TECHNICAL REPORT

# ISO/TR 11925-1

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# Reaction to fire tests — Ignitability of building products subjected to direct impingement of flame —

## Part 1:
Guidance on ignitability

*Essais de réaction au feu — Allumabilité des produits de bâtiment soumis à l'incidence directe de la flamme —*

*Partie 1: Lignes directrices sur l'allumabilité*

Reference number
ISO/TR 11925-1:1999(E)

## 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.

Technical Reports are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

The main task of 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 Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.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 11925-1, which is a Technical Report of type 3, was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 1, *Reaction to fire*.

ISO/TR 11925 consists of the following parts, under the general title *Reaction to fire tests — Ignitability of building products subjected to direct impingement of flame*:

— *Part 1: Guidance on ignitability*

— *Part 2: Single flame source test*

— *Part 3: Multi-source test*





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## Introduction

Ignitability of materials is of basic importance when fire hazard is analysed because of two reasons: First, at the initiation of a fire some object or local area is ignited, and second, during the fire growth period ignitability is an essential factor in fire spread to the other parts of a room or compartment.

In buildings the structural, lining and furnishing materials are solids, which require external heating to achieve flaming combustion. The ignition condition can be characterized by the minimum surface temperature at which the flow of volatiles is sufficient for sustained flaming. However, the difference in these temperatures between materials is not large. Hence it is usually more important to take into account the time of exposure and the thermal properties of the material when assessing risk of ignition.

When a material is exposed to an external heat flux (radiative, convective, conductive or a combination), its surface temperature starts to rise. The temperature inside the solid also increases with time, but at a slower rate. Provided the net flux into the material is sufficiently high, eventually the surface temperature reaches a level at which pyrolysis begins. The vapours generated emerge through the exposed surface and mix with air in the boundary layer. Under certain conditions this mixture exceeds the lower flammability limit and ignites. The initiation of flaming combustion as described above is termed *flaming ignition*. For some materials or under certain conditions, combustion is not in the gas phase but in the solid phase. In such cases no flame can be observed and the surface is glowing. This quite different phenomenon is termed *smouldering ignition*.

The definition of ignition has been debated in many fora. It is most usually defined as the presence of a flame on a surface, or more simply the persistence of flame. Some documents try to subdivide the ignition process in three ways: flashing (less than 1s of flaming); transient ignition (greater than 1s and less than 4s); and sustained ignition (more than 4s of flame). Other documents define ignition as the persistence of flame for greater than 10s. Many of the definitions have been derived from apparatus-dependent parameters. All definitions have their merits and all have been well discussed.

This Technical Report describes and characterizes the "real fire" ignition sources, the ignition sources used in the testing of materials and products, and any correlation between those and "real fire" sources. Some of the theoretical principles of ignition and ignitability are also addressed.

The majority of ignitability tests used internationally are based on the direct application of a flame. A few tests involve radiative heating of the material but generally also require some form of pilot source whether a flame or a spark. In general the ignition sources used have some relevance to end-use hazard.

ISO/TC 92/SC 1 has concentrated on the development of tests to simulate ignitability by a range of flame sources of increasing size and also a piloted (by flame) radiative ignition source, see ISO 11925-2 and ISO 11925-3 and ISO 5657, respectively.

The guidance given in this Technical Report should enable choice of the appropriate ignition source when related to the end-use application of the material or product being assessed.

A comprehensive review of piloted ignition and ignitability test methods is also given in ISO/TR 11696-1. ISO 11093 also provides a brief description for a number (13) of different types of ignition source and is a reference document for persons seeking descriptions of the standardized source apparatus

# Reaction to fire tests — Ignitability of building products subjected to direct impingement of flame —

# Part 1:
Guidance on ignitability



## 1 Scope

This Technical Report provides guidance on "ignitability" tests for building products. It describes the principles of ignitability and characterizes different ignition sources.

The results of small-scale ignitability tests may be used as a component of a total hazard analysis of a specified fire scenario. It is therefore important that the flame or radiative source chosen is fully characterized so that relevant conclusions may be made from the test results.

Guidance given in this Technical Report may also have relevance to other application areas (e.g. building contents, plastics, etc.)

## 2 References

ISO 5657:1997, *Reaction to fire tests — Ignitability of building products using a radiant heat source.*

ISO 5658-2:1996, *Reaction to fire tests — Spread of flame — Part 2: Lateral spread on building products in vertical configuration.*

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

ISO 9239-1:1997, *Reaction to fire tests — Horizontal surface spread of flame on floor-covering systems — Part 1: Flame spread using a radiant heat ignition source.*

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

ISO 10093:1998, *Plastics — Fire tests — Standard ignition sources.*

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

ISO 11925-2:1997, *Reaction to fire tests — Ignitability of building products subjected to direct impingement of flame — Part 2: Single flame source test.*

ISO 11925-3:1997, *Reaction to fire tests — Ignitability of building products subjected to direct impingement of flame — Part 3: Multisource test.*

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1) To be published.

# 3 Typical 'real fire' ignition sources

## 3.1 General

Fires are caused by a wide range of ignition sources. Statistical analysis of real fires conducted in many countries has identified the most common primary and secondary sources especially in fires within buildings. The most frequent sources of fires may be the following.

a) Cooking appliances (electric and gas)

b) Space heating appliances (electric, gas and solid fuel)

c) Electrical wiring

d) Other electrical appliances (such as washing machines, bedwarmers, televisions, water heaters)

e) Cigarettes

f) Matches and smokers' gas lighters

g) Blow lamps, blow torches and welding torches, hot metal

h) Rubbish burning, e.g. in waste paper baskets or in bins or accumulated piles

i) Candles

The items first ignited are probably the following.

a) Food including cooking fat

b) Gases, i.e. mains gas and bottled gasses

c) Liquids, e.g. petroleum, paint spirits

d) Textiles, e.g. clothing, curtains

e) Upholstery, e.g. chairs, beds, sofas, etc.

f) Floorcoverings

g) Building structures, e.g. wall linings, ceilings, partitions.

h) Electrical wiring

Smouldering ignition sources are particularly insidious in real fire situations since they can involve a considerable induction period before flaming combustion develops. In general, the real source is used in standardized tests (e.g. the cigarette, which is defined in terms of its burning rate).

Primary ignition sources (i.e. sources which directly cause ignition), range from relatively common sources such as matches to fires ignited from radiant heaters. Gas flames (e.g. cigarette lighters, welding torches' etc.) can also cause fires if carelessly used. Gas or electric radiant heaters may raise the temperature of materials above their flash or self-ignition temperatures. Radiant heaters can cause ignition by radiant heat alone. Other radiant heat sources include electric light bulbs which can cause high local temperatures.

Secondary ignition sources do not directly cause ignition but can be ignited using primary sources (e.g. matches or cigarettes) and then burn to produce a large ignition source. Secondary sources include waste paper baskets, newspapers or journals, clothing, loose furnishings, upholstery, etc. These items, once themselves ignited, may then spread the fire either by direct flame impingement or by radiative and convective ignition.

The list below details the type of sources in each category.

**a) Primary source**

| | |
|---|---|
| Smouldering | Cigarette |
| Flaming | Match |
| | Smoker's gas lighter |
| | Candle |
| | Chip-pan |
| | Blowlamp |
| Electrical | Wiring |
| | Appliances |
| Radiative | Space heater |
| | Light bulbs |
| Conductive | Sparks |
| | Hot coals |
| Convective | Hot gases |
| | Hot air guns |

**b) Secondary sources**

| | |
|---|---|
| Smouldering | Cellulose materials |
| Flaming | Building contents (e.g. furniture, waste bins, curtains, etc.) |
| Radiative | Large non-contacting flames from burning items. |

## 3.2 Characteristics of flame sources

A major consideration in the selection of the type of ignition source in any test must come from a knowledge of the real fire and its associated heat fluxes. In theory, this could range from zero to an upper value of $FT^4$ where $T$ is the maximum flame temperature. The maximum flame temperature for most common fuels is approximately 2300 K [1]. Since the Stefan Boltzman constant $F$ is 5,67 x $10^{-11}$ $kWm^{-2}K^{-4}$, a maximum irradiance of 1500 $kWm^{-2}$ can be expected, which is approximately 10 times greater than the maximum actually found.

Since theory gives little guidance on the characteristics of typical ignition sources in real fires, experimental data must be used to characterize real fire sources.

The main characteristics of ignition sources and their relation to the test specimen may be defined by the following factors:

a) The intensity of the ignition source, i.e. the thermal input to the material to be ignited, which includes the conductive, convective and radiative effects of the ignition source.

b) Area of flame contact of the ignition source.

c) Duration of exposure to the ignition source.

d) Orientation of the specimen relative to the ignition source.

e) Ventilation conditions around ignition source.

An ignition source may be as small as an electrical spark or as large as a burning building which can act as an ignition source to an adjacent building. For the purpose of this Technical Report, however, ignition sources are limited to those which are commonly found to be the cause of a room fire, and the range of potential ignition sources will generally have heat fluxes of less than 50 $kWm^{-2}$.

Table 1 shows the characteristics of various real flame sources in terms of the temperature, area of flame contact and imposed heat fluxes [2].

**Table 1**

| Source | Temperature (°C) | Area of flame contact[a] ($mm^2$) | Maximum heat flux[a] ($kW/m^2$) |
|---|---|---|---|
| First flame after electrical failure of cable | 800[b] | 50 | 30 |
| Match | 850[b] | 500 | 35 |
| Lighter | 800[b] | 800 | 30 |
| 4 sheets tabloid newspaper | >600 | 60,000 | 25 |
| Deep fat fryer fire (Domestic) | >1100 | 125,000[c] | 50 |
| Plumbers blow-torch (Specialist tool) | >1000 | 4,000 | 140 |
| Oxyacetylene premixed flame (Specialist welding source) | >1800 | 2,500 | 150 |
| Waste paper basket | >900 | 110,000[c] | 50 |
| Cigarette | >1000 | 100 | <5 |

[a] The values quoted are all nominal and are subject to the conditions of the investigation. The values were derived by measuring against a flat non-combustible thermally thick board.

[b] Measured in the luminous part of the flame.

[c] Function of diameter of the receptacle and its location.

From table 1, it can be seen that diffusion flame sources give very similar imposed heat fluxes. Work by Babrauskas et al. [2] has shown a direct linear relationship between the fuel input to a diffusion burner and the area of flame contact with a significant increase in the imposed heat flux. To increase the heat flux seen by the surface in the area of flame contact, it is necessary to increase the depth of the flame. It is for this reason that higher heat flux values are recorded for the deep fat fryer and waster paper basket fires where the flames may be of an order of 100 mm to 200 mm thick.

In general, therefore, the real fire sources fall into two types, when assessed in terms of their imposed heat fluxes - those with premixed flames giving heat fluxes in the order of 150 $kW/m^2$ and those with diffusion flames with heat fluxes in the order of 30 to 50 $kW/m^2$.

Two of the diffusion flames, the deep fat fryer and the waste-paper basket, have heat fluxes in the order of 50 $kW/m^2$: This is due to the thickness of the flame created, the thicker the flame, the greater the imposed heat flux. This phenomenon should also be considered when producing standardized ignition sources since in general only "thin" flames are used as standard sources, with the exception of the sand burner used in ISO 9705.

### 3.3 Characteristics of electrical sources

The main ignition sources created by misuse of electrical supply and appliances are:

a) overloaded wires and cables where breakdown of the insulation occurs and adjacent combustible materials are ignited by hot wires (by conduction or radiation);

b) mechanical failure of the insulation resulting from ageing or physical damage (conductive heating);

c) heaters where glowing wires or bars emit high radiant energy (radiative ignition);

d) high temperature arcing (radiative and convective).

### 3.4 Characteristics of radiative sources

Radiative sources generally consist of either electrical or gas fired radiant panels or elements (e.g. gas fires, electrical bar heaters). They are normally sited remote from the item to be ignited and are the primary source of the fire. The type of scenario envisaged would be the ignition of an object placed too close to the "radiator".

The main characteristics of radiant sources are defined by:

a) the intensity of the radiation and effectiveness of radiation transfer;

b) the duration of exposure;

c) spectral distribution.

NOTE Large flames or hot gas layers produced from an item already ignited (secondary source) can also act as a radiative source to ignite other remote items.

## 4 Factors affecting ignitability tests

### 4.1 General

The choice of ignition source in any fire experiment is significant. It is important to identify what real ignition source is being simulated in terms of heat duration, irradiance, area of heat contact, etc.

A typical ignition source could be chosen or a range selected in order of severity. Occasionally, a worst case example could be employed.

The size of the ignition source should be selected with due consideration of the fire to be simulated and should not be excessive in relation to the dimensions, shape and ventilation of the test specimen or construction. The ignition source will also have some affect on the ventilation conditions prevalent in the fire enclosure. The specimen presented for testing should be appropriately sized and not scaled down with relation to the ignition source, i.e. one specimen should be of sufficient size not for the flame to influence or overwhelm the thermal properties of the specimen.

It is important to choose an ignition source which will not adversely affect measurements (for example, by generating high levels of smoke, or toxic gases, or reducing the available oxygen for combustion). For this reason, it may be necessary to carry out preliminary tests to estimate the likely effects of the chosen ignition source on such measurements and to correct these after the test.

When an attempt is made to simulate a real ignition source, it is essential to realize that burning characteristics may be affected by environmental conditions and therefore recognize that the design parameters chosen may not be correct and may require subsequent adjustment.

Possible ignition sources can be characterized by:

a) total fuel content

b) type of fuel

c) rate and nature of fuel release (e.g. ramped, stepped or steady state)

d) rate of heat release

e) height of flame for given location

f) convective and radiative heat

g) time of burning

Annex A gives guidance on the development of ignition sources for fire tests.

## 4.2 Type of heat source

The complete character of the ignition source should be determined, including mass, material identification, morphology dimensions and all other physical and chemical characteristics necessary to repeat each ignition scenario. Typical ignition sources are solid, liquid or gaseous fuels including gas burners, liquid pool fires, wood cribs, electrical sources, etc.

### 4.2.1 Gas burners

Gas burner flames have the following advantages:

a) they are reproducible;

b) they are well-defined; i.e. their heat production rate is readily determined from the gas flow rates;

c) they can be varied with time to represent the burning of different products or be maintained constant to facilitate analytical studies;

d) their burning rates are not influenced by heat feedback (unless controlled artificially).

Their disadvantages are:

a) the radiation properties of the flames are different from those of the product simulated;

b) gas flames do not resemble what is seen in real fires;

c) soot production is much less than from real fires therefore flames are less luminous.

Differences between diffusion and premixed burners should be recognized. As an example, the flames from a premixed burner will be hotter, shorter and have lower emissivities. In order to avoid locally high velocities, the gas can be delivered through a large-area diffusing surface, such as a porous plate or a layer of sand.

### 4.2.2 Liquid pool fires

These fire sources have the following advantages:

a) their rate of fuel production is readily determined from their rate of mass loss or the flow rate necessary to maintain a constant depth in the pool;

b) they have an interaction with the fire environment which can be quantified by their change in heat production rate;

c) they are reproducible under the same exposure conditions;

d) their radiation characteristics can be controlled by the choice of fuel.

Their disadvantages are:

a) the effect of feedback is not quantitatively the same as for real products; and

b) they lack visual realism unless they are intended to represent liquid fuel spills. A variation of the liquid pool fires is obtained by supplying the liquid fuel in a matrix of sand in order to vary its burning rate.

#### 4.2.3 Solid fuels

The solid fuels which have been used routinely as ignition sources have included waste containers and wood cribs, with the latter having the longest history. The dimensions of the sticks, type of wood and spacing as well as total mass have a large effect on the burning rate of the wood cribs.

Waste containers and wood crib fires have the following advantages:

a) they provide the best visual simulation of the burning of products;

b) their interaction with the environment of the fire room is, perhaps, closer to, though not the same as, that of the burning products; and

c) their radiation characteristics more nearly match those of the real product fire.

Waste containers and wood cribs have the following disadvantages:

a) their reproducibility is not as good as that for gas burners; and

b) the ratio of their heat release rates to their measured mass loss rates vary throughout the test.

#### 4.2.4 Radiative sources

Radiative sources are powered either by electricity or gas. These sources have the following advantages:

a) they are reproducible;

b) they can provide either a uniform or gradient of irradiance;

c) the heat output can be quantified;

d) the gas fuelled sources are controllable with rapid responses;

e) they can produce a wide range of irradiance.

The main disadvantages to these sources are that

a) electrical radiant sources are not immediately controllable;

b) for lamp type sources, the radiation properties are different to those of the product simulated;

c) radiant sources generally require a form of piloted ignition and the flame or spark needs to be positioned in an area in which the decomposition gases (from the effects of the radiant heat) are at their most concentrated;

d) radiant sources usually assume a set distance between the source and the item to be ignited (some materials shrink or swell under heat, therefore, this distance changes and this change cannot be quantified).

#### 4.2.5 Electrical sources

Electrical ignition sources for use in large tests can be simulated using sources from smaller-scale fire tests (e.g. glow-wires at temperatures up to 960 °C).

Electrical sources are usually contact (conductive) sources. The advantages of the conductive sources are that they are simple and the tests are easy to conduct. The disadvantages are that the tests are only effective for small scale ignition of materials and are generally a function of the materials autoignition temperatures.

#### 4.2.6 Smouldering sources

The most widely used smouldering source is the glowing cigarette and considerable work has been done to study the effect of this low intensity ignition source [5]. The major disadvantages of using this standardized ignition source, which is generally specified in terms of burning rate and mass, are:

a) it has rather poor repeatability and reproducibility;

b) its behaviour and its ability to act as an effective ignition source is very dependent upon its location which in turn affects its reproducibility.

Its main advantages are that:

a) it is easy to use; and

b) it is the "real" ignition source and therefore should mirror real fire performance.

### 4.3 Size

The size of the flame or area of radiative influence greatly affects the fire behaviour of the material being exposed to the ignition source, since it affects the area of flame contact. The larger the area of flame contact, the less the influence of the material to be ignited since the ability of the material to dissipate the heat or conduct it away from the area of flame contact is reduced and earlier ignition can be expected.

The depth of the flame source is also important since the greater the depth, the greater the resultant heat flux on the surface of the material exposed.

The ignitability of a flame retardant treated product is also influenced by the relative sizes of the flame source and the object to be ignited.

### 4.4 Location

The location of the ignition source is one of the most important considerations in conducting compartment experiments. Its position in relation to the wall can significantly influence the rate of burning. When it is close to the wall, there can be major feedback influences and the ignition source will burn more quickly, although this will depend to some extent on the properties of the lining, the availability of air and the type of ignition source. The flame height is affected by the entrainment of air into the plume which itself is critically affected by the position of the ignition source in relation to the wall/corner. For example, if the access of air to the flame is blocked from one side, such as would occur by placing the ignition source against a wall, then an increased flame height for the same rate of gaseous fuel leaving the source would result. This analogy can be extended further to an ignition source in a corner which would give an even higher flame height.

In addition, the height of the flame source from the floor will have an effect on the ignitability of test specimens within a compartment.

### 4.5 Physical and chemical response of exposed material

In ignitability tests, the thermophysical response of the material can be significant. When a specimen shrinks, flows, melts, deforms, chars, intumesces, etc., it can significantly change the critical distances between the ignition source or flame combustion zone and the material. Therefore, results on the ignitability of these types of materials can be

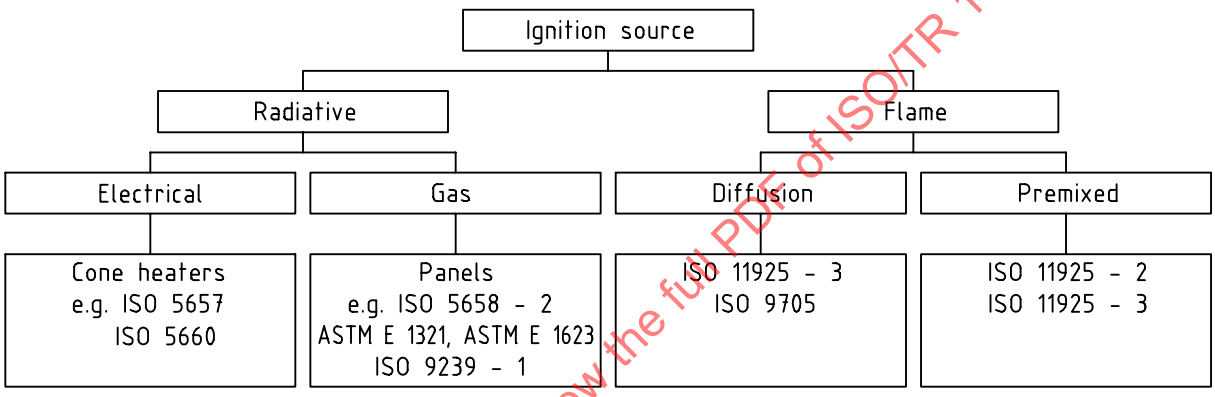
variable as ignition may be difficult to achieve. Preheating of a material prior to the application of an ignition source may also cause physical changes such that the materials propensity to ignite may be altered, e.g. charring.

One form of behaviour, would be for the specimen to melt or expand sufficiently under the influence of the flame or radiant heat to extinguish the ignition source by blocking the burner orifice or completely obscuring the radiator.

The incorporation of flame retardants or the coating of the product with a flame retardant agent can affect the behaviour of the product to ignition sources. Products may have different behaviour when applying ignition sources of different sizes. Performance in the small scale may not be the same as in the larger scale.

## 5 Ignitability tests

The following diagram indicates the types of ignition sources which have been developed within ISO/TC 92/SC 1. Also indicated are two ASTM Standards upon which the subcommittee is currently working. The diagram is included to provide an easy reference to the ignition sources available in the ISO/TC 92/SC 1 portfolio.




### 5.1 Radiative sources

There are generally two types of radiative ignition source used; electrical and gaseous.

#### 5.1.1 Electrical

Both the test methods which utilize this type of ignition source are based on truncated cone heaters.

**a) ISO 5657**

This ignitability test (figure 1a) is designed to assess the possibility of secondary ignition by radiative heat transfer, however, a pilot flame is used to ignite any volatile gases released from the specimen.

The radiator (figure 1b) is in the shape of a truncated cone with an upper diameter of 66 mm and a lower diameter of 200 mm. The internal windings on the cone are capable of producing an imposed irradiance on the flat surface of a specimen positioned below the heater of between 0 and 50 kW/m$^2$.

The specimen is mounted on a pressure plate which keeps the specimen in the vicinity of the cone heater during the test, which results in a partially closed system (i.e. limited ventilation). The pilot flame which is applied to the area just above the centre of the specimen surface is not present continuously but is positioned on a dipping mechanism such that it is only present for 1 second in every 4.

The specimen size is 165 mm square and is placed on base board of 6 mm non-combustible insulation material of density 825 kg/m$^2$.

**b) ISO 5660**

This test method (figure 2) is primarily used to determine heat release rates, however, as part of the test procedure, the time to ignition is also determined.

The radiator is similar to that used in ISO 5657 with an upper and lower diameter of 80 mm and 177 mm respectively. The internal windings produce an imposed irradiance on the surface of between 0 and 100 kW/m$^2$. The specimen is mounted 25 mm below the lower edge of the cone giving an open system in terms of ventilation which is added by an exhaust gas system which uses an airflow of 24 litres/s. This results in free ventilation conditions for the specimens.

A spark igniter is positioned 13 mm above the centre of the specimen and is applied continuously.

The specimen size is 100 mm square and is placed on a backing material with a density of 65 kg/m$^2$ giving a heated area of 0,01 m$^2$.

**c) Differences between tests**

The main differences between the two tests which will have an effect on the ignitability behaviour of products are therefore: specimen size, the backing material, the pilot ignition source and the convective heat losses which occur due to one being an open and the other a closed ventilation system. The effect of these differences are shown in 6.5.

**5.1.2 Gaseous**

There are two test methods which rely on gas fired radiant panels as the heating source to determine ignitability performance:

**a) ASTM E1321 [3] (ISO/TR 5658-3)**

This test method, also known as the Lateral Ignition and Flame Spread Test (LIFT) (figure 3), is used to provide data on flame spread to incorporate into fire models to predict fire growth within compartments. The initial part of the procedure requires the measurement of ignition. This is accomplished by exposing a number of specimens to a nearly uniform heat flux and the time to sustained flaming determined. The time to sustained flaming is plotted against imposed irradiance and the minimum irradiance required to achieve ignition is determined.

The ignition source used consists of a premixed gas fuelled panel 280 mm × 483 mm orientated at 15° from the specimen.

The panel is composed of sintered or porous ceramic tiles moulded into a stainless steel frame, the gas forming at the surface of these tiles thus producing a surface radiator.

The panel is set to a defined irradiance, initially 30 kW/m$^2$ measured at the 50 mm position, and this irradiance altered in defined integers until there have been sufficient values obtained for time to ignition against different irradiance levels to enable the critical irradiance value to be determined.

The panel is capable of being controlled between 0 and 70 kW/m$^2$. However it produces a gradient of irradiance over the specimen due to the imposed angle, the irradiance falling quite quickly with distance.

A non-impinging acetylene fuelled pilot flame is placed parallel to the surface of the specimen to ignite any volatiles released.

**b) ISO 5658-2**

This test method (figure 4) measures the lateral spread of flame on a material when exposed to a gradient of irradiance from 0 to 50,5 kW/m$^2$. The ignition source is the same panel described in a) above, and includes the same pilot flame fuelled by propane.

**c) ASTM E1623, Intermediate scale calorimeter (ICAL) [4] (ISO/TR14696)**

This test method is primarily used to determine the heat release from 1 $m^2$ planar specimens (figure 5), however, as part of this procedure, time to ignition is also measured.

The ignition source used consists of a bank of nine ceramic faced gas fired panels fuelled by natural gas and air. The face of each burner is covered by a stainless steel mesh to produce a higher surface temperature. The panel is operated at a constant irradiance creating a measured flux on a specimen of between 0 and 50 $kW/m^2$ depending on the distance from the panel to the specimen.

Ignition wires, electrically heated, are placed around the perimeter of the specimen to ignite any volatiles.

**d) ISO 9239-1, Radiant panel flooring test**

The propensity of a floorcovering to spread flame is determined by this test method. The specimen (1050 mm × 230 mm) is mounted horizontal face up and is exposed to a gradient of irradiance from 11 $kW/m^2$ to 1,1 $kW/m^2$ created by a natural gas fired radiant panel. A pilot flame produced by a manifold burner with 19 evenly spaced burner holes is positioned at the "hot end" of the specimen. The flame generated impinges directly on the specimen and has a heat release value of approximately 8,3 kW. The flames from the burner extend by approximately 60 mm to approximately 120 mm across the width of the specimen, giving an imposed heat flux of 20 $kW/m^2$ to 30 $kW/m^2$ over an area of 0,072 $m^2$.

The experimental apparatus showing both the radiant panel and the pilot flames is given in perspective view in figure 6.

The radiant panel is nominally 300 mm by 450 mm and is manufactured from porous refractory material mounted in a steel framework. The panel is mounted with its longer side at 30° to the horizontal plane (figure 6).

**e) Differences between the tests**

The main differences between the tests are the size of the ignition source, the gradient of heating to the specimen, and the pilot ignition sources. With all four gaseous panels, the ventilation conditions to the specimens may be considered to be open.

## 5.2 Flame sources

The majority of flame sources available within the test methods produced by ISO/TC 92/SC 1 are based on diffusion flames. However, two premixed flames are also specified.

### 5.2.1 Diffusion flames

The flames specified within the following two test methods vary in size and heat output from 0,05 kW to 300 kW.

**a) ISO 11925-3**

This method provides a variety of diffusion flame sources which equate to flames from real sources. The smallest flame is produced from a steel tube with an inner diameter of 0,5 mm and represents the first flame after electrical failure through flames presenting matches and cigarette lighters from tubes of inner diameters of 6,5 mm to a manifold burner comprising 14 gas jets (1,5 mm diameter) (figure 7) giving a sheet of flame representing a burning newspaper or a deep fat fryer or waste basket fire.

Full characteristics of these sources are detailed in 5.3.2.

**b) ISO 9705**

The recommended burner given within ISO 9705 consists of a sand box through which propane percolates and is ignited and burns as a diffusion flame above its surface (figure 8). The heat output from the burner is 100 kW for 10 min and 300 kW for a further 10 min. The burner is supposed to be representative of an armchair or similar item burning.

The burner is 170 mm square and 145 mm high, filled for 100 mm with gravel and the remainder with sand; a metal gauze separating the two components. Gas enters the burner centrally through the box; the burner itself standing 300 mm above the floor and adjacent and touching the corner of a room.

ISO 9705 also details an alternative source of dimensions 300 mm square, again filled with a sand and gravel mix which produces a diffusion flame (figure 9). The recommended heat output for this source is 40 kW/m$^2$ and 167 kW/m$^2$. The sand burner is also placed in the corner of the room 300 mm above the floor.

#### 5.2.2 Premixed flames

**a) ISO 11925-2**

The small premixed flame described in detail in ISO 11925-2 is also described as Source B in ISO 11925-3 and uses the same burner (figure 10). The ignition source is a low intensity burner fuelled by propane with a flow rate of 25 ml/min giving a flame height of 20 mm. The characteristics of the flame are given in 5.3.2.

**b) ISO 11925-3**

Three premixed flames are specified in this Technical Report, Source B (described above) G and H. All are representative of real fire sources, i.e. a match, plumbers blowtorch and roofers torch respectively. The latter burners (G and H) are of similar design (figure 11) and are fabricated from nickel plated mild steel with premixing airholes in the rear section of the flame stabilizer section. The Source F burner has an internal diameter of 13,5 mm and the Source G burner 34 mm.

The burners are fuelled with propane and given a flame length of 120 mm and 230 mm respectively.

### 5.3 Comparison of ignition sources of ISO/TC 92/SC 1 tests

#### 5.3.1 Characteristics of radiative sources

**Table 2**

| Ignition Source | Characteristics | | | | |
|---|---|---|---|---|---|
| | Heat Flux Distribution | Type of Heater | Area of Irradiance m$^2$ | Area of Heater m$^2$ | Heat Flux Levels kW/m$^2$ |
| ISO 5657 | Uniform | Electrical | 0,015 | 0,032 | 0 - 100 |
| ISO 5660 | Uniform | Electrical | 0,01 | 0,020 | 0 - 100 |
| ISO 5658-2 | Gradient | Gas | 0,020 | 0,135 | 0 - 50 |
| ASTM E1623 | Uniform | Gas | 1,0 | 2,05 | 0 - 50 |
| ASTM E1321 | Gradient (almost uniform on specimen) | Gas | 0,020 | 0,135 | 0 - 70 |
| ISO 9239-1 | Gradient | Gas | 0,242 | 0,135 | 0 - 11* |
| * These values refer to the gas fired radiant panel alone. Where the pilot flame also impinges on the specimen, the heat flux levels are 20 to 30 kW/m$^2$. | | | | | |

### 5.3.2 Characteristics of ISO 11925 and ISO 9705 flame sources

**Table 3**

| Ignition source | Description | Characteristics | | | | |
|---|---|---|---|---|---|---|
| | | **Calculated Heat Release** kW | **Measured Heat Release** kW | **Heat flux** (Average) kW/m$^2$ | **Flame Length** (Average) mm | **Flame Width** (Average) mm |
| ISO 11925-3 A | Syringe burner micro flame | 0,05 | * | 36 | 12 | 5 |
| ISO 11925-3 B | Small pre-mixed flame | 0,05 | * | 39 | 20 | 5 |
| ISO 11925-3 C | Tube burner short flame | 0,08 | 0,08 | 40 | 35 | 11 |
| ISO 11925-3 D | Tube burner long flame | 0,28 | 0,21 | 36 | 120 | 12 |
| ISO 11925-3 E | Manifold burner | 3,4 | 3,1 | 45 | 240 | 170 |
| ISO 11925-3 F | Manifold burner simulated chip pan | 16,6 | 14-20 | 47 | 780 | 170 |
| ISO 11925-3 G | Plumbers torch pre-mixed flame | 0,5 | 0,3 | 100 | 120 | 14 |
| ISO 11925-3 H | Roofers torch pre-mixed flame | 8,5 | 13-14 | 140 | 230 | 30 |
| ISO 9705 | Sand box burner | 100 | 100 | 40* | 2200 | 250 |
| ISO 9705 | Sand box burner | 300 | 300 | 60* | >3000 | 250 |
| Alternative ISO 9705 | Sand box burner | 40 | 40 | 35* | 1500 | 450 |
| Alternative ISO 9705 | Sand box burner | 167 | 167 | 40* | >2400 | 450 |

* In the case of larger ignition sources, mapping of the heat fluxes upon the specimen is important, cf. ISO/TR 9705-2.



# 6 Models for the piloted ignition of solids

## 6.1 Introduction and general review

Ignition can be described as the initiation of a rapid exothermic reaction which then propagates and causes the material involved to undergo change [6]. The exothermic reaction of combustive oxidation is referred to as *smouldering* if it is situated within the subsurface layers of the solid, *glowing* if at the solid-gas interface, and *flaming* if in the gas phase. In ignition tests a material is heated so as to generate pyrolysis gases which subsequently ignite, and two common types of ignition may be distinguished, namely *piloted*, where flaming is brought about by a spark or independent flame, and *spontaneous* (or *autoignition*), where flaming develops spontaneously. A full description of piloted ignition studies and the results is given also in ISO/TR 11696-1.

Kanury, in his comprehensive review of the flaming ignition of solid fuels [7], states that time to ignition in a given situation is broadly influenced by three factors: a) the degradative thermal response of the solid to yield the combustible gases; b) the mixing of these gases with the oxidant gas; and c) the increase of the rate of the combustion reaction to a sufficiently high level to be measurable and self-supporting. It should be noted that in certain situations, time to ignition may be so short that it is immeasurable.

The following common assumptions are often made in theoretical treatments of ignition. The initial temperature of the solid is uniform and equal to that of the ambient air. The solid surface is grey and diffuse with radiosity (i.e. the heat flux arriving at or leaving the surface due to radiation is uniform). The imposed irradiance is uniform over the exposed surface and remains constant. Variations in the transient gas boundary layer are usually restricted to two spatial dimensions (parallel and normal to the exposed surface). The transient heat conduction to the solid is usually one dimensional (normal to the exposed surface). The solid absorbs radiation only at the surface. The thermal properties of the solid and the char (if there is one) are independent of temperature. The pyrolysis kinetics are usually described by a single step Arrhenius rate law with a reaction order of 1. Clearly some of these assumptions grossly oversimplify the problem. For example, the thermal properties will not be constant over the relevant temperature range, and there is evidence that both the pyrolysis gases and products of combustion absorb significant amounts of radiation [8]. Despite these problems some correlations have been achieved between theoretical predictions and experiment, but it is recognized that several aspects of ignition are currently poorly understood and require further investigation [9].

Various attempts based on experimental evidence and intuition have been made to formulate criteria for ignition, e.g. a critical surface temperature [10, 11], and a critical pyrolyzate mass flux flow rate [12].

Mikkola and Wichman [13] use a linear heat diffusion equation to model heat transfer through a sample of material that is heated externally. A form of constant re-radiative loss from the sample surface is incorporated, as is Newtonian cooling. Calculated results are compared with some experimental data for wood and thermoplastics. Theoretical results imply that for thermally thin samples time to ignition decreases linearly as a function of $1/q$, where $q$ is the incident heat flux. For thermally thick samples results imply that time to ignition decreases linearly as a function of $1/q^2$. By plotting the appropriate function of the ignition time against the heat flux it is easy to determine two important parameters, namely the critical heat flux, $q_c$, which is an estimate of the minimum heat flux required for ignition to occur, and the thermal inertia ($kDc$) of the solid which is the product of the thermal conductivity $k$, the specific heat $c$ and the density of the material $D$.

Abu-Zaid [14] has made a thorough integral analysis of the thermally thick case with correct boundary conditions for re-radiation from the sample surface, and the resulting formula for the time to ignition is equivalent to that determined by Mikkola and Wichman to within a constant multiplicative factor.

Janssens has written a comprehensive review of the piloted ignition of wood [15]. The author states that simple thermal models used in conjunction with a critical surface temperature have been the most successful when compared with experiment.

In the first comprehensive study of the piloted ignition of wood Lawson and Simms used a model in which thermal properties were assumed to be constant, heat losses from the surface were linearized, a critical surface temperature was taken as the criterion for ignition, and the samples were treated as semi-infinite solids [16]. This model has the following solution:

$$T_{ig} = T_4 + (q/h)\, F(\tau_{ig}) \qquad (1)$$

where

$T_{ig}$ = the surface temperature at ignition (critical surface temperature)

$T_4$ = the ambient temperature

$q$ = the incident heat flux

$h$ = an average heat transfer coefficient

$F(J_{ig})$ = $[1 - \exp(J_{ig})\mathrm{erfc}(\%J_{ig})]$

$\tau_{ig}$ = the ratio of the ignition time to the time interval $k\rho c/\tau^2$

erfc = the complementary error function

This equation is not in a form suitable for the correlation of experimental data because the complementary error function is an integral that has to be calculated numerically. However, Janssens has carried out a non-linear least-squares fit of a simple power law function to $F(\tau_{ig})$ and found that to a good approximation $(1/t_{ig})^{0,55}$ varies linearly with $q$ [15]. The equation he obtained is

$$q = q_c [\, 1 + 0{,}73\, (k\rho c/h_{ig}^2 t_{ig})^{0{,}547}\, ] \qquad (2)$$

A value for the critical heat flux can be obtained as the intercept with the $x$ axis of a straight line fit through the data in a graph of $(1/t_{ig})^{0,55}$ versus $q$. The critical surface temperature, $T_{ig,}$ can then be calculated and a total heat transfer coefficient, $h_{ig}$, can be obtained. Once $h_{ig}$ has been calculated a value for $k\rho c$ can be found from the slope of the graph.

## 6.2 Power laws and the critical irradiance for ignition

Ignition time, $t_{ig}$, falls as the external heat flux, $q$, rises. Plots of $t_{ig}$ versus $q$ have a characteristic shape with $t_{ig}$ falling to low values at high heat fluxes, but tending towards infinity at low heat fluxes. Many attempts have been made to correlate ignition times with incident heat flux and they generally take the form of a power law,

$$(t_{ig})^{-n} = aq + b \qquad [a \text{ and } b \text{ are constants}] \qquad (3)$$

In other words a plot of $(t_{ig})^{-n}$ versus $q$ should give a straight line.

However, as discussed above in 6.1, different workers have suggested different values for $n$. The simplest approach is to assume, empirically, that $n$ = 1. A more sophisticated study [16] predicts that $n$ = 1/2 for thermally thick samples, whereas $n$ = 1 for thermally thin materials. Janssens, from his work on various timbers, also calculated that $n$ = 0,547 for thermally thick samples [17].

Equation 3 can be rewritten in the alternative form

$$(t_{ig})^{-n} = a(q - q_c) \qquad \text{where } q_c = -b/a \qquad (4)$$

$q_c$ is the critical irradiance for ignition or 'critical heat flux'. When $q = q_c$, $(t_{ig})^{-n}$ will be zero and $t_{ig}$ will be infinitely large. $q_c$ can be thought of as the maximum heat flux which will never cause the sample to ignite. To find an estimated value for $q_c$, $(t_{ig})^{-n}$ is plotted against $q$ and the best-fit straight line is extrapolated to $(t_{ig})^{-n} = 0$. However, care should be taken to know whether the specimen is thermally thin, thick or intermediate in order to determine the correct value for $n$ and to use this in the extrapolation. Whiteley [18] considers the errors that can be made in calculating $q_c$ and warns against using $q_c$ in the fire hazard rating of a material. He suggests that in assessing fire hazard it would be better to select a given minimum ignition time, based on the end-use of the material, and determine by interpolation, instead of extrapolation, the heat flux required to give that ignition time.

## 6.3 Thermal thickness and substrate effects

The characteristic thermal conduction length ($\Delta$) is defined as

$$\Delta = \sqrt{(\alpha\, t_{ig})}$$

$$= \sqrt{[(k t_{ig})/(\rho c)]}$$

where $\alpha$ is thermal diffusivity, $t_{ig}$ is ignition time, $k$ is thermal conductivity, $\rho$ is density and $c$ is specific heat. In the case of thermally thin samples the characteristic thermal conduction length is much greater than the sample thickness $L_o$. In practice this usually means sample thicknesses of the order of 1 mm.

Thin combustibles on insulating substrates where there is no heat conduction away from the surface, can ignite very rapidly because of the low total heat input needed to warm up the material to ignition temperature. Therefore, the substrate plays a major role in the fire behaviour of the surface product, and as a general rule, the thinner the thermal thickness of the material then the greater the effect of the substrate on the time to ignitions ($t_{ig}$).

For thermally thick materials the sample thickness is much greater than the characteristic thermal conduction length

and therefore any substrate has no effect on fire behaviour. This means that the practical specimen thickness must be in the order of centimetres.

There are no substrate effects for ignition results if the specimen is thermally thick for the time exposure.

It is very important to note that to know the physical thickness of a specimen is not enough to be able to know the thermal thickness. Heat flux has to be known, because it determines the ignition time, which determines the characteristic thermal conduction length. For composites the situation can be very complex. In case of "homogeneous" mixtures average values for the thermal properties can be used and if there are distinct layers, their thickness and thermal values have to be known separately. One simple example of a kind of composite is a physically thick particle board. Because of the higher density of the surface when compared to the core, particle board can have nearly thermally thin behaviour in ignition tests.

## 6.4 Variables affecting ignitability

The key variables affecting ignitability are:

| | |
|---|---|
| $k\rho c$ | thermal inertia |
| $T_i$ | surface temperature at ignition |
| $q$ | irradiance |
| $q_c$ | critical irradiance for ignition |
| $h_c$ | convection coefficient |
| $L_o$ | specimen thickness |

Many materials can absorb significant amounts of water in normal room conditions. For instance wood based products normally contain about 10 % water. The effect of moisture content for time to ignition has to be known to be able to make accurate calculations. For instance, parameters $D$, $c$ and $k$ are moisture dependent.

## 6.5 Comparisons of experimental methods

### 6.5.1 Radiative sources

Test results of the ISO Ignitability test and the Cone Calorimeter have been compared in detail recently [19]. In the latter study possible errors because of differences in heat flux levels, conditioning, etc. have been minimized to give the real differences between the two methods. The main result was that the empirically derived relation between the results of time to ignition in Cone Calorimeter ($t_{i,Cone}$) and in ISO Ignitability test 5657 ($t_{i,IG}$) can be drawn as follows

$$(t_{i,Cone}/t_{i,IG})^{-n} \approx 0{,}86 \qquad (6)$$

where $n$ is 1, 2/3 or 1/2 for thermally thin, intermediate or thick cases, respectively.

### 6.5.2 Flame sources

Extensive work within the UK on a wide range of real and standardized ignition sources during the development of ISO 11925-3 has resulted in greater understanding of the effects of different flame sources on a wide range of materials [21]. The conclusions which can be drawn from this work are as follows.

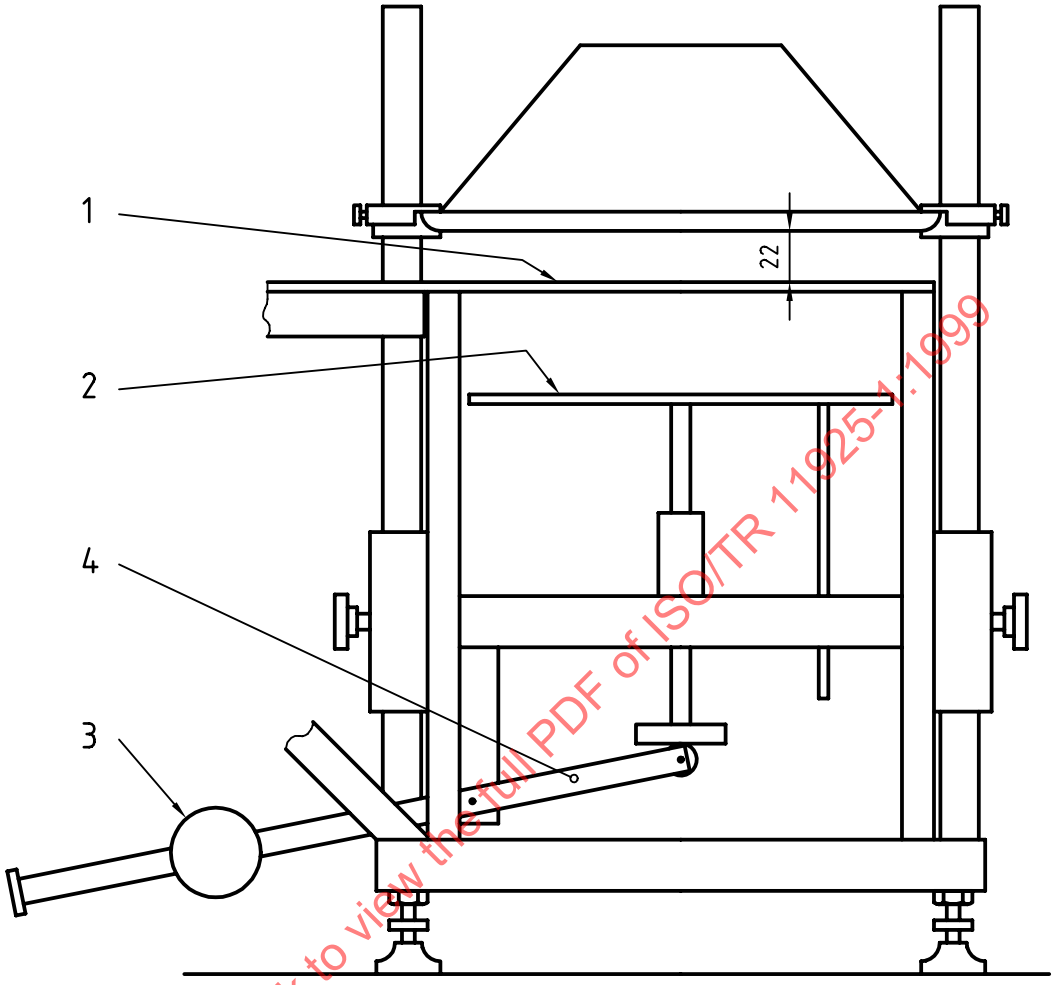
a) A longer flame application time for small flames is not necessarily more stringent than the shorter time interval. For example, material may melt or shrink away and not ignite whereas the product may ignite from a transient application. Materials may also form protective chars so that ignition is not possible (e.g. wood).

b) A more intense flame C (i.e. higher heat flux) and the same flame application time may also not be as stringent as a less intense flame. For example, the paper facing to gypsum may be ignited with Source A (ISO 11925- 3)

but not with Source H, since the paper is completely consumed during the flame contact, or the thin textile may be ignited by the same small flame, but form a heavy charred coating when a larger flame is applied.

Therefore a large or more intense flame may not always be more stringent than the smaller flame and that to apply a flame for a longer duration does not necessarily lead to a more onerous condition.

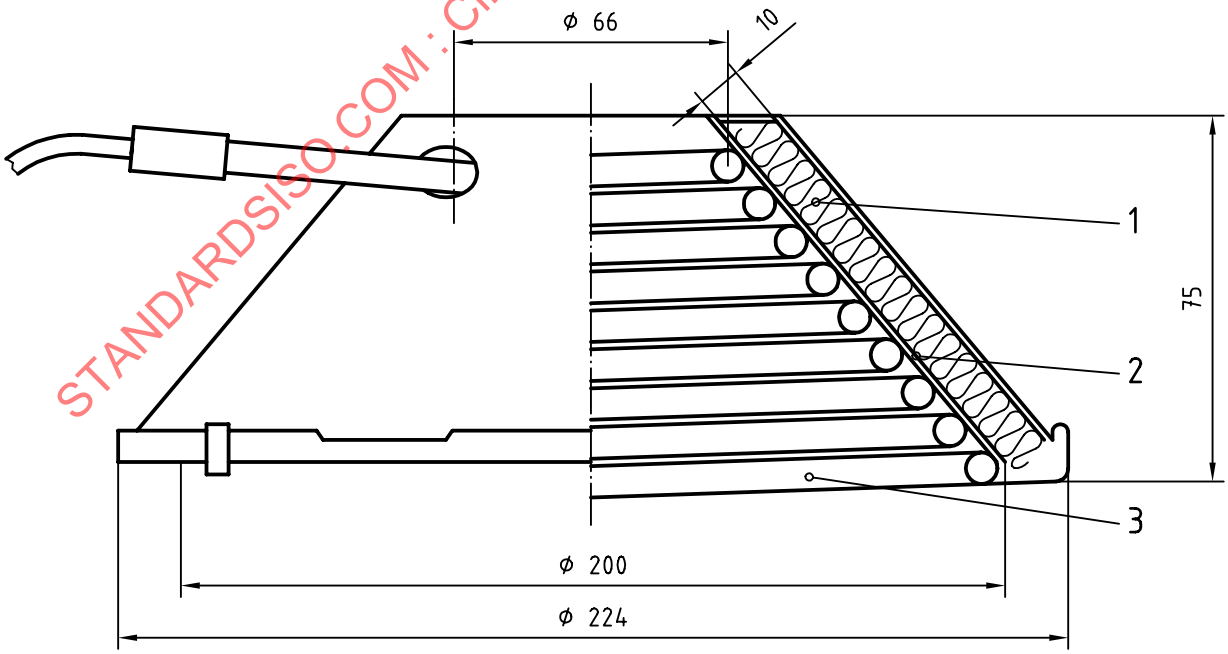
Dimensions in millimetres




**Key**

1 Masking plate
2 Pressing plate
3 Counterweight
4 Pivot arm

**Figure 1 a) — Specimen support framework and radiator cone**

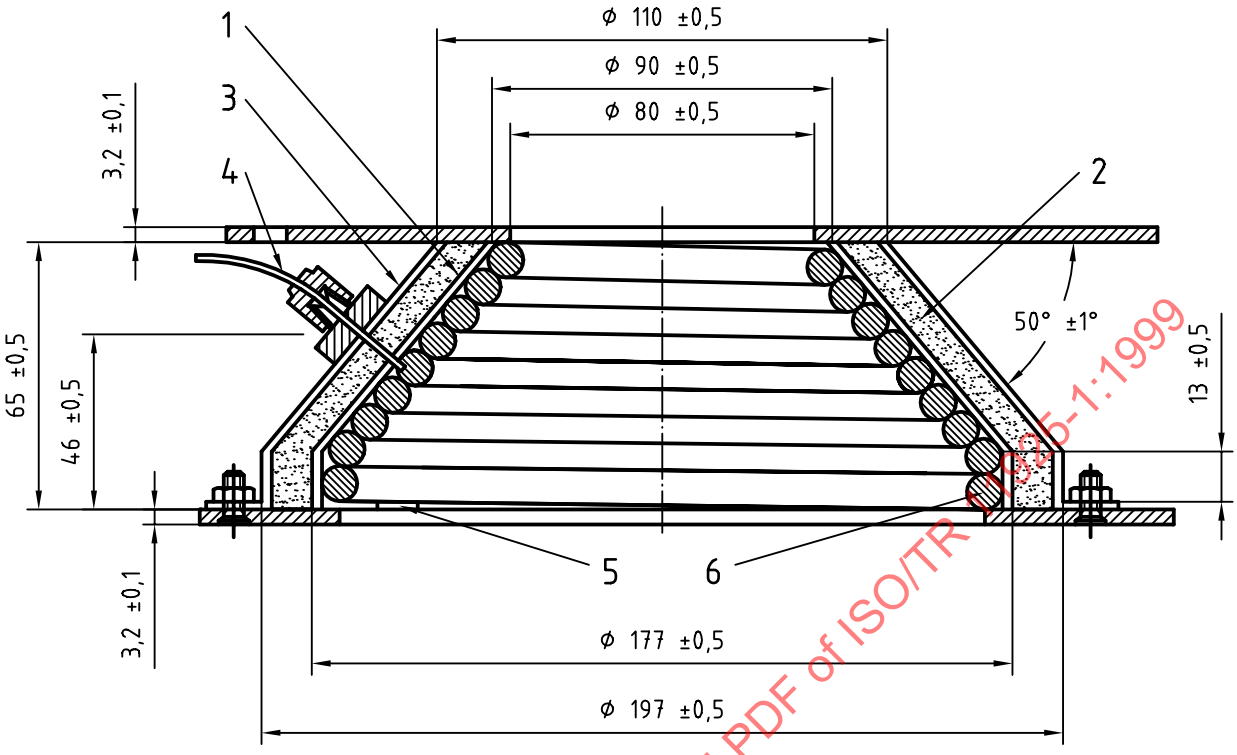



**Key**

1 Ceramic fibre insulation
2 Shade
3 Heating element

**Figure 1 b) — Radiator cone**

Dimensions in millimetres

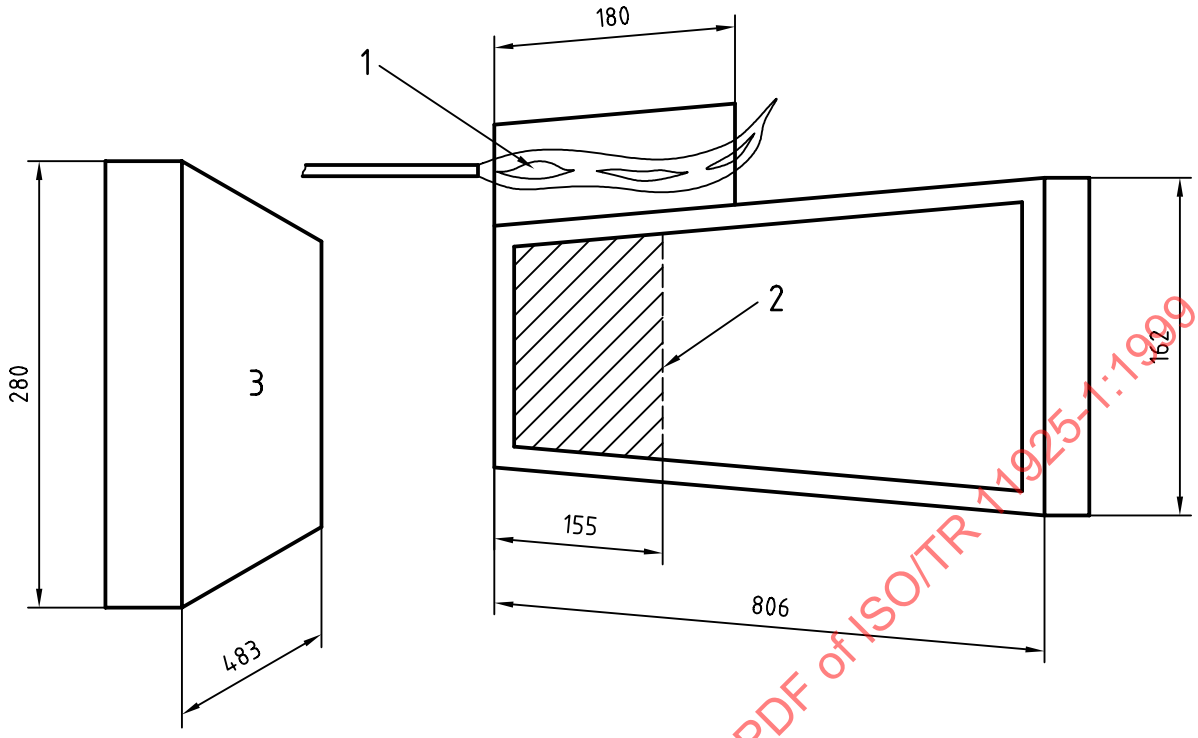



**Key**

1 Inner shell
2 Refractory fibre packing
3 Outer shell
4 Thermocouple
5 Spacer block
6 Heating element

**Figure 2 — Cone heater**

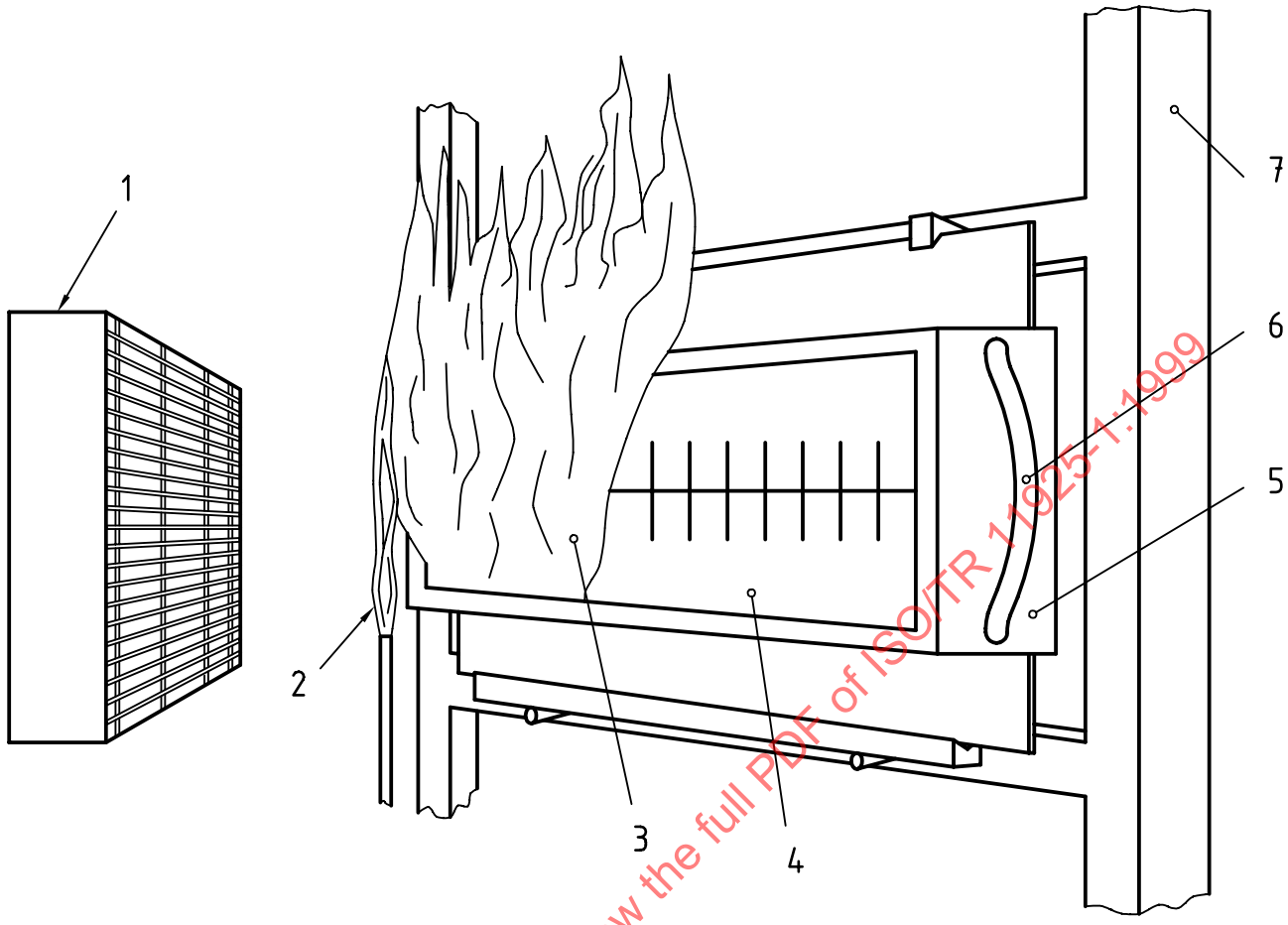
Dimensions in millimetres




**Key**

1 Acetylene-air pilot
2 Ignition specimen
3 Radiant panel

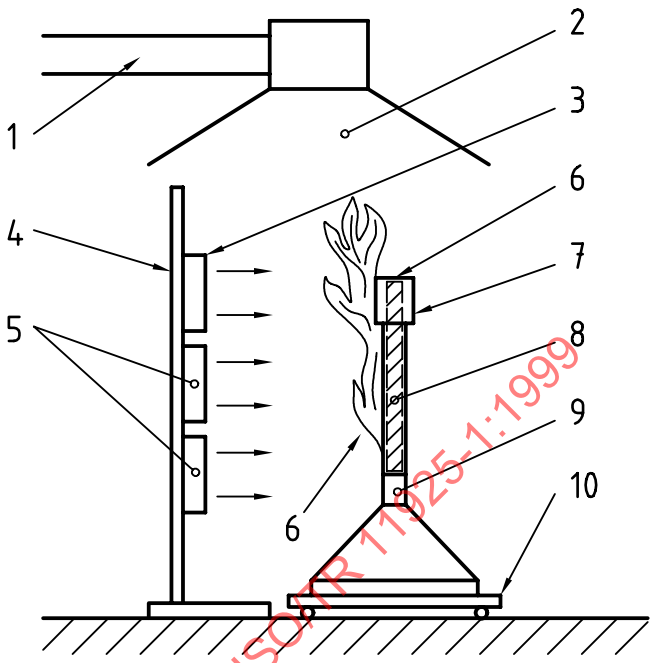
**Figure 3 — Schematic of apparatus with ignition specimen**




**Key**

1 Radiant panel inclined at 15° to specimen
2 Pilot flame
3 Flame front
4 Specimen
5 Specimen holder
6 Handle
7 Framework supporting specimen holder

**Figure 4 — Apparatus specified in ISO 5458-2**

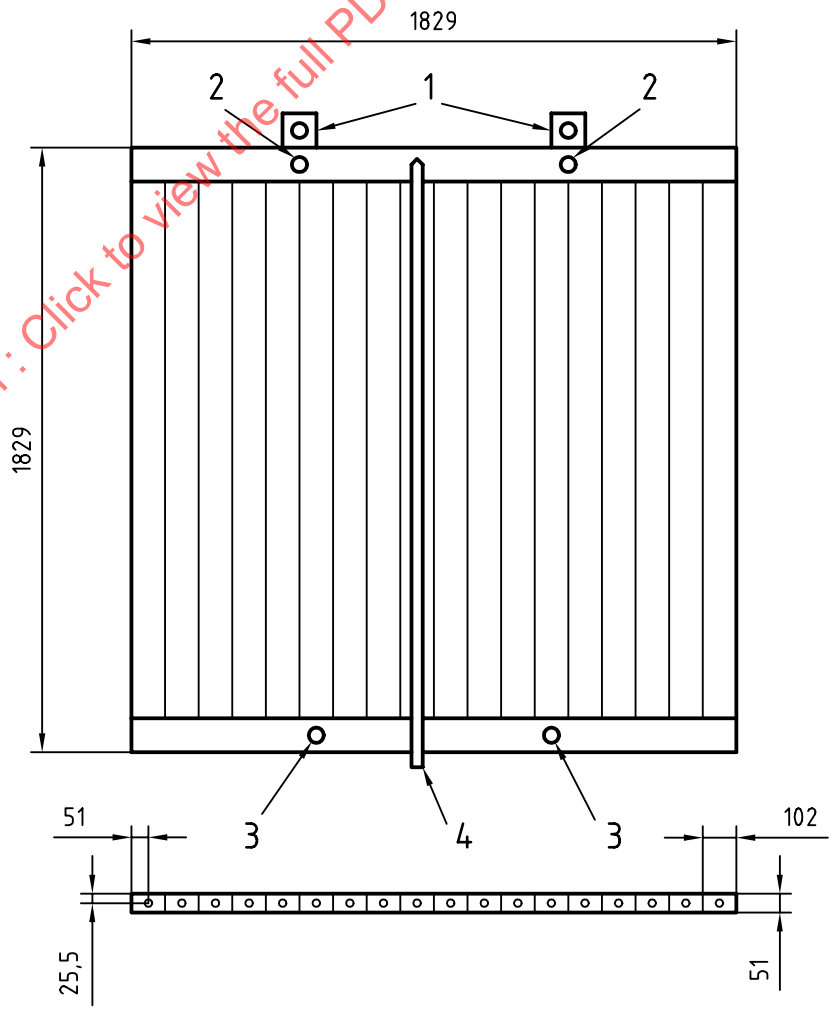



**Key**

1 Gas sampling port
2 Collection hood
3 Radiant panel
4 Water cooled supporting frame
5 Radiant heat units
6 Wire igniter
7 Top cap of the sample holder
8 Sample
9 Sample holder
10 Trolley

**Figure 5 a) — Intermediate-scale calorimeter**

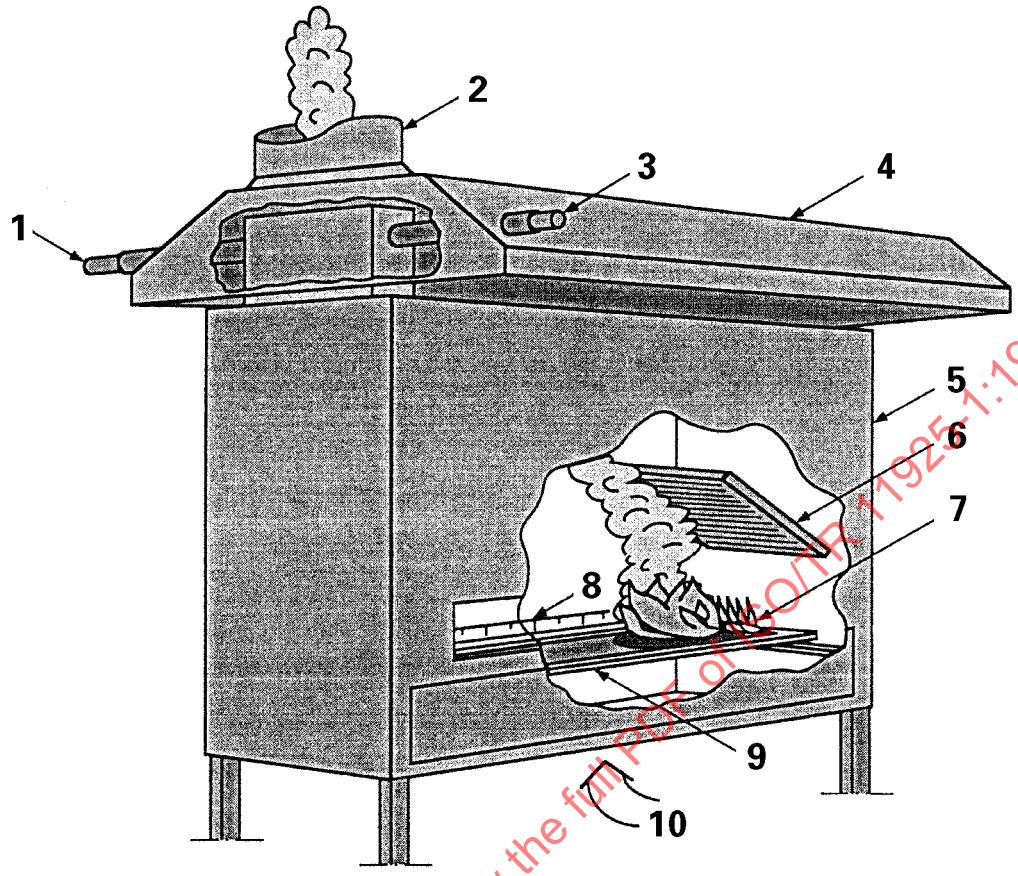
Dimensions in millimetres




**Key**

1 Support trolley attachment points
2 Water outlet
3 Water inlet
4 Emergency vent line

**Figure 5 b) — Heat shield**

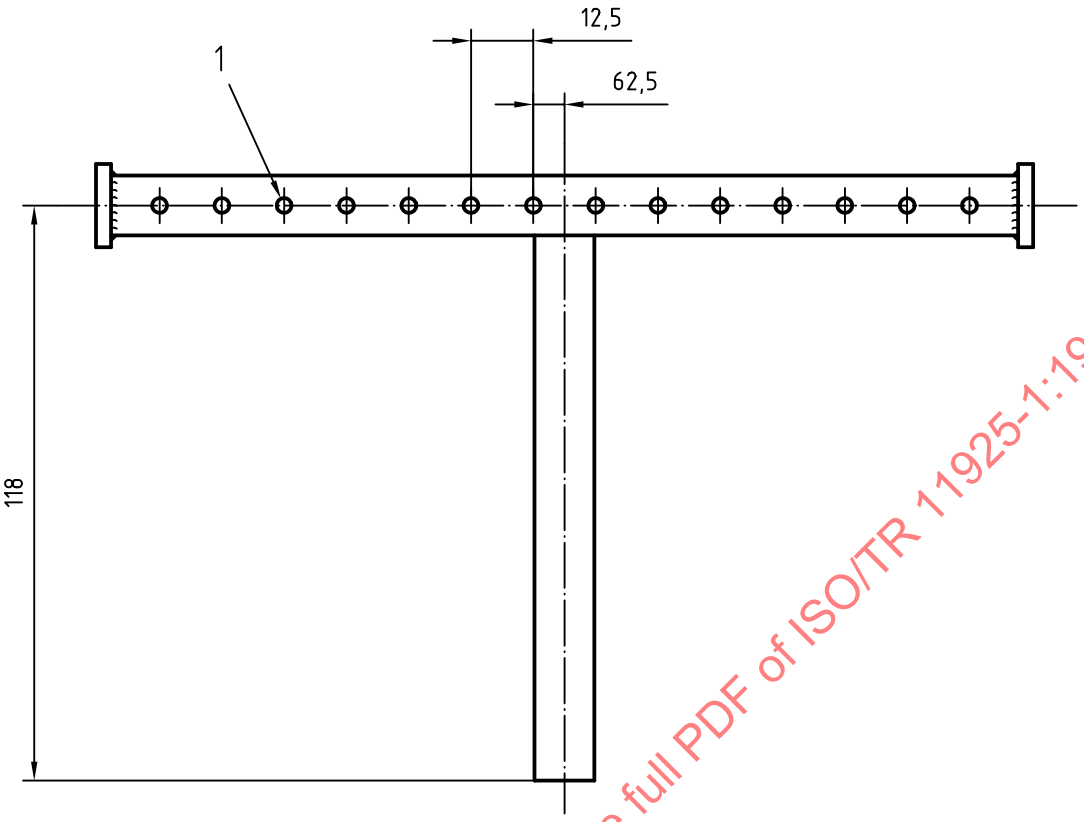



**Key**

1 Illumination unit
2 Exhaust duct
3 Light receiver
4 Exhaust hood
5 Test chamber
6 Gas fired radiant panel
7 Pilot flames from line burner
8 Scale
9 Specimen holder with specimen
10 Air inlet all around specimen at bottom of chamber

**Figure 6 — Radiant panel apparatus (ISO 9239)**

Dimensions in millimetres




**Key**

1 14 off holes ∅ 1,5 cf. 12,5 pitch

**Figure 7 — Burner for ignition sources E and F (ISO 11925-3)**