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Critique of "ISO TS 13571 - 2002 - Life-threatening components of fire — Guidelines for the estimation of time available for escape using fire data"

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ISO TS 13571 is a document which addresses the following issue: how to assess the time available for escape from a fire and to compare it with the time required for escape. In order for fire victims to be able to safely leave the location of a fire, the time available for escape must be greater than the time required for escape. In principle that is a relatively worthwhile project, but "the devil is in the details". After setting out this laudable premise, ISO TS 13571 starts narrowing what it actually does and ends up being used primarily as a way to help develop limits on the use of plastic materials which contain elements other than carbon, hydrogen and oxygen, based on their generation of irritants. It is worthwhile to discuss in detail what is contained in ISO TS 13571, the scientific basis of each section, and its practical implications.

1. The time required for escape is a function of a variety of parameters associated with the fire scenario, including the intensity of the fire and the geometry of the fire area. As ISO TS 13571 says: "The time required for escape is the time required for occupants to travel from their location at the time of ignition to a place of safe refuge. As occupants are exposed to heat and fire effluent, their escape behaviour, movement speed, and choice of exit route are also affected, reducing the efficiency of their actions and delaying escape (ISO/TR 13387-8). These factors affect the time required for escape and are, therefore, not considered in this Technical Specification." Thus, in fact, ISO TS 13571 does not really address a calculation of the time required for escape.

2. The time available for escape is the time between when ignition occurs and the time when the fire victims have reached a safe place. In order to do that they need to survive the exposure to: heat (radiated and convected), inhalation of toxic products (asphyxiants and irritants) and lack of visibility (smoke obscuration). Traditionally it has always been assumed that lethality is the key end point, but this document uses incapacitation as its end point. Therefore, ISO TS 13571 calculates the time available for escape before incapacitation is reached. It does so by assessing time to incapacitation for each insult separately, without combining the effects of the various insults.

3. Clearly, lack of visibility does not have a physiological effect (i.e. people don't normally become ill simply because they are in a dark area). However, clearly also, lack of visibility can lead fire victims to fail to find the way out, and thus become trapped and suffer the effects of other fire effluents (heat and toxicity). It can also lead potential rescuers to be delayed while they search for fire victims, or even become unable to find the victims needing rescue before they are overcome by the fire. Therefore ISO TS 13571 validly discusses the known effects of smoke obscuration, although it might be criticized for ignoring the seminal work by T. Jin [1-2] on the effects of smoke obscuration on progress by real people. However, the more important criticism is the fact that ISO TS 13571 states, up front in the introduction, that it will not consider that analysis further, by stating: "The initial impact of visual obscuration due to smoke is on factors affecting the

time required for occupants to escape (see A.2). This aspect of smoke obscuration is, therefore, not considered here. However, smoke obscuration of such severity that occupants become disoriented to a degree that prevents effective action to accomplish their own escape also places a limitation on the time available for escape and is considered in this Technical Specification." Therefore, ISO TS 13571 cannot be used to assess the effect of smoke obscuration (or lack of visibility) on tenability. This is a key failure since it has been found by many experts that lack of visibility is often the first criterion to be reached when assessing tenability [e.g. 3-4]. In fact, the analysis by Beyler [3] is particularly pertinent as it reaches three key conclusions: (a) "Toxic gases generally are not the controlling hazard except for very long exposure times", (b) "Visibility criterion is reached before carbon monoxide hazards arise in most egress situations and © "Soot & CO yields are well correlated". None of this is included in ISO TS 13571, which just deals with lack of visibility as a side issue. However, the analysis made is adequate for expansion to get proper results.

4. ISO TS 13571 presents a good analysis of heat effects, when it states: "There are three basic ways in which exposure to heat may lead to life threat: a) hyperthermia, b) body surface burns, c) respiratory tract burns." It then goes on to state that for use in the modelling of life threat due to heat exposure in fires, it is necessary to consider only two criteria: the threshold of burning of the skin, and the exposure where hyperthermia is sufficient to cause mental deterioration and, therefore, threaten survival. ISO TS 13571 then goes on to use the tenability criteria for radiant heat (no effect until a heat flux of 2.5 kW/m^2) and for convective heat and to develop an equation that states that the fractional effective dose (or FED) for heat incapacitation is the summation of the acquired "doses" of radiant heat and convective heat. In other words it adds all the fractional exposure period heat effects instant by instant. This is an excellent analysis, and should be expanded by combining it with the other tenability criteria so as to get overall effects on time available for escape.

5. ISO TS 13571 presents a "mass loss model", which correctly assumes that the smoke toxicity of the vast majority of combustible materials is virtually the same. This has been demonstrated by a large amount of work, both in the USA (NIST) and in France (LNE), principally [5-6]. Thus, this mass loss model states that the fractional effective dose (or FED) for toxicity by mass loss is the summation of the exposure dose of toxic gases, based on an average smoke toxicity lethal concentration time product of 900 g min/m^3 (or half of that for incapacitation). ISO TS 13571 states that this value is valid for well-ventilated fires pre-flashover fires and that half of that value is valid for vitiated post-flashover fires. The mass loss model work on tenability is supported by abundant existing research. Unfortunately, ISO TS 13571 then tries to show that this model is not valid when it states: "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 will depend on the material or product decomposed in a laboratory test method and the thermal decomposition conditions in a test." It then goes on to state: "Uncertainties in calculations associated with using the preflashover and postflashover values for prevention of occupants' escape are

estimated to be ± 75 % and ± 30 %, respectively. It is cautioned that "generic" L*Ct*50 values represent only an approximation. Their use is subject to appropriate sensitivity analyses, as well as to expert toxicological and engineering judgment." The mass loss model is probably the most adequate way to assess tenability due to smoke toxicity, but ISO TS 13571 presents it in a dismissive way.

6. ISO TS 13571 addresses the issue of smoke toxicity of individual toxicants by separating asphyxiants from irritants. Asphyxiants are properly addressed by using the N-gas model, whereby the fractional effective dose (or FED) for toxicity by asphyxiants is the summation of the exposure dose of the individual toxic gases, based on their individual concentration at each time period (while using a concentration-time period "that would prevent occupants' escape", and was obtained from animal exposures). There may be some concern regarding the concentrations used but the general concept is good. ISO TS 13571 states: "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 may 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." It also states: "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." ISO TS 13571 properly uses, for asphyxiants, the concept of exposure dose for FED, namely it considers both concentration and time, so that incapacitation occurs only after adding the effects of exposure to a toxic concentration at every time period. However, ISO TS 13571 calculates an FED based on animal exposures of asphyxiants which looks at the concentrations of asphyxiants in isolation of everything else, particularly in isolation of irritant effects, heat effects and lack of visibility effects. Abundant work has shown that the N-gas model should not be limited to asphyxiants and that the effect of irritants is also dose-related and should be added to the FED equation, including work by the FAA [7-8], by NIST [9] and by SwRI [10-12]. In summary, ISO TS 13571 incorrectly deals with irritants in the calculation of this FED for toxicants.

7. ISO TS 13571 addresses the issue of smoke toxicity of individual irritants by inventing a brand new concept, which has no proven validity: "incapacitating concentration". The way this is used by ISO TS 13571 leads to a Fractional Effective Concentration (FEC), which states that immediate incapacitation occurs as soon as a critical concentration has been reached. ISO TS 13571 defines FEC as the "ratio of the concentration of an irritant to that expected to produce a given effect on an exposed subject of average susceptibility". This is the most critical problem with the document. ISO TS 13571 states: "The guidance in this Technical Specification is based on the best available scientific judgment in using a state-of the- art, but less-than-complete knowledge base of the consequences of human exposure to fire effluents. In particular, the methodology may not be protective of human health after escape, as the interactions of all potential life threats and the short- or long-term consequences of heat and fire effluent exposure

have not been completely characterized and validated." However, there has been no published scientific information validating this approach. For example the following are the concentrations to be used for calculating FEC (in the order given) for the 7 gases specifically mentioned: HCl 1000 ppm, NO_2 250 ppm, HBr 1000 ppm, acrolein 30 ppm, HF 500 ppm, formaldehyde 250 ppm and SO_2 150 ppm. This means that as soon as, for example, there are 30 ppm of acrolein in the air, the fire victim will become instantly incapacitated. Anyone who has worked in a laboratory knows that exposure to irritant gases, such as halogen acids, is uncomfortable and that its avoidance is desirable, but that short exposures do not lead to incapacitation. Moreover, ISO TS 13571 also states: "It is estimated that the uncertainty associated with the use of Equation (4) is ± 50 %.", thus hinting that this should add up to a maximum allowable FEC of 0.5. In summary, ISO TS 13571 incorrectly deals with irritants with a flawed concept.

8. Dr. Louise Speitel (of the Federal Aviation Administration) has been extremely critical of this concept, and she wrote the following as part of her vote in the US TAG opposing the conversion of ISO TS 13571 into a standard: "Incapacitation/ability to escape is dose related for irritant gases and should be treated as such in ISO TS 13571. Using threshold concentrations and assuming no time dependence results in an unreasonably harsh standard for evaluating ability to escape. I favor using a time dependent fractional lethal concentration (FEDL) for irritant gases, since the lethal concentration for a given exposure time is less than the escape concentration. The database for time dependent lethality (inclusive of post-exposure lethalities) is good. A threshold of one fifth the FEDL would be a good pass/fail criteria for the toxicity of the irritants. An FEDL model is available for the irritant gases HF, HCl, HBr, NO_2, SO_2, acrolein and formaldehyde, the irritant gases called out in ISO TS 13571. LC_{50}s are the basis for this model. This FEDL model is strongly substantiated [7-8]. In addition, it considers the enhanced uptake of other gases due to the presence of CO_2." At the US TAG vote, no 2/3 majority was achieved and the US abstained. Unless enough other countries oppose the change, ISO TS 13571 will become an international standard, something which is a particular problem for US industry.

9. The pungent odor of most irritant gases (and their low odor detection level, often in the order of 1 ppm, [13]) means the warning appears at levels much lower than those at which effects occur. This is not being considered by ISO TS 13571.

10. It has been shown that irritants (such as hydrogen chloride or acrolein) do not cause incapacitation at dose levels so high that the victim eventually dies of inhalation toxicity after the exposure. This is a complex concept, but is critical: when primates have been exposed to doses of irritants at levels where they died a few days after exposure, they were still capable of performing the necessary avoidance responses to escape the exposure, thus not being incapacitated [14]. Interestingly, it has also been found that incapacitation from asphyxiants occurs at levels very similar to those leading to lethality, and not at levels an order of magnitude lower [15]. This is inconsistent with the statements in ISO TS 13571.

11. The major problem with ISO TS 13571 is that, if it is applied properly, very small amounts of virtually any plastic material containing elements other than C, H and O will generate smoke that the document considers incapacitating, limiting the potential use of such plastics, especially in a litigious area, such as the United

States. To understand the problem, an analysis is shown in Tables 1 and 2. Table 1 shows some literature yields of toxicants [9, 16-18]; note that "Irritant" in Table 1 refers to generic non HCl irritant. Under the assumption that a typical 50 kW fire requires 2 ft^2 (0.19 m^2) of burning surface [17], it is possible to calculate the amount of the critical toxicant that would be emitted from such a surface burning for three different materials. Table 2 shows calculations based on literature yields of combustion products and fire data [19]. The results indicate the following:

a. A small amount of PVC (corresponding, for example, to a floor cove trim 6 ft long and 4 inches wide) weighing 0.6 kg could not be used in a room, because it would give an FEC level of 0.9 (based on the recommended value for HCl (1000 ppm). However, when the material burns, its heat release rate is only ca. 20 kW, a level smaller than a burning waste basket. Such small fires are usually not reported to the fire departments, but controlled in house.

b. A similar amount of a halogen-free cross-linked polyolefin material (perhaps intended for a similar application) releases ca. 2.5 times the level of irritants. However, in spite of generating a much higher incapacitating level, the irritants it generates are of unknown composition, and thus not usually assessed by ISO TS 13571, although they should actually be included in the term that has the summation of irritant concentrations (if the corresponding levels were known). From the point of view of a realistic fire hazard (namely heat release) such a material releases only 30 kW, still less than a burning waste basket.

c. A similar surface and thickness of fire retarded wood (with smaller mass, because of its lower density, which could also be used as interior trim) releases carbon monoxide and virtually no irritants, and is thus unaffected by the assessment in ISO TS 13571. From the point of view of a realistic fire hazard (namely heat release) this material releases 60 kW, making it a slightly more severe problem than the two earlier materials (and one that is likely to be reported), but still a small fire.

d. Dr. Fredric Clarke conducted an analysis that addresses PVC but which can be applied to fires with small amounts of almost any plastic [18]. "NFPA data shows that between 1989-1993 there have been 54,000 residential fires, reported to the fire departments, where the material first ignited is wire and cable insulation or a wall covering, many (if not most) of which are made of PVC. Some 14,000 of these fires were big enough to spread beyond the room of fire origin (and thus reach flashover). Flashover fires where upholstered furniture was the item first ignited kill at least 10 people for each 100 fires, and it is logical to suppose that other residential flashover fires cause similar fatalities, and expose at least 10 times as many people. As less than 1 kg of burning PVC is sufficient to cause incapacitation, it is logical to assume that virtually all exposed people in a flashover fire became incapacitated, and most died. However, the actual number of fatalities in these fires was not 14,000, as results from this analysis, but a *miraculously low* 343 fatalities, more than 40 times less."

12. The analysis above indicates that a small amount of any material releasing the named irritants (halogen acids, sulphur dioxide, nitrogen oxides, formaldehyde or acrolein) even if it causes a fire that is probably not even reported, would trigger the threshold for incapacitation of ISO TS 13571 (or get close to it). This would

then indicate to a designer, architect, or specifier, that 1 kg of that material cannot be used in any compartment. There is, however, no toxicological evidence that incapacitation of exposed victims ever occurs as a function of a certain concentration of any toxicant. In consequence, the concept of "FEC" has no technical validity and has not been proven with experimental studies. Moreover, the concept of incapacitation levels being lower than lethality levels, although logical on paper, is flawed in reality, when applied to irritants.

13. It is worthwhile remembering that human exposures to various toxic gases (especially including irritants) have been conducted in Europe, in the late 19th century and early 20th century [20-24]. The following statement in ISO TS 13571 is misleading "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" This statement ignores the work, all of which was summarized in a modern publication [25]; the European work clearly showed how researchers were able to continue being active and alert during exposure to high concentrations of irritants.

14. The irritant thresholds in ISO TS 13571 will not result in credit to a material that has been adequately fire retarded since they do not address fire performance properties of a material or product, including ignition resistance, lower heat release rate, lower burning rate or lower flame spread. In consequence, it appears clear that the implications of using those threshold levels would be that products made with combustible materials should be removed from inhabited areas, and replaced by ones made with non combustible ones or with materials which do not contain elements other than carbon, hydrogen and nitrogen.

15. The separate calculation in ISO TS 13571 of each type of incapacitation, via loss of tenability through lack of visibility, heat (or other thermal effects) and smoke toxicity mass loss or by asphyxiants, is inadequate. The analysis as shown in ISO TS 13571, without combining the effects, suggests that humans could be incapacitated or killed separately by each effect. In reality, of course, human fire victims will become incapacitated (or die) as a consequence of a combination of effects. This needs to be incorporated into the document

In conclusion, ISO TS 13571 contains some very useful work addressing tenability by lack of visibility, heat (or other thermal effects) and smoke toxicity mass loss or by asphyxiants, except that they are treated separately. The most serious flaw, however, is the treatment of incapacitation by irritants; this is the most widely used aspect of the document, has no basis whatsoever on scientific studies and, when used, has the effect of creating artificial limits on the use of plastics.

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Table 1. Yields of Toxicants From Common Materials

Material/Yield	CO (g/g)	HCl (g/g)	HCN	Irritants
Flashover	0.2	Decay	Decay	?
PVC	0.06-0.07	0.25-0.40	-	HCl + Irritant
PVC (flash)	0.2	0.4	-	0.4
Polyolefins	0.08-0.10	-	-	(HCl + Irritant) * 3
Douglas Fir	0.011-0.02	-	-	?
Douglas Fir (flash)	0.2	-	-	?
FR Rigid Polyurethane	0.06-0.08	-	0.002-0.005	?
FR Rigid Polyurethane (flash)	0.2	-	0.005-0.011	?
Polystyrene	0.1-0.5	-	-	?
Polyphen. Oxide	0.1-0.3	-	-	?
Flex. Polyurethane	0.01	-	0.001	?
Ethyl. Vinyl Acetate	0.1-0.3	-	-	?
GR Polyester	0.1	-	-	

Table 2. Results of Burning 2 Square Feet of Three Different Materials

Estimates	PVC	FR Douglas Fir	XL Polyolefin
Heat Release Rate (kW)	20	60	30
Density (kg/m^3)	1490	550	1500
Thickness (mm)	2	2	2
Mass Material (kg)	0.6	0.2	0.6

Heat of Combustion (MJ/kg)	12	15	20
Toxicant yield (g/g)	0.4 - (HCl)	0.1 - (CO)	> 1 * - (Irritant)
Burning rate (g/s)	1.5	3.7	1.4
Toxicant Emission (g/s)	0.6	0.4	1.7 *
Air Entrainment (L/s)	490	490	490
Toxicant Level (ppm)	900	500	2400 *
Lethality FED Toxicant	0.24 **	ca. 0.12	?

*: Based on the finding that the irritancy of the combustion products of such materials exceeds that of PVC combustion products by a factor of 3-5 [17].

**: Based on an LC_{50} for HCl of 3,700 ppm

Definitions taken verbatim from ISO TS 13571:

fractional effective concentration - FEC - ratio of the concentration of an irritant to that expected to produce a given effect on an exposed subject of average susceptibility
NOTE 1 As a concept, FEC may refer to any effect, including incapacitation, lethality or even other endpoints. Within the context of this Technical Specification, FEC refers only to incapacitation.

fractional effective dose - FED
ratio of the *Ct* product for an asphyxiant toxicant to that *Ct* product of the asphyxiant expected to produce a given effect on an exposed subject of average susceptibility
NOTE 1 As a concept, FED may refer to any effect, including incapacitation, lethality or even other endpoints. Within the context of this Technical Specification, FED refers only to incapacitation.
NOTE 2 When not used with reference to a specific asphyxiant, the term FED represents the summation of FEDs for all asphyxiants in a combustion atmosphere.

incapacitation
state of physical inability to accomplish a specific task
EXAMPLE Inability to take effective action to accomplish one's own escape from a fire.

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

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

<u>Statements taken verbatim from ISO TS 13571:</u>

"**4.2 Toxic gas model**
4.2.1 The basic principle for assessing the asphyxiant component of toxic hazard analysis involves the exposure dose of each toxicant, i.e. the area integrated under each concentration-time curve (see ISO/TR 9122-5). Fractional effective doses (FEDs) are determined for each asphyxiant at each discrete increment of time. The time at which their accumulated sum exceeds a specified threshold value represents the time available for escape relative to chosen safety criteria.

4.2.2 The basic principle for assessing the irritant gas component of toxic hazard analysis involves only the concentration of each irritant. Fractional effective concentrations (FECs) are determined for each irritant at each discrete increment of time. The time at which their sum exceeds a specified threshold value represents the time available for escape relative to chosen safety criteria."

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

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

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