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Requirements for large-scale test methods to represent fire threats to people in different fire scenarios

Exigences relatives aux méthodes d'essai à grande échelle pour représenter les dangers dus au feu pour les personnes dans différents scénarios d'incendie

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Foreword

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

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

A number of small-scale test methods are used to measure smoke and toxic fire effluent components (particulates and gases). They have been reviewed by ISO/TC 92/SC 3 in terms of their usefulness with respect to the measurement of toxicity and toxic product yields. However, proper assessment of smoke and fire threat is usually not a scalable phenomenon, so data from small-scale tests only reflect a limited degree of real fire scenarios. In this context, large-scale test methods with a wider range of applicability and better relationships to combustion conditions in real-scale fires are currently under consideration.

Various standardized large-scale tests are currently used to measure the reaction-to-fire properties of materials and products. The main purpose of such tests is to measure local effects such as the rate and extent of flame spread across surfaces and rates of heat release from the defined heat sources. Although apparatus used for these purposes (such as the ISO 9705-1 room corner test) may potentially be modified to address some toxic fire hazard scenarios, they generally have limited applicability to the measurement of hazardous conditions in real-scale fires in multi-enclosure buildings. Limitations include:

— limitation of fire scenarios reproduced and their relevance compared to real fires;

— use of a single, small enclosure;

— use of propane gas as a primary fire source (which itself produces fire effluents interacting with those from the fuel of interest);

— ventilation and plume dispersion characteristics poorly related to those in real-scale multi-enclosure fires.

This document gives the requirements and guidelines for large-scale test methods to represent fire threats to people in fire scenarios for application in fire effluent hazard assessment.

Requirements for large-scale test methods to represent fire threats to people in different fire scenarios

WARNING — In order for suitable precautions to be taken to safeguard health, the attention of all concerned in fire tests is drawn to the possibility that toxic or harmful gases can be evolved during combustion of test specimens. The test procedures involve high temperatures and combustion processes from ignition to a fully developed room fire. Therefore, hazards can exist for burns, ignition of extraneous objects or clothing. The operators should use protective clothing, helmets, face-shields and equipment for avoiding exposure to toxic gases. Means of extinguishing a fully developed fire should be available.

1 Scope

This document specifies requirements for the determination of methods and fire scenarios for fire threat assessment as a basis for designing and constructing large-scale fire tests. It covers different generic design requirements for large-scale fire test rigs to simulate the real fire scenarios of interest.

This document addresses fire threats to people under acute exposure to fire effluents according to the evaluation of tenability conditions. It does not address any chronic effects of that exposure on susceptible populations and firefighters.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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*

ISO 13571, *Life-threatening components of fire — Guidelines for the estimation of time to compromised tenability in fires*

ISO 19701, *Methods for sampling and analysis of fire effluents*

ISO 19702, *Guidance for sampling and analysis of toxic gases and vapours in fire effluents using Fourier Transform Infrared (FTIR) spectroscopy*

ISO 14934-1, *Fire tests — Calibration and use of heat flux meters — Part 1: General principles*

ISO 14934-2, *Fire tests — Calibration and use of heat flux meters — Part 2: Primary calibration methods*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943 apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

4 General principles

4.1 Compromised tenability

One of the main purposes of a large-scale fire test is to estimate the time to the compromised tenability of the environment in a well-defined fire scenario with respect to potential victims. Potential hazards depend on various factors, but in general relate the exposure of occupants in any fire scenario to fire effluents, such as smoke, toxic gases and heat. Important factors are therefore the time-concentration profiles for the major toxic products, optical density of the smoke, and temperature of the gases being inhaled by the occupants. Algorithms have been developed in ISO 13571 to use these input data to predict time to impact on exposed subjects in terms of compromised tenability in any specific scenarios.

The data obtained from a large-scale test conducted in accordance with this document can be used as input for these algorithms. ISO/TR 13571-2 gives examples of tenability calculation based on data from large-scale fire tests or principles of fire safety engineering. Sampling and analysis of fire effluents are conducted according to ISO 19701 and ISO 19702, while the fire stages and their characteristics are described in ISO 19706.

The time to compromised tenability is the shortest of four distinct times estimated by considering asphyxiant fire gases, irritant fire gases, heat, and visual obscuration due to smoke. Even in the same fire test rig, the predominant threat to the occupant can differ from one fire scenario to the other, from time to time and from location to location. The appropriate tenable level should therefore be determined considering the final goal of the estimation.

4.2 Fire profile

For the purpose of this document, it is important to obtain profiles of gas concentrations over time. These profiles in a fire scenario depend on:

— the fire growth curve in terms of the mass-loss rate (kg/s) of the fuel, which in turn is related to ventilation conditions and the volume (kg/m^3) into which it is dispersed with time;

— the yields of toxic smoke and heat in the fire, for example, kg of CO per kg of material burned;

— the mass vectors of emissions, for example kg/s of CO released.

These aspects are affected by many features of the specific fire scenario, one of which is the ventilation conditions. As such, the fire profile should be characterized in terms of the following minimum range of parameters, measured at the breathing zone of a potential victim or along the potential victim pathway during escape.

a) Combustion-related parameter:

  1) mass loss of material divided by the volume of air into which the material is dispersed (mass-loss concentration).

b) Toxicity-related parameters:

  1) carbon monoxide concentration;

  2) hydrogen cyanide concentration;

  3) carbon dioxide concentration;

  4) oxygen concentration;

  5) acid gas concentrations (HF, HCl, HBr, SO2, and NOx);

6) total organic concentration, and as far as possible organic product profile, particularly oxidized organic species (i.e. acrolein and formaldehyde).

c) Heat-related parameters:

1) incident radiant heat flux to subject;

2) air temperature.

d) Visibility-related parameter:

1) smoke optical density (or particulate concentration).

Fire classification and typical characteristics are given in Annex A.

5 Significance and use

5.1 Application of large-scale test

When designing a large-scale fire test, it is necessary to ensure that the conditions of the formation and dispersal of the effluent plume are representative of the real fire scenario of interest. The concentration-time profile should be comparable to that predicted in the real-scale scenario. Alternatively, an appropriate calculation can be applied to the measured data to enable real conditions to be predicted. It is particularly important in this context that the emission and dispersion of fire effluents be calculated from the measured data and that the combustion conditions be similar to those predicted for the real fire scenario of interest. The emission pattern can then be used as input for any calculations used to extrapolate from large-scale to real-scale. The emission pattern can also be used as a reference scenario for validation of data obtained from small-scale toxicity and smoke tests.

It should be noted that the place where the toxicants are generated and the place where the people are exposed to the toxicants can differ. In some cases, it is the same enclosure, but in other cases, it is not the same enclose, e.g. a hallway connected to the enclosure where the fire actually occurred.

The main purpose of this document is to provide the basic requirements for a potential large-scale test to represent a real fire scenario. Large-scale tests have two applications:

a) tests that enable a product to be burned in a realistic end-use configuration and in an enclosure environment providing combustion conditions and a fire effluent plume similar to that predicted in different kinds of real fire scenarios (enabling measurements of concentration-time profiles and calculation of toxic product yields with time);

b) tests that enable a relatively large mass of material (or composite) to be burned in a large-scale enclosure environment under closely defined combustion conditions for comparison with data from small-scale toxicity tests (i.e. as a reference scenario for small-scale validation).

The test result can be utilized for various purposes, such as computational fluid dynamics (CFD) model validation and fire investigation, etc.

5.2 Fire test scenario

The fire scenario in a large-scale test should be carefully designed to represent the fire threats to people that would be encountered in the real fire scenario. A real fire scenario of interest may be selected considering fire statistics, in particular the most frequent fire cases or those with a severe consequence. A detailed description of the real fire scenario includes:

— a description of the facility in which the fire occurs, including the occupancy type (i.e. residences, hospitals, office buildings and schools), its geometry and topology, potential escape routes and places of refuge, and any installed fire mitigation devices (suppression system, etc.);

— the combustible products potentially involved in the fire;

— a description of the specific fire incident, comprising an ignition event (type and location), the involvement of one or more combustible products at various rates of fire growth and heat and smoke production, various stages of fire development (ISO 19706), and the eventual extent of the fire;

— the safety provisions that affect the progression of the fire, e.g. compartmentation,[3] smoke control, fire suppression;[4]

— the people occupying the facility at the time of the fire, including the types of people normally in the facility, their ages, their physical capabilities, their sensitivities to smoke and heat, and their location histories relative to the fire.

Selecting or defining a suitable fire scenario is the starting point for assessing fire threats to people for generating the necessary data output from the large-scale test. This enables a determination of a suitable test rig and instrument requirements. Experience is used to define instrument placement.

5.3 Suitable test rig

Conventional and standardized large-scale fire test rigs consist of one small, medium or large size enclosure with or without a door (see ISO 9705-1, ISO 13784 series, ISO 24473, for example). One of these enclosures may be used in the test with some modifications, i.e. window, corridor for occupants and adjacent room connected to the fire room.

From the description of the real fire scenarios and combustion conditions it is possible to identify a range of hazard scenarios faced by building occupants depending on the fire conditions and their location relative to the fire enclosure. These will have implications on the experimental designs required to reproduce representative conditions, and thus also on the characteristics of test rigs needed. The following general hazard scenarios are identified, although it is possible to envisage many other specific variants.

a) Small smouldering or flaming fire developing in a small and fully-enclosed room, with the subject inside the room of fire origin (e.g. lounge or bedroom in a dwelling, hotel room).

b) As in a), but with a fire room door opening onto a fully-enclosed space (such as a hallway or dwelling interior volume). Exposed subjects may be in the fire enclosure or in an enclosure remote from the fire.

c) As in a) or b), but a window is partly open to the exterior.

d) As in a) or b), but one or more large exterior vents are open.

e) Flaming fire in a fully-enclosed space with a relatively low ceiling but a large floor area (such as a supermarket or store).

f) Flaming fire as in e), but with exterior vents.

g) Flaming fire in a large space with a large floor area and high ceiling (or smoke venting or extraction).

Examples of some suitable test rigs are provided in Annex B.

6 Suitable test rig design

6.1 General

The dimensions of the test rig have an impact on the outcome of the test. The relative position of the different elements (ignition system, burning item, ventilation, sensors) will have an impact on the development of the fire, combustion, efficiency, ventilation, etc. In addition to the content of the test, specific details that lead to a specific fire scenario and temporal evolution of heat release rate, temperature and hence toxicants release, are important.

6.2 Non-flaming fires in a small room

In terms of a large-scale test strategy, it is relatively straightforward to replicate the essential elements of the real fire scenario in a relatively small “large-scale” test enclosure (such as an ISO 9705-1 room), or a standard smoke detector test room. The essential features are that the disposition of the fuel and the heat source are realistic and do not directly contribute to the effluent. For this reason, gas flames should not be used as a radiant heat source unless the combustion products are contained within a flue as part of the scenario.

6.3 Small smouldering or flaming fire in a small room

6.3.1 General

This is a typical scenario for many dwellings fires (e.g. in a lounge or bedroom in a dwelling, or a hotel room) resulting in injury or death, especially when the occupant is sleeping or disabled. If the fire progresses to flaming, the room is quickly filled with an effluent layer descending from the ceiling. The fire is well-ventilated at the beginning. It then typically becomes under-ventilated and very small, or self-extinguishes when the layer descends to near floor level (unless exterior vents are opened during the incident such as doors or windows).

NOTE Smouldering is defined as the combustion of a material without flame and with or without visible light. This includes "glowing combustion" in ISO 13943.

6.3.2 Suitable test rig

The suitable test rig for this scenario is a fully-enclosed rig of sufficient size to enable the main fuel load items to be represented at real-scale. Measurements of fire effluent composition are sampled from one or more locations (minimum at head height). If possible, fuel mass loss rate is measured directly using a load cell. If this is not possible, it may be calculated from the effluent composition in the enclosure. The latter is prone to being highly unreliable due to many parameters, such as the sensitivity of the measuring device, hypothesis of full recovery of the effluent, etc. Weighing the fuels before and after the tests is recommended.

Although small for some cases, an ISO 9705-1 room with a door closure can be suitable for this scenario, with the addition of suitable sampling and measurements taken directly from the room. An example of a one-bedroom fire scenario is provided in Annex B.

6.4 Small fire in a room with the door opened

6.4.1 General

This scenario consists of a fire in a small enclosure with a room door opening onto a fully enclosed space (such as a hallway or dwelling interior volume). Exposed subjects may be in the fire enclosure or in an enclosure remote from the fire. This is another typical scenario for many dwelling fires causing injury and death. In this scenario the effluent plume typically passes into a hallway beyond the fire enclosure with little air entrainment as it moves horizontally through open building spaces and cools, or with somewhat more air entrainment and plume dilution if it moves up through a stairwell. Once the spaces beyond the fire enclosure have been filled, the diluted effluent is re-circulated into the fire at a low level. The upper layer gradually fills down until the fire is extinguished, or alternatively becomes very small. As with the previous case, there is a short period of well-ventilated flaming followed by an under-ventilated combustion condition due to the oxygen availability.

6.4.2 Suitable test rig

Large-scale testing for this scenario requires a fully-enclosed test rig consisting of more than one enclosure. An ISO 9705-1 room (or similar enclosure) can be suitable as the fire enclosure, although it is smaller than most real-scale room-sized enclosures. The fire enclosure is then connected to another (fully-enclosed) enclosure via a door that can be set to various openings using a sliding panel. Since in many real-scale cases this will be a corridor or hall, and because it provides a suitable environment for fire effluent plume to spread and cool in, a room-corridor rig provides an appropriate set-up for this scenario. The corridor can be connected to another fully enclosed room. A set-up such as this has been found to provide a close generic reproduction of domestic-sized buildings or small offices for measuring developing hazards from burning items such as furniture or wall coverings. Although there are differences between the development of conditions in single-story and two-story buildings resulting from the vertical plume entrainment, in practice the differences in terms of time-concentration profiles in the main locations tend to be small, so that a horizontal rig is probably adequate, because it contains two or more separated enclosures and has a sufficient volume (i.e. approximately 100 m^3 to 2 000 m^3).

Where the real fire scenario of interest involves effluent spreading from a small fire enclosure through a large interior building volume, the room-corridor rig may be used. Instead of the corridor ending in a second room, it may be left open under a calorimeter hood. Measurements for calorimetry and yield calculations are made in the hood, but also in the effluent plume within the corridor and in the fire room, since these are the conditions to which occupants are exposed. The use of calorimeter hoods alone is problematic because the entrainment ratio between the effluent plume and the entrained air entering the hood is unknown. It is difficult to estimate the gas concentrations in the undiluted effluent plume to which building occupants would be exposed.

6.5 Small smouldering or flaming fire in a small room with window partially opened

6.5.1 General

In many fire incidents, vents such as exterior windows can be partly open, or a degree of venting can occur if partial glazing failure occurs. Exterior doors can be partly or fully open, or can open as occupants escape from the building.

6.5.2 Suitable test rig

Scenarios such as these can be examined with a simple single enclosure (e.g. bedroom with a closed door but an open window) by adding a suitable vent, or for a multi-enclosure building by adding suitable vents or an open-ended corridor.

6.6 Small smouldering or flaming fire in a small room with large exterior vents opened

6.6.1 General

When large vents are present, especially more than one large vent such as an open door and window, the fire is likely to progress to a post-flashover under-ventilated condition.

NOTE See ISO 19706:2011, Table 1 for the typical characteristics of fire stages.

Measurement of toxic gases in the enclosure of origin is of academic interest only since room occupants are likely to die before or at the point of flashover. As the fire plume leaves the fire enclosure through exterior vents and rises vertically, either into the laboratory or calorimeter hood, a considerable amount of air entrainments can lead to significant secondary combustion outside the fire enclosure. Any gas measurements made in this plume do not represent the conditions in the upper effluent layer inside the enclosure. Where the fire occurs in a multi-enclosure building with horizontally connected enclosures, the composition of the fire effluent plume is preserved somewhat as it moves along the corridor away from the fire enclosure. The effluent plume is extremely under-ventilated, with a very low oxygen concentration, but some combustion can potentially continue at the interface between the base of the upper layer and the incoming air below it. As the fuel-rich effluent plume moves away from the fire enclosure and cools, the under-ventilated composition (with high concentrations of toxic gases) is preserved to a considerable degree more than that of a plume turning vertically, with greater air entrainment and secondary combustion. A toxic plume like this can then spread through open spaces in large buildings from a flashed-over source.

NOTE In ISO 13943, "fuel-rich combustion" is defined as combustion in which the equivalence ration is greater than unity. In ventilation-controlled fires, the fuel/air mixture is fuel-rich, and relatively high concentrations of pyrolysis products and incomplete combustion gases will result.

6.6.2 Suitable test rig

To measure the composition of fire effluent spreading through a building from a flashed-over source, a room-corridor rig or similar rig with connecting enclosures is required. The burning fuel is placed in one enclosure and the effluent flows horizontally through the corridor (usually opening under a calorimeter hood). Suitable measurements of the composition of the spreading plume can then be made in the corridor. For such experiments, the rig and calorimeter need to be able to withstand the more extreme conditions of post-flashover fires.

6.7 Flaming fire in a large space with a large floor and high ceiling

6.7.1 General (Scenario 1)

Relevant scenarios in large buildings can include a fire in a single burning object in an atrium or similar space. For such a scenario, the object is burning in a well-ventilated situation with ample air supply and the plume is rising vertically.

6.7.2 Suitable test rig — Scenario 1

For this scenario, the most relevant large-scale test is to burn the object in an open laboratory and collect the effluent in a calorimeter hood. To relate the test effluent composition to that of the fire hazard in a real-scale building, for example at a high balcony level that can potentially be engulfed in an upper layer, suitable effluent dilution calculations would be required for application to the calorimeter data.

6.7.3 Scenario 2

Another scenario of interest can be effluent from a pre- or post-flashover fire in a small shop unit, with the effluent emerging into an atrium space.

6.7.4 Suitable test rig — Scenario 2

For this scenario, a single enclosure like ISO 9705-1 room with an open doorway could be used for the source fire. The effluent could then be captured in a suitable calorimeter hood. Where flashover occurs inside the room with secondary combustion of the effluent plume as it rises vertically outside the room, this would be considered a real phenomenon predicted to occur in practice in the real fire scenario of interest.

NOTE 1 Backdraught conditions and pulsing fire phenomena often occur in real-scale fires. They can also be studied in room-corridor and multi-enclosure rigs. It is important to recognize that violent changes in fire conditions can occur suddenly in many of the test scenarios described.

NOTE 2 Other categories of fires in which particular conditions and hazards can occur are basement fires, for which the access stair or vents are in the ceiling, and tunnel fires. The generic rigs described can be used to study such scenarios with the appropriate set-up and vent placement. Real-scale tunnel fire tests would often require the use of larger-scale rigs than those described.

7 Preparation of test

7.1 Occupants of interest

Test scenarios should simulate the occupants of interest such as their status (sleep or active), age, and mobility. If the test scenario includes the evacuation of an occupant, life-threatening factors such as heat, smoke, and toxic gas should be determined considering the evacuation path and the height of the breathing zone of the occupants versus time.

Examples of some different types of targeted occupants:

a) A sleeping person in a bedroom apartment:[5]

This case explores a bed fire scenario, in which a person accidentally lights their quilt (and then mattress) with a cigarette or a small flame after falling asleep. The door and window remain closed during the entire test, and the fire decreases rapidly to become insignificant because of a lack of oxygen.

b) A scenario of an occupant escaping, depending on pre-movement delay and alarm time:[5]

This is a case of a ventilated fire in a small living room. The window remains closed, but the door is opened for a short time after ignition, to simulate an occupant's pre-movement and escape after having detected the fire.

c) A scenario of an occupant starting to escape and being blocked during their escape, e.g. door closed, wrong direction, etc.

7.2 Test rig

The test rig should be designed so that it represents a real fire scenario. Considering the description and examples in Clause 6, the fire room, adjacent room, or connected spaces are to be determined carefully. The floor area and the height of the ceiling, and some important elements of the rig related to ventilation conditions such as windows, doors and vents should be included to reproduce the real-scale environment. If any connected area away from the fire is not subjected to flames or extreme temperatures, cheap materials such as gypsum board on a light frame can be used for this part of the construction. Considerations about smoke trapping, adsorption, and desorption should be considered if these materials are used for several consecutive tests.

7.3 Ignition source

Ignition sources should be selected such that they do not affect the combustion chemistry of the fuel in the test scenario. The relative size of the ignition source and distance between the ignition source and other fuels should be as identical as possible to real fire scenarios.

The ignition source in a standardized test method may be used, as indicated in the following list.

— Cribs no.4-7 in accordance with BS 6807, consisting of differing arrangements of small wood sticks with a tissue at the base. This tissue is filled with approximately 1,4 mL of isopropanol prior to the test and then ignited.[5]

— A standard cigarette according to EN 597-1 and EN 597-2 may be used to represent a cigarette ignition source such as the quilt ignition.[5]

— Trash fires can be simulated using a fire ignited in a wastepaper basket containing a plastic trash bag and 500 g of creased paper balls.[5]

— A trash bag fire can also be simulated using a 25 kW sand burner.[6]

— Electrical sources such as glow wire can be used according to IEC 60695-2-10.[7]

— A heating cartridge can be used to simulate hot spot problems such as battery faults.

When using the burner as an ignition source, either its contribution should be limited to the ignition phase, or this contribution should be known, or both. ISO 10093 describes a range of laboratory ignition sources for use in fire tests on plastics and products consisting substantially of plastics. These are suitable to use for simulating the initial thermal abuse to which plastics are potentially exposed in certain actual fire risk scenarios.

7.4 Fuel

The location and arrangement of combustibles should mimic that of real fire scenarios. This should also be documented before the test.

Prior to the test, all combustibles in the scenario should be weighed and the main elemental composition of the fuels should be identified. Some combustion products such as HCN, HCl, and SO_2 can be expected from the compositions. It is recommended to determine the analytes ahead of the large-scale tests. This could be achieved through a combination of elemental analysis of the fuels, and analysis of fire effluents from bench-scale tests. The preparatory tests should be performed at different heat fluxes and different O_2 content.

7.5 Instrumentation

7.5.1 General

In general, necessary data should be obtained to determine the time to compromised tenability. Therefore, temperature for convective heat, heat flux for radiant heat, smoke obscuration for visibility, and toxic gas concentration shall be measured. All the data should be collected in relation to time(s), in order to record the time at which each threatening factor approaches the pre-defined safety level.

The sampling position should be determined taking into consideration the purpose of measurement. When global information is needed, sampling devices are positioned in the doorway of the fire room or exhaust duct. In the latter case, fresh air is entrained in the fire effluent. When local information is needed, the sampling device or probe should be as near as possible to the position of interest.

Preliminary modelling may be requested to select the suitable sensors and the range of measurements. Metrology should include uncertainty estimation and validation according to the ISO 12828 series.

The location and arrangement of all instrumentation should be documented before the test.

7.5.2 Sampling and analysis of toxic fire effluents

7.5.2.1 Overview

According to the selected fire test scenario, it can be necessary to analyse fire effluents at one or more positions along the occupant's evacuation path in the scenario.

Sampling and analysis methods are chosen considering the expected fire composition. Methods for sampling and analysis of fire effluent shall be in accordance with ISO 19701 and ISO 19702. Sampling is one of the most critical parts of the procedures for the analysis of gases in fire effluents. The sample presented to the analyser should be representative of the fire atmosphere.

After the generation of combustion products, two choices are available for sampling and analysis:[8] either in situ for immediate analysis, or extractive for subsequent analysis. In situ sampling describes a method in which the chemical species are measured directly at their point of generation. Extractive sampling describes a method in which the samples are collected from the fire test or experiment for analysis either immediately or at a later time.

Continuous extractive measurement includes the use of non-dispersive infrared (NDIR), paramagnetic analysis and Fourier transform infrared spectroscopy (FT-IR) for direct continuous and semi-continuous analysis for the determination of carbon dioxide (CO_2), carbon monoxide (CO), oxygen and a variety of volatile inorganic and organic species.

Extraction of samples may be achieved by several methods, including:

— use of a sampling line connected to gas chromatography (GC) or gas chromatography coupled to mass spectrometry (GC-MS) for analysis of many inorganic and organic species;

— use of a trapping solid adsorbent, such as activated charcoal, followed by gas chromatography and mass spectrometry (GC-MS) or gas chromatography equipped with flame ionization detector (GC-FID) for analysis of benzene, volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs);

— use of a trapping solution in the liquid phase such as sodium hydroxide (NaOH) and hydrogen peroxide(H_2O_2) in gas-washing bottles, bubblers or impingers followed by gas chromatography and mass spectrometry (GC-MS) for analysis of the volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs);

— use of gas bags for analysis of nitrogen oxides and some volatile organic compounds (VOCs).

Examples of appropriate selection of sampling and analysis methods can be found in References [9] and [10].

An example of a gas sampling probe can be found in Reference [11], where in each test, gases and soot were sampled at some of or all four locations.

— Single probe, 1 m inside the burn room door, inserted through the ceiling, for sampling CO_2, CO, and O_2: for the tests with the burn room door closed, room gas was extracted from a similar, adjacent port for analysis using a Fourier transform infrared (FTIR) spectrometer.

— Four-probe array, 1 m outside the burn room doorway: this location was selected to be in the quenched doorway jet at a location where minimal dilution of the combustion products would have occurred after leaving the burn room. However, for the more intense fire stages, the flames were not always quenched at this location. When using a multi-probe array for sampling, it should be considered whether or not the sampled gas represents the compositions of the effluents.

— Single probe, 2,1 m downstream from the burn room doorway: the purpose of measurement at this location was to characterize the composition of the fixed gases just before they reached the exhaust vent.

— Four-probe array, 9,4 m from the burn room door or approximately 1 m upstream from the open end of the corridor: this location was selected to be as far down the corridor as possible, yet minimizing the edge effects at the end of the corridor.

7.5.2.2 Mass loss

The mass loss or mass loss rate of fuels during the test provides useful information about fuel consumption and thus the fire environment. To obtain mass loss of fuel, the fuel or the burn room may be on a load cell(s) with appropriate protection against damage from the heat.

7.5.2.3 Fire detector

If necessary, conventional heat and smoke detectors may be installed to investigate the efficiency of fire alarms to activate early to allow occupants to escape before conditions of compromised tenability occur.[5]

7.5.2.4 Other devices for recording

Camcorders, security cameras or webcams can be positioned to observe and record important fire phenomena including fire initiation and spread and smoke layer descent.

8 Measurements

8.1 Heat

8.1.1 General

The thermal effect models in ISO 13571 shall be used for calculation. These effects can be due to the temperature of the air (convective effect) or to the received radiation (radiative effect). These two effects are cumulative and dose-related.

8.1.2 Convective effect

Generally, a K-type thermocouple is used for convective heat measurement. Caution should be taken when the thermocouple is installed close to the fire because the radiant heat flux can affect the output from the thermocouple.

8.1.3 Radiant effect

A water-cooled Schmidt-Boelter type or Gardon-type heat flux meter can be suitable. The calibration and use of the heat flux meter in the fire test shall be according to ISO 14934-1 and ISO 14934-2. The specifications of the heat flux meter should be selected considering the measuring range and minimum required detection threshold.

A plate thermometer to estimate the radiant effect (incident radiative heat flux) can be used. In conjunction with a K-type thermocouple, close to the surface, the convective effect (and hence the total heat flux) is measured at the same location.

8.2 Smoke obscuration

The smoke obscuration model in ISO 13571 shall apply. These effects relate to visibility and are considered as one factor that worsens the ability of people to move in a fire environment.

The actual measurement is typically made with a collimated light source and a directly opposed photometer receiver is applicable. This provides a measure of the percentage of the light output by the source that reaches the photometer, and it is typically expressed in terms of an extinction coefficient. ISO 3182 specifies a measuring system that enables the determination of the transmittance and the optical density of smoke emission tests under laboratory conditions. ISO 3182 also provides the calibration method for the system. ISO 3182 should be used when measuring the smoke obscuration.

Correlations with obscuration and visibility along with methods for interpretation, can be found in References [13] and [14]. For an unknown evacuation path, Jin and Rasbash proposed a limit of optical density (OD) equal to OD = 0,06, and limit OD = 0,08, respectively. For a known evacuation path, Jin proposed a limit of OD = 0,2.

Suitable examples of smoke sensors are found in References [15] and [16]. An example of opacimeter trees with a short path length for checking obscuration versus smoke layer height can be found in Reference [17].

8.3 Toxic gas

Fractional effective dose (FED) and fractional effective concentration (FEC) calculations shall be in accordance with ISO 13571.

8.4 Equivalence ratio

The fuel/air equivalence ratio is one of the important factors that give information on the combustion environment. The use of a phi-meter was suggested by Vytenis Babrauskas.[18] The fuel/oxygen equivalence ratio was measured in real-scale fire tests using a phi-meter.[19],[20]

8.5 Mass loss

Mass loss and mass-loss rate are used for the calculation of gas yield. When combined with a measure of the heat of combustion of the fuel, they can also provide estimates of the heat release rate of the fire.

8.6 Miscellaneous

Pressure measurements or profiles are often measured across a doorway, window or other locations to estimate gas flow through the opening.

The surface temperatures or heat fluxes impinging on the solid surface can also be measured. The purpose is not only to generate data at important locations of the tenability assessment but also to have additional information allowing the validation of the various aspects of a CFD code, such as the velocity profile, fire intensity and the resulting gas temperature or radiant energy or both.

9 Data analysis and interpretation

9.1 General

The statistical meaning of a tenability assessment (FED or FEC due to thermal, asphyxiant, and irritant effect) is described in ISO 13571. It should be considered whether the data obtained during tests provide global or local information.

For toxic gases which are easily condensed or deposited during transfer, check whether there is any cooling point from the sampling probe to the gas analyzer input. This effect should be avoided as far as possible according to the guidance in ISO 19702.

Note also that for toxic gases which are easily condensed or deposited during transfer, when travelling a long distance, a certain amount of toxic gas like HCl can be lost. This effect was investigated in References [21], [22] and [23]. This effect could be quantified through appropriate techniques, such as wiping or chemical analysis, or both

Be careful that average measurements in large-scale testing are often the average across many detailed physical phenomena. In this case, interpretation should consider potential local variations in comparison with averaged values at the point of measurement

9.2 Repeatability of test

Large-scale fire tests have been performed and the data analysed with respect to repeatability and error propagation using statistical analysis.[24] Although the experiments were designed to be repeated under the same conditions, in reality, even simple design fire tests proved to be difficult to reproduce with respect to their physical quantities. Results of thermocouple temperature and smoke density meter measurement provided reliable values, whereas there was a spatial error in the distributions between the fire source and smoke layer. The mass-loss rate, as well as gas concentrations, were connected with a high level of uncertainty.

The repeatability of fire behaviour in real-scale compartment fires involving realistic compartment configurations and complex fuel packages has also been investigated.[25] Three sets of custom-built upholstered furniture with differing upholstery materials formed the fuel. Three repeat tests were conducted for each set of furniture, for a total of nine instrumented tests.

In this study, the overall fire behaviour in the compartment was repeatable even with the complex fuel loadings involved. Measured temperatures, mass loss rate, flame spread rate, carbon monoxide production and other environmental conditions were consistent within each set of repeated tests. When control of external conditions and variables can be maintained, only a single test is necessary to capture representative fire dynamics for a given fuel source in a compartment, particularly when overall trends in fire behaviour are of most interest. At the same time, measurements of local conditions at a specific point within the compartment do have a greater degree of variability and thus can often require multiple repeats to capture a representative picture of the detailed behaviour at a given point.

9.3 Reproducibility of test

A study of 45 pool fire tests is presented in reference [26]. All tests were conducted in the same experimental setup but with four different ventilation scenarios. The tests were conducted over a 6-year period under slightly different ambient conditions. The temperature rise measured in the same experimental setup with four different ventilation scenarios varied ±7 % to 35 % around the mean, depending on the location of the measurement and the scenario considered. Variations in the results are due to both the variation of different weather conditions and other unknown parameters.

10 Reporting requirements

The details for reporting the test results should include:

a) reference that the test was carried out in accordance with this document;

b) name and address of test laboratory;

c) name and address of sponsor (if any);

d) date of the test;

e) detailed specifications of all combustibles (fuel): dimension, weight, composition, or generic identification;

f) test rig configuration: construction detail, area, height, finish material;

   1) fire performance classification according to national regulations should be reported (if any);

g) distribution of the fuel in a plan view: schematic representation of the layout;

h) graphical expression of an ignition source and relative position to fuels;

i) ventilation conditions including door and/or windows including their opening area (m^2);

j) specifications, parameters, conditions and locations of main measuring instruments;

   1) parameters related to FT-IR in accordance with ISO 19702;

k) graphs showing the following data versus time at the breathing zone of the target person (including position with time):

   1) temperature (°C),

   2) heat flux (kW/m^2),

   3) gas concentrations ($\mu L \cdot L^{-1}$),

   4) $[CO]/[CO_2]$ ratio,

   5) light transmission or optical density,

   6) calculated visibility (m),

   7) tenability calculation of each factor (FED and FEC) according to ISO 13571;

l) video and photo before, during, and after the tests;

m) total mass loss or heat release rate if measured (optional);

n) measurement uncertainty of all quantities;

o) visual observations (event-time log) such as ignition, flame and smoke spread, and extinguishment.

Annex A
(informative)

Fire classification and typical characteristics

A.1 Fire classification

Once a fire has started, the developing situation in terms of the basic fire scenario, the chemistry of combustion and the effects on the occupants depend upon the interaction between the developing fire in the fuel items first ignited and the characteristics of the fire enclosure (especially its size and ventilation characteristics).

Fires are classified into 3 main types on the preceding basis:

— non-flaming/smouldering fires;

— well-ventilated flaming fires;

— under-ventilated flaming fires: pre-and post-flashover fires.

A particular fire scenario can progress through one or more of these types at different stages of development, subject to defined conditions. For the purpose of designating combustion conditions for test purposes, key characteristics of different fire types/stages are set out in ISO 19706:2011, Table 1.

The example of bedding fire scenarios is studied in Reference [5]: in this scenario, the fire is classified as smouldering to begin, then undergoes a period of well-ventilated flaming, and later flashover. In the first two classifications, conditions of tenability matter in the room of fire and to a lesser extent outside. In the third classification, only conditions outside the room matter as conditions are already worsened in the initial enclosure.

NOTE Bench-scale test methods with details on related fire stages reproduced and limitations are detailed in ISO 16312-1 and ISO/TR 16312-2.

A.2 Typical characteristics of each fire stage

A.2.1 Non-flaming/smouldering fires

Non-flaming/smouldering fires involve local exposure of a product to a heat source. If the fuel is a solid, such as an item of furniture or a wall lining, then once the temperature of the surface is raised sufficiently (generally approximately 300 °C), a process of thermal decomposition by oxidative pyrolysis begins. In a fire scenario, this process is often triggered by exposure to a radiant heat source (such as an electric fire) or in an electrical appliance due to some form of current overload. Smouldering is a more complex process involving an exothermic reaction within a solid (initiated by some source of overheating) leading to a self-propagating non-flaming decomposition. The products of non-flaming decomposition tend to be rich in partly decomposed irritant organics, carbon monoxide, and smoke particulates. Hazards are mainly the exposure of a sleeping subject to the decomposition products in a small enclosure such as a bedroom, as they develop over a prolonged time scale. A smouldering fire could move to a well-ventilated fire, or to an under-ventilated fire, depending on ventilation, volume, openings, etc.

A.2.2 Well-ventilated flaming fires

An early well-ventilated flaming fire is relatively small compared to the size of the enclosure. Its flames do not penetrate the upper smoke layer. Thus, it denotes the early stages of flaming fires while it is characterized by an ample supply of fresh air to support combustion. The fuel-air equivalence ratio of the enclosure is less than 1, and during the early stages, it is likely to be less than 0,5. This means that there is always more than sufficient oxygen mixed with fuel vapor generated from the burning object for complete combustion. If the fire remains small compared to the size and ventilation of the enclosure, it is regarded as a well-ventilated fire. This kind of fire could grow to flashover or decay, changing the fire stage. The picture on the right of Figure A.1 shows an armchair burning under a calorimeter hood in a large laboratory. As long as the flames remain below the hood this remains a well-ventilated fire. Fires outside or in large atria are generally well-ventilated (unless they cover a wide area). The picture on the left of Figure A.1 shows the air flow to the flame and upper smoke layer in early well-ventilated fires.

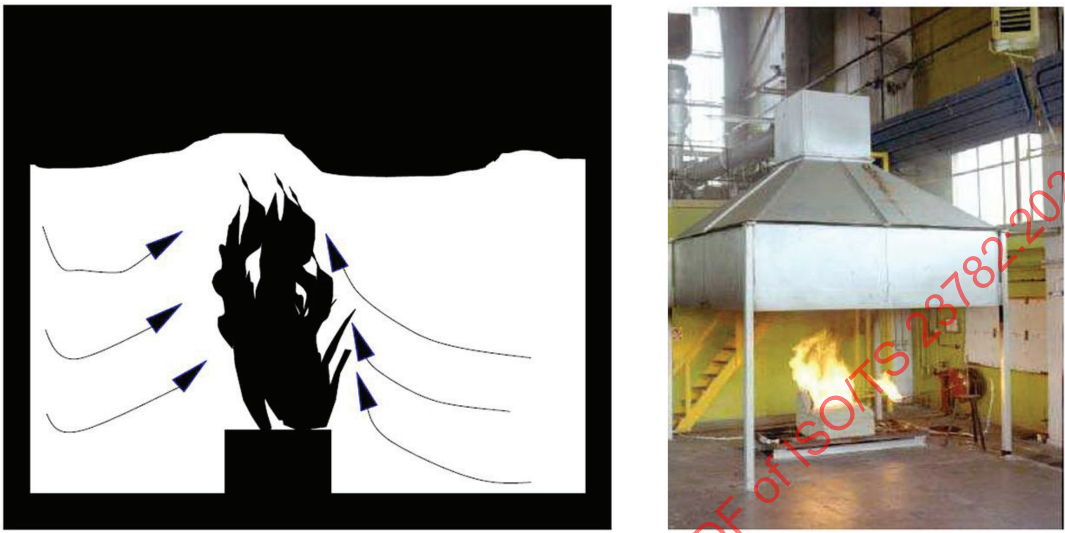

Figure A.1 — Early well-ventilated fires

A.2.3 Under-ventilated flaming fires

A.2.3.1 Pre-flashover under-ventilated fires

Pre-flashover under-ventilated flaming fires are fires inside enclosures with restricted ventilation, such that the availability of oxygen limits their size. They are therefore usually relatively small and are often restricted to the object of origin. The under-ventilated condition follows early flaming when the concentration of oxygen in the enclosure begins to decrease and the upper layer fills down such that the flames penetrate the upper layer and entrain air already depleted in oxygen. This is the most common combustion condition in enclosed buildings, particularly small buildings (houses, shops, offices), and modern airtight, energy-efficient designs. Yet, this combustion condition is often not adequately addressed in fire engineering design, as toxic products with a yield more appropriate to well-ventilated conditions are often used for design calculations. Large-scale fire tests are seldom undertaken in such a way as to obtain under-ventilated combustion conditions, although these conditions have been obtained frequently during real-scale experiments using enclosed rigs or rigs with restricted vents.

A typical example of a pre-flashover under-ventilated fires would be a small fire developing in a closed lounge or bedroom in a domestic dwelling or hotel room. If the door and windows are closed, the upper layer fills down below the upper part of the flames within a few minutes. The combustion conditions become under-ventilated such that the fire remains small but high yields of smoke and toxic products including CO, HCN and irritants fill the room. A room occupant is exposed to a mix of highly toxic effluents capable of causing incapacitation and death from asphyxiation within a few minutes. The occupant can also suffer from exposure to heat, with possible burns. If the door and windows remain closed, the fire can self-extinguish due to insufficient oxygen, wherein the oxygen concentration of the air entrained into the fire decreases to levels below 12 % to 15 %.

If the room door is open, then the effluent spreads beyond the room of origin once the smoke layer descends below the doorway soffit. Fresh air enters the room at a low level to maintain the fire [see Figure A.2 a)]. However, once the effluent has filled any enclosed areas of the dwelling beyond the room of origin (such as the hall), the layer descends significantly, and coupled with the oxygen-depleted environment, reduces or extinguishes the fire [see Figure A.2 b)]. In this case, the entire volume beyond the room of origin is filled with highly toxic effluent, although the temperature of the diluted smoke beyond the room of origin is likely to be too low for "heat" from the smoke to be hazardous. Figure A.2 c) shows an armchair burning under pre-flashover under-ventilated combustion conditions in the lounge of an enclosed two-storey house, with the lounge door open. The whole house has filled with smoke and the armchair is still burning under pre-flashover under-ventilated conditions, but the fire self-extinguished soon after.

a) Fresh air into the room

b) Fire reduction or extinguishment

c) Self-extinguishment

Figure A.2 — Ventilation-controlled pre-flashover under-ventilated fires

A.2.3.2 Post-flashover under-ventilated fires

The final category of the flaming fire scenario is the post-flashover under-ventilated flaming fire. Flashover can occur when the temperature of the upper layer, in particular the downward radiation from the upper layer, is sufficiently high to cause ignition of combustible materials in the fire enclosure remote from the point of origin of the fire. For this to happen, the temperature of the upper layer needs to reach around 600 °C or above.[27] At this level, tenability conditions inside the enclosure of fire have already worsened for a period of time, but tenability conditions along smoke dispersion pathways are of concern. In most cases, flashover does not occur in fully-enclosed spaces, but occurs when there are sufficiently large external vents to provide sufficient air to support a large fire. Expressions exist to enable calculations of whether and when a particular enclosure can flashover, based upon the vent size.[28]

In general, a room-sized space requires a complete failure of a very large window, a door open to the outside, or a combination of an open window and open door, in order for a fire to progress to flashover. The effluent plume from a flashed-over fire is similar in composition to that of a pre-flashover under-ventilated fire. Both are under-ventilated, as the normal fuel load in a building and fuel mass loss rate in post-flashover are usually sufficient to provide fuel-rich combustion conditions, with very low oxygen concentrations, and high concentrations of asphyxiant gases (CO, HCN), organic irritants and smoke particulates. In this situation, the temperatures are higher and the conditions somewhat more extreme. Post-flashover fires are therefore extremely hazardous because a large amount of hot under-ventilated effluent plume material can rapidly fill extensive building spaces remote from the seat of the fire. As the plume is hot, the flashover process can also propagate rapidly beyond the area of origin. Post-flashover fires have therefore been the cause of multiple deaths in several large fire disasters, such as the MGM Grand[29] and the DuPont Plaza hotel fires.[30]