INTERNATIONAL STANDARD

ISO 19706

Second edition
2011-09-01

Guidelines for assessing the fire threat to people

Lignes directrices pour l'évaluation des dangers du feu pour les personnes

Reference number
ISO 19706:2011(E)

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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 19706 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 19706:2007), which has been technically revised.

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Introduction

All fires produce toxic gases, smoke and heat. Whether the fire occurs in a residence, a commercial building, or a transportation vehicle, exposure to this effluent can have serious consequences for the occupants, responding fire safety personnel, and for larger fires, people in the environment surrounding the structure.

It is necessary to anticipate the effects of a possible fire on the safety of the occupants when considering both the design and construction of the enclosure, and also the burning behaviour of the contents. Building codes and similar documents for transportation vehicles generally provide for the egress or refuge of occupants: it is necessary that the time available for escape exceed the time required for escape. Underestimating the effects of fire effluent on the former can result in not providing the intended degree of safety or in overestimating the impact of fire-mitigation tactics, whereas overestimating the threat can inappropriately limit the use of construction, finish and furnishing materials and products, as well as constrain occupancy design options and escalate costs.

Thus, it is important in the fire safety engineering of facilities to include the effects of fire effluent and to include them accurately and in full awareness of available knowledge. From a complementary perspective, it is necessary that information on fire effluent toxic potency be combined with additional consideration of design fire scenarios, the combined effects of ignitability, heat release and mass loss rate, smoke density, the occupancy and the occupants themselves in a fire hazard or risk assessment, rather than selecting, banning or demeaning a construction or furnishing material or product based on its smoke production and toxic potency alone.

All measurements, calculations and assumptions are characterized by a degree of uncertainty. The utility of the outcome of a fire hazard or risk assessment, or the evaluation of the toxic potency of the fire effluent from products and materials, depends on knowing the uncertainties in the assessment methodology and the uncertainties in the input data. This International Standard addresses the uncertainty in the characterization of fire effluent, the measurement of effluent effects and the accuracy of the measurements.

The purpose of this International Standard is to provide general guidelines for estimating the fire threat to people and to the development of quantitative information on effluent potency for use in fire hazard and risk assessment and for the determination of the toxic potency of the fire effluent from burning products and materials.

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INTERNATIONAL STANDARD **ISO 19706:2011(E)**

Guidelines for assessing the fire threat to people

1 Scope

This International Standard is intended to serve as general guidelines for the assessment of the fire threat to people. It encompasses the development, evaluation and use of relevant quantitative information for use in fire hazard and risk assessment. This information, generally obtained from fire-incidence investigation, fire statistics, real-scale fire tests and from physical fire models, is intended for use in conjunction with computational 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 [ISO/TR 13387 (all parts)]. Aspects of the methodology described in this International Standard are further amplified in ISO 13571 and ISO 13344.

This International Standard is intended to facilitate addressing the consequences of a single, acute human exposure to fire effluent. This International Standard does not address other effects of the heat, gases and aerosols, such as effects on electronic equipment and effects of frequent, multiple environmental exposures of people, which are of importance in fire safety design.

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
fire hazard analysis
fire hazard assessment
evaluation of the possible causes of fire, the possibility and nature of subsequent fire growth, and the possible consequences of fire

4 General principles

4.1 Fire effluent and escape time

4.1.1 Life safety in a fire is greatly enhanced if the time available for occupants to escape exceeds the time required for them to escape and is threatened if the time required exceeds the time available.

4.1.1.1 As specified in ISO/TR 13387-8, the time required for escape includes the time from ignition of a fire to its detection, the time from its detection to an evacuation warning to occupants, an occupant's pre-movement time (the time between becoming aware of an emergency and initiating egress) and the actual travel time to a place of safety.

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4.1.1.2 The time available for escape is the interval between the time of ignition and the time after which conditions become untenable, such that occupants are unable to take effective action to accomplish their own escape to a place of safe refuge. Guidelines for estimation of the time available for escape are specified in ISO 13571:2007. It involves procedures to evaluate the life threat components in a fire hazard analysis, e.g. toxic gases, heat and smoke obscuration, in terms of the status of exposed subjects at discrete time intervals. The time at which occupants' exposure exceeds a threshold criterion represents the time available for escape. Users of ISO 13571:2007 have the flexibility to set such criteria according to their chosen life safety objectives. Thus, an estimated time available for escape might or might not be equivalent to an ASET (available safe escape time).

4.1.2 The quantity and nature of the fire effluent are prime factors in estimating the time available for escape. The effluent nature is a function not only of the product from which it is generated, but also of the conditions under which the product participates in the fire and the nature of the fire.

4.2 Effects of fire effluent on people

During and following a fire, the products of combustion can have lethal and sub-lethal effects on occupants of the facility and responders to the fire. The severity of the effects depends on the composition of the effluent, the extent of the exposure and the physical condition of the subject. Information relative to the effects on people can be extracted from physical and chemical characterization of the effluent (e.g. using ISO 13571:2007), from estimation of the toxic potency of fire effluent (e.g. using ISO 13344) or from accidental exposures of people to the chemical and thermal components of the effluent.

The effects of the effluent on people are not unique in severity or immediacy, but fall into a distribution. This is due to the range of sensitivity of people to the fire effluent and variations in the progress of a fire.

4.3 Use of fire-effluent data

Because the effect of the fire effluent on people depends on factors beyond the combustible(s) as a source of the effluent, it is necessary that the fire-effluent composition data be combined with additional information about the facility, the fire and the people into a fire hazard or risk assessment, rather than being used alone as an indicator of fire hazard or risk.

4.4 Data accuracy and uncertainty

All measurements, calculations and assumptions are characterized by a degree of uncertainty. The utility of the outcome of a fire hazard or risk assessment depends on knowing the uncertainties in the assessment methodology and the uncertainties in the input data. This International Standard addresses the uncertainty in the characterization of fire effluent, the measurement of effluent effects and the accuracy of the measurements.

5 Significance and use

5.1 The projected response of people to fire effluent frequently determines the fire-safety design limits for occupancy. This International Standard provides guidelines on the type of effluent information required to enable such a projection and how to use the data.

5.2 The information derived using the guidelines in this International Standard is for use in fire hazard and risk assessment

NOTE See ISO/TR 13387.

5.3 The methodologies developed using the guidelines in this International Standard cannot be validated from fire experiments using people. Thus, there is some uncertainty in the accuracy of the quantitative exposure/response relationship. It is necessary that this uncertainty be included in the estimation of the overall uncertainty of a fire hazard or risk analysis. The user can then perform a sensitivity analysis and determine the significance of the uncertainty in the human effects in the context of the problem at hand.

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6 Generation and nature of effluent

6.1 Gases, liquid aerosol, soot particles and heat are generated during the flaming combustion and non-flaming pyrolysis of products during a fire.

NOTE Calculation methods for the calculation of effluent yields are found in ISO 19703.

6.2 The yield and nature of the effluent are controlled by the involved fuels and the prevalent thermal and oxygen conditions in the current stage of the fire. These conditions affect the burning rate of the products and the degree of oxidation of the emitted effluent. The stages of fire are characterized in Table 1.

NOTE The divisions between the fire stages are approximate.

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Table 1 — Characteristics of fire stages

Fire stage	Heat flux to fuel surface kW/m^2	Max. temperature °C		Oxygen volume %		Fuel/air equivalence ratio (plume)	$\frac{[CO]}{[CO_2]}$ v/v	$\frac{100\times[CO_2]}{([CO_2]+[CO])}$ % efficiency
		Fuel surface	Upper layer	Entrained	Exhausted			
1. Non-flaming								
a. self-sustaining (smouldering)	n.a.	450 to 800[1][2][3]	25 to 85[4][d]	20	20	—	0,1 to 1[4]	50 to 90
b. oxidative pyrolysis from externally applied radiation	—	300 to 600[a]	[b]	20	20	< 1	[c]	[c]
c. anaerobic pyrolysis from externally applied radiation	—	100 to 500[5]	[b]	0	0	>> 1	[c]	[c]
2. Well-ventilated flaming[d]	0 to 60[6]	350 to 650[7]	50 to 500	≈ 20	≈ 20	< 1	< 0,05 [e]	> 95
3. Under-ventilated flaming[f]								
a. small, localized fire, generally in a poorly ventilated compartment	0 to 30[6]	300 to 600[a]	50 to 500[8]	15 to 20[9][10]	5 to 10[8][9][10]	> 1	0,2 to 0,4[9][10][11]	70 to 80
b. post-flashover fire	50 to 150[12]	350 to 650[g]	> 600	< 15[9][10]	< 5[9][11]	> 1[h]	0,1 to 0,4[9][10][11][13][i]	70 to 90

[a] The upper limit is lower than for well ventilated flaming combustion of a given combustible.

[b] The temperature in the upper layer of the fire room is most likely determined by the source of the externally applied radiation and room geometry.

[c] There are few data; but for pyrolysis, this ratio is expected to vary widely depending on the material chemistry and the local ventilation and thermal conditions.

[d] The fire's oxygen consumption is small compared to that in the room or the inflow, the flame tip is below the hot gas upper layer or the upper layer is not yet significantly vitiated to increase the CO yield significantly, the flames are not truncated by contact with another object, and the burning rate is controlled by the availability of fuel.

[e] The ratio can be up to an order of magnitude higher for materials that are fire-resistant. There is no significant increase in this ratio for equivalence ratios up to ≈ 0,75. Between ≈ 0,75 and 1, some increase in this ratio can occur.

[f] The fire's oxygen demand is limited by the ventilation opening(s); the flames extend into the upper layer.

[g] Assumed to be similar to well ventilated flaming.

[h] The plume equivalence ratio has not been measured; the use of a global equivalence ratio is inappropriate.

[i] Instances of lower ratios have been measured. Generally, these result from secondary combustion outside the room vent.

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6.3 The yield and nature of the effluent are affected by human or mechanical interventions in the fire.

NOTE These include the opening or closing of doors and windows, application of fire suppressant, movement of the burning products, etc.

6.4 The harmful components of fire effluent are the following:

a) asphyxiant gases: carbon monoxide (CO), hydrogen cyanide (HCN), oxygen-depleted air;

b) irritant gases: halogen acids (HCl, HBr, HF), partially oxidized organic molecules (e.g. acrolein, formaldehyde), nitrogen oxides, other fuel-specific gases;

c) aerosols and soot particles, particularly those of a size that are readily respirable and those that scatter light efficiently;

d) heat (radiative and convective) and elevated temperature.

NOTE Carbon dioxide and some other gases also have an effect on the rate of uptake of toxicants.

7 Sources of data on fire effluent

7.1 Laboratory data

7.1.1 General

For a given product, quantitative information on effluent and effluent components, required as input to the calculations of the effect on people, cannot routinely be obtained from accidental fires. It is obtained from real-scale fire tests and from physical fire models. In each case, the uncertainty and repeatability of the measurements shall be reported. Furthermore, if a physical fire model is used, the accuracy of the results shall be reported. The conditions under which all data are developed shall be compatible with the fire conditions in the computational fire model in which they are used.

NOTE Guidance is given in ISO 16312-1.

7.1.2 Specimen mass loss

This measurement enables calculation of the yields of effluent components. It is most desirable to weigh the specimen continuously during a test, since the yields of effluent components can vary as the chemistry of the remaining specimen fraction changes. Measurement of the initial and final mass of the test specimen allows a determination of the average yields over the full combustion period.

7.1.3 Yields of toxic gases

The concentration of a gas or the mass of a gas produced during a fire experiment or from a physical fire model can be obtained using any of several analytical chemical techniques documented in ISO 19701 and ISO 19702. It is preferable that concentrations or masses be obtained as a function of time during the test, although integrated values are sufficient. Since the transport, dilution and loss of these gases are a function of facility geometry, it is common practice to convert the concentration or mass generated into a yield using the mass-lost or mass-changed information from 7.1.2.

7.1.4 Yields of condensed phase smoke

The mass of generated solid and liquid aerosols can be obtained using appropriate equipment, such as a filter collector, a cascade impactor (which also provides particle/droplet size information), or a tapered-element, oscillating microbalance (which also provides time-dependent mass information).

NOTE See Reference [14].

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7.1.5 Optical density of smoke

The obscuration of smoke over a chosen distance is obtained by measuring the degree of interruption of a light beam across a known path length. The scattering by an aerosol is wavelength-dependent, so it is necessary to correct the result for the response of the human eye. A relationship exists between mass density and optical density of fire effluent.

NOTE See Reference [15].

7.1.6 Heat

The rate of heat release can be measured using oxygen-consumption calorimetry (preferable) or by measuring the temperature increase in the surroundings.

7.1.7 Radiant flux

A calibrated radiometer can measure the energy transmitted radiatively from the burning specimen. The value depends strongly on the size of the burning test specimen, the luminosity of the flame and the location of the instrument relative to the flame.

7.1.8 Dose-response curve

If laboratory animals are to be used to obtain EC_{50} information, they should be exposed to varying concentrations of effluent.

NOTE See ISO 13344.

7.2 Effluent potency

7.2.1 Living organisms provide the most direct relationships between exposure to fire effluent and the possible effects from the exposure. However, most information is now generated using chemical and physical measurement of the effluent, combined with information deduced from prior human and laboratory-animal exposures. This International Standard provides guidelines for obtaining information with and without the use of laboratory animals.

7.2.2 Laboratory animals provide a direct measure of the effect of a single effluent component or a combination of components. They also integrate the effect of total fire effluent. It is necessary to relate the quantitative response of the selected animal species to the equivalent response in people. For the lethal and incapacitating effects of some effluent components, there are toxicological conventions and data for such relationships. For sub-lethal effects from some components, these relationships might be too uncertain or might not exist. There is some variability among animals of a given species, which it is necessary to include in the assessment of experimental uncertainty.

7.2.3 In many cases, conducting animal testing can be impractical.

7.2.3.1 Non-vertebrate bioassay is not yet applicable to the complex mixtures of components found in fire effluents due to the yet-unknown pathological mechanisms of the individual and combined effluent components.

7.2.3.2 Equations have been derived that relate the exposure to effluent components to lethal effects in rats and incapacitating effects in people (ISO 13344, ISO 13571:2007). These equations are empirically derived from studies involving laboratory animals and/or accidental exposures of people. The only input to these equations is derived from chemical and physical measurements of the effluent components. Thus, components that have not previously been identified as important are overlooked, and the resulting determination of effluent effects contains an unrecognized uncertainty of unknown magnitude. Nonetheless, the contributions of a small set of toxic gases have been shown to estimate rat lethality within about ± 20 % for a wide variety of materials and products. Since physical incapacitation of rats occurs at effluent exposures of one half of those that cause death (again for a wide variety of materials and products), it is inferred that rat physical incapacitation can be attributed to a small set of toxic gases. There is an empirical relationship between the exposure to fire effluent that is lethal to rats and the exposure that incapacitates especially smoke-sensitive people[26].

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NOTE 1 For the majority of products composed of commonly used materials and additives, the toxic potency to humans of combustion product mixtures can be evaluated adequately on the basis of data obtained by chemical analysis. For novel materials or additives, research incorporating some limited animal exposures is likely to be necessary for the evaluation of the combustion toxicity.

NOTE 2 To the extent that unusual toxic phenomena are observed during the bioassay, additional research into the cause can be required. To date, such situations have been very rarely encountered.

7.3 Large-scale fire tests

7.3.1 Fire tests of a complete construction, interior finish or furnishing product provide the best evaluation of the contribution of that product to a fire.

7.3.2 Each fire stage can be investigated using instrumental and/or animal measurements. The effects of the surrounding air flow conditions and compartment geometry can be investigated.

7.3.3 Such tests are expensive, require specialized expertise and facilities to perform, and are time-consuming to cover the effects of different compartment and fire conditions on effluent yield and nature.

7.3.4 Measurements beyond those of the effluent components are necessary to relate the measured mass or concentration of the components to the yields of those components.

7.3.5 The uncertainty of the data is necessary for comparison of yields and properties between scales and among experiments, as well as for uncertainty propagation in risk and hazard assessments.

7.4 Bench-scale combustion devices

7.4.1 A physical fire model can provide information for the evaluation of the contribution of the effluent from a product to a fire.

7.4.2 The fire effluent data depend on the similarity of the combustion conditions in the physical fire model to those in the selected fire stage. The data also depend on the manner in which the product is represented in a small test specimen.

7.4.3 The uncertainty in these data includes the accuracy with which data from the physical fire model have been shown to replicate data for the same products in real-scale fire tests.

7.4.4 The uncertainty of the data and the accuracy of the physical fire model are necessary for comparison of yields and properties between scales and among experiments, as well as for uncertainty propagation in risk and hazard assessments.

7.5 Evolution of the effluent

7.5.1 The magnitude of the effluent components changes both with time and distance from the fire. It is necessary to include these changes in fire hazard and risk analyses.

7.5.1.1 Heat is transferred by convection and radiation, lowering the temperature of the effluent.

7.5.1.2 The effluent stream can mix with additional air, diluting the gaseous and aerosol species and further decreasing the temperature.

7.5.1.3 Some gaseous species, notably acid gases, can be adsorbed onto soot particles or absorbed by aerosol droplets.

NOTE See References [16], [17].

7.5.1.4 Some effluent components, notably acid gases and aerosols, can be adsorbed on surfaces.

NOTE See Reference [18].

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7.5.2 The effects listed in 7.5.1 occur to some extent in the real-scale and bench-scale tests from which the effluent composition data are obtained.

8 Effects of fire effluent on people

8.1 People exposed to fire effluent can experience a range of effects.

a) Death: this can occur during the effluent exposure or after the fire as a result of pathological or pathophysiological trauma from the exposure.

b) Incapacitation: this is the most serious sub-lethal effect and can leave a person susceptible to further effluent exposure, possibly leading to death.

c) Reduced egress speed or behaviour modification such as choice of a longer egress path.

   This can result from the following:

   1) physiological effects due to exposure to asphyxiant toxicants that result in central nervous system depression, sensory/upper respiratory and pulmonary irritants that affect respiration, and/or heat and smoke obscuration;

      NOTE For a more detailed discussion of these effects, as well as how an assessment of occupants' tenability fits within the fire safety engineering context of fire hazard analysis, see ISO 13571:2007.

   2) psychological escape impairment as a result of a person's perception of danger relative to the various possible courses of action.

d) Long-term physiological effects: these can result from a single exposure, such as can be experienced by a building occupant, or from chronic exposure, such as is experienced by fire responders.

8.2 The exposure of a person to fire effluent is a function of the location of the person and the concentration of the effluent, both of which vary with time, and the time of exposure.

8.3 There are few quantitative data on the exposure of people to fire effluent or its components. Most are instances of accidental exposure after which some blood measurements were made and symptoms were recorded.

NOTE 1 See References [19] and [20].

NOTE 2 There are numerous references to quantitative and qualitative data on the effects of total fire effluent and the components of the effluent on laboratory animals. Most are for lethality, less for incapacitation, and very little on other sub-lethal effects; see Reference [21]. These data are predominantly for rodents. There are data[22][23][24] on the exposure of a variety of laboratory animals to single components of fire effluent and some limited data on the effects of combinations of components; see References [25] and [27]. There are guidelines that relate the effects of some effluent components in laboratory animals to the expected effects on people; see References [26] and [27].

8.4 People, in general, exhibit a range of sensitivities to the products of combustion.

8.5 The overall human population contains a number of sub-populations that can exhibit greater-than-average sensitivity to fire-effluent toxicants, heat and smoke obscuration. The largest of these are the very young, the elderly and those with compromised cardiovascular and/or respiratory systems. Guidance on providing for these sensitive subpopulations is given in ISO 13571:2007.

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Annex A
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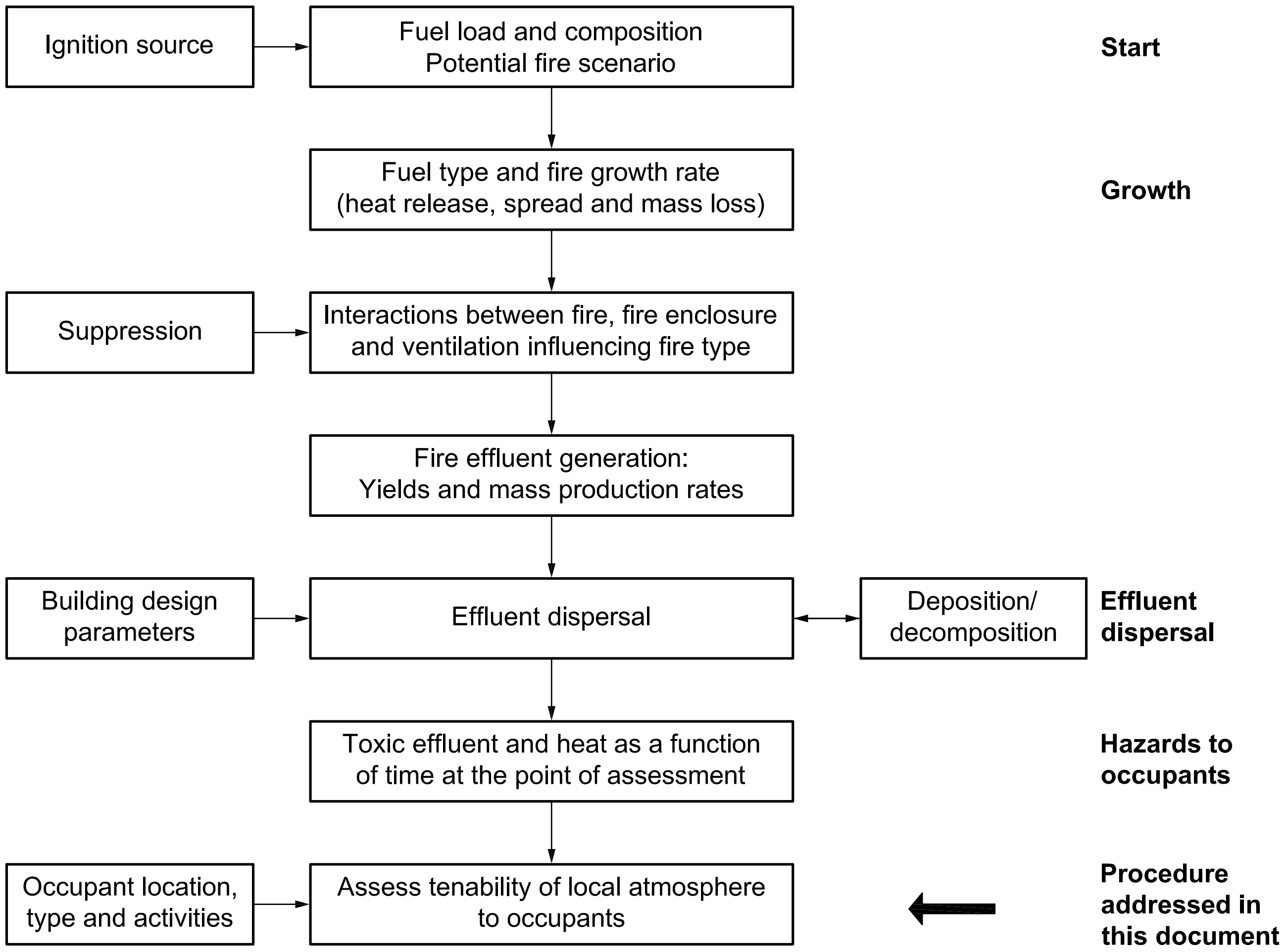
Factors affecting fire threat to people

A.1 Elements of fire hazard analysis



A.2 Relationship between smoke effluent characterization and fire safety engineering

As described in ISO/TR 13387-2, the design fires used in fire safety engineering are idealized descriptions of the variation with time of important fire variables such as heat release rate, fire propagation, smoke and toxic species yields, and temperature. The characterization of fire effluent in this International Standard further defines these variables and relates their values to the specific stages of a fire. This suggests that the design fire explicitly specify the involved fire stages, smouldering, under-ventilated flaming, etc., in order that the proper yields of effluent components can be used in the fire safety engineering analysis.

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