

INTERNATIONAL STANDARD

NORME INTERNATIONALE

BASIC SAFETY PUBLICATION

PUBLICATION FONDAMENTALE DE SÉCURITÉ

Fire hazard testing –

Part 6-2: Smoke obscuration – Summary and relevance of test methods

Essais relatifs aux risques du feu –

Partie 6-2: Opacité des fumées – Résumé et pertinence des méthodes d'essais

Withdawn



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

FIRE HAZARD TESTING –

**Part 6-2: Smoke obscuration –
Summary and relevance of test methods**

FOREWORD

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International Standard IEC 60695-6-2 has been prepared by IEC technical committee 89: Fire hazard testing.

This standard cancels and replaces IEC/TS 60695-6-2 published in 2005. This first edition constitutes a technical revision.

The main changes with respect to the previous edition are listed below:

- this publication has been re-designated as an International Standard;
- updated normative references;
- updated terms and definitions;
- new test method Clause 7.3.2;
- numerous editorial changes of a technical nature throughout the publication.

This standard is to be used in conjunction with IEC 60695-6-1.

It has the status of a basic safety publication in accordance with IEC Guide 104 and ISO/IEC Guide 51.

The text of this standard is based on the following documents:

Enquiry draft	Report on voting
89/1057/FDIS	89/1071/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 60695 series, under the general title of *Fire hazard testing*, can be found on the IEC website.

Part 6 consists of the following parts:

Part 6-1: Smoke obscuration – General guidance

Part 6-2: Smoke obscuration – Summary and relevance of test methods

Part 6-30: Guidance and test methods on the assessment of obscuration hazard of vision caused by smoke opacity from electrotechnical products involved in fires – Small scale static method – Determination of smoke opacity – Description of the apparatus

Part 6-31: Smoke obscuration – Small-scale static test – Materials

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

The risk of fire needs to be considered in any electrical circuit, and the objective of component, circuit and equipment design, and the choice of materials, is to reduce the likelihood of fire, even in the event of foreseeable abnormal use, malfunction or failure.

Electrotechnical products, primarily as victims of fire, may nevertheless contribute to the fire. One of the contributing hazards is the release of smoke, which may cause loss of vision and/or disorientation which could impede escape from the building, or fire fighting.

This international standard describes smoke test methods in common use to assess the smoke release from electrotechnical products, or from materials used in electrotechnical products. It forms part of the IEC 60695-6 series which gives guidance to product committees wishing to incorporate test methods for smoke obscuration in product standards.

Withdrawn

FIRE HAZARD TESTING –

Part 6-2: Smoke obscuration – Summary and relevance of test methods

1 Scope

This part of IEC 60695 provides a summary of the test methods that are used in the assessment of smoke obscuration. It presents a brief summary of static and dynamic test methods in common use, either as international standards or national or industry standards. It includes special observations on their relevance to electrotechnical products and their materials and to fire scenarios, and it gives recommendations on their use.

This basic safety publication is intended for use by technical committees in the preparation of standards in accordance with the principles laid down in IEC Guide 104 and ISO/IEC Guide 51.

One of the responsibilities of a technical committee is, wherever applicable, to make use of basic safety publications in the preparation of its publications. The requirements, test methods or test conditions of this basic safety publication will not apply unless specifically referred to or included in the relevant publications.

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.

IEC 60695-6-1:2005, *Fire hazard testing – Part 6-1: Smoke obscuration – General guidance*

IEC Guide 104:., *The preparation of safety publications and the use of basic safety publications and group safety publications*

ISO/IEC 13943:2008, *Fire safety – Vocabulary*

ISO 5725-2:1994, *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 19706:2007¹, *Guidelines for assessing the fire threat to people*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 13943, some of which are reproduced below for users' convenience, apply.

3.1

combustion

exothermic reaction of a substance with an oxidising agent

¹ This publication cancels and replaces ISO 9122-1:1989, Toxicity testing of fire effluents – Part 1: General.

NOTE Combustion generally emits fire effluent accompanied by flames and/or glowing.

[ISO/IEC 13943, definition 4.46]

3.2

extinction area of smoke

product of the volume occupied by smoke and the extinction coefficient of the smoke

NOTE It is a measure of the amount of smoke, and the typical units are square metres (m^2).

[ISO/IEC 13943, definition 4.92]

3.3

extinction coefficient

natural logarithm of the ratio of incident light intensity to transmitted light intensity, per unit light path length

NOTE Typical units are reciprocal metres (m^{-1}).

[ISO/IEC 13943, definition 4.93]

3.4

fire

(general) process of combustion characterized by the emission of heat and fire effluent and usually accompanied by smoke, flame, glowing or a combination thereof

NOTE In the English language the term "fire" is used to designate three concepts, two of which, fire (3.5) and fire (3.6), relate to specific types of self-supporting combustion with different meanings and two of them are designated using two different terms in both French and German.

[ISO/IEC 13943, definition 4.96]

3.5

fire

(controlled) self-supporting combustion that has been deliberately arranged to provide useful effects and is limited in its extent in time and space

[ISO/IEC 13943 definition 4.97]

3.6

fire

(uncontrolled) self-supporting combustion that has not been deliberately arranged to provide useful effects and is not limited in its extent in time and space

[ISO/IEC 13943 definition 4.98]

3.7

fire effluent

totality of gases and aerosols, including suspended particles, created by combustion or pyrolysis in a fire

[ISO/IEC 13943, definition 4.105]

3.8

fire hazard

physical object or condition with a potential for an undesirable consequence from fire

[ISO/IEC 13943, definition 4.112]

3.9**fire model****fire simulation**

calculation method that describes a system or process related to fire development, including fire dynamics and the effects of fire

[ISO/IEC 13943, definition 4.116]

3.10**fire scenario**

qualitative description of the course of a fire with respect to time, identifying key events that characterise the studied fire and differentiate it from other possible fires

NOTE It typically defines the ignition and fire growth processes, the fully developed fire stage, the fire decay stage, and the environment and systems that impact on the course of the fire.

[ISO/IEC 13943 definition 4.129]

3.11**heat flux**

amount of thermal energy emitted, transmitted or received per unit area and per unit time

NOTE The typical units are watts per square metre ($\text{W} \cdot \text{m}^{-2}$).

[ISO/IEC 13943, definition 4.173]

3.12**ignition****sustained ignition (deprecated)**

(general) initiation of combustion

[ISO/IEC 13943, definition 4.187]

3.13**ignition****sustained ignition (deprecated)**

(flaming combustion) initiation of sustained flame

[ISO/IEC 13943 definition 4.188]

3.14**mass optical density of smoke**

optical density of smoke multiplied by a factor, $V/(\Delta m L)$, where V is the volume of the test chamber, Δm is the mass lost from the test specimen, and L is the light path length

NOTE The typical units are square metres per gram ($\text{m}^2 \times \text{g}^{-1}$).

[ISO/IEC 13943, definition 4.225]

3.15**obscuration by smoke**

reduction in the intensity of light due to its passage through smoke

cf. **extinction area of smoke** (3.2) and **specific extinction area of smoke** (3.23).

NOTE 1 In practice, obscuration by smoke is usually measured as the transmittance, which is normally expressed as a percentage.

NOTE 2 Obscuration by smoke causes a reduction in visibility.

[ISO/IEC 13943 definition 4.242]

3.16

optical density of smoke

measure of the attenuation of a light beam passing through smoke expressed as the logarithm to the base 10 of the opacity of smoke

cf. **specific optical density of smoke** (3.24)

NOTE The optical density of smoke is dimensionless.

[ISO/IEC 13943, definition 4.244]

3.17

physical fire model

laboratory process, including the apparatus, the environment and the fire test procedure intended to represent a certain phase of a fire

[ISO/IEC 13943, definition 4.251]

3.18

real-scale fire test

fire test that simulates a given application, taking into account the real scale, the real way the item is installed and used, and the environment

NOTE Such a fire test normally assumes that the products are used in accordance with the conditions laid down by the specifier and/or in accordance with normal practice.

[ISO/IEC 13943, definition 4.273]

3.19

small-scale fire test

fire test performed on a test specimen of small dimensions

NOTE A fire test performed on a test specimen of which the maximum dimension is less than 1 m is usually called a small-scale fire test

[ISO/IEC 13943, definition 4.292]

3.20

smoke

visible part of fire effluent

[ISO/IEC 13943, definition 4.293]

3.21

smoke production rate

amount of smoke produced per unit time in a fire or fire test

NOTE 1 It is calculated as the product of the volumetric flow rate of smoke and the extinction coefficient of the smoke at the point of measurement.

NOTE 2 The typical units are square metres per second ($\text{m}^2 \times \text{s}^{-1}$).

[ISO/IEC 13943 definition 4.295]

3.22

smoke release rate

see **smoke production rate** (3.21)

3.23

specific extinction area of smoke

extinction area of smoke produced by a test specimen in a given time period divided by the mass lost from the test specimen in the same time period

NOTE The typical units are square metres per gram ($\text{m}^2 \cdot \text{g}^{-1}$).

[ISO/IEC 13943 definition 4.301]

3.24

specific optical density of smoke

optical density of smoke multiplied by a geometric factor

NOTE 1 The geometric factor is $V/(A \cdot L)$, where V is the volume of the test chamber, A is the area of the exposed surface of the test specimen, and L is the light path length.

NOTE 2 The use of the term “specific” does not denote “per unit mass” but rather denotes a quantity associated with a particular test apparatus and area of the exposed surface of the test specimen.

NOTE 3 The specific optical density of smoke is dimensionless.

[ISO/IEC 13943 definition 4.303]

3.25

visibility

maximum distance at which an object of defined size, brightness and contrast can be seen and recognized

[ISO/IEC 13943 definition 4.350]

4 Types of test method

4.1 General

Test methods are characterised by whether they are static or dynamic and/or by the nature of the test specimen.

4.2 Physical fire model

The amount and rate of smoke released from a given material or product is not an inherent property of that material or product, but is critically dependent on the conditions under which that material or product is burnt. Decomposition temperature, amount of ventilation and fuel composition are the main variables which affect the composition of fire effluent, and hence the amount of smoke and smoke production rate.

It is critical to show that the test conditions defined in a standardised test method (the physical fire model) are relevant to, and replicate the desired stage of a real fire. ISO has published a general classification of fire stages in ISO 19706, shown in Table 1. The important factors affecting smoke production are oxygen concentration and irradiance/temperature.

4.3 Static test methods

A static smoke test is one in which the smoke generated is allowed to accumulate within the test chamber. Some re-circulation and secondary combustion of smoke particles may occur. The obscuration by smoke may be affected by deposition, agglomeration, stirring and progressive oxygen depletion.

4.4 Dynamic test methods

A dynamic smoke test is one in which there is a continuous flow of fire effluent through the measuring device without re-circulation. In this test, the smoke particles generated are not allowed to accumulate and are dispersed in the controlled air flow through the test apparatus. Decay of the smoke can occur in a dynamic test, and may involve coagulation of particles and/or their deposition on cooling.

Table 1 – Characteristics of fire stages (ISO 19706)

Fire stages	Heat flux to fuel surface kW/m ²	Max. temperature °C		Oxygen volume %		Fuel/air equivalence ratio (plume)	$\frac{[\text{CO}]}{[\text{CO}_2]}$ v/v	$\frac{100 \times [\text{CO}_2]}{([\text{CO}_2] + [\text{CO}])}$ % efficiency
		Fuel surface	Upper layer	Entrained	Exhausted			
1. Non-flaming								
a. self-sustaining (smouldering)	not applicable	450 to 800	25 to 85 ^a	20	20	—	0,1 to 1	50 to 90
b. oxidative pyrolysis from externally applied radiation	—	300 to 600 ^a	^b	20	20	< 1	c	c
c. anaerobic pyrolysis from externally applied radiation	—	100 to 500	^b	0	0	>> 1	c	c
2. Well-ventilated flaming ^d	0 to 60	350 to 650	50 to 500	≈ 20	≈ 20	< 1	< 0,05 ^e	> 95
3. Under-ventilated flaming ^f								
a. small, localized fire, generally in a poorly ventilated compartment	0 to 30	300 to 600 ^a	50 to 500	15 to 20	5 to 10	> 1	0,2 to 0,4	70 to 80
b. post-flashover fire	50 to 150	350 to 650 ^g	> 600	< 15	< 5	> 1 ^h	0,1 to 0,4 ⁱ	70 to 90
a The upper limit is lower than for well-ventilated flaming combustion of a given combustible. b The temperature in the upper layer of the fire room is most likely determined by the source of the externally applied radiation and room geometry. c There are few data; but for pyrolysis, this ratio is expected to vary widely depending on the material chemistry and the local ventilation and thermal conditions. d The fire's oxygen consumption is small compared to that in the room or the inflow, the flame tip is below the hot gas upper layer or the upper layer is not yet significantly vitiated to increase the CO yield significantly, the flames are not truncated by contact with another object, and the burning rate is controlled by the availability of fuel. e The ratio may be up to an order of magnitude higher for materials that are fire-resistant. There is no significant increase in this ratio for equivalence ratios up to ≈ 0,75. Between ≈ 0,75 and 1, some increase in this ratio may occur. f The fire's oxygen demand is limited by the ventilation opening(s); the flames extend into the upper layer. g Assumed to be similar to well-ventilated flaming. h The plume equivalence ratio has not been measured; the use of a global equivalence ratio is inappropriate. i Instances of lower ratios have been measured. Generally, these result from secondary combustion outside the room vent.								

5 Types of test specimen

The test specimen may be a manufactured product, a component of a product, a simulated product (representative of a portion of a manufactured product), a basic material (solid or liquid), or a composite of materials.

6 Published static test methods

6.1 General

The static test methods reviewed below were selected on the basis that they are published international, national or industry standards, and are in common usage in the electrotechnical field. It is not intended to review all possible test methods.

NOTE These summaries are intended as a brief outline of the test methods, and should not be used in place of full published standards.

6.2 Determination of smoke opacity in a 0,51 m³ chamber

6.2.1 Standards which use a vertically oriented test specimen

6.2.1.1 Standards

Two international and four national standards are based on testing a vertically oriented test specimen in a single chamber of 0,51 m³ volume.

NOTE The chamber was developed in the USA by the National Bureau of Standards (now known as the National Institute of Standards and Technology) and is often referred to as the "NBS chamber".

These are: IEC/TR 60695-6-30 [1]² and IEC 60695-6-31 [2], ASTM E662 [3], BS 6401 [4], NF C20-902-1 [5] and NF C20-902-2 [6].

6.2.1.2 Purpose and principle

This small-scale fire test is used to assess the opacity of the smoke generated by a vertically oriented test specimen of material exposed to a specified thermal irradiance, with or without pilot flames, in a closed chamber 0,51 m³ in volume. The luminous flux through the smoke is continuously recorded.

6.2.1.3 Test specimen

The test specimen is a flat piece 76,2 mm × 76,2 mm, with a maximum thickness of 25,4 mm.

6.2.1.4 Method

The method employs an electrical radiant energy source mounted so as to produce a heat flux of 25 kW/m² on a vertically mounted test specimen. Two modes of test are commonly used:

- a) non-flaming, where only the radiant energy source is used, or
- b) flaming, where a small burner is used in addition to the radiant energy source. This burner produces a row of pilot flames along the lower edge of the test specimen, which ignite any combustion products.

A photometric system using polychromatic white light, with a vertical light path is used to measure the variation in light transmission during the test.

² Figures in square brackets refer to the Bibliography.

Results are expressed in terms of specific optical density, D_s , which is calculated using the following equation:

$$D_s = (V / AL) \log_{10}(I / T)$$

where

- V is the volume of smoke (i.e. the volume of the chamber);
- A is the exposed surface area of the test specimen;
- L is the path length of the light used to measure the smoke;
- I is the incident luminous flux;
- T is the transmitted luminous flux.

D_s is related to the extinction area of the smoke (S) by the equation:

$$D_s = S / [A \times \ln(10)]$$

i.e.

$$D_s = S / [2,303 \times A]$$

where S is the extinction area of smoke.

NOTE D_m is used instead of D_s in NF C20-902-1 & -2 (see A.1).

6.2.1.5 Repeatability and reproducibility

Repeatability and reproducibility have been determined in an interlaboratory trial, based on the French standards NF C20-902-1 and NF C20-902-2.

The results, presented in accordance with ISO 5725-2, are given in Annex A.

6.2.1.6 Relevance of test data and special observations

Test methods based on the NBS smoke chamber have been in worldwide use since about 1970, primarily for material evaluation purposes. However, these methods have now, in many cases, been superseded by ISO 5659-2 (see 6.2.2), which overcomes the following significant limitations of the NBS method:

- a) The heat flux is relatively low, and the air supply limited, which means that the method is only able to replicate conditions found in ISO 19706 fire stages 1 b) and, possibly, 2 (see Table 1).
- b) The test specimen is small, vertically mounted and is essentially flat, which limits the scope of the method to the evaluation of materials only, and excludes liquids and some thermoplastics. Test specimens which swell towards the furnace also give problems, as the incident heat flux experienced by the front of the test specimen increases significantly, and the pilot flames can be extinguished, rendering the test invalid.
- c) The limitations of the low heat flux and test specimen geometry mean that it is difficult to establish a link between data from the NBS chamber and other fire scenarios.

Further limitations of methods based on the NBS smoke chamber include the following:

- d) There is little or no correlation between data from this test, and the behaviour of products in fires or real-scale fire tests.
- e) There are no means of monitoring test specimen mass during the test.
- f) The air supply is limited and the test specimen ceases to burn if the oxygen concentration falls below approximately 14 %.
- g) The deposition of smoke on the walls is significant.

- h) The repeatability and reproducibility of the method have been studied several times and found to be very poor (see Annex A), and dependent on the nature of the material under test. Materials with high flow, excessive swelling or irreproducible ignitability produce less reliable results.

The method does however offer the useful option to evaluate smoke production from both flaming and non-flaming combustion, albeit at a low heat flux.

The data generated are not suitable for use as input to fire hazard assessment or for fire safety engineering.

Overall, this method is not recommended for further development for electrotechnical products. Neither is it recommended as the basis for regulation or other controls on smoke release for electrotechnical products, due to the limitations on the physical fire model and test specimen geometry.

6.2.2 Standard which uses a horizontally oriented test specimen

6.2.2.1 Standard

One International standard, ISO 5659-2 [7], is based on the following method:

6.2.2.2 Purpose and principle

This test is used to assess the opacity of the smoke generated by a horizontally oriented test specimen of material exposed to a specified thermal irradiance, with or without a pilot flame, in a closed chamber 0,51 m³ in volume. The luminous flux through the smoke is continuously measured and recorded.

NOTE This method uses essentially the same apparatus as described in 6.2.1, with the exception of modifications to the source of thermal irradiance and test specimen orientation.

6.2.2.3 Test specimen

The test specimen is a flat piece 75 mm × 75 mm with a maximum thickness of 25 mm.

6.2.2.4 Method

This test method employs an electrically heated conical radiant energy source to expose horizontally mounted test specimens to an incident flux of 25 kW/m² or 50 kW/m². The heat source consists of electrical windings contained within a truncated steel cone. The exposure can be in flaming mode or in non-flaming mode, depending on whether or not a pilot flame, consisting of a small gas burner, is used.

The test chamber is a closed chamber, 0,51 m³ in volume, and the smoke opacity is assessed by means of a photometric system, with a white light shining vertically through the chamber. The photodetector measures the decrease in light transmission due to the accumulation of smoke.

Test specimens are placed horizontally under the conical radiant heater with a distance of 25 mm between the surface of the test specimen and the lower edge of the heater. For test specimens which intumesce when exposed to the conical radiant heater, the distance should be increased to 50 mm. The heat flux applied to the test specimen is calibrated, prior to the tests, for the distance used.

The light transmission measurements are used to determine the specific optical density of smoke.

Optionally, the test specimen mass loss can also be monitored continuously during the test, by means of a load cell located under the test specimen. If the load cell is used, the mass optical density of smoke can also be determined.

Results are expressed in terms of specific optical density 10 min after the start of the test, D_{s10} , which is calculated using the following equation:

$$D_{s10} = (V / AL) \log_{10}(100 / T_{10})$$

where

V is the volume of smoke (i.e. the volume of the chamber);

A is the exposed surface area of the test specimen;

L is the path length of the light used to measure the smoke;

T_{10} is the percentage transmittance after 10 min;

D_{s10} is related to the extinction area of the smoke produced after 10 min, $S_{(t=10 \text{ min})}$, by the equation:

$$D_{s10} = S_{(t=10 \text{ min})} / [A \times \ln(10)], \text{ i.e.}$$

$$D_{s10} = S_{(t=10 \text{ min})} / [2,303 \times A]$$

Results can also be expressed in terms of mass optical density, D_{mass} , by the equation:

$$D_{\text{mass}} = [(V / L) \log_{10}(100 / T)] / \Delta m$$

where

T is the percentage transmittance;

Δm is the mass consumed.

The relationship between D_{mass} and the extinction area of the smoke is given by:

$$S = D_{\text{mass}} \Delta m \ln(10) = 2,303 D_{\text{mass}} \Delta m$$

6.2.2.5 Repeatability and reproducibility

An interlaboratory trial involving eight laboratories has been carried out during the development of ISO 5659-2. The results, presented in accordance with ISO 5725-2, are given in Table B.1 in Annex B.

An additional interlaboratory trial involving ten laboratories has been carried out for two intumescent plastics (polycarbonate and PVC flooring) using the test specimen-heater distance of 50 mm, during a revision of ISO 5659-2. The results, presented in accordance with ISO 5725-2, are given Table B.2 and Table B.3 in Annex B.

6.2.2.6 Relevance of test data and special observations

This method is based on the NBS smoke chamber method (see 6.1) and incorporates many useful enhancements:

- The test specimen is horizontally oriented, which allows for the evaluation of thermoplastics. With further development this method may be suitable for liquids. However, the method is still only suitable for essentially flat test specimens. Test specimens which swell will still move towards the heat source and experience non-standard heat fluxes.
- The maximum heat flux is increased to 50 kW/m², which means that the method can replicate ISO 19706 fire stage 3a), in addition to stages 1b) and 2 (see Table 1). This heat flux can also provide a greater discrimination between flame retardant materials.

- c) If mass loss rate data are recorded, they may be suitable for use as input to hazard assessment, or to calculate mass optical density. The data generated may be suitable for use as input to fire hazard assessment or fire safety engineering.
- d) A test method for intumescent materials is added.

The repeatability and reproducibility of the method have been found to be very variable, and dependent on the nature of the material under test. In particular, smoke generation is critically dependent on the ignition behaviour of the material under test.

This method is used as the basis for regulatory control by the IMO (International Maritime Organisation). It is not recommended as the basis for the regulatory control of electrotechnical products, unless the electrotechnical product to be tested falls within the limitations on test specimen geometry.

6.3 Determination of smoke density in a 27 m³ smoke chamber

6.3.1 Standards

Four international standards are based on a 27 m³ (3 m × 3 m × 3 m) smoke chamber. These are: IEC 61034-1 [8], IEC 61034-2 [9], EN 61034-1 [10], EN 61034-2 [11]. The chamber is often referred to as the “three metre cube”.

Two national standards use the “three metre cube” chamber. These are BS 6853 [12] and CEI 20-37-3 [13].

6.3.2 Purpose and principle

This test is used to assess the density of smoke generated by materials or products exposed to a combustion source with flame in a closed chamber. The luminous flux through the smoke is continuously measured and recorded.

6.3.3 Test specimen

The test specimen consists of horizontally oriented materials or products, typically 1 m long, positioned above the ignition source.

6.3.4 Method

The test method employs a pan of burning alcohol (one litre) as the flame source under the test specimen, within a closed chamber, 27 m³ in volume. The smoke density is measured by means of a photometric system, using a white light, shining horizontally across the chamber, at a height of 2,15 m. The photodetector measures the decrease in light transmission due to the accumulation of smoke. The light transmission measurements are used to assess the maximum obscuration achieved during the test. A fan is used throughout the test to homogenize the smoke and minimize stratification.

In some standards, percentage transmittance (% T) values are recorded, using the following formula:

$$\%T = 100 (T/I)$$

where

I is the incident luminous flux;

T is the transmitted luminous flux.

In some standards, primarily for cables, optical density values (referred to as A_m) are calculated using the following formula:

$$A_m = \log_{10} (I/T)$$

NOTE A_m is also incorrectly known in some standards as absorbance.

and results are reported in terms of a parameter A_0 :

$$A_0 = A_m V/nL$$

where

V is the volume of the chamber (27 m³);

L is the light path length (3 m);

n is the number of units of test specimen.

The extinction area of the smoke (S) can be calculated from A_m or A_0 as follows:

$$S = A_m V \ln(10) / L = 2,303 V / L$$

$$S = A_0 n \ln(10) = 2,303 A_0 n$$

6.3.5 Repeatability and reproducibility

Repeatability and reproducibility have been determined in an interlaboratory trial, based on IEC 61034-2.

The results, presented in accordance with ISO 5725-2, are given in Annex C.

6.3.6 Relevance of test data and special observations

This method was originally developed as the basis for the evaluation of smoke release from cables and other underground railway products. The fire scenario parameters (test chamber geometry, fire source and test specimen positioning) have been designed to be relevant to underground railways. The method is able to replicate the conditions of ISO 19706, fire stage 2 (see Table 1).

The optical system used is such that the method cannot discriminate between products with a smoke release which results in a light transmission through the chamber of less than 10 %. The data, as presented, are not suitable for use as direct input to quantitative fire hazard assessment or fire safety engineering, but with further processing may be suitable.

In some countries, this method is used as the basis for regulatory control.

This method is suitable for further development for other electrotechnical products, providing that the physical fire model is appropriate, and that the limitations on test specimen geometry and discrimination are acceptable.

6.4 Determination of specific optical density using a dual-chamber test

6.4.1 Standards

One international technical report, ISO/TR 5924 [14], is based on the following method.

6.4.2 Purpose and principle

This test is used to assess the opacity of smoke generated by materials or products subjected to a specified thermal irradiance in a closed dual chamber.

6.4.3 Test specimen

The test specimen measures 165 mm × 165 mm and has a maximum thickness of 70 mm.

6.4.4 Method

The test specimens are mounted horizontally in a decomposition chamber and exposed to a thermal irradiance of up to 60 kW/m². The smoke generated is collected in a second chamber and the opacity is measured.

6.4.5 Repeatability and reproducibility

No data are available.

6.4.6 Relevance of test data and special observations

This method is now little used, has essentially been superseded by ISO 5659-2, and is now regarded as obsolescent.

It is not recommended for further development.

7 Published dynamic test methods

7.1 General

The dynamic test methods reviewed below have been selected on the basis that they are published international, national or industry standards, and are in common usage in the electrotechnical field. It is not intended to review all possible test methods.

NOTE These summaries are intended as a brief outline of the test methods and should not be used in place of full published standards.

7.2 Determination of smoke density generated by electric cables mounted on a horizontal ladder

7.2.1 Standards

Several national and industry standards are based on the following method. For example, NFPA 262 [15], ULC S102.4 [16], and EN 50289-4-11 [17].

7.2.2 Purpose and principle

This test is used to assess the smoke obscuration generated by cables in a horizontal tunnel with induced draught.

7.2.3 Test specimen

Test specimens consist of cables in 7,32 m lengths installed in a single layer over the rungs of a cable ladder 286 mm wide.

7.2.4 Method

The test specimens are exposed, at one end of the ladder, to a 300 000 BTU/h (87,9 kW) flame for 20 min, inside a tunnel. A forced air flow is applied along the tunnel away from the ignition source. During the test, both the peak and average values of the optical density of the smoke are measured at the opposite end of the tunnel using a photo cell.

7.2.5 Repeatability and reproducibility

An interlaboratory trial involving five laboratories has been carried out to evaluate NFPA 262. The results are given in Annex D.

7.2.6 Relevance of test data and special observations

This method is used to simulate a specific fire scenario involving movement of environmental air with severe fire source and ventilation conditions.

The method is able to replicate ISO 19706, fire stage 3b (see Table 1).

This method is used to provide data for the regulatory control of some types of cables, in some countries.

7.3 Determination of smoke generated by electrical cables mounted on a vertical ladder

7.3.1 Standards

There are two north American vertical ladder standards that involve the measurement of smoke. These are ASTM D5424 [18] and UL 1685 [19].

7.3.1.1 Purpose and principle

Cables are mounted on a vertical ladder, which is enclosed in a chamber with a controlled air flow. Smoke obscuration is measured, and smoke release rate and total smoke release are calculated. In some cases, mass loss and heat release may also be measured.

7.3.1.2 Test specimens

Cables are mounted on a ladder in several configurations depending on the specified protocol.

7.3.1.3 Method

The ladder containing the cables is mounted vertically inside the enclosure, and optionally on a load cell.

The cable(s) is(are) exposed to a 20 kW flame for 20 min. The smoke obscuration is measured by a photoelectric cell located in the exhaust duct.

A smoke release rate (SRR) is calculated using the extinction coefficient in the duct and the volumetric flow rate.

7.3.1.4 Repeatability and reproducibility

No data are available.

7.3.1.5 Relevance of test data and special observations

These methods are adaptations of the standard cable industry tests for flame propagation, with instrumentation added to the exhaust duct to allow for the dynamic measurement of smoke.

Test specimens are linear, should be self-supporting and should normally be installed vertically in enclosed ducts.

The ventilation conditions and fire source are such that the test method is able to replicate ISO 19706, fire stage 2 (see Table 1).

This method is suitable for further development of electrotechnical products, providing that the installation environment of the products is appropriate, the limitations on the test specimen geometry is acceptable, and the physical fire model is suitable.

This method is used to provide data for the regulatory control of cables designated low smoke in the United States and Canada.

7.3.2 prEN 50399

7.3.2.1 Standards

There is a European vertical ladder standard that involves the measurement of smoke. This is prEN 50399 [20].

7.3.2.2 Purpose and principle

prEN 50399 specifies the test apparatus and test procedures for the assessment of the reaction to fire performance of cables. It was developed from the FIPEC research programme [21] in response to the European Construction Products Directive (CPD) [22] to enable classification under the CPD to be achieved.

The test method describes a real-scale fire test of cable samples mounted on a vertical cable ladder and is carried out with a specified ignition source to evaluate the burning behaviour of the cable. The test provides data for the early stages of a cable fire from ignition of cable samples. It addresses the hazard of propagation of flames along the cable, the potential, by the measurement of the heat release rate, for the fire to affect areas adjacent to the compartment of origin, and the hazard, by the measurement of production of light obstructing smoke, of reduced visibility in the room of origin and surrounding enclosures.

The following parameters, under defined conditions, may be determined during the test: flame spread, rate of heat release, total heat release, rate of smoke production, total smoke production, fire growth rate index, and the occurrence of flaming droplets/particles.

The apparatus is based upon that of EN 60332-3-10 but with changes to the mounting and airflow through the chamber and additional instrumentation to measure heat release and smoke production during the test.

NOTE 1 The mounting changes make comparison with EN 50266-1 tests impossible.

NOTE 2 The IEC standard which corresponds to EN 50266-1 is IEC 60332-3-10 [24].

prEN 50399 contains two protocols. In one protocol the flame ignition source has a nominal power of 20,5 kW. In the other protocol it has a nominal power of 30 kW.

There are three different classifications for smoke based on this test. They are based on the total smoke production and the peak rate of smoke production.

7.3.2.3 Test specimens

The test specimens are manufactured lengths of cables having a length of $(3,5 + 0,1 - 0,0)\text{m}$. The loading depends on the diameter of the cable. The spacing of the test specimens on the ladder also depends on the diameter of the cable.

7.3.2.4 Test method

The cables are mounted on the front of a vertical ladder in the test enclosure. The heat release rate is determined by measuring the oxygen concentration, the flow rate and the temperature in the exhaust duct, using the principle of oxygen consumption.

The airflow through the test chamber is $8,0 \text{ m}^3 \times \text{min}^{-1} \pm 0,8 \text{ m}^3 \times \text{min}^{-1}$.

The test flame is applied for 20 min, after which it is extinguished. The air flow through the test chamber is maintained for a further 30 s after which it is stopped.