TECHNICAL REPORT

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Fire safety engineering —

Part 4:
Initiation and development of fire and generation of fire effluents

Ingénierie de la sécurité contre l'incendie —

Partie 4: Amorçage et développement des feux et production des effluents du feu

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Contents

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Foreword

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

The main task of ISO technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 13387-4, which is a Technical Report of type 2, was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

It is one of eight parts which outlines important aspects which need to be considered in making a fundamental approach to the provision of fire safety in buildings. The approach ignores any constraints which might apply as a consequence of regulations or codes; following the approach will not, therefore, necessarily mean compliance with national regulations.

ISO/TR 13387 consists of the following parts, under the general title *Fire safety engineering:*

— *Part 1: Application of fire performance concepts to design objectives*

— *Part 2: Design fire scenarios and design fires*

— *Part 3: Assessment and verification of mathematical fire models*

— *Part 4: Initiation and development of fire and generation of fire effluents*

— *Part 5: Movement of fire effluents*

— *Part 6: Structural response and fire spread beyond the enclosure of origin*

— *Part 7: Detection, activation and suppression*

— *Part 8: Life safety — Occupant behaviour, location and condition*

Annex A of this part of ISO/TR 13387 is for information only.

Introduction

Evaluation of the initiation and development of fire and the generation of smoke and toxic species is an essential step in the fire safety design of buildings, processes, etc. These phenomena have been actively studied especially during the last twenty years. Calculation methods and computer codes have been developed to make the necessary evaluations. At the same time, advances in experimental techniques have made it possible to produce input data for the calculation methods and to run large-scale tests for assessing the validity and limitations of the models.

In most of the existing fire safety regulations, measures are taken to prevent the ignition of a fire by controlling the use of materials and by controlling the amount and location of possible ignition sources. It is not, however, possible to prevent all ignitions, and therefore measures are taken to control the fire development and the generation of smoke and toxic species. In most of the existing building regulations, ignitability, flame spread, burning rate, smoke production and toxic-species production are controlled by what are known as reaction-to-fire and flammability classifications. These are to a great extent empirical and based on product performance in a specific small-scale test. Similar regulations have been set on building contents, e.g. upholstered furniture, stored goods, etc., in some countries.

A more modern approach for prescriptive regulations is to establish the classification scheme based on small-scale tests in such a fashion that relative performance in one or more full-scale fire scenarios is replicated. If the scenarios are sufficiently representative of real fire scenarios, the classification system becomes more reliable than those based on performance in small-scale tests alone.

In this document, the initiation and development of fire and the generation of hazardous species is considered as part of a global fire safety evaluation system. This part of ISO/TR 13387 is intended for use together with the other parts as described in clause 6. For some applications, this part alone may be sufficient.

Clause 6 of this part of ISO/TR 13387 describes and provides guidance on the methods available to describe the physical and chemical processes involved in:

- initiation of fire;
- fire development;
- smoke generation;
- toxic-species generation.

Clause 7 is a discussion of the engineering methods available to evaluate the initiation and development of fire and the generation of smoke and gaseous species.

Quantitative information may be related to specific test conditions and/or specific commercial products, and thus the application of data under different conditions may result in significant errors.

Fire safety engineering —

Part 4:
Initiation and development of fire and generation of fire effluents

1 Scope

This part of ISO/TR 13387 is intended to provide guidance to designers, regulators and fire safety professionals on the use of engineering methods for the prediction of the initiation of fire, the generation of fire effluents and the development of fire inside the room of origin. It is not intended as a detailed design guide, but could be used as the basis for the development of such a guide.

This part of ISO/TR 13387 provides a framework for critically reviewing the suitability of an engineering method for assessing the potential for the initiation and development of fire and the generation of fire effluents. It also provides guidance on the means to assess the effectiveness of fire safety measures meant to reduce the probability of ignition, to control fire development and to reduce the accumulation of heat, smoke and toxic products or products causing non-thermal damage. The methods for calculating the effects of design fires for use in the design and assessment of fire safety of a building are also addressed.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO/TR 13387. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO/TR 13387 are encouraged to investigate the possibility of applying the most recent additions of the normative documents indicated below. For undated references, the latest addition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid international standards.

ISO 31-0:1992, *Quantities and units — Part 0: General principles.*

ISO 1000:1992, *SI units and recommendations for the use of their multiples and certain other units.*

ISO 5660-1:1993, *Fire tests — Reaction to fire — Part 1: Rate of heat release from building products — (Cone calorimeter method).*

ISO 7345:1987, *Thermal insulation — Physical quantities and definitions.*

ISO 9705:1993, *Fire tests — Full-scale room test for surface products.*

ISO/TR 11696-1, *Use of reaction to fire tests — Part 1: Application of results to predict fire performance of building products by mathematical modelling.*

ISO/TR 13387-1, *Fire safety engineering — Part 1: Application of fire performance concepts to design objectives.*

ISO/TR 13387-2, *Fire safety engineering — Part 2: Design fire scenarios and design fires.*

ISO/TR 13387-3, *Fire safety engineering — Part 3: Assessment and verification of mathematical fire models.*

ISO/TR 13387-5, *Fire safety engineering — Part 5: Movement of fire effluents.*

ISO/TR 13387-6, *Fire safety engineering — Part 6: Structural response and fire spread beyond the enclosure of origin.*

ISO/TR 13387-7, *Fire safety engineering — Part 7: Detection, activation and suppression.*

ISO/TR 13387-8, *Fire safety engineering — Part 8: Life safety — Occupant behaviour, location and condition.*

ISO 13571, *Fire hazard analysis — Life-threatening components of fire.*

ISO 13943, *Fire safety — Vocabulary*.

3 Terms and definitions

For the purposes of this part of ISO/TR 13387, the terms and definitions given in ISO 13943 and ISO/TR 13387-1 and the following apply.

3.1
emissivity
the ratio of the power per unit area radiated from a surface to that radiated from a black body at the same temperature

3.2
extinction coefficient
a constant determining the decay of the light intensity in smoke per unit path length, given by $K = (1/l) \ln (I_0/I)$

It is expressed in m^{-1}.

3.3
fire exposure
a process by which, or the extent to which, humans, animals, materials, products or assemblies are subjected to the conditions created by a fire

3.4
heat flux
the rate at which heat crosses a surface per unit area of surface, expressed in W/m^2

In ISO 1000 and ISO 31-0, this is referred to as "density of heat flow rate".

3.5
heat of combustion
the energy which unit mass of material or product is capable of releasing by complete combustion, expressed in J/kg

3.6
heat of gasification
the quantity of energy required to change a unit mass of material from condensed phase to vapour without change of temperature, expressed in J/kg

3.7
ignition temperature
the minimum temperature measured on a material at which sustained combustion can be initiated under specific test conditions, expressed in K

3.8
opening factor
$A_V(h_V)^{1/2}/A_T$

It is expressed in $m^{1/2}$.

For the meanings of the symbols, see clause 4.

3.9
pyrolysis
a process of simultaneous phase and chemical-species change caused by heat

3.10
smoke point
minimum height of a laminar axisymmetric diffusion flame (fuel volumetric mass loss rate) at which smoke escapes from the tip of a flame, expressed in m

3.11
specific heat capacity
heat capacity divided by mass, expressed in J/(kg·K)

3.12
thermal conductivity
ratio of heat flux to temperature gradient, defined by the relation $\vec{q}'' = -k \times \nabla T$

It is expressed in W/(m·K).

3.13
thermal diffusivity
κ
thermal conductivity divided by the density and the specific heat capacity, given by $\kappa = k/\rho c$

It is expressed in m^2/s.

3.14
thermal inertia
the product of the thermal conductivity, the density and the specific heat capacity, given by $k\rho c$

It is equal to the square of thermal effusivity as defined in ISO 7345. It is expressed in $J^2/(m^4 \cdot K^2 \cdot s)$.

3.15
total cross-sectional area of smoke
the average cross-sectional area of smoke particles perpendicular to the light path multiplied by the number of smoke particles, expressed in m^2

3.16
ventilation factor
$A_v(h_v)^{1/2}$

It is expressed in $m^{5/2}$.

For the meanings of the symbols, see clause 4.

4 Symbols and abbreviated terms

A_v	area of an opening, expressed in m^2
A_{fuel}	surface area of fuel, expressed in m^2
A_F	floor area, expressed in m^2
A_T	total area of the bounding surfaces in an enclosure, expressed in m^2

α $\dot{Q}_0 t_g^{-2}$, expressed in W·s^{-2}

F_0 opening factor, expressed in m$^{1/2}$

F_V ventilation factor, expressed in m$^{5/2}$

f_X yield of species X, where X = CO, CO_2, etc.

g acceleration due to gravity, expressed in m/s^2

h_v height of an opening, expressed in m

I intensity of light after passing through smoke, expressed in W/m^2

I_0 intensity of light in clean air, expressed in W/m^2

k thermal conductivity, expressed in W/(m·K)

K extinction coefficient, expressed in m^{-1}

κ thermal diffusivity, expressed in W/(m·K)

l optical path length, expressed in m

L thickness of a specimen, expressed in m

m smoke density, expressed in dB/m

$\dot{m}_{fuel}$ mass loss rate of fuel, expressed in kg/s

$\dot{m}_X$ generation rate of species X, where X = CO, CO_2, etc., expressed in kg/s

N total number of smoke particles

n number density of smoke particles, expressed in m^{-3}

ϕ fuel to air equivalence ratio

$\dot{Q}$ heat release rate, expressed in W

$\dot{Q}_0$ heat release rate at the growth time in t^2 fires, expressed in W; usually taken as 1 MW

$\vec{q}''$ heat flux (density of heat flow rate), expressed in W/m^2

$\dot{q}''_{ext}$ external heat flux, expressed in W/m^2

$\dot{q}''_{loss}$ heat loss from the surface by convection or radiation, expressed in W/m^2

ρ density, expressed in kg/m^3

σ effective absorption cross-section of a smoke particle, expressed in m^2

T temperature, expressed in °C

T_{ig} ignition temperature, expressed in °C

T_L the lowest temperature at which a flammable mixture at its lean limit may burn, expressed in °C

T_0 initial surface temperature, expressed in °C

T_U the lowest temperature at which a flammable mixture at its rich limit may burn, expressed in °C

t time, expressed in s

t_g growth time in a t^2 fire, expressed in s

t_{ig} time to ignition (ignition delay), expressed in s

τ time constant, expressed in s

$\dot{V}_f$ volume flow rate, expressed in m^3/s

V_X volumetric production rate of species X, where X = CO, CO_2, etc., expressed in m^3/s

x_f flame height, expressed in m

x_p position of pyrolysis front, expressed in m

5 Subsystem 1 of the total design system

The approach adopted in the work of ISO/TC 92/SC 4 is to consider the global objective of fire safety design. The global design, described in more detail in ISO/TR 13387-1, is sub-divided into what are called "subsystems" of the total design. A key principle is that inter-relation and interdependence of the various subsystems are appreciated, and that the consequences of all the events in any one subsystem on all other subsystems are identified and addressed. Another key principle is that the design is time-based to reflect the fact that real fires vary in severity and extent with time. Ignition represents zero time.

In ISO/TR 13387-1, the total fire safety design is illustrated by an information bus analogy. The information bus has three layers: global information, evaluation information and process information. In this information bus analogy, subsystem 1 (SS1) concerns the initiation and development of fire and generation of fire effluent and is illustrated in Figure 1. SS1 draws on other subsystems for the prescription or characterization of a fire and, in turn, provides information for the other subsystems to employ. Definitions of terms concerning the global information bus are given in ISO/TR 13387-1.

For example, SS1 provides the information on heat, smoke and species generation, which is then used by SS2 for the calculation of smoke movement out of the room and in the building and by SS5 to assess evacuation and rescue provisions. SS1 also calculates the temperature history in the enclosure of fire origin, which then is employed by SS3 to predict the structural behaviour. The temperature and flow profiles in the room are employed by SS4 to predict the detection of fire, as well as the activation of smoke control and suppression systems. The time of activation of active control systems is then fed back by SS4 to SS1 for the prediction of subsequent fire development and smoke and species generation. The initiation of a fire and its development outside the enclosure of origin are also calculated by SS1.

The evaluations, and processes needed to do the evaluations, are discussed in detail in clause 6.

6 Subsystem 1 evaluations

6.1 General

In this clause, various fire phenomena and consequences of fire will be discussed. The required input information and the possible output information will be identified. Areas for which shortages in engineering methods and lack of knowledge are known to exist will be addressed. The text makes reference to existing acknowledged literature, whenever such is available.

6.2 Initiation of fire

6.2.1 Evaluation of initiation of fire

In deterministic fire safety engineering design, ignition is often simply assumed to occur and no calculations on the ignition process are performed. In other instances, especially when the combustible contents and the distribution of ignition sources in the room of fire origin are known, performing calculations on the ignition process can provide valuable information on the possible fire development in the room. Evaluation of ignition is needed especially when the fire safety engineer has to evaluate whether one product can be replaced by another, all other design parameters being fixed. Often the task is to consider if a potential ignition source is likely to cause ignition of adjacent items, i.e. if the first item ignited will cause a second item to be ignited, and thereby the fire to spread to a hazardous extent.

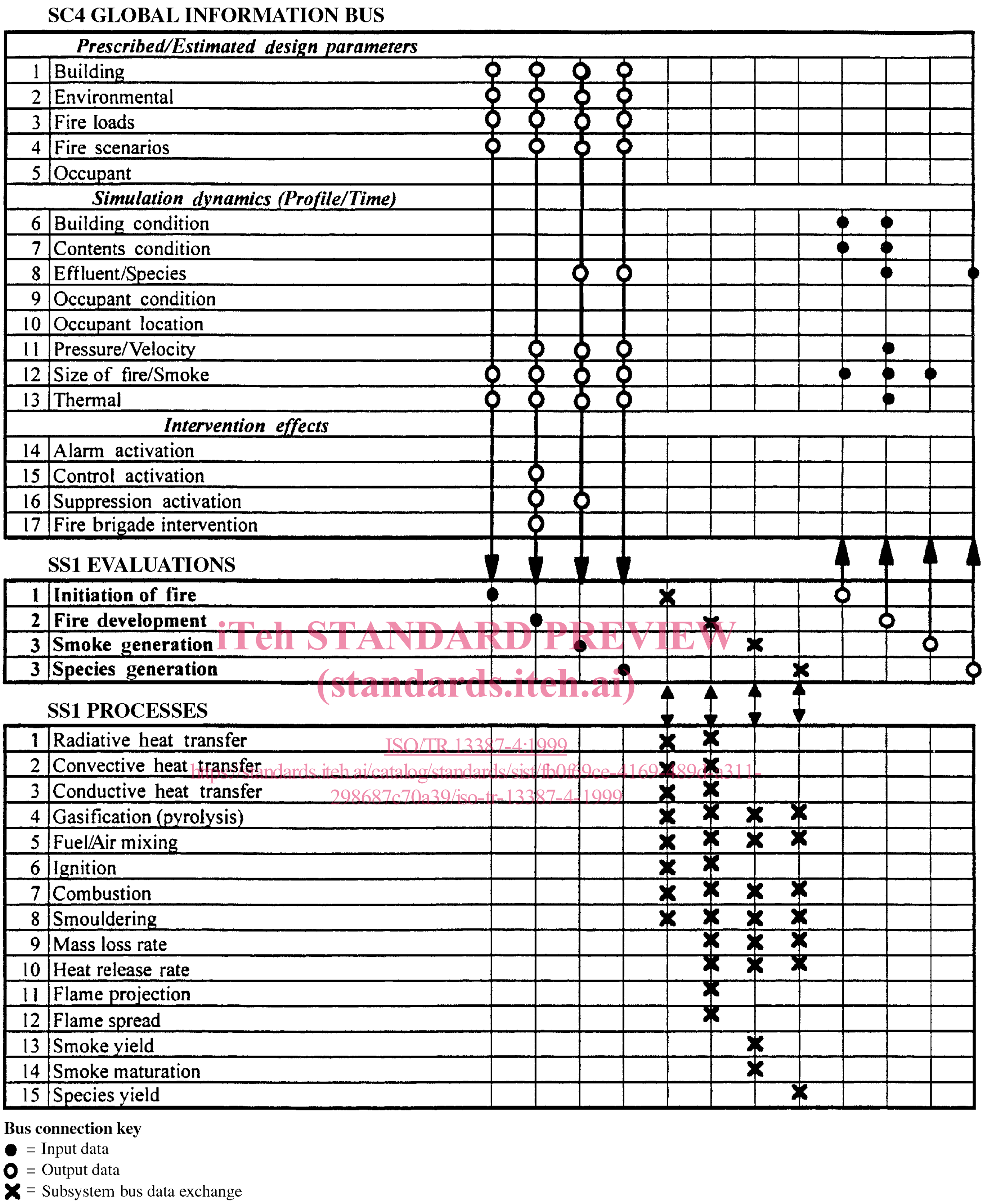

Figure 1 — Illustration of the global information, evaluation and process buses for SS1

The probability of ignition is a subset of design fires which is addressed in ISO/TR 13387-2. Assessment of the probability of ignition is needed when making decisions about the design fire scenarios and event trees used in risk assessment. Probabilistic design and risk assessment are discussed in more detail in ISO/TR 13387-1.

This subclause discusses ignition of items which are in one way or another exposed to heating from an external source. This source of heat can be of various intensities and shapes, varying from (say) a match flame to an actively burning fuel package. Fire development as discussed in 6.3 can be considered to be a series of non-simultaneous ignitions, each of which generally behaves in the theoretical manner discussed herein.

Figure 2 identifies parameters having an influence on the ignition of various kinds of fuel. A condition for ignition is that both a flammable substance and an ignition source exist. The flammable substance may appear in a number of different forms. The heat transfer from the ignition source to the flammable substance may also take different forms, the processes being, in addition, sensitive to the local environment around the source and the exposed substance.

6.2.1.1 Input

The evaluation of the initiation of a fire (see Figure 1) requires as input information from the global information the following:

- building parameters (e.g. lining materials, their thermal and chemical properties, their location with respect to heat sources);
- fire loads (building contents, thermal and chemical properties of building contents, location with respect to heat sources);
- fire scenarios (properties of ignition sources, their number and their locations);
- thermal profile (radiative, conductive and convective heat fluxes, gas temperature, initial fuel temperature);
- size of fire/extent of smoke (area exposed to a burning fire).

NOTE This information is also needed for evaluating the ignition of second, etc., items. Therefore, e.g. the size of fire/extent of smoke is an input or output, depending on when it is used during an evaluation.

6.2.1.2 Output

The evaluation of the initiation of a fire (see Figure 1) provides the following information to the global information:

- fire scenarios (object first ignited, time to ignition);
- size of fire/ extent of smoke (area first ignited, size of initial flame).

6.2.2 Gas phase ignition

The process of ignition to give flames requires mixtures of gas phase combustibles at an appropriate fuel-to-air ratio and either local temperature fields higher than the auto-ignition limit or a pilot source. The necessary conditions for any gaseous mixture of fuel are usually expressed as ignitability regions as in Figure 3. If a fuel is not naturally in the gas phase, energy must be applied to the substance to bring it to the gaseous state. For liquids, the amount of energy required depends on the vaporisation rate and the way in which the liquid is distributed or the material upon which the liquid is absorbed, i.e. bulk liquids will not ignite until the bulk temperature equals or exceeds the flash point. If the liquid is atomised, its ignition propensity will approach the ignitability of gaseous mixtures of the same material, depending on the degree of atomisation and the temperature of the environment. If the liquid is absorbed in a porous medium, the energy demand for ignition will depend on how fast the porous material will absorb energy and heat up. In this case, the thermal properties of the porous medium will dominate the process.

In the case of gaseous or liquid fuels, the engineering task is usually to consider whether a flammable mixture can be created in the space of concern. In the case of solids, the task can usually be reduced to evaluating whether the surface temperature will become high enough to cause ignition, and no gas phase considerations are needed as we can see in 6.2.3.

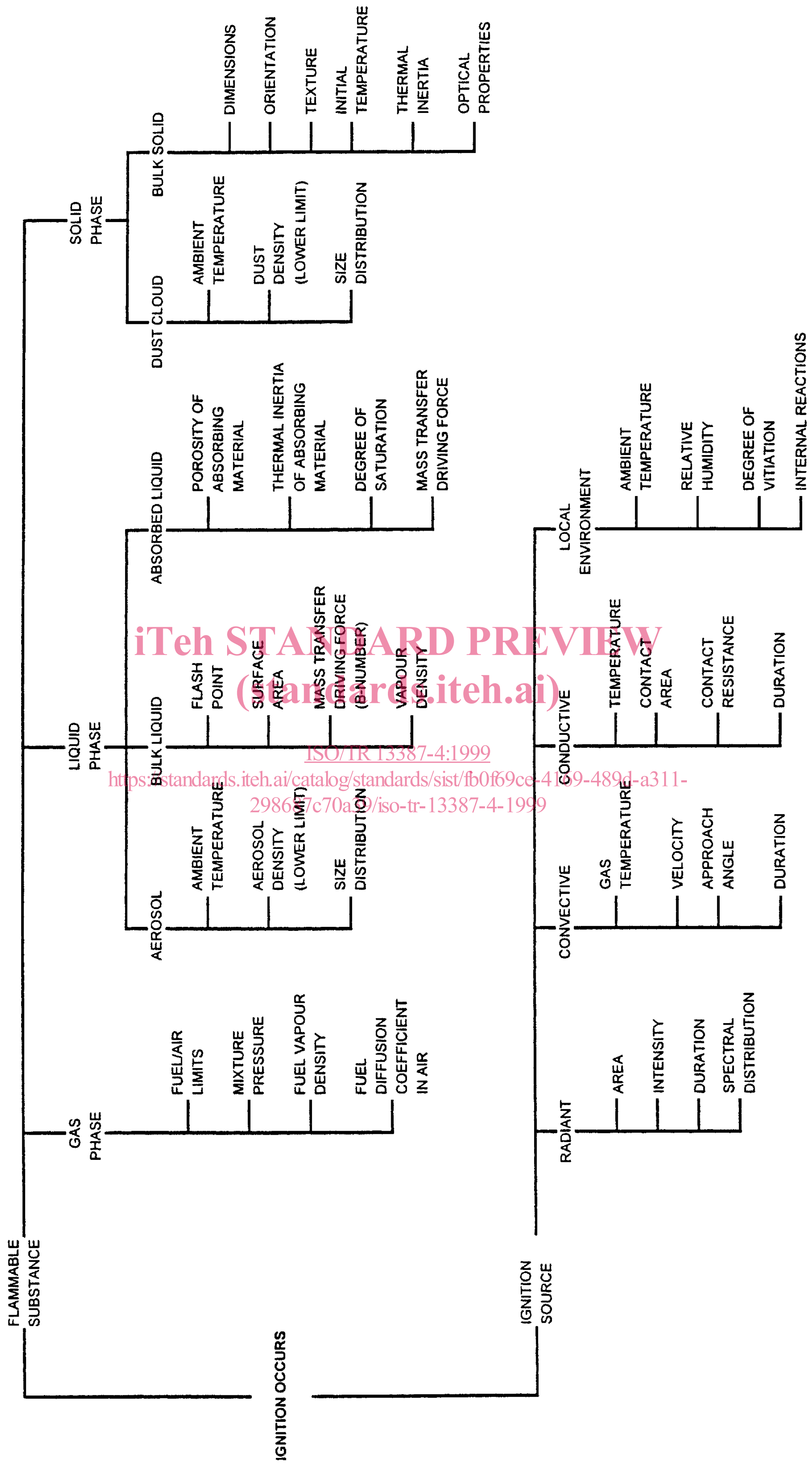

Figure 2 — Factors to be taken into account when assessing ignition potential