

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Fire hazard testing –

Part 7-2: Toxicity of fire effluent – Summary and relevance of test methods

Essais relatifs aux risques du feu –

Partie 7-2: Toxicité des effluents du feu – Résumé et pertinence des méthodes d'essai



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d'essai**

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

FIRE HAZARD TESTING –**Part 7-2: Toxicity of fire effluent –
Summary and relevance of test methods**

FOREWORD

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International Standard IEC 60695-7-2 has been prepared by IEC technical committee 89: Fire hazard testing.

This first edition of IEC 60695-7-2 cancels and replaces the first edition of Technical Report IEC/TR 60695-7-2 published in 2002. It constitutes a technical revision and now has the status of an International Standard.

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

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

- editorial changes throughout;
- expanded normative references;
- revised terms and definitions;

- modifications to “Repeatability and reproducibility” data throughout;
- modifications to “Relevance of test data” throughout;
- modifications to Clause 5;
- new Table 1 and Figure 1;
- introduction of ISO test method in new Subclause 6.6;
- introduction of test method from EN 50305 in new Subclause 6.8;
- revised Annex A and new Table A.1;
- expanded Bibliography.

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

FDIS	Report on voting
89/1059/FDIS	89/1073/RVD

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

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

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

IEC 60695-7 consists of the following parts:

- Part 7-1: Toxicity of fire effluent – General guidance
- Part 7-2: Toxicity of fire effluent – Summary and relevance of test methods
- Part 7-3: Toxicity of fire effluent – Use and interpretation of test results
- Part 7-50: Toxicity of fire effluent – Estimation of toxic potency – Apparatus and test method
- Part 7-51: Toxicity of fire effluent – Estimation of toxic potency – Calculation and interpretation of test results

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

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

INTRODUCTION

The IEC 60695-7 series provides guidance to IEC product committees on the adoption and implementation of the recommendations of ISO/TC 92, for the minimization of toxic hazard from fires involving electrotechnical products.

Electrotechnical products, primarily as the objects of a fire, may contribute to the fire hazard due to release of toxic effluent, which may be a significant contributing factor to the overall fire hazard.

IEC product committees incorporating requirements for the assessment of toxic hazard from fire in product standards should note that toxic potency and other measurements of toxicity which are described in this international standard should not be used directly in product specifications. Data from toxic potency test methods should only be used as part of a toxic hazard assessment, in conjunction with other product-based reaction to fire data such as mass loss rate.

FIRE HAZARD TESTING –

Part 7-2: Toxicity of fire effluent – Summary and relevance of test methods

1 Scope

This part of IEC 60695 gives a brief summary of the test methods that are in common use in the assessment of acute toxic potency, and other toxicity tests. It includes special observations on their relevance to real fire scenarios and gives recommendations on their use.

It advises which tests provide toxic potency data that are relevant to real fire scenarios, and which are suitable for use in fire hazard assessment and fire safety engineering.

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

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

2 Normative references

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

IEC 60695-7-1:2010, *Fire hazard testing – Part 7-1: Toxicity of fire effluent – General guidance*

IEC/TS 60695-7-3, *Fire hazard testing – Part 7-3: Toxicity of fire effluent – Use and interpretation of test results*

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

ISO/IEC 13943, *Fire safety – Vocabulary*

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

ISO 13344, *Estimation of the lethal toxic potency of fire effluents*

ISO 13571:2007, *Life-threatening components of fire – Guidelines for the estimation of time available for escape using fire data*

ISO 16312-1:2010, *Guidance for assessing the validity of physical fire models for obtaining fire effluent toxicity data for fire hazard and risk assessment – Part 1: Criteria*

ISO/TR 16312-2:2007, *Guidance for assessing the validity of physical fire models for obtaining fire effluent toxicity data for fire hazard and risk assessment – Part 2: Evaluation of individual physical fire models*

ISO 19701, *Methods for sampling and analysis of fire effluents*

ISO 19702, *Toxicity testing of fire effluents – Guidance for analysis of gases and vapours in fire effluents using FTIR gas analysis*

ISO 19703:2010, *Generation and analysis of toxic gases in fire – Calculation of species yields, equivalence ratios and combustion efficiency in experimental fires*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 13943:2008, some of which are reproduced below for the user's convenience, as well as the following, apply.

3.1

acute toxicity

toxicity that causes rapidly occurring toxic effects

cf. **toxic potency** (3.45).

[ISO/IEC 13943:2008, definition 4.5]

3.2

burn, intransitive verb
undergo combustion

[ISO/IEC 13943:2008, definition 4.28]

3.3

burn, transitive verb
cause combustion

[ISO/IEC 13943:2008, definition 4.29]

3.4

combustible, adjective
capable of being ignited and burned

[ISO/IEC 13943:2008, definition 4.43]

3.5

combustible, noun
item capable of combustion

[ISO/IEC 13943:2008, definition 4.44]

3.6

combustion

exothermic reaction of a substance with an oxidizing agent

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

[ISO/IEC 13943:2008, definition 4.46]

3.7

combustion efficiency

ratio of the amount of heat release in incomplete combustion to the theoretical heat of complete combustion

NOTE 1 Combustion efficiency can be calculated only for cases where complete combustion can be defined.

NOTE 2 Combustion efficiency is dimensionless and is usually expressed as a percentage.

[ISO/IEC 13943:2008, definition 4.47]

3.8

complete combustion

combustion in which all the combustion products are fully oxidized

NOTE 1 This means that, when the oxidizing agent is oxygen, all carbon is converted to carbon dioxide and all hydrogen is converted to water.

NOTE 2 If elements other than carbon, hydrogen and oxygen are present in the combustible material, those elements are converted to the most stable products in their standard states at 298 K.

[ISO/IEC 13943:2008, definition 4.50]

3.9

concentration

mass per unit volume

NOTE 1 For a fire effluent the typical units are grams per cubic metre ($\text{g} \times \text{m}^{-3}$).

NOTE 2 For a toxic gas, concentration is usually expressed as a volume fraction at $T = 298 \text{ K}$ and $P = 1 \text{ atm}$, with typical units of microlitres per litre ($\mu\text{L/L}$), which is equivalent to cm^3/m^3 or 10^{-6} .

NOTE 3 The concentration of a gas at a temperature, T , and a pressure, P , can be calculated from its volume fraction (assuming ideal gas behaviour) by multiplying the volume fraction by the density of the gas at that temperature and pressure.

[ISO/IEC 13943:2008, definition 4.52]

3.10

enclosure

(built environment) volume defined by bounding surfaces, which may have one or more openings

[ISO/IEC 13943:2008, definition 4.77]

3.11

equivalence ratio

fuel/air ratio divided by the fuel/air ratio required for a stoichiometric mixture

NOTE 1 Standard, dry air contains 20,95 % oxygen by volume. In practice, the oxygen concentration in entrained air can vary and calculation of the equivalence ratio to a standard, dry air basis is required.

NOTE 2 The equivalence ratio is dimensionless.

[ISO/IEC 13943:2008, definition 4.81]

3.12

exposure dose

measure of the maximum amount of a toxic gas or fire effluent that is available for inhalation, calculated by integration of the area under a concentration-time curve

NOTE 1 For fire effluent, typical units are grams times minutes per cubic metre ($\text{g} \times \text{min} \times \text{m}^{-3}$).

NOTE 2 For a toxic gas, typical units are microlitres times minutes per litre ($\mu\text{L} \times \text{min} \times \text{L}^{-1}$) (at $T = 298 \text{ K}$ and $P = 1 \text{ atm}$); see 'volume fraction' 3.49.

[ISO/IEC 13943:2008, definition 4.89]

3.13

exposure time

length of time for which people, animals or test specimens are exposed under specified conditions

[ISO/IEC 13943:2008, definition 4.90]

3.14

F factor

minimum concentration of a toxic gas irritant that is expected to seriously compromise the ability to escape from a fire

NOTE The concentration is usually expressed as a volume fraction at $T = 298 \text{ K}$ and $P = 1 \text{ atm}$, in which case the typical units are microlitres per litre ($\mu\text{L/L}$), which is equivalent to cm^3/m^3 or 10^{-6} .

[ISO/IEC 13943:2008, definition 4.94]

3.15

fire

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

[ISO/IEC 13943:2008, definition 4.96]

3.16

fire effluent

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

[ISO/IEC 13943:2008, definition 4.105]

3.17

fire hazard

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

[ISO/IEC 13943:2008, definition 4.112]

3.18

fire hazard assessment

evaluation of the possible causes of fire, the possibility and nature of subsequent fire growth, and the possible consequences of fire

3.19

fire plume

plume

buoyant gas stream and any materials transported within it, above a fire

[ISO/IEC 13943:2008, definition 4.118]

3.20

fire-safety engineering

application of engineering methods based on scientific principles to the development or assessment of designs in the built environment through the analysis of specific fire scenarios or through the quantification of risk for a group of fire scenarios

[ISO/IEC 13943:2008, definition 4.126]

3.21

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 13943:2008, definition 4.129]

3.22

fire test

test that measures behaviour of a fire or exposes an item to the effects of a fire

NOTE The results of a fire test can be used to quantify fire severity or determine the fire resistance or reaction to fire of the test specimen.

[ISO/IEC 13943:2008, definition 4.132]

3.23

flame retardance

property of a material whereby flaming combustion is slowed, terminated or prevented

NOTE 1 Flame retardance can be an inherent property of the basic material or it may be imparted by specific treatment.

NOTE 2 The degree of flame retardance exhibited by a material during testing can vary with the test conditions.

[ISO/IEC 13943:2008, definition 4.138]

3.24

flame retardant, noun

substance added, or a treatment applied, to a material in order to suppress or delay the appearance of a flame and/or reduce the flame-spread rate

NOTE The use of (a) flame retardant(s) does not necessarily suppress fire or terminate combustion.

[ISO/IEC 13943:2008, definition 4.139]

3.25

flame retarded

treated with a flame retardant

[ISO/IEC 13943:2008, definition 4.141]

3.26

flashover

(stage of fire) transition to a state of total surface involvement in a fire of combustible materials within an enclosure

[ISO/IEC 13943:2008, definition 4.156]

3.27

fractional effective concentration

FEC

ratio of the concentration of an irritant to that concentration expected to produce a specified effect on an exposed subject of average susceptibility

NOTE 1 As a concept, fractional effective concentration may refer to any effect, including incapacitation, lethality or other endpoints.

NOTE 2 When not used with reference to a specific irritant, the term "FEC" represents the summation of FEC values for all irritants in a fire-generated atmosphere.

NOTE 3 The FEC is dimensionless.

[ISO/IEC 13943:2008, definition 4.159]

3.28

fractional effective dose

FED

ratio of the exposure dose for an asphyxiant to that exposure dose of the asphyxiant expected to produce a specified effect on an exposed subject of average susceptibility

NOTE 1 As a concept, fractional effective dose may refer to any effect, including incapacitation, lethality or other endpoints.

NOTE 2 When not used with reference to a specific asphyxiant, the term “FED” represents the summation of FED values for all asphyxiants in a combustion atmosphere.

NOTE 3 The FED is dimensionless.

[ISO/IEC 13943:2008, definition 4.160]

3.29

fully developed fire

state of total involvement of combustible materials in a fire

[ISO/IEC 13943:2008, definition 4.164]

3.30

heat flux

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

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

[ISO/IEC 13943:2008, definition 4.173]

3.31

ignition source

source of energy that initiates combustion

[ISO/IEC 13943:2008, definition 4.189]

3.32

incapacitation

state of physical inability to accomplish a specific task

NOTE An example of a specific task is to accomplish escape from a fire.

[ISO/IEC 13943:2008, definition 4.194]

3.33

lethal concentration 50

LC_{50}

concentration of a toxic gas or fire effluent, statistically calculated from concentration-response data, that causes death of 50 % of a population of a given species within a specified exposure time and post-exposure time

NOTE 1 For fire effluent, typical units are grams per cubic metre ($\text{g} \times \text{m}^{-3}$).

NOTE 2 For a toxic gas, the typical units are microlitres per litre ($\mu\text{L}/\text{L}$) at $T = 298 \text{ K}$ and $P = 1 \text{ atm}$; see ‘volume fraction’ 3.49.

[ISO/IEC 13943:2008, definition 4.207]

3.34

lethal exposure dose 50

LCt_{50}

product of LC_{50} and the exposure time over which it is determined

cf. **concentration** (3.9) and **exposure dose** (3.12).

NOTE 1 LCt_{50} is a measure of lethal toxic potency.

NOTE 2 For fire effluent, the typical units are grams times minutes per cubic metre ($g \times min \times m^{-3}$).

NOTE 3 For a toxic gas, typical units are microlitres times minutes per litre ($\mu L \times min \times L^{-1}$) at $T = 298\text{ K}$ and $P = 1\text{ atm}$; see 'volume fraction' 3.49.

[ISO/IEC 13943:2008, definition 4.208]

3.35

lethal toxic potency

toxic potency where the specific toxic effect is death

cf. **lethal exposure dose 50**, LCt_{50} (3.34).

3.36

mass loss concentration

(closed system) mass of the test specimen consumed during combustion divided by the test chamber volume

NOTE The typical units are grams per cubic metre ($g \times m^{-3}$).

[ISO/IEC 13943:2008, definition 4.222]

3.37

mass loss concentration

(open system) mass of the test specimen consumed during combustion divided by the total volume of air passed through the test apparatus

NOTE 1 The definition assumes that the mass is dispersed in the air flow uniformly over time.

NOTE 2 The typical units are grams per cubic metre ($g \times m^{-3}$).

[ISO/IEC 13943:2008, definition 4.223]

3.38

physical fire model

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

[ISO/IEC 13943:2008, definition 4.251]

3.39

pyrolysis

chemical decomposition of a substance by the action of heat

NOTE 1 Pyrolysis is often used to refer to a stage of fire before flaming combustion has begun.

NOTE 2 In fire science, no assumption is made about the presence or absence of oxygen.

[ISO/IEC 13943:2008, definition 4.266]

3.40

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 13943:2008, definition 4.273]

3.41

smoke

visible part of fire effluent

[ISO/IEC 13943:2008, definition 4.293]

3.42

test specimen

item subjected to a procedure of assessment or measurement

NOTE In a fire test, the item may be a material, product, component, element of construction, or any combination of these. It may also be a sensor that is used to simulate the behaviour of a product.

[ISO/IEC 13943:2008, definition 4.321]

3.43

thermal decomposition

process whereby the action of heat or elevated temperature on an item causes changes to the chemical composition

NOTE This is different from thermal degradation.

[ISO/IEC 13943:2008, definition 4.323]

3.44

toxic

poisonous

NOTE A poisonous substance produces adverse effects upon a living organism, e.g. irritation, narcosis or death.

[ISO/IEC 13943:2008, definition 4.335]

3.45

toxic hazard

potential for harm resulting from exposure to toxic combustion products

cf. **fire hazard** (3.17).

[ISO/IEC 13943:2008, definition 4.337]

3.46

toxic potency

measure of the amount of toxicant required to elicit a specific toxic effect

cf. **lethal exposure dose 50** (3.34).

NOTE A small value of toxic potency corresponds to a high toxicity, and vice versa.

[ISO/IEC 13943:2008, definition 4.338]

3.47

toxicant

toxin

toxic substance

[ISO/IEC 13943:2008, definition 4.340]

3.48

toxicity

toxic quality

cf. **acute toxicity** (3.1) and **toxic potency** (3.46).

[ISO/IEC 13943:2008, definition 4.341]

3.49

volume fraction

⟨gas in a gas mixture⟩ ratio of

- the volume that the gas alone would occupy at a defined temperature and pressure, to:
- the volume occupied by the gas mixture at the same temperature and pressure

NOTE 1 The concentration of a gas at a temperature, T , and a pressure, P , can be calculated from its volume fraction (assuming ideal gas behaviour) by multiplying the volume fraction by the density of the gas at that temperature and pressure.

NOTE 2 Unless stated otherwise, a temperature of 298 K and a pressure of 1 atm are assumed.

NOTE 3 The volume fraction is dimensionless and is usually expressed in terms of microlitres per litre ($\mu\text{L/L}$), which is equivalent to cm^3/m^3 or 10^{-6} , or as a percentage.

[ISO/IEC 13943:2008, definition 4.351]

3.50

volume yield

volume, at 298 K and 1 atm, of a component of fire effluent divided by the mass loss of the test specimen associated with the production of that volume

NOTE The typical units are cubic metres per gram ($\text{m}^3 \times \text{g}^{-1}$).

[ISO/IEC 13943:2008, definition 4.352]

4 Role of small-scale toxicity tests

4.1 General

Small-scale toxicity tests, and toxic potency tests in particular, serve a very specific purpose – to generate data to be used in toxic hazard assessments, fire hazard assessments, or fire-safety engineering calculations.

These tests are often wrongly interpreted as providing data which give a direct indication of the toxicity or toxic hazard associated with a material or product. Such interpretations are invalid and are contrary to the guidance given in ISO 19706 and IEC 60695-7-1, and are likely to lead to incorrect assumptions about the contribution of a given material or product to toxic hazard.

Therefore, the data from small-scale toxicity tests should not be used directly in product specifications, or to imply in isolation, any level of toxic hazard.

Data from toxic potency test methods should only be used as part of a toxic hazard assessment in conjunction with other product based reaction to fire data such as mass loss rate.

4.2 Toxic potency

The term toxic potency is a specific technical term in fire science. It is the measure of the amount of toxicant required to elicit a specific toxic effect. One specific toxic potency that is

commonly used is the exposure dose that causes the death of 50 % of exposed organisms. This is known as the LCt_{50} (lethal exposure dose 50).

The exposure dose of the i^{th} toxic component, $[D]_i$, in a mixture of toxic components, is defined by the following equation:

$$[D]_i = \int C_i dt = X_i \frac{1}{V} \int m dt = X_i D_m$$

or, if the volume fraction of the i^{th} toxic component is constant over time,

$$[D]_i = C_i \times t$$

where

- C_i is the volume fraction of the i^{th} toxic component;
- X_i is the volume yield of the i^{th} toxic component from a toxic potency test;
- D_m is the mass loss concentration integral, which is the integral of the mass lost over the exposure time, t , divided by the volume of the fire effluent;
- m is the mass of the test specimen lost during the time of exposure;
- t is the exposure time, and
- V is the volume into which the fire effluent is dispersed.

In both cases the exposure dose has units of volume fraction $\times$ time, e.g. min.

In some cases, m/V , known as "mass loss concentration", is used instead of the volume fraction, in which case the exposure dose has units of concentration $\times$ time, e.g. $\text{g} \times \text{min} \times \text{m}^{-3}$.

Suppose that a 30 min exposure to a mass loss concentration of $20 \text{ g} \times \text{m}^{-3}$ causes the defined effect, then the toxic potency of the material is $600 \text{ g} \times \text{min} \times \text{m}^{-3}$. This means that, for example, an exposure of 10 min to a mass loss concentration of $60 \text{ g} \times \text{m}^{-3}$ is assumed to cause the defined effect. Similarly, an exposure of 20 min to a mass loss concentration of $30 \text{ g} \times \text{m}^{-3}$ is also assumed to cause the same defined effect.

The toxic potency of the fire effluent from a given material will vary according to the physical fire model used to generate the fire effluent. In particular, temperature and ventilation conditions are critical variables. This is discussed further in 5.1.

4.3 Fractional effective dose (FED) and toxic hazard

Toxic potency is only one of the factors which determines the toxic hazard posed in any given fire scenario in that it defines the toxic effect caused by the fire effluent, expressed per unit of mass loss. To estimate the toxic hazard posed by a particular product in a given scenario, it is equally important to have the data which define how much fire effluent is released, as a function of time (the mass loss characteristics of the product), and to know the volume into which this fire effluent is dispersed.

For a given dispersal volume, the toxic hazard is proportional to the product of the toxic potency and the mass loss rate characteristics of the product in question. Therefore a material with a high toxic potency and low end product mass loss rate could pose a similar toxic hazard to a material with low toxic potency and high end product mass loss rate.

4.4 Fractional effective concentration (*FEC*)

For sensory and/or upper respiration irritants, the basic principle for assessing the toxic hazard involves only the concentration of each irritant. Fractional effective concentrations (*FECs*) are determined for each irritant at each discrete increment of time. The time at which their sum exceeds a specified threshold value represents the time available for escape relative to chosen safety criteria (see ISO 13571).

4.5 Generic toxic potencies

It is important to realise that to carry out a toxic hazard assessment it is not always necessary to have toxic potency data on the material(s) in question. Extensive work in ISO and work published elsewhere has shown that most materials produce fire atmospheres of similar toxic potency.

Therefore, for the purpose of an initial toxic hazard assessment of any fire scenario, it is recommended that a generic toxic potency of $900 \text{ g} \times \text{min} \times \text{m}^{-3}$ is assumed for all materials in well-ventilated pre-flashover fires and $450 \text{ g} \times \text{min} \times \text{m}^{-3}$ for vitiated post-flashover fires (see 7.4 of ISO 13571:2007). The robustness of assuming a generic toxic potency can then be evaluated by repeating the assessment, using toxic potency values of 50 % and 200 % of the assumed generic value. If the alternative toxic potency values significantly change the outcome of the assessment, then further, more accurate toxic potency data may be required.

5 General aspects of small-scale toxicity tests

5.1 General

Small-scale toxicity tests are comprised, essentially, of two parts:

- a) decomposition conditions (the physical fire model), which should be such that they generate fire effluent which has the same relative composition as that which would be produced in a specific stage of a real fire, and
- b) evaluation methods for the fire effluent to assess or calculate toxic potency, which can be carried out by either exposing animals to the fire effluent, in a controlled manner, and monitoring their response, or by carrying out chemical analyses of the fire effluent and estimating toxic potency from their concentrations.

A critical part of any method is to be able to relate the toxic effect or concentrations observed to the mass loss of the material under test.

5.2 Physical fire models

A given material does not have a single toxic potency associated with it.

The composition of the fire effluent from a given material is not an inherent property of that material, but is critically dependent on the conditions under which that material is burnt. Therefore, the toxic potency of fire effluent is dependent on burning conditions. Decomposition temperature and the amount of ventilation are the main variables which affect the composition of fire effluent, and hence the toxic potency.

These variables have a critical effect because they affect the nature and the amounts of both asphyxiant and irritant species that are produced. For example, if a material contains nitrogen, then in vitiated conditions ammonia and hydrogen cyanide tend to be formed, whereas in well-ventilated conditions oxides of nitrogen tend to be produced.

Burning conditions also affect the efficiency of the conversion of carbon to oxides of carbon (carbon monoxide and carbon dioxide – the CO_2/CO ratio). A lower CO_2/CO ratio indicates a

higher proportion of carbon monoxide, which will result in a lower toxic potency value (i.e. more toxic)

It is critical to show that the test conditions defined in a standardized test method (the physical fire model) are relevant to, and replicate, the desired fire type in the fire scenario of concern. ISO has published a general classification of fire types in ISO 19706, as shown in Table 1. The important factors affecting the toxic potency of fire effluent are oxygen concentration and irradiance/ temperature.

In ISO 16312-1 guidance is given concerning the criteria for the assessment of the validity of physical fire models for obtaining fire effluent toxicity data for fire hazard and risk assessment and ISO/TR 16312-2 gives evaluations of individual physical fire models.

ISO 19703 provides definitions and equations for the calculation of toxic product yields and the fire conditions under which they have been derived in terms of equivalence ratio and combustion efficiency.

Table 1 – Characteristics of fire types (ISO 19706)

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

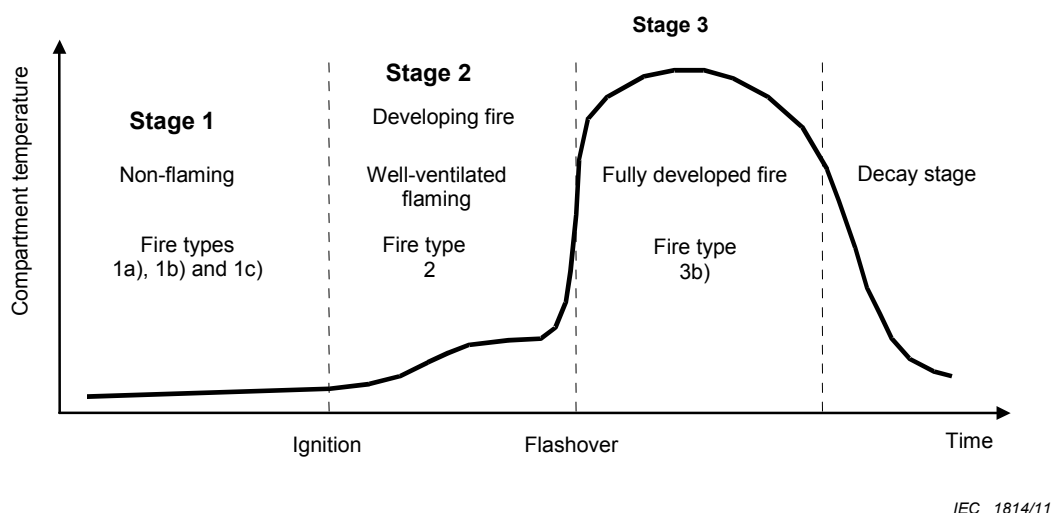
5.3 Fire stages in a compartment fire

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 and Table 1).

Stage 1 (non-flaming decomposition) is the incipient stage of the fire prior to sustained flaming, with little rise in the fire room temperature. Smoke and toxic effluent production are the main threats during this stage. Fire types 1a, 1b and 1c can all occur during this stage. Stage 2 (developing fire) starts with ignition and ends with an exponential rise in fire room temperature. Spread of flame, heat release and the production of smoke and toxic effluent are the main threats during this stage. Fire type 2 corresponds to 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 (flashover). Fire type 3b corresponds to this stage.

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 the decay stage.

In each of these stages, a different mixture of decomposition products may be formed and this, in turn, will influence the toxicity of the fire effluent produced during that stage.



IEC 1814/11

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

5.4 Methods of analysis

Early studies on the toxicity of fire effluent were based largely on the chemical analysis of fire gases and often gave faulty conclusions because of the poor quality of the data concerning the toxic potency of individual gases, and the lack of appreciation of the role of decomposition temperature and ventilation.

Work in the 1970s and early 1980s focused on animal tests on the basis that a complete understanding of the potential interactions between the individual components of fire effluent, and the possible presence of products exhibiting unusually high specific toxicity, could only be determined by animal exposure.

The conclusions from this work are that there are only moderately interactive effects between the constituents of fire effluent, and that there has not been an example of the presence of

products exhibiting unusually high specific toxicity in fire effluent. Toxic potencies of fire effluent from most materials have been found to be within one and a half orders of magnitude.

It is possible to calculate toxic potencies of fire gas mixtures reasonably accurately, based on the results of chemical analyses, and the toxicological data already available from animal testing. This avoids the need to use animals in the routine measurement of toxic potency, although it is recognized that some limited use of animal based tests may be necessary when the base toxicological data for a particular fire effluent are not available.

5.4.1 Chemical analysis based methods

Chemical analysis based methods use conventional laboratory analytical techniques to measure, either statically or dynamically, the concentrations of various gases in the fire effluent generated by the physical fire model [1]¹.

There are several factors which have a critical impact on the accuracy of chemical analysis based techniques:

- a) the effluent species selected for analysis should be broad enough to cover the species that could reasonably be expected to be released, based on knowledge of the composition of the material under test.

In all cases, carbon dioxide, carbon monoxide and oxygen should be measured.

- b) there shall be a reliable method to assess the mass loss of the test specimen during the test, in order to be able to convert the gas concentrations measured to concentrations per unit mass loss of test specimen;
- c) it shall be possible to convert the measured gas concentrations and mass loss into toxic potency values. See IEC 60695-7-3 for a calculation method.

In ISO 19701, methods for the sampling and analysis of fire effluents are reviewed, and in ISO 19702 guidance is given on the use of FTIR (Fourier transform infra-red analysis).

5.4.2 Methods based on animal exposure

It is not recommended that any further work should be conducted on methods based on animal testing.

NOTE If test specimen mass loss is not measured in an animal exposure test, then the yields of toxic components cannot be calculated.

6 Summary of published chemical analysis based test methods

6.1 General

This summary does not replace published standards, which are the only valid reference documents.

The chemical analysis based test methods reviewed in this clause were selected on the basis that they are published international, national or industry standards, and are in common use in the electrotechnical field. It is not intended to review all possible test methods.

¹ Numbers in square brackets refer to the bibliography.

6.2 UK Ministry of Defence – Defence Standard (DS)

6.2.1 Summary

The test described in DS 02-713 [2] explores the toxicity of products of combustion in terms of small molecular species arising when a small sample of a material is completely burnt in excess air under specified conditions.

6.2.2 Purpose and principle

Analytical data of certain small molecular gaseous species arising from the complete combustion under flaming conditions of the material under test are mathematically computed using the exposure level (volume fraction) of each gas to cause death within 30 min as a base, to derive a combined toxicity index.

6.2.3 Test specimen

A sufficient number of test specimens (normally three) are cut from the material under test. The mass of the test specimen is chosen so as to provide optimum analytical precision, dependent on the nature of the combustion products and the sensitivity of the analytical procedure.

6.2.4 Test method

The apparatus is an airtight enclosure of at least 0,7 m³ lined with opaque plastic sheeting such as polypropylene. The chamber is equipped with a mixing fan. A methane bunsen burner having a temperature of 1 150 °C ± 50 °C is the heat source, and the test specimen is supported to locate it within the flame boundary. The burn period is continued to ensure complete combustion of the whole test specimen, and the time is recorded.

The test chamber atmosphere is sampled using colorimetric gas detection tubes. After complete combustion, the burner is extinguished. For a period of 30 s a mixing fan is used. This is switched off and the gases are sampled. Tests for halogen containing gases are performed first. The gases monitored are: carbon monoxide, carbon dioxide, hydrogen sulphide, ammonia, formaldehyde, hydrogen chloride, acrylonitrile, sulphur dioxide, oxides of nitrogen (NO_x), phenol, hydrogen cyanide, hydrogen bromide, hydrogen fluoride, and phosgene.

A background correction factor for the gases to be measured is also determined using a test run with no sample present.

The results are expressed as a toxicity index, based on a weighted calculation as follows:

$$\text{Toxicity index} = \sum C_{\theta} / C_f$$

where

C_f is the volume fraction of the gas considered lethal for a 30 min exposure time as shown in Table 2;

C_{θ} is the volume fraction of each gas produced when 100 g of material is burnt and the combustion products are dispersed into 1 m³ of air.

Table 2 – C_f values taken from DS 02-713 for various gases

Gas	C_f value $\times 10^6$
Carbon dioxide	100 000
Carbon monoxide	4 000
Hydrogen sulphide	750
Ammonia	750
Formaldehyde	500
Hydrogen chloride	500
Acrylonitrile	400
Sulphur dioxide	400
Nitrogen oxides	250
Phenol	250
Hydrogen cyanide	150
Hydrogen bromide	150
Hydrogen fluoride	100
Phosgene	25

6.2.5 Repeatability and reproducibility

No data are available.

Early versions of the test suffered from poor reproducibility due to the inadequate specification of the test chamber. The use of colorimetric tubes also introduces significant errors both due to the lack of precision of the tubes, and also the time delay caused by the sequential analysis method. There can be significant decay in the gas concentrations during the sampling period, which can be as long as 30 min.

6.2.6 Relevance of test data and special observations

This test method is now widely criticized (see e.g. 6.5.10 of ISO 16312-2:2007 and reference [3]):

- a) the combination of flame temperature and ventilation conditions mean that the physical fire model used in this method does not correspond to any of the fire types described in Table 1;
- b) the weighting values used in the calculation of the overall toxicity index are outdated and liable to cause unjustified bias against certain classes of materials, and
- c) the data are expressed in a format which is unsuitable for use in toxic hazard assessment.

Overall, this method is not recommended as the basis for further development for electrotechnical products. It should not be used as the basis for regulation or other controls on the toxic hazard for electrotechnical products, because of the limitations of the physical fire model, the calculation method and the format of the final data. The data from this test should not be used as input to toxic hazard assessments, fire hazard assessments or fire safety engineering calculations.

In common with many physical fire models, no indication is given about the rate of combustion, so flame retarded materials can be forced to undergo combustion at the same rate as materials without any flame retardance. Therefore, additional data input on combustion rates in different fire types is required for fire hazard assessments.

This test method is discussed in ISO 16312-2.

The UK Ministry of Defence intends to replace this test with NATO AFAP-3 (see 6.4.6).

6.2.7 Reference document

DS 02-713 [2].

6.3 Airbus industry

6.3.1 Summary

Airbus ABD 0031 [4] contains the fire worthiness design criteria for use inside the pressurized section of the fuselage of Airbus commercial aeroplanes. It specifies the fire-smoke-toxicity (FST) requirements and the applicable test methods. The following relates to the toxicity requirements only.

6.3.2 Purpose and principle

Non-metallic parts and sub-assemblies that are intended to be used inside the pressurized portion of the fuselage of transport category aircraft, except for materials used in small parts such as knobs, handles, rollers, fasteners, clips, grommets, rubber strips, pulleys and small electrical parts, are tested as described in 6.3.4.

6.3.3 Test specimen

The test method uses the same size test specimens as described in IEC 60695-6-30 [5], i.e. 76,2 mm × 76,2 mm × the intended installation thickness.

6.3.4 Test method

The test is performed in combination with (not simultaneously) the smoke density test in the NBS (National Bureau of Standards) smoke chamber according to ASTM E-662 [6].

The gas sampling procedure starts immediately after the 4 min smoke test run and after 16 min for electrical wire/cable insulation materials.

At least two test specimens are tested for each test condition (flaming and non-flaming).

Methods used for chemical analysis are e.g. ion chromatography or gas chromatography. Other methods may be used but it has to be demonstrated by comparison tests that equivalent results are obtained.

The observed volume fractions of the following gases are compared against the specification limits. The average volume fraction of the following gas components of smoke should not exceed the limits listed in Table 3 within the relevant test duration (4 min and 16 min respectively), under both flaming and non-flaming conditions.

Table 3 – Volume fraction limits for gas components

Gas component	Limit of volume fraction × 10 ⁶
Hydrogen fluoride	100
Hydrogen chloride	150
Hydrogen cyanide	150
Sulfur dioxide	100
Nitrous gases	100
Carbon monoxide	3 500

6.3.5 Repeatability and reproducibility

No data are available.

6.3.6 Relevance of test data and special observations

Fire and ventilation conditions do not allow a comparison between this physical fire model and any of the fire types described in Table 1.

Only a limited number of gas components is considered.

6.3.7 Reference documents

ASTM E-662 [6]

AITM 2.0007 [7]

AITM 2.0008 [8]

AITM 3.0005 [9]

6.4 Comitato Elettrotecnico Italiano (CEI)

6.4.1 Summary

The test described in CEI 20-37/7 [10] is used for the determination of opacity and corrosivity of smoke, and a toxicity index of gases evolved during the combustion of electric cables and their compounds.

6.4.2 Purpose and principle

This test is used to measure the quantity of various gases evolved during the combustion of a small test specimen of material in a tube furnace with continuous air flow.

A toxicity index is calculated based on measured gas concentrations and a series of weighting factors.

6.4.3 Test specimen

The test specimen, with a typical mass of 1,0 g, consists of a piece of material or a test specimen cut from an end-product.

6.4.4 Test method

The test specimen is introduced into a quartz tube in a tube furnace set at $800\text{ °C} \pm 10\text{ °C}$ and an air flow of $120\text{ l} \times \text{h}^{-1} \pm 5\text{ l} \times \text{h}^{-1}$ is passed through the tube and over the test specimen.

The fire effluent is passed through wash bottles, and the insoluble effluent is collected in a gas bag.

The gases monitored include: carbon monoxide, carbon dioxide, sulphur dioxide, formaldehyde, ammonia, hydrogen cyanide, hydrogen chloride, hydrogen bromide, hydrogen fluoride, hydrogen sulphide, acrylonitrile and nitrogen oxides.

Different methods are used for chemical analysis, e.g. spectrophotometry, gas chromatography, infrared analysis and potentiometry.

6.4.5 Repeatability and reproducibility

No data are available.

6.4.6 Relevance of test data and special observations

The test temperature and ventilation conditions in this method are such that the physical fire model does not correspond to any of the fire types described in Table 1. However, with modifications to either the test temperature or air flow rate, the physical fire model could be made to replicate fire types 2 or 3b (see Table 1).

The mass loss of the test specimen is not recorded during or after the test and, therefore, results cannot be expressed as toxic potency.

In common with many physical fire models, no indication is given about the rate of combustion, so flame retarded materials can be forced to undergo combustion at the same rate as materials without any flame retardance. Therefore, additional data input on combustion rates in different fire types is required for fire hazard assessments.

A similar test, AFAP-3[11], has been developed by NATO, in which tests are carried out at 350 °C or 800 °C in an air flow of $2 \text{ l} \times \text{min}^{-1}$. In addition to the determination of carbon monoxide, carbon dioxide, hydrogen cyanide, hydrogen fluoride, hydrogen chloride, hydrogen bromide, nitrogen oxides and sulphur dioxide, this variant requires the determination of acrylonitrile, ammonia, phenol, benzene, styrene and toluene under both conditions, and also the determination of hydrogen sulphide, formic acid, carbon disulphide and acetaldehyde at 350 °C [12].

6.4.7 Reference documents

CEI 20-37/7 [10]

NATO AFAP-3 [11]

6.5 Norme Française (NF)

6.5.1 Summary

The tests described in NF C20-454 [13] and NF X70-100 [14], [15] are used for the determination of a toxicity index of gases evolved during the combustion of test specimens in a tube furnace. NF C20-454 is for materials used in electrotechnical applications, and NF X70-100 was developed for testing products and materials used in the railway industry.

6.5.2 Purpose and principle

This tests measure and quantify the different gases evolved during the combustion or pyrolysis of test specimens.

The gases monitored include: carbon monoxide, carbon dioxide, hydrogen chloride, hydrogen bromide, hydrogen fluoride, hydrogen cyanide, oxides of nitrogen (NO and NO₂), sulphur dioxide, formaldehyde and acrolein.

6.5.3 Test specimen

The test specimen, with a typical mass of 1,0 g, consists of a piece of material or a test specimen cut from an end-product.

6.5.4 Test method

The test specimen is placed in a porcelain boat inside a quartz combustion tube and introduced into an annular furnace set at 800 °C or, in the case of NF X70-100, 400 °C or 600 °C. An air flow of $120 \text{ l} \times \text{h}^{-1}$ is passed through the tube, over the test specimen.

A variety of analytical methods can be used, including chromatography, potentiometry, classical wet chemistry, IR and FTIR.

6.5.5 Repeatability and reproducibility

Data from interlaboratory testing are reported in NF X70-100-1 [14].

6.5.6 Relevance of test data and special observations

The test temperature and ventilation conditions in this method means that the physical fire model does not correspond to any of the fire types as described in Table 1. However, with modifications to either the test temperature or air flow rate, the physical fire model could be made to replicate fire types 2 or 3b (see Table 1).

The mass loss of the test specimen is not recorded during or after the test and, therefore, results cannot be expressed as toxic potency.

In common with many physical fire models, no indication is given about the rate of combustion, so flame retarded materials can be forced to undergo combustion at the same rate as materials without any flame retardance. Therefore, additional data input on combustion rates in different fire types is required for fire hazard assessments.

Results from NF X70-100 tests have been compared with gas yields from real-scale fire tests of materials used in trains [16]. Some reasonable correlations were found for the toxicity of structural materials.

NF X70-100 is one of the toxicity test methods specified in CEN TS 45545-2 [17].

NF X70-100 is discussed in ISO 16312-2.

6.5.7 Reference documents

NF C20-454 [13]

NF X70-100-1 [14]

NF X70-100-2 [15]

CEN TS 45545-2 [17]

6.6 International Electrotechnical Commission (IEC)

6.6.1 Summary

IEC 60695-7-50 [18] describes the generation of fire effluent and the identification and measurement of its constituent combustion products. This test method uses a moving test specimen and a tube furnace at different temperatures and air flow rates. The method is designed to reproduce certain decomposition conditions in a range of fire types as characterized in Table 1.

This test method is designed to model closely fire types 1b, 2 and 3b (see Table 1), and also has the potential to model others, as necessary. In this test, the measurement of fire effluent is made using test specimens which may be taken from end-products, or, if the apparatus and method allows, may be an end-product.

6.6.2 Purpose and principle

The test method described is based upon the same concept as the DIN 53436-1 [19] method. The types of tube furnace and quartz furnace tube selected are those currently specified by IEC 60754-2 [20] which gives a known performance under the conditions of test and is widely available.

In this test method, a test specimen of material in the form of a strip, broken up in small pieces, is introduced into a quartz furnace tube at a constant rate, and a current of primary air is passed through the quartz furnace tube over the test specimen to support combustion. The