BSI Standards Publication

Fire hazard testing

Part 7-3: Toxicity of fire effluent —
Use and interpretation of test results

bsi.

...making excellence a habit.™

National foreword

This British Standard is the UK implementation of EN 60695-7-3:2011. It is identical to IEC 60695-7-3:2011. It supersedes DD IEC/TS 60695-7-3:2004 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GEL/89, Fire hazard testing.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© BSI 2011

ISBN 978 0 580 68369 5

ICS 13.220.40; 29.020

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 November 2011.

Amendments issued since publication

Amd. No.	Date	Text affected

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 60695-7-3

October 2011

ICS 13.220.40; 29.020

English version

Fire hazard testing -
Part 7-3: Toxicity of fire effluent -
Use and interpretation of test results
(IEC 60695-7-3:2011)

Essais relatifs aux risques du feu -
Partie 7-3: Toxicité des effluents du feu -
Utilisation et interprétation des résultats
d'essai
(CEI 60695-7-3:2011)

Prüfungen zur Beurteilung der
Brandgefahr -
Teil 7-3: Toxizität von Rauch und/oder
Brandgasen -
Anwendung und Beurteilung von
Prüfergebnissen
(IEC 60695-7-3:2011)

This European Standard was approved by CENELEC on 2011-10-04. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Management Centre: Avenue Marnix 17, B - 1000 Brussels

Ref. No. EN 60695-7-3:2011 E

Foreword

The text of document 89/1058/FDIS, future edition 1 of IEC 60695-7-3, prepared by IEC/TC 89 "Fire hazard testing" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60695-7-3:2011.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2012-07-04
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2014-10-04

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

Endorsement notice

The text of the International Standard IEC 60695-7-3:2011 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following note has to be added for the standard indicated:

IEC 60695-6-1:2005   NOTE   Harmonized as EN 60695-6-1:2005 (not modified).

Annex ZA
(normative)

Normative references to international publications
with their corresponding European publications

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.

NOTE   When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60695-1-10	-	Fire hazard testing - Part 1-10: Guidance for assessing the fire hazard of electrotechnical products - General guidelines	EN 60695-1-10	-
IEC 60695-1-11	-	Fire hazard testing - Part 1-11: Guidance for assessing the fire hazard of electrotechnical products - Fire hazard assessment	EN 60695-1-11	-
IEC 60695-7-1	-	Fire hazard testing - Part 7-1: Toxicity of fire effluent - General guidance	EN 60695-7-1	-
IEC 60695-7-2	-	Fire hazard testing - Part 7-2: Toxicity of fire effluent - Summary and relevance of test methods	EN 60695-7-2	-
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 13344	2004	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 13943	2008	Fire safety - Vocabulary	EN ISO 13943	2010
ISO 16312-1	-	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	-	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	-	-

Publication	Year	Title	EN/HD	Year
ISO 19706	-	Guidelines for assessing the fire threat to people	-	-

CONTENTS

INTRODUCTION

Electrotechnical products sometimes become involved in fires. However, except for certain specific cases (e.g. power generating stations, mass transit tunnels, computer suites), electrotechnical products are not normally present in sufficient quantities to form the major source of toxic hazard. For example, in domestic dwellings and places of public assembly, electrotechnical products are usually a very minor source of fire effluent compared with, for example, furnishings.

It should be noted that the IEC 60695-7 series of publications is subject to the ongoing evolution of fire safety philosophy within ISO/TC 92.

The guidance in this international standard is consistent with the principles of fire safety developed by ISO TC 92 SC 3 on toxic hazards in fire, as described in ISO 13344, ISO 13571. ISO 16312-1, ISO 16312-2, ISO 19701, ISO 19702 and ISO 19706. General guidance for the fire hazard assessment of electrotechnical products is given in IEC 60695-1-10 and IEC 60695-1-11.

In 1989, the following views were expressed in ISO/TR 9122-1.

"Small-scale toxic potency tests as we know them today are inappropriate for regulatory purposes. They cannot provide rank orderings of materials with respect to their propensity to produce toxic atmospheres in fires. All currently available tests are limited because of their inability to replicate the dynamics of fire growth which determine the time/concentration profiles of the effluent in full-scale fires, and the response of electrotechnical products, not just materials. This is a crucial limitation because the toxic effects of combustion effluent are now known to depend much more on the rates and conditions of combustion than on the chemical constitution of the burning materials."

Because of these limitations IEC TC 89 has developed IEC 60695-7-50 and ISO subsequently developed ISO/TS 19700 [1] [1]. Both these standards use the same apparatus. It is a practical small-scale apparatus which is used to measure toxic potency and which, by virtue of its ability to model defined stages of a fire, yields toxic potency data suitable for use, with appropriate additional data, in a full hazard assessment. Both methods use variations in air flow and temperature to give different physical fire models, but the ISO test method additionally uses the equivalence ratio as a key parameter.

The evidence from fires and fire casualties, when taken with data from experimental fire and combustion toxicity studies, suggests that chemical species with unusually high toxicity are not important (see Clause 7). Carbon monoxide is by far the most significant agent contributing to toxic hazard. Other agents of major significance are hydrogen cyanide, carbon dioxide and irritants. There are also other important, non-toxic, threats to life such as the effects of heat, radiant energy, depletion of oxygen and smoke obscuration, all of which are discussed in ISO 13571. General guidance on smoke obscuration is provided in IEC 60695-6-1.

IEC TC89 recognizes that effective mitigation of toxic hazard from electrotechnical products is best accomplished by tests and regulations leading to improved resistance to ignition and to reduced rates of fire growth, thus limiting the level of exposure to fire effluent and facilitating escape.

_____

1 Figures in square brackets refer to the bibliography.

FIRE HAZARD TESTING –

Part 7-3: Toxicity of fire effluent –
Use and interpretation of test results

1   Scope

This part of IEC 60695 concerns laboratory tests used to measure the toxic components of the fire effluent from either electrotechnical products or materials used in electrotechnical products. It provides guidance on the use and interpretation of results from such tests. It discusses currently available approaches to toxic hazard assessment consistent with the approach of ISO TC 92 SC 3, as set out in ISO 13344, ISO 13571, ISO 16312-1, ISO 16312-2, ISO 19701, ISO 19702 and ISO 19706. It also provides guidance on the use of toxic potency data in fire hazard assessment and on principles which underlie the use of combustibility and toxicological information in fire hazard assessment.

The methods described are applicable to data concerning both the incapacitating effects and the lethal effects of fire effluents.

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 60695-1-10, *Fire hazard testing – Part 1-10: Guidance for assessing 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 60695-7-1, *Fire hazard testing – Part 7-1: Toxicity of fire effluent – General guidance*

IEC 60695-7-2, *Fire hazard testing – Part 7-2: Toxicity of fire effluent – 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/IEC 13943:2008, *Fire safety – Vocabulary*

ISO 13344:2004, *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, *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, *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 19706[2], *Guidelines for assessing the fire threat to people*

3   Terms and definitions

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

3.1
asphyxiant
toxicant that causes hypoxia, which can result in central nervous system depression or cardiovascular effects

NOTE   Loss of consciousness and ultimately death can occur.

[ISO/IEC 13943:2008, definition 4.17]

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]

_____

2   ISO 9122-1: *Toxicity testing of fire effluents – Part 1: General* has been withdrawn and replaced by ISO 19706.

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
concentration
mass per unit volume

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

NOTE 2   For a toxic gas, concentration is usually expressed as a volume fraction at T = 298 K and P = 1 atm, with typical units of microlitres per litre (μL/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]

3.8
effective concentration 50
EC_{50}
concentration of a toxic gas or fire effluent, statistically calculated from concentration-response data, that causes a specified effect in 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 ($g \times m^{-3}$).

NOTE 2   For a toxic gas, typical units are microlitres per litre (μL/L) (at T = 298 K and P = 1 atm); see volume fraction.

NOTE 3   The observed effect is usually a behavioural response, incapacitation, or death. The EC_{50} for incapacitation is termed the IC_{50}. The EC_{50} for lethality is termed the LC_{50}.

[ISO/IEC 13943:2008, definition 4.72]

3.9
effective exposure dose 50
ECt_{50}
product of EC_{50} and the exposure time over which it was determined

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

NOTE 2   For a toxic gas, typical units are microlitres times minutes per litre (μL $\times$ min $\times$ L^{-1}) (at T = 298 K and P = 1 atm); see volume fraction.

NOTE 3 ECt_{50} is a measure of toxic potency

[ISO/IEC 13943:2008, definition 4.73]

3.10
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 may 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]

3.11
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 (g × min × m^{-3}).

NOTE 2   For a toxic gas, typical units are microlitres times minutes per litre (μL × min × L^{-1}) (at T = 298 K and P = 1 atm); see volume fraction.

[ISO/IEC 13943:2008, definition 4.89]

3.12
fire
(general) process of combustion characterized by the emission of heat and fire effluent and usually accompanied by smoke, flame, glowing or a combination thereof

NOTE   In the English language, the term "fire" is used to designate three concepts, two of which, fire (3.13) and fire (3.14), 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 13943:2008, definition 4.96]

3.13
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 13943:2008, definition 4.97]

3.14
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 13943:2008, definition 4.98]

3.15
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]

3.16
fire hazard
physical object or condition with a potential for an undesirable consequence from fire

[ISO/IEC 13943:2008, definition 4.112]

3.17
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 13943:2008, definition 4.116]

3.18
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]

3.19
flame spread
propagation of a flame front

[ISO/IEC 13943:2008, definition 4.142]

3.20
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]

3.21
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, FEC 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]

3.22
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]

3.23
fully developed fire
state of total involvement of combustible materials in a fire

[ISO/IEC 13943:2008, definition 4.164]

3.24
hyperventilation
rate and/or depth of breathing which is greater than normal

[ISO/IEC 13943:2008, definition 4.180]

3.25
ignition
sustained ignition (deprecated)

⟨general⟩ initiation of combustion

[ISO/IEC 13943:2008, definition 4.187]

3.26
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]

3.27
irritant, noun
⟨sensory/upper respiratory⟩ gas or aerosol that stimulates nerve receptors in the eyes, nose, mouth, throat and respiratory tract, causing varying degrees of discomfort and pain with the initiation of numerous physiological defence responses

NOTE Physiological defence responses include reflex eye closure, tear production, coughing, and bronchoconstriction.

[ISO/IEC 13943:2008, definition 4.203]

3.28
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 $g \times m^{-3}$.

NOTE 2   For a toxic gas, the typical units are microlitres per litre ($\mu L/L$) (T = 298 K and P = 1 atm); see volume fraction.

[ISO/IEC 13943:2008, definition 4.207]

3.29
lethal exposure dose 50
LCt_{50}
product of LC_{50} and the exposure time over which it is determined

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 K and P = 1 atm; see volume fraction.

[ISO/IEC 13943:2008, definition 4.208]

3.30
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]

3.31
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]

3.32
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]

3.33
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]

3.34
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 13943:2008, definition 4.292]

3.35
smoke
visible part of fire effluent

[ISO/IEC 13943:2008, definition 4.293]

3.36
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]

3.37
toxic gas
toxic vapour

NOTE   In the context of fire effluent, the term is usually applied to a single chemical element or compound.

[ISO/IEC 13943:2008, definition 4.336]

3.38
toxic hazard
potential for harm resulting from exposure to toxic combustion products

[ISO/IEC 13943:2008, definition 4.337]

3.39
toxic potency
measure of the amount of toxicant required to elicit a specific toxic effect

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

[ISO/IEC 13943:2008, definition 4.338]

3.40
toxicant
toxin
toxic substance

[ISO/IEC 13943:2008, definition 4.340]

3.41
toxicity
toxic quality

[ISO/IEC 13943:2008, definition 4.341]

3.42
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 at 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 (μL/L), which is equivalent to cm^3/m^3 or 10^{-6}), or as a percentage.

[ISO/IEC 13943:2008, definition 4.351]

3.43
yield
mass of a combustion product generated during combustion divided by the mass loss of the test specimen

NOTE   The yield is dimensionless.

[ISO/IEC 13943:2008, definition 4.354]

4   Principles of toxic hazard assessment

4.1   General

Fire hazard assessment is the discipline of predicting the expected degree of human harm or property loss resulting from the action of a fire. Toxic hazard assessment is the branch of fire hazard assessment which addresses the effect of inhaled fire effluent on those exposed. General guidance on the fire hazard of electrotechnical products is given in IEC 60695-1-10, and a comprehensive description of the technical background for fire hazard assessment is presented in IEC 60695-1-11. ISO 13571 address the consequences of human exposure to the life threat components of fire as occupants move through an enclosed structure, and it includes the effects of toxic fire effluent.

Toxic hazard assessment attempts to quantify the potential for harm resulting from exposure to the toxic products of combustion. Until recently, studies have tended to be based on calculations of exposure times that cause death. However, the emphasis is moving to the calculation of exposure times that cause incapacitation and which render the victim unable to escape from the effects of the fire.

Some toxic species act as asphyxiants, e.g. carbon monoxide and hydrogen cyanide. and others act as irritants, e.g. acrolein, hydrogen chloride and sulphur dioxide. These two types of toxicants are treated differently. The effects of an asphyxiant depend upon the accumulated

dose, known as the exposure dose, whereas the effects of an irritant depend on whether a threshold concentration has been reached.

4.2 Exposure dose

For most asphyxiant components of fire effluent, it is commonly assumed that the severity of the toxic effect is roughly proportional to both the concentration and the time of exposure. This is known as Haber's rule. Thus, if the concentration of asphyxiant is doubled and the exposure time is halved, the toxic effect on an exposed organism is usually about the same [2]. For some fire effluent components, the toxic response may be more complex. For more information, the user is referred to ISO 13344 and ISO 13571.

This behaviour is reflected in the use of a parameter known as the exposure dose which is related to the amount of toxicant available for inhalation from the fire effluent. It is calculated by integration of the concentration, C, with respect to time, t (see also Figure 1).

$$\text{Exposure dose} = \int C \times dt \qquad (1)$$

If the concentration is constant the exposure dose is simply the product of the concentration and the exposure time, Ct, but this is not normally the case because in fires the concentrations of toxicants vary with time.

NOTE Toxicologists sometimes use the symbol Ct for exposure dose even though it is normally calculated by integration.
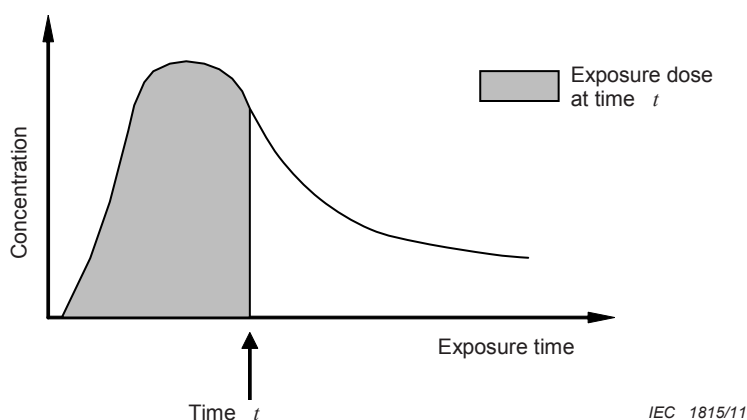

Figure 1 – Exposure dose as a function of time and concentration

The units of exposure dose are concentration multiplied by time, usually expressed as grams per cubic metre times minutes (g × min × m^{-3}). Sometimes volume fraction (see 3.42) is used instead of concentration and exposure doses are then usually quoted in units of $10^{-6} \times$ min.

NOTE The use of volume fractions makes an assumption that the gas mixture is at a temperature of 25 °C and at a pressure of 0,1 Mpa. The concentration of the toxicant can be calculated by multiplying the volume fraction by the density of the pure toxicant at 25 °C and 0,1 Mpa.

Each contributor to the fire effluent will have its own concentration-time curve, and in many studies all the significant toxic species are considered independently and then their effects are summed. This approach is known as the "toxic gas model".

An alternative approach is to consider the fire effluent from a given material or product as a single toxicant (if its toxic potency is known or can be assumed). In this case the exposure dose is a function of the exposure time and a parameter known as the mass loss

concentration. The different materials or products are considered independently and then their effects are summed. This approach is known as the "mass loss model".

4.3   Determination of concentration-time data

There are two ways to determine concentration-time data:

a) by direct measurement in a full-scale simulation of the fire scenario; or

b) by computation of the mass loss rate of the fuels in a model fire scenario.

The computational method can take two forms. For simple situations involving one or two burning items, hand calculations are often adequate. One such example is presented in Annex B. In other cases, the approach is often to make use of computer-based mathematical models. These fire models have so far been developed for simple environments and usually require as input not only the characteristics of the fire scenario, but also the time-based mass loss rate of all combustible products exposed to the fire, including electrotechnical products.

Net mass loss for a given product begins when its previously determined ignition conditions (radiant flux or temperature) are reached. The mass loss rate is proportional to the exposed surface area and the amount of heat reaching the surface from the fire. The proportionality constant is determined for each product by laboratory measurements of the mass loss rate per unit of exposed surface area at a series of known radiant fluxes. Mass loss ceases when the all the fuel has been calculated to be consumed.

Using mass loss rates and scenario specific information as input, computer codes take into account the effects of the structure, ventilation and victim location, and calculate effluent temperature and concentrations at successive times at the selected location. Time dependent behaviour of various aspects of fire hazard can be obtained as output as illustrated in Figure 2
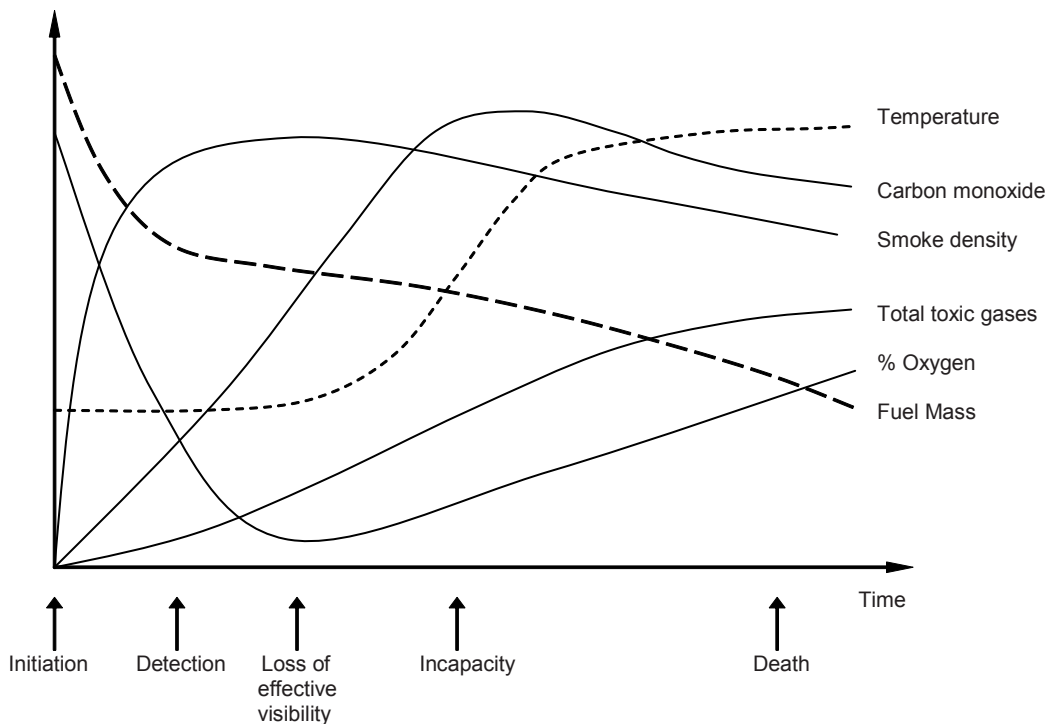
IEC 1816/11

Figure 2 – Time dependent components of fire hazard

4.4   Asphyxiants and the fractional effective dose, *FED*

4.4.1   General

The toxic potency of an asphyxiant component is characterized by the size of the exposure dose required to produce an observed toxic effect. The exposure dose of the toxicant required to produce a defined effect in 50 % of an exposed population is called the effective exposure dose 50, ECt_{50}. The lower the ECt_{50} value, the greater the toxicity. This same principle applies to single gases, mixtures of gases, and to fire effluents, even when the chemical composition is not known.

Toxic hazard assessment involves the computation of the exposure dose, usually as a function of time, and division by the effective exposure dose 50. This ratio is the fractional effective dose, or *FED* [3].

$$FED = \frac{\text{exposure dose}}{\text{effective exposure dose}} = \frac{\int C \times dt}{ECt_{50}} \qquad (2)$$

The numerator, the exposure dose, is determined by the burning behaviour of the product and the fire scenario. The denominator, the effective exposure dose 50, ECt_{50}, is the only place in the expression where toxic potency appears. Toxic potency data are discussed further in Clause 6. When the exposure dose at the victim's location equals the effective exposure dose 50 (i.e. when *FED = 1*) the defined effect, such as incapacity or death, is deemed to occur.

As described above, there are two distinct, but closely-related, approaches to estimating exposure dose and the *FED* in fire situations. The first is to view the fire effluent as a mixture of toxic components; this is called the "toxic gas model". The second is to view the effluent as composed of contributions from the various burning products and materials; this approach is known as the "mass loss model".

4.4.2   Properties of the *FED*

The *FED* is a time-dependent quantity. Its principle determinants are:

– the type and size of the fire,
– the time of exposure to the fire effluent and the relative location of those exposed,
– the volume of the compartment into which the effluent is dispersed, and
– the toxic potency of the fire effluent.

For a given scenario, the total *FED* is the sum of the toxic contribution of all components of the fire effluent. Each effluent component's contribution, f_i, is in turn given by:

$$f_i = \frac{[\int C \times dt]_i}{[ECt_{50}]_i} = \frac{\text{exposure dose of effluent component, } i}{\text{effective dose of effluent component, } i} \qquad (3)$$

and the total *FED* = f_1 + f_2 + f_3 +...(see Figure 3).

This is true, either when the contributors are individual gases as in the toxic gas model, or when the contributors are different burning items as in the mass loss model.
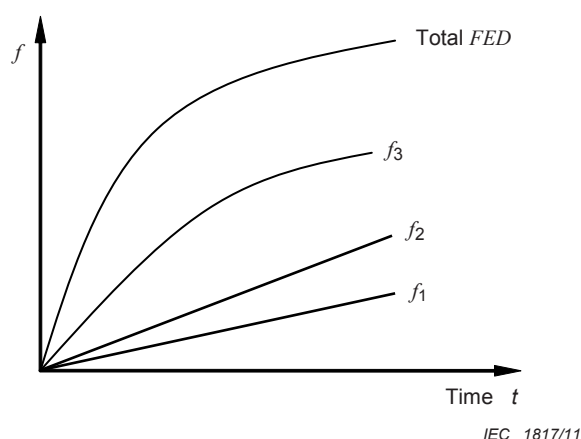
Figure 3 – Total *FED* and contributors, as a function of time

4.4.3 Uses of the *FED*

The uses of the *FED* include the determination of the following:

– the time at which the atmosphere becomes untenable (this requires that the *FED* does not exceed a predetermined value chosen to provide tenability for continuity of operation, escape or rescue).
– comparisons of materials or products
– comparisons with a standard, e.g. a reference standard material or a reference fire scenario.

4.5 Irritants and the fractional effective concentration, *FEC*

Sensory/upper respiratory irritation stimulates nerve receptors in the eyes, nose, throat and upper respiratory tract. When considering incapacitation, effects appear to be related only to concentration. The effects lie on a continuum from mild eye and upper respiratory discomfort to severe pain.

The basic principle for assessing the irritant gas component of toxic hazard analysis 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.

$$FEC = \sum \left[\frac{\text{irritant gas concentration}}{\text{threshold concentration}} \right]_i = \sum \frac{[C]_i}{F_i} \qquad (4)$$

where

$[C]_i$ is the concentration (or volume fraction) of irritant gas, i

F_i is the threshold concentration (or threshold volume fraction) of irritant gas, i.

The volume fractions of irritant gases that are expected to seriously compromise an occupant's ability to take effective action to accomplish escape (*F* values) for some of the more important irritants are listed in Annex C.

NOTE Irritant toxicants can also be lethal, and in this case it appears that it is the exposure dose that is relevant, see 5.2.

4.6 Carbon dioxide

At low concentrations carbon dioxide is not toxic but it does cause hyperventilation and therefore increases the effective toxicity of other fire effluents. Some formulae for calculating *FED* values take this effect into account – see ISO 13344 and ISO 13571.

4.7 Oxygen vitiation

Low levels of oxygen are harmful and some formulae for calculating *FED* values take this effect into account – see ISO 13344 and [4].

4.8 Heat stress

Heat stress can cause both incapacitation and death. Heat stress appears to act like an added toxicant [5], [6] , and a heat stress term can be added to the *FED* calculation – see ISO 13571.

4.9 Effects of stratification and transport of fire atmospheres

Concentrations of fire effluents are often calculated directly from the mass of fuel burned relative to the volume into which the effluent is dispersed. More refined models take into account the effects of stratification and transport on fire effluent concentration in specific physical environments.

5 Methods of toxic hazard assessment

5.1 General approach

The objective of toxic hazard assessment is to calculate the *FED* and/or *FEC* associated with a fire involving the electrotechnical product. The first step is to describe the electrotechnical product and how it is used. The detailed circumstances under which the fire occurs are then described. This constitutes a "fire scenario". Specifying the scenario includes identifying the enclosing structure, how the fire starts and how the product becomes involved in the fire, the location of those persons exposed and how they are considered to be affected.

The end effect that is considered is usually either death, or incapacitation such that the subject is rendered unable to escape from the fire.

There is often more than one possible scenario for a given electrotechnical product, and a distinct toxic hazard is associated with each one. For each scenario identified, *FED* and/or *FEC* values are calculated.

5.2 Equations used to predict death

5.2.1 Simple toxic gas model

The toxic effects of the separate effluent components are generally additive, so the *FED* is the sum of the contributions of all the components.

$$FED_{total} \; = \; \sum_{i=1}^{n} \frac{[\int C \times dt]_i}{[LCt_{50}]_i} \tag{5}$$

where

$[\int C \times dt]_i$ is the exposure dose of effluent component, i;

$[LCt_{50}]_i$ is the lethal exposure dose 50 of effluent component, i.

As with a single toxicant, when the total *FED* reaches unity, death is predicted to occur.

5.2.2 The N-gas model

This use of the *FED* principle has been termed the "N-gas model" by the National Institute of Standards and Technology (NIST) [7].

It takes into account the effects of carbon dioxide on the toxicity of carbon monoxide, as expressed empirically from studies conducted at NIST. It also takes into account oxygen vitiation, should that be significant.

$$FED_{total} = \sum_{i=1}^{n} \frac{[\int C \times dt]_i}{[LCt_{50}]_i} + \frac{m\phi_{CO}}{\phi_{CO_2} - b} + \frac{0{,}21 - \phi_{O_2}}{0{,}156}$$ (6)

where

ϕ_{CO} is the volume fraction of carbon monoxide;

ϕ_{CO_2} is the volume fraction of carbon dioxide;

m and b are respectively the slope and intercept of the interactive curve of carbon monoxide and carbon dioxide which depicts the increasing toxicity of carbon monoxide as carbon dioxide concentration increases;

ϕ_{O_2} is the volume fraction of oxygen.

For volume fractions of carbon dioxide less than 5 %, $m = -18$ and $b = 0{,}122$.

For volume fractions of carbon dioxide more than 5 %, $m = 23$ and $b = -0{,}039$.

5.2.3 Hyperventilatory effect of carbon dioxide

In cases when the CO_2 volume fraction exceeds 0,02, *FED* values should be multiplied by a frequency factor, ν_{CO_2}, to allow for the increased rate of asphyxiant uptake due to hyperventilation.

$$\nu_{CO_2} = \exp(X_{CO_2} / 0{,}05)$$ (7)

where X_{CO_2} equals the volume fraction of carbon dioxide (see ISO 13571).

5.2.4 Lethal toxic potency values

LCt_{50} values used in Equations (5), (6) and (8) are given below in Table 1.

Table 1 – Some toxic potency values

(From ISO 13344)

Toxicant	LC_{50} value × 10⁶ (30 min exposure, volume fraction value)	LCt_{50} value × 10⁶ (min)
Carbon monoxide (CO)	5 700	171 000
Acrolein (CH₂=CHCHO)	150	4 500
Formaldehyde (HCHO)	750	22 500
Hydrogen cyanide (HCN)	165	4 950
Nitrogen oxides (NOₓ)	170	5 100
Hydrogen chloride (HCl)	3 800	114 000

Toxicant	LC_{50} value × 10⁶ (30 min exposure, volume fraction value)	LCt_{50} value × 10⁶ (min)
Hydrogen fluoride (HF)	2 900	87 000
Hydrogen bromide (HBr)	3 800	114 000
Sulphur dioxide (SO_2)	1 400	42 000

5.2.5 Mass loss model

In the mass loss model, fire hazard assessments are made on the basis of the mass contribution of individual burning products or materials. The effluent concentration term in the exposure dose is replaced by a mass loss concentration term, see 4.2

$$FED_{total} = \sum_{j=1}^{k} \frac{[\int C \times dt]_j}{[LCt_{50}]_j} \qquad (8)$$

The sum is taken over each of the k burning materials or products whose combustion effluents are contained in the total fire effluent. $[LCt_{50}]_j$ is the lethal exposure dose 50 of the effluent from the jth product, measured in a laboratory combustion effluent toxicity test.

When dealing with electrotechnical products it is usual to employ the mass loss model, where the goal of fire hazard assessment is to compare one electrotechnical product with another, or when the electrotechnical product contributes a relatively small part of the total hazard.

5.3 Equations used to predict incapacity

5.3.1 Asphyxiant gas model

The basic principle for assessing asphyxiants for the determination of the toxic hazard of incapacitation involves the exposure dose of each toxicant, i.e. the integrated area under each concentration-time curve. Fractional effective doses (FEDs) are determined for each asphyxiant at each discrete increment of time. The time at which their accumulated sum exceeds a specified threshold value represents the time available for escape relative to chosen safety criteria.

For carbon monoxide, the ECt_{50} for incapacitation is 0,035 min [9].

For hydrogen cyanide, the incapacitating dose is not a constant, but varies depending on the volume fraction [5]. The FED is calculated using an exponential expression

$$FED = \sum_{t_1}^{t_2} \frac{\{\exp(\phi_{HCN} / 4,3 \times 10^{-5})\} - 1}{220 \text{ min}} \times \Delta t \qquad (9)$$

where ϕ_{HCN} is the average volume fraction of hydrogen cyanide over the time increment Δt.

NOTE   This equation is based on data obtained with values of ϕ_{HCN} in the range 30 × 10⁻⁶ to 400 × 10⁻⁶.

If the volume fraction of carbon dioxide exceeds 0,02, the effective exposure doses of asphyxiants can be considered to be increased because of hyperventilation by a factor of $\exp(\phi_{CO_2} / 0,05)$, where ϕ_{CO_2} equals the volume fraction of carbon dioxide (see ISO 13571).

5.3.2 Irritant gas model

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 4.5 and Annex C.

5.3.3 Mass loss model

Concentrations of fire effluent toxicants as a function of time cannot readily be determined in many cases. The basic FED concept can still be employed using mass loss, the volume into which the fire effluents are dispersed and known lethal toxic potency values. One-half of the LCt_{50} value is recommended as an approximate exposure dose when relating incapacitation to lethality [10]. Although based on experimental data obtained from exposure of rats, this relationship is also expected to be appropriate for human exposure, see ISO 13571.

6 Toxic potency values

6.1 Generic values of toxic potency

It is often possible to carry out first approximations for hazard assessment using average or generic toxic potency values because the fire effluents from most materials are, within approximately an order of magnitude, the same.

It has been suggested that an LCt_{50} value of 900 g·min·m^{-3} can be used for well-ventilated, pre-flashover fires and that a value of 450 g·min·m^{-3} can be used for for vitiated post-flashover fires. For evaluation of occupants' escape, values of 450 g·min·m^{-3} and 220 g·min·m^{-3}, respectively, are recommended in ISO 13571. The validity of this convention can be checked by recalculating the outcome of a toxic hazard assessment where the toxic potency values used differ from the general value by a factor of 2 or 3. If a significant difference in the potential escape time results, it may be advantageous to seek specific toxic potency data for electrotechnical materials and the products in question.

6.2 Toxic potency values obtained from chemical analyses

The lethal effective doses of the major fire gases are known from previous biological tests and are available from published sources. Some values are given in Table 1 (see 5.2.4). These data support hazard assessment based on chemical analyses of fire effluents. This approach is becoming more widely favoured because of increasing knowledge of the toxic effects of both individual fire gases and certain multicomponent fire effluents. Also, it avoids routine use of animals, relying upon the fact that the toxic potencies of all common individual gases generated in fires have already been determined by animal exposure. With sufficient analytical data, it permits toxic potency to be treated as single-valued for a given stage of fire.

6.3 Toxic potency values obtained from animal tests

All toxic potencies are ultimately based on exposure of animals (usually rats or mice) to a known concentration of a toxic gas or fire effluent and the observation of behaviour as a function of time. A typical product or material, when burning, produces a complex mixture of toxic substances. These combustion products can interact chemically with one another, and can further interact biologically once inhaled. Burning the material and exposing animals to the effluent captures the effects from any such interactions, most of which are not predictable from chemical analysis.

7 Limitations on the interpretation of toxicity test results

Toxic potency test results alone are an inadequate basis on which to determine fire hazard and, therefore, fire safety. They are not to be interpreted directly to rank order materials or electrotechnical products. Limits for toxic potency should not be incorporated into material and product specifications. No conclusions should be drawn or safety decisions made until after all

relevant fire test and fire scenario data have been incorporated into an appropriate quantitative hazard assessment framework.

In the past it was common to promote toxicity testing as a means of identifying materials which, when subjected to thermal decomposition, yield combustion effluents characterized by unusually high toxic potency. However, there is at present (2011), no recorded instance of a fire in which the hazard resulted from extreme toxic potency.

The presence or absence of specific chemical elements such as nitrogen, halogen, or phosphorus in the product is, by itself, no indicator of the level of lethal toxic hazard. Therefore no conclusions should be drawn from the presence or absence of a particular toxic chemical species in the fire effluent. Conclusions on the significance of the threat posed by a fire and its effluent require hazard assessment to evaluate and integrate all threat factors such as heat, smoke, toxicity, and oxygen depletion in a time-dependent quantitative analysis.

8 Effluent components to be measured

8.1 Minimum reporting

When organic materials burn, oxygen is consumed and carbon oxides are produced which are always important toxicological components of fire effluents. Carbon dioxide, carbon monoxide and oxygen levels should always be reported.

8.2 Additional reporting

8.2.1 Gaseous fire effluent components

Other gaseous effluent components should be measured if their presence is known or is suspected.

The known or suspected presence of other elements in the fuel dictates which additional analyses need to be performed. Table 2 lists the most significant gaseous effluent components which would be expected to be produced from elements in the fuel. All of these, with the exception of water vapour, will contribute to the toxic hazard of the effluent.

Many other gaseous effluent components may be produced, especially if the fuel is not completely oxidized. If the composition of the fuel is known, the organic fraction of the effluent can be estimated from a carbon balance of the products. Fourier transform infra-red and gas chromatograph/mass spectrometer techniques can give detailed information about the composition of gaseous effluent.

NOTE   In the case of electrical insulating oils (see IEC 60695-1-40) the following toxic species can be produced:

– acrolein and formaldehyde,

– dioxins and furans (for oils suspected of being contaminated with polychlorinated biphenyls,

– polyaromatic hydrocarbons (for mineral oils).

The production of these toxic species is not limited to electrical insulating oils.

Table 2 – Combustion products

Element(s) in the fuel	Principal effluent component(s)
Carbon, hydrogen, oxygen	Water (H_2O), Carbon dioxide (CO_2), Carbon monoxide (CO) Acrolein (CH_2=CHCHO), formaldehyde (HCHO)
Nitrogen	Hydrogen cyanide (HCN), nitrogen oxides (NO_x)
Chlorine	Hydrogen chloride (HCl)
Fluorine	Hydrogen fluoride (HF)
Bromine	Hydrogen bromide (HBr)
Sulphur	Sulphur dioxide (SO_2)

8.2.2 Airborne particulates

Airborne particulates can contribute to the overall toxicity of fire efluents. It may therefore be useful to measure the total particulate matter (milligrams per litre) in the effluent. The particle size distribution of the particulate matter is also useful information.

Annex A
(informative)

Guidance for the use of LC_{50} values

A.1 General

The toxic potency of the effluent from a burning or pyrolyzing product is most often characterized by the concentration of that effluent likely to cause harm to people during a given exposure. There is a range of adverse impacts that one might suffer in a fire. The most severe is death. Lesser symptoms, such as disorientation or eye irritation, may affect survival and may or may not have lasting effects.

Most studies of toxic hazard in fires have centred on effects leading directly to death. The lethal toxic potency of a toxicant is characterized by the LC_{50}. This is the concentration of toxicant which, when held constant for a specified exposure time (usually 30 min) causes the death of half the exposed subjects. In fires, people are exposed to a changing concentration of fire effluent, and so their exposure is calculated from the integral of the concentration with respect to time.

A.2 Limiting hazard

There are several means by which one's life is threatened in a fire. These include the most common – effluent inhalation and burns – as well as falling down stairs because of poor visibility. The threat that is realized first is referred to as the limiting hazard. Identifying whether this limit is due to the toxicity of the fire effluent is the first step in toxic hazard analysis.

A.3 Use of LC_{50} values in specific types of fires

A.3.1 Smouldering fires

None of the currently used equipment for measuring the toxic potency of fire effluent does so for self-sustaining, non-flaming combustion. One can presume this mode is similar to thermal or radiative pyrolysis, but it has not yet been established if the combustion products or the LC_{50} values are the same.

These fires generate little effluent or heat because of their slow mass burning rates. If the effluent were to mix throughout a room, the concentration would be low and unless the LC_{50} value is very low indeed, the threat to life safety is low as well. In the electrotechnical field, many of these fires originate with overheated components, and people are rarely close to the smouldering source. Only if the effluent is contained within a small volume is a person capable of receiving a harmful dose.

A.3.2 Flaming, pre-flashover fires

LC_{50} values are measurable for products involved in small flaming fires. Most of these values fall in a narrow range, although there are a few combustibles with very high (low toxicity) or very low (high toxicity) values. In both the measurement apparatus and the fire, there is an ample supply of oxygen.

When the FED approach is employed, the toxic effluent components should be determined by chemical analysis.

Nearly all common fuels generate heat at the same rate they consume oxygen, and oxygen consumption is often used to measure the rate of heat release during a fire. As a product

burns, the heat buoyantly propels the hot effluent into the upper layer of the compartment. People who are near the fire and who are exposed to that upper layer simultaneously experience two threats to life safety: high temperature and toxic effluent. It is important to determine which is the limiting hazard. An analysis shows that, in many situations, burns or heat become life-threatening well before effluent toxicity for normal values of the LC_{50} [11]. Therefore, precise measurement of the LC_{50} is not important for a hazard analysis of this type of fire. Rather, it is most important to know that the toxic potency of the effluent is not extreme. In other exposure situations, the heat of the fire is dissipated by travel of the fire effluent through the building before reaching the people. In such cases, the toxic fire effluent will probably be the life-threatening factor.

A.3.3 Flaming, post-flashover fires

A.3.3.1 General

When a compartment fire becomes large enough, it consumes oxygen faster than the inflow through doors and windows can replenish it. The underventilation results in a high degree of incomplete combustion and the fire effluent becomes more toxic.

A.3.3.2 Enhanced carbon monoxide

Usually within a room on fire, the temperature and thermal radiation level soon become too high for survival. The threat to be determined, then, is to people in contiguous compartments and remote locations. As the hot, toxic effluent leaves the room, it is diluted by external air and loses heat by convection and conduction. The limiting hazard depends on the competitive rates of these processes, and these are building-dependent.

LC_{50} values can also be determined for products involved in large flaming fires, and most of these values again fall in a narrow range. However, the measurement method requires inclusion of the effect of oxygen depletion in the flashed-over compartment. This depletion results in enhanced yields of incomplete combustion products, notably carbon monoxide which is responsible for at least half of the FED in nearly all fires. Thus its accurate inclusion in an LC_{50} determination is important. Open (flow-through) systems can pre-determine the carbon monoxide yield by adjustment of the flow conditions. Closed systems can post-determine the carbon monoxide yield by matching the results from real-scale fires.

A.3.3.3 Simplification of LC_{50} values

Some simplification of the LC_{50} determination is possible because of the enhanced carbon monoxide yields in post-flashover fires. Laboratory measurements have shown that carbon dioxide enhances the toxicity of carbon monoxide, and that the LC_{50} of carbon dioxide-potentiated carbon monoxide is about 5 g $\times$ m^{-3}. Analysis of a range of post-flashover room fire tests shows that, although there is some variation, the typical yield of carbon monoxide is about 0,2 g/g of fuel burned. This high value is a result of the underventilation of the fire compartment. Combining these two values, the LC_{50} of post-flashover fire effluent is seen to be about 25 g $\times$ m^{-3} [12]. This is based on the expected carbon monoxide and carbon dioxide content only. No higher values are possible. The presence of other toxicants or even more enhanced carbon monoxide yields would only lower the value.

Next, it is appropriate to consider the accuracy of the bench-scale measurement method, i.e. the degree to which the laboratory test replicates the real-scale phenomenon. Pilot validation studies of a radiant apparatus for LC_{50} measurement showed that the results could be used to predict real-scale toxic potency to about a factor of 3 [13]. Therefore, LC_{50} values for post-flashover fire effluent between 8 g $\times$ m^{-3} (25 ÷ 3) and 75 g $\times$ m^{-3} (25 × 3) are indistinguishable. Since all post-flashover fire effluent has an LC_{50} value no greater than 25 g $\times$ m^{-3}, all LC_{50} values for post-flashover fire effluent greater than 8 g $\times$ m^{-3} and determined using this method are indistinguishable from each other. This type of calculation can be applied to other bench-scale devices once their accuracy has been determined.

Most common electrotechnical products have LC_{50} values substantially higher than this. Thus, for those combustibles one would conservatively use a common value of 8 g $\times$ m^{-3} in a post-flashover hazard analysis.

When the fire community has sufficient experience with LC_{50} measurements using this approach, some groupings of products could be exempted from further determinations by inspection and be described as "having an LC_{50} greater than 8 g $\times$ m^{-3}". Some possible examples are:

– wood and other cellulosics, since all species would be expected to show LC_{50} values similar to the existing Douglas fir value;

– synthetic materials containing only C, H, and O;

– polymer/additive mixtures that have been shown to follow the N-Gas equation (see 5.2.2), i.e. they produce no additional toxicants, and have been shown to have LC_{50} values greater than 8 g $\times$ m^{-3};

– products that are only present in small quantities;

– products that would not be expected to become fuel for a flashed-over fire, such as those items only installed behind a sufficiently protective barrier.

Based on an overview of reported toxic potency values, this process could result in an extremely small fraction of electrotechnical products that would need to be measured. Indeed, when such a product is but one contributor to the effluent in a post-flashover fire scenario, which exists because of the burning of numerous other products and materials as well, its contribution to the total toxic effect may be very low even if its toxicity is quite high. Note that this applies to post-flashover scenarios only.

Annex B
(informative)

A simple worked example to illustrate the principles
of a toxic hazard analysis

NOTE   This example does not refer to an electrotechnical product but the general principles involved are valid for electrotechnical products.

B.1   The problem scenario

Replacing the floor covering material in a room is considered. It is intended that if the material is ignited by a small ignition source, the rate of development of toxic hazard from the new material (material B) should not be worse than that from the old material (material A). It is considered that the most likely scenario would involve a closed room which would rapidly fill with smoke and that the effluent can be considered as evenly mixed throughout the room volume (i.e. layering effects can be considered very transient, and can be ignored). In this worked example the toxicity of the fire effluent from material B is twice that of material A, but it burns more slowly once ignited.

B.2   Information available

The volume of the room is 40 m^3. The floor covering material has an area density of 4 kg/m^2. Horizontal burning tests have shown that both materials burn through rapidly so that a front of combustion spreads from the point of ignition. Both materials lose 3 kg $\times$ m^{-2} of mass when they burn. For material A, the rate of flame spread is 10 cm $\times$ min^{-1} while for material B, the rate of flame spread is only 5 cm $\times$ min^{-1}. However, small-scale fire tests have shown that, under well-ventilated flaming conditions, the fire effluent from material B is twice as toxic (i.e. has half the toxic potency value) as the fire effluent from material A.

Mass loss concentration based toxic potencies:

Material A: LC_{50} = 20 g $\times$ m^{-3}, lethal exposure dose 50 = 600 g $\times$ min $\times$ m^{-3}.

Material B: LC_{50} = 10 g $\times$ m^{-3}, lethal exposure dose 50 = 300 g $\times$ min $\times$ m^{-3}.

B.3   Hazard analysis

Assuming a small point ignition source, both materials will burn through, and a circle of burned area will spread out from the point of ignition (see Figure B.1). Since material A burns twice as quickly as material B, the area of material A consumed will be four times that of material B at any time during the early stages of the fire.
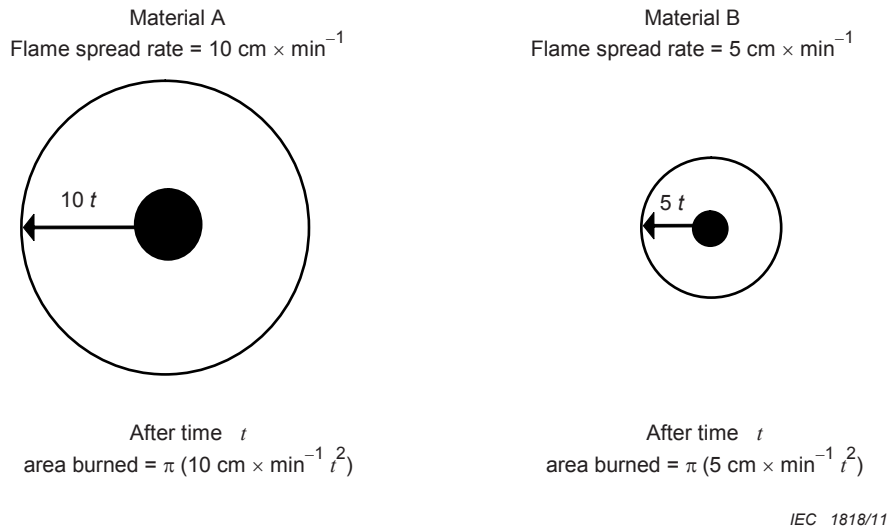
Material A
Flame spread rate = 10 cm × min^{-1}

Material B
Flame spread rate = 5 cm × min^{-1}

10 *t*

5 *t*

After time *t*
area burned = π (10 cm × min^{-1} *t*^{2})

After time *t*
area burned = π (5 cm × min^{-1} *t*^{2})

IEC   1818/11

Figure B.1 – Flame spread rate for materials A and B

For material A the mass loss concentration, C, at time, t, is given by the equation:

$$C \;=\; \text{area burned} \times \text{mass loss per unit area} \div \text{volume of the room}$$

$$=\; 3{,}1416 \times (10\ \text{cm} \times \text{min}^{-1} \times t\,)^2 \times 0{,}3\ \text{kg} \times \text{m}^{-2} \div 40\ \text{m}^3$$

$$=\; 2{,}356\ \text{g} \times \text{m}^{-3} \times \text{min}^{-2} \times t^{\,2}$$

$$\text{The exposure dose} \;=\; \int C \times dt \;=\; 2{,}356\ \text{g} \times \text{m}^{-3} \times \text{min}^{-2} \times t^{\,3}/3$$

Table B.1 shows calculated values for material A. The *FED* for each point in time is the exposure dose at that time divided by the lethal exposure dose 50 for that material. When the *FED* reaches unity the toxicological endpoint, in this case death, is predicted.

The corresponding values for material B are shown in Table B.2.

Figure B.2 is a graph showing the results of the *FED* calculations for materials A and B in the 40 m^3 room. The analysis shows that lethal conditions are attained after approximately 9 min for material A, and approximately 2,5 min later for material B.
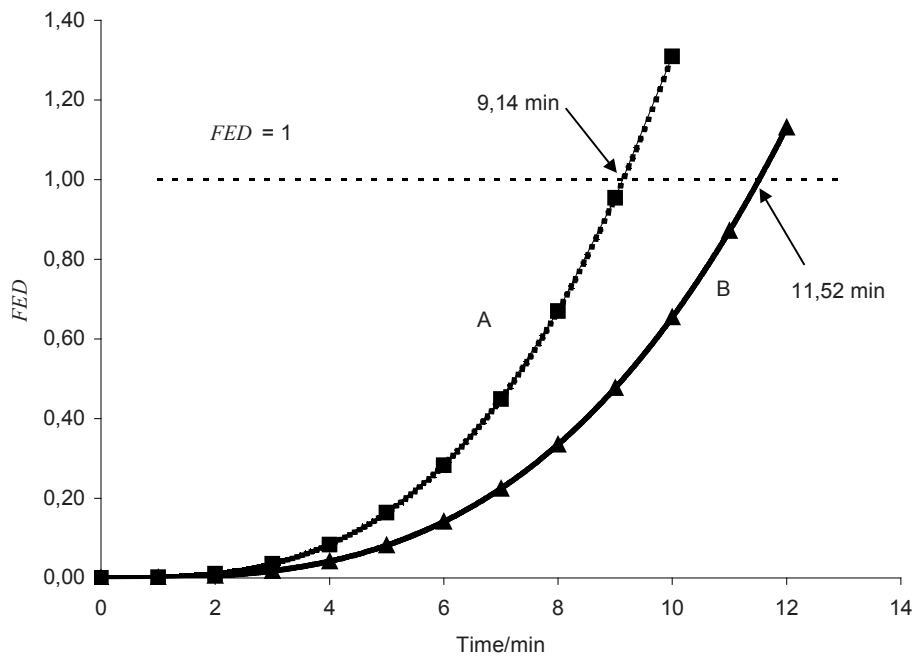
It can therefore be concluded that material B presents less of a toxic hazard than material A in this scenario, despite the fact that the fire effluent from material B is twice as toxic as that from material A.

Table B.1 – Example *FED* calculation data for material A

Time	Area burned	Mass burned	Mass loss concentration at time t	Mass loss concentration (integrated over time) = exposure dose	*FED*
min	cm^2	g	g $\times$ m^{-3}	g.min $\times$ m^{-3}	
0	0	0	0,0	0,0	0,000
1	314	94	2,4	0,8	0,001
2	1 257	377	9,4	6,3	0,010
3	2 827	848	21,2	21,2	0,035
4	5 027	1 508	37,7	50,3	0,084
5	7 854	2 356	58,9	98,2	0,164
6	11 310	3 393	84,8	169,6	0,283
7	15 394	4 618	115,5	269,4	0,449
8	20 106	6 032	150,8	402,1	0,670
9	25 447	7 634	190,9	572,6	0,954
10	31 416	9 425	235,6	785,4	1,309

Table B.2– Example *FED* calculation data for material B

Time	Area burned	Mass burned	Mass loss concentration at time t	Mass loss concentration (integrated over time) = exposure dose	*FED*
min	cm^2	g	g $\times$ m^{-3}	g.min $\times$ m^{-3}	
0	0	0	0.0	0,0	0,000
1	79	24	0,6	0,2	0,001
2	314	94	2,4	1,6	0,005
3	707	212	5,3	5,3	0,018
4	1 257	377	9,4	12,6	0,042
5	1 964	589	14,7	24,5	0,082
6	2 827	848	21,2	42,4	0,141
7	3 848	1 155	28,9	67,3	0,224
8	5 027	1 508	37,7	100,5	0,335
9	6 362	1 909	47,7	143,1	0,477
10	7 854	2 356	58,9	196,4	0,655
11	9 503	2 851	71,3	261,3	0,871
12	11 310	3 393	84,8	339,3	1,131

IEC   1819/11

Material A: toxic potency 600 g $\times$ m^{-3} $\times$ min flame spread 10 cm $\times$ min^{-1}.

Material B: toxic potency 300 g $\times$ m^{-3} $\times$ min flame spread 5 cm $\times$ min^{-1}.

Scenario: horizontal flame spread across a floor covering in a closed 40 m^3 room.

Figure B.2 – Relative toxic hazard of two materials – time to lethality, i.e. $FED \geq 1$

Annex C
(informative)

F values for irritants

Volume fractions of irritant gases that are expected to seriously compromise an occupants' ability to take effective action to accomplish escape (F values) for some of the more important irritants are listed in Table C.1.

Table C.1 – F values for irritants

(From ISO 13571)

Irritant	F value × 10^6
Acrolein	30
Sulphur dioxide	150
Formaldehyde	250
Nitrogen dioxide	250
Hydrogen fluoride	500
Hydrogen bromide	1 000
Hydrogen chloride	1 000

Bibliography

[1] ISO/TS 19700:2007, *Controlled equivalence ratio method for the determination of hazardous components of fire effluents*

[2] Hartzell, G.E., *Smoke toxicity test development and use: Historical perspectives relevant to today's issues*. In "Hazards of Combustion Products", Interscience Communications Ltd., 2008, London.

[3] Hartzell, G.E., and Emmons, H.E., *The Fractional Effective Dose Model for Assessment of Hazards Due to Smoke from Materials*, Journal of Fire Sciences, 6, (5), pp. 356-362 (1988)

[4] Levin, B.C., Paabo, M., Gurman, J.L. and Harris, S.E., *Effects of exposure to single and multiple combination of the predominant toxic gases and low oxygen atmospheres produced in fires*. Fundamental and Applied Toxicology. 9, 236-250 (1987).

[5] *Engineering Guide for Predicting 1st and 2nd Degree Skin Burns* (2000), Society of Fire Protection Engineers, Bethesda, MD

[6] Crane, C., *Human Tolerance Limit to Elevated Temperature: An Empirical Approach to the Dynamics of Acute Thermal Collapse,* Federal Aviation Administration, Memorandum Report No. ACC-114-78-2, 1978.

[7] Babrauskas, V., Levin, B.C., Gann, R.G., Paabo, M., Harris, R.H., Peacock, R.D., Yusa, S*., Toxic potency measurements for fire hazard analysis*. NIST Special Publication 827, National Institute of Standards and Technology, Gaithersburg, MD 20899, USA (1991).

[8] Kaplan, H. L., Grand, A. F., Switzer, W. G., Mitchell, D. S., Rogers, W. R. and Hartzell, G. E., *Effects of Combustion Gases on Escape Performance of the Baboon and the Rat*, J. Fire Sciences, 3 (4), pp. 228-244 (1985).

[9] Purser, D.A., *Physiological effects of combustion products*. In "Hazards of Combustion Products", Interscience Communications Ltd., 2008, London.

[10] Gann, R.G., *Fire effluent, people, and standards: Standardization philosophy for the effects of fire effluent on human tenability.* In "Hazards of Combustion Products", Interscience Communications Ltd., 2008, London.

[11] Gann, R.G., Babrauskas, V., Peacock, R.D., and Hall, Jr., J.R., *Fire Conditions for Smoke Toxicity Measurements.* Fire and Materials, 18, 193-199 (1994).

[12] Babrauskas, V., Harris, R.H., Braun, E., Levin, B.C., Paabo, M., and Gann, R.G*., The Role of Bench-Scale Test Data in Assessing Full-Scale Toxicity*, NIST Technical Note 1284, National Institute for Standards and Technology USA (1991).

[13] Babrauskas, V., Levin, B.C., Gann, R.G., Paabo, M., Harris, R.H., Peacock, R.D., Yusa, S*., Toxic potency measurements for fire hazard analysis*. NIST Special Publication 827, National Institute of Standards and Technology, Gaithersburg, MD 20899, USA (1991).

[14] IEC 60695-6-1:2005, *Fire hazard testing – Part 6-1: Smoke opacity – General guidance*

[15] IEC/TS 60695-7-50:2002, *Fire hazard testing – Part 7-50: Toxicity of fire effluent – Estimation of toxic potency – Apparatus and test methods*

_____

British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards -based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at bsigroup.com/standards or contacting our Customer Services team or Knowledge Centre.

Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at bsigroup.com/shop, where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to bsigroup.com/subscriptions.

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

PLUS is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit bsigroup.com/shop.

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email bsmusales@bsigroup.com.

Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

Copyright

All the data, software and documentation set out in all British Standards and other BSI publications are the property of and copyrighted by BSI, or some person or entity that owns copyright in the information used (such as the international standardization bodies) and has formally licensed such information to BSI for commercial publication and use. Except as permitted under the Copyright, Designs and Patents Act 1988 no extract may be reproduced, stored in a retrieval system or transmitted in any form or by any means – electronic, photocopying, recording or otherwise – without prior written permission from BSI. Details and advice can be obtained from the Copyright & Licensing Department.

Useful Contacts:

Customer Services
Tel: +44 845 086 9001
Email (orders): orders@bsigroup.com
Email (enquiries): cservices@bsigroup.com

Subscriptions
Tel: +44 845 086 9001
Email: subscriptions@bsigroup.com

Knowledge Centre
Tel: +44 20 8996 7004
Email: knowledgecentre@bsigroup.com

Copyright & Licensing
Tel: +44 20 8996 7070
Email: copyright@bsigroup.com

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

bsi.

...making excellence a habit.™