TECHNICAL REPORT

ISO/TR 11696-1

First edition
1999-12-15

Uses of reaction to fire test results —

Part 1:
Application of test results to predict fire performance of internal linings and other building products

Utilisation des résultats des essais de réaction au feu —

Partie 1: Application des résultats à la prédiction de la performance au feu des revêtements intérieurs et d'autres produits de bâtiment

Reference number
ISO/TR 11696-1:1999(E)

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Printed 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 3.

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is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.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 part of ISO/TR 11696 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TR 11696-1, was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 1, *Fire initiation and growth*.

ISO/TR 11696 consists of the following parts, under the general title *Uses of reaction to fire test results*:

- *Part 1: Application of test results to predict fire performance of internal linings and other building products*
- *Part 2: Fire hazard assessment of construction products*

Introduction

This Technical Report deals with a methodology for describing fire development from building products in fire rooms under real life conditions by the use of results from small-scale tests, mostly those described in ISO/TR 3814, as input for different types of fire models.

Fire is a complex phenomenon. Its behaviour depends upon a number of inter-related factors. The behaviour of materials and products depends upon the characteristics of the fire, the end-use application and the environment in which they are exposed. The tests described in ISO/TR 3814 provide the basis for obtaining important physical data describing ignition, flame spread, rate of heat release and smoke. Each single test explained in this Technical Report deals only with a simple representation of a particular aspect of the potential fire situation and cannot alone provide any direct guidance on behaviour or safety in fire.

Uses of reaction to fire test results —

Part 1: Application of test results to predict fire performance of internal linings and other building products

1 Scope

This Technical Report describes how information on basic values for ignition, spread of flame, rate of heat release and smoke can be used in fire growth models for internal linings and other building products to describe the fire hazard in a limited number of scenarios starting with fire development in a small room. Other scenarios include fire spread in a large compartment and fire propagation down a corridor.

The types of models to be used are:

a) mathematical models based on fire growth physics, which calculate fire room variables, the results of which may be used for fire safety engineering purposes; and

b) generalized engineering calculations.

Sub-models can be included within the above models, provided the consistency of the whole is not prejudiced.

The models in general are not limited to one fire scenario.

The models should be used to calculate and describe the fire properties of building products in their end-use conditions. The use of models should not be limited by difficult materials, but it is recognized that some products may not be capable of being modelled (for example due to their complex assembly or to their thermoplastic properties).

Input parameters for models are based on ISO tests, mainly those in ISO/TR 3814.

The quality of a fire model for wall and ceiling linings is assessed by comparison with test results from a full-scale small room test for surface products and by sensitivity analysis on the model itself.

2 References

ISO/IEC Guide 52, *Glossary of fire terms and definitions*.

ISO 3261, *Fire tests — Vocabulary*.

ISO/TR 3814, *Tests for measuring "reaction-to-fire" of building materials — Their development and application*.

ISO 5657, *Reaction to fire tests — Ignitability of building products using a radiant heat source*.

ISO/TR 5658-1, *Reaction to fire tests — Spread of flame — Part 1: Guidance on flame spread.*

ISO 5658-2, *Reaction to fire tests — Spread of flame — Part 2: Lateral spread on building products in vertical configuration.*

ISO 5660-1, *Reaction to fire tests — Heat release, smoke production and mass loss rate — Part 1: Heat release rate (Cone calorimeter method).*

ISO 5660-2, *Reaction to fire tests — Heat release, smoke production and mass loss rate from building products — Part 2: Smoke production rate (dynamic measurement).*

ISO 5725-1, *Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions.*

ISO 5725-2, *Accuracy (trueness and precision) of measurement methods and results — Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method.*

ISO/TR 5924, *Fire tests — Reaction to fire — Smoke generated by building products (dual-chamber test).*

ISO/TR 9122-1, *Toxicity testing of fire effluents — Part 1: General*.

ISO/TR 9122-2, *Toxicity testing of fire effluents — Part 2: Guidelines for biological assays to determine the acute inhalation toxicity of fire effluents (basic principles, criteria and methodology).*

ISO/TR 9122-3, *Toxicity testing of fire effluents — Part 3: Methods for the analysis of gases and vapours in fire effluents*.

ISO/TR 9122-4, *Toxicity testing of fire effluents — Part 4: The fire model (furnaces and combustion apparatus used in small-scale testing)*.

ISO/TR 9122-5, *Toxicity testing of fire effluents — Part 5: Prediction of toxic effects of fire effluents.*

ISO/TR 9122-6, *Toxicity testing of fire effluents — Part 6: Guidance for regulators and specifiers on the assessment of toxic hazards in fires in buildings and transport.*

ISO 9239-1, *Reaction to fire tests — Part 1: Determination of the burning behaviour with a radiant heat source.*

ISO 9239-2, *Reaction to fire tests — Horizontal surface spread of flame on floor coverings — Part 2: Flame spread at higher heat flux levels.*

ISO 9705, *Fire tests — Full-scale room test for surface products*.

ISO/TR 11925-1, *Reaction to fire tests — Ignitability of building products subjected to direct impingement of flame — Part 1: Guidance on ignitability.*

ISO/TR 14696, *Reaction to fire tests — Determination of fire parameters of materials, products and assemblies using an intermediate-scale heat release calorimeter (ICAL)*.

3 Terms and definitions

For the purposes of this part of ISO TR 11696, the terms and definitions given in ISO/IEC Guide 52 and ISO 3261 apply.

4 Fire scenarios

4.1 There is a need to improve preventive fire protection because of public demand for more safety against fire hazards which have increased during the last decade.

4.2 To evaluate the fire hazard, technical fire tests have to be used. Since these will provide the basis for safety requirements they must be relevant to the end use of a product.

4.3 Fire growth, smoke production and generation of toxicants or corrosive gas depend on the specific properties of a material, its mass, its form and orientation and its surface area.

4.4 To start a fire and for fire development, three components are necessary: heat, air and combustible material (see Figure 1).

4.5 The development of fire can be split into different phases (see Figure 2, which describes two different fire growth courses).

4.6 Traditionally, fire types in rooms have been subdivided into combustion categories, as is done in ISO/TR 9122 (all parts). This scheme suggests that there are six different fire types, each with a characteristic value of oxygen concentration, CO_2/CO ratio, etc.

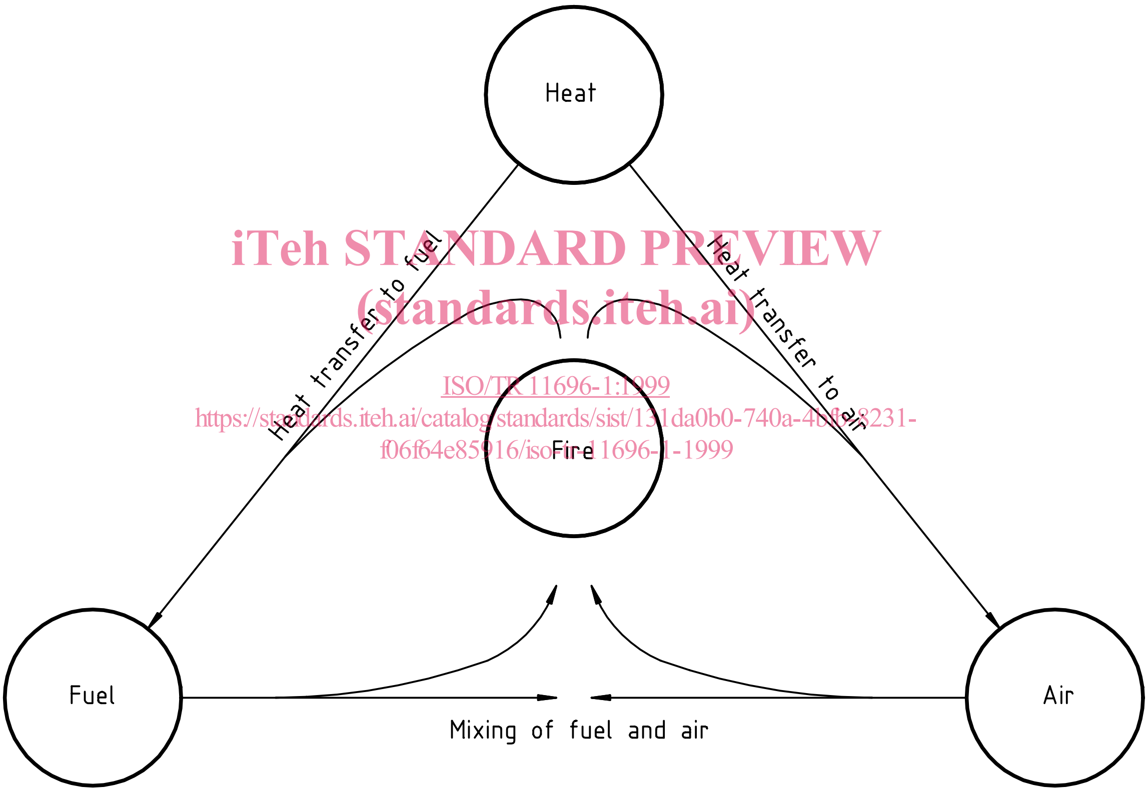
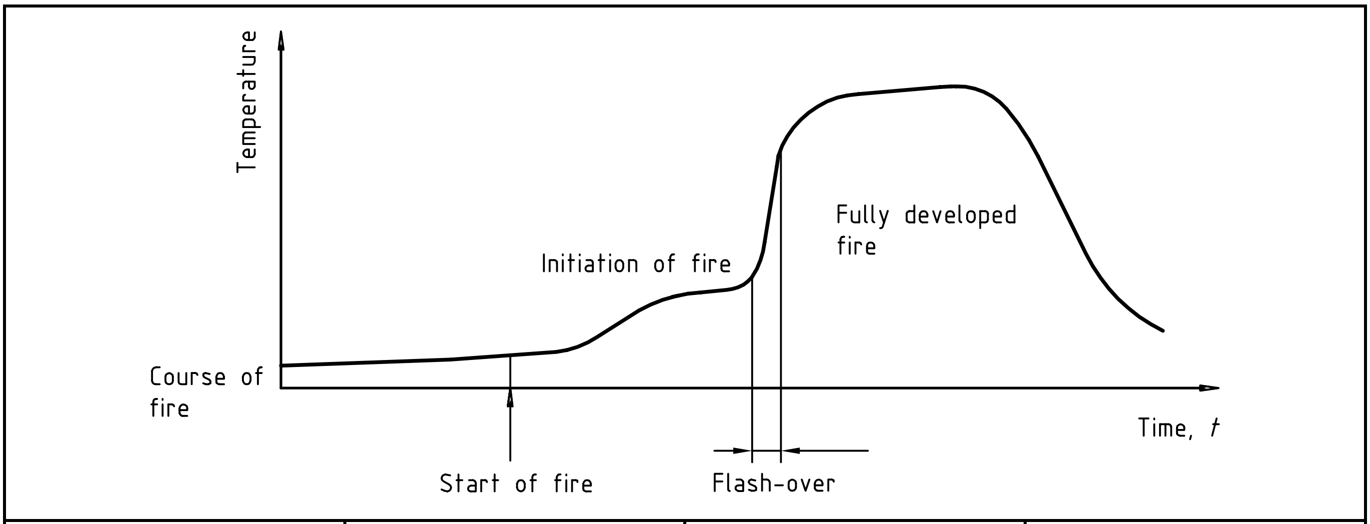


Figure 1 — Components necessary for starting a fire



<table>
<tr><td rowspan="3">Hazard</td><td colspan="4">Ignition</td><td colspan="4">Spread of flame</td><td colspan="4">Fire spread</td></tr>
<tr><td colspan="12">Heat release</td></tr>
<tr><td colspan="3">Visibility</td><td colspan="3">Irritation</td><td colspan="3">Toxicity</td><td colspan="3">Corrosivity</td></tr>
</table>

Figure 2 — Fire growth course

5 Experimental methods and their limitations

5.1 Generally, fire tests do not simulate all aspects of a real fire. No single test result can reflect all aspects of each phase in a developing fire.

5.2 Small-scale tests may simulate some aspects of fire growth of real fires. There is a need for wide experience of using test data from such tests and a recognition of difficulty of interpretation with respect to the behaviour of products under real fire situations.

5.3 In general, ISO/TC 92/SC 1 tests can be used if they give physically-based test results which yield parameters relevant to the model employed. Preferably, tests included in ISO/TR 3814 should be used.

5.4 One aim of using small-scale fire tests is to provide data for predicting full-scale fire behaviour of building products.

5.5 Small-scale tests for smoke development, production of toxicants and corrosive gases from building products are under development. There is a need for development of a hazard model using test results of small-scale tests.

5.6 For reasons of cost and practicality, bench-scale tests are normally used for measuring fire properties. The results from a bench-scale test can occasionally be used directly to predict real-scale fire performance. More commonly, the use of some form of fire model is needed to relate the bench-scale test results to expected real-scale fire performance. This is because bench-scale engineering tests endeavour to quantify a material fire property. The performance in the real-scale fire, however, is not necessarily simply or linearly proportional to the underlying material fire properties; this makes the use of some mathematical treatment often necessary.

5.7 Another issue when trying to predict full-scale performance from bench-scale testing is that there is not just one possible full-scale fire scenario. Often, equally plausible fire scenarios can lead to significantly different numeric results. A bench-scale test prediction cannot equally closely conform to two such different full-scale scenarios.

There is a number of physical apparatus-related issues in bench-scale specimen testing. The results can be influenced by:

a) melting, shrinking, slumping and dripping;

b) intumescence;

c) spalling;

d) charring of products;

e) reflective coating;

f) thermal conductivity of facings.

The following test conditions can influence the result:

1) substrate;

2) holder frame;

3) ignition source;

4) orientation of specimen (direction of flame spread);

5) end-use condition of product, for example joints, fixings and adhesives;

6) air gaps;

7) roughness of surface;

8) effects of geometry;

9) ventilation.

Some of these features can often make it difficult to interpret the results and there is a need to recognize the difficulty of representing this in small-scale tests. Clear guidance for testing procedure and interpretation are needed to obtain valid results. Specialist tests may be needed for certain "difficult-to-test" products, for example ISO/TC 61/SC 4 has developed tests for thermoplastics. ISO/TC 92/SC 1 has developed intermediate and large-scale tests for composites.

5.8 The most important parameters for fire growth process measurements are:

a) ignitability;

b) flame spread rate;

c) heat release rate;

d) smoke production rate.

Effort should be made to use thermal exposures which relate to some real fire situation, preferably to one that will also give results which can be used for fire modelling calculations.

The following four sections of this technical report examine each of the above phenomena in terms of their contribution to the hazard of fire growth, the variables that control these processes and the apparatus or techniques available for measuring the required properties. The motivation for these phenomenological statements is to provide a basis for predicting the fire performance of building products in terms of engineering formulae and material test data. Each section reflects the state of the art and is oriented to allow for continual scientific improvement.

6 Ignitability

6.1 Introduction

In assessing the fire performance of a building product, it is essential to know under what conditions and how quickly the product ignites. Such information is needed to predict the onset of flaming combustion of the first item or area ignited at the initiation of a fire. In addition, the information is an important element in the calculation of fire spread to other parts of a room or compartment, either due to remote ignition of objects or due to flame spread over surfaces. The propensity for ignition is characterized by a number of material properties which can be calculated from bench-scale ignition data on the basis of a mathematical model of the ignitability test. The resulting properties can then be used to predict ignition under real fire conditions, provided these conditions are known or estimated via a computer fire model or other means. This section describes the ignition phenomenon in a bench-scale test, the material properties related to ignition, procedures to calculate these properties from ignition test data, and the use of these properties in assessing the fire performance of building products.

6.2 Ignition theory and related material properties

When a material is exposed in a fire, a major part of the incident heat flux is conducted into the material. This conduction results in a temperature rise of the material, with a maximum at the exposed surface. The temperature profile in the material is a function of the magnitude of the absorbed heat flux and how this flux varies with time. After being exposed for some time, the surface temperature may reach a critical level at which the material starts to decompose and release combustible volatiles. The volatiles mix with the surrounding gases. If this mixture is flammable and if the gas phase temperature, at least locally, is sufficiently high, flaming ignition will result.

From the above description of the piloted ignition phenomenon, it is obvious that detailed ignition models consist of a number of equations describing heat and mass transfer in the solid and gas phase. Such models are too complex and are not very useful for analysing ignition test data in terms of the material properties that are needed for predicting fire performance. A number of simplified ignition models have been developed, and have been used with great success. The guidelines in this section are based on such a simplified model.

The model is based on two major assumptions. First, a critical surface temperature, T_{ig}, is used as the criterion for ignition. T_{ig} is primarily a material property, but its value also depends on the mode of ignition, piloted or unpiloted. Second, it is assumed that the material behaves as an inert solid, and pyrolysis effects prior to ignition are negligible. Strictly speaking, these assumptions are not always valid. However, experience has shown that these assumptions are reasonable for an engineering analysis.

A thermal model as conceptually outlined above, applied to a bench-scale ignition test, is described in detail in 6.3. The model assumes that ignition tests are conducted under exposure to radiant heat, in the presence of a pilot flame. This is consistent with ISO/TC 92 ignition test methods (see 6.6). The solution of the model equations leads to a method for correlating piloted ignition data. These data generally consist of ignition time t_{ig}, measured over a range of irradiance levels, $\dot{q}''_{e}$. The correlation can be used to obtain the following material properties:

$\dot{q}''_{cr}$ = critical irradiance for piloted ignition (kW/m^2),

$\dot{q}''_{min}$ = minimum irradiance for piloted ignition (kW/m^2),

T_{ig} = surface temperature at piloted ignition (°C or K), and

$k\rho c$ = apparent thermal inertia (kJ^2·m^{-4}·K^{-2}·s).

The critical irradiance, $\dot{q}''_{cr}$, is the heat flux level for which the model predicts $t_{ig} \rightarrow \infty$. Since $\dot{q}''_{cr}$ is a function of not only T_{ig} but also of the surface heat transfer characteristics in the ignition test, it is a model parameter rather than a material property. The minimum irradiance $\dot{q}''_{min}$, is the highest heat flux level below which piloted ignition under practical conditions does not occur. Often, but not always, $\dot{q}''_{cr}$ is a reasonable estimate for $\dot{q}''_{min}$.

The material properties that result from an analysis of bench-scale ignition data can generally be used to predict ignition performance under fire conditions and configurations that are different from those in the bench-scale test. For example, the properties needed to predict ignition of a material under flaming exposure are identical to those that can be obtained from ignition tests under radiant exposure. Annex A gives a practical example to illustrate the procedure for calculating material properties from piloted ignition data, and the use of these properties to estimate ignitability under room fire exposure conditions.

6.3 Procedures for calculating material properties from ignition test data

A schematic illustration of a thermal model for a slab of a material exposed in a bench-scale ignition test is shown in Figure 3. It is assumed that L is sufficiently thick so that the material behaves as a semi-infinite solid. Only a fraction, equal to emissivity ε of the incident irradiance $\dot{q}''_{\mathrm{e}}$ is absorbed by the solid. Heat losses from the surface are partly radiative and partly convective, with $h_{\mathrm{c}} \approx 10\ \mathrm{W \cdot m^{-2} \cdot K^{-1}}$ to $15\ \mathrm{W \cdot m^{-2} \cdot K^{-1}}$ typical for bench-scale ignition tests. The ignition time t_{ig}, is the time needed for the surface temperature to reach $T_{\mathrm{s}} = T_{\mathrm{ig}}$. It is further assumed that the material behaves as an inert solid. Thus, the problem is reduced to a one-dimensional heat conduction problem with non-linear boundary conditions.

Extensive numerical solutions of the heat conduction over a wide range of values for $\dot{q}''_{\mathrm{e}}$, T_{ig}, and thermal properties (constant k and c, as well as linear functions of temperature) by Janssens [47] resulted in the following functional relationship between $\dot{q}''_{\mathrm{e}}$ and t_{ig} 1):

$$\dot{q}''_{\mathrm{e}} = \dot{q}''_{\mathrm{cr}} \left[1 + 0{,}73 \left(\frac{k\rho c}{h_{\mathrm{ig}}{}^{2} t_{\mathrm{ig}}} \right)^{0{,}55} \right] \qquad (1)$$

where the steady surface heat transfer coefficient at ignition h_{ig}, is given by:

$$\varepsilon \dot{q}''_{\mathrm{cr}} = h_{\mathrm{c}}(T_{\mathrm{ig}} - T_{\infty}) + \varepsilon\sigma \left(T_{\mathrm{ig}}^{4} - T_{\infty}^{4} \right) = h_{\mathrm{ig}}(T_{\mathrm{ig}} - T_{\infty}) \qquad (2)$$

Equation (1) suggests plotting $(1/t_{\mathrm{ig}})^{0{,}55}$ as a function of $\dot{q}''_{\mathrm{e}}$. The critical irradiance, $\dot{q}''_{\mathrm{cr}}$ is then obtained as the intercept of a straight-line fit through the data points and the abscissa. T_{ig} and h_{ig} are calculated from $\dot{q}''_{\mathrm{cr}}$ via equation (2). Finally, an apparent thermal inertia is calculated from the slope of the straight-line fit via equation (1).

A slightly inferior fit to Janssens's solutions is given by:

$$\dot{q}''_{\mathrm{e}} = \dot{q}''_{\mathrm{cr}} \left[1 + 0{,}71 \left(\frac{k\rho c}{h_{\mathrm{ig}}^{2}\, t_{\mathrm{ig}}} \right)^{0{,}5} \right] \qquad (3)$$

Although this equation is slightly less accurate than equation (1), the 0,5 power is consistent with many other investigators who have proposed functional forms for correlating piloted ignition data. Both equations (1) and (3) are valid for thick solids only.

Mikkola and Wichman [48] analysed the thermal ignition model in two ways:

a) exact solution via Laplace transforms of the linearized problem for thermally thick and thermally thin specimens, and

b) approximate integral solution of the problem with non-linear heat losses for thermally thick, thermally thin and thermally intermediate specimens.

Both approaches resulted in the same recommendation i.e. to correlate $(1/t_{\mathrm{ig}})^{n}$ with $\dot{q}''_{\mathrm{e}}$ where $n = 0{,}5$ for thermally thick materials, $n = 1$ for thermally thin materials and $n = 0{,}6$ for thicknesses in between. Some guidance was given on how to estimate thermal thickness from physical thickness for wood products: thermally thick specimens are over 20 mm, thermally thin specimens are thinner than 1 mm, while $n = 0{,}7$ corresponds to a thickness around

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1) In reference [47] the value of the exponent was 0,547. Since this gives a false sense of precision, it is rounded here to 0,55 for correlating piloted ignition data. Both equations (1) and (3) are valid for thick solids only.