IEC 60695-6-1

Edition 3.0 2021-08
REDLINE VERSION

INTERNATIONAL STANDARD

HORIZONTAL PUBLICATION

Fire hazard testing –
Part 6-1: Smoke obscuration – General guidance

IEC 60695-6-1:2021-08 RLV(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 13.220.99; 29.020

ISBN 978-2-8322-1013-1

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition IEC 60695-6-1:2005+AMD1:2010 CSV. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

International Standard IEC 60695-6-1 has been prepared by IEC technical committee 89: Fire hazard testing.

This third edition cancels and replaces the second edition of IEC 60695-6-1 published in 2005 and Amendment 1:2010. It constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

– References to IEC TS 60695-6-30 (withdrawn in 2016) have been removed.
– References to IEC TS 60695-6-31 (withdrawn in 2016) have been removed.
– References to ISO 5659-2 have been inserted.
– The scope contains some additional text.
– Terms and definitions have been updated.
– Subclause 3.2 has been updated.
– Subclause 7.1 has been updated.

The text of this International Standard is based on the following documents:

Draft	Report on voting
89/1472/CDV	89/1504/RVC

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

The language used for the development of this International Standard is English.

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

This International Standard is to be used in conjunction with IEC 60695-6-2.

In this standard, the following print types are used:

- *italic font: terms defined in Clause 3.*

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

IEC 60695-6 consists of the following parts:

Part 6-1: Smoke obscuration – General guidance

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

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

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

~~Electrotechnical products, primarily victims of a fire, may nevertheless contribute to the fire.~~

In the design of an electrotechnical product the risk of fire and the potential hazards associated with fire need to be considered. In this respect the objective of component, circuit and equipment design, as well as the choice of materials, is to reduce the risk of fire to a tolerable level even in the event of reasonably foreseeable (mis)use, malfunction or failure.

IEC 60695-1-10, IEC 60695-1-11, and IEC 60695-1-12 [1][1] provide guidance on how this is to be accomplished.

Fires involving electrotechnical products can also be initiated from external non-electrical sources. Considerations of this nature are dealt with in an overall fire hazard assessment.

The aim of the IEC 60695 series is to save lives and property by reducing the number of fires or reducing the consequences of the fire. This can be accomplished by:

– trying to prevent ignition caused by an electrically energised component part and, in the event of ignition, to confine any resulting fire within the bounds of the enclosure of the electrotechnical product.
– trying to minimise flame spread beyond the product's enclosure and to minimise the harmful effects of fire effluents including heat, *smoke*, and toxic or corrosive combustion products.

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.

Smoke particles reduce the *visibility* due to light absorption and scattering. Consequently, people may experience difficulties in finding exit signs, doors and windows. *Visibility* is often determined as the distance at which an object is no longer visible. It depends on many factors, but close relationships have been established between *visibility* and the measurements of the *extinction coefficient of smoke* – see Annex A.

The production of *smoke* and its optical properties can be measured as well as other fire properties, such as heat release, flame spread, and the production of toxic gas and corrosive effluent. This document serves as a guidance document and focuses on obscuration of light by *smoke*.

[1] Numbers in square brackets refer to the bibliography.

FIRE HAZARD TESTING –

Part 6-1: Smoke obscuration – General guidance

1 Scope

This part of IEC 60695 gives guidance on:

a) the optical measurement of *obscuration of smoke*;

b) general aspects of optical *smoke* test methods;

c) consideration of test methods;

d) expression of *smoke* test data;

e) the relevance of optical *smoke* data to hazard assessment.

This basic safety publication focusing on safety guidance is primarily intended for use by technical committees in the preparation of safety publications 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.

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.

IEC 60695-1-10, *Fire hazard testing – Part 1-10: Guidance for assessing the fire hazard of electrotechnical products – General guidelines*

IEC 60695-1-11~~[2]~~, *Fire hazard testing – Part 1-11: Guidance for assessing the fire hazard of electrotechnical products – Fire hazard assessment*

IEC 60695-4~~:2005~~, *Fire hazard testing – Part 4: Terminology concerning fire tests for electrotechnical products*

IEC 60695-6-2~~[3]~~, *Fire hazard testing – Part 6-2: Smoke obscuration – Summary and relevance of test methods*

~~IEC 60695-6-30:1996, *Fire hazard testing – Part 6: Guidance and test methods on the assessment of obscuration hazard of vision caused by smoke opacity from electrotechnical products involved in fires – Section 30: Small-scale static method – Determination of smoke opacity – Description of the apparatus*~~

~~IEC 60695-6-31:1999, *Fire hazard testing – Part 6-31: Smoke obscuration – Small-scale static test – Materials*~~

~~[2] To be published.~~

~~[3] To be published.~~

IEC Guide 104~~:1997~~, *The preparation of safety publications and the use of basic safety publications and group safety publications*

ISO/IEC Guide 51~~:1999~~, *Safety aspects – Guidelines for their inclusion in standards*

~~ISO 5659-2:2006, *Plastics – Smoke generation – Part 2: Determination of optical density by a single-chamber test*~~

~~ISO 5660-2:2002, *Reaction-to-fire tests – Heat release, smoke production and mass loss rate – Part 2: Smoke production rate (dynamic measurement)*~~

ISO 13943:~~2008~~2017, *Fire safety – Vocabulary*

~~ISO 19706:2007, *Guidelines for assessing the fire threat to people*~~

~~NOTE ISO 9122-1:1989, *Toxicity testing of fire effluents – Part 1: General*, has been withdrawn and replaced by ISO 19706:2007.~~

~~ASTM E 1354:2008, *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter*~~

~~EN 13823:2002, *Reaction to fire tests for building products – Building products, excluding floorings, exposed to thermal attack by a single burning item*~~

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO~~/IEC~~ 13943:2017 and IEC 60695-4, some of which are reproduced below, apply.

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

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

~~**3.1.1**~~
~~**combustion**~~
~~exothermic reaction of a substance with an oxidizing agent~~

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

~~[ISO/IEC 13943, definition 4.46]~~

~~**3.1.4**~~
~~**fire**~~
~~⟨general⟩ process of combustion characterized by the emission of heat and fire effluent and usually accompanied by smoke, flame or glowing or a combination thereof~~

~~NOTE In the English language the term "fire" is used to designate three concepts, two of which, fire (3.1.5) and fire (3.1.6), 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]~~

~~**3.1.5**~~
~~**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]~~

~~**3.1.6**~~
~~**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]~~

~~**3.1.7**~~
~~**fire effluent**~~
~~totality of gases and aerosols, including suspended particles, created by combustion or pyrolysis in a fire~~

~~[ISO/IEC 13943, definition 4.105]~~

~~**3.1.8**~~
~~**fire hazard**~~
~~physical object or condition with a potential for an undesirable consequence from fire~~

~~[ISO/IEC 13943, definition 4.112]~~

~~**3.1.9**~~
~~**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]~~

~~**3.1.10**~~
~~**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]~~

~~**3.1.11**~~
~~**flashover**~~
~~⟨stage of fire⟩ transition to a state of total surface involvement in a fire of combustible materials within an enclosure~~

~~[ISO/IEC 13943, definition 4.156]~~

~~**3.1.12**~~
~~**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 ($W \cdot m^{-2}$).~~

~~[ISO/IEC 13943, definition 4.173]~~

~~**3.1.13**~~
~~**ignition**~~
~~sustained ignition (deprecated)~~

~~⟨general⟩ initiation of combustion~~

~~[ISO/IEC 13943, definition 4.187]~~

~~**3.1.14**~~
~~**ignition**~~
~~sustained ignition (deprecated)~~

~~⟨flaming combustion⟩ initiation of sustained flame~~

~~[ISO/IEC 13943, definition 4.188]~~

~~**3.1.15**~~
~~**large-scale fire test**~~
~~fire test, that cannot be carried out in a typical laboratory chamber, performed on a test specimen of large dimensions~~

~~NOTE A fire test performed on a test specimen of which the maximum dimension is greater than 3 m is usually called a large-scale fire test.~~

~~[ISO/IEC 13943, definition 4.205]~~

~~**3.1.20**~~
~~**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]~~

~~**3.1.21**~~
~~**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]~~

3.1.1
extinction area of smoke
product of the volume occupied by *smoke* (3.1.10) and the *extinction coefficient* (3.1.2) of the smoke

Note 1 to entry: The extinction area of smoke is a measure of the amount of smoke. The typical unit is m^2.

[SOURCE: ISO ~~/IEC~~ 13943:2017, ~~definition 4.92~~ 3.110]

3.1.2
extinction coefficient
natural logarithm of the ratio of incident light intensity to transmitted light intensity, per unit light path length

Note 1 to entry: The typical unit is m^{-1}.

[SOURCE: ISO ~~/IEC~~ 13943:2017, ~~definition 4.93~~ 3.111]

3.1.3
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~~

optical density of smoke (3.1.6) multiplied by a factor which is the volume of the test chamber divided by the product of the mass lost from the test specimen and the light path length

Note 1 to entry: The typical unit is $m^2 \cdot g^{-1}$.

Note 2 to entry: Optical density of smoke = $V/(\Delta m\ L)$, where V is test chamber volume, Δm is test specimen mass loss and L is light path length.

[SOURCE: ISO ~~/IEC~~ 13943:2017, ~~definition 4.225~~ 3.265]

3.1.4
obscuration ~~by~~ of smoke

reduction in the intensity of light due to its passage through *smoke* (3.1.10)

~~cf. **extinction area of smoke** (3.1.2) and **specific extinction area of smoke** (3.1.26).~~

Note 1 to entry: Compare with the terms *extinction area of smoke* (3.1.1), *extinction coefficient* (3.1.2), *opacity of smoke* (3.1.5), *optical density of smoke* (3.1.6), *smoke obscuration* (3.1.11), *specific extinction area of smoke* (3.1.13) and *specific optical density of smoke* (3.1.14).

Note 2 to entry: In practice, obscuration ~~by~~ of smoke is usually measured as the transmittance which is normally expressed as a percentage.

Note 3 to entry: The obscuration ~~by~~ of smoke causes a reduction in *visibility* (3.1.6).

[SOURCE: ISO ~~/IEC~~ 13943:2017, ~~definition 4.242~~ 3.286]

3.1.5
opacity of smoke

ratio of incident light intensity to transmitted light intensity through *smoke* (3.1.10), under specified conditions

~~cf. **obscuration by smoke** (3.1.17).~~

Note 1 to entry: Also, *obscuration of smoke* (3.1.4), *smoke obscuration* (3.1.11).

Note 2 to entry: The opacity of smoke is the reciprocal of transmittance.

Note 3 to entry: The opacity of smoke is dimensionless.

[SOURCE: ISO ~~/IEC~~ 13943:2017, ~~definition 4.243~~ 3.287]

3.1.6
optical density of smoke

measure of the attenuation of a light beam passing through *smoke* (3.1.10) expressed as the logarithm to the base 10 of the *opacity of smoke* (3.1.5)

Note 1 to entry: Compare with the term *specific optical density of smoke* (3.1.14).

Note 2 to entry: The optical density of smoke is dimensionless.

[SOURCE: ISO ~~/IEC~~ 13943:2017, ~~definition 4.244~~ 3.288]

3.1.7
physical fire model

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

[SOURCE: ISO 13943:2017, 3.298]

3.1.8
SMOGRA
smoke growth rate parameter that is a function of the rate of smoke production and the time of smoke production

Note 1 to entry: Further details are given in 6.2.4.

3.1.9
SMOGRA index
maximum value of *SMOGRA* (3.1.8) during a defined test period

Note 1 to entry: Further details are given in 6.2.4.

3.1.10
smoke
visible part of a fire effluent

[SOURCE: ISO ~~/IEC~~ 13943:2017, ~~definition 4.293~~ 3.347]

3.1.11
smoke obscuration
reduction of light transmission by *smoke* (3.1.10), as measured by light attenuation

Note 1 to entry: Compare with the terms *extinction area of smoke* (3.1.1), *extinction coefficient* (3.1.2), *obscuration of smoke* (3.1.4), *opacity of smoke* (3.1.5), *optical density of smoke* (3.1.6), *specific extinction area of smoke* (3.1.13) and *specific optical density of smoke* (3.1.14).

[SOURCE: ISO 13943:2017, 3.349]

3.1.12
smoke production rate
amount of *smoke* (3.1.10) produced per unit time in a fire or fire test

Note 1 to entry: The smoke production rate is calculated as the product of the volumetric flow rate of *smoke* (3.1.10) and the *extinction coefficient* (3.1.2) of the smoke at the point of measurement.

Note 2 to entry: The typical unit is $m^2 \cdot s^{-1}$.

[SOURCE: ISO ~~/IEC~~ 13943:2017, ~~definition 4.295~~ 3.351]

3.1.13
specific extinction area of smoke
extinction area of smoke (3.1.1) 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 1 to entry: The typical unit is $m^2 \cdot g^{-1}$.

[SOURCE: ISO ~~/IEC~~ 13943:2017, ~~definition 4.301~~ 3.358]

3.1.14
specific optical density of smoke
optical density of smoke (3.1.6) multiplied by a geometric factor

Note 1 to entry: The geometric factor is ~~equal to~~ $V/(A \cdot L)$, 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 to entry: 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 to entry: The specific optical density of smoke is dimensionless.

[SOURCE: ISO ~~/IEC~~ 13943:2017, ~~definition 4.303~~ 3.360]

3.1.15
visibility
maximum distance at which an object of defined size, brightness and contrast can be seen and recognized

[SOURCE: ISO ~~/IEC~~ 13943:2017, ~~definition 4.350~~ 3.420]

3.2 Symbols

Symbol	Quantity	Typical units
A	exposed area of test specimen	m^2
D	linear decadic absorption coefficient (commonly called optical density per metre)	m^{-1}
D'	*optical density of smoke*	dimensionless
D_{mass}	*mass optical density of smoke*	$m^2\ kg^{-1}$
D_s	*specific optical density of smoke*	dimensionless
D_{max} (also D_m)	maximum *specific optical density of smoke*	dimensionless
I	intensity of incident light	~~W~~ cd
I/T	*opacity of smoke* (ratio of incident light to transmitted light)	dimensionless
k	linear Napierian absorption coefficient (commonly called *extinction coefficient*)	m^{-1}
L	light path length through *smoke*	m
Δm	mass loss of test specimen	kg
$\dot{m}$	mass loss rate	$kg\ s^{-1}$
S	*extinction area of smoke (also total smoke)*	m^2
$\dot{S}$	*smoke production rate* (rate of change of extinction area)	$m^2\ s^{-1}$
t	time	s
Δt	sampling time interval	s
T	intensity of transmitted light	~~W~~ cd
V	volume of chamber	m^3
$\dot{V}$	volume flow rate of *smoke*	$m^3\ s^{-1}$
σ_f	*specific extinction area of smoke*	$m^2\ kg^{-1}$
γ	a constant of proportionality between *visibility* and *extinction coefficient*	dimensionless
ω	*visibility*	m

NOTE 1 The quantities based on $\log_{10}$, i.e. D, D', D_{max}, D_{mass} and D_s, have similar symbols but they are different quantities and have different units.

NOTE 2 The use of the term "specific" in the case of *specific optical density of smoke*, D_s, does not denote "per unit mass".

4 General aspects of smoke test methods

4.1 Fire scenarios and physical fire models

During recent years, major advances have been made in the analysis of fire effluents. It is recognized that the composition of the mixture of combustion products is particularly dependent upon the nature of the combusting materials, the prevailing temperatures and ventilation conditions, especially access of oxygen to the seat of the fire. Table 1 shows how the different types of fire relate to the changing atmosphere. Conditions for use in laboratory tests (small or large-scale) can be derived from the table in order to correspond, as far as possible, to real-scale fires.

Fire involves a complex and interrelated array of physical and chemical phenomena. As a result, it is difficult to simulate all aspects of a real-scale fire in a smaller scale apparatus. This problem of *physical fire model* validity is perhaps the single most perplexing technical problem associated with all fire testing.

General guidance for assessing the fire hazard of electrotechnical products is given in IEC 60695-1-10 and IEC 60695-1-11.

After ignition, fire development may occur in different ways depending on the environmental conditions, as well as on the physical arrangement of the combustible materials. However, a general pattern can be established for fire development within a compartment, where the general temperature-time curve shows three stages, plus a decay stage (see Figure 1).

Stage 1 is the incipient stage of the fire prior to sustained flaming, with little rise in the fire room temperature. Ignition and *smoke* generation are the main hazards during this stage. Stage 2 (developing fire) starts with ignition and ends with an exponential rise in the fire room temperature. Spread of flame and heat release are the main hazards in addition to *smoke* during this stage. Stage 3 (fully developed fire) starts when the surface of all of the combustible contents of the room has decomposed to such an extent that sudden ignition occurs all over the room, with a rapid and large increase in temperature (flash-over).

At the end of stage 3, the combustibles and/or oxygen have been largely consumed and hence the temperature decreases at a rate which depends on the ventilation and the heat and mass transfer characteristics of the system. This is known as decay.

In each of these stages, a different mixture of decomposition products may be formed and this, in turn, influences the *smoke* ~~density~~ produced during that stage. ~~Moreover~~ In order to select an appropriate fire test, information is required on the fire scenario being considered, in particular the conditions of incident heat flux, oxygen availability and the facilities for venting the *smoke*.

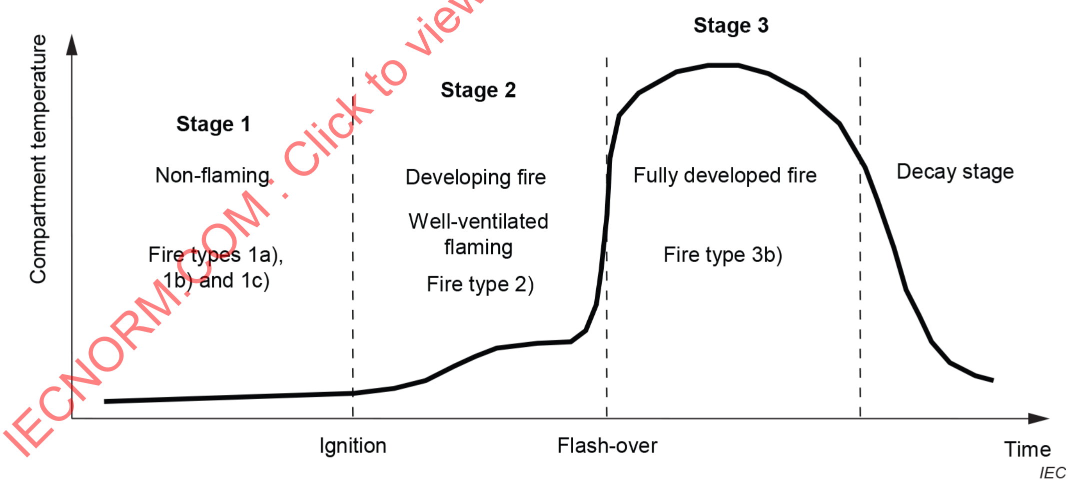

Figure 1 – Different phases in the development of a fire within a compartment

4.2 Factors affecting smoke production

4.2.1 General

Many factors affect the production of *smoke* and the properties of *smoke*. A full description of such properties is not possible, but the influence of several important variables is recognized.

4.2.2 Modes of decomposition

Smoke is a consequence of combustion. Combustion may be flaming or non-flaming, including smouldering, and these different modes of combustion may produce quite different types of *smoke*. In non-flaming combustion, volatiles are evolved at elevated temperatures. When they mix with cool air, they condense to form spherical droplets which appear as a light-coloured *smoke* aerosol.

Flaming combustion produces a black carbon-rich *smoke* in which the particles have a very irregular shape. The *smoke* particles from flaming combustion are formed in the gas phase and in regions where oxygen concentrations are low enough to cause incomplete combustion. The carbonaceous *smoke* particles in the flames emit radiant energy (as black-body emission) which is seen as yellow luminosity.

The particle size of the spherical droplets from non-flaming combustion is generally of the order of 1 µm, whereas the size of the irregular soot particles from flaming combustion is often larger but much harder to determine and is dependent on the measuring technique.

It is often observed for wood fires that the amount of *smoke* is less with flaming combustion than with non-flaming combustion. For plastics, however, no such generalization can be made: the *smoke* produced under non-flaming conditions can be less or more than under flaming conditions. For these reasons, it is important to record in a *smoke* test whether ignition occurs, as well as the times of ignition and extinction of flames on the test specimen. In addition, cold *smoke* may be generated from the rear of composites; this may differ substantially in colour and composition from the *smoke* produced from the exposed surface.

Table 1 – Characteristics of fire stages (from Table 1 in ISO 19706:2011) [4]

Fire stage	Heat flux to fuel surface kW/m2	Max. temperature °C		Oxygen volume %		Fuel/air equivalence ratio (plume)	$\frac{[CO]}{[CO_2]}$ v/v	$\frac{100 \times [CO_2]}{([CO_2]+[CO])}$ % efficiency
		Fuel surface	Upper layer	Entrained	Exhausted			
1. Non-flaming								
a. self-sustaining (smouldering)	not applicable	450 to 800	25 to 85 [d]	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. Underventilated 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

4 *The Table 1 — Characteristics of fire stages taken from ISO 19706:2011, Guidelines for assessing the fire threat to people*, is reproduced with the permission of the International Organization for Standardization, ISO. This standard can be obtained from any ISO member and from the website of the ISO Central Secretariat at the following address: www.iso.org. Copyright remains with ISO.

[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~~ can 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.

The heat flux on the test specimen influences how the material burns; it is good practice to evaluate the *smoke* generated from materials at low levels of incident irradiance (e.g. 15 kW·m^{-2} to 25 kW·m^{-2}) as well as at higher levels (e.g. 40 kW·m^{-2} to 50 kW·m^{-2}). In this way, the effects of the growth phases of a fire on the smoke-generating propensity of a material can be assessed.

4.2.3 Ventilation and the burning environment

Smoke production depends upon the fire scenario and not just on what material is being burnt. It is known that, for some materials, the production of *smoke* is increased considerably by restricted ventilation.

The rate of burning and the area involved in burning should always be considered when determining *smoke* production in fires. A material generating small quantities of *smoke* per element of burning area may give large quantities of *smoke* in a fire due to the rapid spread of flames over large surface areas.

4.2.4 Time and temperature

The particle size distribution of *smoke* aerosols changes with time; *smoke* particles coagulate as they age. Some properties also change with temperature so that the properties of aged, or cold *smoke* may be different from young, hot *smoke*. These factors are important for fire engineers when they are considering potential *smoke* movement in large buildings. These factors also have to be considered when designing *smoke* tests.

NOTE Guidance on fire safety engineering is given in IEC 60695-1-12 [1].

4.2.5 Removal mechanisms for smoke particles

Large *smoke* particles may be removed by a number of mechanisms. In cumulative test procedures where a radiant heat source is immersed in the combustion gases, reheated decomposition may occur as the *smoke* particles recirculate. Other mechanisms for removal of larger particles include the deposition of particles on the internal surfaces of the chamber and the action of fan stirrers. Aspects of these mechanisms also occur in real fires when *smoke* circulates within a fire compartment. Because these effects are possible in cumulative *smoke* tests, it is recognized that the early stages of the exposure (for example the first 10 min) are the most relevant for the determination of the rate of *smoke* generation.

5 Principles of smoke measurement

5.1 General

Smoke consists of an aerosol of particles. It can either be measured as a function of its gravimetric properties (the mass of *smoke* particles), its light-obscuring properties, or a mixture of the two [3]. This document is concerned with the reduction of *visibility* caused by the *obscuration* of ~~visibility~~ *smoke* and therefore gravimetric methods are not discussed. Obscuring properties are a function of the number, size and nature of the particles in the light path. If the particles are considered as opaque, the capacity of the *smoke* to obscure light is related to the sum of the cross-sectional areas of the particles in the light path. It is measured in units of area, e.g. square metres (m^2).

The measurements may be made in small-, large-, or real-scale tests. They may be performed in closed systems which are called cumulative or static methods. They may also be performed in flow-through systems, and these are called dynamic methods.

5.2 Bouguer's law

Optical *smoke* measurements are derived from Bouguer's law which describes the attenuation of monochromatic light by an absorbing medium:

$$I/T = e^{kL} \quad (1)$$

$$k = (1/L)\ln(I/T) \quad (2)$$

(The units of k are reciprocal length, e.g. m^{-1})

where

T is the intensity of transmitted light;

I is the intensity of incident light;

L is the light path length through the *smoke*;

k is the linear Napierian absorption coefficient (*extinction coefficient*), see Figure 2.

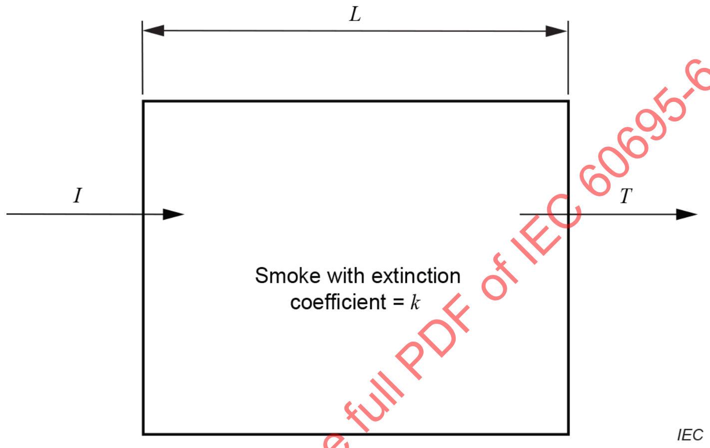

Figure 2 – Attenuation of light by smoke

5.3 Extinction area

A useful measurement of the amount of *smoke* is the total effective cross-sectional area of all the *smoke* particles. This area is known as the *extinction area of smoke*, S. ~~The extinction area~~ This can be thought of as the total area of the shadows cast by the *smoke* particles in a beam of light (see Figure 3).

If the smoke is homogeneous, i.e. not layered, the *extinction area of smoke* is related both to the *extinction coefficient* of the *smoke* and to the volume in which the *smoke* is contained by the equation:

$$S = kV \quad (3)$$

where V is the volume of the chamber in which the *smoke* is contained.

~~This equation only applies if the smoke is homogeneous.~~

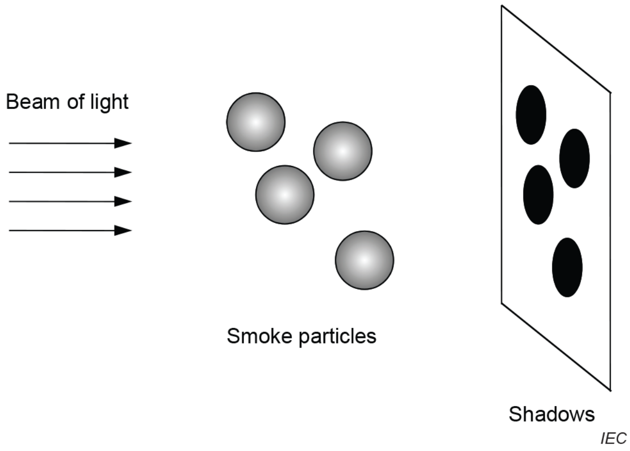

Figure 3 – Extinction area

5.4 Log$_{10}$ units

In some studies, base 10 logarithms are used to calculate the optical density per unit light path length, (D), which is properly named the linear decadic absorption coefficient and, like k (linear Napierian absorption coefficient), also has units of reciprocal length (e.g. m^{-1}).

$$I / T = 10^{DL} \tag{4}$$

$$D = (1/L) \log_{10}(I/T) \tag{5}$$

$$k = D \ln(10) \quad \text{or} \quad k = 2{,}303\, D \tag{6}$$

The *extinction area of smoke* (S) can also be calculated from D using the equation:

$$S = 2{,}303\, DV \tag{7}$$

Several variants of base 10 units can be found in the literature. A commonly used quantity is the dimensionless *optical density of smoke*, $D' = \log_{10}(I/T)$. For a given amount of *smoke*, D' is proportional to the light path length and is thus apparatus-dependent; results from one apparatus cannot be directly compared to results from other apparatus.

5.5 Light sources

Both white light and monochromatic laser light sources are used for *smoke* measurement.

Since light attenuation through *smoke* is dependent on the absorption and scattering of light, and since the latter is dependent on wavelength, caution should be exercised when comparing data obtained from measuring systems using different light sources.

5.6 *Specific extinction area of smoke*

In tests where the mass loss of the test specimen is measured, the *specific extinction area of smoke*, σ_f, can be calculated:

$$\sigma_f = S / \Delta m \tag{8}$$

where Δm is the mass loss of the test specimen.

The units of σ_f are area/mass, e.g. $m^2 \cdot kg^{-1}$.

The *specific extinction area* *of smoke*, σ_f, is a basic measurement of *smoke* that can be made in all scales of tests. It is independent of

– the light path length over which the measurement is taken;
– the flow rate of gases;
– the surface area of the exposed product; and
– the mass of the test specimen.

The *specific extinction area* *of smoke*, σ_f, is used to define the smoke-producing capacity of a unit mass loss of the test specimen.

For example, consider an 80 g test specimen that is tested under non-flaming conditions. It loses 50 g of mass leaving a residue of 30 g. The *smoke* produced from the 50 g of volatile pyrolysis products has an extinction area of 4 m^2. The σ_f value will therefore be 0,08 $m^2 \cdot g^{-1}$. Suppose that the same test specimen is tested under flaming conditions and that it loses 60 g of mass leaving 20 g of residue. The *smoke* produced from the combustion of the 60 g of volatile degradation products has an extinction area of 30 m^2. The σ_f value in this case will be 0,5 $m^2 \cdot g^{-1}$.

It is important to realise that σ_f does not give information on either the amount of *smoke* generated in a fire or the rate of *smoke* generation in a fire. ~~To obtain this information,~~ Either the mass loss of the test specimen (Δm) or the mass loss rate of the test specimen ($\dot{m}$) ~~must also be known~~ is necessary to obtain the information. Then, the extinction area of the *smoke* generated is given by:

$$S = \sigma_f \Delta m \tag{9}$$

In dynamic systems (see 6.2), the specific extinction area may be obtained from:

$$\sigma_f = k\dot{V} / \dot{m} \tag{10}$$

where

$\dot{V}$ is the volume flow rate;

$\dot{m}$ is the mass loss rate;

and the smoke production rate, $\dot{S}$, is given by:

$$\dot{S} = \sigma_f \dot{m} \tag{11}$$

5.7 *Mass optical density of smoke*

When working in $\log_{10}$ units the equivalent variable to σ_f is called the *mass optical density of smoke* (D_{mass}) and is related to σ_f as follows:

$$D_{mass} = \sigma_f / \ln(10) = \sigma_f / 2,303 \tag{12}$$

The unit of D_{mass} is area per mass, e.g. m^2 kg^{-1}.

In static systems (see 6.1):

$$D_{mass} = D' \cdot V / (\Delta m \cdot L) \tag{13}$$

where

D_{mass} is the *mass optical density* of smoke;

D' is the *optical density* of smoke;

V is the volume of the chamber;

Δm is the mass loss of the test specimen;

L is the light path length.

In dynamic systems, the *mass optical density* of smoke can be obtained from:

$$D_{mass} = D\dot{V} / \dot{m} \tag{14}$$

5.8 *Visibility*

If the constant of proportionality (γ) between *visibility* (ω) and k (or D) is known, then *visibility* can be readily calculated if the amount of *smoke* (extinction area) is known and if the volume occupied by the *smoke* is also known.

$$\omega = \gamma (V/S) \tag{15}$$

and $$\gamma = \omega k = 2{,}303 \omega D \tag{16}$$

The calculation of *visibility* is described in more detail in Annex A, and examples of the relationships between *smoke* parameters measured in various tests, using various measurement units, are given in Annex B and Annex C.

6 Static and dynamic methods

6.1 Static methods

6.1.1 Principles

In a static *smoke* test, the test specimen burns in a closed chamber and the *smoke* produced builds up over time. In some tests, a fan stirs the *smoke* to prevent layering and to make it homogeneous. The amount of *smoke* is measured by monitoring the attenuation of a light beam shining through the *smoke*.

6.1.2 *Extinction area* of smoke

The *extinction area of smoke* is a useful measure of the amount of *smoke* produced, and is a function of the *opacity of smoke*, (I/T), the volume of the chamber, V, and the light path length, L.

$$S = (V/L) \ln(I/T) \tag{17}$$

This equation only applies if the *smoke* is homogeneous. The units of extinction area are typically square metres (m^2).

See Annex C for relationships between per cent transmission, as measured in a "three metre cube" enclosure, and extinction area.

6.1.3 *Specific optical density of smoke*

In some tests, ~~including IEC 60695-6-30 and~~ e.g. ISO 5659-2 [4], the amount of *smoke* is calculated from the optical density of the *smoke*, and it is normalised to the surface area of the test specimen, A. The quantity calculated is D_s, the *specific optical density of smoke*.

$$D_s = [V/AL]\log_{10}(I/T) \tag{18}$$

The thickness of the test specimen will affect the amount of *smoke* produced. D_s values should not be directly compared for test specimens of different thicknesses. Conversely, if comparisons are made, then the test specimen thickness ~~should~~ shall be kept constant.

See Annex B for relationships between D_s and some other smoke parameters as measured in ISO 5659-2 [4].

6.1.4 Prediction of *visibility*

The purpose of measuring D_s (or S) is to enable the prediction of *visibility*. However, the *visibility* within the test chamber is not usually what is required to be known. What is required is an estimation of *visibility* in a given fire scenario. It is possible to make such estimations based on data obtained in static tests such as ~~IEC 60695-6-30~~ ISO 5659-2 [4] but it ~~must~~ has to be appreciated that such calculations are only estimates, as changing the *physical fire model* will probably change both the *smoke* production process and the way in which the *smoke* will age.

6.2 Dynamic methods

6.2.1 Principles

In dynamic tests, the *smoke* from the test specimen is drawn through an exhaust system at a measured flow rate and the *opacity of* ~~the~~ *smoke* ~~stream~~ is measured at regular intervals by monitoring the transmitted intensity of a light beam shining through the *smoke* (see Figure 4). The flow rate of the smoke is measured at a position close to where the *opacity of smoke* is measured.

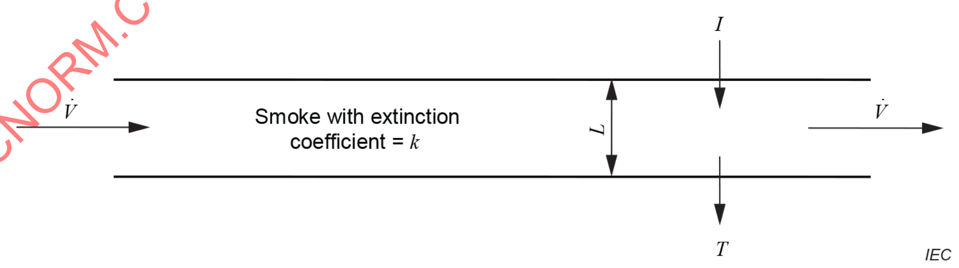

Figure 4 – Dynamic smoke measurement

6.2.2 Smoke production rate

The *smoke production rate* at any given moment ($\dot{S}$) is calculated using the equation:

$$\dot{S} = k\dot{V} \tag{19}$$

where

$\dot{V}$ is the volume flow rate of the exhaust gases;

$\dot{S}$ has units of area/time, e.g. $m^2 \cdot s^{-1}$.

The *smoke production rate* is readily ascertained in dynamic systems. It expresses the *extinction area of smoke* produced per unit time.

$$\dot{S} = k\dot{V} = (1/L)\ln(I/T)\dot{V} \quad (20)$$

When the exposed test specimen area involved is known, as in the cone calorimeter ASTM E1354 [5] and ISO 5660 [6], or in furniture calorimeters, the *smoke production rate* can be normalized per unit area of the exposed test specimen. The units then become reciprocal time, e.g. $(m^2/s)/m^2$, i.e. s^{-1}.

6.2.3 Total smoke production

Integrated data ~~on~~ to give *total smoke production* is also of interest, especially when comparing materials or scenarios which may produce *smoke* for unequal periods of time. *Total smoke production* is measured as the extinction area produced in the defined time interval and is given by:

$$S = \int \dot{S}.\mathrm{d}t \quad (21)$$

where

S is the *total smoke production*, i.e. the total *extinction area of smoke*;

t is the time.

The time over which the summation is performed should be specified. In the cone calorimeter, this is to the end of the test, which, in simple cases, is when the mass loss rate per unit area of the test specimen has reached a specified value (for example 25 $g \cdot m^{-2} \cdot s^{-1}$). The *total smoke production* may be expressed per unit of burning area if this is known.

The *total smoke production* from a burning test specimen, measured in a closed system, will often be substantially less than the *total smoke production* from a similar burning test measured in a dynamic system. This is because measurements in static systems are more influenced by losses due to ageing and deposition or interaction at the chamber walls.

6.2.4 SMOGRA index

SMOGRA is an abbreviation for smoke growth rate. *SMOGRA* values are affected by both the *smoke production rate* and the time at which the *smoke* is being produced, and are calculated using the following formula:

$$\text{SMOGRA} = 10\,000 \times [SPR_{\text{av}}(t) / (t - t_0)] \quad (22)$$

where

$SPR_{\text{av}}(t)$ is the *smoke production rate* at time t, and

t_0 is the time at which the test specimen is first exposed to the test flame.

The *SMOGRA index* is defined as the maximum value of the function during the time period of the test. The *SMOGRA index* was devised in the development of EN 13823 [7], which is an intermediate scale corner test used for the regulation of building products in Europe. As a single value parameter for regulatory purposes, some consider that the *SMOGRA index* gives a better indication of the severity of smoke production than either *total smoke production* or the average *smoke production rate*.

NOTE In EN 13823 the SPR value is a 60 s moving average, and the start of exposure of the test specimen to the test flame is at t = 300 s.

Figure 5 shows an example SPR_{av} versus t curve, and Figure 6 shows the *SMOGRA* curve derived from these data. The peak *smoke production rate* is 0,5 $m^2 \cdot s^{-1}$ at t = 960 s, and the *SMOGRA index* is 8,2 $m^2 \cdot s^{-2}$ at t = 857 s.

The *SMOGRA index* may be a useful parameter for assessing smoke hazard because it combines the *smoke production rate* with the time elapsed to reach it. Note that the *SMOGRA index* always refers to a time shorter than the time of maximum smoke production (in the given curves, 857 s compared to 960 s).

However, the *SMOGRA index* should be treated with extreme caution in cases where there is an early rapid but low smoke production. In such cases, the *SMOGRA* value at small $t - t_0$ values may be larger than values calculated from the significant part of the curve and the obtained *SMOGRA index* may be both irrelevant and misleading.

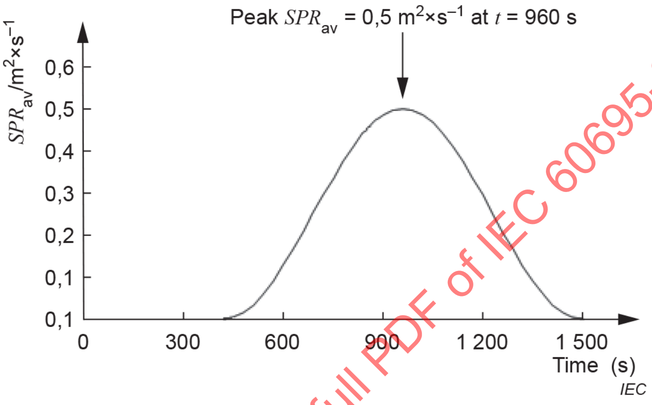

Figure 5 – Example SPR_{av} versus t curve

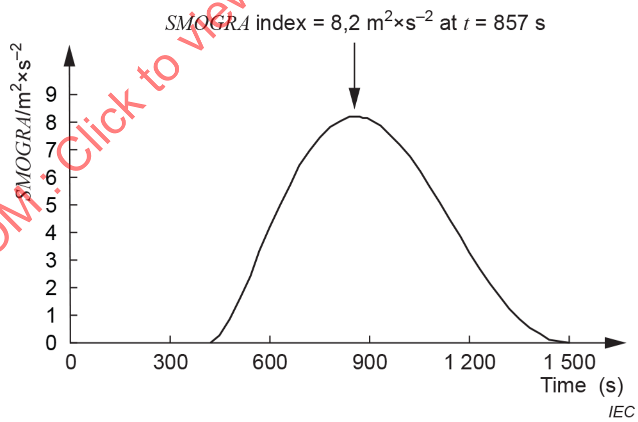

Figure 6 – *SMOGRA* curve derived from Figure 5

7 Test methods

7.1 Consideration of test methods

It is important to consider the *physical fire model* or models most relevant to the hazard being assessed, and to select tests which have *physical fire models* similar to those being assessed (see IEC 60695-6-2).

In the selection of test methods, the following questions should be asked of each method under consideration:

- can the test accommodate the geometry and configuration of the product in question?
- does the test method replicate the stage of fire of interest?
- does the test give data in an appropriate format, and with sufficient discrimination and resolution?

If the answer to any of these questions is no, the method under consideration ~~will need modification,~~ shall either be modified or an alternative method shall be considered. The test method(s) selected shall be relevant to the fire scenario of concern.

In cases where fire tests are not yet specified, and need to be developed or altered for the special purpose of an IEC technical committee, this shall be done in liaison with IEC technical committee 89.

A flow chart outlining the stages to be followed in assessing the suitability of an existing method for a new application is shown in Figure 7.

7.2 Selection of test specimen

Different types of test specimens may be tested. In product testing, the test specimen is a manufactured product. In simulated product testing, the test specimen is representative of a portion of a product. The test specimen may also be a basic material (solid or liquid) or a composite of materials.

The nature of the test specimen is governed to a large extent by the scale of the *smoke* test. Small-scale tests are suited more to the testing of materials and small products, or of representative test specimens of larger products. On a larger scale, whole products may be tested. Given the choice, it is always preferable to select a test specimen that most closely reflects end use.

8 Presentation of data

There are many different ways of presenting *smoke* data. This makes it difficult, and sometimes impossible, to make comparisons between *smoke* data from different tests. It also makes it difficult to relate the results of tests to a measure of the fire hazard presented by the material or by the product being tested. To help overcome these problems, it is recommended that, wherever possible, *smoke* data should be reported in terms of the *extinction area of smoke*. All other relevant parameters shall be reported. These include full details of the nature of the test specimen, the conditions of the test and any observations of unusual behaviour.

Normalized *smoke* data are often reported, e.g. *smoke* production per unit mass and *smoke* production per unit surface area. When this is the case, it is important that the primary data (i.e. before being normalized) should also be reported.

9 Relevance of data to hazard assessment

Realistic assessments of the fire performance of a product can only be obtained by testing a real-scale test specimen in the form and orientation in which it is actually used. An isolated small-scale test, not representative of the final use of the product, can only indicate the response of a product to the *physical fire model* selected. It is emphasized that no fire or *smoke* test can, in normal circumstances, measure fire or *smoke* hazard; in addition, it cannot be assumed that satisfactory results of a single standard fire or *smoke* test will guarantee a given level of safety. Results from a variety of fire tests will provide information to assist in the determination and subsequent control of fire and *smoke* hazards.

The potential hazard due to the *obscuration of* ~~light~~ *smoke* caused by ~~smoke production from~~ burning material depends on a number of factors. These include:

– the *total smoke* produced;

– the *specific extinction area of smoke*, i.e. the amount of *smoke* produced per unit mass loss of the burning material;

– the mass loss rate of the burning material (this will depend on how much material is involved in the fire, and on how easily it burns);

– the *smoke production rate* (this is the product of the above two quantities);

– the volume into which the *smoke* is spreading.

There are many other factors associated with *visibility* in an escape route, including:

– size, luminance, contrast and intensity of a light-emitting sign;

– size and contrast of reflecting objects;

– presence of external illumination;

and human response factors, including

– visual acuity;

– dark adaptation;

– irritancy.

It follows, therefore, that just considering the *smoke* producing potential of a unit mass or unit area of a material is not sufficient to enable a hazard assessment to be made. A material with a high *specific extinction area of smoke* or a high D_s value may not present a hazard if the amount of material present in the hazard scenario is small, and/or if the volume into which the *smoke* can spread is large. Similarly, a material with a low *specific extinction area of smoke* or a low D_s value may present a hazard if the amount of material present in the hazard scenario is large, and/or if the volume into which the *smoke* can spread is small.

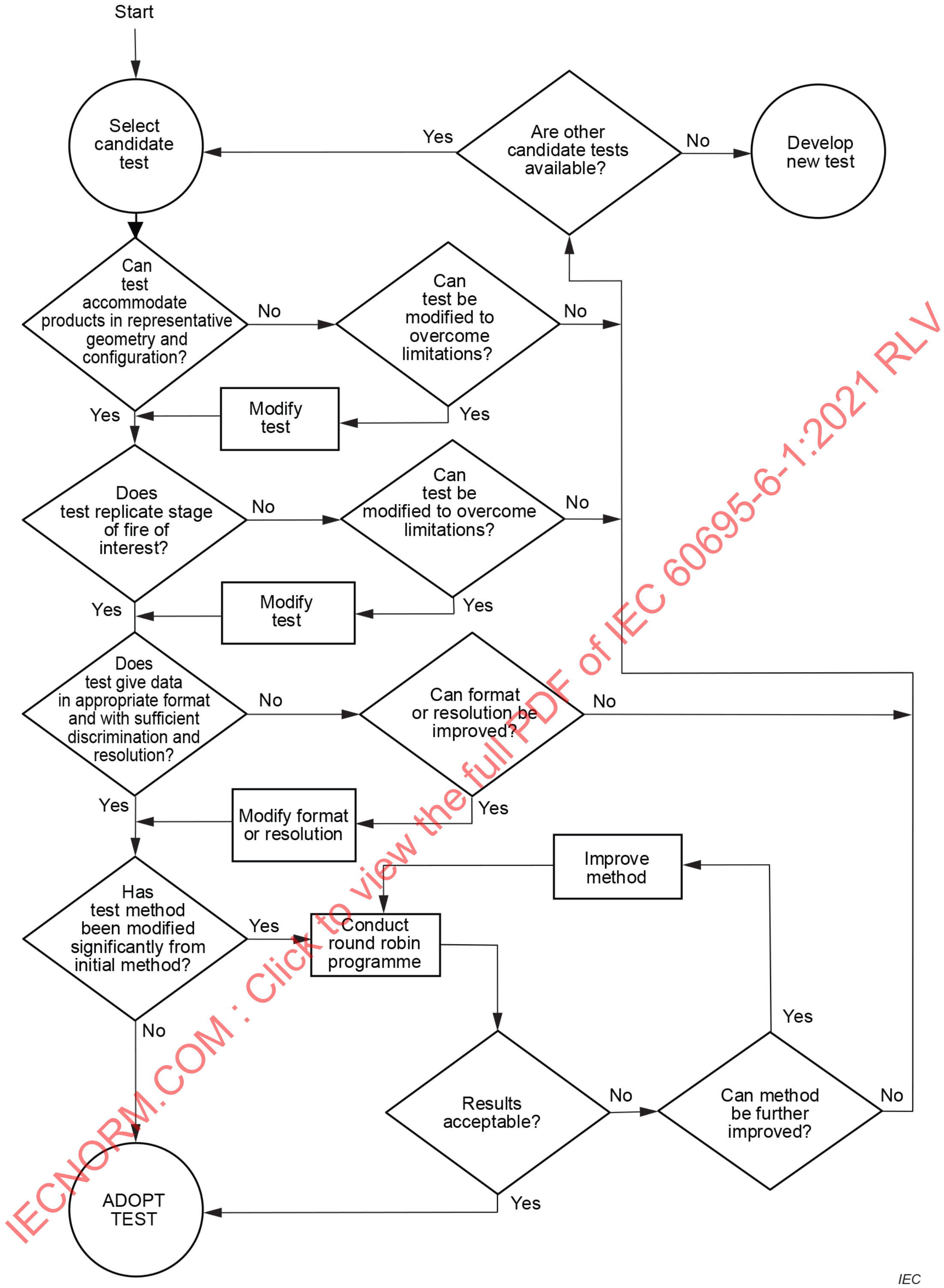

Figure 7 – Evaluation and consideration of smoke test methods

Annex A
(informative)

Calculation of *visibility*

A.1 General

Figure A.1 shows the relationships reported by Jin [8] between *visibility* and the *extinction coefficient* of the *smoke* which is causing obscuration. Two lines are shown in Figure A.1; one is for light-emitting signs and the other is for light-reflecting signs. *Visibility* is approximately inversely proportional to the *extinction coefficient*, i.e. $\omega = \gamma / k$, γ being the constant of proportionality. However, there is a considerable spread in the experimental data, and *visibility* also depends on other factors such as external illumination, the brightness of light-emitting signs, and the reflectance of light-reflecting signs. Calculations of *visibility* using this relationship should therefore only be considered as estimates.

Jin selected values for γ of 3 and 8 for light-reflecting and light-emitting signs, respectively. In BS DD240-1 [9], values of 2,30 and 5,76 ~~have been selected~~ were reported.

NOTE BS DD240-1 has been superseded and replaced by BS 7974:2001 [10].

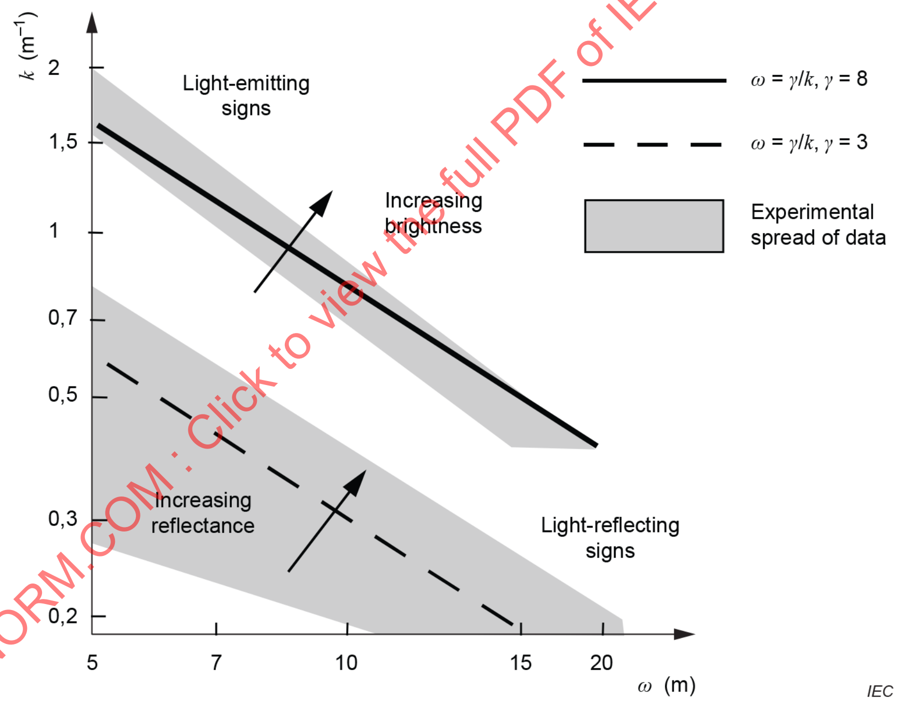

Figure A.1 – *Visibility* (ω) versus *extinction coefficient* (k)

A.2 Example

An example of a typical estimation of *visibility* is as follows.

Suppose a 10 mm thick test specimen of material is tested in an ~~IEC 60695-6-30~~ ISO 5659-2 apparatus. The maximum D_s value obtained is D_{max}. Suppose we wish to calculate an estimate of the minimum *visibility* of a light emitting sign in a room of volume V if a 10 mm thick test specimen of the material, with a surface area of A, burns in a similar manner in the room.

We know that:

$$\omega = \gamma (V/S) \quad \text{(A.1)}$$

and, for the purpose of the estimation, we assume that $\gamma = 8$ for a light-emitting sign.

We first need to calculate how much *smoke* will be produced in the postulated scenario. This is given by:

$$S = 2{,}303\, D_{max}\, A \quad \text{(A.2)}$$

so the estimated *visibility* is given by:

$$\omega = 8 \times [V / (2{,}303\, D_{max}\, A)] \quad \text{(A.3)}$$

It should be noted that such a calculation assumes that the *smoke* is homogeneous whereas in many real fires, the *smoke* tends to form in a buoyant hot layer. It is also assumed that *smoke* production varies linearly with the area of the test specimen burned. Also, no consideration of the effect of irritants is made. Some limited research suggests that eye irritants might reduce vision by 50 % up to 95 %.

Note also that the simple relationship $\omega = \gamma / k$ reported by Jin is only valid over a relatively small range of viewing distances. It also refers to the *visibility* of targets whereas the recognition of signs requires the resolution of the sign details. A more complex equation has been proposed for recognition distances in *smoke* [11] which will properly extrapolate to clear air conditions. The determination of the *visibility* of an illuminated exit sign in a corridor-like scenario has been examined by Rubini *et al.* [12].

Annex B
(informative)

Relationships between D_s and some other smoke parameters as measured in ~~IEC 60695-6-30 and IEC 60695-6-31~~ ISO 5659-2 [4]

A simple calculation can be performed to convert the *specific optical density of smoke*, D_s, as measured in ~~IEC 60695-6-30 and IEC 60695-6-31~~ ISO 5659-2, to an extinction area S.

Although such a conversion may prove to be useful to compare *smoke obscuration* data using the same units, caution should be exercised when doing so, as such a calculation does not take into account the different conditions of testing from one set of experiments to another (e.g. geometric factors of the testing chambers).

Thus, a D_s measurement, expressed in terms of S, should not be directly compared with another value of S, measured from a different testing method.

For a given test specimen surface area, the *specific optical density of smoke*, D_s, is directly proportional to the *extinction area of smoke*, S. In the case of ~~IEC 60695-6-30~~ ISO 5659-2, the exposed surface area of the test specimen is 0,004 225 m² and

$$S = (0{,}009\,73\ \text{m}^2)\ D_s \tag{B.1}$$

Table B.1 shows the relationship between the *specific optical density of smoke*, the percent transmission and the *extinction area of smoke* for ~~IEC 60695-6-30 and IEC 60695-6-31~~ ISO 5659-2 data.

Table B.1 – Conversion from D_s to some other smoke parameters as measured in ~~IEC 60695-6-30 and IEC 60695-6-31~~ ISO 5659-2

D_s	Percent transmission %	Extinction area, S m²
450	0,04	4,38
400	0,09	3,89
350	0,22	3,41
300	0,53	2,92
250	1,28	2,43
200	3,05	1,95
150	7,31	1,46
100	17,48	0,97
75	27,03	0,73
50	41,80	0,49
30	59,26	0,29
20	70,55	0,19
15	76,98	0,15
10	83,99	0,10
5	91,65	0,05
0	100,00	0,00

Figure B.1 gives a useful visual representation of the *smoke* parameters listed in Table B.1.

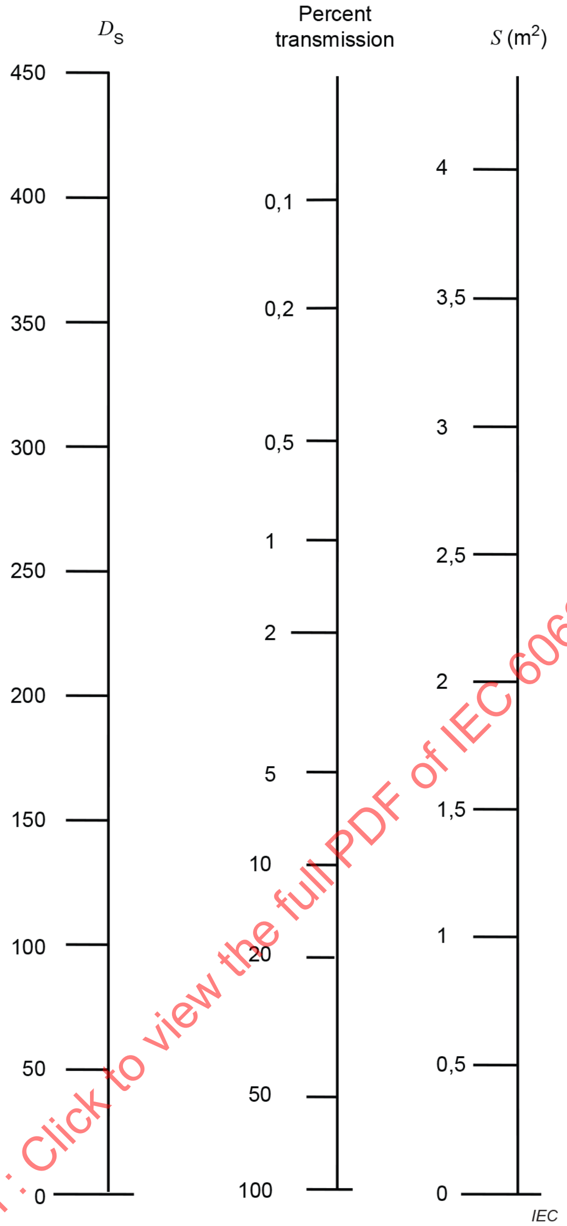

Figure B.1 – Smoke parameters related to D_s as measured in ~~IEC 60695-6-30 and IEC 60695-6-31~~ ISO 5659-2

Annex C
(informative)

Relationships between per cent transmission, as measured in a "three metre cube" enclosure, and extinction area

The test specimen is burned in a "three metre cube" enclosure and the per cent transmission of light is calculated from the ratio of the incident light to the transmitted light (I/T). The test is a static *smoke* test.

The test specified in IEC 61034-1 [13] and IEC 61034-2 [14] is a specific application of this type of test relating to cables.

Table C.1 shows the conversions between the per cent transmission and extinction area for the "three metre cube". Figure C.1 gives a useful visual representation of the *smoke* parameters listed in Table C.1.

NOTE For cables with an overall diameter above 20 mm, the recorded minimum light transmittance is a normalized value.

Table C.1 – Conversions from per cent transmission, as measured in the "three metre cube" to amount of smoke (extinction area)

Percent transmission	Amount of smoke, S m^2
0,10	62,18
0,20	55,94
0,40	49,70
1,00	41,45
2,00	35,21
4,00	28,98
5,00	26,97
10,00	20,73
15,00	17,08
20,00	14,49
30,00	10,84
40,00	8,25
50,00	6,24
60,00	4,60
70,00	3,21
80,00	2,01
90,00	0,95
100,00	0,00

~~Figure C.1 gives a useful visual representation of the smoke parameters listed in Table C.1.~~

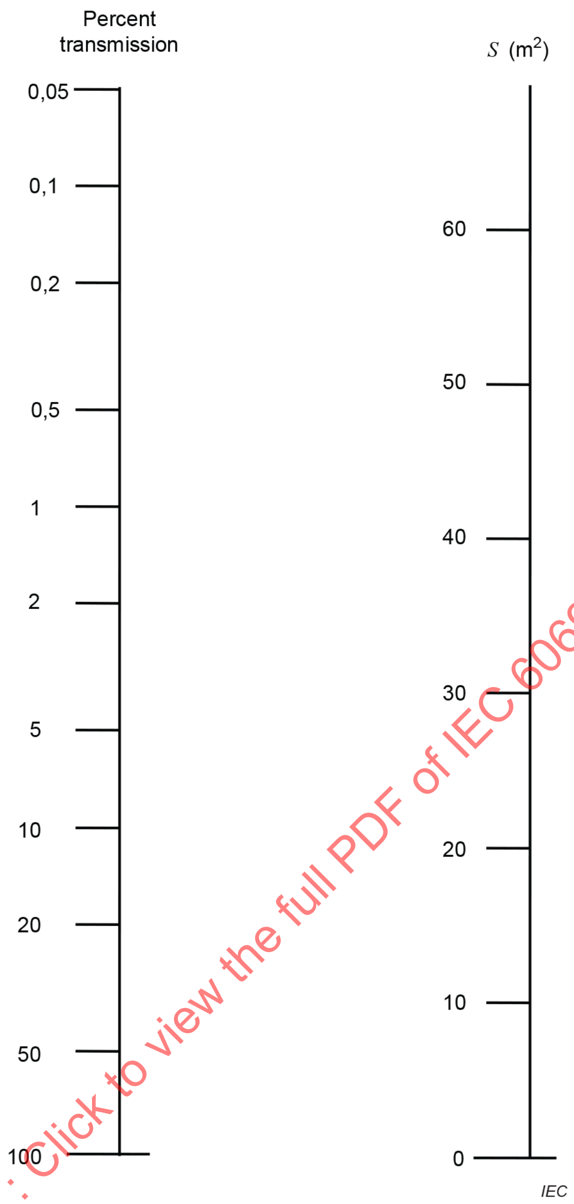

Figure C.1 – Extinction area (amount of smoke) related to per cent transmission as measured in the "three metre cube"

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[6] ISO 5660-1, *Reaction-to-fire tests – Heat release, smoke production and mass loss rate – Part 1: Heat release rate (cone calorimeter method) and smoke production rate (dynamic measurement)*

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[13] IEC 61034-1~~:1997~~, *Measurement of smoke density of cables burning under defined conditions – Part 1: Test apparatus*

[14] IEC 61034-2~~:1997~~, *Measurement of smoke density of cables burning under defined conditions – Part 2: Test procedure and requirements*

IEC 60695-6-1

Edition 3.0 2021-08

INTERNATIONAL STANDARD

NORME INTERNATIONALE

HORIZONTAL PUBLICATION
PUBLICATION HORIZONTALE

Fire hazard testing –
Part 6-1: Smoke obscuration – General guidance

Essais relatifs aux risques du feu –
Partie 6-1: Obscurcissement dû à la fumée – Recommandations générales

IEC 60695-6-1:2021-08(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

FIRE HAZARD TESTING –

Part 6-1: Smoke obscuration –
General guidance

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 60695-6-1 has been prepared by IEC technical committee 89: Fire hazard testing.

This third edition cancels and replaces the second edition of IEC 60695-6-1 published in 2005 and Amendment 1:2010. It constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

– References to IEC TS 60695-6-30 (withdrawn in 2016) have been removed.
– References to IEC TS 60695-6-31 (withdrawn in 2016) have been removed.
– References to ISO 5659-2 have been inserted.
– The scope contains some additional text.
– Terms and definitions have been updated.

– Subclause 3.2 has been updated.
– Subclause 7.1 has been updated.

The text of this International Standard is based on the following documents:

Draft	Report on voting
89/1472/CDV	89/1504/RVC

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

The language used for the development of this International Standard is English.

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

This International Standard is to be used in conjunction with IEC 60695-6-2.

In this standard, the following print types are used:

- *italic font: terms defined in Clause 3.*

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

IEC 60695-6 consists of the following parts:

Part 6-1: Smoke obscuration – General guidance

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

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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

INTRODUCTION

In the design of an electrotechnical product the risk of fire and the potential hazards associated with fire need to be considered. In this respect the objective of component, circuit and equipment design, as well as the choice of materials, is to reduce the risk of fire to a tolerable level even in the event of reasonably foreseeable (mis)use, malfunction or failure.

IEC 60695-1-10, IEC 60695-1-11, and IEC 60695-1-12 [1][1] provide guidance on how this is to be accomplished.

Fires involving electrotechnical products can also be initiated from external non-electrical sources. Considerations of this nature are dealt with in an overall fire hazard assessment.

The aim of the IEC 60695 series is to save lives and property by reducing the number of fires or reducing the consequences of the fire. This can be accomplished by:

– trying to prevent ignition caused by an electrically energised component part and, in the event of ignition, to confine any resulting fire within the bounds of the enclosure of the electrotechnical product.
– trying to minimise flame spread beyond the product's enclosure and to minimise the harmful effects of fire effluents including heat, *smoke*, and toxic or corrosive combustion products.

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.

Smoke particles reduce the *visibility* due to light absorption and scattering. Consequently, people may experience difficulties in finding exit signs, doors and windows. *Visibility* is often determined as the distance at which an object is no longer visible. It depends on many factors, but close relationships have been established between *visibility* and the measurements of the *extinction coefficient of smoke* – see Annex A.

The production of *smoke* and its optical properties can be measured as well as other fire properties, such as heat release, flame spread, and the production of toxic gas and corrosive effluent. This document serves as a guidance document and focuses on obscuration of light by *smoke*.

1 Numbers in square brackets refer to the bibliography.

FIRE HAZARD TESTING –

Part 6-1: Smoke obscuration – General guidance

1 Scope

This part of IEC 60695 gives guidance on:

a) the optical measurement of *obscuration of smoke*;
b) general aspects of optical *smoke* test methods;
c) consideration of test methods;
d) expression of *smoke* test data;
e) the relevance of optical *smoke* data to hazard assessment.

This basic safety publication focusing on safety guidance is primarily intended for use by technical committees in the preparation of safety publications 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.

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.

IEC 60695-1-10, *Fire hazard testing – Part 1-10: Guidance for assessing the fire hazard of electrotechnical products – General guidelines*

IEC 60695-1-11, *Fire hazard testing – Part 1-11: Guidance for assessing the fire hazard of electrotechnical products – Fire hazard assessment*

IEC 60695-4, *Fire hazard testing – Part 4: Terminology concerning fire tests for electrotechnical products*

IEC 60695-6-2, *Fire hazard testing – Part 6-2: Smoke obscuration – Summary and relevance of test methods*

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

ISO/IEC Guide 51, *Safety aspects – Guidelines for their inclusion in standards*

ISO 13943:2017, *Fire safety – Vocabulary*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943:2017 and IEC 60695-4, some of which are reproduced below, apply.

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

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
extinction area of smoke
product of the volume occupied by *smoke* (3.1.10) and the *extinction coefficient* (3.1.2) of the smoke

Note 1 to entry: The extinction area of smoke is a measure of the amount of smoke. The typical unit is m^2.

[SOURCE: ISO 13943:2017, 3.110]

3.1.2
extinction coefficient
natural logarithm of the ratio of incident light intensity to transmitted light intensity, per unit light path length

Note 1 to entry: The typical unit is m^{-1}.

[SOURCE: ISO 13943:2017, 3.111]

3.1.3
mass optical density of smoke
optical density of smoke (3.1.6) multiplied by a factor which is the volume of the test chamber divided by the product of the mass lost from the test specimen and the light path length

Note 1 to entry: The typical unit is $m^2 \cdot g^{-1}$.

Note 2 to entry: Optical density of smoke = $V/(\Delta m\ L)$, where V is test chamber volume, Δm is test specimen mass loss and L is light path length.

[SOURCE: ISO 13943:2017, 3.265]

3.1.4
obscuration of smoke
reduction in the intensity of light due to its passage through *smoke* (3.1.10)

Note 1 to entry: Compare with the terms *extinction area of smoke* (3.1.1), *extinction coefficient* (3.1.2), *opacity of smoke* (3.1.5), *optical density of smoke* (3.1.6), *smoke obscuration* (3.1.11), *specific extinction area of smoke* (3.1.13) and *specific optical density of smoke* (3.1.14).

Note 2 to entry: In practice, obscuration of smoke is usually measured as the transmittance which is normally expressed as a percentage.

Note 3 to entry: The obscuration of smoke causes a reduction in *visibility* (3.1.6).

[SOURCE: ISO 13943:2017, 3.286]

3.1.5
opacity of smoke
ratio of incident light intensity to transmitted light intensity through *smoke* (3.1.10), under specified conditions

Note 1 to entry: Also, *obscuration of smoke* (3.1.4), *smoke obscuration* (3.1.11).

Note 2 to entry: The opacity of smoke is the reciprocal of transmittance.

Note 3 to entry: The opacity of smoke is dimensionless.

[SOURCE: ISO 13943:2017, 3.287]

3.1.6
optical density of smoke
measure of the attenuation of a light beam passing through *smoke* (3.1.10) expressed as the logarithm to the base 10 of the *opacity of smoke* (3.1.5)

Note 1 to entry: Compare with the term *specific optical density of smoke* (3.1.14).

Note 2 to entry: The optical density of smoke is dimensionless.

[SOURCE: ISO 13943:2017, 3.288]

3.1.7
physical fire model
laboratory process, including the apparatus, the environment and the fire test procedure intended to represent a certain phase of a fire

[SOURCE: ISO 13943:2017, 3.298]

3.1.8
SMOGRA
smoke growth rate parameter that is a function of the rate of smoke production and the time of smoke production

Note 1 to entry: Further details are given in 6.2.4.

3.1.9
SMOGRA index
maximum value of *SMOGRA* (3.1.8) during a defined test period

Note 1 to entry: Further details are given in 6.2.4.

3.1.10
smoke
visible part of a fire effluent

[SOURCE: ISO 13943:2017, 3.347]

3.1.11
smoke obscuration
reduction of light transmission by *smoke* (3.1.10), as measured by light attenuation

Note 1 to entry: Compare with the terms *extinction area of smoke* (3.1.1), *extinction coefficient* (3.1.2), *obscuration of smoke* (3.1.4), *opacity of smoke* (3.1.5), *optical density of smoke* (3.1.6), *specific extinction area of smoke* (3.1.13) and *specific optical density of smoke* (3.1.14).

[SOURCE: ISO 13943:2017, 3.349]

3.1.12
smoke production rate
amount of *smoke* (3.1.10) produced per unit time in a fire or fire test

Note 1 to entry: The smoke production rate is calculated as the product of the volumetric flow rate of *smoke* (3.1.10) and the *extinction coefficient* (3.1.2) of the smoke at the point of measurement.

Note 2 to entry: The typical unit is $m^2 \cdot s^{-1}$.

[SOURCE: ISO 13943:2017, 3.351]

3.1.13
specific extinction area of smoke
extinction area of smoke (3.1.1) 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 1 to entry: The typical unit is $m^2 \cdot g^{-1}$.

[SOURCE: ISO 13943:2017, 3.358]

3.1.14
specific optical density of smoke
optical density of smoke (3.1.6) multiplied by a geometric factor

Note 1 to entry: 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 to entry: 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 to entry: The specific optical density of smoke is dimensionless.

[SOURCE: ISO 13943:2017, 3.360]

3.1.15
visibility
maximum distance at which an object of defined size, brightness and contrast can be seen and recognized

[SOURCE: ISO 13943:2017, 3.420]

3.2 Symbols

Symbol	Quantity	Typical units
A	exposed area of test specimen	m^2
D	linear decadic absorption coefficient (commonly called optical density per metre)	m^{-1}
D'	*optical density of smoke*	dimensionless
D_{mass}	*mass optical density of smoke*	$m^2\ kg^{-1}$
D_s	*specific optical density of smoke*	dimensionless
D_{max} (also D_m)	maximum *specific optical density of smoke*	dimensionless
I	intensity of incident light	cd
I/T	*opacity of smoke* (ratio of incident light to transmitted light)	dimensionless
k	linear Napierian absorption coefficient (commonly called *extinction coefficient*)	m^{-1}
L	light path length through *smoke*	m
Δm	mass loss of test specimen	kg
$\dot{m}$	mass loss rate	$kg\ s^{-1}$

Symbol	Quantity	Typical units
S	*extinction area of smoke (also total smoke)*	m^2
$\dot{S}$	*smoke production rate* (rate of change of extinction area)	$m^2\ s^{-1}$
t	time	s
Δt	sampling time interval	s
T	intensity of transmitted light	cd
V	volume of chamber	m^3
$\dot{V}$	volume flow rate of *smoke*	$m^3\ s^{-1}$
σ_f	*specific extinction area of smoke*	$m^2\ kg^{-1}$
γ	a constant of proportionality between *visibility* and *extinction coefficient*	dimensionless
ω	*visibility*	m

NOTE 1 The quantities based on $\log_{10}$, i.e. D, D', D_{max}, D_{mass} and D_s, have similar symbols but they are different quantities and have different units.

NOTE 2 The use of the term "specific" in the case of *specific optical density of smoke*, D_s, does not denote "per unit mass".

4 General aspects of smoke test methods

4.1 Fire scenarios and physical fire models

During recent years, major advances have been made in the analysis of fire effluents. It is recognized that the composition of the mixture of combustion products is particularly dependent upon the nature of the combusting materials, the prevailing temperatures and ventilation conditions, especially access of oxygen to the seat of the fire. Table 1 shows how the different types of fire relate to the changing atmosphere. Conditions for use in laboratory tests (small or large-scale) can be derived from the table in order to correspond, as far as possible, to real-scale fires.

Fire involves a complex and interrelated array of physical and chemical phenomena. As a result, it is difficult to simulate all aspects of a real-scale fire in a smaller scale apparatus. This problem of *physical fire model* validity is perhaps the single most perplexing technical problem associated with all fire testing.

General guidance for assessing the fire hazard of electrotechnical products is given in IEC 60695-1-10 and IEC 60695-1-11.

After ignition, fire development may occur in different ways depending on the environmental conditions, as well as on the physical arrangement of the combustible materials. However, a general pattern can be established for fire development within a compartment, where the general temperature-time curve shows three stages, plus a decay stage (see Figure 1).

Stage 1 is the incipient stage of the fire prior to sustained flaming, with little rise in the fire room temperature. Ignition and *smoke* generation are the main hazards during this stage. Stage 2 (developing fire) starts with ignition and ends with an exponential rise in the fire room temperature. Spread of flame and heat release are the main hazards in addition to *smoke* during this stage. Stage 3 (fully developed fire) starts when the surface of all of the combustible contents of the room has decomposed to such an extent that sudden ignition occurs all over the room, with a rapid and large increase in temperature (flash-over).

At the end of stage 3, the combustibles and/or oxygen have been largely consumed and hence the temperature decreases at a rate which depends on the ventilation and the heat and mass transfer characteristics of the system. This is known as decay.

In each of these stages, a different mixture of decomposition products may be formed and this, in turn, influences the *smoke* produced during that stage. In order to select an appropriate fire test, information is required on the fire scenario being considered, in particular the conditions of incident heat flux, oxygen availability and the facilities for venting the *smoke*.

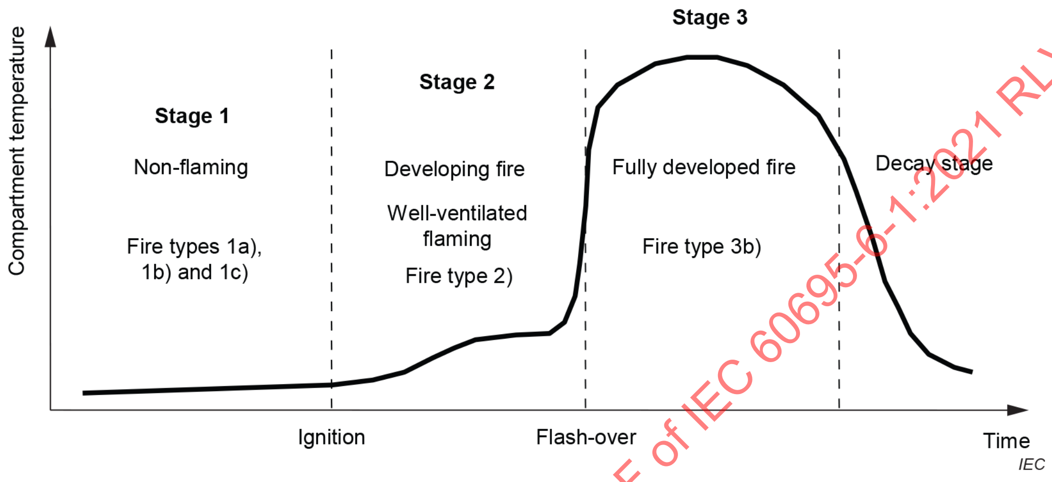

Figure 1 – Different phases in the development of a fire within a compartment

4.2 Factors affecting smoke production

4.2.1 General

Many factors affect the production of *smoke* and the properties of *smoke*. A full description of such properties is not possible, but the influence of several important variables is recognized.

4.2.2 Modes of decomposition

Smoke is a consequence of combustion. Combustion may be flaming or non-flaming, including smouldering, and these different modes of combustion may produce quite different types of *smoke*. In non-flaming combustion, volatiles are evolved at elevated temperatures. When they mix with cool air, they condense to form spherical droplets which appear as a light-coloured *smoke* aerosol.

Flaming combustion produces a black carbon-rich *smoke* in which the particles have a very irregular shape. The *smoke* particles from flaming combustion are formed in the gas phase and in regions where oxygen concentrations are low enough to cause incomplete combustion. The carbonaceous *smoke* particles in the flames emit radiant energy (as black-body emission) which is seen as yellow luminosity.

The particle size of the spherical droplets from non-flaming combustion is generally of the order of 1 µm, whereas the size of the irregular soot particles from flaming combustion is often larger but much harder to determine and is dependent on the measuring technique.

It is often observed for wood fires that the amount of *smoke* is less with flaming combustion than with non-flaming combustion. For plastics, however, no such generalization can be made: the *smoke* produced under non-flaming conditions can be less or more than under flaming conditions. For these reasons, it is important to record in a *smoke* test whether ignition occurs, as well as the times of ignition and extinction of flames on the test specimen.

In addition, cold *smoke* may be generated from the rear of composites; this may differ substantially in colour and composition from the *smoke* produced from the exposed surface.

Table 1 – Characteristics of fire stages (from Table 1 in ISO 19706:2011)[2]

Fire stage	Heat flux to fuel surface kW/m2	Max. temperature °C		Oxygen volume %		Fuel/air equivalence ratio (plume)	$\frac{[CO]}{[CO_2]}$ v/v	$\frac{100 \times [CO_2]}{([CO_2]+[CO])}$ % efficiency
		Fuel surface	Upper layer	Entrained	Exhausted			
1. Non-flaming								
a. self-sustaining (smouldering)	not applicable	450 to 800	25 to 85 [d]	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. Underventilated 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

2 *The Table 1 — Characteristics of fire stages taken from ISO 19706:2011, Guidelines for assessing the fire threat to people*, is reproduced with the permission of the International Organization for Standardization, ISO. This standard can be obtained from any ISO member and from the website of the ISO Central Secretariat at the following address: www.iso.org. Copyright remains with ISO.

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 can 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.

The heat flux on the test specimen influences how the material burns; it is good practice to evaluate the *smoke* generated from materials at low levels of incident irradiance (e.g. 15 $kW \cdot m^{-2}$ to 25 $kW \cdot m^{-2}$) as well as at higher levels (e.g. 40 $kW \cdot m^{-2}$ to 50 $kW \cdot m^{-2}$). In this way, the effects of the growth phases of a fire on the smoke-generating propensity of a material can be assessed.

4.2.3 Ventilation and the burning environment

Smoke production depends upon the fire scenario and not just on what material is being burnt. It is known that, for some materials, the production of *smoke* is increased considerably by restricted ventilation.

The rate of burning and the area involved in burning should always be considered when determining *smoke* production in fires. A material generating small quantities of *smoke* per element of burning area may give large quantities of *smoke* in a fire due to the rapid spread of flames over large surface areas.

4.2.4 Time and temperature

The particle size distribution of *smoke* aerosols changes with time; *smoke* particles coagulate as they age. Some properties also change with temperature so that the properties of aged, or cold *smoke* may be different from young, hot *smoke*. These factors are important for fire engineers when they are considering potential *smoke* movement in large buildings. These factors also have to be considered when designing *smoke* tests.

NOTE Guidance on fire safety engineering is given in IEC 60695-1-12 [1].

4.2.5 Removal mechanisms for smoke particles

Large *smoke* particles may be removed by a number of mechanisms. In cumulative test procedures where a radiant heat source is immersed in the combustion gases, reheated decomposition may occur as the *smoke* particles recirculate. Other mechanisms for removal of larger particles include the deposition of particles on the internal surfaces of the chamber and the action of fan stirrers. Aspects of these mechanisms also occur in real fires when *smoke* circulates within a fire compartment. Because these effects are possible in cumulative *smoke* tests, it is recognized that the early stages of the exposure (for example the first 10 min) are the most relevant for the determination of the rate of *smoke* generation.

5 Principles of smoke measurement

5.1 General

Smoke consists of an aerosol of particles. It can either be measured as a function of its gravimetric properties (the mass of *smoke* particles), its light-obscuring properties, or a mixture of the two [3]. This document is concerned with the reduction of *visibility* caused by the *obscuration of smoke* and therefore gravimetric methods are not discussed. Obscuring properties are a function of the number, size and nature of the particles in the light path. If the particles are considered as opaque, the capacity of the *smoke* to obscure light is related to the sum of the cross-sectional areas of the particles in the light path. It is measured in units of area, e.g. square metres (m^2).

The measurements may be made in small-, large-, or real-scale tests. They may be performed in closed systems which are called cumulative or static methods. They may also be performed in flow-through systems, and these are called dynamic methods.

5.2 Bouguer's law

Optical *smoke* measurements are derived from Bouguer's law which describes the attenuation of monochromatic light by an absorbing medium:

$$I/T = e^{kL} \quad (1)$$

$$k = (1/L)\ \ln(I/T) \quad (2)$$

(The units of k are reciprocal length, e.g. m^{-1})

where

T is the intensity of transmitted light;

I is the intensity of incident light;

L is the light path length through the *smoke*;

k is the linear Napierian absorption coefficient (*extinction coefficient*), see Figure 2.

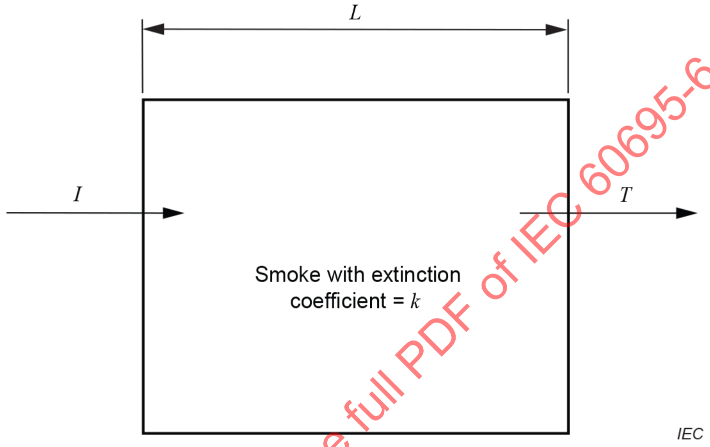

Figure 2 – Attenuation of light by smoke

5.3 Extinction area

A useful measurement of the amount of *smoke* is the total effective cross-sectional area of all the *smoke* particles. This area is known as the *extinction area of smoke*, S. This can be thought of as the total area of the shadows cast by the *smoke* particles in a beam of light (see Figure 3).

If the smoke is homogeneous, i.e. not layered, the *extinction area of smoke* is related both to the *extinction coefficient* of the *smoke* and to the volume in which the *smoke* is contained by the equation:

$$S = kV \quad (3)$$

where V is the volume of the chamber in which the *smoke* is contained.

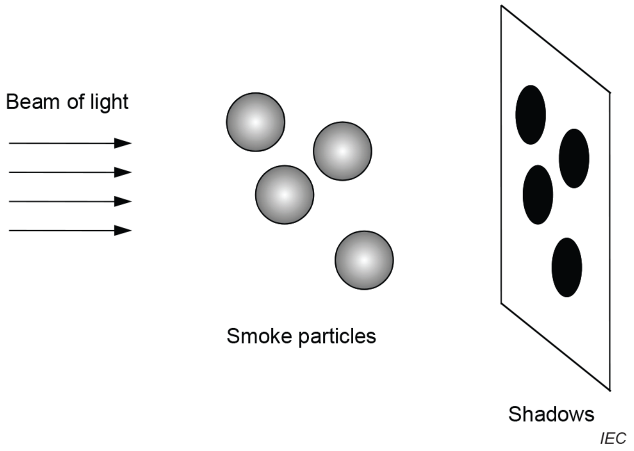

Figure 3 – Extinction area

5.4 Log$_{10}$ units

In some studies, base 10 logarithms are used to calculate the optical density per unit light path length, (D), which is properly named the linear decadic absorption coefficient and, like k (linear Napierian absorption coefficient), also has units of reciprocal length (e.g. m^{-1}).

$$I / T = 10^{DL} \tag{4}$$

$$D = (1/L) \log_{10}(I/T) \tag{5}$$

$$k = D \ln(10) \;\text{ or }\; k = 2{,}303\, D \tag{6}$$

The *extinction area of smoke* (S) can also be calculated from D using the equation:

$$S = 2{,}303\, DV \tag{7}$$

Several variants of base 10 units can be found in the literature. A commonly used quantity is the dimensionless *optical density of smoke*, $D' = \log_{10}(I/T)$. For a given amount of *smoke*, D' is proportional to the light path length and is thus apparatus-dependent; results from one apparatus cannot be directly compared to results from other apparatus.

5.5 Light sources

Both white light and monochromatic laser light sources are used for *smoke* measurement.

Since light attenuation through *smoke* is dependent on the absorption and scattering of light, and since the latter is dependent on wavelength, caution should be exercised when comparing data obtained from measuring systems using different light sources.

5.6 *Specific extinction area of smoke*

In tests where the mass loss of the test specimen is measured, the *specific extinction area of smoke*, σ_f, can be calculated:

$$\sigma_f = S / \Delta m \tag{8}$$

where Δm is the mass loss of the test specimen.

The units of σ_f are area/mass, e.g. $m^2 \cdot kg^{-1}$.

The *specific extinction area of smoke*, σ_f, is a basic measurement of *smoke* that can be made in all scales of tests. It is independent of

- the light path length over which the measurement is taken;
- the flow rate of gases;
- the surface area of the exposed product; and
- the mass of the test specimen.

The *specific extinction area of smoke*, σ_f, is used to define the smoke-producing capacity of a unit mass loss of the test specimen.

For example, consider an 80 g test specimen that is tested under non-flaming conditions. It loses 50 g of mass leaving a residue of 30 g. The *smoke* produced from the 50 g of volatile pyrolysis products has an extinction area of 4 m^2. The σ_f value will therefore be 0,08 $m^2 \cdot g^{-1}$. Suppose that the same test specimen is tested under flaming conditions and that it loses 60 g of mass leaving 20 g of residue. The *smoke* produced from the combustion of the 60 g of volatile degradation products has an extinction area of 30 m^2. The σ_f value in this case will be 0,5 $m^2 \cdot g^{-1}$.

It is important to realise that σ_f does not give information on either the amount of *smoke* generated in a fire or the rate of *smoke* generation in a fire. Either the mass loss of the test specimen (Δm) or the mass loss rate of the test specimen ($\dot{m}$) is necessary to obtain the information. Then, the extinction area of the *smoke* generated is given by:

$$S = \sigma_f \Delta m \tag{9}$$

In dynamic systems (see 6.2), the specific extinction area may be obtained from:

$$\sigma_f = k\dot{V} / \dot{m} \tag{10}$$

where

$\dot{V}$ is the volume flow rate;

$\dot{m}$ is the mass loss rate;

and the smoke production rate, $\dot{S}$, is given by:

$$\dot{S} = \sigma_f \dot{m} \tag{11}$$

5.7 *Mass optical density of smoke*

When working in $\log_{10}$ units the equivalent variable to σ_f is called the *mass optical density of smoke* (D_{mass}) and is related to σ_f as follows:

$$D_{mass} = \sigma_f / \ln(10) = \sigma_f / 2{,}303 \tag{12}$$

The unit of D_{mass} is area per mass, e.g. $m^2\ kg^{-1}$.

In static systems (see 6.1):

$$D_{mass} = D' \cdot V / (\Delta m \cdot L) \tag{13}$$

where

D_{mass} is the *mass optical density of smoke*;

D' is the *optical density of smoke*;

V is the volume of the chamber;

Δm is the mass loss of the test specimen;

L is the light path length.

In dynamic systems, the *mass optical density of smoke* can be obtained from:

$$D_{mass} = D\dot{V} / \dot{m} \tag{14}$$

5.8 *Visibility*

If the constant of proportionality (γ) between *visibility* (ω) and k (or D) is known, then *visibility* can be readily calculated if the amount of *smoke* (extinction area) is known and if the volume occupied by the *smoke* is also known.

$$\omega = \gamma (V/S) \tag{15}$$

and $$\gamma = \omega k = 2{,}303 \omega D \tag{16}$$

The calculation of *visibility* is described in more detail in Annex A, and examples of the relationships between *smoke* parameters measured in various tests, using various measurement units, are given in Annex B and Annex C.

6 Static and dynamic methods

6.1 Static methods

6.1.1 Principles

In a static *smoke* test, the test specimen burns in a closed chamber and the *smoke* produced builds up over time. In some tests, a fan stirs the *smoke* to prevent layering and to make it homogeneous. The amount of *smoke* is measured by monitoring the attenuation of a light beam shining through the *smoke*.

6.1.2 *Extinction area of smoke*

The *extinction area of smoke* is a useful measure of the amount of *smoke* produced, and is a function of the *opacity of smoke*, (I/T), the volume of the chamber, V, and the light path length, L.

$$S = (V / L) \ln(I/T) \tag{17}$$

This equation only applies if the *smoke* is homogeneous. The units of extinction area are typically square metres (m^2).

See Annex C for relationships between per cent transmission, as measured in a "three metre cube" enclosure, and extinction area.

6.1.3 *Specific optical density of smoke*

In some tests, e.g. ISO 5659-2 [4], the amount of *smoke* is calculated from the optical density of the *smoke*, and it is normalised to the surface area of the test specimen, A. The quantity calculated is D_s, the *specific optical density of smoke*.

$$D_s = [V/AL] \log_{10}(I/T) \tag{18}$$

The thickness of the test specimen will affect the amount of *smoke* produced. D_s values should not be directly compared for test specimens of different thicknesses. Conversely, if comparisons are made, then the test specimen thickness shall be kept constant.

See Annex B for relationships between D_s and some other smoke parameters as measured in ISO 5659-2 [4].

6.1.4 Prediction of *visibility*

The purpose of measuring D_s (or S) is to enable the prediction of *visibility*. However, the *visibility* within the test chamber is not usually what is required to be known. What is required is an estimation of *visibility* in a given fire scenario. It is possible to make such estimations based on data obtained in static tests such as ISO 5659-2 [4] but it has to be appreciated that such calculations are only estimates, as changing the *physical fire model* will probably change both the *smoke* production process and the way in which the *smoke* will age.

6.2 Dynamic methods

6.2.1 Principles

In dynamic tests, the *smoke* from the test specimen is drawn through an exhaust system at a measured flow rate and the *opacity of smoke* is measured at regular intervals by monitoring the transmitted intensity of a light beam shining through the *smoke* (see Figure 4). The flow rate of the smoke is measured at a position close to where the *opacity of smoke* is measured.

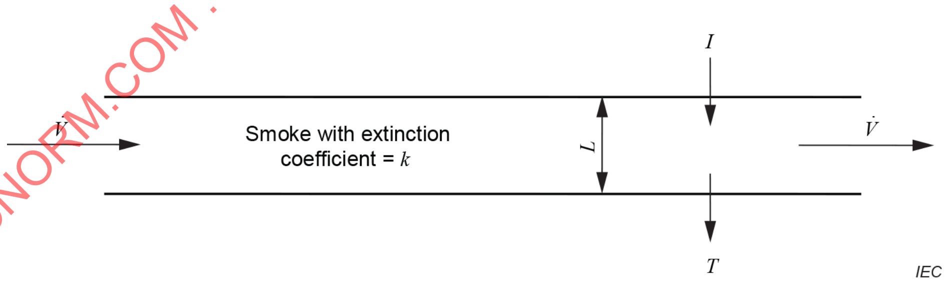

Figure 4 – Dynamic smoke measurement

6.2.2 Smoke production rate

The *smoke production rate* at any given moment ($\dot{S}$) is calculated using the equation:

$$\dot{S} = k\dot{V} \tag{19}$$

where

$\dot{V}$ is the volume flow rate of the exhaust gases;

$\dot{S}$ has units of area/time, e.g. $m^2 \cdot s^{-1}$.

The *smoke production rate* is readily ascertained in dynamic systems. It expresses the *extinction area of smoke* produced per unit time.

$$\dot{S} = k\dot{V} = (1/L)\ln(I/T)\dot{V} \tag{20}$$

When the exposed test specimen area involved is known, as in the cone calorimeter ASTM E1354 [5] and ISO 5660 [6], or in furniture calorimeters, the *smoke production rate* can be normalized per unit area of the exposed test specimen. The units then become reciprocal time, e.g. $(m^2/s)/m^2$, i.e. s^{-1}.

6.2.3 Total smoke production

Integrated data to give *total smoke production* is also of interest, especially when comparing materials or scenarios which may produce *smoke* for unequal periods of time. *Total smoke production* is measured as the extinction area produced in the defined time interval and is given by:

$$S = \int \dot{S}.\mathrm{d}t \tag{21}$$

where

S is the *total smoke production*, i.e. the total *extinction area of smoke*;

t is the time.

The time over which the summation is performed should be specified. In the cone calorimeter, this is to the end of the test, which, in simple cases, is when the mass loss rate per unit area of the test specimen has reached a specified value (for example 25 $g \cdot m^{-2} \cdot s^{-1}$). The *total smoke production* may be expressed per unit of burning area if this is known.

The *total smoke production* from a burning test specimen, measured in a closed system, will often be substantially less than the *total smoke production* from a similar burning test measured in a dynamic system. This is because measurements in static systems are more influenced by losses due to ageing and deposition or interaction at the chamber walls.

6.2.4 SMOGRA index

SMOGRA is an abbreviation for smoke growth rate. *SMOGRA* values are affected by both the *smoke production rate* and the time at which the *smoke* is being produced, and are calculated using the following formula:

$$\mathrm{SMOGRA} = 10\,000 \times [SPR_{\mathrm{av}}(t) \,/\, (t - t_0)] \tag{22}$$

where

$SPR_{\mathrm{av}}(t)$ is the *smoke production rate* at time t, and

t_0 is the time at which the test specimen is first exposed to the test flame.

The *SMOGRA index* is defined as the maximum value of the function during the time period of the test. The *SMOGRA index* was devised in the development of EN 13823 [7], which is an intermediate scale corner test used for the regulation of building products in Europe. As a single value parameter for regulatory purposes, some consider that the *SMOGRA index* gives a better indication of the severity of smoke production than either *total smoke production* or the average *smoke production rate*.

NOTE In EN 13823 the SPR value is a 60 s moving average, and the start of exposure of the test specimen to the test flame is at t = 300 s.

Figure 5 shows an example SPR_{av} versus t curve, and Figure 6 shows the *SMOGRA* curve derived from these data. The peak *smoke production rate* is 0,5 $m^2 \cdot s^{-1}$ at t = 960 s, and the *SMOGRA index* is 8,2 $m^2 \cdot s^{-2}$ at t = 857 s.

The *SMOGRA index* may be a useful parameter for assessing smoke hazard because it combines the *smoke production rate* with the time elapsed to reach it. Note that the *SMOGRA index* always refers to a time shorter than the time of maximum smoke production (in the given curves, 857 s compared to 960 s).

However, the *SMOGRA index* should be treated with extreme caution in cases where there is an early rapid but low smoke production. In such cases, the *SMOGRA* value at small $t - t_0$ values may be larger than values calculated from the significant part of the curve and the obtained *SMOGRA index* may be both irrelevant and misleading.

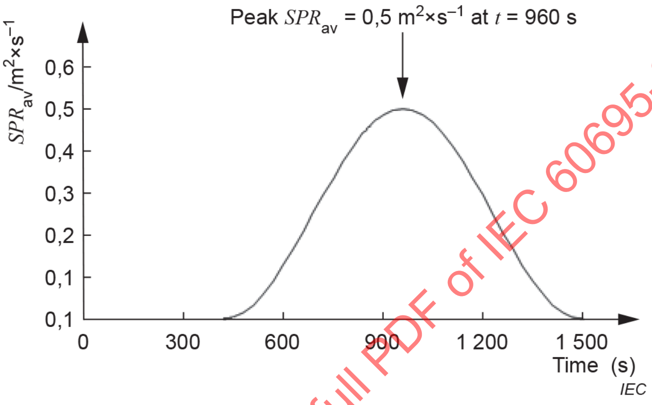

Figure 5 – Example SPR_{av} versus t curve

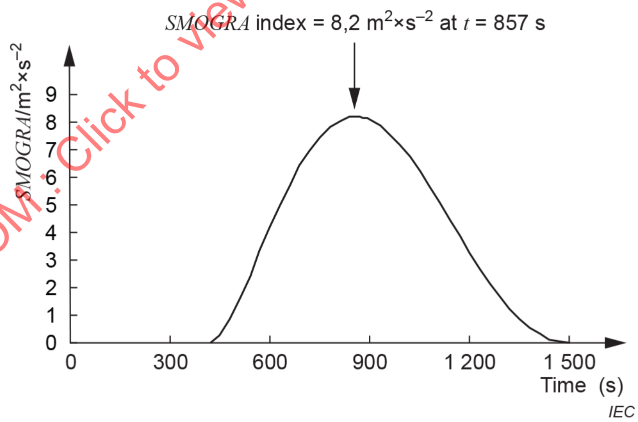

Figure 6 – *SMOGRA* curve derived from Figure 5

7 Test methods

7.1 Consideration of test methods

It is important to consider the *physical fire model* or models most relevant to the hazard being assessed, and to select tests which have *physical fire models* similar to those being assessed (see IEC 60695-6-2).

In the selection of test methods, the following questions should be asked of each method under consideration:

- can the test accommodate the geometry and configuration of the product in question?
- does the test method replicate the stage of fire of interest?
- does the test give data in an appropriate format, and with sufficient discrimination and resolution?

If the answer to any of these questions is no, the method under consideration shall either be modified or an alternative method shall be considered. The test method(s) selected shall be relevant to the fire scenario of concern.

In cases where fire tests are not yet specified, and need to be developed or altered for the special purpose of an IEC technical committee, this shall be done in liaison with IEC technical committee 89.

A flow chart outlining the stages to be followed in assessing the suitability of an existing method for a new application is shown in Figure 7.

7.2 Selection of test specimen

Different types of test specimens may be tested. In product testing, the test specimen is a manufactured product. In simulated product testing, the test specimen is representative of a portion of a product. The test specimen may also be a basic material (solid or liquid) or a composite of materials.

The nature of the test specimen is governed to a large extent by the scale of the *smoke* test. Small-scale tests are suited more to the testing of materials and small products, or of representative test specimens of larger products. On a larger scale, whole products may be tested. Given the choice, it is always preferable to select a test specimen that most closely reflects end use.

8 Presentation of data

There are many different ways of presenting *smoke* data. This makes it difficult, and sometimes impossible, to make comparisons between *smoke* data from different tests. It also makes it difficult to relate the results of tests to a measure of the fire hazard presented by the material or by the product being tested. To help overcome these problems, it is recommended that, wherever possible, *smoke* data should be reported in terms of the *extinction area of smoke*. All other relevant parameters shall be reported. These include full details of the nature of the test specimen, the conditions of the test and any observations of unusual behaviour.

Normalized *smoke* data are often reported, e.g. *smoke* production per unit mass and *smoke* production per unit surface area. When this is the case, it is important that the primary data (i.e. before being normalized) should also be reported.

9 Relevance of data to hazard assessment

Realistic assessments of the fire performance of a product can only be obtained by testing a real-scale test specimen in the form and orientation in which it is actually used. An isolated small-scale test, not representative of the final use of the product, can only indicate the response of a product to the *physical fire model* selected. It is emphasized that no fire or *smoke* test can, in normal circumstances, measure fire or *smoke* hazard; in addition, it cannot be assumed that satisfactory results of a single standard fire or *smoke* test will guarantee a given level of safety. Results from a variety of fire tests will provide information to assist in the determination and subsequent control of fire and *smoke* hazards.

The potential hazard due to the *obscuration of smoke* caused by burning material depends on a number of factors. These include:

– the *total smoke* produced;
– the *specific extinction area of smoke*, i.e. the amount of *smoke* produced per unit mass loss of the burning material;
– the mass loss rate of the burning material (this will depend on how much material is involved in the fire, and on how easily it burns);
– the *smoke production rate* (this is the product of the above two quantities);
– the volume into which the *smoke* is spreading.

There are many other factors associated with *visibility* in an escape route, including:

– size, luminance, contrast and intensity of a light-emitting sign;
– size and contrast of reflecting objects;
– presence of external illumination;

and human response factors, including

– visual acuity;
– dark adaptation;
– irritancy.

It follows, therefore, that just considering the *smoke* producing potential of a unit mass or unit area of a material is not sufficient to enable a hazard assessment to be made. A material with a high *specific extinction area of smoke* or a high D_s value may not present a hazard if the amount of material present in the hazard scenario is small, and/or if the volume into which the *smoke* can spread is large. Similarly, a material with a low *specific extinction area of smoke* or a low D_s value may present a hazard if the amount of material present in the hazard scenario is large, and/or if the volume into which the *smoke* can spread is small.

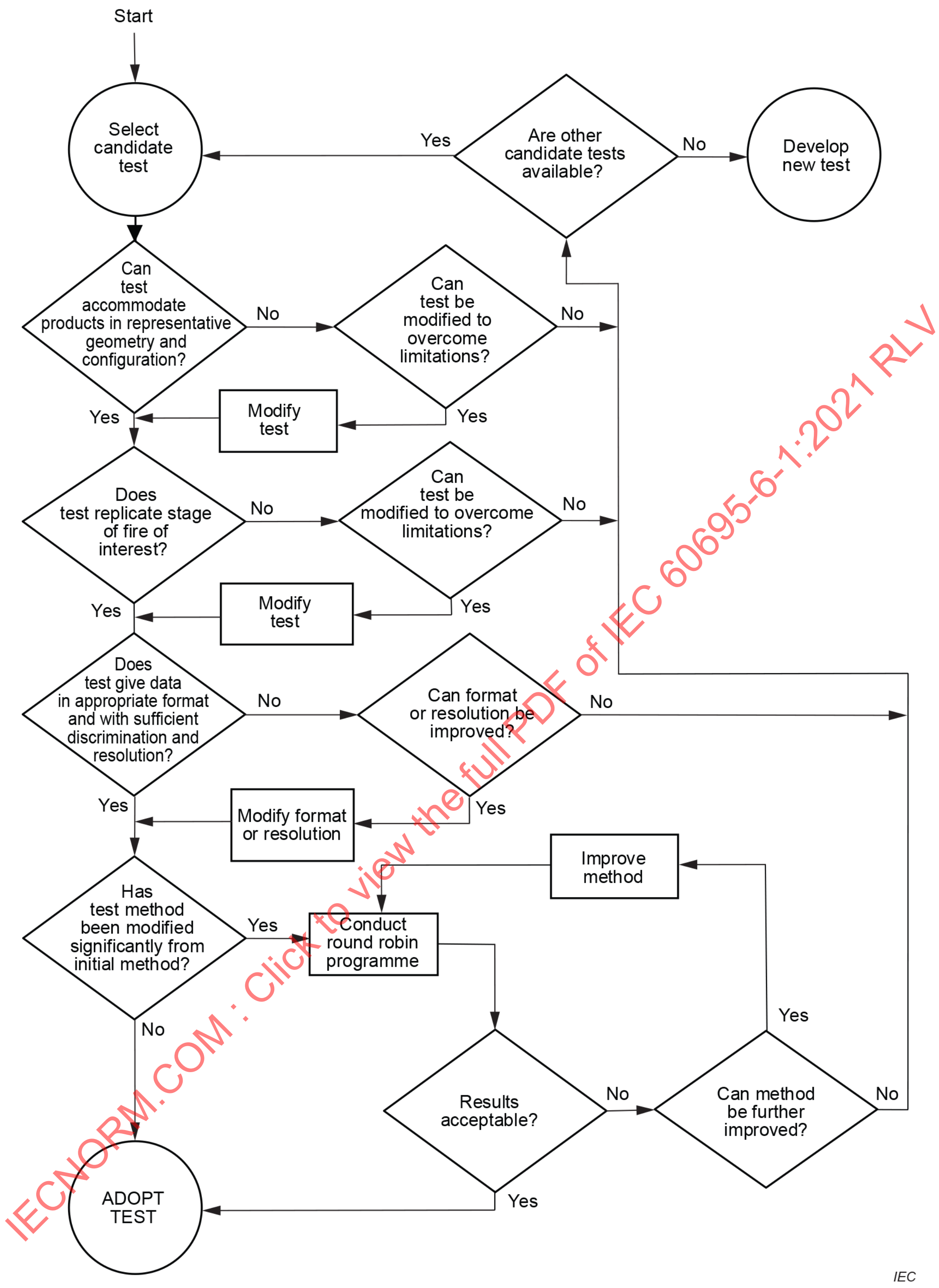

Figure 7 – Evaluation and consideration of smoke test methods

Annex A
(informative)

Calculation of *visibility*

A.1 General

Figure A.1 shows the relationships reported by Jin [8] between *visibility* and the *extinction coefficient* of the *smoke* which is causing obscuration. Two lines are shown in Figure A.1; one is for light-emitting signs and the other is for light-reflecting signs. *Visibility* is approximately inversely proportional to the *extinction coefficient*, i.e. $\omega = \gamma/k$, γ being the constant of proportionality. However, there is a considerable spread in the experimental data, and *visibility* also depends on other factors such as external illumination, the brightness of light-emitting signs, and the reflectance of light-reflecting signs. Calculations of *visibility* using this relationship should therefore only be considered as estimates.

Jin selected values for γ of 3 and 8 for light-reflecting and light-emitting signs, respectively. In BS DD240-1 [9], values of 2,30 and 5,76 were reported.

NOTE BS DD240-1 has been superseded and replaced by BS 7974:2001 [10].

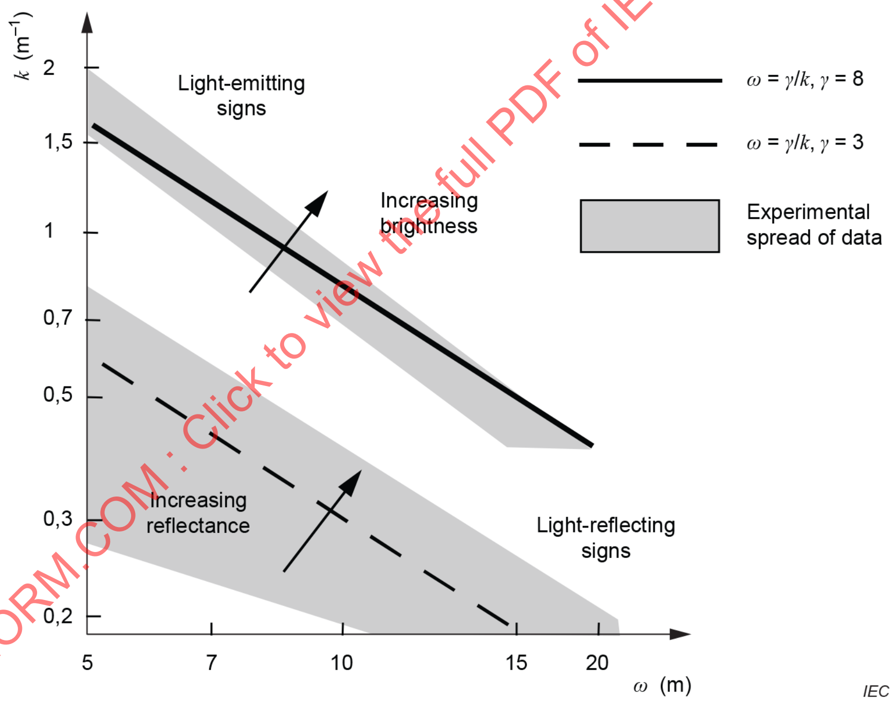

Figure A.1 – *Visibility* (ω) versus *extinction coefficient* (k)

A.2 Example

An example of a typical estimation of *visibility* is as follows.

Suppose a 10 mm thick test specimen of material is tested in an ISO 5659-2 apparatus. The maximum D_s value obtained is D_{max}. Suppose we wish to calculate an estimate of the minimum *visibility* of a light emitting sign in a room of volume V if a 10 mm thick test specimen of the material, with a surface area of A, burns in a similar manner in the room.

We know that: $$\omega = \gamma\,(V/S) \quad \text{(A.1)}$$

and, for the purpose of the estimation, we assume that $\gamma = 8$ for a light-emitting sign.

We first need to calculate how much *smoke* will be produced in the postulated scenario. This is given by:

$$S = 2{,}303\,D_{max}\,A \quad \text{(A.2)}$$

so the estimated *visibility* is given by:

$$\omega = 8 \times [V\,/\,(2{,}303\,D_{max}\,A)] \quad \text{(A.3)}$$

It should be noted that such a calculation assumes that the *smoke* is homogeneous whereas in many real fires, the *smoke* tends to form in a buoyant hot layer. It is also assumed that *smoke* production varies linearly with the area of the test specimen burned. Also, no consideration of the effect of irritants is made. Some limited research suggests that eye irritants might reduce vision by 50 % up to 95 %.

Note also that the simple relationship $\omega = \gamma/k$ reported by Jin is only valid over a relatively small range of viewing distances. It also refers to the *visibility* of targets whereas the recognition of signs requires the resolution of the sign details. A more complex equation has been proposed for recognition distances in *smoke* [11] which will properly extrapolate to clear air conditions. The determination of the *visibility* of an illuminated exit sign in a corridor-like scenario has been examined by Rubini *et al.* [12].

Annex B
(informative)

Relationships between D_s and some other smoke parameters as measured in ISO 5659-2 [4]

A simple calculation can be performed to convert the *specific optical density of smoke*, D_s, as measured in ISO 5659-2, to an extinction area S.

Although such a conversion may prove to be useful to compare *smoke obscuration* data using the same units, caution should be exercised when doing so, as such a calculation does not take into account the different conditions of testing from one set of experiments to another (e.g. geometric factors of the testing chambers).

Thus, a D_s measurement, expressed in terms of S, should not be directly compared with another value of S, measured from a different testing method.

For a given test specimen surface area, the *specific optical density of smoke*, D_s, is directly proportional to the *extinction area of smoke*, S. In the case of ISO 5659-2, the exposed surface area of the test specimen is 0,004 225 m² and

$$S = (0{,}009\,73\ \text{m}^2)\ D_s \tag{B.1}$$

Table B.1 shows the relationship between the *specific optical density of smoke*, the percent transmission and the *extinction area of smoke* for ISO 5659-2 data.

Table B.1 – Conversion from D_s to some other smoke parameters as measured in ISO 5659-2

D_s	Percent transmission %	Extinction area, S m²
450	0,04	4,38
400	0,09	3,89
350	0,22	3,41
300	0,53	2,92
250	1,28	2,43
200	3,05	1,95
150	7,31	1,46
100	17,48	0,97
75	27,03	0,73
50	41,80	0,49
30	59,26	0,29
20	70,55	0,19
15	76,98	0,15
10	83,99	0,10
5	91,65	0,05
0	100,00	0,00

Figure B.1 gives a useful visual representation of the *smoke* parameters listed in Table B.1.

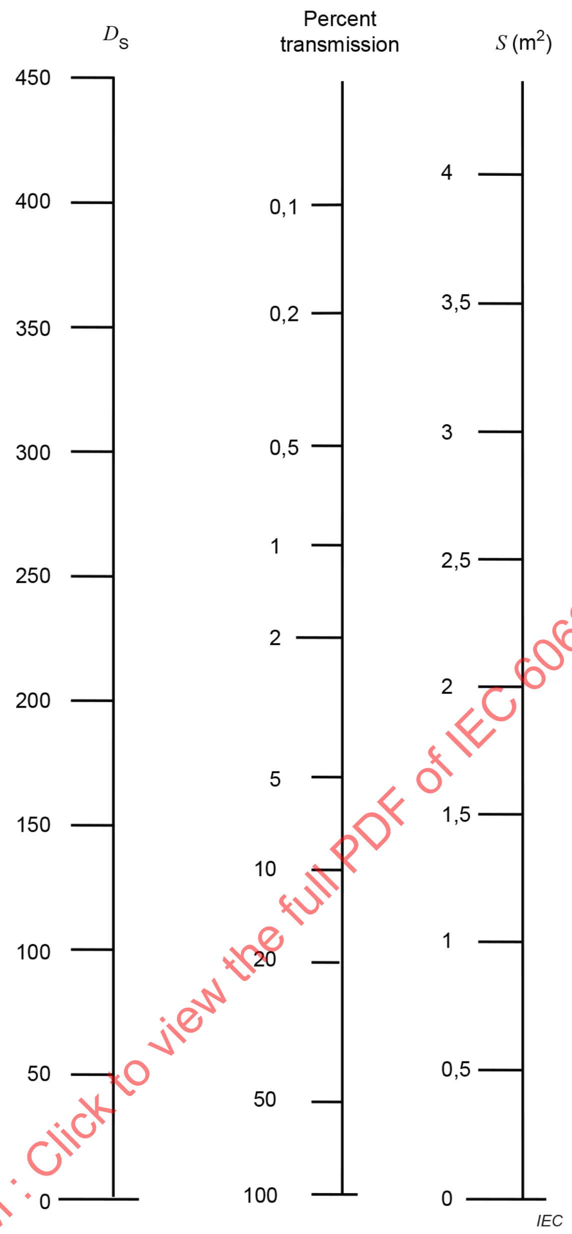

Figure B.1 – Smoke parameters related to D_s as measured in ISO 5659-2

Annex C
(informative)

Relationships between per cent transmission, as measured in a "three metre cube" enclosure, and extinction area

The test specimen is burned in a "three metre cube" enclosure and the per cent transmission of light is calculated from the ratio of the incident light to the transmitted light (I/T). The test is a static *smoke* test.

The test specified in IEC 61034-1 [13] and IEC 61034-2 [14] is a specific application of this type of test relating to cables.

Table C.1 shows the conversions between the per cent transmission and extinction area for the "three metre cube". Figure C.1 gives a useful visual representation of the *smoke* parameters listed in Table C.1.

NOTE For cables with an overall diameter above 20 mm, the recorded minimum light transmittance is a normalized value.

Table C.1 – Conversions from per cent transmission, as measured in the "three metre cube" to amount of smoke (extinction area)

Percent transmission	Amount of smoke, S m^2
0,10	62,18
0,20	55,94
0,40	49,70
1,00	41,45
2,00	35,21
4,00	28,98
5,00	26,97
10,00	20,73
15,00	17,08
20,00	14,49
30,00	10,84
40,00	8,25
50,00	6,24
60,00	4,60
70,00	3,21
80,00	2,01
90,00	0,95
100,00	0,00

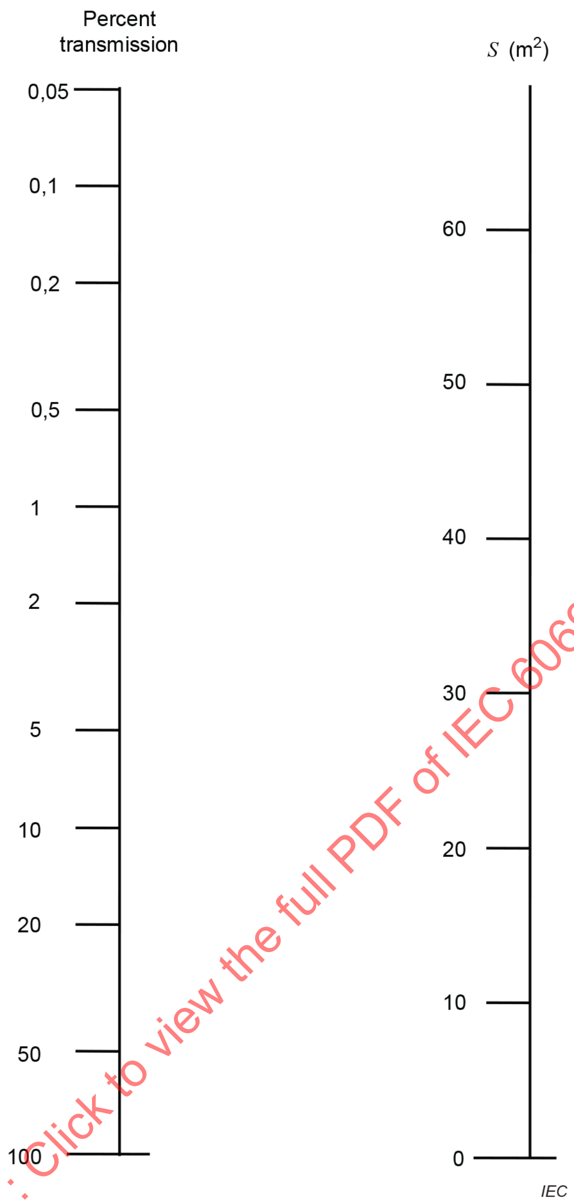

Figure C.1 – Extinction area (amount of smoke) related to per cent transmission as measured in the "three metre cube"

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[14] IEC 61034-2, *Measurement of smoke density of cables burning under defined conditions – Part 2: Test procedure and requirements*

SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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ESSAIS RELATIFS AUX RISQUES DU FEU –

Partie 6-1: Obscurcissement dû à la fumée – Recommandations générales

AVANT-PROPOS

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8) L'attention est attirée sur les références normatives citées dans cette publication. L'utilisation de publications référencées est obligatoire pour une application correcte de la présente publication.
9) L'attention est attirée sur le fait que certains des éléments du présent document de l'IEC peuvent faire l'objet de droits de brevet. L'IEC ne saurait être tenue pour responsable de ne pas avoir identifié de tels droits de brevets.

La Norme internationale IEC 60695-6-1 a été établie par le comité d'études 89 de l'IEC: Essais relatifs aux risques du feu.

Cette troisième édition annule et remplace la deuxième édition de l'IEC 60695-6-1 parue en 2005 et l'Amendement 1:2010. Elle constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

– Les références à l'IEC TS 60695-6-30 (annulée en 2016) ont été supprimées.
– Les références à l'IEC TS 60695-6-31 (annulée en 2016) ont été supprimées.
– Des références à l'ISO 5659-2 ont été ajoutées.
– Le domaine d'application contient du texte supplémentaire.

– Les termes et définitions ont été mis à jour.
– Le paragraphe 3.2 a été mis à jour.
– Le paragraphe 7.1 a été mis à jour.

Le texte de cette Norme internationale est issu des documents suivants:

Projet	Rapport de vote
89/1472/CDV	89/1504/RVC

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à son approbation.

La langue employée pour l'élaboration de cette Norme internationale est l'anglais.

Elle a le statut de publication fondamentale de sécurité, conformément au Guide IEC 104 et au Guide ISO/IEC 51.

Cette Norme internationale doit être utilisée conjointement avec l'IEC 60695-6-2.

Dans cette norme, les caractères suivants sont utilisés:

- *italique: termes définis à l'Article 3.*

Une liste de toutes les parties de la série IEC 60695, publiées sous le titre général *Essais relatifs aux risques du feu*, peut être consultée sur le site web de l'IEC.

L'IEC 60695-6 est constituée des parties suivantes:

Partie 6-1: Opacité des fumées – Recommandations générales

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

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2, il a été développé selon les Directives ISO/IEC, Partie 1 et les Directives ISO/IEC, Supplément IEC, disponibles sous www.iec.ch/members_experts/refdocs. Les principaux types de documents développés par l'IEC sont décrits plus en détail sous www.iec.ch/standardsdev/publications.

Le comité a décidé que le contenu de ce document ne sera pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous webstore.iec.ch dans les données relatives au document recherché. À cette date, le document sera

- reconduit,
- supprimé,
- remplacé par une édition révisée, ou
- amendé.

INTRODUCTION

Lors de la conception d'un produit électrotechnique, il est nécessaire d'envisager le risque d'incendie et les dangers potentiels associés au feu. Dans cette perspective, l'objectif lors de la conception des composants, des circuits et des équipements ainsi que le choix des matériaux est de réduire le risque d'incendie à un niveau tolérable dans le cas d'une (mauvaise) utilisation, d'un mauvais fonctionnement ou d'une défaillance raisonnablement prévisible.

L'IEC 60695-1-10, l'IEC 60695-1-11 et l'IEC 60695-1-12 [1][1] fournissent des recommandations pour atteindre cet objectif.

Les incendies impliquant des produits électrotechniques peuvent également être déclenchés par des sources externes non électriques. Les considérations de cette nature sont traitées dans une évaluation globale du danger d'incendie.

La série IEC 60695 a pour objectif de sauver des vies humaines et de protéger les biens matériels en réduisant le nombre d'incendies ou les conséquences de l'incendie. Pour ce faire, il est possible de:

– tenter de prévenir l'allumage provoqué par un composant sous tension électrique et, en cas d'allumage, de confiner tout incendie en résultant dans les limites de l'enveloppe du produit électrotechnique.
– tenter de réduire le plus possible la propagation des flammes au-delà de l'enveloppe du produit et de réduire le plus possible les effets dangereux des effluents du feu comprenant la chaleur, la *fumée*, ainsi que les produits de combustion toxiques ou corrosifs.

L'un des dangers impliqués est le dégagement de *fumée*, qui peut entraîner une perte de vision et/ou une désorientation pouvant entraver l'évacuation des immeubles ou la lutte contre l'incendie.

Les particules de *fumée* réduisent la *visibilité* du fait de l'absorption de la lumière et de sa diffusion. En conséquence, les personnes peuvent avoir des difficultés à trouver les signaux de sortie, les portes et les fenêtres. La *visibilité* est souvent définie comme étant la distance à partir de laquelle un objet n'est plus visible. Elle dépend de nombreux facteurs, mais des relations étroites ont été établies entre la *visibilité* et les mesurages du *coefficient d'extinction de la fumée* – voir l'Annexe A.

Le dégagement de *fumée* et ses propriétés optiques peuvent être mesurés avec d'autres propriétés du feu telles que le dégagement de chaleur, la propagation des flammes et la production de gaz toxiques et d'effluents corrosifs. Le présent document fournit des recommandations et traite de l'obscurcissement de la lumière par la *fumée*.

[1] Les nombres entre crochets se réfèrent à la bibliographie.

ESSAIS RELATIFS AUX RISQUES DU FEU –

Partie 6-1: Obscurcissement dû à la fumée – Recommandations générales

1 Domaine d'application

La présente partie de l'IEC 60695 fournit des recommandations relatives:

a) au mesurage optique de l'*obscurcissement de la lumière par la fumée*;
b) aux aspects généraux des méthodes d'essais optiques de la *fumée*;
c) aux considérations concernant les méthodes d'essai;
d) à l'expression des résultats d'essais de *fumée*;
e) à la pertinence des résultats des mesurages optiques de la *fumée* pour l'évaluation du danger.

La présente publication fondamentale de sécurité portant sur des recommandations de sécurité est avant tout destinée à être utilisée par les comités d'études dans le cadre de l'élaboration de publications de sécurité, conformément aux principes établis dans le Guide 104 de l'IEC et dans le Guide ISO/IEC 51.

L'une des responsabilités d'un comité d'études consiste, le cas échéant, à utiliser les publications fondamentales de sécurité dans le cadre de l'élaboration de ses publications.

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu'ils constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60695-1-10, *Essais relatifs aux risques du feu – Partie 1-10: Lignes directrices pour l'évaluation des risques du feu des produits électrotechniques – Lignes directrices générales*

IEC 60695-1-11, *Essais relatifs aux risques du feu – Partie 1-11: Lignes directrices pour l'évaluation du danger du feu des produits électrotechniques – Évaluation du danger du feu*

IEC 60695-4, *Essais relatifs aux risques du feu – Partie 4: Terminologie relative aux essais au feu pour les produits électrotechniques*

IEC 60695-6-2, *Essais relatifs aux risques du feu – Partie 6-2: Opacité des fumées – Résumé et pertinence des méthodes d'essais*

Guide IEC 104, *The preparation of safety publications and the use of basic safety publications and group safety publications* (disponible en anglais seulement)

ISO/IEC Guide 51, *Aspects liés à la sécurité – Principes directeurs pour les inclure dans les normes*

ISO 13943:2017, *Sécurité au feu – Vocabulaire*

3 Termes, définitions et symboles

3.1 Termes et définitions

Pour les besoins du présent document, les termes et les définitions de l'ISO 13943:2017 et de l'IEC 60695-4, dont certains sont reproduits ci-dessous, s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp

3.1.1
surface d'extinction de la fumée
produit du volume occupé par la *fumée* (3.1.10) et le *coefficient d'extinction* (3.1.2) de la fumée

Note 1 à l'article: La surface d'extinction de la fumée est une mesure de la quantité de fumée. Elle est exprimée en m^2.

[SOURCE: ISO 13943:2017, 3.110]

3.1.2
coefficient d'extinction
logarithme népérien du rapport de l'intensité lumineuse incidente à l'intensité lumineuse émise, par unité de longueur de la trajectoire optique

Note 1 à l'article: Il est exprimé en m^{-1}.

[SOURCE: ISO 13943:2017, 3.111]

3.1.3
densité optique massique de la fumée
densité optique de la fumée (3.1.6) multipliée par un coefficient, qui est le volume de la chambre d'essai divisé par le produit de la perte de masse de l'éprouvette d'essai et la longueur du trajet optique

Note 1 à l'article: Elle est exprimée en $m^2 \cdot g^{-1}$.

Note 2 à l'article: Densité optique de la fumée = $V/(\Delta m\ L)$, où V est le volume de la chambre d'essai, Δm est la perte de masse de l'éprouvette d'essai et L est la longueur du trajet optique.

[SOURCE: ISO 13943:2017, 3.265]

3.1.4
obscurcissement de la lumière par la fumée
réduction de l'intensité de la lumière lors de son passage à travers la *fumée* (3.1.10)

Note 1 à l'article: À comparer avec les termes *surface d'extinction de la fumée* (3.1.1), *coefficient d'extinction* (3.1.2), *opacité de la fumée* (3.1.5), *densité optique de la fumée* (3.1.6), *obscurcissement dû à la fumée* (3.1.11), *surface spécifique d'extinction de la fumée* (3.1.13) et *densité optique spécifique de la fumée* (3.1.14).

Note 2 à l'article: En pratique, l'obscurcissement de la lumière par la fumée est mesuré généralement comme la transmittance, qui est exprimée normalement en pourcentage.

Note 3 à l'article: L'obscurcissement de la lumière par la fumée provoque une diminution de la *visibilité* (3.1.6).

[SOURCE: ISO 13943:2017, 3.286, modifié – Le terme "obscurcissement par la fumée" a été remplacé par "obscurcissement de la lumière par la fumée".]

3.1.5
opacité de la fumée
rapport de l'intensité lumineuse incidente à l'intensité lumineuse transmise à travers la *fumée* (3.1.10), dans des conditions spécifiées

Note 1 à l'article: Également, *obscurcissement de la lumière par la fumée* (3.1.4), *obscurcissement dû à la fumée* (3.1.11).

Note 2 à l'article: L'opacité de la fumée est l'inverse de la transmittance.

Note 3 à l'article: L'opacité de la fumée est une grandeur sans dimension.

[SOURCE: ISO 13943:2017, 3.287]

3.1.6
densité optique de la fumée
mesure de l'atténuation du rayon lumineux passant à travers la *fumée* (3.1.10), exprimée comme le logarithme décimal de l'*opacité de la fumée* (3.1.5)

Note 1 à l'article: À comparer avec le terme *densité optique spécifique de la fumée* (3.1.14).

Note 2 à l'article: La densité optique de la fumée est une grandeur sans dimension.

[SOURCE: ISO 13943:2017, 3.288]

3.1.7
modèle physique du feu
procédé de laboratoire, incluant l'appareillage, l'environnement et le mode opératoire d'essai au feu, destiné à représenter une certaine étape d'un incendie

[SOURCE: ISO 13943:2017, 3.298]

3.1.8
SMOGRA
paramètre de vitesse de développement de la fumée qui dépend du rapport entre la production de la fumée et le temps de production de la fumée

Note 1 à l'article: De plus amples informations sont données en 6.2.4.

3.1.9
indice SMOGRA
valeur maximale de *SMOGRA* (3.1.8) pendant une période d'essai définie

Note 1 à l'article: De plus amples informations sont données en 6.2.4.

3.1.10
fumée
partie visible des effluents du feu

[SOURCE: ISO 13943:2017, 3.347]

3.1.11
obscurcissement dû à la fumée
réduction de la transmission de la lumière due à la *fumée* (3.1.10), mesurée par l'atténuation du rayon lumineux

Note 1 à l'article: À comparer avec les termes *surface d'extinction de la fumée* (3.1.1), *coefficient d'extinction* (3.1.2), *obscurcissement de la lumière par la fumée* (3.1.4), *opacité de la fumée* (3.1.5), *densité optique de la fumée* (3.1.6), *surface spécifique d'extinction de la fumée* (3.1.13) et *densité optique spécifique de la fumée* (3.1.14).

[SOURCE: ISO 13943:2017, 3.349]

3.1.12
taux de dégagement de fumée
quantité de *fumée* (3.1.10) produite par unité de temps au cours d'un feu ou au cours d'un essai au feu

Note 1 à l'article: Le taux de dégagement de fumée est calculé comme étant le produit du débit volumétrique de *fumée* (3.1.10) par le *coefficient d'extinction* (3.1.2) de la fumée au point de mesure.

Note 2 à l'article: Il est exprimé en $m^2 \cdot s^{-1}$.

[SOURCE: ISO 13943:2017, 3.351]

3.1.13
surface spécifique d'extinction de la fumée
surface d'extinction de la fumée (3.1.1) produite par une éprouvette d'essai pendant une période donnée divisée par la perte de masse de l'éprouvette pendant la même période

Note 1 à l'article: Elle est exprimée en $m^2 \cdot g^{-1}$.

[SOURCE: ISO 13943:2017, 3.358]

3.1.14
densité optique spécifique de la fumée
densité optique de la fumée (3.1.6) multipliée par un coefficient géométrique

Note 1 à l'article: Le coefficient géométrique est $V/(A \cdot L)$, où V est le volume de la chambre d'essai, A est l'aire de la surface exposée de l'éprouvette d'essai, et L est la longueur du trajet optique.

Note 2 à l'article: Le terme "spécifique" ne signifie pas "par unité de masse", mais indique plutôt une grandeur associée à un appareillage d'essai particulier et à l'aire de la surface exposée de l'éprouvette.

Note 3 à l'article: La densité optique de la fumée est une grandeur sans dimension.

[SOURCE: ISO 13943:2017, 3.360]

3.1.15
visibilité
distance maximale à laquelle un objet de dimension, luminosité et contraste définis peut être vu et reconnu

[SOURCE: ISO 13943:2017, 3.420]

3.2 Symboles

Symbole	Grandeur	Unités types
A	surface exposée de l'éprouvette d'essai	m^2
D	coefficient d'absorption linéaire décimal (communément appelé densité optique par mètre)	m^{-1}
D'	*densité optique de la fumée*	sans dimension
D_{mass}	*densité optique massique de la fumée*	m^2 kg–^{1}
D_s	*densité optique spécifique de la fumée*	sans dimension
D_{max} (aussi D_m)	*densité optique spécifique* maximale *de la fumée*	sans dimension
I	intensité du flux lumineux incident	cd
I/T	*opacité de la fumée* (rapport du flux lumineux incident sur le flux lumineux transmis)	sans dimension
k	coefficient d'absorption linéaire népérien (communément appelé *coefficient d'extinction*)	m^{-1}
L	longueur du flux lumineux traversant la *fumée*	m
Δm	perte de masse de l'éprouvette d'essai	kg

Symbole	Grandeur	Unités types
$\dot{m}$	vitesse de perte de masse	kg s–1
S	*surface d'extinction de la fumée (aussi fumée totale)*	m^2
$\dot{S}$	*taux de dégagement de fumée* (vitesse de changement de la surface d'extinction)	$m^2\ s^{-1}$
t	temps	s
Δt	intervalle de temps	s
T	intensité du flux lumineux transmis	cd
V	volume de la chambre	m^3
$\dot{V}$	vitesse du flux volumique de la *fumée*	$m^3\ s^{-1}$
σ_f	*surface spécifique d'extinction de la fumée*	$m^2\ kg^{-1}$
γ	constante de proportionnalité entre la *visibilité* et le *coefficient d'extinction*	sans dimension
ω	*visibilité*	m

NOTE 1 Les grandeurs fondées sur $\log_{10}$, c'est-à-dire D, D', D_{max}, D_{mass} et D_s, ont des symboles semblables mais sont des grandeurs différentes et elles ont des unités différentes.

NOTE 2 L'utilisation du terme "spécifique" dans l'expression *densité optique spécifique* de la fumée, D_s, ne signifie pas "par unité de masse".

4 Aspects généraux des méthodes d'essai de fumée

4.1 Scénarios et modèles physiques du feu

Au cours des dernières années, des progrès importants ont été réalisés dans l'analyse des effluents du feu. Il est reconnu que la composition du mélange des produits de combustion dépend particulièrement de la nature des matériaux en combustion, des températures sur le site et des conditions de ventilation, notamment l'accès d'oxygène sur le foyer de l'incendie. Le Tableau 1 présente la manière dont les différents types de feu sont liés aux changements d'atmosphère. Les conditions à utiliser lors des essais de laboratoire (à petite ou à grande échelle) peuvent être tirées du tableau afin qu'elles correspondent, autant que possible, à des feux en grandeur réelle.

Un incendie met en œuvre un ensemble complexe de phénomènes physiques et chimiques étroitement liés. Il en résulte qu'il est difficile de simuler tous les aspects d'un incendie en grandeur réelle à l'aide d'un appareillage à échelle plus petite. Le problème de la validité du *modèle physique du feu* est peut-être le problème technique le plus préoccupant lié à tous les essais au feu.

Des recommandations générales pour l'évaluation du danger d'incendie des produits électrotechniques sont données dans l'IEC 60695-1-10 et dans l'IEC 60695-1-11.

Après l'allumage, l'incendie peut se développer de différentes façons, selon les conditions d'environnement et la disposition des matériaux combustibles. Il est cependant possible d'établir un schéma général du développement d'un incendie à l'intérieur d'un compartiment, dans lequel la courbe générale temps-température présente trois phases ainsi qu'une phase de déclin (voir la Figure 1).

La phase 1 correspond à la naissance du feu avant la combustion soutenue avec flammes, s'accompagnant d'une faible augmentation de la température de la pièce. L'allumage et le dégagement de *fumée* sont les principaux dangers durant cette phase. La phase 2 (feu en cours de développement) commence avec l'allumage et finit avec une augmentation exponentielle de la température de la pièce. La propagation des flammes et le dégagement de chaleur sont les principaux dangers, en plus de la fumée, durant cette phase. La phase 3 (feu pleinement développé) débute lorsque la surface de tous les objets combustibles dans la pièce s'est suffisamment décomposée pour que survienne un allumage soudain dans toute la pièce, avec un accroissement de température rapide et important (embrasement éclair).

À la fin de la phase 3, les combustibles et/ou l'oxygène ont été en grande partie consumés et la température décroît à une vitesse dépendant de la ventilation et du transfert de chaleur et de masse du système. C'est la phase de déclin.

À chacune de ces phases, il peut se former un mélange différent de produits de décomposition, et cela exerce une influence sur la *fumée* produite pendant ces phases. Afin de choisir un essai au feu adapté, des informations sur le scénario d'incendie envisagé sont exigées, en particulier, sur les conditions de flux thermique incident, l'oxygène disponible et les équipements de ventilation de la *fumée*.

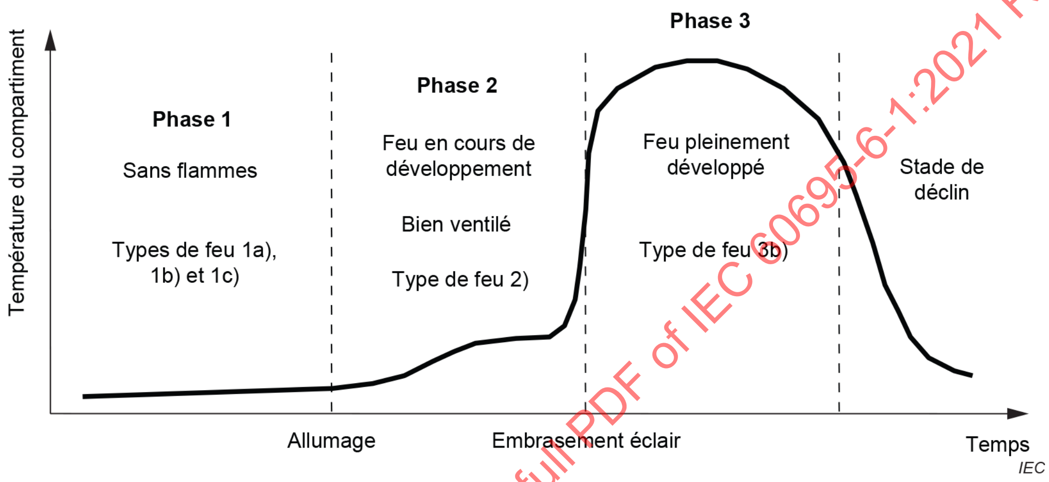

Figure 1 – Différentes phases du développement d'un feu à l'intérieur d'un compartiment

4.2 Facteurs affectant le dégagement de fumée

4.2.1 Généralités

De nombreux facteurs influent sur le dégagement de *fumée* ainsi que sur ses caractéristiques. Une description complète de ces caractéristiques n'est pas possible, mais il est reconnu que plusieurs variables importantes exercent une influence.

4.2.2 Modes de décomposition

La *fumée* est le produit d'une combustion. Cette dernière peut être une combustion avec ou sans flammes, y compris le feu couvant, et ces différents modes de combustion peuvent produire différents types de *fumée*. Dans une combustion sans flammes, des substances volatiles sont dégagées aux températures élevées. Lorsqu'elles se mélangent avec de l'air frais, elles se condensent en gouttes sphériques qui apparaissent sous forme d'aérosol de *fumée* légèrement coloré.

La combustion avec flammes produit une *fumée* noire, riche en carbone, dont les particules ont une forme très irrégulière. Les particules de *fumée* provenant de la combustion avec flammes vives sont formées en phase gazeuse et dans des zones où les concentrations d'oxygène sont assez basses pour causer une combustion incomplète. Les particules de *fumée* charbonneuse dans les flammes émettent une énergie rayonnante (identique à l'émission de corps noirs) qui est visible sous la forme d'une lumière jaune.

La taille des particules des gouttelettes sphériques provenant de la combustion sans flammes est généralement de l'ordre de 1 µm, celle des particules de suie irrégulières issues d'une combustion avec flammes vives est, par contre, souvent plus grande mais bien plus difficile à déterminer et elle dépend de la technique de mesure.

Dans les feux de bois, il est souvent observé que la quantité de *fumée* est moins importante dans une combustion avec flammes que dans une combustion sans flammes. Cependant, en ce qui concerne les plastiques, une telle généralisation n'est pas possible: la *fumée* produite par un feu sans flammes peut être plus importante ou moins importante que celle produite lors d'une combustion avec flammes. Pour ces raisons, il est important de noter, pendant l'essai de *fumée*, s'il y a allumage ou pas, et, le cas échéant, les temps d'allumage et de disparition des flammes de l'éprouvette d'essai. En outre, une *fumée* froide, dont la couleur et la composition peuvent être sensiblement différentes de la *fumée* produite par la surface exposée, peut être émise par la face non visible des composites.

Tableau 1 – Caractéristiques des stades de développement d'un feu (tiré du Tableau 1 de l'ISO 19706:2011)[2]

Stades de développement d'un feu	Flux de chaleur à la surface du combustible kW/m²	Température max. °C		Volume d'oxygène %		Rapport d'équivalence combustible/air (panache)	$\frac{[CO]}{[CO_2]}$ v/v	$\frac{100 \times [CO_2]}{([CO_2]+[CO])}$ Efficacité en %
		À la surface du combustible	Dans la couche supérieure des fumées	Entraîné	Dégagé			
1. Sans flammes								
a. autoentretenu (couvant)	non applicable	450 à 800	25 à 85 [d]	20	20	–	0,1 à 1	50 à 90
b. pyrolyse oxydante due à un rayonnement externe appliqué	–	300 à 600 [a]	[b]	20	20	< 1	[c]	[c]
c. pyrolyse anaérobie due à un rayonnement externe appliqué	–	100 à 500	[b]	0	0	>> 1	[c]	[c]
2. Avec flammes, bien ventilé [d]	0 à 60	350 à 650	50 à 500	≈ 20	≈ 20	< 1	< 0,05 [e]	> 95
3. Avec flammes, sous-ventilé [f]								
a. petit feu localisé, en général dans un compartiment mal ventilé	0 à 30	300 à 600 [a]	50 à 500	15 à 20	5 à 10	> 1	0,2 à 0,4	70 à 80
b. feu post-embrasement éclair	50 à 150	350 à 650 [g]	> 600	< 15	< 5	> 1 [h]	0,1 à 0,4 [i]	70 à 90

[2] *Le Tableau 1 — Caractéristiques des stades de développement d'un feu extrait de la norme ISO 19706:2011, Lignes directrices pour l'évaluation des dangers du feu pour les personnes*, est reproduit avec l'autorisation de l'Organisation Internationale de Normalisation, ISO. Cette norme peut être obtenue auprès de tout membre de l'ISO et sur le site web du Secrétariat Central de l'ISO à l'adresse suivante: www.iso.org. ISO demeure le propriétaire des droits d'auteur.