remaining within their flats even during tactical operations of fire and rescue service intervention. However, experience suggests that there might be uncontrolled movement of occupants within common areas. This can put occupants at risk and managing uncontrolled occupant movements takes up fire and rescue service resources and therefore delays tactical operations.

Fire safety building design codes often address these risks by sub-dividing corridors with smoke doors that limit the distance that occupants and/or fire-fighters have to travel in smoke.

Fire-fighters might have to travel along corridors to reach safety in situations where fire conditions deteriorate during tactical operations. Cross-corridor doors provide a high degree of assurance to fire-fighters that under such circumstances they only have to travel a short distance to a place of refuge.

Fire engineering is not constrained by such codes and can determine that active corridor smoke control may be used as a compensating feature for extended corridors with few smoke doors. However, unless designed specifically for the purpose, the capacity of a corridor smoke control system could be overwhelmed during uncontrolled occupant movement and during fire-fighting operations.

The operational effectiveness of a corridor smoke control system should extend into the predicted time of tactical operations to maintain fire and rescue service efficiency and effectiveness.

7.4.2 Automatic fire suppression

Automatic fire sprinklers are a proven technology that reliably control a fire by keeping it at a small size while fire-fighters proceed to the building, prepare their equipment and travel through the building to find casualties or the seat of the fire.

Sprinklers do sometimes extinguish fires without any other form of fire-fighting. However, their design criterion is typically to reduce the rate of fire growth or to control fire to a fixed size.

Fighting a sprinkler-controlled fire is less hazardous than fighting an uncontrolled fire. Fire-fighters are therefore much more likely to enter a building and quickly extinguish a sprinkler-controlled fire than they are an uncontrolled fire.

Other automatic fire suppression systems may be acceptable, subject to adequate technical review.

7.4.3 Fire control centres

A fire control centre should be provided in all buildings designed for phased evacuation and in large or complex buildings to enable the fire service to assume control of an incident immediately on attendance. This reduces fire and rescue service preparation time and enables tactical operations to take place more quickly.

If an FSE design is to incorporate a fire control centre, it should do so in accordance with BS 9999.

7.4.4 Automatic fire detection and alarm systems

Automatic fire detection and alarm systems (and other systems such as CCTV) can provide useful information for the fire and rescue service.

7.5 Evacuation routes and muster points

When considering evacuation routes and muster points, the QDR should take account of any conflict that there might be between the outward flow of occupants and inward movement of fire-fighters and their equipment.

The width of exit routes, including staircases and other areas where such conflict could occur, should be increased to allow movement in both directions that neither adversely affects evacuation nor slows down fire and rescue service intervention.

This is particularly true of tall buildings, hospitals, stadia and other buildings with protracted evacuation procedures.

7.6 Occupant characteristics

The primary concern of the fire and rescue service is the safety of occupants. In most cases, fire-fighters do not begin fire-fighting until the evacuation of the building is complete or they are satisfied that the occupants are in no danger from the fire. Modelling fire and rescue service intervention should therefore take into account the planned building evacuation strategy and the occupant characteristics (see PD 7974-6) that are likely to impact upon their behaviour, including the following:

- on evacuation, occupants might move quickly to assembly points and await further instructions;
- during the evacuation of a large multi-storey building, evacuation could still be under way while the fire and rescue service is attempting to enter the building and reach the seat of the fire;
- in certain types of premises (including night clubs) occupants might be difficult to control after evacuation and could interfere with the ability of the fire and rescue service to carry out rescue and fire-fighting.

7.7 Fire and rescue service access

7.7.1 Site access and security

*COMMENTARY ON **7.7.1***

Fire and rescue service preparation time includes time needed to gain access to the site of a building and time required to gain access to the inside of the building.

Site security measures (for example, security gates or bollards) can hinder fire appliance access to a site, particularly at times when the site is unoccupied.

Door security systems can hinder fire-fighter access to a building. This can be the case even in occupied buildings if doors are not permanently staffed.

Preparation time can be reduced by engineering measures into the fire safety strategy that improve site and building access for fire-fighters. Such measures therefore increase the likelihood that design objectives are achieved.

7.7.2 Fire appliance access

*COMMENTARY ON **7.7.2***

In low rise or low depth buildings, effective fire-fighting can be afforded solely by perimeter access for pumping appliances.

In medium rise, shallow plan buildings, effective fire-fighting can be afforded by perimeter access for a high reach appliance.

In other situations, effective fire-fighting can be afforded by provision of access for pumping appliances to fire main inlet connection points and by providing access to a protected route served by the fire main for fire-fighters.

7.7.2.1 General

Good fire appliance access improves the effectiveness of fire-fighting.

Roadways of adequate width, loadbearing capacity and suitable gradient enable fire appliances to reach the perimeter of a complex and gain access to entry points into a complex. These roadways can be public highways or, if within the boundaries of a large complex, they can be service roadways used by vehicles delivering goods.

Access for fire appliances should take into account the following issues:

- parking for an appropriate number of fire and rescue service vehicles;
- parking for fire appliances should be located at a sufficient distance from the risk so that they do not become untenable later in the fire;
- access to water supplies for pumping appliances;
- the line that hose would follow between water supplies and fire ground pumping appliances;
- the interaction between attending fire appliances and evacuating occupants and occupants at muster points;
- the interaction between attending fire appliances and the cars belonging to people who have evacuated from the building (e.g. those who have evacuated from a shopping centre who might collect their cars from the car park rather than collect at a muster point); and
- access can be made available to upper levels or podium decks where there might be access across the open or top deck to other structures within a complex. Any such routes should also be of suitable gradient, loadbearing capacity and width for fire appliance use.

7.7.2.2 Low-rise buildings

Low-rise complexes pose fewer access difficulties for fire-fighters than high-rise complexes. For example, there is no need to transport personnel and equipment up multiple levels. However, a low-rise complex can cover an extensive area and therefore access roadways are still necessary to enable fire appliances to drive near to selected entry points to the complex.

Hose laying distances from the appliance to the entry point and from the entry point to the seat of fire should be kept to a minimum in order to reduce preparation time.

7.7.2.3 High-rise buildings

In high-rise buildings, fire-fighting and rescue is unlikely to be carried out from outside the building. This is because fire service ladders are limited in their reach and jets of water from fire-fighting hose is limited in the distance it can be projected. High-rise appliances can project water to a greater height and can perform rescues, but even these are limited in their reach and the time it takes for them to attend and begin to work can be extensive.

As a result, fire-fighting and rescue in high-rise buildings is more likely to be carried out from inside the building. It is therefore only necessary to provide fire appliance access that leaves a short distance from a fire appliance parking area to an external door.

Fire appliance access should ensure that the hose can be connected from hydrants to fire appliances and then from fire appliances to fire main inlets as quickly as possible. The process is quickest if only one length of fire-fighting hose is required for each connection. One length of fire-fighting hose should reach 18 m, so a distance of no more than 18 m from hydrant to appliance and 18 m from appliance to main inlet minimizes the time required.

7.7.2.4 Vehicle access within the building

COMMENTARY ON ***7.7.2.4***

In some buildings with a large footprint, vehicle access is provided inside the building or to the roof of the building for the delivery of goods and the collection of waste. These service areas are prone to fire, and it is foreseeable that fire-fighters might drive their appliances into these areas in order to gain access to the scene of a fire quickly and extinguish it.

It is for the QDR and the fire and rescue service to take into account the advantages and disadvantages of driving fire appliances inside and on top of a building. Whether the decision is to allow fire appliance access or not, the FSE should be designed to support that decision.

If enclosed or covered access roads are to be used by fire appliances to gain access, then special provisions might be necessary. The fire resistance of any floors over an access roadway should be such that the possibility of collapse onto fire appliances at work during a fire is remote. If access roads are enclosed at any level, then exhaust fumes and heat and smoke should be vented. Water supplies, communication facilities and emergency lighting should also be taken into account by the QDR.

7.7.2.5 Road width, load capacity, clearance and turning facilities

Fire appliances are not standardized. Road width, load capacity (including point loads for the jacks of high rise appliances) and the requirements for overhead clearance turning circles, widths, lengths, headroom and proximity to fire main inlets should all be agreed at the QDR with local fire and rescue service officers.

Many fire safety building design codes give a maximum distance from a building that can be reached by fire appliances. BS 9999 recommends a distance of 45 m from every point on the footprint of the building or 15% of the perimeter, whichever is less onerous.

Such codes may also give recommended turning circles to be provided for fire appliances where access roads are dead-ends. BS 9999 recommends that turning facilities should be provided in any dead-end access route that is more than 20 m long.

Fire safety engineering is not bound by fire safety building design codes; however, before disregarding the recommendations of such codes, considerations such as the following should be taken into account by the QDR team.

- Fire appliances should be able to drive to within a reasonable distance of a building to park so that fire-fighters only have to carry equipment and run out lengths of hose for a short distance from their appliance to the scene of a fire. Increasing the distance increases the time between fire appliance attendance and the commencement of tactical operations.
- Running out and connecting lengths of hose, and filling hose with water takes time. Increasing the distance over which hose is connected increases the time between fire appliance attendance and the commencement of tactical operations.
- Fire appliance turning circles are needed to enable appliances to leave the scene quickly if the fire worsens. But they are also there in case the appliance is called away to attend another (more serious) incident.

Fire appliance access should also take account of the general access to the building for multiple appliances and quantities of equipment that might be required at a reasonable worst case fire.

7.7.2.6 Compensating for poor vehicle access

Where fire appliance access to the perimeter of a building is difficult (for example, where an access road to a building or a perimeter road is not suitable for use by a fire appliance), the provision of a fire hydrant from a town main is not acceptable as a suitable alternative to improving vehicle access. This is because mains water pressure alone is not adequate to fight fires. Water from fire hydrants is first fed through a fire-fighting pump before it can be projected onto a fire. A remote fire hydrant is therefore likely to be of little use to fire-fighters.

A fixed horizontal fire main, with an inlet near to a fire appliance parking area and an outlet valve suitable for fire-fighting hose at the remote end, allows fire-fighting water pressure to be provided in areas where vehicle access is poor. However, this only alleviates the need to run out hose.

A fixed horizontal fire main should only be considered as a solution if it has the support of the local fire and rescue service.

In determining the acceptability of measures being proposed to compensate for poor vehicle access, the QDR should take into account the following points.

- The operability of the mains should be assured at all times and maintenance and testing should be undertaken in accordance with BS 9990.
- Fire fighting inside buildings might rely on high pressure hose reels, which cannot be operated from a water supply via a horizontal fire main.
- In most circumstances, the provision of sprinklers in a building causes a fire to develop more slowly and is likely to control a fire at a relatively small size. This means that fire-fighters have additional time to carry their

equipment to the building allowing them to pace their work and remain physically capable of mounting an attack on the fire once their equipment is in place.

- Fire-fighters have to carry their equipment from the appliance to the building, which takes time and causes fatigue. For example, ladders are heavy and need a number of fire-fighters to carry them, therefore a horizontal dry main might be acceptable as compensation for poor vehicle access in a single-storey building but not an equivalent multi-storey building.
- The surface of the route between the fire appliance parking area and the building should be taken into account. It is easier, quicker and safer to carry equipment along a well-lit road or paved surface than an unlit rough track.

7.8 Facilities for the fire and rescue service

7.8.1 General

The QDR should take into account the position and characteristics of any planned facilities that are likely to improve the efficiency of the fire-fighting operation.

7.8.2 Water supplies

A sufficient supply of uninterrupted water should be secured to ensure that intervention is not delayed while water supplies are located and hose is laid.

Guidance on water supplies is contained in BS 9990 and the *National guidance document on the provision of water for fire fighting* [3]. For an engineered approach, the adequacy of a water supply should be assessed using analysis (see **8.5**). Adequate water supplies can be provided from private hydrants, from tanks, from natural sources such as rivers or from man-made ponds.

Early consultation on water supplies should be carried out with the approving local water and fire authorities.

Water supplies for manual fire-fighting are usually provided from hydrants, either those of the water authority fitted on street mains, or private hydrants installed by the building owner or developer.

The following factors should be taken into account when determining the location of fire hydrants:

- hydrants should be located in positions which are near to fire appliance parking positions; and
- hydrants should not be so close to risks that they cannot be accessed safely in the event of a fire.

NOTE These conditions apply whether fire appliance access is at ground level or below ground level.

Analysis on the appropriate location of hydrants and water supplies should include an assessment of the fire and rescue service water supply needs at a reasonable worst case fire (see **7.7**).

In areas without an adequate water main, an alternative supply should be provided. An unlimited and guaranteed natural water source might be acceptable, subject to access and hard standing for fire appliances being provided – this should be agreed with the local fire and rescue service through the QDR. The capacity should be related to the size of the building and the risk involved.

7.8.3 Protected stairs and fire fighting shafts

7.8.3.1 The provision of fire-fighting shafts

Fire-fighting shafts should be provided in tall buildings, buildings with deep basements and buildings with large floor areas so that fire-fighters can gain access to the interior of the building and perform rescues and fire-fighting from a place of relative safety.

The arrangements expected in terms of fire fighting shaft provision are covered in BS 9999 and BS 9991. However, in a building based on the principles of FSE rather than a prescriptive code, the provision of fire-fighting shafts in line with a code can be varied.

The provision of fire-fighting shafts should be discussed by the QDR team including local fire and rescue service officers.

7.8.3.2 Number of protected stairs or fire-fighting shafts

Many fire safety building design codes describe the provision of fire-fighting shafts in buildings according to the height and depth of a building, its use, and the distance to parts of a relevant floor.

Fire safety engineering is not bound by such codes, but they should form the basis for the FSE design and the provision of fire-fighting shafts. There are two reasons for this:

a) the provisions contained within these codes are partly based on the physical capabilities of fire-fighters. This is an overriding constraint that cannot be altered;

b) fire and rescue service techniques and equipment are based on the assumption that the provisions contained within fire safety building design codes are met. Significant deviation might mean that the fire and rescue service are unable to operate effectively.

BS 9999:2008, **21.2.3** gives recommendations for the design of fire-fighting shafts.

Fire and rescue service procedures, policies and equipment have their limitations, as does fire-fighter physiology. When fighting a fire in an unsprinklered building, the efficiency and effectiveness of the fire and rescue service diminishes as working distances exceed 45 m from a bridgehead in a place of relative safety. One reason for this is because a typical fire-fighter’s breathing apparatus set only holds sufficient air to last for 30 min to 45 min when worn during moderate working. Under extreme conditions this working duration can be significantly reduced (see **6.8**).

Increasing the travel distance from the bridgehead to the scene of a fire (and back again) reduces the amount of air that fire-fighters have available for use while fire-fighting.

A FSE building design should keep within the parameters given in BS 9999:2008, **21.2.3** unless additional measures are provided to assist fire-fighters (e.g. smoke control).

NOTE Fire-fighters are likely to use fire-fighting shafts at times after evacuation is expected to have been completed, so fire-fighting shafts are typically given the highest appropriate levels of fire resistance.

Fire-fighting shafts should serve all parts of the building through which they pass with all consideration given to potential bridgehead locations. They should be located so that they allow access to every part of every storey that they serve. Where storeys are large, more than one fire-fighting shaft might be necessary to provide access to all parts of the relevant floor within a reasonable distance.

7.8.3.3 Selection of protected stairs or fire-fighting shafts

In low rise buildings, reaching the scene of a fire on an upper storey might not be unduly arduous. In taller buildings it becomes more difficult for fire-fighters to reach the scene of a fire on an upper storey with the equipment they need to carry out their work.

Therefore, the criteria for protected stairs/fire-fighting shafts should increase with increasing building height and depth below ground:

- a simple protected staircase can be adequate in low rise buildings;
- a protected staircase with a rising main might be more appropriate in medium rise buildings (e.g. buildings with a topmost floor level 11 m to 18 m above fire and rescue service access level);
- a fire-fighting shaft with a fire-fighting lift and a rising main is often used in a tall building (e.g. buildings with a topmost floor level more than 18 m above fire and rescue service access level);
- in very tall buildings and buildings with very deep basements, it might be deemed necessary in addition to fire-fighting shafts to provide equipment for the fire and rescue service on upper floors (e.g. buildings with a topmost floor level more than 30 m above fire and rescue service access level) subject to agreement with the fire and rescue service.

NOTE The principles described above also apply to deep basements and buildings with large footprints.

The fire-fighting staircase is the final line of retreat for fire-fighters, in case the fire-fighting lift fails. Therefore the fire-fighting staircase needs to serve every storey of the building. The lift and stairs are used together during the fire-fighting operation.

In buildings with a variety of uses, fire-fighting shafts can serve separate parts of the building. For example, in a building consisting of high-rise offices over a shopping centre, the offices might be provided with a dedicated fire-fighting shaft that does not serve the shopping centre. Design of fire-fighting shafts within buildings with a variety of uses should be logical and simple, so that fire service personnel have no difficulty in identifying the fire-fighting shafts serving the areas they need to reach.

Buildings that are not sufficiently high and do not have deep basements, but have a large footprint, can still benefit from the provision of fire-fighting shafts. A fire-fighting lift might not be necessary in such buildings because the vertical transport of personnel and equipment is less difficult, but the fire-fighting shaft should contain a fire-fighting stair and fire-fighting lobbies.

7.8.3.4 Fire-fighting lifts

A fire-fighting lift is used to transport fire-fighters and their equipment to a floor of their choice. Unlike a normal passenger lift, it should be designed to operate so long as is practicable when there is a fire in parts of the building beyond the confines of the fire-fighting shaft. The lift can be used in normal times as a passenger lift by the occupants of the building but, in order to prevent the risk of the entrance being obstructed when it is required to go into the fire-fighting mode, it should not be used for moving refuse or goods.

If the only lift in the building is a fire-fighting lift, that lift should not be used for the transport of goods unless essential, lift lobbies should be kept clear and, when used for moving goods, the doors should not be propped open, to ensure that the lift remains at a particular level.

Different fire and rescue services have different operational procedures regarding the use of fire-fighting lifts for disabled evacuation. These should be agreed by the QDR including the fire and rescue service.

If a FSE design is to incorporate a fire-fighting lift, it should be designed in accordance with BS 9999 and BS EN 81-72.

7.8.3.5 Design of protected stairs or fire-fighting shafts

If a FSE design is to incorporate a protected stair or a fire-fighting shaft, it should be designed in accordance with BS 9999.

7.8.3.6 Identification of fire-fighting main inlets

In buildings with multiple fire-fighting mains, it can be difficult for fire-fighters to identify which inlet leads to which part of the building. This is particularly true when inlets are grouped together on the outside of a building and which lead to mains that are remote from the inlets.

Fire and rescue service intervention is accelerated if fire-fighting main inlets are clearly marked with the location of the main which they supply. The location of the main may be referred to as a particular staircase (see **7.3.2** regarding the signage and identification of staircases). The format of this signage should be discussed and agreed with the local fire and rescue service.

7.8.4 Protected corridors

The principle of reducing the distance between a place of relative safety for fire-fighters and the seat of a fire applies to large footprint, low-rise buildings such as shopping centres and exhibition centres, as well as to tall buildings. Protected corridors can be provided to allow fire-fighters access to within 45 m or 60 m of any part of the floor area of the building.

NOTE Protected corridors are corridors enclosed with fire resisting construction (other than any part that is any external wall of a building).

The level of fire resistance afforded to the corridor should be appropriate to the conditions under which it is expected to be used.

This use of protected corridors is described in BS 9999:2008, **E.2.1.1**. It is not used in common building situations and fire-fighters might be unfamiliar with it. The entrance to the protected corridor(s) should be clearly indicated and they should be clearly marked so that fire-fighters have confidence in their functionality.

The designer should take into account that, unlike a fire-fighting shaft, a fire-fighting corridor does not contain a lift. Therefore fire-fighters have no choice but to walk and to carry all of their equipment from the appliance to the bridgehead. This takes time and causes fatigue.

A dry horizontal main terminating in a valve suitable for fire-fighting hose can be provided inside the building at the end of the protected route to relieve fire-fighters from the need to run hose into the building. In this case, there should be a fire hydrant and fire appliance parking within less than 18 m of the main inlet (18 m is recommended because the standard length of a piece of fire hose is 20 m to 25 m).

7.8.5 Basement stairs

Hot gases from basement fires flow up staircases making basement access staircases difficult and dangerous for fire-fighters to negotiate.

To improve fire-fighter access to basements, basement stairs should be separated from basement floors. To increase fire-fighter safety and to accelerate tactical operations, a suitable fire-resisting door or lobby should be provided between the stairs and each basement level.

Fire-fighters can then descend basement stairs without being exposed to excessive heat and can enter the basement floor via the door or lobby at the foot of the stairs, below the level of the hot fire gasses.

The provision of suitable basement ventilation is particularly beneficial in reducing risk to fire-fighters and increasing the likelihood that fire-fighting design objectives are achieved (see *Fire Research Report 26/2008* [4]).

7.9 Fire and rescue service equipment

7.9.1 The provision of fire-fighting equipment

There are extreme circumstances where standard fire and rescue service equipment is not appropriate or would take a long time to reach the fire. In such cases, the fire strategy should specify that the owner/occupier of the building should provide equipment within or near to the risk or even at the local fire station for fire and rescue service use. Maintenance and training are critical so the provision of such equipment should not be routinely relied upon and should only be considered with the full agreement of the fire and rescue service.

Examples of such equipment are the provision of long duration breathing apparatus sets for tunnels and underground buildings, or the provision of hose and branches and breaking in equipment on the upper floors of very tall buildings or at the end of fire-fighting corridors.

- The provision of this equipment can reduce fire and rescue service preparation time.
- Ownership of the equipment should be agreed between the building occupier and the local fire and rescue service.
- Testing and maintenance of the equipment should be agreed between the building occupier and the local fire and rescue service.

It might be reasonable to expect the occupier to pay for the equipment and its ongoing care; however, if fire-fighter safety relies on the equipment, the fire and rescue service should regularly assure itself that the equipment is fit for purpose. If the fire and rescue service is to use the equipment provided, they should also have the freedom to train with it on a regular basis.

NOTE This option for development is entirely at the discretion of the local fire and rescue service.

7.9.2 In-built communication systems for fire-fighters

Effective and efficient fire-fighting relies on good communication. Fire and rescue services use hand-held radios at emergency incidents, but in some circumstances, hand-held radios do not work effectively. Problems can arise particularly in basements, tunnels and in large steel-framed buildings.

If fire and rescue service radio communications could be a problem, the QDR including local fire officers should consider options to improve communications and thereby improve the ability of the fire and rescue service to support the achievement of the design objectives.

7.10 Operation of fire systems

On attendance at a building on fire, fire-fighters need preparation time to prepare an operational plan and amass the necessary personnel and equipment to implement the plan before they begin their tactical operations.

If preparation time is reduced, tactical operations take place sooner and rescue and/or fire-fighting are more likely to be successful. Preparation time can be considerably reduced if key information about the building, its fire safety systems, its occupants and the fire situation are conveyed to the fire and rescue service quickly and effectively.

There are a multitude of different user interfaces for fire protection systems such as detection equipment, suppression systems, smoke control vents and fans. Fire-fighters cannot be expected to know how to operate the systems in all the buildings within their area of operations. The fire strategy for a building cannot therefore rely on fire-fighters operating such equipment without support and/or pre-planning.

- The QDR should discuss the provision of information to fire-fighters and the on-going management of active fire control systems in the event of a fire.
- A complex building should be provided with a fire control centre that could be used by the fire and rescue service and building services staff to manage operational activity (see BS 9999).
- The information that the fire and rescue service requires on attendance and the on-going liaison that is needed in order to manage a fire situation should be recorded and kept up to date.

8 Analysis of the effectiveness of fire and rescue service intervention and outputs

8.1 General

An analysis of fire and rescue service intervention might need:

a) modelling of fire growth and spread and the behaviour of occupants;

b) modelling of the attendance and build-up of fire and rescue service resources; and

c) modelling how effective fire and rescue service intervention is expected to be in achieving the design objectives.

NOTE Modelling fire growth and spread and the behaviour of occupants is described in sub-systems 1, 2, 3, 4 and 6.

Modelling the effectiveness of fire and rescue service intervention involves some qualitative judgement. However, if the state of the fire is predicted through sub-systems 1 to 4 and 6, and the build-up of fire and rescue service resources is predicted through computational tools, qualitative judgement about overall fire and rescue service preparation and tactical operations can be broken down into individual fire-fighter activities. Each of the fire-fighters who are in attendance can only perform one task at a time using the equipment that they have available to them.

Breaking down fire and rescue service preparation and tactical operations into individual fire-fighter activities is carried out using a Gantt chart approach (see Table 1).

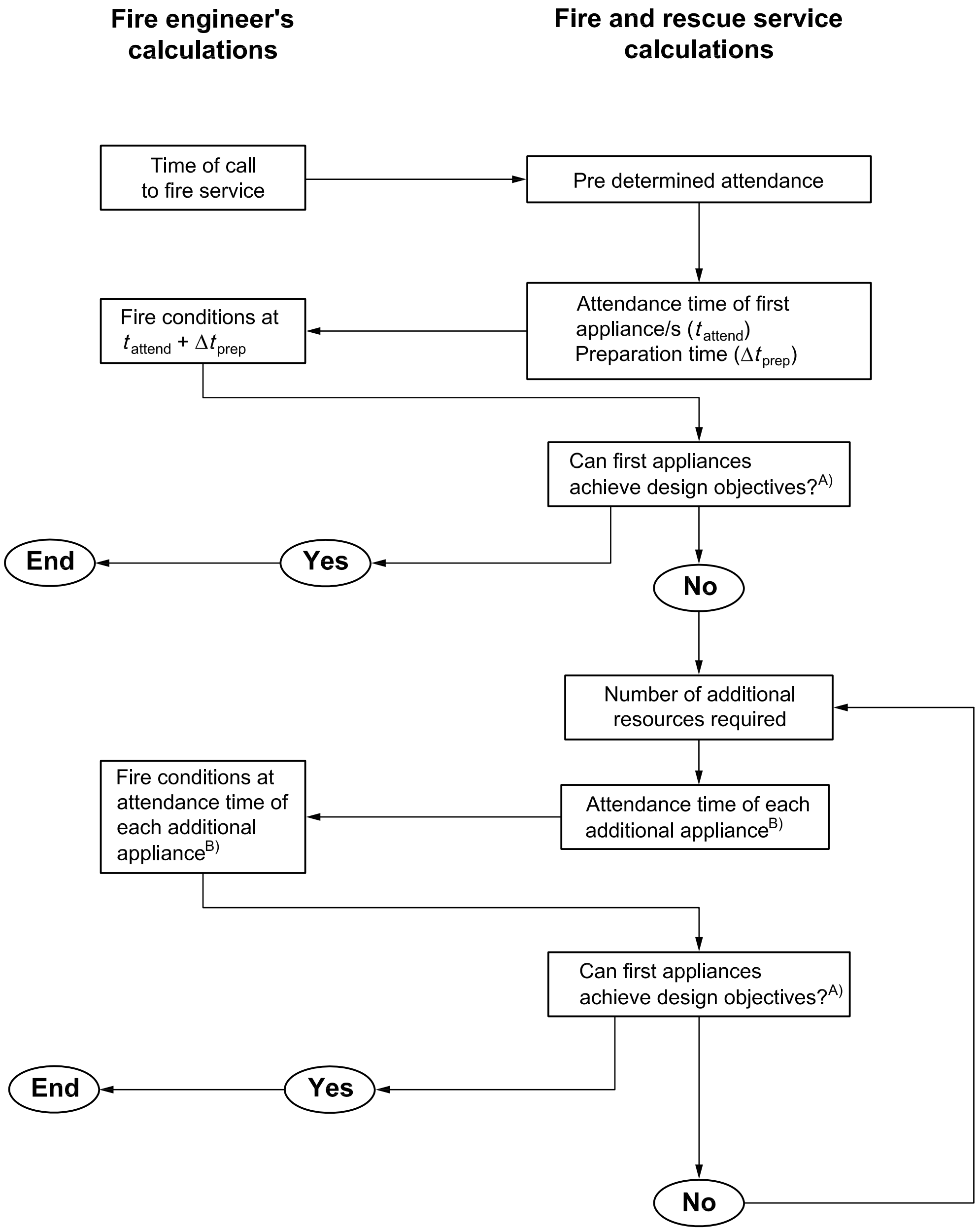
Table 1 **Fire-fighter task analysis**

<table>
<tr><th></th><th colspan="9">Time</th></tr>
<tr><td>Officer in charge</td><td>Activity 1</td><td colspan="2">Activity 4</td><td colspan="6">Activity 7</td></tr>
<tr><td>Fire-fighter 1</td><td colspan="5">Activity 2</td><td colspan="2">Activity 9</td><td colspan="2">–</td></tr>
<tr><td>Fire-fighter 2</td><td>–</td><td colspan="3">Activity 5</td><td colspan="2">Activity 8</td><td colspan="2">Activity 10</td><td>–</td></tr>
<tr><td>Fire-fighter 3</td><td>–</td><td colspan="3">Activity 5</td><td colspan="2"></td><td colspan="2">Activity 10</td><td>–</td></tr>
<tr><td>Fire-fighter 4</td><td colspan="2">Activity 3</td><td colspan="5">Activity 6</td><td colspan="2">–</td></tr>
</table>

This structured approach enables a detailed model to be developed and therefore a reasonably accurate result to be reached. For example, it highlights safety critical and other sequential activities that need to be completed before other activities can begin.

Integrating fire-fighter task analysis with the FSE study of fire growth and the reaction of the building to fire enables an assessment to be made of the effectiveness of fire and rescue service intervention in achieving the design objectives. This is illustrated in Figure 5.

Figure 5 **Linking together fire modelling with fire and rescue service resource build-up and fire-fighter task analysis**



A) The ability of appliances to achieve design objectives is evaluated using task analysis.

B) If multiple additional appliances are requested, they might not all arrive at once. The arrival time of each additional appliance needs to be calculated, the fire conditions at that time evaluated and fire-fighter task analysis needs to take place with only the number of fire-fighters present at that time.

8.2 Modelling fire growth and spread

In sub-system 1 (see PD 7974-1) it is stated that a design fire can either be a steady state fire with a constant heat output or a time-dependent growing fire. The assumption of a steady state fire allows the smoke control system to cater for all fires up to design fire size and, by not considering the growth phase of the fire, can introduce a significant margin of safety into the system design.

However, fire and rescue service preparation and tactical operations typically take place after evacuation when a fire might have grown in size beyond that of a design fire that was a reasonable assumption during the period of evacuation.

Such fire growth could be caused by spread to adjacent fuel, changes in ventilation caused by failure of windows, doors or compartment boundaries, and/or spread of the fire beyond the compartment of origin.

A steady state fire continuing from ignition into the period of fire service tactical operations might not be conservative; this should not be assumed without justification such as the presence of a sprinkler system or an isolated fuel load.

Unless the fire is confined, it should be modelled using one of the following alternatives:

a) a dynamically time-dependent fire should be modelled (see Figure 6); or

b) larger steady state fires may be assumed to progress in a stepwise fashion unless fire and rescue service tactical operations cause the fire to reduce in size (see Figure 7).

Figures 6 and 7 are only illustrative. The timing of changes to the design fire should be assessed using information on the structural response and fire spread beyond the enclosure of origin that is provided by the QDR and sub-system 3 (see PD 7974-5).

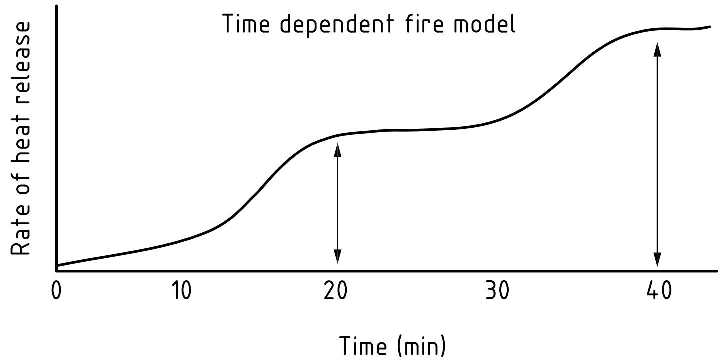
If the fire decreases in size, the modelling of the fire should reflect this.

One of the key aspects of effective fire and rescue service intervention modelling is the evaluation of the balance between fire and rescue service tactical operations and fire growth. In effect, the fire begins to be extinguished once fire and rescue service tactical operations outweigh the fire.

If a single, continuous and unchanged steady state fire is assumed to exist from the moment of fire and rescue service attendance, this key aspect of the modelling might not be successful. It is inevitable that tactical operations eventually outweigh the fire while the harm caused by the fire is independent of time (see Figure 8).

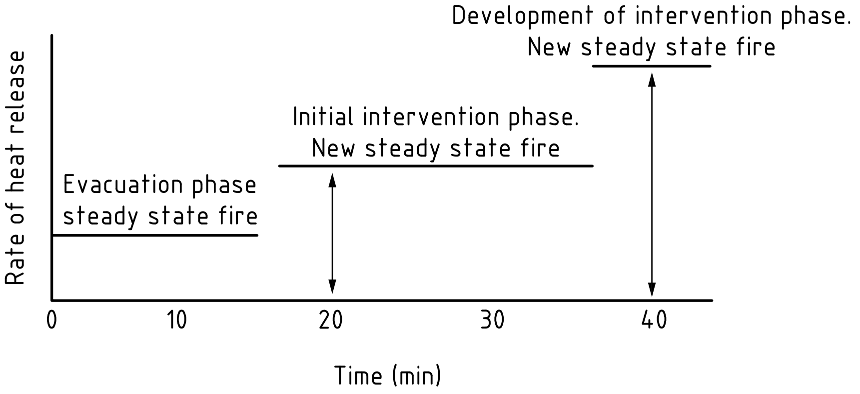
If tactical operations take the form of direct fire fighting, the application of water and ventilation should be taken into account in the model of the design fire. The fire engineer, in association with the fire and rescue service, should determine whether tactical operations are expected to cause the fire to reduce in size, to reduce its rate of growth or to have no noticeable effect.

Figure 6 **Intervention modelling using a time-dependent fire**



NOTE Modelling a time-dependent fire can reveal that if tactical operations occur at 20 min, the fire might be controlled. After 40 min, the fire is calculated to have grown, so the same tactical operations after 40 min might be unsuccessful.

Figure 7 **Intervention modelling using a progression of steady state fires**



NOTE As with Figure 6, a stepwise progression of steady state fires also reveals that if tactical operations occur at 20 min, the fire might be controlled. After 40 min, the same tactical operations might be unsuccessful.

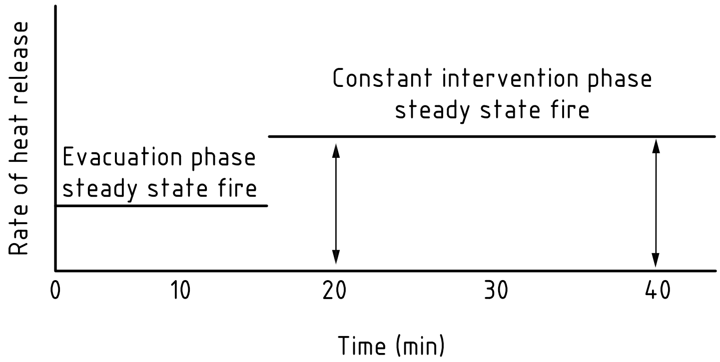
8.3 Modelling the attendance time of fire appliances

8.3.1 Margin for error in fire and rescue service attendance/time modelling

Individual fire and rescue services publish the maximum attendance time that they aim to achieve on the majority of occasions (see **6.5**). However, the fire appliances identified in the PDA cannot be assumed to be available 24 hours per day, seven days per week. Additionally, the actual speed, size and nature of the PDA to an initial report of a fire at any given location depends on many things, including:

- the location of fire appliances at the time of the call;
- whether fire appliances are available or already committed to another incident;
- road conditions en route to the premises.

Figure 8 **Intervention modelling using a continuous steady state fire**



NOTE Unlike Figure 6 or Figure 7, the assumption of a continuous steady state fire suggests that if tactical operations occur at 20 min, the fire might be controlled, but that after 40 min, the same tactical operations might be equally successful. Such an assumption can only be made if it can be justified by circumstances such as the presence of a sprinkler system or an isolated fuel load.

Therefore, the attendance time of the initial fire and rescue service appliances should not be thought of as a fixed value. Rather, it is variable within a range. Its value and margin for error should be determined by the QDR in conjunction with the local fire and rescue service (see Figure 9).

The margin for error in fire and rescue service attendance time is critical to the underpinning of intervention modelling.

8.3.2 Criteria for successful fire and rescue service intervention

An analysis of fire and rescue service attendance and intervention determines the ability of the fire and rescue service to:

a) assist with evacuation and/or carry out rescues (in exceptional circumstances); and

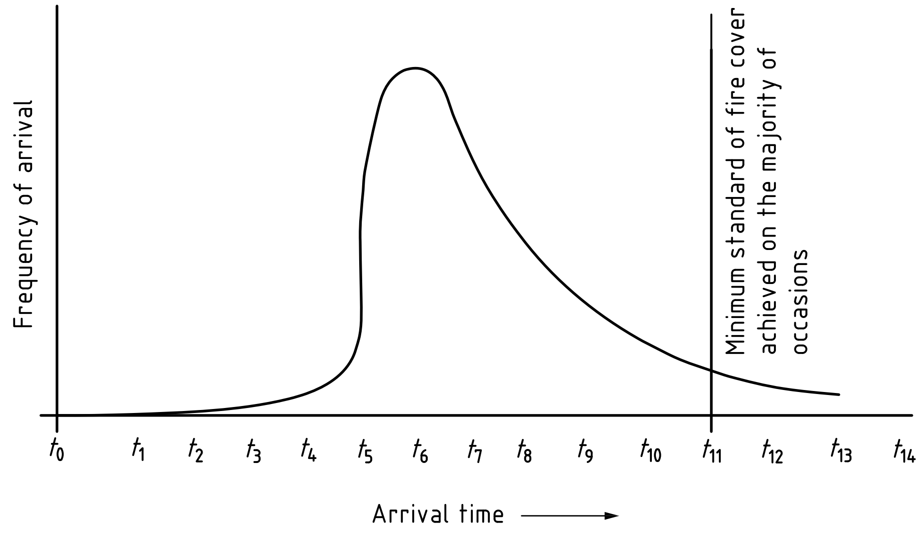
b) contribute to loss control and/or environmental protection by the control and extinguishment of fire.

To ensure that fire and rescue service intervention is effective, it should be established that fire-fighters are able to complete their tasks before untenable conditions are reached. In this case, "untenable" refers to conditions that are untenable for fire-fighters. Since fire-fighters wear personal protective equipment, conditions that are untenable for fire-fighters are significantly different from conditions that are untenable for the normal occupants of a building.

The time from the receipt of an emergency call to conditions becoming untenable for fire-fighters is the available safe intervention time, or ASIT.

The time that the fire and rescue service actually requires in order to achieve successful intervention is the required safe intervention time, or RSIT.

Figure 9 **Example attendance time of fire appliance**



NOTE 1 The figure shows the distribution of probable fire appliance attendance times at a building.

NOTE 2 The time scale is as an example.

NOTE 3 The sub five minute attendance occurs occasionally when the appliance is already on the road in the vicinity of the building.

NOTE 4 The most likely attendance time is in the range 5 min to 6 min, depending of traffic conditions and weather.

NOTE 5 Attendance time greater than 6 min is possible if the appliance is on the road far away from the building or if it is already committed at another incident.

NOTE 6 Fire services not serving large urban areas might have an increased arrival time as discussed at the QDR.

Intervention modelling is deemed successful if it can be shown that the time available for intervention is greater than the time required for intervention:

$$\text{ASIT} > \text{RSIT}$$

where:

ASIT	is the available safe intervention time (the time that fire-fighters have to intervene successfully before untenable conditions);
RSIT	is the required safe intervention time.

8.3.3 Application of attendance time modelling

Figure 10 shows a situation where Δt_{prep} is assumed to start at a modal attendance time of 5.5 min. Δt_{prep} lasts for 3 min followed by tactical operations that take 9 min.

$\text{RSIT} = \Delta t_{\text{attend}} + \Delta t_{\text{prep}} + \Delta t_{\text{to}} = 17.5$ min after the fire and rescue service is notified

Figure 10 also shows fire conditions deteriorating until intervention begins at 17.5 min, conditions are so poor that they are no longer tenable for successful tactical operations.

ASIT = 20.5 min after the fire and rescue service is notified

Thus, ASIT > RSIT and the success criteria would be met.

However, t_{attend} is not a fixed value. If fire appliances are unavailable or delayed, the attendance time might be more than 5.5 min after the fire and rescue service is notified (see Figure 11).

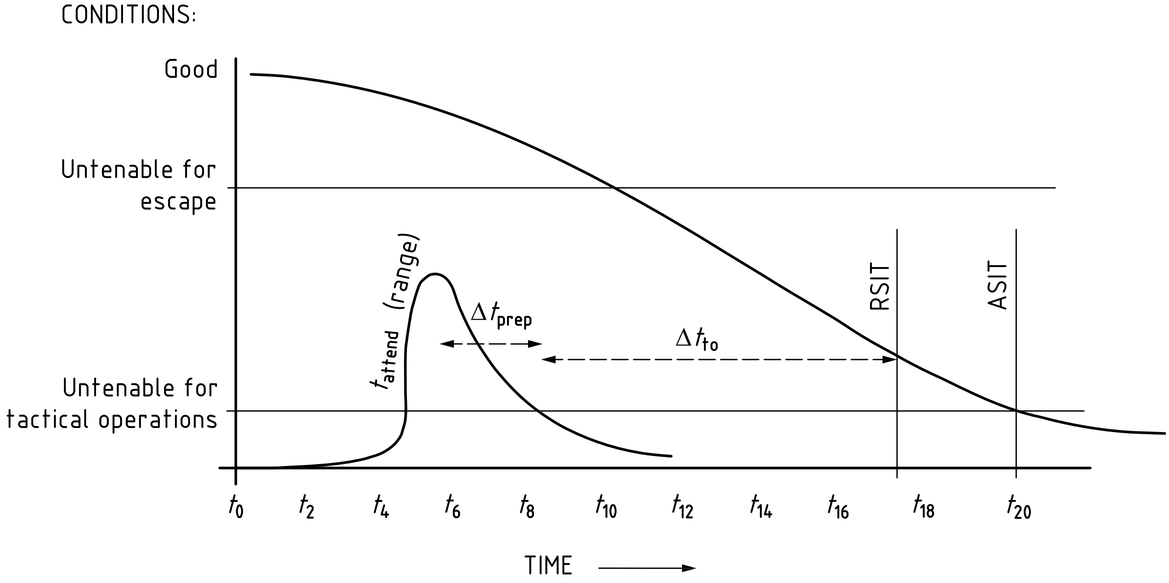
In Figure 10, attendance time is shown to be within a range that extends to 12 min.

If attendance does take 12 min, Δt_{prep} still lasts for 3 min followed by tactical operations that take 9 min. In this case:

RSIT = $t_{attend} + \Delta t_{prep} + \Delta t_{to}$ = 24 min after the fire and rescue service is notified

ASIT is still 20.5 min after the fire and rescue service is notified, but because t_{attend} is increased from 5.5 min to 12 min, conditions become untenable for firefighters before intervention can begin. ASIT < RSIT and the success criteria would not be met.

Figure 10 **The potential range of attendance time and the deterioration of fire conditions**

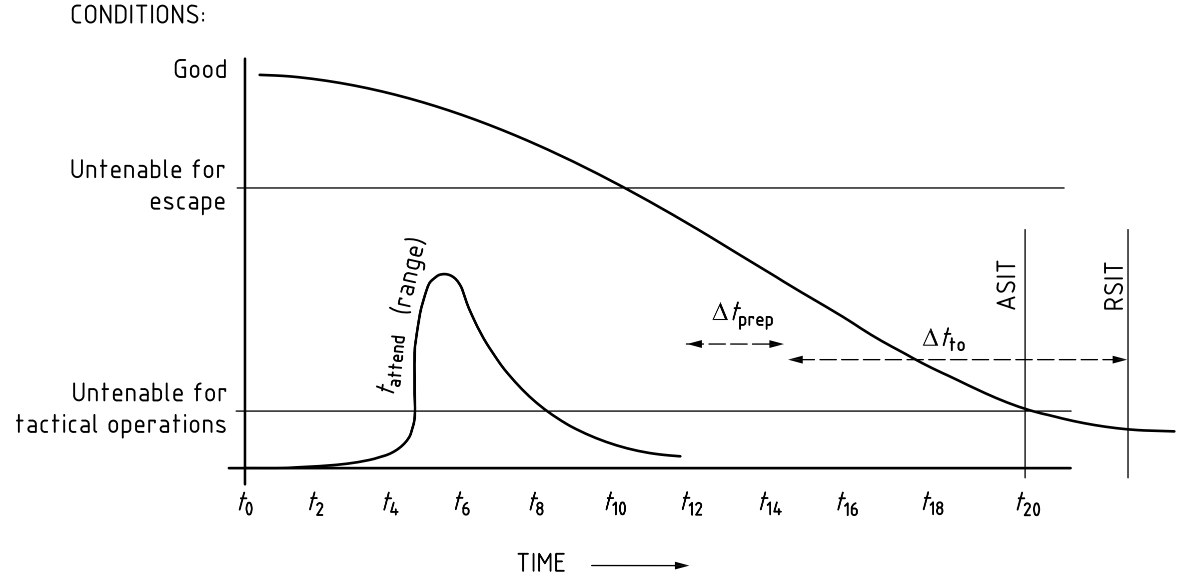


NOTE 1 Actual attendance time is assumed to be the modal value.

NOTE 2 The threshold for the conditions that are untenable for tactical operations varies according to the nature of the tasks (see Figure 16).

NOTE 3 The threshold for the conditions that are untenable for occupant escape is covered in PD 7974-6.

Figure 11 **Actual attendance time towards the higher end of the spectrum so RSIT > ASIT**



NOTE 1 The threshold for the conditions that are untenable for tactical operations varies according to the nature of the tasks (see Figure 16).

NOTE 2 The threshold for the conditions that are untenable for occupant escape is covered in PD 7974-6.

Integrating fire-fighter task analysis with the FSE study of fire growth might show that by beginning tactical operations after 15 min (12 min Δt_{attend} + 3 min Δt_{prep}) instead of after 8.5 min (5.5 min Δt_{attend} + 3 min Δt_{prep}), the fire would be more developed by the time tactical operations started and success would take longer.

Attention is drawn to the Building Regulations [5] [6] [7] [8] which require that facilities are provided within a building to allow fire-fighters to assist in the protection of life. To achieve this, ASIT should always be greater than RSIT, even in the worst likely case fire scenarios. This means that a significant margin of safety should be incorporated into the design where ASIT is much greater than RSIT:

For life safety modelling:

ASIT > RSIT

The margin for safety should be sufficient even to allow the local fire and rescue service to reconfigure its resources in the future without adversely affecting the life safety provisions in the building.

Where the function of fire and rescue service intervention is to deliver loss control and environmental protection, the margin of safety between ASIT and RSIT can be smaller, at the discretion of the QDR.

The fire and rescue service should be involved in the determination of ASIT and RSIT.

The amount of variation in fire and rescue service provision on which the design is based should be recorded so that at a future date, the responsible person/building operator can assess the implications of any alterations to fire and rescue service resources.

NOTE It is not realistic to expect access and facilities for fire fighters to remain in place and working indefinitely. A comparative study (see BS 7972:2001, ***6.4.6.1.4****) shows that even in buildings constructed to prescriptive codes, smoke can eventually get into fire-fighting shafts and flames can penetrate fire resisting walls.*
A comparative study might therefore be of benefit to demonstrate the suitability of facilities provided for fire fighters and the safety margin between ASIT and RSIT.

8.3.4 Modelling the build-up of fire and rescue service resources

If it is necessary for the fire officer in charge of the PDA to request additional fire appliances, the attendance time of those subsequent fire appliances should be assessed.

Local attendance standards exist for the PDA; however, if more appliances are required, their attendance time should be calculated on a case by case basis.

Fire and rescue services have sophisticated computer software that calculates fire appliance attendance times. One such system is the Fire Service Emergency Cover Toolkit (FSEC) which includes road networks, based on Ordnance Survey mapping. Default road speeds provided with the FSEC model are user configurable. Fire and rescue services are able to modify these speeds using actual response times derived from incident data.

The model can have risk data sets specific to different days, and in principle to different times of day, automatically called up within the software. The default data sets are 365 day/24 hour averages, although data such as building occupancy and road travel times can be varied by time period. Data sets include road network, stations, crews, vehicles and default drive times.

The fire officer on the QDR team might be able to use the service’s software to calculate attendance times; however, the benefit of the computer is primarily that it is able to carry out attendance time planning for a whole fire and rescue service and model changes to resource deployment. For a “one off” attendance time planning problem, the process is straightforward and it can be carried out by the QDR team without the software tool.

Task analysis should take account of variability in the attendance time of subsequent appliances in the same way as described in **8.3.1**. An experienced local fire officer should make a professional judgement regarding the attendance times of subsequent appliances. Fire and rescue services hold historic data that can support the judgement.

NOTE In most cases, if it is modelled that the fire and rescue service requires many more fire engines than were in the PDA and still cannot achieve design objectives, it quickly becomes apparent that fire and rescue service resources can never outweigh fire growth in time to achieve the design objectives (unless the design objectives are set very low). If design objectives cannot be met, the whole problem has to return to the QDR team so it is unlikely that intervention modelling ever has to concern itself with the attendance time of more than ten fire engines at most.

8.4 Fire-fighter task analysis modelling

*COMMENTARY ON **8.4***

In 2004, the English government department responsible for the fire and rescue service developed a software tool called the Brigade Response Options System (BROS). The benefit of BROS is primarily that it stores and retrieves information about standard fire-fighting tasks and it provides an auditable log of the development of planning scenarios for fire and rescue services. The planning process itself is straightforward and for a specific case it could be carried out by the QDR team without the software tool.

For fire and rescue services, the purpose of BROS is to identify the resources that need to be delivered to a particular area to deal with an incident. It does this by identifying the tasks that have to be carried out in a given scenario, and allocating them to a sufficient number of fire-fighters to perform them safely. This results in a list of the required resources expressed in terms of equipment, number of fire-fighters and associated specialist attributes considered necessary for fire-fighters to tackle the incident safely.

When used by fire and rescue services, the BROS process is applied to generic situations to facilitate wide-scale planning. However, the same process can be applied to a specific situation, such as a design fire in a building incorporating FSE. The result would be a prediction of the impact that the fire and rescue service would be able to have in achieving the FSE design objectives.

In BROS, scenarios are presented as bar charts showing how the fire-fighting tasks have been allocated amongst the fire-fighters. This serves to record the thought processes of those who developed the scenario.

- The first appliance in attendance is faced with a fire as determined by the fire engineer.
- The number of fire-fighters in the appliance crew, their attributes and the equipment available to them is identified by the local fire and rescue service officer.
- A detailed scenario task analysis is carried out identifying crew roles. The sequential nature of tasks should be taken into account.
- The result of the task analysis is best presented in a bar chart which shows how the tasks have been allocated amongst those present, their duration and the sequence in which they occur.
- On first attendance, the priority of the fire and rescue service might be search and rescue. The capacity of fire-fighters to undertake this task is determined by the fire conditions as calculated using FSE techniques. Where the fire-fighter task is fire-fighting, the impact that fire-fighting has on the fire is determined by the use of FSE techniques.
- If the fire and rescue service need additional fire appliances and crew to deal with the fire, task analysis plus the FSE assessment of fire conditions can identify the time at which the fire officer on the scene would request more resources. The attendance times of oncoming fire appliances should be calculated.
- Once each additional fire appliance or officer has reached the incident, they can be added to the bar chart and tasks can be allocated to them.
- The process is then repeated where fire-fighters activities are recorded, the fire conditions are calculated and the impact of fire-fighting is determined by the use of FSE techniques.

- Eventually, sufficient resources should be brought to bear to contain the fire and extinguish it. The total amount of assessed damage should be recorded. If the amount of damage is within the FSE design objectives, the process is complete. If not, additional measures to assist the fire and rescue service should be incorporated into the design and the process repeated.

Table 2 shows part of a simplified schematic of the output of fire-fighter task analysis.

Fire-fighter physiology should be taken into account when undertaking task analysis. For example, after strenuous work in breathing apparatus in a hot and humid environment, task analysis should include a period of time for fire-fighters to recover.

Fire-fighter task analysis is largely a subjective process based on the judgement and the experience of those performing it. However, it needs a methodical approach to be taken and when carried out in conjunction with fire officers who have local knowledge, it incorporates the procedures and equipment that are likely to be used locally. It can therefore produce results that are sufficiently reliable to be used as the basis of an FSE solution.

Table 2 **Completed task analysis**

	Time from attendance of first appliance							
	1 min	**2 min**	**3 min**	**4 min**	**5 min**	**6 min**	**7 min**	**8 min**
First appliance:								
Officer in charge	Risk assessment			Supervision		Briefing	Supervision	
Fire-fighter 1	Pump operation							
Fire-fighter 2	–			BA rescue				–
Fire-fighter 3	–			BA rescue				–
Fire-fighter 4	Supplying water			Managing hose			–	First aid
Second appliance: (attendance time 5 min after first appliance)								
Officer in charge						Briefing	Com support	
Fire-fighter 1						–	Fire-fighting	
Fire-fighter 2						–	Fire-fighting	
Fire-fighter 3						–		First aid
Incident development:								
	Ground floor room post flashover			Fire spread beyond room or origin			Casualty rescued. Start of fire-fighting	
Incident outcome:	Fire contained to floor of origin, smoke damage to 100% of property, casualty rescued and resuscitation carried out at scene							

NOTE 1 Fire-fighter safety is of the utmost importance to the fire and rescue service. Tasks that secure fire-fighter safety therefore take priority.

NOTE 2 Fire-fighter safety, fire-fighter physiology and the ability to undertake fire-fighting tasks are all linked to the fire conditions within the building. As fire-fighter task analysis is completed, it is therefore critical that FSE calculations are constantly updated to keep a check on conditions including visibility through smoke, air temperature, radiated heat and humidity.

NOTE 3 If all fire-fighters are committed to tasks, the scenario is not robust against injuries to fire-fighters or unplanned tasks like replacing burst lengths of hose. A margin of safety is therefore included in the task analysis if there are fire-fighters present who have no specific task allocated to them. These fire-fighters are referred to as a tactical reserve.

8.5 Adequate fire-fighting water provision

*COMMENTARY ON **8.5***

An effective resource allocation of fire cover relies on an adequate fire-fighting water provision along with sufficient fire-fighter access, both to the exterior and within a building, in line with effective fire-fighting facilities and fixed fire protection systems to support a safe and extended fire-fighting operation, for what is considered a "reasonable" time period. The fire service has a responsibility to ensure that an adequate supply of fire-fighting water is available.

This section considers what an "adequate" fire-fighting water provision might mean and demonstrates the limitations on fire-fighting suppressive capacity in relation to the design fire and the resources needed to mount a successful intervention.

When developing FSE solutions for buildings, it has traditionally been common practice for the fire safety engineer to concentrate largely, or even solely, on life safety and evacuation objectives. In buildings employing phased evacuation or "defend in place" strategies, the ability of the fire service to promptly contain and extinguish a fire before it spreads beyond the compartment of origin is a key aspect of any life safety strategy.

Although life safety is of the utmost importance, a building design which focuses exclusively on life safety might not adequately protect property and business continuity and further meet environmental expectations. Therefore, enhancing the effectiveness of fire service intervention should be a key objective and adequate provisions for fire-fighting water and storage are important elements during the design process.

8.5.1 General

Recent research (see GCU research [9] and Annex A) suggests that adequate fire-fighting water requirements may, in some cases, exceed the amounts (L/min) recommended in existing regulatory guidance that is based on research undertaken in the 1950-60s. Analyses of open-plan floor space, larger window openings and changes in the distributions of fire load, in an ever evolving built environment, demonstrate a need for increasing water flow-rates in specific circumstances. The proposed design methodology for determining adequate water (see Equation 2) for a fully involved fire compartment utilizes fire load density (MJ/m^2) as an input and further incorporates a range of likely ventilation factors that results in a water flow requirement at the changeover point from ventilation to fuel control (Q_{max}).

Alternative approaches may be used to determine the practical limitations of fire service intervention against compartment fire development on a time dependent curve, necessitating the need for a realistic and accurate design fire.

- Use of Equation 1 requires Q_{max} as an input and determines the limits of fire service intervention (L/s) against a fully developed compartment fire demonstrating peak heat release.
- Use of Equations 3 and 4 requires Q as an input and can be used to determine the limits of fire service intervention (L/s) against a growing (time dependent) fire.
- Use of Equation 5 can be used to determine the limits of fire service intervention by assessing the flow-rate of the fire service's primary attack hose-line (L/s required as an input) and calculating the maximum absorptive capacity (MW) against a time dependent intervention on a design fire growth curve.

Using such an approach enables the design team to determine how effective fire service intervention is likely to be in any particular situation and at what point any further enhancement to active or passive fire protection might be considered beneficial. Further information and examples are provided in Annex A.

8.5.2 The efficiency of fire-fighting water applications

The efficiency factor most commonly used to determine the effectiveness of actual fire-fighting water applications to date has been 0.3 (32-33% effective), which supports laboratory or experimental research. More recently however, empirical fire flow data obtained from recent research (see Annex A) of a large number of UK building fires is used to support a 0.5 water application efficiency factor (k_W at 50% effective) in the proposed methodology below. By considering the use of buildings involved in fire and the area damaged by the time the fires were extinguished, a relationship is identified between the area of a fire and the quantity (L/min) of water required to effectively extinguish it.

8.5.3 Combining the efficiencies of combustion and water applications

Compartment fires rarely burn at 100% efficiency. Most enclosure fires are only able to burn to a maximum of 0.45 (45% efficiency) (see *SFPE (NZ) Technical Publication TP 2004/1* [10]) with most of the fuel burning or escaping via openings. Using a k_F factor of 0.50 as a general design input whilst combining the efficiencies of fire-fighting water applications with combustion efficiency, Barnett uses the following formula:

$$F = \frac{k_F \times Q_{max}}{k_w \times Q_w} \qquad (1)$$

where:

F is the required fire fighting water flow in L/s;

k_F is the heating efficiency of fire (conservatively 0.50);

k_w is the cooling efficiency of applied water (conservatively 0.50);

Q_{max} is the maximum heat output of fire in MW;

Q_w is the absorptive capacity of water at 100 °C = 2.6 MW/L/s.

In simple terms, this means that for each MW of Q_{max} in a fire, the fire-fighting water flow needs to be 0.50 / (0.50 × 2.6 MJ/kg) = 0.38 L/s/MW (23 L/min/MW) of Q_{max}.

8.5.4 Objectives of an effective flow-rate methodology

The majority of developed building fires in the UK involve floor space up to 500 m^2 and demand fire-fighting water flow-rates up to 6 000 L/min to deal (see GCU research [9]). A few larger fires occur each year where water demands might increase further. However, logistically it often proves difficult to meet the high flow-rate demands of such large fires unless adequate hydrant provisions or nearby open water sources are immediately available and an effective means of transporting this water to the fire scene are provided.

An engineering methodology which supports design objectives is useful where optimum flow-rates needed by the fire service to control and suppress fires could be compared with other passive and active control measures, in order to demonstrate where fixed protection can assist intervention or compensate in other ways where intervention efforts are likely to fail at an early stage.

It is important that an effective methodology is founded in the physics of fire suppression within the field of fire safety engineering. Equally important is that the approach is validated by detailed empirical analysis of real building fires in all occupancy types, rather than just laboratory based research.

There are critical flow-rates below which a fire is unlikely to be controlled, as well as optimum (needed) flow-rates where control is achievable. Any methodology should recognize that underground piped water supplies might be unable to meet optimum fire-fighting water requirements in some situations. It could therefore be necessary to consider on-site water storage and/or access to external open water sources as a critical part of the design process.

It is beneficial to be able to approach flow-rate design strategies using either fire load density (MJ/m^2), peak heat release rates (MW) or floor area (m^2) in a range of occupancies, as core inputs to the modelling. When using fire load density in the modelling it is important to differentiate between horizontal and vertical fire load distributions as well as using up-to-date and relevant fire load density distributions.

Where fire service intervention is to be considered as part of the engineering strategy for a building, the effectiveness of such an intervention may be improved in some cases by the provision of 150 mm internal fire mains with twin outlets at every floor as opposed to single outlet 100 mm mains. The reason for this is because any increase in calculated fire-fighting water demands may be more readily available for deployment per m^2 of open-plan floor space. The additional provision of protected lobbies allow stairs to remain smoke free for longer and enable fire-fighters to deploy two hose-lines at the fire floor and intervene far more quickly and effectively. In open-plan floor space, time to deployment may be critical.

8.5.5 Design fire analysis

Equation 2 produces a design flow-rate for full involvement of a fire compartment with steady state burning at Q_{max}, given as a reasonable worst-case scenario that might begin to impact on the structure or enable the fire to spread beyond the compartment in question if the fire is not extinguished by intervention.

During the development of Equation 2, extensive zone modelling of various floor areas, ventilation opening ratios and fire load energy densities were carried out as background research (see *SFPE (NZ) Technical Publication TP 2004/1* [10]). The floor areas ranged from 100 m^2 to 5 000 m^2. Ventilation openings ranged from 2% to 20% of floor area. Ceiling heights ranged from 2.4 m to 6.0 m using the former for small buildings and the latter for large. Growth and decay constants were selected as 225 s/MW and 900 s/MW respectively. Net heat of combustion was selected as 18 MJ/kg to cover a mix of wood and plastic. It was noted that the fires were ventilation controlled at the low end of percentage openings but, at some point as the ventilation increased, the fires switched to fuel bed controlled. The fire intensity did not increase from that point onward regardless of any further increase in ventilation openings. It was therefore found that the greatest fire intensity occurred at the ventilation to fuel bed controlled changeover point (Q_{max}). This was then taken as the most conservative answer for that particular floor area and the corresponding fire-fighting water flow.

$$F_{\mathrm{design}} = 0.00741(q_{\mathrm{k}} \times A_{\mathrm{f}})^{0.666} \quad (2)$$

where:

F_{design} is the design flow-rate for a fully involved fire compartment >100 m^2 burning at maximum intensity (L/s);

q_{k} is the fire load density for the compartment (MJ/m^2);

A_{f} is the total internal floor area of the compartment (m^2).

NOTE Designing a fire-fighting water requirement for a fully involved compartment burning at Q_{max} *may imply that the structural elements serving the compartment could be approaching the limit state. It is for the fire service commander to decide at what point offensive interior fire-fighting operations should be curtailed, taking account of the extent and duration of fire resistance provided and the performance of the structure as observed during fire-fighting. It is possible that in some circumstances a fire compartment may be subjected to full fire involvement and the fire then fully suppressed, long before the designed limit state region is approached. (Limit states are the states beyond which the structure no longer satisfies the performance requirements specified).*

8.5.6 Growing fire analysis

When modelling the incident development using fire service task analysis (see **8.4**), it might be beneficial from a design perspective to consider the effect of applying fire-fighting water in the early stages of a growing fire. There is a need to request from the fire service the actual (minimum) flow capability (L/min) of the primary attack hose-line likely to be deployed and the time following arrival on-scene that this may take to deploy (water applied onto fire). Much data is publicly available that supports fire service intervention time-lines for a range of scenarios, including high-rise buildings, but this should be agreed at the QDR. This information may then be matched against the selected design fire curve on a time-line.

When fire-fighting water is applied to a growing fire there are several possible outcomes (see Figure 12).

a) Fire fully extinguished.

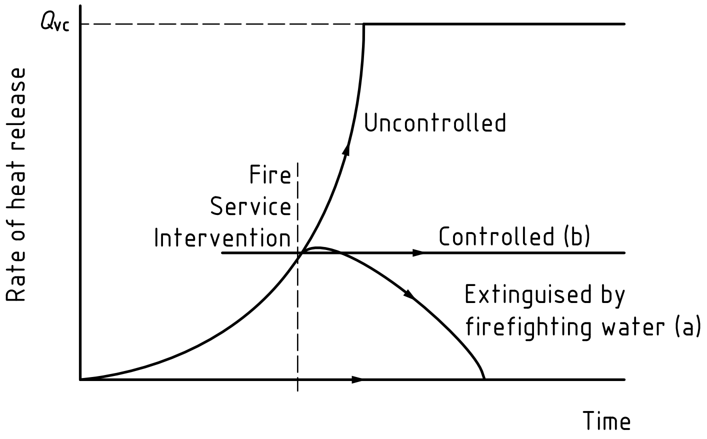
b) Fire is controlled but not extinguished; does not spread or become worse.

c) Water flow rate is inadequate and fire continues to spread, uncontrolled.

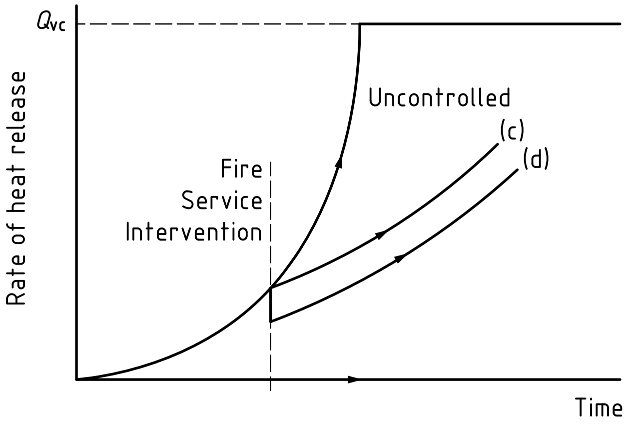
d) Fire spread is only partially suppressed; continuing to spread at a slower rate.

There are several routes open to the fire engineer in determining the heat release (Q) of both a pre- and post-flashover fire (see PD 7974-1). These generally base themselves around the calorific values of involved fuel loads (MJ/kg) and fuel mass loss rates (kg/s). The design fire used should represent the most reasonable worst-case scenario, taking a range of ventilation conditions into account. Simple hand calculations might only provide estimates, whereas computer modelling or reference to ventilation restricted fire growth curves (for example) can offer more accurate design fire data that can be used in predicting fire development.

Figure 12 **Potential impacts of applied water on the rate of heat release**



a) Effect of control/suppression



b) Effect of partial suppression

NOTE Q_{vc} is the rate of heat release under ventilation-controlled conditions.

For example, using a t^2 approach to early stage fire growth:

$$Q = \alpha(t - t_i)^2 \tag{3}$$

where:

Q	is the total heat release rate from the fire during the growth phase (kW);
t	is the time from ignition (s);
t_i	is the time of ignition (s), taken as the length of the incubation period (s);
α	is the fire growth parameter (kJ/s³).

Then by using:

$$F_{growth} = 0.38 \times \frac{Q}{1000} \tag{4}$$

where:

F_{growth}	is the fire-fighting flow-rate (L/s) required during the growth stages;
0.38	for each MW of Q the required flow-rate is 0.38 L/s.

The required flow-rate (L/s) for a growing fire has been obtained and can be matched against the estimated beginning of fire-fighting operations (time water is applied), based on any given task analysis.

The purpose of a growing fire analysis is to take a point in time during the development of a compartment fire at which stage the time-lined task analysis enables the fire service to apply water or suppressive agent to the fire. It is useful for the fire engineer to estimate the fire size at the start of fire-fighting and evaluate if the fire service suppressive capacity at that point is likely to be able to control the fire, reduce the fire's rate of spread, suppress the fire or have no effect on the fire's development whatsoever. With this information it can then be ascertained if the enhancement or provision of further passive or active fire protection measures might become important considerations in the design process or if fire service intervention is likely to control the fire within a reasonable time-frame, with additional hose-lines deployed.

8.6 Tenability for fire-fighters

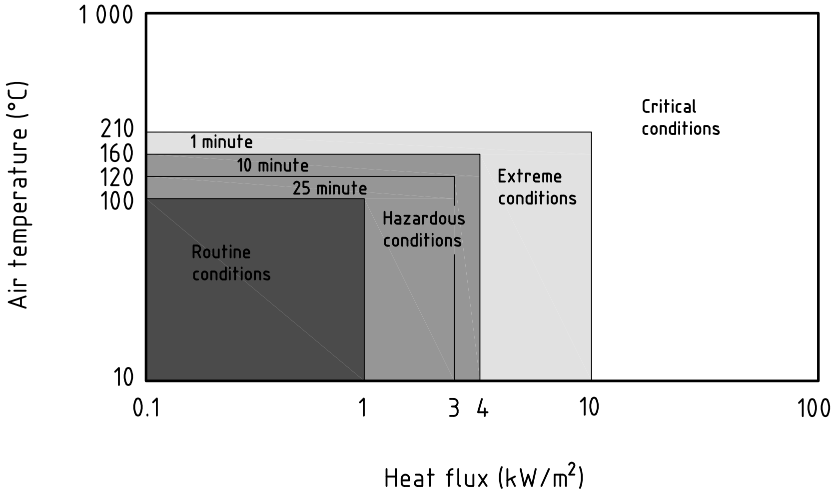
The conditions in which it is possible for fire-fighters to work depends largely on the personal protective equipment of the local fire and rescue service. Tenability conditions for fire-fighters should therefore be discussed with the local fire and rescue service in conjunction with FSE calculations of temperature, heat flux and humidity.

Fire Research Report 61/1994 [11] classifies fire-fighting environments into categories and specified the maximum time, temperature and heat flux associated with each type of exposure. The result was a recommendation of four thermal classes of fire-fighter exposure, which are displayed in Figure 13. The proposed maximum fire-fighter exposure time for each class is listed within the shaded area showing the range of air temperatures and heat flux values at each thermal class.

For exposures during search and rescue activities, maximum air temperature and heat flux exposures might be misleading as fire-fighters often spend little time in the fire compartment but longer searching areas heated by the fire. Fire-fighters who are searching for and fighting fires are likely to spend longer periods of time in compartments of high temperature and heat flux.

A time-weighted average should therefore be used to model thermal exposures (see *Fire Research Technical Report 1/2005* [2]).

Figure 13 **Recommendations for thermal classes of fire-fighter environments, showing range of air temperature, heat flux and duration**



NOTE 1 Under routine conditions, the humidity has a significant effect on the tolerance times for routine conditions but the combined effects of temperature and humidity were not explored in the research.

NOTE 2 Humidity is not a significant factor above 100 °C because it decreases rapidly to low relative humidity values.

NOTE 3 Exposure to extreme conditions for up to 1 min might be tolerable if the outcome is to save life. However, damage to personal protective equipment can occur under these conditions and it would not be accepted operationally.

NOTE 4 Critical conditions could be life threatening. A fire-fighter would not be expected to operate in these conditions.

EXAMPLE 1

If a fire-fighter spends 10 min in a room at a temperature of 40 °C and <1 kW/m^2 and 1 min in a different room where the temperature was 140 °C and 1.5 kW/m^2 then the time-weighted average of the two values would be:

(10 min × 40 °C) + (1 min × 140 °C) = 540 min °C

or

49 °C for 11 min

This is within the limitations of Figure 13.

However, the time-weighted average should not mask peak exposures.

EXAMPLE 2

If a fire-fighter spent 5 min in a room at a temperature of 60 °C and <1 kW/m^2 and 3 min in a different room where the temperature was 300 °C and 3 kW/m^2 then the time-weighted average of the two values would be:

(5 min × 60 °C) + (3 min × 300 °C) = 1 200 min °C

or

150 °C for 8 min

This time-weighted average is within the limitations given in Figure 16, but the peak exposure of 300 °C for 3 min exceeds the limitations.

The above calculations assume that fire-fighters are not already fatigued when they begin breathing apparatus operations. If fire-fighters have already worn breathing apparatus recently, have carried equipment to the scene of the fire or have climbed stairs for example, their core body temperature could already be elevated. Under such circumstances, interpretation of Figure 16 should be adapted to take account of the fire-fighter's reduced capacity for further work.

8.7 Reliability of fire safety systems

The FSE design of a building should enable occupants of the building to be protected from a fire, or to evacuate, without external assistance. However, there may be exceptional circumstances where the fire and rescue service might have to assist with evacuation or even rescue occupants (see **5.2**).

The likelihood that the fire and rescue service is called upon to rescue people is therefore partly dependent upon the robustness of the FSE design.

Fire safety design solutions rely on contribution from a number of systems including early warning of fire, adequate means of escape, control of fire spread and containment of fire within compartments. There are few areas within code compliant fire safety design solutions where life safety depends wholly on one critical system working. Multiple systems have to fail before life safety relies on the safety net provided by the facilities to assist the fire and rescue service.

However, the same is not necessarily true of FSE design solutions. FSE design solutions can rely much more heavily on only one or two systems. Such systems should be identified, with consideration given to the specific assessment of their reliability as part of the QDR process in order to ensure that all life safety objectives can be achieved, without reliance being placed on the fire and rescue service.

Once identified:

a) critical systems should be highlighted and information should be passed on to the occupier so that they can be managed with the appropriate degree of care; or

b) a more layered approach to overall fire safety should be provided.

For example, if reasonable fire safety is delivered by three independent systems, all three have to fail simultaneously before safety is fully compromised. This means that the probability of failure of any individual system can be relatively high and yet the overall reliability is good (see PD 7974-7 for probabilistic risk assessment):

- System A: probability of failure = 0.21 (21%)
- System B: probability of failure = 0.21 (21%)
- System C: probability of failure = 0.21 (21%)
- Probability of total failure = 0.21 × 0.21 × 0.21 = 0.01 (1%)

If reasonable fire safety is delivered by only two different systems, the probability of failure of any individual system should be less to deliver the same overall reliability:

- System A: probability of failure = 0.10 (10%)
- System B: probability of failure = 0.10 (10%)
- Probability of total failure = 0.10 × 0.10 = 0.01 (1%)

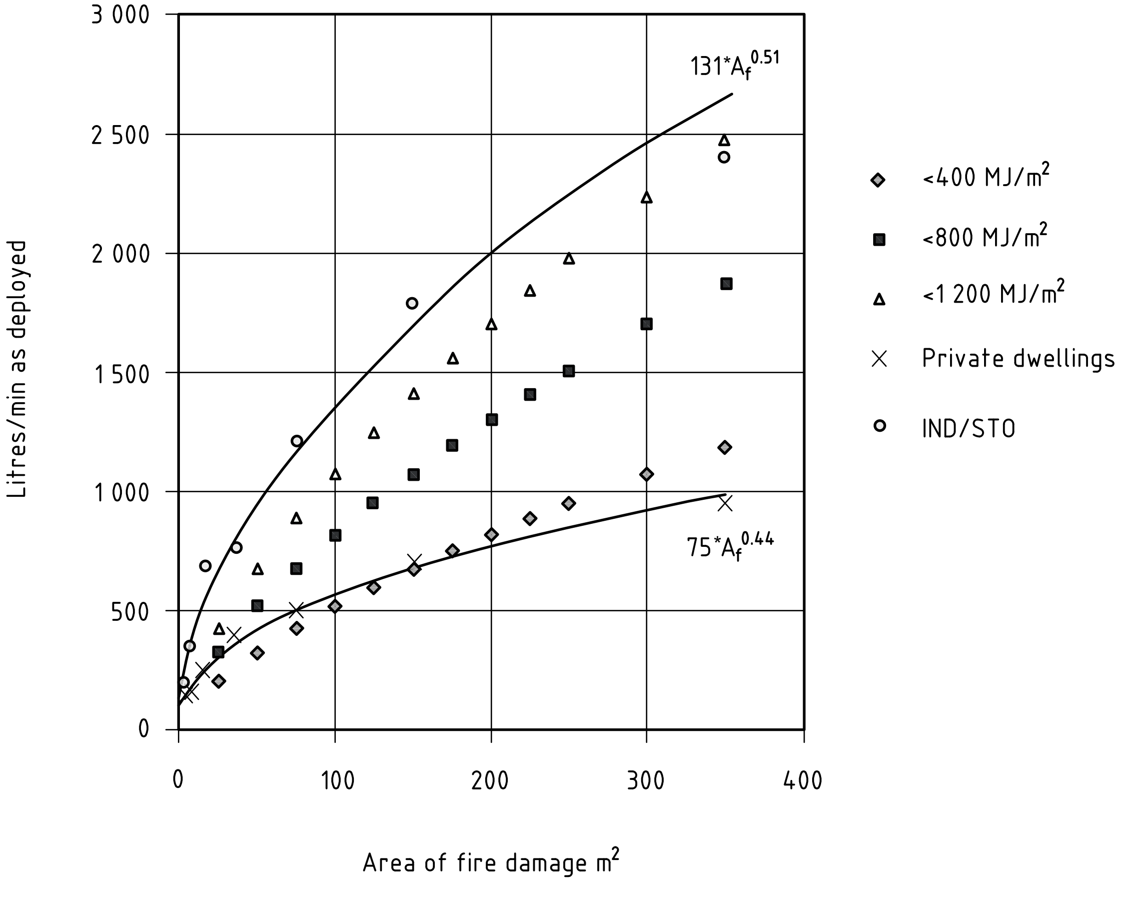
But if reasonable fire safety relies on only one system, that system should be 99% reliable on its own to deliver the same overall reliability.

Annex A (informative) Providing adequate fire-fighting water in large, tall or complex buildings

A.1 UK research 2009–2012 of >5 000 building fires

The flow-rate methodology in **8.5** can be compared to the Glasgow Caledonian University (GCU) research (see GCU research [9]) undertaken of a large number of UK building fires that occurred in two fire authority areas over a three-year period from 2009–2012 (see Figure A.1 and *Fire Risk Management Journal* [12]). The research is specific to internal building fires, not including derelicts, exterior roof or chimney fires. The data have been refined to those fires where an area of internal fire damage was recorded and water was deployed by hose-reel and/or main-line jets/monitors. The data resulted in over 5 000 working building fires (>4 000 metropolitan and >1 000 county areas). Previous similar research in the UK has rarely looked at more than 400 building fires. This research offers useful benchmark data against which the various fire-fighting flow-rate methodologies can be compared or validated.

Figure A.1 **Glasgow Caledonian University (GCU) UK fire research data with results from Barnett's Equation 2 inserted**



NOTE Close correlations exist between the GCU >5 000 building fire research data (lower (dwellings) and upper (industrial) boundary lines) and Equation 2 proposed by Barnett (400 MJ/m², 800 MJ/m² and 1 200 MJ/m² fire load densities used as examples). The GCU curves represent "deployed" flow-rates that include some tactical "safety" hose-lines (additional to that flowed purely for suppression).

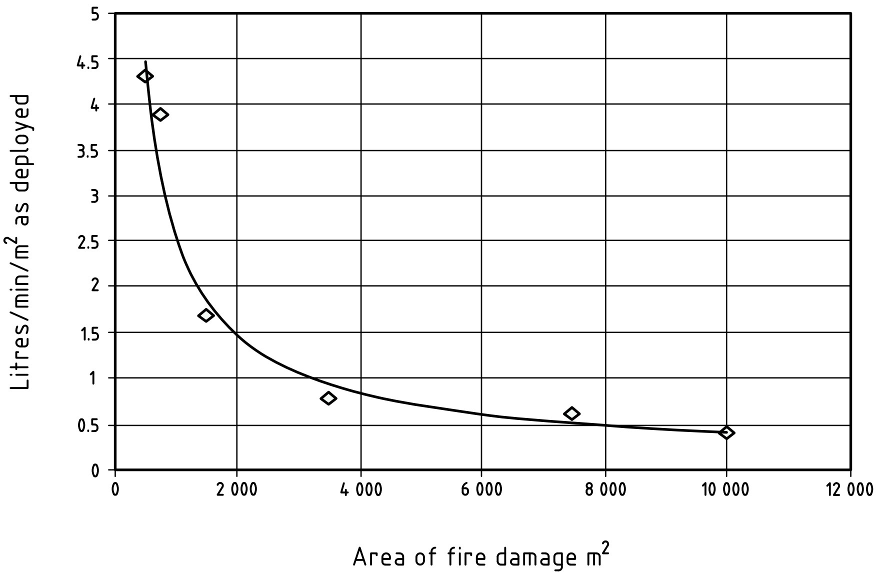
A.2 Large fires >500 m²

Large fires >500 m² to 10 000 m² have also been researched by GCU (see Figure A.2) where it was generally noted that beyond 600 m² of floor space fire involvement, the fire service are generally restricted in their capacity to transport sufficient amounts of water to the fire scene whilst a fire remains on the growth side, or at steady state peak, of any fire development curve.

When open floor space >600 m² becomes rapidly involved in fire it normally requires a greater depletion of the fuel load, into the decay stage, before the available flow-rate can begin to have any positive effect in suppression. The suppressive capacity of a fire attack generally begins to lose effectiveness as the applied flow-rate falls below 3.75 LPM/m². The critical flow-rate below which fire-fighting hose-lines can generally be expected to fail in suppression is seen below an applied rate of 2 L/min/m² (see *Euro firefighter* [13]).

The flows as deployed at 70 large fires in the GCU research match closely to current guidance provided (see *National guidance document on the provision of water for fire fighting* [3]) although minimum applied flows over large areas are higher in actual fires (see Figure A.2) at 0.4 L/min/m² compared to 0.1 L/min/m² recommended in the UK national guidance document.

Figure A.2 **GCU research of 70 large fire >500m²**



NOTE Where building fires spread rapidly to involve floor space >600 m² it is generally the case that the fire depletes much of the fuel load and burn into the decay stages before the fire service are able to gain effective control and complete extinguishment.

A.3 Travelling fire analysis

A review of fires in large open-plan compartments (see Table A.1) reveals that, in general, these fires do not conform to normal flashover fire development involving the entire enclosure at one time. Instead, these fires tend to move across floor plates, reaching peak levels of heat releases across a limited or zoned area at any one time. These fires have been labelled “travelling fires” and in some texts this process of fire development has been referred to as “progressive burning”.

Where a fire is spreading across a large open-plan office floor, for example, it might eventually appear that the entire floor-plate is burning. However, the fire is likely to be at different levels of intensity. In some areas, the fire might still be in its growth stages whilst elsewhere on the floor-plate, the fire might have reached its peak intensity burning at steady state, with other far field areas burning into the decay stages.

In terms of meeting an adequate fire-fighting water provision, the concept of a travelling fire in large enclosures should be looked at primarily using a growing fire analysis. If fire service intervention is unlikely to control the fire at the point the primary hose-line is deployed, then additional active or passive fire protection features, or the effective siting of additional fire-fighting shafts with 150 mm fire mains to support multiple secondary hose-line deployments at the fire floor, should be considered and discussed with the fire service at the QDR stage.

Whilst medium *t*-squared growth rates might apply to cellular office floor layouts, in modern open-plan office space, experience has demonstrated (see *Fire Risk Management Journal* [12]) that fire spread during the growth stages can be “fast to ultra-fast” (see Table A.1) and a sensitivity analysis should be considered on this basis.

Table A.1 **Fire growth rates and travelling fire spread rates observed at past high-rise incidents**

High-rise office building fire	Initial fire floor area (m^2)	Fire spread (m/min)	Fire spread (m^2/min)	t-squared fire growth rate
Interstate Bank, Los Angeles 1988	1 400 m^2 Open-plan offices	3.00	22.2	>Fast
Windsor Tower, Madrid 2005	900 m^2 Partitioned offices	1.09	7.6	Medium
CCAB Building, Chicago 2003	240 m^2 Open-plan offices	2.00	20.0	>Fast

A.4 Horizontal or vertical fire spread analysis

Fire load density in a compartment should be effectively represented as a basis for all calculations and modelling inputs. In some cases, it might be useful to carry out a more specific detailed analysis of fire loading as published fire loadings applied to occupancy types might, in some cases, appear inappropriate.

The variance between horizontal and vertical fire load distributions could be critical in any assessment and, in particular, retails stores, warehouses, industrial units and some other high ceiling spaces might present vertical fire loads of great relevance. In assessing fire load density, high rack storage, including sports clothing on hangers or shoes in cardboard boxes, should be taken into account and/or modelled for fire spread. Other commodity type storage, stack heights, vertical fire spread rates through racking and in between stacks, and radiated heat flux across aisles should also be taken into account and possibly modelled, with further consideration given to fire spread caused by burning brands travelling on thermal currents.

On an intervention time-line it can be seen that the extinguishing capacity of the primary attack hose-line could be overrun by a fast spreading fire within a few minutes. The additional hazards of a rapidly lowering smoke layer and the potential for collapsing stock trapping fire-fighters are always of major concern.

A.5 Example calculations

EXAMPLE 1 – Flats and apartments

A 70 m^2 apartment (flat) on the tenth level of a high rise building with 60 min fire resistance to the separating compartment walls.

Fire load density for 80% fractile of dwellings = 870 MJ/m^2 (see PD 7974-1:2003, Table A.19) using Equation 2.

$$\begin{aligned} F_{\text{design}} &= 0.00741 \times (870 \times 70)^{0.666} \\ &= 0.00741 \times 60\,900^{0.666} \\ &= 11.4 \text{ L/s} \\ &= 683 \text{ L/min} \end{aligned}$$

Where the actual fire load density for specific compartments has been calculated then this should be used in the equations. Compartment fires involving dwellings are generally limited in growth and development by small rooms and small openings. Therefore, it is important to insert accurate fire load densities into the equation. An applied fire load density of 450 MJ/m^2, for example, would yield a needed flow-rate of 440 L/min. Other important considerations might include the impact large windows and combustible floor coverings may have on fire intensity (MW).

NOTE Flats (apartments) in the UK are generally significantly smaller than other property types, averaging 70 m². They are around 27 m² smaller than a typical terraced house and just half the size of an average detached property.

EXAMPLE 2 – Open-plan office floors

A 600 m^2 open plan office floor on the seventh level of a high rise building with 60 min fire resistance to the compartment walls.

Fire load density for 80% fractile of offices = 570 MJ/m^2 (see PD 7974-1:2003, Table A.19) using Equation 2.

$$\begin{aligned} F_{\text{design}} &= 0.00741 \times (570 \times 600)^{0.666} \\ &= 0.00741 \times 342\,000^{0.666} \\ &= 35.9 \text{ L/s} \\ &= 2\,156 \text{ L/min} \end{aligned}$$

The fire service often requires an additional amount of water at an incident that is over and above that required to extinguish the fire, to deal with unusual fire spread or multi-floor fires, etc. This should be discussed with the FRS at the QDR stage of design. In Example 1, a 1 500 LPM fire main might suffice whereas in Example 2, at least two 1 500 LPM fire mains would be needed to provision the open-plan 600 m^2 floor plate with an adequate fire-fighting water supply.

EXAMPLE 3 – Growing fire analysis cellular partitioned offices – Medium growth

The fire service have ascertained from resources likely to be available that it takes them 20 min, following arrival on-scene, to be able to deploy an initial attack hose-line into a 600 m^2 partitioned office floor on the seventh level.

The fire engineer needs to estimate early stage fire development at the point of proposed intervention on a time-line that suggests 1 200 s as the intervention time following arrival on scene, using Equation 3.

$$Q = \alpha(t - t_i)^2$$

where:

Q	is the total heat release rate from the fire during the growth phase (kW);
t	is the time from ignition (s);
t_i	is the time of ignition (s);
α	is the fire growth parameter (kJ/s^3) (see PD 7974-1).

Taking a "medium" fire growth rate for cellular office design, where the fire has an estimated incubation period of 540 s coupled with an attendance time of the same for two fire engines to arrive on scene:

$$= 0.012 \times (1740 - 540)^2$$

$$= 0.012 \times 1\,200^2$$

$$= 17\,280 \text{ kW}$$

Then by using Equation 4:

$$F_{\text{growth}} = 0.38 \times \frac{Q}{1000}$$

where:

Q	is the *t*-squared heat release rate of a growing fire (kW);
0.38	for each MW of Q the required flow-rate is 0.38 L/s.

$$= 0.38 \times (17\,280/1\,000)$$

$$= 0.38 \times 17.2 \text{ MW}$$

$$= 6.5 \text{ L/s}$$

$$= 390 \text{ L/min}$$

The analysis demonstrates that at 20 min after a medium *t*-squared fire has entered its growth curve, a minimum flow-rate of 390 L/min is required for deployment in order to extinguish the fire. The fire is still spreading as crews advance into the fire floor and it is important to ensure the calculations take into account a reasonable estimation of intervention as the time water is actually applied to the fire.

EXAMPLE 4 – Flow-rate versus heat release rate

Another simple approach could be taken into account by taking the maximum extinguishing capacity based on the target flow-rate of the primary deployment of an attack hose-line, which the relevant fire service state in their case is capable of 450 L/min (7.5 L/s).

$$Q_s = \frac{F(k_w \times Q_w)}{k_f} \tag{5}$$

where:

Q_s is the heat absorption in the water used directly on the fire for suppression;

F is the hose-line flow-rate in L/s;

k_f is the heating efficiency of fire (conservatively 0.50);

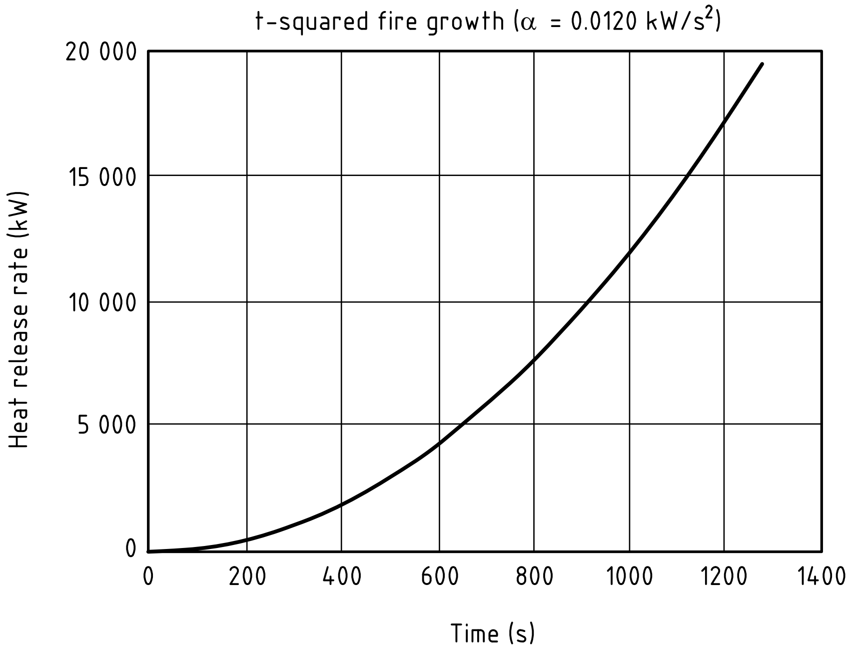
k_w is the cooling efficiency of applied water (conservatively 0.50 for a jet nozzle);

Q_w is the absorptive capacity of water at 100 °C = 2.6 MW/L/s.

$$= 7.5\left(\frac{0.5 \times 2.6}{0.50}\right) = 7.5\left(\frac{1.3}{0.50}\right) = 19.5\ \text{MW}$$

Then, by matching this result (MW) on the relevant fire growth curve (see Figure A.3) it is relatively straightforward to ascertain the time(s) when the suppressive capacity of any particular hose-line is outpaced by fire development

Figure A.3 **Medium *t*-squared growth curve**



NOTE On a medium t-squared growth curve 19.5 MW is attained in 1275 s so 450 L/min is applied onto the fire within 21 min 15 s from the time of ignition (t).

EXAMPLE 5 – Growing fire analysis open-plan offices – Fast growth

$$Q = \alpha(t - t_i)^2 \qquad \text{(using Equation 3)}$$

Taking a "fast" fire growth rate where the fire has an estimated incubation period of 540 s coupled with an attendance time of the same for two fire engines to arrive on scene:

$$= 0.047(1\,740 - 540)^2$$

$$= 0.047 \times 1\,200^2$$

$$= 67\,680 \text{ kW}$$

Then by using Equation 4:

$$F_{\text{growth}} = 0.38 \times \frac{Q}{1000}$$

$$= 25.7 \text{ L/s}$$

$$= 1\,543 \text{ L/min}$$

The analysis demonstrates that at 20 min after a fast *t*-squared fire has entered its growth curve a minimum flow-rate of 1 543 L/min is required for deployment in order to extinguish the fire.

This suggests that at 20 min intervention time, a fast *t*-squared growth rate in an open-plan office floor might see the fire develop beyond the capability of any immediate fire service intervention.

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