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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 disponible pour l'évacuation, utilisant les caractéristiques du feu

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Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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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.

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

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

This first edition of ISO 13571 cancels and replaces ISO/TS 13571:2002 which has been technically revised.

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 International Standard, escape can 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;

d) visual obscuration due to smoke.

The time available for escape is the calculated time interval between the time of ignition and the time at which conditions become such that an occupant is unable to take effective action to escape to a safe refuge or place of safety. As occupants are exposed to heat and fire effluents, their escape behaviour, movement speed and choice of exit route are also affected, reducing the efficiency of their actions and delaying escape; see ISO/TR 13387-8. These factors affect the time required for escape and are, therefore, not considered in this International Standard.

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 International Standard are used as input to a fire hazard or risk analysis; see 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. 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 is likely to have a different estimated time available for escape (see also Clause A.5).

Annex A describes the context and mechanisms of the fire-effluent toxicity component of life threat. Effects such as those of the asphyxiant toxicants, carbon monoxide and hydrogen cyanide (Clause 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 Clause 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 International Standard.

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 (Clause A.6), but are considered secondary in this International Standard.

The toxic effects of aerosols and particulates and any interactions with gaseous fire-effluent components are not considered in this International Standard. 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 International Standard, 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 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 can 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 then require consideration by the fire safety engineer.

The guidance in this International Standard 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 might 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 International Standard 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.

Annex A is for information only.

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

1 Scope

This International Standard 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 International Standard is to be used only within this context.

This International Standard 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 Clause A.1). Once these are determined, the methodology presented in this International Standard can be used for the estimation of the available escape time.

This International Standard 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 are no longer able to take effective action to accomplish their own escape (see Clause 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 International Standard (see the Introduction).

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.

ISO 13943, *Fire safety — Vocabulary*

3 Terms and definitions

For the purposes of this document, 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 gaseous toxicant or fire effluent as a function of time

NOTE The typical units for the concentration of a toxic gas are $\mu l \cdot l^{-1}$ and, for fire effluent, $g \cdot m^{-3}$. The units of $\mu l/l$ are numerically identical to ppm by volume, a deprecated unit.

3.3
escape
effective action by occupants to accomplish their own escape to a place of safe refuge

3.4
exposure dose
measure of a gaseous toxicant or of a fire effluent available for inhalation, calculated by integration of the area under a concentration-time curve

NOTE The typical units are $\mu l \cdot l^{-1} \cdot min$ for a gaseous toxicant and $g \cdot m^{-3} min$ for fire effluent.

3.5
fractional effective concentration
FEC
ratio of the concentration of an irritant to that expected to produce a specified effect on an exposed subject of average susceptibility

NOTE 1 As a concept, FEC can refer to any effect, including incapacitation, lethality or even other endpoints. Within the context of this International Standard, 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.

3.6
fractional effective dose
FED
ratio of the exposure dose for an asphyxiant toxicant 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, FED can refer to any effect, including incapacitation, lethality or even other endpoints. Within the context of this International Standard, 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.

3.7
incapacitation
inability to take effective action to accomplish one's own escape from a fire

3.8
irritant, 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 along with the initiation of numerous physiological defence responses

3.9
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 typical units are $\mu l \cdot l^{-1}$ for a gaseous toxicant and $g \cdot m^{-3}$ for fire effluent.

3.10
LCt_{50}
measure of lethal toxic potency equal to the product of LC_{50} and the exposure duration over which it was determined

NOTE The typical units are $\mu l \cdot l^{-1} \cdot min$ for a gaseous toxicant and $g \cdot m^{-3} \cdot min$ for fire effluent.

3.11
mass-loss rate
test specimen mass loss per unit time under specified conditions

3.12
available safe escape time
ASET
for an individual occupant, the calculated time interval between the time of ignition and the time at which conditions become such that the occupant is estimated to be incapacitated, i.e. unable to take effective action to escape to a safe refuge or place of safety

NOTE 1 The time of ignition may be known, e.g. in the case of a fire model or a fire test, or it may be assumed, e.g. it may be based upon an estimate working back from the time of detection. It is necessary to state the basis on which the time of ignition is determined.

NOTE 2 This definition equates incapacitation with failure to escape. Other criteria for ASET are possible. It is necessary to state if an alternative criterion is selected.

NOTE 3 Each occupant may have a different value of ASET, depending on that occupant's personal characteristics.

3.13
time required for escape
RSET
calculated time required for occupants to travel from their location at the time of ignition to a place of safe refuge

3.14
toxic hazard
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 toxic-gas models described in this International Standard address effects that are considered detrimental to human escape, rather than lethality. Effects that are detrimental to escape and those that cause lethality are both dose-related in the case of the asphyxiant fire gases, carbon monoxide and hydrogen cyanide. Both toxicants are transported by the circulatory system and result in central nervous system depression due to hypoxia. This permits a reasonable estimation of incapacitating effects on human escape from lethality data. On the other hand, sensory/upper-respiratory irritation that is detrimental to escape and pulmonary (deep lung) irritation leading to lethality are physiologically unrelated and mechanistically independent. The detrimental effects of sensory/upper-respiratory irritants are manifest by lachrymation, pain in the nose, throat and chest tightness, coughing, laryngeal spasms and broncho-constriction (comparable to an asthma attack) and are concentration-related. Lethality from pulmonary irritation is often due to pulmonary oedema or obliterating bronchiolitis, which require a latency period to develop. These effects are dose related. Because of their different physiological mechanisms, human sensory/upper-respiratory irritant effects cannot simply be deduced from an arbitrarily selected lower dose than that required to cause lethality, particularly when derived from an animal model.

NOTE Apart from the difficulties in transposing such animal data to humans, it is also necessary to realize that an animal model is associated only with a specific human response and is not a model for the entire collective human physiological system.

4.2.2 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. 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.

4.2.3 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). 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 become unaware of their location relative to doors, walls, windows, etc., even if they are familiar with the premises. When this occurs, occupants can 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 International Standard. Both concepts relate to the manifestation of specified physiological effects exhibited by exposed subjects.

5.2 Given the scope of this International Standard, 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 can be more resistant (see Clause 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 can be used for most general occupancies in order to provide for escape by the more sensitive subpopulations. However, the user of this International Standard has the flexibility to choose other FED and/or FEC threshold criteria as is 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 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 an FED and/or FEC threshold criteria of 0,3, then 11,4 % of the population is susceptible to less severe exposures (lower than 0,3) and, therefore, is statistically unable to accomplish their own escape. Lower threshold criteria reduce that portion of the population. However, there is no threshold criterion so low as to be statistically safe for every exposed occupant.

The ability of occupants to escape should not be construed as equating to no post-exposure harm to occupants. Exposure to concentrations of fire-gas toxicants sufficiently close to those that are incapacitating can result in a variety of effects that can impair escape and thus increase exposure intensity to fire effluents and/or lead to post-exposure health problems; see Annex A. However, quantification of these effects, especially under conditions where effective post-traumatic measures are common practice through medical intervention, is beyond the scope of this document.

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 International Standard.

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 can 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 International Standard and the resulting estimations of the outcome of more protracted fire scenarios are not known. The user of this International Standard 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, X_{FED}, is shown in Equation (1):

$$X_{\text{FED}} = \sum_{i=1}^{n} \sum_{t_1}^{t_2} \frac{C_i}{(C \cdot t)_i} \Delta t \qquad (1)$$

where

C_i is the average concentration, expressed in microlitres per litre, of an asphyxiant gas "i" over the chosen time increment;

Δt is the chosen time increment, expressed in minutes;

$(C{\cdot}t)_i$ is the specific exposure dose, expressed in minutes multiplied by microlitres per litre, that can prevent the occupants' safe escape.

