TECHNICAL
REPORT

ISO/TR
17252

Second edition
2019-05

Fire tests — Applicability of reaction to fire tests to fire modelling and fire safety engineering

Essais au feu — Applicabilité des résultats de l'essai de réaction au feu aux techniques de modélisation et de sécurité contre l'incendie

Reference number
ISO/TR 17252:2019(E)

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Published in Switzerland

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www. iso. org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www. iso .org/iso/foreword. html.

This document was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 1, *Fire initiation and growth*.

This second edition cancels and replaces the first edition (ISO/TR 17252:2008), which has been technically revised. The main changes compared with the previous edition are as follows:

- The title of Clause 5 was changed;
- Former subclauses 5.1.1 and 5.1.2 have been merged into 5.1;
- New subclause 5.2 has been added: “Quantitative definition of fires and fire scenarios”;
- Clause 6 has been re-written, the title has been changed to “Sources and types of input data for fire safety engineering”, subclauses 6.2 and 6.3 have been added;
- Clause 7 has been re-written, the subclauses have been re-arranged and text has been added;
- Clause 8 has been integrated in Clause 7 and totally changed, the title also has been changed to “Limitations of generalizing product behavior”;
- Annex A has been re-written, tests have been added, description of the tests has been compressed with more focus on FSE.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

There is a current trend towards performance-based approaches in national building regulations. This trend has seen rapid advancement internationally in the development of fire safety engineering. This has been supported by the application of fire modelling over the last 15 years, as marked by the originally published ISO/TR 13387-1 to 8[1], and followed by ISO 23932-1, ISO/TS 16733, ISO 16730, ISO/TS 24679 and ISO/TR 16738. The impact of these documents and activities carried out nationally, have clearly identified that there are inconsistencies between the requirements of fire safety engineering (including the application of fire modelling) and the data reported from standard fire tests and ad hoc experiments.

The document is intended to assist in the development of an internationally consistent approach to support fire safety engineering activities by appropriate fire test methods that, where possible, are also used for the primary function of fire safety regulation of the use of construction products.

It examines the majority of the current reaction to fire test methods in the TC 92/SC 1 portfolio and provides information to support the use of the data that the tests provide for fire safety engineering and fire modelling.

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1) The ISO/TR 13387 series is withdrawn.

Fire tests — Applicability of reaction to fire tests to fire modelling and fire safety engineering

1 Scope

This document gives guidelines on the applicability of the existing reaction to fire tests to fire safety engineering and fire modelling. It also gives general guidance on the type of data needed for fire safety engineering calculations and for fire modelling.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 13943, *Fire safety — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
design fire
quantitative description of assumed fire characteristics within the design fire scenario

3.2
design fire scenario
specific fire scenario on which an analysis will be conducted

3.3
fire scenario
qualitative description of the course of a fire with time, identifying key events that characterise a particular fire and differentiate it from other possible fires

4 Symbols and abbreviated terms

FSE	Fire safety engineering
t_g	is the characteristic time from reference ignition to reach heat release rate Q_0 (s)
$\dot{Q}$	is heat release rate (MW)
$\dot{Q}_0$	is the reference heat release rate, often taken to be 1 MW

5 Fire initiation and growth

5.1 Specification of fires and fire scenarios

5.1.1 Background

Design fire scenarios are at the core of the fire safety engineering methodology described in ISO 23932-1, ISO/TS 16733, ISO 16730-1, ISO 24679-1 and ISO/TR 16738. An additional series of standards: ISO 16734, ISO 16736, ISO 16737 and ISO 16732-1, extend and implement these concepts.

The methodology is based upon analysing particular design fire scenarios and then drawing inferences from the results with regard to the adequacy of the proposed fire safety system to meet the performance criteria that have been defined. Identification of the appropriate scenarios requiring analysis is crucial to the attainment of a building that fulfils the fire safety performance objectives.

The characterisation of a design fire scenario for analysis purposes should involve a description of such things as fire initiation, growth and extinction of fire, together with the likely smoke and fire spread routes under a defined set of conditions. This may include consideration of such conditions as different combinations of outcomes or events of different fire safety subsystems, different internal ventilation conditions and different external environmental conditions. The consequences of each design fire scenario should be considered. For example, it is important to realise that smouldering fires may have the potential to cause a large number of fatalities in certain occupancies such as residential buildings although there is no reaction-to-fire test in the TC 92/SC 1 portfolio which covers smouldering conditions.

Examples of typical design fire scenarios include:

- Room fire (corner, ceiling, wall, floor);
- Fires in corridors and stairwells;
- Single burning item fire (furniture, waste paper basket, fittings);
- Developing fire;
- Cable tray or duct fire;
- Roof fires (underside);
- Cavity fire (wall, floor, façade, plenum);
- Fire in transport vehicles;
- Arson
    1) Internal
    2) External;
- Fire in neighbouring building;
- Fire in external fuel packages;
- Fire on roof and flying brands from adjacent buildings;
- Fire on façade;
- Subterranean fires;
- Forest fires or wild fires;
- Fire in tunnels and underground facilities.

Following identification of the relevant design fire scenarios, it is necessary to describe the assumed characteristics of the fire on which the design will be based. A combination of fire characteristics is used to define the design fire and usually requires quantification of the following variables with respect to time:

— Heat release rate [HRR (peak, mean, total, etc.)];

— Toxic species production rate;

— Smoke production rate (SPR);

— Fire size (including flame length);

— Time to key events such as flashover;

— Other factors such as temperature, emissivity and location may also be required.

The fire characteristics listed above, are influenced by a number of factors which include:

— type, size and location(s) of ignition source;

— ignitability of fuel;

— distribution and type(s) of fuel (with material related parameters as heat of combustion, combustion efficiency);

— fire load density;

— rate of heat release characteristics;

— geometry of enclosure;

— exposed surface area;

— status of doors and/or windows (open or closed);

— internal ventilation conditions (e.g. building air handling system);

— external environmental conditions (e.g. outside temperature, wind velocity and directions);

— external heat flux.

Additionally, events that happen during the fire can modify the design fire and these are typically accounted for in a fire safety engineering approach to design. For example, the breakage of a window will alter the ventilation conditions and will influence the design fire. The incorporation of active fire protection measures into a design will also impact upon the design fire. It is therefore important that the effects changes in ventilation, of suppression systems, smoke control systems and intervention by the fire service are considered when appropriate.

5.1.2 Design fire types

For design purposes, often an estimate of the heat release rate of the fire or the temperature rise in the room as function of time is used. The design fire curves represent an idealization of a real fire that might occur, and there is a great variety in the way they are mathematically expressed. For example, the design fire curves used for tunnels include different types of fire growth rates, including, linear growth, quadratic growth or exponential etc. Typical fire curves are given for instance in ISO 834-1, Eurocode 1, EN 13501-2 or ISO/TS 3814, where heat release rate, Q, growth in design fires is often characterized in terms of exponential or power-law rate of time, *t*, from the reference ignition time. The most commonly used relationship for these models is the t-squared fire given by:

$$Q = Q_0 \left(t / t_g \right)^2 \qquad (1)$$

Where time, *t*, is measured from the reference ignition time, and the growth time t_g is the time from the reference ignition time to reach heat release rate Q_0.

For design of more realistic fires, the fire growth functions can be combined with a maximum HRR value and a decay function to resemble abatement[33][34]. However, in building fire safety design, usually the growth rate alone, e.g. Formula (1) is considered when growing fires are the unique fire scenario to be dealt with, whereas in other specific applications, such as in tunnel fires, the entire fire curve may be considered. Using different types of growth and decay rates combined with maximum HRR profiles as peak values or plateau periods means that the curve has to be represented mathematically for different time periods. Figure 1 gives examples of different design fire types including the growth phase, a constant phase on a maximum level and a decay phase. Three different curves (1, 2 and 3) are given as heat release rate versus time. All three fires are assumed to have a growth phase following a t-square relation and then a phase of constant maximum heat release rate and then a decay phase. The constant phase of the maximum level can be reduced to 0 s. In this case the design fire may have a triangular shape. Curve 4 shows a steeper increase in the heat release rate in the beginning which can represent circumstances where the fire develops faster than in other design scenarios.

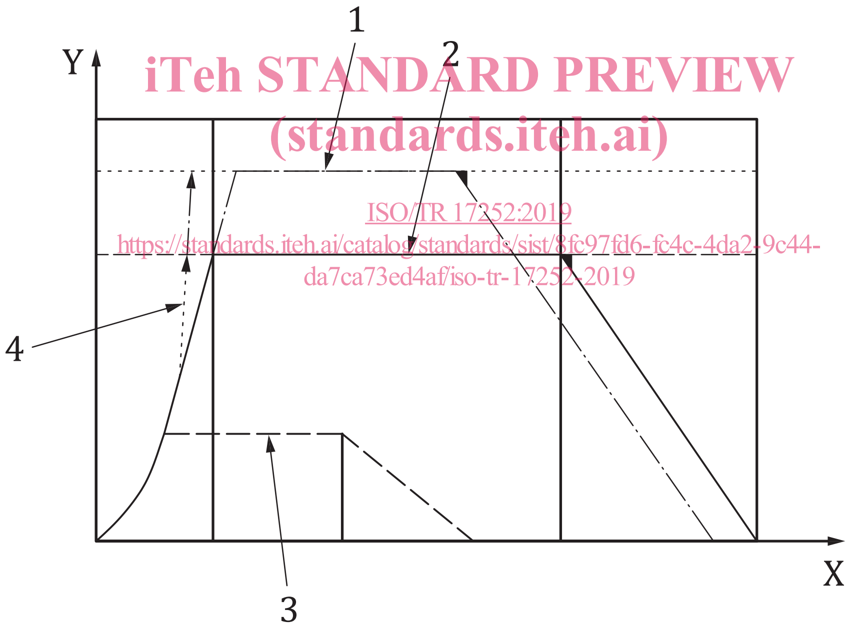

Figure 1 — Examples for different design fire types (curves 1, 2, 3 and 4)

In addition, when the fuel package for a particular design fire scenario is well defined and unlikely to change significantly during the life of the building, the actual burning characteristics of the fuel package can be used as the design fire. In such cases, oxygen consumption calorimetry, for example, ISO 9705-1 is useful for providing quantitative data.

Because of the growing complexity of buildings or other enclosures of interest, and the very different nature of fires associated with such places, it is not always possible or desirable to use a given heat release rate or temperature-time curve. In some cases, the fire spread through the building or enclosure might be important and cannot be predicted easily. In other cases, a fire which already occurred is to be investigated. Moreover, the materials involved in fire (e.g. property, facades, ducts, ceilings etc.) inside a building/enclosure respond differently and in a complex manner to the fire scenarios, in comparison to a mathematical design fire. Therefore, in such cases, it is not always possible nor desirable to use a design fire size a as input to the calculations. In many such cases, it may be preferable to use the geometry of the building or enclosure, provide material pyrolysis properties, and use the initial fire load as an input for computational fluid dynamics (CFD) model simulations/calculations. CFD models are field models which solve the balances of mass, momentum and energy either in sub volumes or on a numerical grid of the computational domain. CFD models on fire usually include additional models for radiation, turbulence, chemical reactions as well as material pyrolysis to solve the balances. The set of equations can only be solved numerically through various software platforms. Such CFD fire modelling codes require material properties to model the pyrolysis of the materials which are involved in the fire. For CFD applications, different pyrolysis models can be used and combined with CFD models to predict the material pyrolysis behaviour, some of which have been applied recently in similar applications[33][34][35][36].

In some cases, it is now possible to predict the fire growth behaviour using calculation and modelling methods. For such approaches, the validation and verification of the approach will be an important consideration and will be dependent upon the quality and reliability of the input data, whether it is generated from test methods or material data. This is described in more detail in section “sources of data for input into design”.

As a result of the calculations the fire development with its consequences regarding the production and spread of smoke and toxic gases might be used to assess the hazard of different situations which is not further discussed here.

5.2 Sensitivity analysis in the design process

The design fire characteristics will have a major impact upon many aspects of the design since they form the inputs into many of the deterministic quantitative design calculations carried out during a fire safety engineering analysis. A sensitivity analysis can be defined as the calculation of changes in outputs for variations in an input parameter of interest. It may be possible to deal with the uncertainties associated with the deterministic design by taking a conservative approach. However, the judgement of conservatism is very subjective. A worst-case design fire in terms of maximum size or growth rate will typically also be the worst case for determination of the:

— Effect of smoke control systems on the fire scenario;

— Effect of suppression systems on fire growth;

— Time to structural failure;

— Time and extent of fire spread within and from enclosure;

— Fire service extinguishing capacity.

However, the same design fire may represent a best-case scenario for:

— Time of activation of alarm system;

— Time of activation of smoke control systems;

— Time of activation of smoke and fire barriers;

— Time of activation of suppression systems.

It is therefore recommended that a sensitivity study be carried out on the consequences of the choice of design fire on the different parts of the quantitative assessment.

The objective of a sensitivity study is to establish the impact on the output parameter(s) caused by variation in the input parameter(s). It is not intended to check the accuracy of the results.

If a single assumption is shown to be critical to the design and potentially the level of safety, consideration should be given to providing a degree of redundancy in the design or to carrying out a further, perhaps probabilistic study related to that assumption.

5.3 Limits of applicability

Application of empirically-based calculation methods and other types of approach to fire safety engineered design, e.g. zone or CFD models, are generally assumed to be adequate provided that the approaches are used within their stated limits of applicability. However, these limits are not always stated and therefore it is incumbent upon the user to determine what these are for each method applied. If an approach is used outside of its limits of applicability, it is important that it is assessed from a theoretical basis and/or by comparison with experimental data. In such cases, it is usual to include some suitable safety factors in the analysis.

6 Sources and type of data for input into design

6.1 Type of data for input into design

In performance-based fire safety engineering, calculation methods are used that need data for the fire performance of various materials or components[1][2][3]. The performance data can be obtained from several ISO international standards test methods, currently in use. In these tests, relatively simple measurements are made to estimate various aspects of the relative fire performance of the materials at each stage of a fire and thereby better understand hazards that might be associated with use of that material should a fire occur.

There are a limited number of ISO international standards test methods that specify apparatus capable of providing quantitative data for the fire parameters of materials and products which can be utilized in the predictive models for the assessment of fire hazards. Some of these standards and their outputs are presented in Table 2, below. Depending on the complexity of a model, the set of required input parameters will vary. However, the fire parameters as used in ISO 16730-1 and presented in Table 1 may be measured in ISO 5658-2, ISO 5657 ($\dot{q}''_{cr}$, T_{ig}, $T_{s,min}$, $k\rho c$, Φ), ISO 5660-1 and ISO 12136 ($\dot{q}''_{cr}$, T_{ig}, $k\rho c$, ΔH_{eff}, ΔH_g, E/A).

Table 1 — Fire parameters obtained in ISO international standards test methods

ISO international standard number[a]	$\dot{q}''_{cr}$	T_{ig}	TRP $(k\rho c)^{1/2}\,\Delta T_{ig}$	HRR	ΔH_{eff}	Q_{PCS}/Q_{PCI}	χ	RHR	E/A	$\dot{m}$	
	(kW/m^2)	(K)	(kW-s $^{1/2}$/ m^2)	(kW)	(kJ/ g)	(MJ/ kg)		(kW/m^2)	(MJ/m2)	(kg/s)	(kJ/g)
12136	X	X	X	X	X		X	X	X	X	X
5660-1	X	X	X	X	X		X	X	X	X	
5658-2	X	X									
14696	X	X		X	X		X	X	X	X	X
5657	X	X	X								
1716						X					
9239-1	X										
9705-1		X		X							
24473		X		X	X					X	

[a] ISO 12136 Fire Propagation Apparatus, ISO 5660-1 Cone Calorimeter test, ISO 5658-2 Spread of flame test, ISO 14696 ICAL test, ISO 5657 Ignitability test, ISO 1716 Bomb Calorimeter test, ISO 9239-1 Flooring Radiant Panel test, ISO 9705-1 Room corner test, ISO 24473 Open Calorimetry test.

NOTE Critical heat flux measured in ISO 9239-1 is not appropriate for modelling purposes.

6.2 Complexity of the modelling approach with regard to input data

One relatively simple approach to simulate a fire is to define the heat release of the fire (often varying over time) as presented earlier in the document. One example of this approach is the t^2-curve, Formula (1). This approach represents an educated guess of the fire (fire size and development) which might occur in a building, transport vehicle or tunnel. The influence of the given fire on the structure or with respect to tenability criteria is then investigated.

In this document, we intend to identify ISO international standards fire test outputs that can be used in fire safety engineering calculations to predict the performance of materials in a realistic fire scenario. For example, there are several models developed by various researchers in order to predict the performance of materials in an ISO 9705-1 room corner scenario using as input the fire performance data derived from several ISO international standards test methods. Most widely used fire safety engineering models[4][9][11][13][18][19] are based on utilizing data from small-scale fire tests to predict heat release rate (HRR) and flashover in the ISO 9705-1 room corner test (US versions are ASTM E2257 and NFPA 265). In these models, the predicted output of the room corner test is the time to flashover, defined as the time taken for the fire to reach a size of 1 000 kW (HRR). Other engineering models[6][7][10][12][13][14][15][16][17][19] have been used in attempts to predict flame spread behaviour based on fire performance data measured using various ISO international standards test methods. These data include ignition temperature, ignition time, critical heat flux for ignition, thermal inertia, heat release and mass loss rates, effective heat of combustion and gasification, total energy per unit area, etc. It should be pointed out that using such measurements as input data for these modelling calculations is expected to provide tools to predict flame spread behaviour of products only for conditions similar to those used in the test. Such scaling laws and models might not work for other fire scenarios and conditions. ISO/TR 17252 provides guidelines for limits for applicability.

The following are some examples of predictive models for the fire behaviour of interior finish materials of buildings:

a) Karlsson Magnusson model[6];

b) Wickstrom-Goransson model[7];

c) Quintiere Room/Corner fire growth model[10];

d) Qian and Saito fire growth model[12];

e) Dillon-Quintiere Room/Corner fire model[13][17];

f) Hughes Associates/Navy Corner fire model[14];

g) WPI Room/Corner fire model[15];

h) Beyler et. al Room/Corner fire model[16];

i) Quintiere-Lian Room/Corner fire model[19].

In these models, ISO 9705-1 room/corner test results were explicitly compared to model predictions. The fire behaviour of materials in a room/corner test was predicted, using as input, information on a set of fire parameters of materials as measured using smaller-scale test methods. These include ISO 5660-1 cone calorimeter, ISO 12136 fire propagation apparatus, ISO 5657, ISO 5658-2, etc. such as those listed in Table 1, taken from Ref. [13]. In Table 1, $\dot{q}''_{cr}$ is the critical heat flux below which piloted ignition cannot occur, T_{ig} is the ignition temperature, $T_{\mathrm{s,min}}$ is the surface temperature of the material at which lateral flame spread ceases, $k\rho c$ is the thermal inertia of the material, Φ is the flame spread parameter, ΔH_{eff} is the effective heat of combustion, ΔH_g is the heat of gasification and E/A is the available energy per unit area (AEP), i.e. the total heat release per unit area. For the most part, fire parameters were determined at room temperature. The specific tests used to determine each parameter are discussed in more detail in a later section.

Development of pyrolysis models coupled with computational fluid dynamics (CFD) is increasing. Behavioural models for materials use input data coming from small scale, many from tests like ISO 5660-1 cone calorimeter or ISO 12136 fire propagation apparatus. The produced data are intrinsic properties of the material or generalised behaviour at the material surface.