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Life-threatening components of fire — Guidelines for the estimation of time available for escape using fire data

Composants dangereux du feu — Lignes directrices pour l'estimation du temps de sauvetage, utilisant les caractéristiques du feu

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Contents

Page

Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of normative document:

— an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;

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Attention is drawn to the possibility that some of the elements of this Technical Specification may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TS 13571 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 3, *Fire threat to people and environment*.

Annex A of this Technical Specification is for information only.

Introduction

When evaluating the consequences to human life, the crucial criterion for life safety in fires is that the time available for escape be greater than the time required for escape. (Within the context of this Technical Specification, escape may be to a place of safe refuge.) The sole purpose of the methodology described here is to provide a framework for use in estimating the time available for escape.

The time available for escape is the interval between the time of ignition and the time after which conditions become untenable such that occupants can no longer take effective action to accomplish their own escape. Untenable conditions during fires result from

a) exposure to radiant and convected heat,

b) inhalation of asphyxiant gases,

c) exposure to sensory/upper respiratory irritants, and

d) visual obscuration due to smoke.

The time required for escape is the time required for occupants to travel from their location at the time of ignition to a place of safe refuge. As occupants are exposed to heat and fire effluent, their escape behaviour, movement speed, and choice of exit route are also affected, reducing the efficiency of their actions and delaying escape (ISO/TR 13387-8). These factors affect the time required for escape and are, therefore, not considered in this Technical Specification.

The methodology described here cannot be used *alone* to evaluate the overall fire safety performance of specific materials or products, and cannot, therefore, constitute a test method. Rather, the equations in this Technical Specification are to be used as input to a fire hazard or risk analysis [ISO 13387 (all parts)]. In such an analysis, the calculated time available for escape depends on many characteristics of the fire, the enclosure, and the occupants themselves. The nature both of the fire (e.g. heat release rate, quantity and types of combustibles, fuel chemistry) and of the enclosure (e.g. dimensions, ventilation) determine the toxic gas concentrations, the gas and wall temperatures, and the density of smoke throughout the enclosure as a function of time. The characteristics of the occupants (e.g. age, state of health, location relative to the fire, activity at the time of exposure) also affect the impact of their exposure to the heat and smoke. The interrelationship of all these factors is shown schematically in Figure A.1 in annex A. Furthermore, estimation of exposure is determined in part by assumptions regarding the position of the occupants' heads relative to the hot smoke layer that forms near ceilings and descends as the fire grows. As a result of all these factors, each occupant will likely have a different estimated time available for escape (also see A.5 in annex A).

Annex A describes the context and mechanisms of the fire effluent toxicity component of life threat. Effects such as the asphyxiant toxicants, carbon monoxide and hydrogen cyanide (A.3), as well as the effects of both sensory/upper respiratory irritants (A.4.2) and pulmonary irritants (A.4.3) are considered.

The heat component of life threat encompasses exposure both to radiant and to convective heat.

The initial impact of visual obscuration due to smoke is on factors affecting the time required for occupants to escape (see A.2). This aspect of smoke obscuration is, therefore, not considered here. However, smoke obscuration of such severity that occupants become disoriented to a degree that prevents effective action to accomplish their own escape also places a limitation on the time available for escape and is considered in this Technical Specification.

Based upon available human and animal data, but in the absence of definitive, quantifiable human data, the effects of asphyxiant toxicants, sensory irritants, heat and visual obscuration are each considered as acting independently. Some degree of interactions between these components are known to occur (A.6), but are considered secondary in this Technical Specification.

The toxic effects of aerosols and particulates and any interactions with gaseous fire effluent components are not considered in this Technical Specification. Based upon available human and animal data, it is known that the physical form of toxic effluents does have some influencing effects on acute incapacitation, but they are considered secondary to the direct effects of vapour phase effluents and are not readily quantifiable.

Adverse health effects following exposure to fire atmospheres are not considered in this Technical Specification although they are acknowledged to occur. Pre-existing health conditions may be exacerbated and potentially life-threatening sequelae may develop from exposure both to asphyxiants and to pulmonary irritants (A.3.2 and A.4.3).

The equations in this methodology enable estimation of the status of exposed occupants at discrete time intervals throughout the progress of a fire scenario, up to the time at which such exposure may prevent occupants from taking effective action to accomplish their own escape. Comparison of this time with the time required for occupants' escape to a place of safety (determined independently, using other methodology), serves to evaluate the effectiveness of a building's fire safety design. Should such comparison reveal insufficient available escape time, a variety of protection strategies will then require consideration by the fire safety engineer.

The guidance in this Technical Specification is based on the best available scientific judgment in using a state-of-the-art, but less-than-complete knowledge base of the consequences of human exposure to fire effluents. In particular, the methodology may not be protective of human health after escape, as the interactions of all potential life threats and the short- or long-term consequences of heat and fire effluent exposure have not been completely characterized and validated.

This Technical Specification includes an indication of uncertainty for each procedure. The user is encouraged to determine the significance of these and all other uncertainties in the estimation of the outcome of a given fire scenario.

Life-threatening components of fire — Guidelines for the estimation of time available for escape using fire data

1 Scope

This Technical Specification is only one of many tools available for use in fire safety engineering. It is intended to be used in conjunction with models for analysis of the initiation and development of fire, fire spread, smoke formation and movement, chemical species generation, transport and decay and people movement, as well as fire detection and suppression. This Technical Specification is to be used only within this context.

This Technical Specification is intended to address the consequences of human exposure to the life threat components of fire as occupants move through an enclosed structure. The time-dependent concentrations of fire effluents and the thermal environment of a fire are determined by the rate of fire growth, the yields of the various fire gases produced from the involved fuels, the decay characteristics of those fire gases, and the ventilation pattern within the structure (see A.1). Once these are determined, the methodology presented in this Technical Specification can be used for the estimation of the available escape time.

This Technical Specification provides guidance on establishing the procedures to evaluate the life threat components of fire hazard analysis in terms of the status of exposed human subjects at discrete time intervals. It makes possible the determination of a tenability endpoint, at which time it is estimated that occupants will no longer be able to take effective action to accomplish their own escape (see A.2). The life threat components addressed include fire effluent toxicity, heat and visual obscuration due to smoke. Two methods are presented for assessment of fire effluent toxicity, the toxic gas model and the mass loss model.

Aspects such as the initial impact of visual obscuration due to smoke on factors affecting the time required for occupants to escape, the toxic effects of aerosols and particulates and any interactions with gaseous fire effluent components and adverse health effects following exposure to fire atmospheres are not considered in this Technical Specification (see the Introduction).

2 Normative reference

The following normative document contains provisions which, through reference in this text, constitute provisions of this Technical Specification. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this Technical Specification are encouraged to investigate the possibility of applying the most recent edition of the normative document indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 13943, *Fire safety — Vocabulary*

3 Terms and definitions

For the purposes of this Technical Specification, the terms and definitions given in ISO 13943 and the following apply.

3.1
asphyxiant
toxicant causing loss of consciousness and ultimately death resulting from hypoxic effects, particularly on the central nervous and/or cardiovascular systems

3.2
concentration-time curve
plot of the concentration of a toxic gas or fire effluent as a function of time

NOTE The concentration of a toxic gas is expressed as a volume fraction in parts per million (ppm) (3.14) or for fire effluent in grams per cubic metre ($g \cdot m^{-3}$).

3.3
***Ct* product**
concentration-time product for a gaseous toxicant or for a fire effluent obtained by integrating the area under a concentration-time curve

NOTE The *Ct* product of a gaseous toxicant is expressed in a volume fraction of parts per million (3.14) multiplied by minutes (ppm·min) or for fire effluent in grams per cubic metre ($g \cdot m^{-3}$).

3.4
escape
effective action by occupants to accomplish their own escape to a place of safe refuge

3.5
exposure dose
Ct product of a gaseous toxicant or of a fire effluent which is available for inhalation, i.e. the integrated area under the concentration-time curve

3.6
fire effluent
total gaseous, particulate or aerosol effluent from combustion or pyrolysis

3.7
fractional effective concentration
FEC
ratio of the concentration of an irritant to that expected to produce a given effect on an exposed subject of average susceptibility

NOTE 1 As a concept, FEC may refer to any effect, including incapacitation, lethality or even other endpoints. Within the context of this Technical Specification, FEC refers only to incapacitation.

NOTE 2 When not used with reference to a specific irritant, the term FEC represents the summation of FECs for all irritants in a combustion atmosphere.

3.8
fractional effective dose
FED
ratio of the *Ct* product for an asphyxiant toxicant to that *Ct* product of the asphyxiant expected to produce a given effect on an exposed subject of average susceptibility

NOTE 1 As a concept, FED may refer to any effect, including incapacitation, lethality or even other endpoints. Within the context of this Technical Specification, FED refers only to incapacitation.

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

3.9
incapacitation
state of physical inability to accomplish a specific task

EXAMPLE Inability to take effective action to accomplish one's own escape from a fire.

3.10
irritation, sensory/upper respiratory
stimulation of nerve receptors in the eyes, nose, mouth, throat and respiratory tract, causing varying degrees of discomfort and pain along with the initiation of numerous physiological defence responses

3.11
LC_{50}
concentration of a toxic gas or fire effluent statistically calculated from concentration-response data to produce lethality in 50 % of test animals within a specified exposure and post-exposure time

NOTE The concentration of a toxic gas is expressed as a volume fraction in parts per million (ppm) or for fire effluent in grams per cubic metre ($g \cdot m^{-3}$).

3.12
LCt_{50}
product of the concentration of a toxic gas or fire effluent and the exposure time causing lethality in 50 % of test animals

NOTE The LCt_{50} is expressed as ppm·min for a single toxic gas and in $g \cdot m^{-3} \cdot min$ for the total fire effluent.

3.13
mass loss rate
mass loss of material per unit time under specified conditions

3.14
parts per million
ppm
volume fraction of a gas $\times 10^6$

NOTE Concentrations of toxic gases are expressed as volume fractions in ppm, rather than as mass fractions, since potential users are more familiar with volume fractions in quantifying human exposures.

3.15
smoke
visible suspension of solid and/or liquid particles in gases resulting from combustion or pyrolysis

3.16
time available for escape
interval between the time of ignition and the time after which conditions become untenable such that occupants are unable to take effective action to accomplish their own escape to a place of safe refuge

NOTE The time available for escape, as used in this Technical Specification, may or may not be equivalent to the commonly used term ASET (Available Safe Escape Time). This is because the user has the choice of setting the intended fire safety objective.

3.17
time required for escape
time required for occupants to travel from their location at the time of ignition to a place of safe refuge

NOTE As used in this Technical Specification, time required for escape is intended to be equivalent to the commonly used term RSET (Required Safe Escape Time). See ISO/TR 13387-8:1999.

3.18
toxic hazard
the potential for harm resulting from exposure to toxic products of combustion

4 General principles

4.1 Time available for escape

The time available for escape from a fire is that time after which occupants can no longer take effective action to accomplish their own escape. It is the shortest of four distinct times estimated from consideration of asphyxiant fire gases, irritant fire gases, heat and visual obscuration due to smoke.

4.2 Toxic gas model

4.2.1 The basic principle for assessing the asphyxiant component of toxic hazard analysis involves the exposure dose of each toxicant, i.e. the area integrated under each concentration-time curve (see ISO/TR 9122-5). 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.

4.2.2 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.

4.3 Mass loss model

The mass loss model provides for a simple assessment of the time available for occupants' escape using the total fire effluent lethal toxic potency data obtained from laboratory test methods (ISO 13344:1996). However, it does not distinguish between the toxic effects of different fire effluent components. The basic principle involves the exposure doses of the fire effluents produced from materials and products, i.e. the integrated areas under their concentration–time curves. Fractional effective doses (FEDs) are determined for fire effluents 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.

4.4 Heat and radiant energy model

Heat and radiant energy are assessed using a fractional effective dose (FED) model, analogous to that used for fire gases. The time at which the accumulated sum of fractional doses of heat and radiant energy exceeds a specified threshold value represents the time available for escape relative to chosen safety criteria.

4.5 Smoke obscuration model

As smoke accumulates in an enclosure, it becomes increasingly difficult for occupants to find their way. This results in a significant effect on the time *required* for their escape. Moreover, at some degree of smoke intensity, occupants can no longer discern boundaries and will become unaware of their location relative to doors, walls, windows, etc., even if they are familiar with the occupancy. When this occurs, occupants may become so disoriented that they are unable to effect their own escape. The time at which this occurs represents the time *available* for escape due to smoke obscuration.

5 Significance and use

5.1 The concepts of fractional effective dose (FED) and fractional effective concentration (FEC) are fundamental to the methodology of this Technical Specification. Both concepts relate to the manifestation of specified physiological effects exhibited by exposed subjects.

5.2 Given the scope of this Technical Specification, FED and/or FEC values of 1,0 are associated, by definition, with sublethal effects that would render occupants of average susceptibility incapable of effecting their own escape. The variability of human responses to toxicological insults is best represented by a distribution that takes into account varying susceptibility to the insult. Some people are more sensitive than the average, while others may be more resistant (see A.5). The traditional approach in toxicology is to employ a safety factor to take into consideration the variability among humans, serving to protect the more susceptible subpopulations [1].

As an example, within the context of reasonable fire scenarios FED and/or FEC threshold criteria of 0,3 could be used for most general occupancies in order to provide for escape by the more sensitive subpopulations. However, the user of this Technical Specification has the flexibility to choose other FED and/or FEC threshold criteria as may be appropriate for chosen fire safety objectives. More conservative FED and/or FEC threshold criteria may be employed for those occupancies that are intended for use by especially susceptible subpopulations. By whatever rationale FED and FEC threshold criteria are chosen, it is necessary to use a single value for both FED and FEC in a given calculation of the time available for escape.

NOTE At present, the distribution of human responses to fire gases is not known. In the absence of information to the contrary, a log-normal distribution of human responses is a reasonable choice to represent a single peak distribution with a minimum value of zero and no upper limit. By definition, FED and FEC threshold criteria of 1,0 would correspond to the median value of the distribution, with one-half of the population being more susceptible to an insult and one-half being less susceptible. Statistics show [2] that at FED and/or FEC threshold criteria of 0,3, then 11,4 % of the population would be susceptible to less severe exposures (lower than 0,3) and, therefore, be statistically unable to accomplish their own escape. Lower threshold criteria would reduce that portion of the population. However, there is no threshold criterion so low as to be statistically safe for every exposed occupant.

5.3 The time-dependent concentrations of fire effluents to which occupants, who are often on the move, are exposed can only be determined using computational fire models and/or a series of real-scale experiments. It is not valid to insert the concentrations of fire effluents or values of smoke optical density obtained from bench-scale test methods in the equations presented in this Technical Specification.

5.4 The methodology described has not been and cannot be validated from experiments using people. It is necessary to recognize that uncertainty exists in the precision of the experimental data upon which the equations are based, the representation of those data by an algebraic function, the accuracy of assumptions regarding non-interaction of fire gases with each other and with heat, the susceptibility of people relative to the susceptibility of test animals, etc. These uncertainties are estimated in the following sections. As with any engineering calculation, uncertainties should be included in the estimation of the overall uncertainty of a fire hazard or risk analysis. This enables the user to determine whether the difference between the outcomes of two such analyses are truly different or are irresolvable.

NOTE The resulting uncertainty in the estimated time available to escape depends in a non-linear manner upon the uncertainty in the FED and FEC calculations. (For instance, these uncertainties could have reduced impact on the estimated outcome of rapidly developing fires.)

5.5 There is very little information on exposures of 1 h or more. Thus, the accuracy of the equations in this Technical Specification and the resulting estimations of the outcome of more protracted fire scenarios are not known. The user of this Technical Specification should exercise particular caution when making estimations that involve occupant exposure times exceeding 1 h.

6 Toxic gas models

6.1 Asphyxiant gas model

6.1.1 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 (see 5.2). The principle of the model in its simplest form for calculating the fractional effective dose (FED) is shown in Equation (1):

