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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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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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 µl/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):

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

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.

6.1.2 An expanded form of Equation (1) is shown as Equation (2), where carbon monoxide (CO) and hydrogen cyanide (HCN) are the asphyxiant gases and where the specific exposure doses are represented by the factors [e.g. 35 000 corresponds to the incapacitating dose, $(C{\cdot}t)$, for CO of 35 000 μl·l^{-1}·min] given for each of these gases; see Notes 2 and 3.

$$X_{\text{FED}} = \sum_{t1}^{t2} \frac{\varphi_{\text{CO}}}{35\,000} \Delta t + \sum_{t1}^{t2} \frac{\exp(\varphi_{\text{HCN}}/43)}{220} \Delta t \qquad (2)$$

where

φ_{CO} is the average concentration, expressed in microlitres per litre, of CO over the time increment, Δt;

φ_{HCN} is the average concentration, expressed in microlitres per litre, of HCN over the time increment, Δt;

Δt is the time increment, expressed in minutes.

It is estimated that the uncertainty in Equation (2) is ± 35 % based on the information in Notes 1 to 7.

NOTE 1 All available evidence supports the working hypothesis that, in typical fire atmospheres, CO and HCN are the only asphyxiant combustion products that exert a significant effect on the time available for escape. Oxygen vitiation can also produce asphyxiation, but its consideration is not required as long as O_2 concentrations do not fall below 13 %. (The user is referred to Reference [5] for consideration of O_2 concentrations less than 13 %.) The narcotic effect of CO_2 is not significant at the concentrations experienced in otherwise tenable fire atmospheres. The increased rate of asphyxiant uptake due to hyperventilation caused by CO_2 is addressed in 6.1.3.

NOTE 2 The incapacitating dose, $(C{\cdot}t)$, for CO of 35 000 μl·l^{-1}min was obtained from experiments on juvenile baboons subjected to an escape paradigm[3]. Using the Stewart-Peterson equation[4], a dose of 35 000 μl·l^{-1}min would produce approximately 30 % carboxyhaemoglobin, COHb, saturation in humans having a respiratory minute volume of 20 l/min.

NOTE 3 The incapacitating dose, $(C{\cdot}t)$, for HCN cannot be represented as a constant. The exponential expression shown was derived from one using data obtained from studies on cynomolgus monkeys[5].

NOTE 4 The dose-effect data used in this subclause are based on human and non-human primate experience. Carbon monoxide and hydrogen cyanide have identical pathomechanisms both in laboratory animals and in humans. Species-specific metabolisms that can modulate the toxic potency of these agents are not known. The dose rate, i.e. kinetics of uptake, is commonly higher for small animals when compared to humans, because the higher energy consumption of the former requires a higher ventilation per unit of body mass. It is, therefore, considered adequately conservative that no adjustment in FED values be made to reflect interspecies differences in susceptibility.

NOTE 5 Guidance on analytical methods is given in ISO 19701 and ISO 19702.

NOTE 6 A moderate level of physical activity, equivalent to brisk walking on a level surface, is assumed. Guidance appropriate for other levels of activity is available[5].

NOTE 7 It is assumed that heat and irritant gases have no effect on FED for asphyxiants. Although some effects are likely, no quantitative information is available. Any interactive effects are considered to be secondary.

6.1.3 In cases when the CO_2 concentration exceeds 2 % by volume, the concentration terms φ_{CO} and φ_{HCN} in Equation (2) at each time increment shall be multiplied by a frequency factor, ν_{CO_2}, to allow for the increased rate of asphyxiant uptake due to hyperventilation[5].

$$\nu_{\text{CO}_2} = \exp\left[\frac{\varphi_{\text{CO}_2}}{5}\right] \qquad (3)$$

where φ_{CO_2} is the average volume percent of CO_2.

NOTE Equation (3) is derived from an empirical fit to human hyperventilation, corrected for uptake inefficiencies in the lung. It is accurate to within ± 20 %.

6.2 Irritant-gas model

6.2.1 The effects of sensory/upper-respiratory irritants and, to some extent, pulmonary irritants also, are assessed using the fractional effective concentration (FEC) concept shown in Equation (4)[5]. As a first-order assumption, direct additivity of the effects of the different irritant gases is employed. It is also assumed that the concentration of each irritant gas reflects its presence totally in the vapour phase. 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 5.2).

$$X_{\text{FEC}} = \frac{\varphi_{\text{HCl}}}{F_{\text{HCl}}} + \frac{\varphi_{\text{HBr}}}{F_{\text{HBr}}} + \frac{\varphi_{\text{HF}}}{F_{\text{HF}}} + \frac{\varphi_{\text{SO}_2}}{F_{\text{SO}_2}} + \frac{\varphi_{\text{NO}_2}}{F_{\text{NO}_2}} + \frac{\varphi_{\text{acrolein}}}{F_{\text{acrolein}}} + \frac{\varphi_{\text{formaldehyde}}}{F_{\text{formaldehyde}}} + \sum \frac{\varphi_{\text{irritant}}}{F_{C_i}} \quad (4)$$

where

φ is the average concentration, expressed in microlitres per litre, of the irritant gas;

F is the concentration, expressed in microlitres per litre, of each irritant gas that is expected to seriously compromise occupants' ability to take effective action to accomplish escape.

It is estimated, based on the information in Notes 1 to 5, that the uncertainty associated with the use of Equation (4) is $\pm$ 50 %. This could be significantly larger if the products involved in the fire generate toxicologically important quantities of additional irritants; see 6.2.2.

NOTE 1 Respiratory-tract irritation is direct and occurs at the first contact of an inhaled irritant with susceptible tissues; see A.4.2. Especially for very short exposures, species-specific metabolisms that can modulate the potency of these irritants are not likely to occur. The effectiveness of an upper-respiratory-tract irritant is commonly described in a concentration-dependent manner, while that of a lower-respiratory-tract irritant acts in a concentration-times-time-dependent manner (see Note 2).

At the beginning of an exposure, it takes some time for an irritant gas to equilibrate with the lining fluids of mucous membranes. However, there are no kinetic data for this initial period, making it difficult to treat as concentration-times-time dependent. This International Standard, therefore, considers sensory irritant effects as instantaneous.

Although the equilibration appears to occur in a time-dependent manner at lower to moderate concentrations, the equilibration transient appears to be negligible at higher concentrations. Thus, use of the FEC (rather than the FED) is considered to be the appropriate option with the most hazardous exposures.

NOTE 2 In addition to causing sensory/upper-respiratory effects, most irritants can also penetrate deeper into the lungs, causing pulmonary-irritation effects that are related both to concentration and to the duration of the exposure, i.e. dose; see A.4.3. Respiratory distress and even death due to pulmonary oedema can occur from a few hours to up to several days after exposure. These effects are not addressed in this International Standard since the primary goal is to enable calculation of the time available for people to remove themselves from the immediate danger of the fire. In most fires, the effects of asphyxiants and heat have reached critical levels well before a significant dose of lung irritants has been inhaled.

NOTE 3 In a manner analogous to the concept of "engineering judgment", "toxicological judgment" was exercised in the establishment of criteria expected to seriously compromise the ability of most exposed occupants to escape in situations where occupants have minimal familiarity with their occupancy and where there is little or no presence of escape management; see A.4.2. Expert cognizance was taken of relevant data cited in References [5], [6], [7] and [8]. Through consensus, the following F-factors are suggested for use in Equation (4).

F_{HCl}	1 000 μl·l^{-1}	F_{NO_2}	250 μl·l^{-1}
F_{HBr}	1 000 μl·l^{-1}	F_{acrolein}	30 μl·l^{-1}
F_{HF}	500 μl·l^{-1}	$F_{\text{formaldehyde}}$	250 μl·l^{-1}
F_{SO_2}	150 μl·l^{-1}		

NOTE 4 Guidance on analytical methods for these gases is given in ISO 19701.

NOTE 5 Since sensory irritation occurs on contact, it is assumed that irritant gases act in a simply additive manner. However, no studies involving humans or laboratory animals have been performed to validate this.

6.2.2 Numerous other irritant species can be formed in fires. The range of other effluent species selected for analysis shall be broad enough to cover those species of toxicological significance that can reasonably be expected to be released, based on the knowledge of the composition of the material under test and in consultation with published documentation for exposure criteria for use in Equation (4).

NOTE Such irritants include, but are not be limited to, isocyatates, aldehydes, alcohols, ketones, nitriles and phosphorus compounds.

7 Mass-loss model

7.1 Concentrations of fire-gas 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 fire effluents are dispersed and lethal toxic potency values as determined from laboratory test methods, e.g. ISO 13344.

7.2 The value of C_i for the concentration of fire effluent produced from material or product "i" is related to the mass loss and the volume into which the fire effluent is dispersed as shown in Equation (5):

$$C_i = \frac{\Delta m}{V} \tag{5}$$

where

Δm is the mass loss, expressed in grams;

V is the volume, expressed in cubic metres.

7.3 Substitution of Equation (5) into Equation (1) yields Equation (6), which is now a mass-loss model (see Note), rather than one for toxic gases.

$$X_{\text{FED}} = \sum_{i=1}^{n} \sum_{t_1}^{t_2} \frac{\Delta m_{\text{aa}}}{V\left(C \cdot t\right)_i} \Delta t \tag{6}$$

where

Δm_{aa} is the average accumulated mass loss, expressed in grams, over the time increment, Δt;

V is the volume, expressed in cubic metres;

Δt is the time increment, expressed in minutes;

$(C{\cdot}t)_i$ is one half of the value of LCti, expressed as minutes times grams per cubic metre.

Care should be taken that the conditions under which laboratory test LCt_{50} data were obtained are relevant to the type of fire being considered (ISO 19706, ISO 13344).

One half of the LCt_{50} is recommended as an approximate exposure dose when relating incapacitation to lethality[11]. Although based on experimental data obtained from exposure of rats, this relationship is also expected to be appropriate for human exposure (ISO/TR 9122-2). It should be recognized that LC_{50} or LCt_{50} values for fire effluents also include the effects of pulmonary irritants, but not necessarily those of sensory/upper-respiratory irritants that can impact ability to escape (see 4.2.1).

NOTE The mass-loss model represents a considerable simplification for assessment of the life threatening effects of fire effluents. It does not distinguish between the different effects of individual fire gases, but derives an estimate of toxic potency from the overall lethal effects of a toxic effluent mixture, the composition of which depends on the material or product decomposed in a laboratory test method and the thermal decomposition conditions in a test. The results from such tests provide an estimate of lethal toxic potency related to a 30-min exposure period and a 14-d post-exposure observation period. The lethal toxic potency estimate, therefore, includes lethality both during and after exposure. When the data are derived from methods described in ISO 13344, the toxic potency data represent estimated lethal toxic potency for specified gas mixtures. When the data are derived from animal exposures, they represent the total lethal effects of the effluent mixture, including any interactions between all known and unknown individual toxic agents present, as well as effects related to the physical form of the effluent in terms of gases and particulate. When several different materials are involved in a fire, the toxic potencies of the effluent from each material are assumed to be directly additive in relation to the estimated mass loss concentrations in the fire enclosure as a function of time.

7.4 Combustible fuel in a fire often consists of a mixture of materials and products that are unidentified as to their nature and relative quantity. In these cases, a "generic" LCt_{50} value may be employed, i.e. 900 g·m^{-3}·min for well-ventilated, pre-flashover fires and 450 g·m^{-3}·min for vitiated post-flashover fires[10],[11]. These values are consistent with analysis of data obtained from laboratory tests on a variety of materials and products[11]. For prevention of occupants' escape, $(C{\cdot}t)_i$ in Equation (6) then becomes 450 g·m^{-3}·min for well-ventilated pre-flashover fires and 220 g·m^{-3}·min for vitiated post-flashover fires.

NOTE The vitiated post-flashover exposure dose of 220 g·m^{-3}·min for prevention of occupants' escape provides for occupants' exposure to 38 000 µl·l^{-1}·min of CO (assuming a CO yield of 0,2). Using the Stewart–Peterson equation[4], a dose of 38 000 µl·l^{-1}·min produces approximately 34 % carboxyhaemoglobin (COHb) saturation in humans having a respiratory minute volume of 20 l/min (see 6.1.2, Note 2).

Uncertainties in calculations associated with using the pre-flashover and post-flashover values for prevention of occupants' escape are estimated to be ± 75 % and ± 30 %, respectively.

It is cautioned that "generic" LCt_{50} values represent only an approximation. Their use is subject to appropriate sensitivity analyses, as well as to expert toxicological and engineering judgment.

7.5 Fractional effect 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; see 5.2.

8 Heat

8.1 There are three basic ways in which exposure to heat can lead to life threat:

a) hyperthermia;

b) body surface burns;

c) respiratory-tract burns.

For use in the modelling of life threat due to heat exposure in fires, it is necessary to consider only two criteria:

— threshold of second degree burning of the skin;

— exposure where hyperthermia is sufficient to cause mental deterioration and, therefore, threaten survival.

NOTE Thermal burns to the respiratory tract from inhalation of air containing less than 10 % by volume of water vapour do not occur in the absence of burns to the skin or the face; thus, tenability limits with regard to skin burns are normally lower than for burns to the respiratory tract. However, thermal burns to the respiratory tract can occur upon inhalation of air above 60 °C when saturated with water vapour.

8.2 The tenability limit for exposure of skin to radiant heat is approximately 2,5 kW·m^{-2}. Below this incident heat flux level, exposure can be tolerated for 30 min or longer without significantly affecting the time available for escape. Above this threshold value, the time, t_{Irad}, expressed in minutes, to second degree burning of skin due to radiant heat decreases rapidly according to Equation (7)[12]:

$$t_{\mathrm{Irad}} = 6{,}9 q^{-1{,}56} \qquad (7)$$

where q is the radiant heat flux, expressed in kilowatts per square metre.

As with toxic gases, an exposed occupant may be considered to accumulate a dose of radiant heat over a period of time. The FED of radiant heat accumulated per minute is the reciprocal of t_{Irad}.

NOTE Radiant heat tends to be directional, producing localized heating of particular areas of skin even though the air temperature in contact with other parts of the body can be relatively low. Skin temperature depends upon the balance between the rate of heat applied to the skin surface and the removal of heat subcutaneously by the blood. Thus, there is a threshold radiant flux below which significant heating of the skin is prevented but above which quite rapid heating occurs.

The time to experiencing pain due to radiant heat, although not necessarily preventing occupants' escape, can have a behavioural effect on time required for escape. The time, t_{Irad}, expressed in minutes, to experiencing pain due to radiant heat is a somewhat more strongly inverse function of radiant heat than that for the burning of skin. It is expressed by Equation (8)[12]:

$$t_{\text{Irad}} = 4{,}2q^{-1{,}9} \tag{8}$$

where q is the radiant heat flux, expressed in kilowatts per square metre.

Based on the above information, it is estimated that the uncertainty associated with the use of Equations (7) and (8) is ± 25 %. Moreover, an irradiance of 2,5 kW·m^{-2} would correspond to a source surface temperature of approximately 200 °C, which is most likely to be exceeded near the fire, where conditions are changing rapidly.

8.3 Calculation of the time to incapacitation under conditions of exposure to convective heat from air containing less than 10 % by volume of water vapour can be made using either Equation (9)[13] or Equation (10)[5].

As with toxic gases, an exposed occupant can be considered to accumulate a dose of convected heat over a period of time. The FED of convected heat accumulated per minute is the reciprocal of t_{Iconv}.

8.3.1 The time, t_{Iconv}, expressed in minutes, to experiencing pain due to convected heat accumulated per minute depends upon the extent to which an exposed occupant is clothed and the nature of the clothing. For fully clothed subjects, Equation (9) is suggested[13]:

$$t_{\text{Iconv}} = (4{,}1 \times 10^{8})T^{-3{,}61} \tag{9}$$

where T is the temperature, expressed in degrees Celsius.

8.3.2 For unclothed or lightly clothed subjects, it may be more appropriate to use Equation (10)[5].

$$t_{\text{Iconv}} = (5 \times 10^{7})T^{-3{,}4} \tag{10}$$

where the variables are the same as for Equation (9).

Equations (9) and (10) are empirical fits to human data. It is estimated that the uncertainty is ± 25 %.

NOTE Thermal tolerance data for unprotected skin of humans suggest a limit of about 120 °C for convected heat, above which there is, within minutes, the onset of considerable pain along with the production of burns[5]. Depending upon the length of exposure, convective heat below this temperature can also cause hyperthermia.

8.4 The body of an exposed occupant may be regarded as acquiring a "dose" of heat over a period of time. A short exposure to a high radiant-heat flux or temperature is generally less tolerable than a longer exposure to a lower temperature or heat flux. A methodology based on additive FEDs similar to that used with toxic gases may be applied and, providing that the temperature in the fire is stable or increasing, the total fractional effective dose of heat acquired during an exposure can be calculated using Equation (11):

$$X_{\text{FED}} = \sum_{t_1}^{t_2} \left(1/t_{\text{Irad}} + 1/t_{\text{Iconv}} \right) \Delta t \tag{11}$$

In areas within an occupancy where the radiant flux to the skin is under 2,5 kW·m^{-2}, the term ($1/t_{Irad}$) in Equation (11) is set at zero.

The uncertainty associated with the use of Equation (11) is dependent upon the uncertainties with the use of Equations (7), (8), (9) and (10).

8.5 In the same manner as with toxic-gas exposures, the time at which the FED accumulated sum exceeds a specified threshold value represents the time available for escape relative to chosen safety criteria; see 5.2.

9 Smoke-obscuration model

The principle of the smoke-obscuration model is based on the concept of minimum detectable contrast, i.e. the minimum visible brightness difference between an object and a background. It is estimated that occupants literally cannot see their hands in front of their faces, thus becoming disoriented, when confronted with a fuel mass loss concentration of 20 g·m^{-3} for well-ventilated fires and 10 g·m^{-3} for under-ventilated fires. The time at which this mass loss concentration is reached represents that after which occupants can no longer take effective action to accomplish their own escape.

NOTE 1 Visual contrast, c_v, is given by Equation (12)[14].

$$\ln c_v = -\sigma \rho_{sm} \cdot L \tag{12}$$

where

σ is the mass specific extinction coefficient, expressed as square metres per gram, for smoke aerosol;

ρ_{sm} is the mass concentration of smoke aerosol, expressed in grams per cubic metre;

L is the smoke-filled distance, expressed in metres, between an object and the viewer.

Symbols used here have been modified from those contained in Reference [14].

Using a minimum detectable contrast of 0,02 [14], and a generic value of σ (corrected for white light) for well-ventilated fire smoke of 10 m^2·g^{-1} [15], it is calculated from Equation (13) that occupants cannot see more than a distance of approximately 0,5 m (about an arm's length) at a mass concentration of light-obscuring smoke aerosol of 0,8 g·m^{-3}.

Equation (13) can be used to convert the mass concentration of smoke aerosol to the corresponding mass loss concentration produced from the burning fuel in a fire:

$$\rho_{bf} = \frac{\rho_{sm}}{W_{sa}} \tag{13}$$

where

ρ_{bf} is the mass loss concentration of burning fuel, expressed in grams per cubic metre;

ρ_{sm} is the smoke mass concentration, expressed in grams per cubic metre;

W_{sa} is the yield of smoke aerosol from the fuel given by Equation (14):

$$W_{sa} = \frac{m_a}{m_{fc}} \tag{14}$$

where

m_a is the mass of the aerosol, expressed in grams;

m_{fc} is the mass, expressed in grams, of fuel consumed.

For well-ventilated flaming fires, a number of common plastics have aerosol yields of 1 % to 10 %, with wood being somewhat lower. Although there is considerable scatter in the measurements, 4 % represents a typical yield, with a smoke aerosol mass concentration of 0,8 g·m^{-3} then equating to a fuel mass loss concentration of about 20 g·m^{-3}. For under-ventilated flaming measurements in a small-scale device, the aerosol yields appear to double (with an uncertainty of ± 50 %[16]) and the yield from wood cribs increases into the same range as the plastics[17]. Thus for under-ventilated combustion, a smoke aerosol mass concentration of 0,8 g·m^{-3} equates to a fuel mass loss concentration of about 10 g·m^{-3}. The change in the value of σ is small compared to the change in yield and is neglected.

NOTE 2 Experiments have shown that the threshold of visibility for light-reflecting signs occurs at an aerosol mass concentration of approximately 0,3 g·m^{-3}·L^{-1} and, for light-emitting signs, at approximately 0,8 g·m^{-3}·L^{-1}, where L is equal to distances of 5 m to 15 m [18]. The former value is recommended for assessing the visibility of stairs, doors, walls, etc. Assuming that the relationship holds at the shorter distance of 0,5 m (about an arm's length), it yields a threshold aerosol mass concentration of 0,6 g·m^{-3}, above which occupants can no longer take effective action to accomplish their own escape. This is within reasonable agreement with the concept.

NOTE 3 In many large- and small-scale tests, smoke is measured in terms of optical obscuration. This aerosol mass concentration of 0,8 g·m^{-3} over a path length of 0,5 m corresponds to a smoke optical density of 1,7. Smoke optical density is defined as $\log_{10} (I_0/I)$, the logarithm of the transmitted light to the emitted or reflected light from a source, and is equal to $-\sigma\rho_{sm}L/2,3$ [see Equation (12) for definition of symbols].

NOTE 4 The best value for a mass loss concentration of smoke estimated to prevent occupants from accomplishing their own escape is 20 g·m^{-3} for well-ventilated fires and 10 g·m^{-3} for under-ventilated fires. The uncertainty in these values is estimated to be plus or minus a factor of two. This reflects

a) the wide variation among measurements of smoke-yield data for a given material,

b) the differences in smoke yields for different materials,

c) the fact that an extrapolation of the experimental findings to short distances has not been validated.

When the fire involves a single material for which the aerosol yield has been measured under combustion conditions germane to that fire, this uncertainty is significantly smaller.

NOTE 5 The equivalent of people who are more susceptible to effects from the inhalation of gases are people whose vision is less precise, i.e. who require a higher degree of contrast to discern an object against a background. There are no data indicating what “exposure factor” provides for the susceptible population in a manner equivalent to that in 5.2 for exposure to fire gases. However, using the same factor of 0,3 and recognizing the logarithmic dependence of Equation (12), the resulting incapacitating concentration of smoke for this population would be 15 g·m^{-3} for well-ventilated fires and 7 g·m^{-3} for under-ventilated fires with the uncertainty estimated to be plus or minus a factor of two.

10 Report

The report shall include the following information for each fire scenario to be assessed:

a) time, expressed in minutes, available for escape from a fire, calculated independently for each of the components evaluated using the described methodology for asphyxiant gases, irritant gases, mass loss, heat and smoke obscuration as well as the following details:

   1) identification of all fire gases considered, including rationale for those chosen,

   2) the safety criterion and associated threshold value selected for each component,

   3) any additional assumptions made in the calculations;

b) the estimated time available for escape for each component, as well as the identification of that which is the shortest (including consideration of uncertainties that may result in the time available for escape being limited by multiple components).

Annex A
(informative)

Context and mechanisms of toxic potency

A.1 Elements of fire hazard analysis

Figure A.1 gives the flowchart of the different elements which are necessary to analyse for a fire hazard.

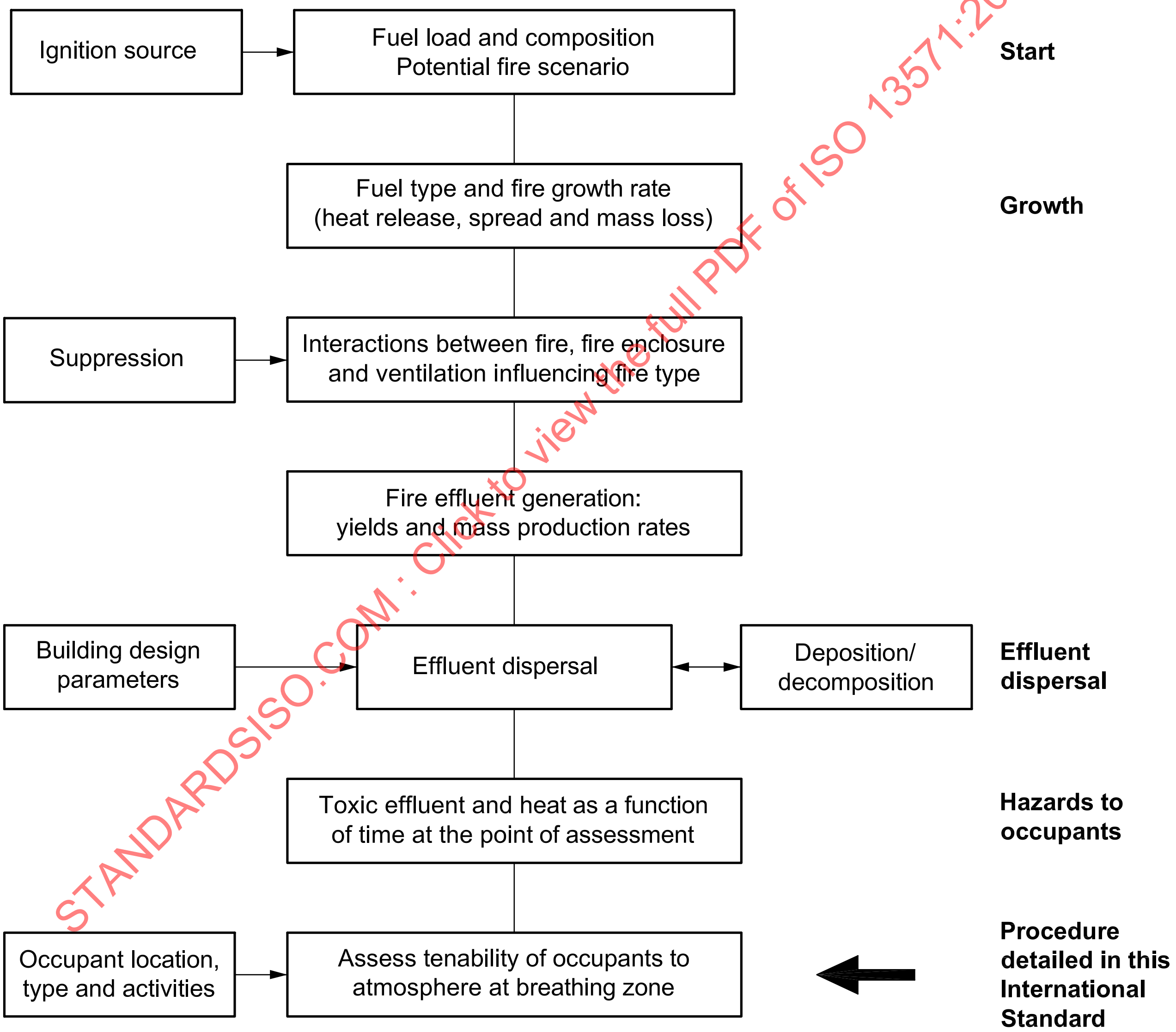


Figure A.1 — Factors in determining the tenability of occupants to fire hazard

A.2 Ability to escape

A.2.1 General

In addition to any pre-existing disabilities, there are both physiological and psychological effects associated with exposure to fire and fire effluents that can impact significantly upon occupants' ability to take effective action to accomplish their own escape.

A.2.2 Psychological effects

Psychological escape impairment is determined by occupants' perception of their tenability associated with various possible courses of action. The decision as to whether or not escape is attempted, as well as the choice of a route, involves their perception of relative risks. This perception is, itself, influenced by a combination of the sight of smoke and fire, the sensation of heat, and irritation of the eyes and upper respiratory tract. Overall, these psychological effects of exposure to fire and smoke are difficult to evaluate quantitatively. Furthermore, their major impact is on the time *required* to escape.

A.2.3 Physiological effects

Often there are a number of simultaneous physiological effects that can have an impact upon the physical ability of occupants to escape. Visual obscuration by smoke affects the ability of occupants to see and negotiate escape routes efficiently. Experimental studies have shown the detrimental effects of increasing smoke optical density upon movement speed and ability. Sensory/upper-respiratory-tract irritation often exacerbates the effects of simple smoke obscuration, with the consequence of affecting movement speed, ability to perform aerobic work, and the ability to negotiate escape routes [19] (see also A.4.2 and A.5). Central-nervous-system depression results mainly from exposure to asphyxiant toxicants (see also Clause A.3). The effects are made manifest by varying degrees of impaired judgement, disorientation, decreased ability to perform aerobic work, loss of motor co-ordination and unconsciousness. Collectively, these effects can impact upon both the time *available* and the time *required* for escape.

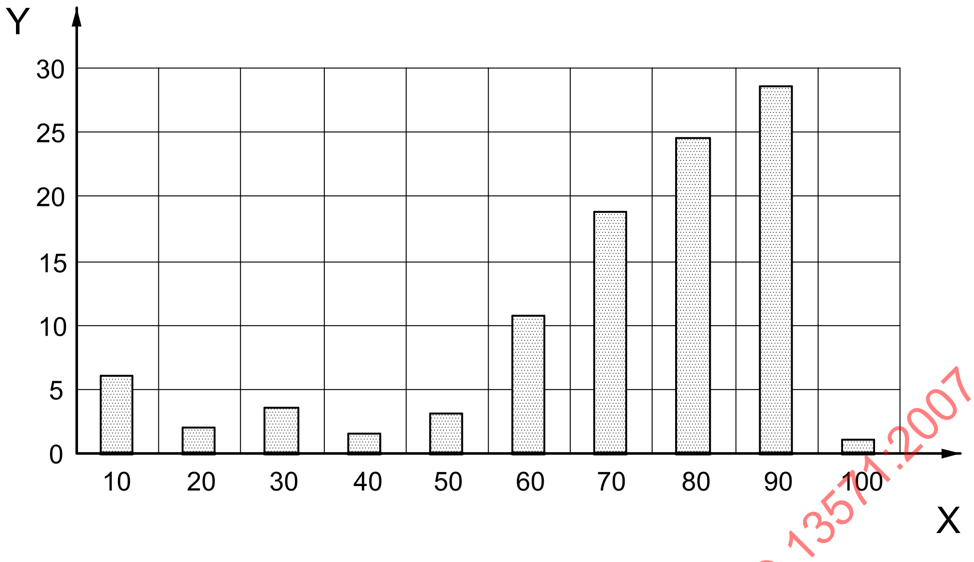
A.3 Asphyxiant toxicants

A.3.1 General

An asphyxiant is a toxicant causing hypoxia (a decrease in oxygen supplied to, or utilized by, body tissue), resulting in central-nervous-system depression with loss of consciousness and, ultimately, death. Effects of these toxicants depend upon accumulated doses, i.e. a function of both concentration and the time or duration of exposure. The severity of the effects increases with increasing dose. Among the fire-gas toxicants, carbon monoxide and hydrogen cyanide have received the most study and are best understood with respect to their capacity to cause incapacitation and death of those exposed [5],[20].

A.3.2 Carbon monoxide

The toxic effects of carbon monoxide are those of anaemic hypoxia, characterized by a lowered oxygen-delivery capacity of the blood, even when the arterial partial pressure of oxygen and the rate of blood flow are normal. This is due to the affinity of haemoglobin for carbon monoxide being about 250 times greater than for oxygen. An insight into the frequency distribution of human responses to intoxication by carbon monoxide can be gained from Figure A.2, which shows the percent of total deaths in one study as a function of increasing doses of carbon monoxide as represented by percent blood carboxyhaemoglobin saturation[21]. (The data in the original reference include carboxyhaemoglobin measurements made by a variety of methods having varying reliability. The distribution shown uses only the results from non-fire fatalities measured using gas chromatography or a CO-oximeter, considered to be the methods with the most confidence. All the human factors of gender, age, health and inebriation are represented to the same extent as in the original data set.)



Key

X carboxyhaemoglobin (COHb), expressed in percent

Y frequency, expressed in percent

Figure A.2 — Frequency distribution of non-fire CO deaths

It is clear that there are human subpopulations that are more susceptible than others to carbon-monoxide intoxication. Exposure to carbon monoxide at levels insufficient to cause death or even unconsciousness can result in varying degrees of impaired judgment, disorientation, confusion and diminished physical coordination such that inappropriate actions can be taken. Significant carbon-monoxide exposure can also result in post-exposure neurological damage[22], including encephalopathy and a resulting memory loss. The incidence of such delayed neurological impairment appears to increase with age[23]; see Clause A.5.

A.3.3 Hydrogen cyanide

Approximately 25 times more toxic than carbon monoxide, hydrogen cyanide owes its toxic effects to the cyanide ion, which is formed by hydrolysis in the blood. Unlike carbon monoxide, which remains primarily in the blood, the cyanide ion is distributed throughout the body water and is in contact with the cells of tissues and organs. The cyanide ion readily reacts with the enzyme, cytochrome oxidase, which occupies a central role in the utilization of oxygen in practically all cells. Its inhibition rapidly leads to loss of cellular functions (cytotoxic hypoxia), then to cell death. In contrast to carbon monoxide, cyanide does not decrease the availability of oxygen but, rather, prevents the utilization of oxygen by cells with the heart and brain being particularly susceptible. Also unlike carbon monoxide, a short exposure to a high concentration of hydrogen cyanide is much more hazardous than a longer exposure to a lower concentration.

A.4 Irritant toxicants

A.4.1 General

In contrast to the direct effects of asphyxiant toxicants, the effects of exposure to irritants are much more complex. Consequently, it is difficult to relate irritant concentrations quantitatively to their impact on ability to escape safely. Most fire-effluent irritants produce signs and symptoms of both sensory/upper-respiratory-tract and pulmonary irritation[5],[20].

A.4.2 Sensory/upper-respiratory irritation

Sensory/upper-respiratory irritation stimulates nerve receptors in the eyes, nose, throat and upper respiratory tract. Appearing to be related only to concentration, the effects lie on a continuum going from mild eye and upper-respiratory discomfort all the way to severe pain. They are largely instantaneous upon exposure[24], [25]. Depending upon the concentration of an irritant and the sensitivity of the individual, effects can include lachrymation and reflex blinking of the eyes, pain in the nose, throat and chest, breath-holding, coughing, excessive mucus secretion, broncho-constriction and even laryngeal spasms; see also Clause A.5. One of the major difficulties in attempting to predict the consequences of exposure to irritants is the poor quality of available human-exposure data. With very few controlled studies having been made with humans, most data are only anecdotal, derived from accidental industrial exposures with only a vague knowledge of actual irritant concentrations[5]. Measurements do exist for sensory/upper-respiratory irritation with mice, with various chemicals exhibiting results over a very wide range of values[7]. However, it is unclear as to the relationship of such data on irritation in mice to the ability of humans to escape. Evidence obtained using healthy animal surrogates under controlled experimental conditions actually suggests that sensory/upper-respiratory irritation (although admittedly often painful) might not impair or prevent escape at all. Particularly significant was the complete failure to cause incapacitation (inability to perform an escape paradigm) of baboons exposed to hydrogen chloride and to acrolein at any concentration up to those that caused post-exposure lethality due to lung irritation[3]; see also A.4.3. Although not statistically significant, it was also observed that exposure to irritants often enhanced escape performance. When macaque monkeys were exposed to irritant smokes, significant effects on lung function and a conditioned behavioural task were observed only at concentrations more than an order of magnitude greater than the mouse RD_{50}[1)] concentration[5]. In another experiment, four human volunteers were exposed under controlled conditions, including medical supervision, to the mouse RD_{50} concentration of the highly irritating smoke produced from red oak without any detectable decrement of behaviour occurring[26]. Other experiments with human subjects exposed to irritating smoke have also shown that initial impairment of ability decreased with time as the subjects appeared to acclimate and become desensitized[17].

In spite of the rather surprising ability of nonhuman primates to perform an escape paradigm when exposed to quite high concentrations of irritants in controlled studies, more conservative criteria were chosen for use in this International Standard; see 6.2.1. Rationale for the choice of more conservative criteria for exposure to irritants were based on two concerns.

The first relates to a study involving exposure of baboons to concentrations of hydrogen chloride at 500 $\mu l \cdot l^{-1}$, 5 000 $\mu l \cdot l^{-1}$ and 10 000 $\mu l \cdot l^{-1}$ for periods of 5 min, 10 min and 15 min [27]. While arterial blood PaO_2 values for those subjects exposed to 500 $\mu l \cdot l^{-1}$ did not differ statistically from control values, subjects exposed to 5 000 $\mu l \cdot l^{-1}$ and 10 000 $\mu l \cdot l^{-1}$ showed a significant drop (about 35 %) in their PaO_2 values. This hypoxemic condition was largely attributed to uneven ventilation resulting from broncho-constriction of airways in the upper respiratory tract. This effect, occurring at HCl concentrations somewhere above 500 $\mu l \cdot l^{-1}$, may be considered quite hazardous if coupled with blood carboxyhaemoglobin saturation at levels commonly encountered in exposures to fire atmospheres. Since elevated blood carboxyhaemoglobin levels are almost always present in those also exposed to irritants, it is considered prudent to suggest exposure criteria for HCl not exceeding 1 000 $\mu l \cdot l^{-1}$. The same rationale is applied to other irritants, as well.

A second concern involved the concept that most people involved in unwanted fires can be expected to have only minimal familiarity with their occupancy, with little or no escape training and without the presence of escape management. These conditions suggest impairment of escape resulting from exposure to concentrations lower than those required for controlled studies using well-trained animal surrogates within familiar environments. The difference can be more one of behavioural, rather than physiological, origin; see A2.2 and A2.3. However, for people without escape training or direction in unfamiliar surroundings, the two cannot realistically be considered separately.

1) The RD_{50} is that concentration of an irritant toxicant statistically determined to depress the respiratory rate of exposed mice by 50 %.

