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Fire tests on building materials and structures —

Part 32: Guide to full scale fire tests within buildings

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Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Fire Standards Policy Committee (FSM/-) to Technical Committee FSM/1, upon which the following bodies were represented:

Association of British Roofing Felt Manufacturers
Association of Building Component Manufacturers Ltd.
Association of Structural Fire Protection Contractors and Manufacturers
British Cement Association
British Fire Services' Association
British Floor Covering Manufacturers' Association
British Plastics Federation
British Railways Board
British Rigid Urethane Foam Manufacturers' Association
British Wood Preserving Association
Chemical Industries Association
Chief and Assistant Chief Fire Officers' Association
Concrete Society
Department of Education and Science
Department of the Environment (Building Research Establishment)
Department of the Environment (Construction Industries Directorate)
Department of the Environment (Property Services Agency)
Department of the Environment for Northern Ireland
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Electricity Supply Industry in England and Wales
Engineering Equipment and Materials User's Association
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RAPRA Technology Ltd.
Royal Institute of British Architects
Steel Construction Institute
Timber Research and Development Association
United Kingdom Atomic Energy Authority
Warrington Fire Research Centre
Wood Wool Slab Manufacturers' Association
Yarsley Technical Centre Ltd.

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

Autoclaved Aerated Concrete Products Association
London Scientific Services
National GRP Construction Federation
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Queen Mary College Industrial Research
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Contents

Foreword

This Part of BS 476 has been prepared under the direction of the Fire Standards Policy Committee.

The guide does not conflict with the concept or recommendations of the ISO/TC 92, Fire tests on building materials and structures, proposal DP 9705 "Room fire test in full scale for surface products" which specifies one configuration of test rig and one degree of ventilation. This proposal is being developed to standardize a test method for the fire performance of surface products under closely specified conditions.

This guide is designed to enable a quantitative assessment to be made of the fire behaviour of a given specimen or a total interacting system, based on sound experimental practice and scientific principles. It will help to eliminate the risk of providing an incorrect assessment of a product such as may inadvertently occur if data from tests based on a limited range of experimental variables are extrapolated to other situations which are not directly comparable.

The complete programme for any test series of full scale enclosed fire experiments usually involves many different considerations and possible simulations. This guide reflects the current state of knowledge and suggests a choice of geometry, ignition sources, ventilation and similar aspects of the experiment, not all of which will be appropriate to every test situation.

Because of the developments in measuring techniques, this Part of BS 476 has been couched in terms of advisory rather than mandatory statements in order to allow the use of up-to-date techniques as they become available.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 14, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

1 Scope

This Part of BS 476 provides comprehensive recommendations on the conduct of full scale experiments simulating fires in buildings. Such tests, of varying scale and configuration, can be used to evaluate the behaviour of building components, assemblies or constructions and/or contents under actual fire conditions. The advice on experimental design and instrumentation and the analysis and reporting of results provides a basis for a consumer/contractor agreement for the execution of *ad hoc* work.

The guide may be used to establish, as far as is reasonably possible, laboratory conditions that represent a specific set of fire conditions, with an emphasis on examination of the pre-flashover behaviour and contribution to fire growth of the product(s) under consideration.

The choice of ignition source and test construction is based on the objective of the fire experiment which may be:

a) a comparison of the fire performance of different materials;

b) a comparison of theory and experiment;

c) a simulation experiment;

d) a measurement of the fire behaviour of composites, assemblies and finished products;

e) an investigation of the interaction of components within the system;

f) an authentication of fire properties measured in small scale tests.

2 Definitions

For the purposes of this Part of BS 476, the definitions given in BS 4422 apply, together with the following.

2.1
closed test arrangement

a form of compartment, capable of imposing a restriction on ventilation at some stage during a fire

2.2
open test arrangement

a form of compartment which enables unrestricted ventilation to the fire throughout the duration of the test

2.3
associated construction

a form of construction that may be required for the testing of some elements of construction and to which the test specimen is connected, e.g. the wall into which a glazed element would be fitted

2.4
test construction

a complete assembly of a specimen and any associated construction

2.5
pilot ignition

ignition by a small flame or spark of the flammable mixture of air and decomposition volatiles evolved from a heated combustible material that may accumulate above its surface

2.6
spontaneous ignition

ignition of the flammable mixture of air and decomposition volatiles evolved from the heated material that may accumulate above its surface without provision of additional energy from spark or flame once the flammable mixture attains its spontaneous ignition temperature

2.7
critical exposure

the minimum irradiance at which ignition (pilot or spontaneous as specified) can be effected, regardless of duration

3 General

If only one test is envisaged, it is preferable to carry out tests in the most severe conditions likely to be encountered including position, orientation and size of ignition source. For example, for wall lining materials the interrelationship between walls, ceilings and ignition source needs careful consideration. Positioning an ignition source in the corner of a test arrangement is recommended if it is the most severe condition. In such a case, additional side wall tests, with the ignition source placed against a plain wall arrangement would not be required, but if it is suspected that such an arrangement would significantly affect behaviour, then such tests would be necessary.

It is thus essential to carry out tests on walls and ceilings in the most stringent arrangement foreseeable. Because of difficulty which might arise from variable weather conditions, it is recommended that full scale tests be carried out within an adequately dimensioned, roofed enclosure.

4 Design and configuration

4.1 General

Configuration of specimens and ignition sources is of importance in a large scale fire test; compartment geometry and ventilation have major effects on test results.

In general the test should be carried out full scale. If this is impracticable the scale should be as large as possible and particular care is needed with interpretation of results. Physical and mechanical fixings and jointing elements which are likely to be used in practice should be incorporated in the specimen in full scale in order to establish the effect of such products under fire conditions.

The minimum height of the test rig should be normal storey height (2.3 m) but it may be necessary to exceed this dimension. The ratio between the height and lateral dimensions of the test rig should be realistic. Normally there should be no scaling of thickness although if this is necessary the minimum thickness of the test rig should be such that there is no change in the thermal effects on fixings nor significant differences in heat loss to the surroundings during the early stages of a test. There should be no scaling of surface irregularities.

With regard to ignition sources there should be no scaling in terms of impingement area, thermal severity, or application time, although with experience, it may be possible to introduce time limits.

It is important to avoid limiting ventilation too severely. Vents should be either to the full height of the test rig, or to door height, whichever is preferred. The latter arrangement will cause a concentration of hot gases in the upper part of the test room. The size of vent may prevent or delay flashover. In situations where it is necessary to use a closed test arrangement, vent area should be representative of full scale so that results can be indicative of performance in practice. Such tests require additional safety measures due to explosibility problems, such as careful monitoring of temperatures and remote venting and exhaust extraction after the fire is considered to be extinguished (see **4.4.2**).

The choice of configuration of the test facility depends on the above considerations and on the required fire scenario. The alternative configurations given in Appendix A provide a sufficiently wide range to take account of these points.

4.2 Size and shape of compartment

The compartment size, shape and openings should be chosen to simulate the nature or type of compartment in which the subject material, product, or system is expected to be used in actual service. If there is a range of sizes, then account should be taken of the fact that for a given ignition exposure, the smaller compartment sizes will usually provide the most severe fire development conditions. Preferably the compartment should be designed to be symmetrical and as simple as possible for ease of analysis. The test construction could be a wall system or a lining applied to an appropriate realistic support but it has to be noted that the results of the test will only apply to that particular combination and care would be needed with the application of those results to systems with variants of that tested. The floor of the test rig should have thermal properties approximately equal to those which will be encountered in use. The roof/ceiling of the test rig should be flat, unless a sloping roof/ceiling is being investigated. If the actual roof/ceiling is not being subjected to test, the roof/ceiling used in the test should have thermal properties approximately equal to those which will be encountered in use.

In a test for linings with unrestricted ventilation the horizontal dimensions of the specimen may be scaled down and are of less importance than the vertical dimensions, although the horizontal dimensions should be sufficient to contain the ignition source and obtain information on fire spread, including spread across junctions. A full height rig with a 1 : 1 ratio of height to horizontal length on both sides of the corner would usually be the minimum required.

The arbitrary decisions made when designing an enclosed test will influence the behaviour in the test and therefore the ranking order of the material performance. It is desirable that flexibility of test configuration is maintained but ISO is developing a test with precise requirements for dimensions and if such a closed test is required on a standard basis then use should be made of the ISO test (ISO/DP 9705).

4.3 Thermal and radiative properties of associated construction

The thermal conductivity, density and heat capacity of the wall lining will affect the rate of fire growth within the test structure. The test structure therefore should be representative of those materials with which the structure will be used in practice and should not influence the fire behaviour of the material under test in an unrealistic way.

During the course of a compartment fire experiment disintegration or cracking of the materials lining the compartment may affect the behaviour of the fire.

In a confined fire test, the vertical pressure gradient developed in the presence of the fire will cause smoke and hot gases to leak to the outside, and cool air to be drawn into the compartment through the cracks in the compartment walls or specimens. The effect of the leakage of hot gases or air will result in lower gas temperatures and reduced smoke density than would occur without leakage. This effect often causes pulsations in burning rate and temperatures.

4.4 Ventilation

4.4.1 In an open fire test, characterized by an uncontrolled and unrestricted degree of ventilation, the structure should not compromise the basic aim of realism and it is important to ensure an essentially draught-free test environment. In general, where the air supply is plentiful (high ventilation), the resulting fire will have a rapid growth rate and high maximum temperatures with a swift transition from the growth to the decay stage. The controlling influence on this type of fire will be the amount of fuel (essentially surface area) available.

4.4.2 With a restricted degree of ventilation the growth of the fire will be controlled by the available air in which the fuel can burn. The difficulties encountered with a ventilation controlled fire will vary with the degree of control and the stage of the fire.

With all polymeric materials the rate of flame propagation is influenced by the concentration of oxygen in the gas phase near the surface of the material under consideration. For this reason, in the early stages of a fire, the rate of growth of the fire initiated within a compartment is controlled by the fuel bed characteristics because of the availability of sufficient air. However, when the fire grows larger, the rate of air supply to the compartment may become the limiting factor. If the air supply becomes the limiting factor, the fire growth decreases, until a constant burning rate is obtained dependent upon the supply of air. The fire duration will be longer than for an equivalent well ventilated fire.

The degree of ventilation will affect smoke production, heat release, nature and concentrations of toxic gases etc. and therefore the choice of ventilation conditions is of vital importance and should be as close to the end use situation as possible to enable realistic product assessment (see also **4.1**). The influence of any extraction system should also be taken into account.

4.4.3 The location of the ignition source has a significant influence on the air inflow rate, the upper gas temperature, and the oxygen concentration profiles within the compartment and should be fixed. If it is varied, the results may be influenced and it may be preferable to standardize this arbitrarily (see also **6.7**).

4.5 Instrumentation

Detailed information is given in clause **7** on the type of instrumentation to be used in monitoring the various parameters of a fire. Its installation within the test enclosure, however, should not affect the configuration of the test, the ventilation to the fire, the air-flow pattern or the burning behaviour of the material being assessed.

In particular, care should be taken when inserting thermocouples and thermal transducers into materials so that fire cannot spread to the back of the specimen or into any cavities which may exist. Damage to the material being tested whilst installing instrumentation can adversely affect that material's fire performance. Conversely, by supporting the materials, the fire performance can be apparently improved.

The sensitivity and response time of instruments should also be considered when selecting which type to install. Fine thermocouples (e.g. 1 mm o.d.) will be more accurate and respond within a shorter timescale than larger diameter types; this is particularly important when monitoring flame spread and heat output. Instruments should also be calibrated at regular intervals. For radiometers, this can be achieved by using the procedure in BS 6809.

5 Specimens

In the range of tests covered by this guide specimens may vary from a room lining material applied to a standard support structure to a full room/corridor as well as complete free standing assemblies.

The specimen should always be tested in the orientation in which it will be used. Fixing methods, joints and surface coatings should reflect typical practice.

Specimens may need to be incorporated into the test facility construction (see **3.3**). The choice of the associated construction may be significant to the performance of the test specimen. This relationship, where the contribution of the wall or ceiling cover may differ, is also influenced by the size of the ignition source and its orientation and position.

6 Ignition sources

6.1 Choice

The choice of an ignition source in a compartment fire experiment is significant. Either a real ignition source or a simulation with equivalent characteristics could be used. This guide presents a list of the important considerations on the choice. It is important to identify what real ignition source is being simulated in terms of convection, heat duration, irradiance, etc.

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

The size of the ignition source should not be excessive in relation to the dimensions, shape and ventilation of the test construction. The ignition source will also have some effect on the ventilation conditions prevalent in the fire enclosure.

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.

6.2 Characterization

When an attempt is made to simulate a real ignition source, it is essential to realise that burning characteristics may be affected by environmental conditions and therefore recognise 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 content;

c) rate of fuel release;

d) rate of heat release;

e) height of flame for given location;

f) convective and radiative heat; and

g) time of burning.

6.3 Type and size

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

6.4 Gas burner flames

Diffusion flames are more representative of actual fires and premixed flames should only be used for specific representations.

6.5 Liquid fuel pool fires

The rate of production of volatiles from liquid pool fires is readily determined from their rate of mass loss or the flow rate necessary to maintain a constant depth in the pool and they have an interaction with the fire environment which can be quantified by their change in heat production rate. Their radiation characteristics can be controlled by the choice of fuel.

6.6 Wood crib fires

The variability of crib sources can be minimized by controlling the moisture content, species and density of the wood. Their use as a simulation of burning contents of buildings has proved very successful. However, it should be noted that the source does not provide a constant ratio of heat release to mass loss throughout the fire test and the rate may be significantly lower than that for some plastics based products.

6.7 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;

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

c) heaters, where glowing wires or bars emit high radiant energy.

Electrical ignition sources for use in room tests can be simulated using sources from smaller-scale fire tests (e.g. glow-wires at temperatures up to 960 °C and radiant cones at irradiances up to 70 kW/m^2).

6.8 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.

7 Monitoring

7.1 General

Monitoring is the process of identifying and recording the performance of the test specimen during and after the test and involves both visual and instrumental techniques. The factors which need to be monitored will vary from test to test depending on the objectives of the test but would normally include ignition, flame spread, heat output, smoke and toxic gas production, mass loss and mechanical behaviour.

Visual observations should be recorded of all important events during the test such as time of ignition, dimensional extent of flame spread, nature and rate of smoke production, mechanical behaviour of the test specimen (such as partial collapse or loss of integrity of all or part of the specimen, melting or other unusual behaviour). It is important that a visual record is made of the test specimen at the end of the test. A visual record should also be made of the test. This should preferably be continuous, such as film or video (see **9.1**).

Instrumental measurements are normally used to monitor the performance of the test specimen for flame spread, temperature, irradiance, mass loss, smoke and toxic gas production. A wide range of different techniques are available and discussed under each heading. Instrumental techniques should preferably be recording types to give a permanent record.

In addition, the ambient conditions should be recorded at the start of the test.

7.2 Ignitability and critical exposure

7.2.1 *General.* When assessing the ignitability and critical exposure of products, it is necessary to consider the irradiance at its surface up to the time of ignition and whether ignition is spontaneous or pilot. The progress of the flame front and time to flashover within the test enclosure are also important.

7.2.2 *Direct measurement.* This is only feasible in cases where the measuring device may be inserted into the body of the component so that the sensitive head is flush with the exposed surface.

Instruments which may be used include the following.

a) *Heat flux meter* (see also **7.4.3**). This measures combined radiative and convective heat flux density on the surface of the specimen. The necessity for water cooling often makes the positioning of the instrument and protection of the tubing the critical factors in its selection for a given purpose. The meter should be mounted so that the face of the instrument is flush with the exposed surface of the product being assessed.

b) *Radiometer.* Simple robust radiometers that may be sacrificial (e.g. copper disc radiometers) may be used in fully developed fires. Alternatively, water-cooled instruments, with a given field of view may be positioned flush with the face of the product so that a noticeable response is given to a localized flame on the surface of the product.

c) *Thermocouples.* A crude method which relies on recording a sudden rise in gas temperature above the surface of the product and which is probably the most effective simple means of timing the onset of ignition. This method however does not provide an indication of the irradiance on the surface of the component at that time, and therefore should be used in conjunction with heat flux meters (see a) above).

d) *Video/cinematograph.* As with c), no quantification of the irradiance at ignition can be recorded but an accurate indication of the time to ignition will be provided. This method relies on the ability of the camera to detect the onset of a small flame on the surface of the specimen. This may not always be achievable and visual observation will be necessary.

7.2.3 *Indirect measurement.* The construction of a test specimen may preclude the insertion of a heat receiver into the body of the product. Provided ignition of the component is caused by the primary ignition source alone (e.g. crib, burner) then a calibration experiment using a control material carried out earlier can provide information on the exposure conditions during tests.

7.3 Flame spread

7.3.1 *General.* Three aspects of flame behaviour are considered:

a) the spread of a flame front over a product caused by progressive ignition of volatiles emitted from the heat surface;

b) flames from both the ignition source and the burning product combining into a flame plume, whose size is influenced by the thermal properties of the product being tested;

c) elongated flames travelling horizontally following the deflection by a ceiling or horizontal obstruction of a substantial body of flame.

These aspects of flame behaviour are influenced by the configuration and thermal properties of materials under test and the test enclosure. However, the recommendations which follow should be used as guidelines and, where appropriate, as minimum requirements.

7.3.2 ***Vertical surfaces***

7.3.2.1 *Vertical spread: flame plume development.* Characterization of this can be difficult because of the speed and often erratic behaviour of the flames at the tip of the plume. A visual assessment (aided by height reference points at intervals of not more than 0.5 m) should always be made and supported by photograph or video record. The top of the plume at a given time should be taken as the uppermost point of a continuous plume averaged subjectively over 3 s. Any anomalous behaviour of the plume such as detached portions of flame should be recorded.

At least four more observations of the time/height relationship of the flame plume should be recorded between ignition and the time at which the flame plume reaches the ceiling, which should also be noted.

As additional methods of recording vertical spread, thermocouples may be suspended in an array in the likely path of the flame plume or cotton trip thread connected to an event recorder.

Material properties which may influence flame spread such as blistering, intumescence, cracking and spalling should be reported.

7.3.2.2 *Vertical spread: flame spread.* Although it is difficult to distinguish the position of a vertical flame front on a surface every attempt should be made to record this phenomenon. The methods commonly used are visual observations (which can be made by looking along the surface and behind the flame plume) and recording by thermocouples fixed with their hot junctions in contact with the surface at intervals not exceeding 0.5 m.

7.3.2.3 *Horizontal spread.* It may be difficult to distinguish realistically between the lateral spread of the flame plume, spread of flame on the surface in the early stages of the test and transitory flaming. However, the lateral extent of the flame plume including flickering, transitory flaming, should be recorded.

The maximum extent of lateral spread on both sides of vertical reference lines as a function of time and the height at which this occurs should be recorded.

The centre point for the reference of lateral spread should be the line projected vertically from the mid point of the side of the ignition source in closest proximity to the test products. The distance between reference lines should not be more than 0.5 m. Records should be made of the maximum extent of spread at given times in both directions from the centre reference line to allow a meaningful plot of lateral spread against elapsed time to be made.

Trip threads may be used to supplement visual observations and video/photographic records. Similarly thermocouples may be employed installed in a lateral array at mid height between floor and ceiling.

7.3.3 *Horizontal surfaces.* The appropriate portions of concentric circles (centred on the vertical reference line) should be marked on the ceiling or floor surface to facilitate visual assessment and photographic records.

Intervals of 1 m on horizontal downward facing surfaces and 0.5 m on upward facing surfaces are usually appropriate.

The time taken for sustained flaming to reach a particular distance line at any point should be recorded together with any major irregularities of spread. Alternatively, flame spread could be recorded at specific time intervals.

7.3.4 *Hot gas layers/flames under ceilings.* Due to their buoyancy, flames and/or hot gases tend to accumulate beneath a ceiling or in the apex of a pitched roof. The depth of this layer as a function of time should be determined either visually, photographically or instrumentally using vertical arrays of thermocouples. Other observations such as flaming at the base of the hot gas layer should also be recorded. Smoke can impair visual observations and alternative methods may need to be used.

7.3.5 *Other considerations regarding flame spread monitoring.* If the test construction contains concealed cavities in which flame spread may occur, consideration should be given to the detection and measurement of such spread by the use of thermocouples.

A test construction should contain representative joints/ junctions. These can noticeably influence the course of flame spread, particularly when they occur on vertical surfaces.

The occurrence of any secondary ignition remote from the ignition source by hot gases, flaming debris etc. should be noted.

A thorough post-fire examination of the test system can be a very valuable aid to interpreting the observations made during the fire. The extent of charring, bubbling, melting, spalling or other physical reaction to the fire should always be recorded after the fire has been extinguished or has burnt out. The limits of such damage can usually be related to the passage or proximity of a flame front on the basis of preliminary checks on a material's reaction to exposure to radiation or flaming.

7.4 Heat output

7.4.1 *General.* A knowledge of the heat output from any fire experiment, whether purely a qualitative evaluation or a quantitative measurement, is one of the most important properties which should be determined. This fundamental characteristic allows the damage and spread potential of a fire to be assessed and is a necessary requirement in the computer modelling of fires.

Except with the more sophisticated methods of measuring heat output, it is normally not possible to arrive at a thermodynamic heat balance for a fire experiment, since this involves many complicated measurements. The total heat output will comprise elements of radiation, convection and conduction and depending upon the objectives of the experiment, one or a combination of these, will assume greatest importance.

There are three main parameters (temperature, irradiance and rate of heat release) which can be used to provide information on heat output.

7.4.2 *Temperature.* This basic measurement, made in most fire experiments allows relative comparisons of the heat output from similar tests to be made, or alternatively, by reference to a calibration test, can indicate the additional contributions made by the presence of the materials, components and assemblies under evaluation.

Sheathed or other appropriately insulated thermocouples are commonly used, their signal leads connected to precalibrated recording media such as chart recorders or data loggers. The thermocouples are usually positioned as follows:

a) within the fire chamber, directly over the centre of the fuel or ignition source and projecting 100 mm from the ceiling;

b) at the ventilation opening of the fire chamber, in the centre-line and 25 mm below the top;

c) within a canopy hood and duct system, in the centre of the duct and positioned where the flow can be expected to be uniform;

d) in the smoke exit stream.

Temperatures are usually recorded continuously throughout the duration of a test with monitoring commencing 1 min prior to the test.

7.4.3 *Irradiance.* The determination of the distribution of energy flux within a fire compartment is necessary in order to understand how the fire spread has occurred and also to give a good indication of the heat output of the product being tested.

A wide range of instruments can be used to measure irradiance, the two most common being the Gardon and Schmidt Boelter. Radiometers are also available which measure radiative heat only and may have a wide or narrow angle of view.

Flux meters can either be air or water-cooled, or sacrificial. It is important the instruments are frequently cleaned, blackened and recalibrated since soot deposits will reduce the sensitivity.

There are four common positions for siting heat flux meters. These are:

a) as close as possible to the specimen initially ignited;

b) close to the specimen at a position likely to become involved by radiative flame spread to adjacent materials;

c) at a position still within the fire chamber but remote from the fire (to determine flashover);

d) outside the fire chamber door and window openings (if any) to determine threat to other buildings.

7.4.4 *Rate of heat release.* The measurement of heat release will give an accurate indication of the heat output of a fire. Three methods by which heat release can be calculated are by monitoring with time, either temperature, mass loss or oxygen depletion.

Temperature profiles give only a very crude estimate of the rate of heat release and use a series of thermocouples to obtain the raw data necessary to calculate the heat release rate.

Mass loss can be a useful technique provided the items involved in the fire are of a single material and can be continuously weighed (using either a load platform or transducers). However, it has the advantage that the method can be used in any test facility.

Oxygen depletion is probably the most commonly used method since, although based on calorimetry, it is not limited by the material being burnt. Oxygen depletion techniques are limited to test facilities where the fire effluent can be channelled into instrumented ducts so that volume flow can be determined and the oxygen concentration can be measured by taking a transverse sample of the atmosphere across the direction of flow, thus avoiding problems with non-uniform flow patterns.

7.5 Smoke production

7.5.1 *General.* The rate of generation of smoke with time during a fire is important since it allows the average smoke concentration to be calculated for communicating compartments and corridors thus giving an indication of the visibility problems which may be presented to persons escaping fire. The smoke generation rate can be determined by measuring the change in optical density and the volume of smoke passing the detection system.

7.5.2 *Positioning of detectors.* Changes in the intensity of a collimated light beam are used to measure optical density. The light beams may extend from ceiling to floor, pass horizontally across rooms, doorways, corridors or duct systems or be limited to a few centimetres in length.

In choosing one or more path lengths for measurement, consideration should be given to the following factors:

a) the normal tendency of smoke to stratify, particularly in the early stages of a fire;

b) routes of spread as determined by the type of test facility used (including leakage, see **4.3**).

In a dynamic fire test, where the smoke generated can be expected to flow from the test facility either through an open doorway, a duct or a corridor, it is usually sufficient to determine smoke density using only the one system sited so that the beam traverses the fire effluents.

In a static situation, where smoke will stratify, density should be determined at multiple levels or using a single vertical beam from floor to ceiling.

7.5.3 *Measurement.* Optical density meters as described in BS 5446-1 can be used for smoke measurement. The most commonly used are quartz halogen lamps with tungsten filaments and a focussing lens assembly in conjunction with an eye response photodiode detector. The detector should be calibrated to various levels of incident radiation using neutral density filters (range ND 0.1 to 0.4).

A frequent source of error in smoke measurement is soot deposition on the windows of the detector system. This can be overcome by using a honeycomb grating or allowing a gentle flow of forced air to flow over the windows.

7.6 Air flow

7.6.1 *General.* Air flow rate is a necessary parameter to the calculation of rates of heat release, smoke and toxic gas generation.

7.6.2 *Measurement.* The usual methods of measuring air flow include the following.

a) Vane anemometer, which is usually used for cold, low velocity air inflow determination with the anemometer head sited in the open doorway or corridor of a test facility. This device is the least accurate method of determining air flow.

b) Pitot tube, which is a differential pressure gas flow measurement device capable only of giving a single point reading.

c) McCaffrey probe, which is a bidirectional impact pressure tube capable only of giving a single point reading.

d) Orifice plate, which can only be used in ducted systems. The plate has to be precalibrated, for example using a pitot tube and the heat output from a propane burner and taking traverses across the duct.

Pitot tubes, McCaffrey probes and orifice plates can be used for high velocity, high temperature outflow recordings and thus can be placed directly in the effluent gases of the fire either at the top of a doorway, corridor or in a duct as appropriate.

Two common problems which need to be considered are the effects of thermal radiation on the anemometer and sooting of the pilot tube. The use of the McCaffrey bidirectional probe or orifice plate, which are not sensitive to either of these factors, can overcome this problem.

NOTE When calculating air flow, a correction has to be made for air expansion at the elevated temperatures within the fire environment, therefore temperature measureements have to be taken in the vicinity of the flow measurement device. Also the calculation of flow has to take account of the influence of the type of flow measured i.e. turbulent or uniform.

7.7 Fire gas analysis

7.7.1 *General.* Fire gas analysis may be carried out to quantify burning behaviour or to assess life hazard from toxic combustion effluents. The chemical species found in fire gases can be considered as follows:

a) oxygen;

b) carbon monoxide and carbon dioxide;

c) inorganic species, e.g. hydrogen cyanide, hydrogen chloride, oxides of nitrogen, sulphur dioxide etc.;

d) organic volatiles, e.g. aldehydes such as acrolein.

Carbon monoxide, hydrogen chloride and hydrogen cyanide are the most abundant toxic gases (depending on fuel type), with carbon monoxide usually being the major toxic agent.

More specific, extensive advice is given in ISO/DTR 9122/2 (in preparation).

7.7.2 *Sampling.* Ideally, all gases should be sampled from the same position within a fire chamber. The positioning of the sample lines is critical; the composition of the gases extracted will vary with the flow patterns within the experimental rig (i.e. the position of fire zone and airflow to it).

Maximum concentrations can be achieved by sampling in the gas plume or layer of decomposition products either just below the ceiling (100 mm) or in an exhaust duct.

The sampling point should not be in the zone of flaming.

Additional positions for sampling in an enclosed rig would be at "nose" and "crawl" heights to give an indication of the concentration of gases likely to be inhaled by persons escaping the fire.

For room/corridor rigs, an additional sampling point, 100 mm below the ceiling at the end of the corridor, would give information on the hazard presented to persons remote from the fire.

The length of the sampling line should be kept as short as possible and the rate of extraction as rapid as possible to prevent sample loss, further reaction of the chemical species in the fire gases and deposition on the walls of the sampling line.

7.7.3 ***Permanent gases***

7.7.3.1 To prevent deposition of soot and water in the analysers used to monitor oxygen, carbon dioxide and carbon monoxide the fire gases should be cleaned and dried. Glass wool and calcium chloride are commonly used for this purpose. Concentrations of these gases are usually monitored continuously throughout the fire test.

7.7.3.2 Oxygen is commonly analysed using paramagnetic or zirconium oxide instruments. Ideally response time should be short (commonly 5 % of final reading in 30 s) and the range of the analyser at least 0 % to 21 %.

NOTE Zirconium oxide analysers can be subject to interference from unburnt organic volatiles.

7.7.3.3 Carbon dioxide can be continuously analysed using a fixed wavelength infra-red spectrophotometer. The response time should be less than 30 s and the range at least 0 % to 20 %. However depending on size of fire load lower ranges may be more applicable.

7.7.3.4 Carbon monoxide analysers are usually fixed wavelength infra-red spectrophotometers with a range of 0 % to 5 % for full scale fire testing and a response time of not more than 30 s.

7.7.4 *Inorganic species.* The concentration of hydrogen halides, hydrogen cyanide and other inorganic species can be estimated using commercially available colorimetric tubes. The gases have to be sampled through heated glasslined stainless steel tubing, the fire effluents being drawn continuously from the fire chamber. Analysis of several different species can be carried out by sampling with various colorimetric tubes from this heated line.

Analysis of hydrogen fluoride is more complex due to its high reactivity but use of PTFE-lined sampling lines does allow an approximate determination of concentrations.

An alternative sampling procedure is the use of a probe, carrying the colorimetric tube at the end, inserted into the fire gases. Although there can be procedural difficulties accuracy can be increased using this technique.

NOTE Colorimetric tubes should only be used in situations where interference from other chemical species will not affect results (consult manufacturers' literature). A knowledge of the elements present can provide a guide to possible errors, e.g. SO_2 will not be present if sulphur is absent. The accuracy of the method is limited and is affected adversely by hot gas streams above 30 °C. A more sophisticated technique, ion chromatography, is available for extremely accurate analysis.

7.7.5 *Organic volatiles.* Analysis for the presence of these gases, some of which may be toxic in trace amounts, often requires specialist techniques. Samples collected in evacuated vessels or on adsorbent solids can be used for assessment of organic volatiles by subsequent laboratory analysis using mass spectrometry, gas chromatography or a combination of these and other techniques.

Total hydrocarbon content can be assessed using equipment sensitive to flammable gases. This apparatus has been used to monitor continuously concentrations of hydrocarbons throughout a test.

7.7.6 *Special information on toxicity.* Chemical analysis alone does not give an evaluation of toxicity due to the complicated interaction of many chemical compounds with human physiology. Therefore, the use of biological models for evaluating the effects of fire effluents will still continue. Further information is available in the various parts of PD 6503 and in DD 180.

7.8 Mass loss

7.8.1 *General.* Mass loss of the product tested can give a good indication of the rate of burning and provide a crude measure of the rate of heat release of that product provided that it is a single material and not a composite.

7.8.2 *Measurement.* In its simplest form, mass loss assessment can consist of a simple measure of the mass of a product both before and after the test using a simple balance arrangement.

This type of assessment can be extended to give a continuous record of mass loss, if the balance is fitted with an analogue output, and if small scale testing only is involved.

The product is placed on the balance which is connected to a suitable recording media and mass loss monitored constantly with time. The balance has to be well protected from the heat generated in the fire.

If large scale testing is required, the continuous record of mass loss throughout the fire test can be achieved using load cells or transducers. Two, three or four load cells or transducers, linked together, are positioned beneath a noncombustible tray or board. The output from these measuring devices can be read directly from a precalibrated meter or can be fed into a logging system or potentiometric recorder. Conversion factors can be used to calculate the mass loss from the millivolt signal recorded.

8 Safety precautions

Attention is drawn to the Health and Safety at Work etc Act, 1974 and the need to ensure that tests are carried out under suitable environmental conditions to provide adequate protection to personnel against the risk of fire and inhalation of smoke and/or toxic products, especially on the occasions when an operator needs to work in the vicinity of the fire.

The following precautions should also be taken into account.

a) Adequate extinguishing equipment should be provided, suitable for the size of the fire.

b) Adequate breathing apparatus and protective clothing should be issued to all personnel in the vicinity of the fire [see also clause **8** d)].

c) Precautions should be taken to mitigate the hazard of explosion (see **4.1**).

d) Instrument cabins should be provided if possible. Instrumentation systems can be controlled from instrument cabins fitted with positive pressure fresh air feed systems. Such cabins can also provide a place of safety for observers. This provision enables operators and observers to monitor the fire without risk of exposure to toxic combustion products and without the need for individual respiratory protection.

e) Adequate extraction and effluent treatment should be available throughout the test to remove toxic combustion products. Alternatively, the test enclosure should have an adequate volume available to allow dilution of combustion products to “safe” concentrations.

f) Personnel should be clear of the experimental site before ignition.

g) Wiring should be checked to ensure electrical safety.

h) Care should be exercised when using primary ignition sources (e.g. flammable liquids and gases).

i) Personnel should not enter the test rig until the fire has extinguished and conditions are declared safe.

j) Consideration should be given to the issue of a safety memorandum in advance of the test, detailing, for example, identification of safety officer, evacuation procedures and routes.

9 Data recording

9.1 General

The recording, storage and presentation of data acquired in any fire test are important and necessary parts of any fire test procedure. Visual records together with any output from the instrumentation used in the fire test have to be obtained in a form which is both durable and usable.

9.2 Video and photographic recording

Records in the form of still and moving visual recordings are valuable for conveying information to other interested parties and for relating instrumental results to events occuring in the fire, Commonly, two systems are used to record visual information.

9.2.1 *The photographic system.* This commonly consists of a camera with an automatic motor-driven film transport, sited at an observation port in the wall of the compartment or in front of an open vent but away from the fire. If the camera cannot be operated manually an automatic unit which permits photographs to be taken remotely can be used in a remote instrument room.

9.2.2 *The video system.* One or more video cameras can be used to provide a permanent visual record of the test. Cameras can be positioned to cover all aspects of the fire test and can be coupled to monitors to enable observers to observe the test from a safe position. If it is possible to control a camera during the test, it is often advantageous to take close-up views of interesting events during the test.

The use of a digital time generator to provide a permanent indication of the elapsed time during the test on the video recording is recommended. The use of video recording enables a detailed examination of the fire test to be made at a later date including frame-by-frame measurements related to scale axes.

Because of the great contrast in light levels which arises when luminous flames develop, it is usually preferable to set the exposure control of the camera before the test is started and to leave it on this setting even though this will result in overexposure of flames. It does, however, facilitate interpretation of the development of the fire.

NOTE Photographic or video records of a test should supplement the recording of visual observations. They should not be considered as an alternative.

9.3 Data acquisition

The output from all the transducers and measuring instruments can be wired to a central display and recording area within an instrumentation compartment.

The most common method of data output is a series of potentiometric pen recorders which give a simultaneous record during the fire test of each parameter measured, thus giving direct information on the progress of the fire.

Data loggers based on microcomputer units are now used either instead of or in addition to chart recorders. Data logging instrumentation consists of a scanner which will scan across any number of input signals over a preset time interval. The scanner is connected to an analogue to digital converter which converts each signal to a form in which it can be stored on either magnetic disc or tape. The speed at which the scanner can operate and the number of input channels used will determine the sensitivity of the system to monitor fluctuations in fire behaviour.

9.4 Data replay and processing

The instrumental data stored on the disc or tape can be replayed and the data fed into the memory of a microcomputer. A variety of software is available to convert the signal recorded on the disc to temperatures, gas concentrations, smoke density, rate of heat release, heat output, irradiance etc., using previously determined conversion factors. Presentation of data can be either in graphic or in tabular form depending on requirements and the availability of hardware i.e. printers and plotters. Results can thus be provided in a form suitable for inclusion in published reports.

9.5 Special treatment of graphics data

Many of the parameters recorded during real fires display some level of transient variations. Optical obscuration information is particularly susceptible to rapid fluctuation owing to the turbulent nature of the smoke plumes measured. Graphic presentation of smoke measurements is often difficult to assess because of this transient noise.

With automatic data handling, however, it is possible to build curve smoothing characteristics into the program. These techniques usually use data point averaging.

10 Test report

The test report should include the following information.

a) *Laboratory.* The name and address of the testing laboratory.

b) *Sponsor.* The name and address of the sponsor.

c) *Test facility.* The design and construction of the fire test facility should be fully described. The ventilation available to the fire should be detailed in terms of size and position of openings.

d) *Test specimens.* Comprehensive information should be sought and reported to fully describe the item or items to be tested. Construction details, materials, masses, dimensions, preparation, positioning and fixing within the test facility should all be detailed within the report.

e) *Instrumentation.* A detailed description of all apparatus and instrumentation used to monitor the progress of the fire and the performance of the test specimen during and after the test should be reported. It is essential that the positioning of the instruments within the test facility are detailed. Calibration procedures and predetermined conversion factors which are to be used in the interpretation of raw data should be reported.

NOTE Use of a diagram to provide information as to the dimensions of the rig and the positioning of instrumentation is recommended.

f) *Data recording.* The methods by which visual observations and raw data from the instrumentation used are recorded, should be reported. Specialist techniques used to prepare and present the final data related to the test report should also be detailed.

g) *Ignition sources.* The method of ignition used in the test should be detailed together with the positioning of the source. The total fuel used and its type should be recorded together with an approximate timescale of burning. Where the ignition source is likely to provide a major contribution to the parameters measured in the early stages of the fire, full details of the proportion of this contribution should be determined and reported by prior calibration if necessary.

h) *Experimental results.* A full description of all timed events occurring during the fire should be reported together with results from each aspect of the fire which has been monitored. Results are commonly presented in a graphical form. Diagrams and/or photographs of the damage should be prepared showing area of scorch/char, depth of char, depth, width and length of cracks and holes formed and any specimen distortion. A sketch showing severe areas of soot deposits is also useful.

Appendix A Fire test facilities

The three most common types of fire facility are as follows.

a) *The room/corridor,* which usually consists of a room with a variable opening to a long corridor along which air enters and the fire effluents can flow out [Figure 1 (a)]. Ventilation to the fire can be controlled by altering the width of the vent or by introducing air via a port directly into the room.

b) *The open corner,* (walls only or walls plus ceiling) which allows for open ventilation only and is frequently used for testing wall-linings and internal insulation on a large scale [Figure 1 (b)].

c) *The single room,* again with a variable vent opening and often connected [as in Figure 1 (c)] to a canopy and duct system used to give an assessment of the rate of heat release from the burning contents of the fire chamber. An example of this type of facility is the room test currently being developed within ISO (ISO/DP 9705).

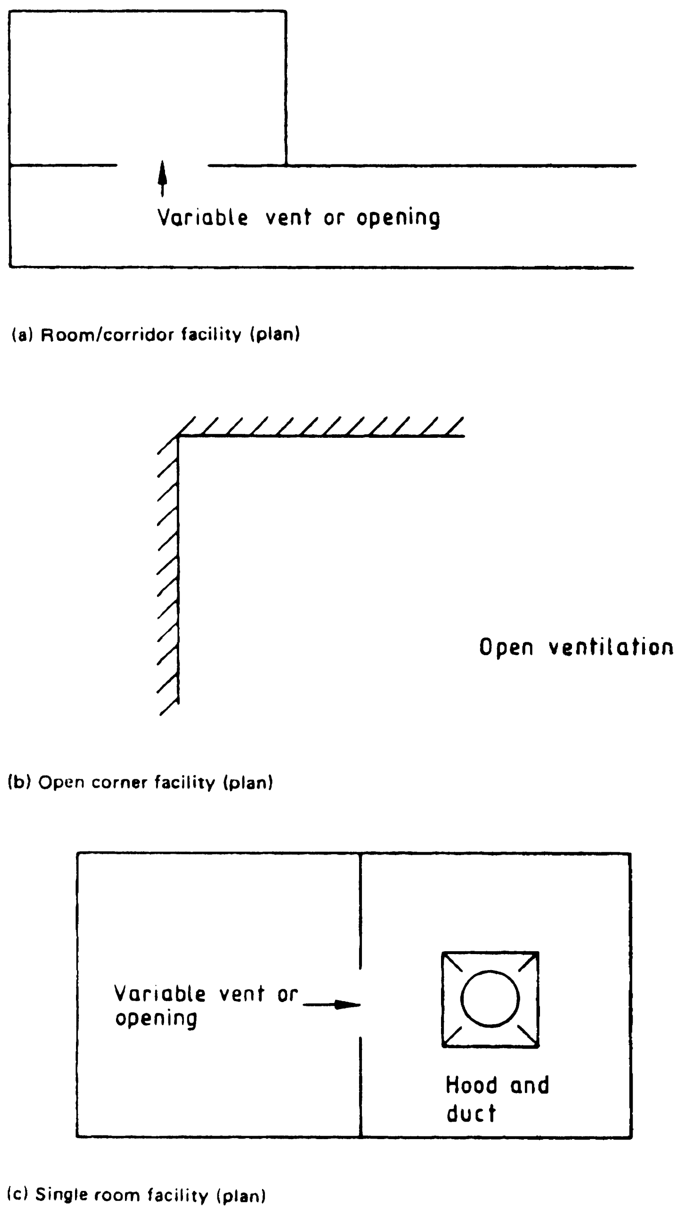

Figure 1 — Fire test facilities

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Publications referred to

BS 4422, *Glossary of terms associated with fire.*

BS 5446, *Specification for components of automatic fire alarm systems for residential premises.*

BS 5446-1, *Point-type smoke detectors.*

BS 6809, *Method for calibration of radiometers for use in fire testing.*

DD 180, *The assessment of toxic hazards in fires.*

PD 6503, *Toxicity of combustion products.*

PD 6503-1, *Toxicity testing of fire effluents: The state of the art 1987*[1].

PD 6503-2, *Guide to the relevance of small scale tests for the toxicity of combustion products of materials and composites.*

[1] In preparation.

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