

First edition
2006-04-01

Review of outputs for fire containment tests for buildings in the context of fire safety engineering

*Examen des résultats des essais d'endiguement du feu pour les
bâtiments, dans le contexte de l'ingénierie de sécurité*



Reference number
ISO/TR 22898:2006(E)

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Case postale 56 • CH-1211 Geneva 20
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Web www.iso.org

Published in Switzerland

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Foreword

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

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

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

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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

ISO/TR 22898 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 2, *Fire containment*.

Introduction

Fire resistance test methods have been in existence for many decades and they permit various forms of structure to be evaluated and classified for regulatory purposes with respect to their fire containment capabilities, against conditions that reproduce one of the many possible fire scenarios that can exist in practice. Because of the changing use of materials and the design of modern buildings, even this one scenario is becoming less relevant to the performance expected in practice. The criteria of failure used in these standardized tests sometimes reflect pseudo-life risk and sometimes a property risk. More recently, tests have been developed to measure the smoke containment potential of doors at ambient temperatures.

When a fire engineer is designing a structure to resist the spread of fire and the products of combustion in order to satisfy a fire strategy that is responding to actual conditions and known exposure variations, both with respect to the life safety of persons and the limitation of damage to the structure, the output of the standard fire tests are not deemed to be relevant in most situations. This Technical Report reviews the relevance of the standard tests and their outputs for the benefit of committees and working groups developing specifications for structure that can satisfy a functionally derived fire safety strategy.

In considering the effectiveness of the test for life safety purposes, it is solely with respect to the ability of the element to contain the fire to the enclosure/compartiment of origin so that people outside of that space, including fire fighters, are not harmed indirectly by the fire or the behaviour of the building. By the time the “flashover” condition exists, it is assumed that the life safety of the persons within the enclosure is no longer a matter of concern because the measures put into the design to ensure escape have achieved their objective.

Once initiated, a fire within an enclosure, during this phase, initially burns in what is known as a “fuel-bed” controlled state. In this condition, in simplistic terms, the rate of combustion (and hence heat release) is controlled by the nature and geometry of the fuel at the seat of the fire. The predominant means of fire spread within the enclosure is by direct flame impingement on other combustible materials or by heat radiation from the flames onto materials positioned very close by. Provided that the hot gases of combustion can vent easily into the open air from the enclosure or compartment (and that the elements of structure forming the compartment’s boundaries are not of a highly insulative nature), then it is conceivable that, for very well ventilated spaces, the fire will continue growing in a fuel-bed controlled state until all combustible material within the enclosure or compartment is either on fire, or has been completely combusted. In large, well ventilated compartments, it has been shown by means of large scale “natural fire” tests that the fire can “leap frog” to adjacent parts of the compartment and that by the time fire reaches combustible materials remote from the original initiation point, the fuel at the initial location has been completely used up. Under such circumstances, the air/gas temperatures within the compartment are likely to be significantly stratified and are unlikely to exceed 500 °C.

In most fire containment applications, however, it is unlikely that there is an adequate supply of air via “natural” ventilation to support a fire in a persistently “fuel bed” controlled state. In these circumstances, the destination of the effluent gases of combustion plays a crucial role in the further development of fire. Once hot effluent gases are being produced by a fire at a rate faster than can be vented from the space, these gases start to collect under the roof or ceiling, thus forming a hot gas layer. As the layer deepens and gets closer to the seat of the fire, the amount of “cold” ambient air drawn into the rising plume becomes less due to the shorter distance available for the plume to entrain the air.

Consequently, the degree to which the smoke products are diluted, and hence cooled, becomes less. This, in turn, increases the temperature of the smoke layer, which also tends to darken due to the increased density of smoke particles. As the magnitude of this temperature approaches 600 °C, the hot smoke layer is radiating significant quantities of heat in its own right and this energy is capable of causing pyrolysis, or even auto-ignition of combustible materials quite remote from the seat of the fire. This phenomenon marks the occurrence of flashover, and, once it occurs, all combustible materials within the enclosure rapidly become involved in the fire.

The fire now enters the post-flashover, or “ventilation” controlled state, which is characterized by turbulent “swirling” flames throughout the entire space in conjunction with large flames from ventilation openings where superheated unburned volatiles escape and burn in the open air. Once a compartment fire is burning in a post-flashover ventilation-controlled state, then temperatures within the compartment are quite likely to be of the order of 1 000 °C.

Whilst the fire-resisting elements of a structure provide a fire containment role during the “fuel-bed” controlled phase, they are primarily designed to provide fire separation with respect to a ventilation-controlled, post-flashover fire phase.

The objective of many fire engineering strategies is to delay or suppress the potential of flashover. This can be achieved by the introduction of suppression measures, e.g. sprinklers (the most common method), smoke exhaust and ventilation, control of contents and/or geometry of the space. Despite such controls, it is naïve to believe that the enclosure boundary, say to a protected stair, or to areas of a different risk category, needs to have no fire-separating abilities. Currently, the fire engineers have no way of determining or measuring the ability of a construction to withstand any condition other than that modelled by the standard fire-resistance test, which could represent an overprovision if the suppression system reliability is high.

As previously stated, it is important to recognize that with the change of lifestyle since the fire-resistance test was developed, there is frequent questioning of the validity of the standard-fire resistance exposure conditions. Few would question the validity of the current conditions for product classification periods, as the experiences of many decades have shown it to be adequate for environments where conventional furnishing materials have been used. Increasingly, though, the validity of the current exposure condition is questioned when using the outputs from a fire-resistance test in a fire-safety engineered strategy. If the rate of heating is increased, the temperature reached could be greater or the pressure could be varied. This Technical Report considers the practicality of changing the exposure conditions, what they should be changed to, and what form the output should take.

Similarly, ISO/TR 5925-1 represents only a limited number of fire scenarios due to the range of pressures and temperatures used in the test. It also measures only the leakage of doorsets, ignoring the leakage of many other forms of construction.

This Technical Report has been prepared to establish how the outputs generated by the tests developed and maintained within ISO/TC92/SC2, i.e. ISO 834 (all parts) test methods, can be modified in due course to support the design codes produced by the working groups of ISO/TC92/SC4, in support of the fire-safety engineering designs of buildings, e.g. ISO 13387, in its various parts.

The Technical Report is of value to the convenors of the working groups developing and maintaining fire containment test procedures. It is also of value in the interim period to fire-safety engineers who wish to understand the limitations of products tested to the SC2-generated test procedures. It is anticipated that further Technical Reports will be prepared giving recommendations to the various working groups as to how their standards, and in particular their criteria, can be improved to reflect the needs of the fire-engineering community.

1

Review of outputs for fire containment tests for buildings in the context of fire safety engineering

1 Scope

This Technical Report has been prepared in order to review whether the current ISO furnace-based fire resistance testing methods remain appropriate for establishing the performance of elements of structure when exposed to fully developed fire conditions in the context of a fire safety engineered strategy for a building. It identifies whether there is a difference between the data produced and the data required. Where there is, it reviews whether the test methods can be easily adapted to improve either the relevance of the test, or the output data, to make it more suitable for use in fire engineering applications.

This Technical Report reviews the mechanisms and routes of fire spread and identifies the criteria used for these tests to aid simple comparison and compares them with the conditions that can lead to fire spread or a loss of tenability for people in reality.

2 Normative references

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

ISO 834-1:1999, *Fire-resistance tests — Elements of building construction — Part 1: General requirements*

ISO 834-4:2000, *Fire-resistance tests — Elements of building construction — Part 4: Specific requirements for loadbearing vertical separating elements*

ISO 834-5:2000, *Fire-resistance tests — Elements of building construction — Part 5: Specific requirements for loadbearing horizontal separating elements*

ISO 834-6:2000, *Fire-resistance tests — Elements of building construction — Part 6: Specific requirements for beams*

ISO 834-7:2000, *Fire-resistance tests — Elements of building construction — Part 7: Specific requirements for columns*

ISO 834-8:2002, *Fire-resistance tests — Elements of building construction — Part 8: Specific requirements for non-loadbearing vertical separating elements*

ISO 834-9:2003, *Fire-resistance tests — Elements of building construction — Part 9: Specific requirements for non-loadbearing ceiling elements*

ISO 3008:—¹⁾, *Fire-resistance tests — Door and shutter assemblies*

ISO 3009:2003, *Fire-resistance tests — Elements of building construction — Glazed elements*

1) To be published (Revision of ISO 3008:1976)

ISO 5925-1:1981, *Fire tests — Evaluation of performance of smoke control door assemblies — Part 1: Ambient temperature test*

ISO/TR 5925-2:1997, *Fire tests — Smoke control door and shutter assemblies — Part 2: Commentary on test method and test data application*

ISO 6944:1985, *Fire resistance tests — Ventilation ducts*

ISO 10294-1:1996, *Fire resistance tests — Fire dampers for air distribution systems — Part 1: Test method*

3 Executive summary and recommendations

The outputs from standard fire containment and structural fire resistance tests were reviewed and found to be of limited value to the fire safety engineering community when carrying out a performance based fire protection design analysis for a building.

The following revisions are therefore recommended to make the outputs of ISO 834-1 more meaningful in response to the needs of the fire safety/protection engineering community.

- a) The deflection and the rate of deflection for beams and floors should be continuously measured and reported without any pre-judgement as to what constitutes failure. No time should be reported as representing failure with respect to load-bearing capacity as this would be defined by the design team or the legislation.
- b) In the future, testing furnaces should be made larger. Floor beam/furnaces should be extended to 6 m span and wall/column furnaces should be increased to 4 m height. This allows new elements for which no design code exists, e.g. new materials and new composites, to be investigated more meaningfully.
- c) Specimen support frames should be re-designed to permit known levels of restraint and fixity to be applied to specimens, thereby increasing the realism with respect to support conditions.
- d) Large-scale testing of homogenous columns and beams should be abandoned in favour of mathematical solutions.
- e) The cotton pad should be applied to all constructions whether insulating or non-insulating.
- f) In the short term, the 6 mm diameter gap gauge should be modified to facilitate the measurement of labyrinth gaps.
- g) The current cotton pad and gap gauges should be replaced by a single quantifiable method of measuring the total heat flux, including flow of heat, either globally (preferred) or locally.
- h) The quantified method of evaluating the passage of flames/heat/gases should be able to be used with all elements, including ducts, dampers, glazing, etc.
- i) A smoke and hot-gas leakage test apparatus should be developed for all vertical and horizontal separating tests.
- j) All temperature data should be recorded continuously and reported as individual time/temperature relationships that should be given along with similar data for the mean and maximum temperatures. No failure time should be recorded.
- k) The use of thermocouples should be replaced with an overall heat flux measurement system that can identify the area of max temperature rise.
- l) Thermal imaging and associated temperature measurement should be investigated and hopefully introduced for all tests to supplement radiation measurements.

- m) Radiation/heat flux measurements should be made and recorded for all separating elements using one or more water-cooled heat-flux meter(s). These measurements should be recorded continuously and included in the report.
- n) In the longer term, a full gas-collecting chamber should be developed and installed in the front of all vertical separating elements, and/or over the top of all horizontal separating elements which incorporate continuous heat flux and gas temperature monitoring equipment.

The following revisions are recommended to improve the outputs of ISO/TR 5925-1 and ISO 834-4, ISO 834-5, ISO 834-8 and ISO 834-9 in recognition of the needs of the fire safety/protection engineering community.

- a) ISO/TR 5925-1 should be amended to permit the determination of smoke leakage at ambient and medium temperatures of all vertical separating elements, not just doors and even including penetration and linear gap seals.
- b) All detachments of material from the unexposed face of the construction should be reported, photographed and where possible a statement as to the hazard that they represent be expressed as part of the report.

The following general revisions are recommended to improve the outputs of all fire containment tests in response to the needs of the fire protection engineering community.

- a) All tests should be recorded on high quality electronic medium (i.e. a DVD) that forms part of the report.
- b) All aspects of the described construction that have not been quantifiably checked by the laboratory staff should be marked clearly by a symbol in the test report as being accepted "based upon manufacturer's self-declaration".

4 Mechanisms of fire spread

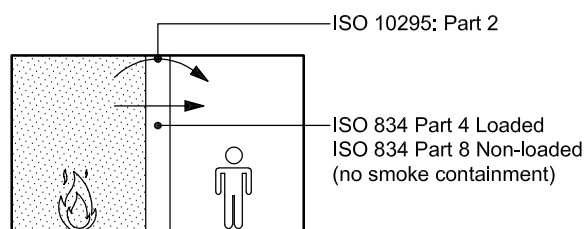
4.1 Routes and mechanisms of fire spread

There are many routes, both direct and indirect, by which fire can resist containment and thereby spread to adjacent enclosures, or spaces, with the attendant risk of secondary ignition and fire growth (see Figure 1). Many of these routes have already been identified by ISO TC92/SC4 in ISO TR 13387-6. The figures have been derived from the mechanisms and routes given in ISO TR 13387-6, and have been expanded and developed by the working group responsible both within the fire enclosure and within the adjacent spaces, including its susceptibility to secondary ignition.

The figures illustrate some of the more common routes for potential fire spread and identify the tests designed to control the spread. In many instances, it is also important that designers consider the potential for fire spread between two adjoining enclosures via independent spaces in addition to identifying direct routes. These routes of fire spread often represent a combination of direct spread routes and need to be considered as a series of separate direct spread mechanisms.

Ideally, all of the potential routes for fire spread from the enclosure need to be quantified and the time for fire spread to reach critical conditions should be determined. Any shortfall between this and the "required" time to resist fire spread should be addressed by enhancing the fire and smoke containment capability of the relevant element(s). However, design effort can be reduced in situations where expert judgement can identify those routes most susceptible to the rapid fire and smoke spread. It is important to remember that the determination as to whether or not fire spread takes place is influenced by the local environment.

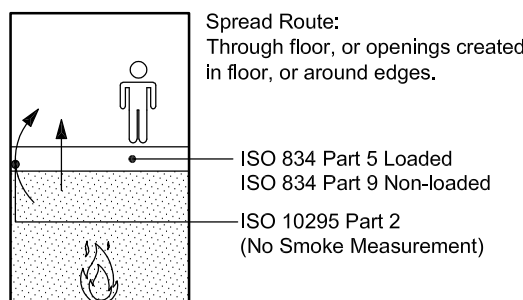
WALLS



Spread Route:
Through wall, or openings created in wall, or around edges.

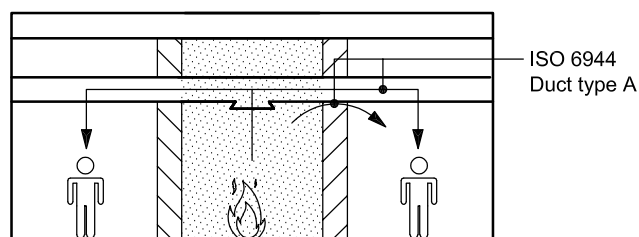
Spread Mechanism:
Conduction [convection] Direct Pyrolysis (collapse or ignition)

FLOORS



Spread Mechanism:
Conduction [convection] Direct Pyrolysis (collapse or ignition)

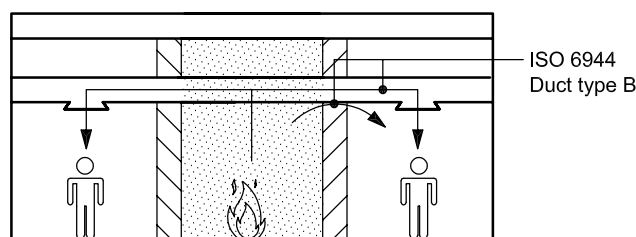
UNDAMPED HORIZONTAL DUCTWORK (1)



Spread Route:
Along or through, Horizontal Duct

Spread Mechanism:
Conduction, Convection

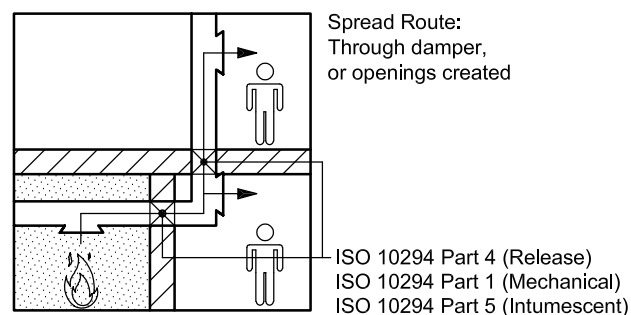
UNDAMPED HORIZONTAL DUCTWORK (2)



Spread Route:
Along or through, Horizontal Duct

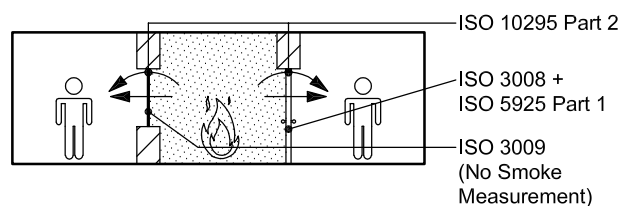
Spread Mechanism:
Conduction, Convection

DAMPED DUCTWORK



Spread Mechanism:
Convection, Conduction

PROTECTED OPENINGS

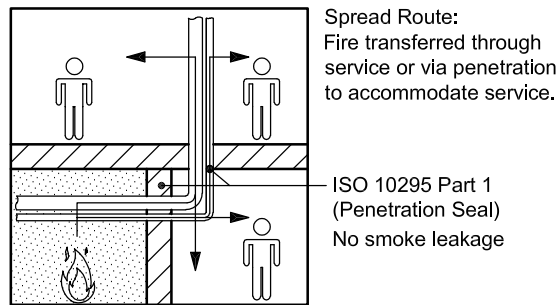


Spread Route:
Through door, glazing etc, or openings created in them, or around edges

Spread Mechanism:
Conduction, radiation, Direct Pyrolysis (collapse or ignition)

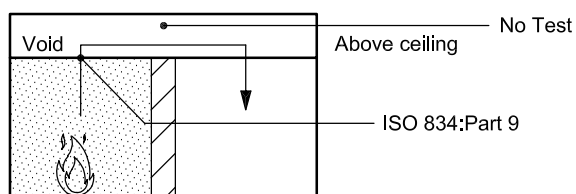
Figure 1 — Routes of fire spread and appropriate standards

SERVICES (PIPES/CABLES AND SUPPORTS)



Spread Mechanism:
Complex including radiation, mass transfer, conduction

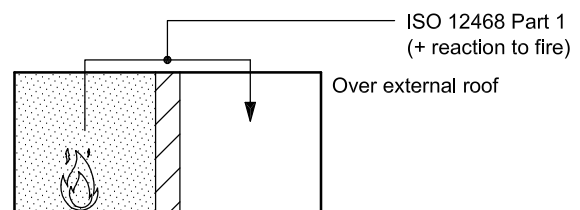
SUSPENDED CEILING VOIDS



Spread Route:
1. Enclosure to Ceiling void
2. Ceiling void to adjacent enclosure

Spread Mechanism:
Complex, including Pyrolysis,
mass transfer and conduction

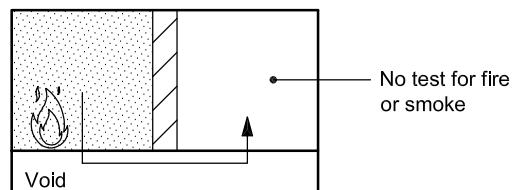
ROOFS



Spread Route:
1. Enclosure to roof
2. Roof to adjacent enclosure

Spread Mechanism:
Pyrolysis, radiation

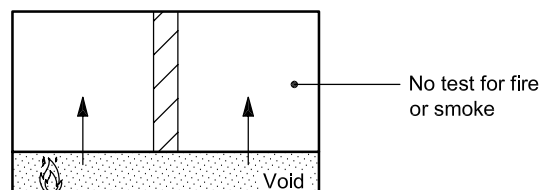
RAISED FLOOR VOIDS (1)



Spread Route:
1. Enclosure to floor void
2. Void to adjacent enclosure

Spread Mechanism:
Complex, including Pyrolysis, mass transfer
conduction and convection

RAISED FLOOR VOIDS (2)

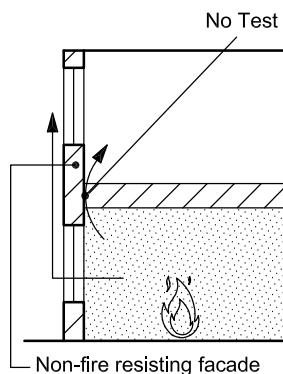


Spread Route:
1. Void to enclosure via floor

Spread Mechanism:
Conduction and convection

Figure 1 — Routes of fire spread and appropriate standards (continued)

EXTERNAL WALLS/WINDOWS



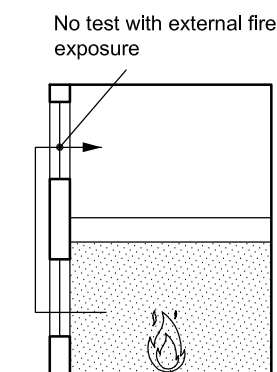
Spread Route:

1. Enclosure to facade surface
2. Facade to adjacent enclosure

Spread Mechanism:

Complex, including Pyrolysis of surface.

EXTERNAL WINDOWS^a



Spread Route:

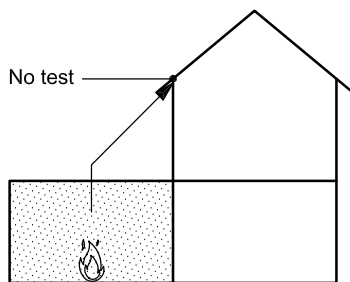
1. Enclosure to outside
2. Outside to adjacent enclosure

Spread Mechanism:

Collapse, convection, radiation

^a Can occur horizontally between windows in certain conditions.

UPPER PARTS OF BUILDINGS



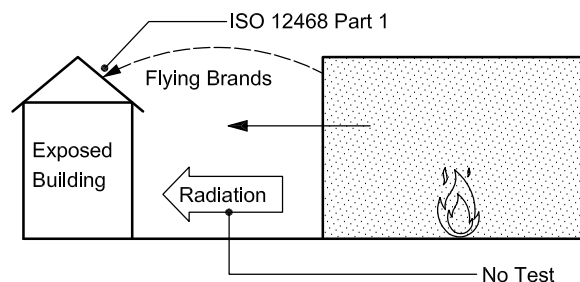
Spread Route:

1. Enclosure to roof outside
2. Roof flames through external envelope eg window

Spread Mechanism:

Pyrolysis (collapse/ignition) convection, radiation

ADJACENT BUILDINGS



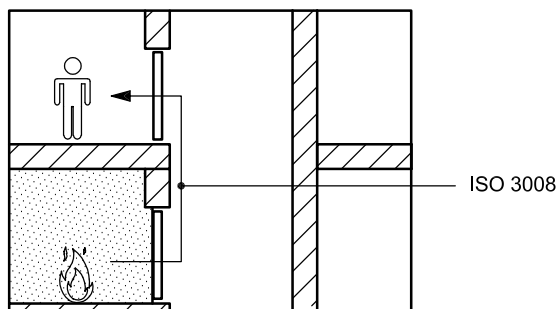
Spread Route:

1. Enclosure to space adjacent to enclosure

Spread Mechanism:

Complex, including radiation, mass transfer

LIFT SHAFT



Spread Route:

1. Enclosure to lift shaft
2. Lift shaft to enclosure

Spread Mechanism:

Convection, conduction

Figure 1 — Routes of fire spread and appropriate standards (*continued*)

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4.2 Review of mechanisms leading to secondary fire initiation, fire growth and damage in adjacent areas directly related to the behaviour of the structure

In 4.2 is described, in some detail, the different mechanisms associated with failure of fire separating elements of structure that can be responsible for directly causing secondary fire development in spaces adjacent to the enclosure on fire. In all of the failure mechanisms considered, the effects are most severe when the fire conditions in the enclosure on fire are in a post-flashover, fully developed condition. It is this condition that is replicated in the fire resistance test.

4.2.1 Failure of an element

Complete failure of a separating element or structural member generally has a devastating influence on the conditions prevailing in an adjacent space. However, there are degrees of failure of such elements, all of which influence the tenability of an adjacent enclosure during fire; these are discussed in 4.2.1.1 to 4.2.1.3.

4.2.1.1 Collapse

The collapse of vertical elements has both a direct and an indirect influence on the safety of persons in adjacent spaces. The action of collapse causes large sections of the element, if not the element in total, to “topple” and fall. The direct consequence is that persons in or around the building, including fire-fighters engaged in fire fighting activities close to the perimeter of the building, can be directly hit by the falling structure. Indirectly, the loss of even part of a vital element, as a result of a collapse, allows the uninterrupted flow of combustion gases into the adjacent space leading to an attendant life threat that this represents.

People are not generally alive in the enclosure directly underneath a horizontal separating element, such as a floor, due to the temperatures that need to be reached to cause the collapse. But the people most at risk, and a very serious risk it is, are those persons who are on the element being attacked, either seeking escape, or being unaware of the fire's presence. The convective heat release also makes conditions above untenable, as well as the obvious risk resulting from these persons falling due to the collapse.

There is an indirect risk to all persons in or around the building as a result of the collapse of a horizontal element, and that is the domino effect.

4.2.1.2 Excessive deformation

The role of deformation of the elements of construction in secondary fire initiation and spread has generally remained unrecognized. Only structural elements are adjudged by maximum deflection criteria and, even then, the degree of distortion permitted is not related to any critical level that could lead to a failure of containment, they are introduced purely as a furnace-protection measure.

The fire tightness (integrity) of an enclosure can be achieved only if the elements are either jointed together in a manner so that

- they cannot physically be separated,
- they cannot bow, or
- they bow in harmony, or else
- the method of jointing is able to accommodate any difference in the direction or magnitude of the bowing between the elements.

Deformation, therefore, leads to an integrity failure and assists in fire and smoke spread if they are not anticipated and accommodated or prevented at the design stage. This aspect has been addressed in an insurance code within the UK ^[1]. A decision tree incorporated within this guide is included in Annex A of this Technical Report.

Often, the only way that joints between elements can be controlled to maintain integrity is to provide the individual elements with higher levels of applied fire protection than that needed to satisfy any of the standard criteria; i.e., loadbearing capacity, integrity and insulation of the fire resistance test (see Clause 6), which has the effect of restricting deflections.

4.2.1.3 Physical degradation

Fire can exploit the boundary of an enclosure and generate secondary ignition as a result of the barrier physically degrading. Typical of such degradation is the conversion of timber to charcoal, the spalling of concrete, the calcining of gypsum, the exhaustion of intumescent barriers or the consumption of binders and the sintering of fibres in insulating slabs. Generally, these failures manifest themselves as gaps through which flames and hot gases can pass, causing direct secondary ignition (see 4.2.2) or insulation failure, where the unexposed temperature of the element can indirectly generate ignition (see 4.2.4).

However, a number of situations can arise where physical degradation can occur that allows parts of the element to become detached from the barrier and cause indirect ignition. In many cases, the detachment is directly on the unexposed face, but in some cases the problem can originate with materials on the exposed face that can flow or roll under the element and arrive at the unexposed face. There is a greater potential for such happenings on doors where there is a direct and obvious functional gap underneath the specimen. However, gaps can develop under many non-homogenous constructions, permitting a limited transfer of some materials, particularly liquids.

Types of physical degradation that can initiate fire spread on the protected face, but which are not identified as direct failure criteria, include the melting of some forms of plastic, low-melting-point metals, or damping fluids from closure mechanisms. The artificiality of the furnace testing environment often prevents such failure modes from being identified (see Clause 6). Uncontrolled floor covering can be ignited by a number of these mechanisms, but they are identified as a failure of the element against the existing criteria.

4.2.2 Flame penetration

Where through-gaps exist or develop in the barrier resulting from distortion, cracking or burn-through, there is the possibility of flames and hot gases penetrating the barrier. This can manifest itself in a variety of ways from small, candle-like flames to an ignition of the barrier and subsequent rapid spread, depending upon the material from which it is constructed.

Flame penetration can cause secondary fire initiation in two ways:

- by directly igniting combustible products or gases in the protected compartments, or
- by igniting the component materials of the barrier itself (see 4.2.3).

The first mechanism can occur when combustible materials are present within a short distance from the barrier itself, normally closer than 0,05 m (unless there is also significant radiation), or when a combustible gas or vapour mixture is present in the adjacent space. There is a critical amount and rate of application of such heat energy onto the material to initiate ignition and to support combustion. Where combustible gas mixtures and vapours are present, again, possibly being given off by the element itself, then the size of the flame is probably only of secondary importance.

4.2.3 Ignition of the surface of the element

Under test, ignition of the component materials forming the construction is often the cause of integrity failure of the barrier. The nature of the materials used in the manufacture of fire separating elements is such that, when this does occur, it is normally associated with heating the material to a temperature at which spontaneous ignition occurs, particularly if the materials used in the centre of the construction are highly conductive.

Whilst the integrity criteria of sustained flaming permits short-duration, transient flaming (see 6.2), i.e. flames of less than 10 s duration, without being deemed to be the cause of failure, the occurrence of such flames adjacent to linings/facings that are close to their spontaneous ignition temperature inevitably lead to ignition of the surface of the element.

Ignition of the surface of an element is, relative to the ignition of a cotton pad, an event that can have serious consequences in a fire. Even a thin combustible lining has the potential to ignite materials in close proximity to the surface, particularly if they are items of low thermal inertia. It is also likely that materials that do ignite on the unexposed face will become detached, either in part or in whole, and fall burning on the floor. The propensity of the floor covering to ignite, therefore, determines to some extent the magnitude of the hazard that ignition of the surface represents.

Burning on the unexposed face affects the tenability of the protected space in terms of thermal load, smoke production and density and the toxicity of the environment (see 4.3).

4.2.4 Heat transfer into the adjacent space

There are a number of mechanisms by which heat can be transferred into the adjacent space(s) and these are discussed in 4.2.4.1 to 4.2.4.4.

4.2.4.1 Conducted heat

Heat conduction is a feature in all types of material, but mainly represents an issue in solids. The mechanism of heat transfer by conduction is the transmission of energy through kinetic interaction between molecules forming the basic structure of the material. The thermal conductivity of materials varies widely. Metals tend to be good conductors of heat and non-metals, a poor conductor. Amongst the common metals, the best conductors of heat are silver and copper, whilst aluminium has about half the thermal conductivity of copper and iron.

Secondary fire initiation can be caused by heat being conducted through a barrier, which could result in ignition of the surface (see 4.2.3), or via an object, possibly a service or an element of structure, passing through the barrier and coming into contact with combustibles within the adjacent enclosure. The materials most likely to be ignited are timber or wood-based elements, such as joists, flooring or studwork, but electrical insulation to cables and services are also likely to be in contact and have the potential to ignite.

4.2.4.2 Convected heat

Items with a higher temperature than its surroundings, i.e. the air, loses heat to those surroundings by means of convection. Convection is the term used to describe the effect of heating a fluid (liquid or gaseous) transmitting medium, such as air, by conduction and radiation, which moves generally upwards as a result of the change in its density. Convection occurs at the unexposed surface of a fire-separating element as the heat conducted is radiated to the air adjacent to the surface, which increases the temperature of the air. This gives buoyancy to the heated air, which then rises causing a convection current as cooler air is drawn in to replace it.

A non-insulating fire-separating barrier that attains an unexposed face temperature of 600 °C within an area gives a total convected heat output of the order of 55 kW/m². Heat output of this magnitude is unlikely to produce non-piloted spontaneous ignition of solid materials due to convection in the short term.

The rise in temperature in an adjacent enclosure as a result of convection can have serious life safety implications (see 4.3.1). The temperature of air in a space 50 m³ could rise to several hundred degrees Celsius in 5 min to 10 min, depending upon the thermal inertia and insulating nature of the adjacent boundary, which can influence the behaviour of some stored goods.

4.2.4.3 Radiated heat

The exact mechanisms of transfer of heat energy by radiation are extremely complex and rely upon physical properties of materials that often change during the heating-up process. For fire-engineering purposes, the emittance of radiation from most surfaces is treated as having diffuse directional characteristics that are independent of wavelength and temperature. In simple terms, the net heat transfer from a hot body to a cold body as a result of radiation can be considered as being proportional to the difference to the fourth power between the hot body and cold body temperatures. The magnitude of this heat flux is controlled by the relative emissivities of the bodies and also by their relative orientations and geometries (accounted for in calculations by configuration factors).

The emissivity of a surface is a measure of the efficiency with which a surface emits heat, rather than reflects it. A “black body” has an emissivity of 1,0 and reflects none of the heat radiation incident on it. Shiny metallic surfaces, such as stainless steel, on the other hand, have emissivities in the range of 0,05 to 0,2, thus reflecting 80 % to 95 % of heat radiation incident on them. All other steel surfaces discolour rapidly due to oxidation of the surface. Under a given received thermal radiation intensity, the temperature rise exhibited by a shiny metal surface is less than that exhibited by a non-metallic, organic or coated metal surface. Conversely, the magnitude of heat radiation emitted by a shiny metallic surface is less than that emitted by a non-metallic, organic or coated metallic surface at the same temperature.

A combustible surface at ambient temperature, positioned 500 mm from the centre of a rectangular “dull” metallic surface at a temperature of 650 °C, typically receives a radiative heat flux of approximately 25 kW/m², which is of a magnitude to cause the non-piloted ignition of cellulose after a prolonged exposure. For some fire-resisting barriers, the situation is worse due to the use of fire-resisting glass, which is transparent to certain received wavelengths of energy under fire exposure but often becomes thermally “opaque” above a certain temperature. This transparency can raise the incident heat radiation on surfaces remote from the barrier. The received radiation intensity at 500 mm from the centre of a glazed screen is typically of the order of 50 kW/m² after 60 min exposure to the standard test for fire resistance. This level of radiative heat flux is sufficient to cause non-piloted ignition of timber in approximately 15 s.

Radiated heat from the fire-separating barrier also warms up the surfaces of any adjacent wall areas, floor areas and structural components that are within the protected environment exposed to the radiated heat flux. Consequently, the air within the protected zone is warmed by convection from these surfaces and, given the volume, geometry, construction and ventilation characteristics of the protected space, this increased heat flux needs to be quantified as part of the overall energy balance, since this can trigger the onset of secondary ignitions.

4.2.4.4 Hot brands

Hot brands are a recognized way by which heat energy is exchanged, particularly in external or wild fires. The mechanism consists of a part of the fuel source, or the building containing the fire source which is itself on fire, and the weight of which is less than that required to resist the upward thrust created by the convection current. In large fires with a high heat release, the plume of combustion gases has such strong upward air currents that it is possible for small items of combustible material to be carried up in the updraft, still burning, and be deposited in the surrounding area once the plume starts to lose its buoyancy.

The mechanism of burnt/decomposed material being taken up in the convection currents does not in itself turn them into brands. These items only become “brands” if they contain sufficient heat energy after they have left the convection current and fallen/landed on combustible materials that they can in themselves cause ignition. Experience suggests that in most cases there needs to be sufficient radiation being received by the surface that the brand has fallen onto for the residual energy to cause it to ignite. Effectively, the brand acts as a pilot light which reduces the temperature needed for an ignition to well below that required if the ignition were non-piloted, i.e., spontaneous.

Ignition by hot brands is a phenomenon normally associated with spread of fire from building to building, rather than from compartment to compartment, although if an internal separating element contains large uninsulated areas, e.g., metal shutters or non-insulating fire glass, then fire development in an adjacent compartment can develop if combustible materials forming part of the construction were to ignite and fall onto combustible furnishings or floor coverings.

Oil-damping fluids in overhead closing devices, whilst not strictly falling under the definition of hot brands, can cause secondary ignition of materials on the unexposed face if they ignite. Plastic ceiling panels, lighting diffusers, or even foamed plastic-cored sandwich panel ceilings adjacent to a fire barrier that is not fully insulating, can result in the dripping or dropping of flaming drips or debris.

4.2.5 Smoke damage

Problems associated with smoke leakage in life safety are discussed in 4.3. Smoke causes damage to property, both the fabric and the contents, if it spreads uncontained throughout the buildings(s) during a fire. The damage generally manifests itself in several ways:

- corrosion;
- contamination;
- odours.

Smoke damage can be as expensive to correct as fire damage itself.

4.2.5.1 Corrosion

The potential for the products of combustion to cause corrosion is directly proportional to the nature of the materials involved in the fire. In the modern structure, it is unlikely that there is a fire that does not involve plastic materials in this day and age. The products of combustion from many plastics will have a pH that is well on the acidic side of neutral and, as such, the smoke condenses on cold surfaces, and if these surfaces are made of untreated metal, then severe attack occurs. Hydrochloric acid condensates are commonly found in, and emitted by, PVC materials and acids as aggressive as this damage coatings and cellulosic material such as paper, card, books, etc.

Electronic equipment is normally destroyed by exposure to gases with a high acid or alkaline content. The modern office, being highly dependent upon electronic data storage and communications, is, therefore, very susceptible to levels of contamination that are likely to be produced from a fairly small fire.

4.2.5.2 Contamination

Unless the construction, or items/components within the structure can be cleaned soon after being exposed to smoke, they become increasingly harder to clean. Should smoke condense onto a surface, the particles adhere to it and, if these items experience an increase in temperature, the particles are baked onto the surface making them almost impossible to remove.

4.2.5.3 Odours

Even if the pH is relatively neutral, smoke consists of particulates that are deposited as the smoke cools, directly contaminating the surfaces. In some cases, e.g. for cellulosic or absorbent materials, this frequently results in staining. Unfortunately, the contamination is not always solely visible, but often leaves a distinct odour that is very difficult to eradicate.

The majority of the bi-products of smouldering combustion, especially in the period just prior to full development of the fire, are in the form of tars and resins, especially when wood is one of the materials that is likely to be burning. These tarry droplets contain much of the particulate matter that is the source of the odour in the fire and inevitably they condense out on the cooler surfaces in the protected space. Being “tarry” in nature, these adhere firmly to these surfaces and resist removal even by washing with water, unless it is in copious quantities, in which case there is likely to be significant water damage in lieu of fire damage.

The smoke odour can persist for intolerable durations both on the contents and the fabric of the building and is best prevented.

4.2.6 Compartmentation general

A fundamental principle of fire protection is to contain the fire to the smallest possible area. For life safety purposes, this should, in all cases, be a time-sufficient process to allow the building occupants to reach a place of safety. For property protection, containment is normally expected to function for the full duration of the fire.

Buildings are normally divided into a number of fire-resisting compartments, which can contain a number of individual rooms. Whilst individual rooms might not necessarily be intended to have fire resistance, they can still, for a limited period, contain the fire.

A problem encountered with existing fire-resistance tests is that measurements of integrity, which are designed to identify a failure to contain the hot gases, are based on a crude measurement of combustion gas leakage, using ignition of a cotton pad to determine if a defined point of "failure" is reached, or to determine if a defined gap size is exceeded. It is, therefore, impossible to directly use the data from fire-resistance tests in any computational simulation of fire spread once a flashover condition is reached at the compartment boundary.

This situation is complicated by having to use two different methods for determining the loss of integrity. The cotton pad evaluates insulated constructions. Uninsulated constructions are tested by using gap gauges. In practice, the development of conditions that can result in secondary ignition, fire growth and damage is the total heat flux received and the level at which it becomes critical is not dependent upon how the criticality is determined in the test. As a consequence of the method of measurement, however, the critical flow of hot combustion gases through, or around, an uninsulating element is much greater and hotter than that from, or around, an insulating element at the time it is deemed to have failed. In terms of the real risk to the protected space, this differentiation between construction forms is irrational.

Some passive fire-protection sealing systems can make a significant contribution to delaying the passage of smoke and hot gases into the next compartment. However, current testing methodology based on furnace testing cannot quantify this potential down-grading of the role of passive fire protection as a barrier for containing smoke.

4.3 Review of secondary indirect mechanisms threatening life safety

The life safety of persons in spaces/buildings adjacent to the one on fire can still be at risk as a result of indirect mechanisms of fire spread. These indirect mechanisms are considered below.

4.3.1 Heat build-up

The temperature of a protected space is likely to rise as a result of conduction and convection from the elements forming the enclosure on fire.

Persons within a space for any length of time can suffer injury solely as a result of heat, or thermal exposure, without being directly exposed to the flames of the fire. Such injuries result either from an increased body temperature, a state known as hyperthermia, or from breathing hot gases. As this is, therefore, critical to life safety, the fire-safety strategy needs to be able to quantify the thermal exposure that persons in the protected space can be subjected to. Information that can help to define the critical temperature of the environment can be found in B.2.

NOTE Additional information is being developed by ISO/TC92/SC4.

4.3.2 Radiation — Skin burn

Radiation from a separating construction can be harmful to the human skin. Exposure to radiant heat can be extremely painful. The human skin can tolerate only a certain level of heat flux for a certain time. The higher the heat flux levels, the shorter the tolerable exposure time. The high heat flux can cause skin burn or even worse, blisters and blackening of the skin. Burn wounds are very difficult to treat as the skin is deeply affected. When large areas of the human body are damaged by skin burn, it becomes more difficult to recover from the injuries. For these reasons, it is important that the fire engineer be able to quantify the tenability of the protected space with respect to this parameter. The life risk associated with radiation is explained in B.3.

NOTE Additional information can be found in publications produced by ISO/TC92/SC4.