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Life-threatening components of fire — Guidelines for the estimation of time to compromised tenability in fires

Composants dangereux du feu — Lignes directrices pour l'estimation du temps disponible avant que les conditions de tenabilité ne soient compromises

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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.

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

This second edition cancels and replaces the first edition (ISO 13571:2007), which has been technically revised.

Introduction

Estimation of occupants' tenability when exposed to a fire environment ultimately involves their ability to perform cognitive and motor-skill functions at an acceptable level. Generally, acceptable performance may include any of a number of desirable outcomes, including escape to a place of refuge, or if escape is not a viable option, continued functioning in place as necessary. The latter situation includes occupants who are not mobile or whose egress is prohibited for a variety of reasons, e.g., from an aircraft in flight. The time from initiation of a fire to the point when tenability is compromised such that acceptable performance is not possible is a central component of fire safety design.

The time required to reach compromised tenability may depend upon each occupant's location and movement, along with numerous other characteristics specific to the occupant (see A.2.2). As a result, each occupant may have a different time to compromised tenability. Guidance for consideration of these factors is provided in other sources, e.g., ISO/TR 13387-8 and ISO/TR 16738.

Each occupant may also have a different time to compromised tenability, depending on their particular exposure to heat and fire effluent combustion products and their individual susceptibility to such exposures (see A.2.3). The purpose of the methodology described in this International Standard is to provide a framework for use in estimating the time at which compromised tenability may occur.

The methodology described cannot be used *alone* to evaluate the overall fire safety performance of specific materials or products and cannot, therefore, constitute criteria for a test method. Rather, the equations are to be used as input to a fire hazard or risk analysis [see ISO/TR 13387 (all parts)]. In such an analysis, the estimated time to compromised tenability also depends on 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). These determine the toxic-gas concentrations, the gas and wall temperatures and the density of smoke throughout the enclosure as a function of time. 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.

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. For ethical reasons, much of the methodology described has not been and cannot be validated experimentally with humans. However, for carbon monoxide, the major contributor to prevention of escape and the most frequent cause of fire fatalities, the database is actually quite extensive and well-validated with human experience.

As with all predictive methodology, uncertainty exists in the application of this International Standard. An estimation of the uncertainty for each procedure is provided, with the user being encouraged to determine the significance of these uncertainties in the estimation of the outcome of a given fire scenario.

Life-threatening components of fire — Guidelines for the estimation of time to compromised tenability in fires

1 Scope

This International Standard is 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-threatening components of fire. 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 (see A.1). Once these are determined, the methodology presented in this International Standard can be used for the estimation of the time at which individuals can be expected to experience compromised tenability.

With care, this guidance can also be applied to estimation of the time limit for rescuing people who are immobile due to injury, medical condition, etc.

This International Standard establishes procedures to evaluate the life-threatening components of fire hazard analysis in terms of the status of exposed human subjects at discrete time intervals. It makes possible the estimation of the time at which occupants can experience compromised tenability (see A.2). It enables estimation of a compromised tenability endpoint for each of the fire effluent components, with the most important endpoint being the earliest to occur.

Although the concept of compromised tenability is consistent with the definition of incapacitation (see ISO 13943), the latter term is not used in this International Standard due to its potentially broad interpretation to include many effects, including collapse and unconsciousness, that are not addressed. This International Standard focuses specifically on compromised tenability as influenced by both physiological and behavioural responses resulting from exposure to a fire's life-threatening components.

The life-threatening components addressed include fire-effluent toxicity, heat, and visual obscuration due to smoke. In cases where the effluent composition is available, the toxic gas model is to be used for assessment of fire-effluent toxicity. For those cases where the effluent composition is unknown, an additional mass-loss model using generic toxic potency values is provided.

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
tenability
ability of humans to perform cognitive and motor-skill functions at an acceptable level when exposed to a fire environment

NOTE If exposed individuals are able to perform cognitive and motor-skill functions at an acceptable level, the exposure is said to be tenable. If not, the exposure is said to result in compromised tenability.

4 General principles

4.1 Time to compromised tenability

The time to compromised tenability for individuals is the shortest of four distinct times estimated from consideration of asphyxiant fire gases, irritant fire gases, heat, and visual obscuration due to smoke.

The context and mechanisms of the fire-effluent toxicity component of life threat are discussed in Annex A. Effects of the asphyxiant toxicants, carbon monoxide and hydrogen cyanide (see A.3), as well as those of eye and upper-respiratory tract sensory irritants (see A.4), are described in detail.

Responses to these exposures involve functions of the human cardiovascular, respiratory and neurological systems that are dependent upon inherent physical characteristics (e.g., age, body weight, pre-existing cardiopulmonary conditions), along with environmental considerations and physical activity at the time of exposure. As a result, individual human responses can be highly variable and, therefore, not readily reduced to usable engineering equations for prediction of compromised tenability without considerable simplification, application of numerous assumptions, and exclusion of unusual circumstances.

With regard to the susceptibilities of individuals to the insults of fire exposure, a primary assumption of this International Standard is that all occupant responses are treated as an *a priori* log-normal statistical distribution with respect to a median time, with half of the population experiencing a tenable exposure and half experiencing compromised tenability (see 5.3). Other statistical distributions are possible, but in the absence of actual data, the log-normal is the most defensible.

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 tenability. Because they are physiologically unrelated and mechanistically independent, asphyxiant toxicants and irritant toxicants are treated separately (see A.3 and A.4).

With irritant toxicants, only those that cause eye and upper-respiratory tract sensory irritation are considered in this International Standard as having effects on tenability (see A.4.2). Serious effects of pulmonary irritation are manifested from a few hours up to several days after exposure and are not normally expected to have a direct impact on tenability (see A.4.3).

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

4.2.3 The basic principle for estimating the eye and upper respiratory tract sensory irritant component of toxic hazard analysis involves 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 to compromised tenability relative to the chosen safety criteria.

4.3 Mass-loss model

The mass-loss model provides for a simplified estimation of the time to occupants' compromised tenability by using 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. 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 to compromised tenability relative to chosen safety criteria.

4.4 Heat and radiant energy model

Heat and radiant energy are assessed using an 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 to compromised tenability relative to chosen safety criteria.

4.5 Smoke-obscuration model

At some degree of smoke density, occupants can no longer visually 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 who may be attempting to escape or perform tasks can become so disoriented that their tenability is compromised. The model is based on the concept of minimum detectable contrast, i.e. the minimum visible brightness difference between an object and a background.

NOTE For occupants who are not engaged in cognitive or motor-skill activity, smoke obscuration, alone, should not compromise tenability.

4.6 Assumptions and exclusions

a) Asphyxiant toxicants, irritants, heat and visual obscuration are each considered as acting independently. Some degrees of interaction between these insults are known to occur (see A.6), but are considered secondary.

b) Asphyxiant toxicants are known to increase somewhat the respiratory rate of exposed occupants, followed by a decrease in respiratory rate as narcosis begins to occur. Resulting fluctuations of toxicant uptake due to these effects are considered secondary.

c) Exposed occupants are considered to be at relatively normal ambient environmental conditions and at altitudes below which reduced oxygen could be a factor, and performing at a moderate level of physical activity. Deviation from these conditions can affect susceptibility, but supporting quantitative data are scarce.

d) The effects of aerosols and particulates and any interactions with gaseous fire-effluent components are not considered. The physical form of toxic effluents is known to have some influencing effects, but in this International Standard they are considered secondary to the direct effects of vapour-phase effluents.

e) Adverse health effects subsequent to exposure to fire atmospheres are not considered, although it is recognized that they occur. Pre-existing health conditions may be exacerbated and potentially life-threatening sequelae may develop from exposure both to asphyxiants and to pulmonary irritants (see A.3 and A.4.3). Lower respiratory tract effects are typically manifested at time scales much longer than those of the actual fire and, although noted, are not considered in the requirements of this International Standard.

f) The early impacts of visual obscuration due to smoke (e.g., recognition that a fire exists, seeing exit paths clearly) are behavioural in nature and are not included. However, smoke obscuration of such severity that occupants become disoriented places a limitation on the time during which escape may be attempted and is considered.

The equations in the methodology described in this International Standard 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 result in compromised tenability. Should the estimated time be deemed excessively limiting, a variety of protection strategies then require consideration by the fire safety professional.

5 Significance and use

5.1 The objective of this International Standard is to provide simplified, but robust, guidance for engineers in estimating occupants' time to compromised tenability as part of an assessment of a structure's fire safety capabilities when subjected to generalized design fire conditions. Such estimation of occupants' tenability ultimately involves their ability to perform cognitive and motor-skill functions at an acceptable level. Generally, acceptable performance may include any of a number of desirable outcomes, including escape to a place of refuge, or if escape is not a viable option, continued functioning in place as necessary.

NOTE If escape to a place of refuge is the outcome to be considered, the time to compromised tenability may reasonably be equated to the available safe escape time (ASET).

5.2 Operating under a considerable number of simplifying assumptions, this International Standard deals with responses of the overall population as represented by a statistical distribution. It is not intended to provide guidance for a detailed assessment of the insult to specific individuals that might be exposed to a given fire atmosphere — such as is commonly required in forensic investigations. Furthermore, the focus of this International Standard is on assessment of an occupant's tenability, while forensic investigations generally focus on the consequences of compromised tenability. These are quite different objectives. Forensic investigations can also be extremely complicated, involving detailed characterization of specific exposed occupants, along with interpretive expertise far beyond that which can reasonably be taught in a guidance standard.

5.3 The concepts of FED[1] and FEC[2] are fundamental to the methodology of this International Standard. Both concepts relate to the manifestation of physiological and behavioural effects exhibited by exposed subjects.

5.4 The variability of human responses to toxicological insults is best represented by a statistical distribution that takes into account varying susceptibility to the insult. Some people are more susceptible than the average, while others may be less susceptible (see A.5). In this International Standard, FED and/or FEC values of 1,0 correspond, by definition, to the median value of a log-normal distribution of responses, with one-half of the population being less susceptible and one-half being more susceptible. This means that, statistically, 50% of the population would be expected to experience tenable conditions (able to perform cognitive and motor-skill functions at an acceptable level), with 50% then expected to experience compromised tenability (unable to perform cognitive and motor-skill functions at an acceptable level).

Recognizing that threshold criteria of 1,0 FED and/or FEC statistically serve to protect only one-half of the population, users of this International Standard shall use reduced FED and/or FEC threshold criteria in order to satisfy more conservative fire safety objectives. This International Standard provides the flexibility to choose FED and/or FEC threshold criteria as may be appropriate. Guidance is provided in A.5.2. Whatever the rationale used when choosing FED and FEC threshold criteria, it is necessary to use a single value for both FED and FEC in a given estimation of the time to compromised tenability.

5.5 The exposure of occupants to tenable conditions should not be construed as equating to no post-exposure harm. Exposure to fire-gas toxicants that do not cause compromised tenability can still result in a variety of effects that may prolong escape and thus increase exposure intensity to fire effluents and 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 International Standard.

5.6 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.

5.7 The methodology described for toxic gas exposures cannot be validated with 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 algebraic functions, the accuracy of assumptions regarding non-interaction of fire gases with each other and with heat, the susceptibility of people relative to that 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 to compromised tenability 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).

5.8 There is very little reliable information on asphyxiant gas exposures of less than 1 min or longer than 1 h. Thus, the accuracy of the equations in this International Standard and the resulting estimations for either very short or very long fire scenarios are uncertain. Due to these uncertainties, estimations of time available to escape of less than 1 min are to be reported as <1 min, with caution exercised when making estimations that involve occupant exposures longer than 1 h.

NOTE Due to the uncertainties involved, differences between comparative estimations of time to compromised tenability of less than 1 min are typically insignificant.

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 to compromised tenability relative to chosen safety criteria (see 5.3). The principle of the model in its simplest form for calculating the fractional effective dose, X_{FED}, is shown in Equation (1):

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

where

C_i is the average concentration, expressed in μl·l^{-1}, 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 exposure dose causing occupants' compromised tenability, expressed in minutes multiplied by μl·l^{-1}.

In estimating incremental effects, ΔX_{FED}, on the fractional effective doses (FEDs), X_{FED}, for each discrete increment of time, Δt, $C_i = C$, and Equation (1) reduces to:

$$X_{\mathrm{FED}} = \sum_{i=1}^{n} \sum_{t_1}^{t_2} \frac{1}{t_i} \cdot \Delta t \qquad (1a)$$

where the time, t_i, to compromised tenability due to component "i" is a function of its concentration, with the units of time cancelling to give a dimensionless fraction for X_{FED}.