BRITISH STANDARD

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Implementation of ISO/TR 9122-4:1993

Toxicity testing of fire effluents —

Part 4: The fire model (furnaces and combustion apparatus used in small-scale testing)

ICS 13.020; 13.300

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by Technical Committee FSH/16, upon which the following bodies were represented:

British Cable Makers Confederation
British Electrical Systems Association (BEAMA Ltd.)
British Plastics Federation
British Railways Board
British Rigid Urethane Foam Manufacturers' Association
British Rubber Manufacturers Association Ltd.
British Textile Technology Group
Chemical Industries Association
Chief and Assistant Chief Fire Officers Association
Consumer Policy Committee of BSI
Department of Health
Department of the Environment (Building Research Establishment)
Department of Trade and Industry (Consumer Safety Unit, CA Division)
International Wool Secretariat
Loss Prevention Council
Queen Mary and Westfield College
RAPRA Technology Ltd.
Warrington Fire Research Centre

This British Standard, having been prepared under the direction of the Consumer Products and Services Sector Board, was published under the authority of the Standards Board and comes into effect on 15 December 1996

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Contents

National foreword

This British Standard reproduces verbatim ISO TR 9122-4:1993 and implements it as the UK national standard. It is related to PD 6503-1:1990 which is the UK adoption of ISO/TR 9122-1:1989. When ISO/TR 9122-1:1989 is revised, it is intended that it will be implemented as the UK national standard.

The Technical Committee had earlier decided not to implement ISO/TR 9122-2 as the UK national standard but to publish a national document (PD 6503-2) instead. PD 6503-2:1988 remains current until the 1990 edition of ISO/TR 9122-2 is revised when it is envisaged that the new edition of ISO/TR 9122-2 will be implemented as a British Standard.

To avoid any further confusion, the decision has been made to implement all the remaining Parts of the ISO/TR 9122 series as British Standards rather than producing national documents as further Parts of PD 6503.

This British Standard is published under the direction of the Consumer Products and Services Sector Board whose Technical Committee FSH/16 has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible international committee any enquiries on interpretation, or proposals for change, and keep UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the ISO title page, pages ii to iv, pages 1 to 17, 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.

TECHNICAL
REPORT

ISO
TR 9122-4

First edition
1993-05-15

Toxicity testing of fire effluents —

Part 4:
The fire model (furnaces and combustion apparatus used in small-scale testing)

Essais de toxicité des effluents du feu —

Partie 4: Modèle feu (fours et appareillages de combustion utilisés dans les essais à petite échelle)

Reference number
ISO/TR 9122-4:1993(E)

Contents

Foreword

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

The main task of 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 9122-4, which is a Technical Report of type 2, was prepared by Technical Committee ISO/TC 92, *Fire tests on building materials, components and structures,* Sub-Committee SC 3, *Toxic hazards in fire.*

This document is being issued in the type 2 Technical Report series of publications (according to subclause G.4.2.2 of part 1 of the ISO/IEC Directives) as a "prospective standard for provisional application" in the field of toxicity testing of fire effluents because there is an urgent need for guidance on how standards in this field should be used to meet an identified need.

This document is not to be regarded as an "International Standard". It is proposed for provisional application so that information and experience of its use in practice may be gathered. Comments on the content of this document should be sent to the ISO Central Secretariat.

A review of this type 2 Technical Report will be carried out not later than two years after its publication with the options of: extension for another two years; conversion into an International Standard; or withdrawal.

ISO/TR 9122 consists of the following parts, under the general title *Toxicity testing of fire effluents:*

- — *Part 1: General*;
- — *Part 2: Guidelines for biological assays to determine the acute inhalation toxicity of fire effluents (basic principles, criteria and methodology)*;
- — *Part 3: Methods for the analysis of gases and vapours in fire effluents*;
- — *Part 4: The fire model (furnaces and combustion apparatus used in small-scale testing)*;
- — *Part 5: Prediction of toxic effects of fire effluents.*

Annex A of this part of ISO/TR 9122 is for information only.

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Introduction

Fire involves a complex and interrelated array of physical and chemical phenomena. As a result, it is essentially impossible to simulate all aspects of a real fire in laboratory-scale apparatus. This problem of fire model validity is perhaps the single most perplexing technical problem associated with all of fire testing.

For fire models used in evaluating fire effluent toxicity, additional restrictions and criteria are necessarily imposed due to the need for the laboratory combustion to be compatible with bioassay procedures using live test animals. For example, reduced oxygen levels and heat must not, in themselves, be unduly compromising to exposed animals. At the same time, sufficiently high concentrations of fire effluents must be produced so as to obtain measurable toxicological effects. As a result of these restrictions, compromises must often be made which can further reduce the apparent validity of the fire model.

Essentially two approaches are used to evaluate the toxicity of fire effluents; i.e. those using full-scale fire models and those using small-scale fire models. In full-scale procedures, fire models consisting of a room, multiple rooms or a complete building are used which are intended to simulate as far as possible the full characteristics of fires including ignition, growth and evolution of toxic fire effluents. Full-scale methods are usually applied in tests of the toxic *hazard* presented by the fire, although some attempts have been made to model the main features of toxic hazard in small-scale tests.

In small-scale fire models, it is considered possible to re-create the reactive chemical environments characteristic of various stages and types of fire conditions in terms of temperature, the presence or absence of flame and oxygen supply. Under these conditions, the relative yields of toxic products in the fire effluents from materials will be similar to those evolved at equivalent stages in full-scale fires. Thus, small-scale fire models are regarded as relevant to the testing of the toxic *potencies* of the chemical products evolved from materials under the defined decomposition conditions. These potency values may then be used as input data in toxic hazard assessments which take into consideration the dynamic characteristics of specific fire scenarios.

1 Scope

This part of ISO/TR 9122 is restricted to the consideration of fire models (i.e. laboratory combustion devices) used in fire effluent toxicity studies, together with suggestions for the appropriate use of the fire models in standard testing. Reference should be made to other parts of ISO/TR 9122 for discussions of analytical methods, bioassay procedures, toxicity testing and prediction of toxic effects of fire effluents.

This part of ISO/TR 9122 defines the criteria for an acceptable fire model, reviews existing fire models against these criteria, and proposes that fire models be selected for use through consideration of these criteria which includes a capacity to generate fire conditions characteristic of known stages of fire.

This part of ISO/TR 9122 does not give a detailed analysis of the physics and chemistry of fire.

2 Characteristics of fire stages

For the purposes of a discussion of fire models and their appropriate use, the combustion conditions shown in Table 1 are generally accepted as being characteristic of certain stages or phases of fire[1].

The primary chemical process leading to formation of combustion products is that of the thermal bond-breaking and decomposition of polymeric materials which, in the presence of oxygen, leads to a variety of oxygenated species. Carbon compounds are pyrolysed into volatile hydrocarbon fragments which can be oxidized to form various oxidized organic species, carbon monoxide or carbon dioxide, depending upon thermal and oxidative conditions. Both carbon monoxide and carbon dioxide are usually present in a fire effluent atmosphere, with the ratio of the two often being used as an indicator characteristic of the particular type or stage of a fire. In small, developing fires, a CO_2/CO ratio of 100 or more would indicate freely-ventilated (fuel-controlled) combustion. In large, fully-developed fires which are usually ventilation controlled when they occur in buildings, a CO_2/CO ratio of 10 or less would indicate relatively low ventilation, while a ratio of more than 10 would be indicative of relatively high ventilation.

Table 1 — General classification of fire stages

Stage or phase of fire	Oxygen content[a] (%)	CO_2/CO ratio[b]	Temperature (°C)	Irradiance[c] (kW/m^2)
Non-flaming decomposition				
a) Smouldering (self-sustaining)	21	not applicable	< 100	not applicable
b) Non-flaming (oxidative)	5 to 21	not applicable	< 500	< 25
c) Non-flaming (pyrolitic)	< 5	not applicable	< 1 000	not applicable
Flaming developing fire	10 to 15	100 to 200	400 to 600	20 to 40
Flaming fully-developed fire				
a) Relatively low ventilation	1 to 5	< 10	600 to 900	40 to 70
b) Relatively high ventilation	5 to 10	< 100	600 to 1 200	50 to 150

[a] General environmental condition (average) within compartment.

[b] Mean value in fire plume near to fire.

[c] Incident irradiation on the sample (average).

Hydrogen is oxidized to water, chlorine is most commonly released as hydrogen chloride and nitrogen appears as nitrogenous organic compounds (especially nitriles), hydrogen cyanide, nitrogen oxides and molecular nitrogen, again depending upon the thermal and oxidative conditions. All flaming and non-flaming (including smouldering) fires can yield a myriad of combustion products due to incomplete decomposition and only partial oxidation of the fuels involved; however, non-flaming fires produce the highest yields of such products. It is important to remember that these are all chemical reactions, subject to the usual principles of thermodynamics and kinetics. Thus, stoichiometry and thermal energy play significant roles in determining the products of combustion that are formed over the range of fire classifications.

3 Criteria for assessment of fire models

3.1 Relevance to real fires

The best approach to the selection of an appropriate fire model for fire effluent toxicity testing involves careful consideration of data which would relate laboratory combustion conditions to the types and stages of real fires (see Table 1).

All the fire models to be described are capable of simulating the conditions of non-flaming decomposition. However, it is recognized that the majority of fire injuries and deaths occur as a result of flaming fires. These include both small fires (often restricted to the item first ignited) where casualties occur in the room of origin and also large, fully-developed fires, where casualties occur remotely from the compartment of origin. In the latter, the toxic threat usually develops after flashover occurs[1] [2].

In terms of a correlation with most fire fatalities, the most important criteria for an appropriate fire model involve the conditions for a well-ventilated, developing fire and for either a low- or highly-ventilated, fully-developed (high temperature) fire. Particularly important are considerations involving ventilation (oxygen availability), CO_2/CO ratios, temperature and/or heat flux and residence times of fire effluents in the high temperature zone.

3.1.1 *Oxygen concentration*

The oxygen concentration is the residual concentration in the primary fire effluent before any dilution. Its value decreases during fire development from the normal ambient level of approximately 21 % to 10 % 15 % in a small or developing fire, and further decreases to between 1 % and 10 % in a fully-developed fire, depending upon the ventilation, burning rate and room geometry.

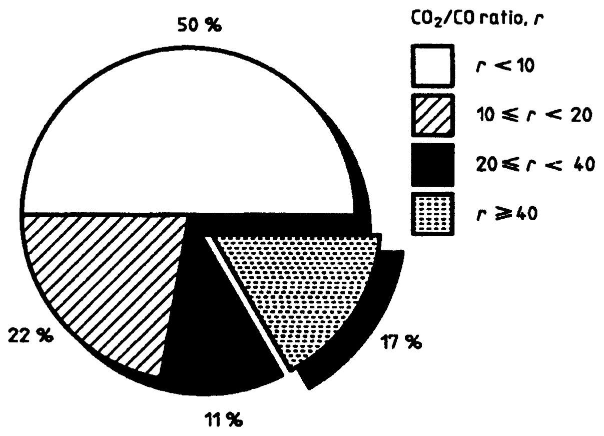
3.1.2 *CO_2/CO ratio*

The CO_2/CO ratio is calculated from the concentrations of these gases in the fire effluent atmosphere. Since its value is independent of dilution, the sampling point is not critical, providing it is beyond the point where oxidation reactions are in progress. The CO_2/CO ratio undergoes rapid changes during the development of a fire. Initially, in small fires under well-ventilated conditions, it is usually high (100 to 200). In fully-developed, ventilation-controlled fires, it reaches an almost constant value (1 to 10) depending upon the ventilation. Real fire data for CO_2/CO ratios are shown in Figure 1[3].

3.1.3 *Temperature and heat flux*

The temperature is the mean value within a compartment. It gives a measure of the thermal exposure to the materials present and also to their thermal decomposition products. The radiant heat flux is also useful as a measure of exposure to thermal energy. In small or early-developing fires, the temperature in the immediate fire environment is typically in the 400 °C to 600 °C range with the radiant flux between 20 kW/m^2 to 40 kW/m^2. In fully-developed fires, the temperature is in the 600 °C to 1 200 °C range with radiant fluxes of 50 kW/m^2 to 150 kW/m^2.

All these factors have a considerable influence on the composition of the fire effluent atmosphere. The important features from a toxicity point of view are that small or early-growing fires generally produce relatively low yields of carbon monoxide and hydrogen cyanide, together with a complex mixture of pyrolysis and oxidation products which have escaped the flame zone. Fully-developed fires, due to the high temperatures and oxygen vitiated conditions, generally produce high yields of toxic low molecular weight species, such as carbon monoxide and hydrogen cyanide.



Source : Boston fire department

Figure 1 — CO_2/CO ratio in real fire situations

3.2 Validity to toxic hazard assessment

Demonstration of the validity of a fire model in generating the toxic hazard of a real fire is an ideal criterion which can be approached but not necessarily reached. A few studies have been conducted using full-scale fires to evaluate the contribution of certain construction materials and furnishings to toxic hazard[2][4][5]. However, considerable caution should be exercised in generalizing conclusions from these studies. Even in full-scale tests, a range of different fires is possible in any one system.

The development of toxic hazard depends upon fire growth, which is essentially a large-scale phenomenon, and carefully conducted, full-scale tests do replicate at least some of the likely types of accidental fires. In general, however, it is economically unfeasible to conduct routine large-scale tests. Thus, the practical requirement becomes to provide bench-scale fire toxicity tests, whose predictions can be validated against the full-scale.

Since CO is the major toxicant in fires, much of the validity of bench-scale tests has traditionally been concerned with CO measurement, typically reported either as CO yield or CO_2/CO ratios. Experimental studies generally indicate that CO production is independent of oxygen concentration until the oxygen/fuel ratio drops to about 50 % more than that needed for complete or stoichiometric combustion[6]. From that point on, CO production rises sharply with decreasing oxygen. In fully-developed, post-flashover fires, CO yields of up to 0,2 kg CO per kilogram of material burned are encountered. This ratio appears to be fairly similar for a wide variety of combustibles.

In addition to differences in the heating of a specimen, the CO evolved from bench-scale experiments can differ from that produced with full-scale tests due to the following factors:

a) Air/fuel ratio. If this ratio is not the same in the two scales, CO production will be different;

b) Residence time effects. The time available to combust CO to CO_2 will often be much greater in the full-scale than in the small-scale device;

c) “Freezing in” of CO. Effects which tend to stop reactions from completion, thereby “freezing in” a certain proportion of CO. This effect is more pronounced for increasing scale size.

The net effect of the above phenomena is that bench-scale tests often have a tendency to show lower yields of CO than are observed in full-scale testing[7].

Small-scale tests, although they can give better reproducibility, provide only remote simulation of actual fire conditions. Despite these limitations, small-scale tests are attractive on the grounds of cost. The best assessments of toxic hazard consist of a combination of small-and large-scale tests, usually together with appropriate engineering calculations.

3.3 Specimen composition and configuration

Small-scale fire models require the use of relatively small sample specimens. The size, orientation and shape of the specimen holder and combustion compartment in the fire model should be considered when selecting a fire model. The model should accommodate the testing of the test specimen in a manner which is consistent with its end-use. Specimens of composites and layered materials, for example, should be tested with a minimum of alteration in their end-use form and configuration.

3.4 Documentation and experience

Protocols for use of the fire model should be well documented. Interlaboratory data and experience with candidate fire models should be considered when selecting a fire model.

3.5 Exposure dose quantification

The actual dose administered in fire effluent toxicity testing is very difficult to establish in terms of grams of toxicant per kilogram body weight. It is generally accepted, however, that the body burden of an inhaled toxicant will be proportional to the product of its concentration in the inspired air and the duration of the exposure. This product is referred to as the exposure dose of fire effluent gases. It is essential that the fire model permits a valid quantification of exposure dose through the measurement, or calculation, of sample specimen mass loss and system volume.

3.6 Procedural criteria

There are a number of criteria to be considered in selecting a fire model that deal with procedural consistency, animal compatibility and safety. These criteria are grouped together as procedural criteria and are as follows:

a) **Repeatability of atmosphere generation**

Intralaboratory repeatability should have been demonstrated.

b) **Reproducibility of atmosphere generation**

Interlaboratory reproducibility should have been demonstrated.

c) **Adaptability to bioassay requirements**

The fire model should be adaptable to animal exposure procedures.

d) **Adaptability to analytical requirements**

The fire model should be adaptable to analytical requirements.

e) **Safety in use and operation**

The device should be safe in its operation.

4 Fire models

Although it is recognized that numerous fire models are available, only a few satisfy sufficient criteria to be detailed in this part of ISO/TR 9122. For example, the OSU rate of heat release apparatus[8] with chemical analysis satisfies major relevant criteria, but is not readily adaptable to animal tests. On the other hand, fire model NES 713[9] definitely does not satisfy major relevant criteria and its use is not recommended by the UK national standards body.

None of the models satisfy all the criteria; however, the types of fire model used which meet most of the requirements, at least partially, are described here.

4.1 "Box" furnace models

4.1.1 *NBS cup furnace*

The NBS[1] test[10] employs a cup or crucible furnace (see Figure 2), often referred to as the "Potts furnace", named after the investigator who first reported its use in combustion toxicology. Heating is considered to be largely conductive, with the bottom and lower portion of the quartz cup constituting the hot zone. Test materials with masses of up to 8 g are introduced into the cup, which has a volume of about 1 l. Procedures for testing materials involve combustion at both just below (non-flaming) and just above (flaming) an autoignition temperature. There has been particular concern regarding air flow into the cup, although it does communicate with a volume of 200 l of air contained in the exposure chamber. With the variable sample sizes used and an ill-defined fuel-to-air ratio, some feel the system fails to carry out combustion in a well-characterized manner. A further criticism has been that various materials are not tested under the same conditions but often at considerably different temperatures.

The method provides a good model for non-flaming oxidative decomposition. It is also a good model for simulating the decomposition conditions during a well-ventilated, early-developing fire. It cannot produce the high temperature, oxygen-vitiated conditions of a fully-developed, post-flashover fire.

Once in fairly common use in a number of laboratories in the US, the NBS cup furnace has been well documented with considerable data available[11]. Its use has declined, however, in favour of other fire models.

4.1.2 *UPitt box furnace*

In the UPitt test method, the combustion device is a muffle or box furnace, which is often used in an inverted position in order to provide for a pedestal connected to a mass sensor (see Figure 3)[12][13]. With this arrangement, continuous monitoring of sample mass is conducted. Combustion is accomplished using a linear temperature increase of 20 °C/min up to a temperature as high as 1 100 °C, while chamber atmosphere is pulled through the furnace at a rate of 11 l/min. Smoke concentration is varied by changing the mass of material charged to the furnace. The fuel/air ratio can, therefore, vary widely depending upon the mass of sample and also on its rate of decomposition. A problem of small explosions has been encountered with some materials which thermally decompose or burn very rapidly once ignition occurs. This phenomenon, possibly the rapid emission of gases whose volume exceeds that being pulled from the furnace, has not been reported to be sufficiently severe as to rupture the apparatus, however.

The test begins in a non-flaming oxidative mode, and at some stage, transition to flaming usually occurs. At this time, the CO_2/CO ratios tend to be low (under 20, usually less than 10), while the temperature is still low (less than 600 °C). This combination of conditions does not, therefore, fit well into the scheme of fire classes shown in Table 1. It best represents the rather special situation of a small fire load in a restricted ventilation environment, for example in a sealed cup-board or cabinet. Although the oxygen concentration is rather low, there are some similarities to the chemical decomposition environment in the early developing fire. The method does not simulate the conditions of a large fully-developed post-flashover fire; however, the method could be used as a test for measuring the toxic potency of products resulting from the decomposition conditions of developing fires.

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[1] The US National Bureau of Standards is now known as the National Institute of Standards and Technology. To avoid confusion, the former name will be retained in this report when reference is made to the NBS testing device.

Another criticism of this method is the 20 °C/min temperature increase, which is quite slow and not associated with observed fires. It results in a gradual fractionation of the pyrolysis products, with a disproportionately high percentage of low temperature decomposition products in the fire effluent which is analysed and presented to the test animals.

In spite of the problems associated with the UPitt fire model, it is specified in a fire effluent toxicity test required for certain construction products in the State of New York[13]. The requirement is such that test data only be submitted, however. There are no criteria for classification of products.

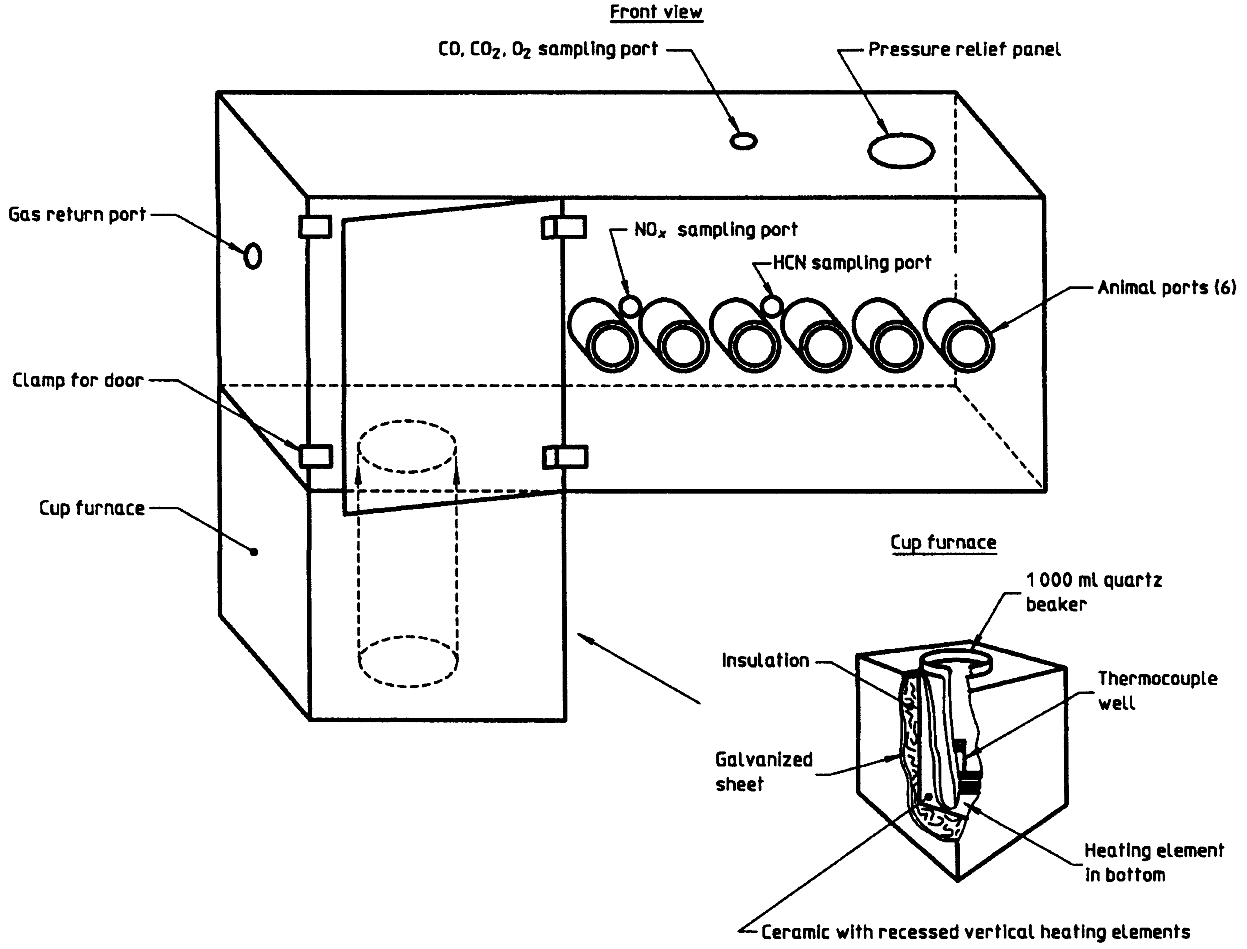


Figure 2 — NBS cup furnace smoke toxicity apparatus

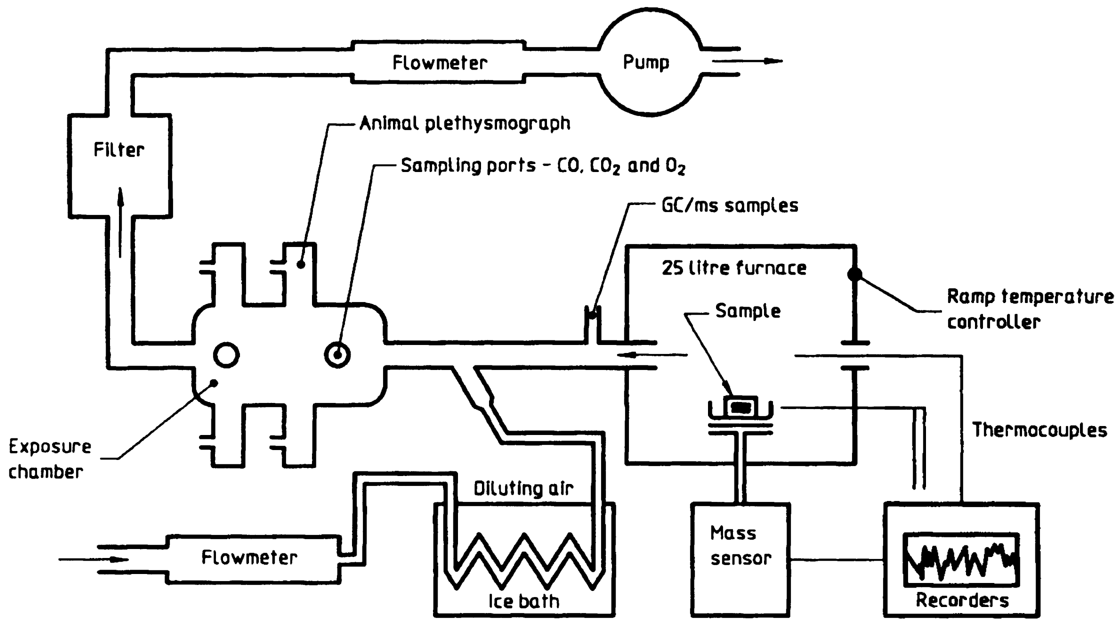


Figure 3 — UPitt smoke toxicity apparatus including box furnace

4.2 Tube furnace models

4.2.1 *DIN 53436 tube furnace*

The DIN 53436 combustion device (see Figure 4) is characterized by the use of a moving annular tube furnace operating at a constant temperature in the range 200 °C to 1 000 °C[14][15]. Radiant heat is the major source of energy transfer. This test device, used in six European countries[15 to 22], offers a rather wide range of well-controlled combustion conditions. Ratios of CO_2/CO can be made to vary widely, depending on the air flow rate used; thus, both freely-ventilated and ventilation-limited fires can be simulated.

Specimens can undergo either flaming or non-flaming combustion, depending on the imposed heat flux level and/or the presence of an ignition device. Some difficulty has been experienced in controlling smouldering and flaming conditions; however, work using sample segmentation has shown promise with these modes of combustion[23]. It must be recognized that such procedures can alter the type of atmosphere produced.

The decomposition of a test material takes place in an air stream counter-current to the flame propagation. This is opposed to the real fire situation, but is done to prevent uncontrolled preheating effects by the combustion products. However, co-current conditions have been imposed[18]. The lack of continuous monitoring of sample weight is compensated for by the continuous decomposition process, which enables one to relate the exposed mass, volume or surface area to the bioassay and/or analytical test data.

The DIN 53436 method is clearly useful for toxic potency testing. It is capable of producing the chemical decomposition environment of any of the seven fire types shown in Table 1 and is the only method which comes close to simulating the high-temperature, oxygen-vitiated conditions in a post-flashover fire. Care must be taken when simulating the CO_2/CO ratios of growing, well-ventilated fires, since they tend to be rather low under standard operating conditions. Self-sustained, smouldering is also difficult to simulate in small samples, as is the case with most small-scale methods.

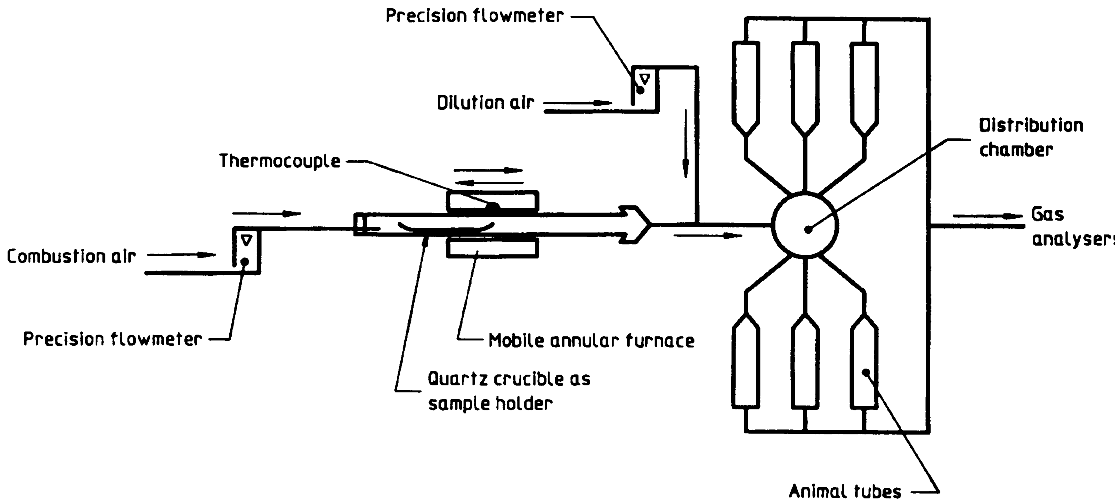


Figure 4 — DIN 53436 smoke toxicity apparatus including tube furnace

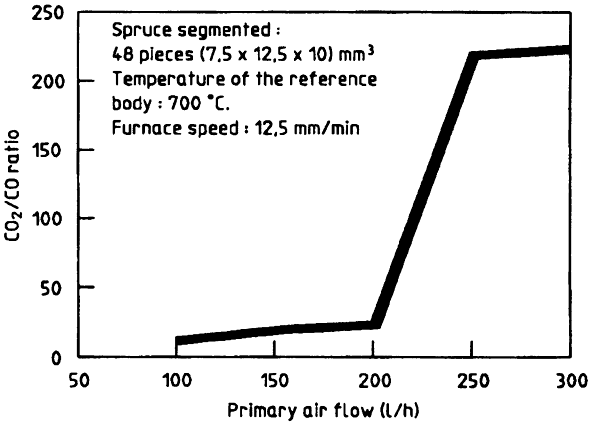


Figure 5 — Combustion of spruce segments in the decomposition apparatus in accordance with DIN 53436

The DIN 53436 model satisfies the procedural criteria quite well. It has been well-documented and widely used. Considerable work demonstrating the validity of the model has been reported[15][24]. it is quite flexible in being able to accommodate a range of controlled ventilation conditions, with CO_2/CO ratios from below 5 to more than 200 being obtained (Figure 5).

The major disadvantages of the system are the difficulties in quantifying the exposure dose of smoke (although it can be estimated) and also in controlling both smouldering and flaming combustion.

4.3 Radiant heat models

4.3.1 *US radiant furnace (modified)*

The combustion device used in the US radiant furnace (modified) methodology (see Figure 6) consists of a horizontally mounted, cylindrical quartz combustion cell, 130 mm inside diameter and approximately 320 mm in length. It is connected to an animal exposure chamber through a stainless steel chimney, which is approximately 30 mm × 300 mm × 300 mm. The chimney is divided into three channels, creating a heat pump action by inducing smoke to flow up the centre channel, while air from the exposure chamber circulates down the outer channels. External to the combustion cell are four tungsten-quartz radiant heat lamps focused onto the plane of the specimen. A platform, accommodating test specimens of 76 mm × 127 mm and up to 51 mm in thickness, is connected to a load cell located underneath the combustion chamber in order to monitor continuously the specimen mass. A high-energy spark plug is used as an ignition source.

Heat fluxes in excess of 50 kW/m^2 have been used. Ratios of CO_2/CO have ranged widely, usually being well in excess of 20. This model, therefore, appears to produce a good simulation of an early-developing, flaming fire. Insufficient data are presently available to establish the exact characteristics, however. Development work is still in progress which should better characterize the use of this fire model.

The US radiant (modified) model meets the procedural criteria quite well. Exposure doses can be well quantified. The major problems are associated with the lack of documentation and availability of data; although, considerable work using an earlier version of the radiant furnace is described in the literature[25].

4.3.2 *Cone calorimeter*

Both ISO and ASTM have adopted an instrument generally termed the cone calorimeter (see Figure 7) for measuring heat release and related properties in the bench scale[26][27].

The cone calorimeter uses specimens of a material cut into 100 mm × 100 mm squares with thickness varying from 6 mm to 50 mm. The specimen is heated by an electric heater in the shape of a truncated cone. The irradiance to the specimen can be set to any desired value from 0 to 100 kW/m^2. If desired, external ignition of the specimen is provided by an electric spark. The mass of the specimen is recorded continuously through use of a load cell. An exhaust system provides air flow rates of between 0,012 m^3/s and 0,035 m^3/s when the cone calorimeter is employed for heat release measurements. It is this high air flow rate and the resulting dilution of fire gas toxicants, that has made it difficult to use the cone calorimeter as a combustion device for smoke toxicity testing.

The method simulates non-flaming oxidative decomposition conditions and early-developing flaming conditions, depending upon the heat flux applied. Since the specimen is always very well ventilated, the cone calorimeter cannot address the high-temperature, oxygen-vitiated conditions found in large, fully-developed fires. However, attempts have been reported in modifying the cone calorimeter to address this limitation[28]. Studies performed whereby the cone calorimeter was used to supply combustion gases to animals suggest that although such a coupling is feasible, it is of questionable practicality due to the high degree of complexity of the resulting apparatus.

4.3.3 *Japanese cone furnaces*

4.3.3.1 *BRI (Building Research Institute) cone furnace*

The combustion device used in the BRI cone furnace methodology (see Figure 8) consists of a cone-shaped quartz tube positioned inside a cone radiative electric furnace as used in ISO 5657[29]. Radiant heat fluxes up to 50 kW/m^2 may be used. An electric igniter is used to initiate the flaming mode as early as possible. Air, or an air/nitrogen mixture, supplied through the bottom of the quartz tube, flows around the sample of 100 mm in diameter during combustion. The mass loss of sample is monitored continuously with a load cell.

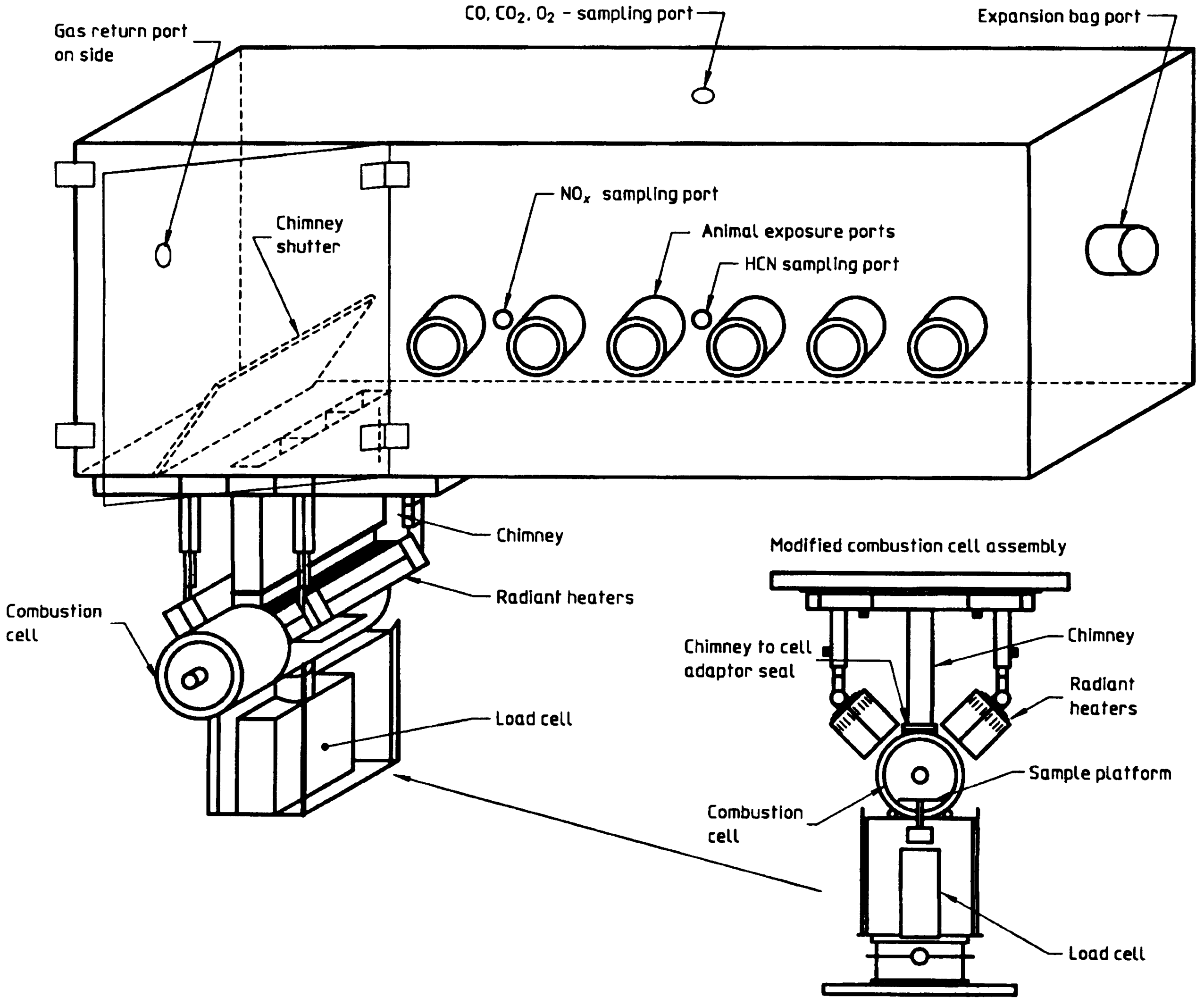


Figure 6 — US radiant smoke toxicity apparatus including radiant furnace

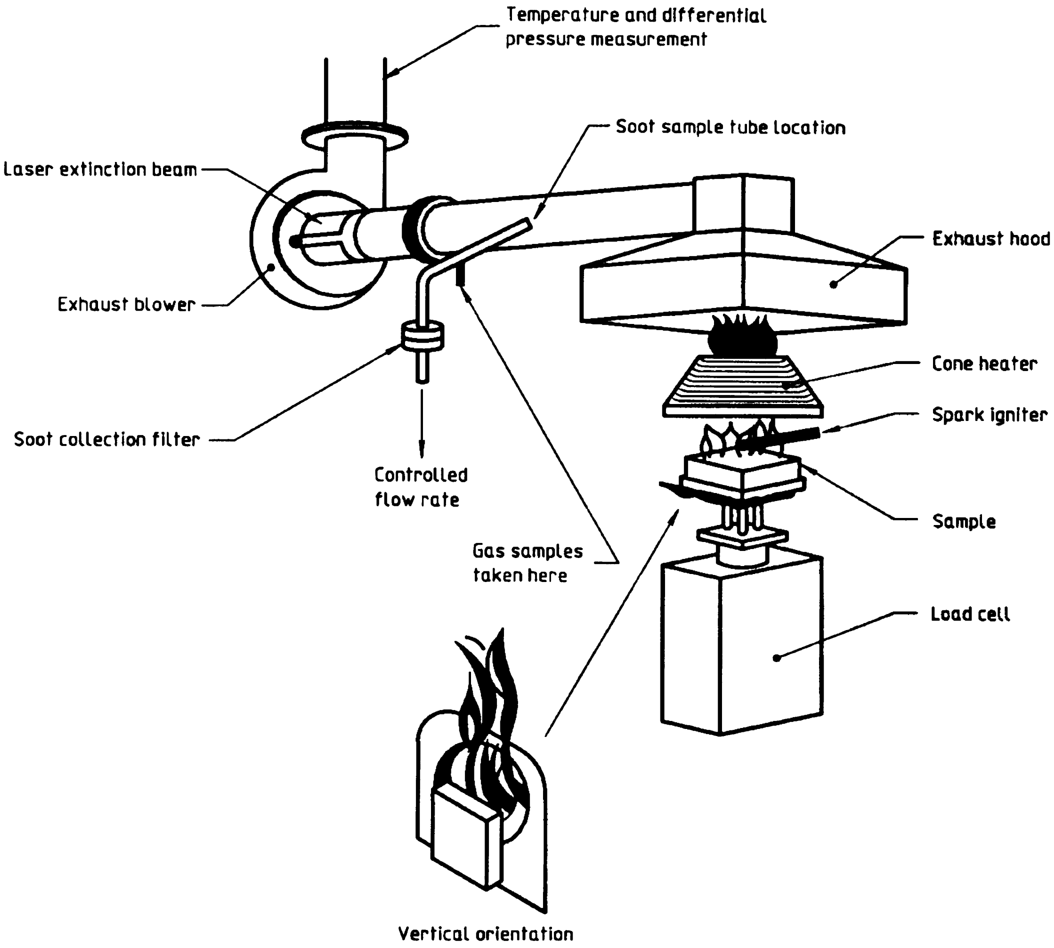
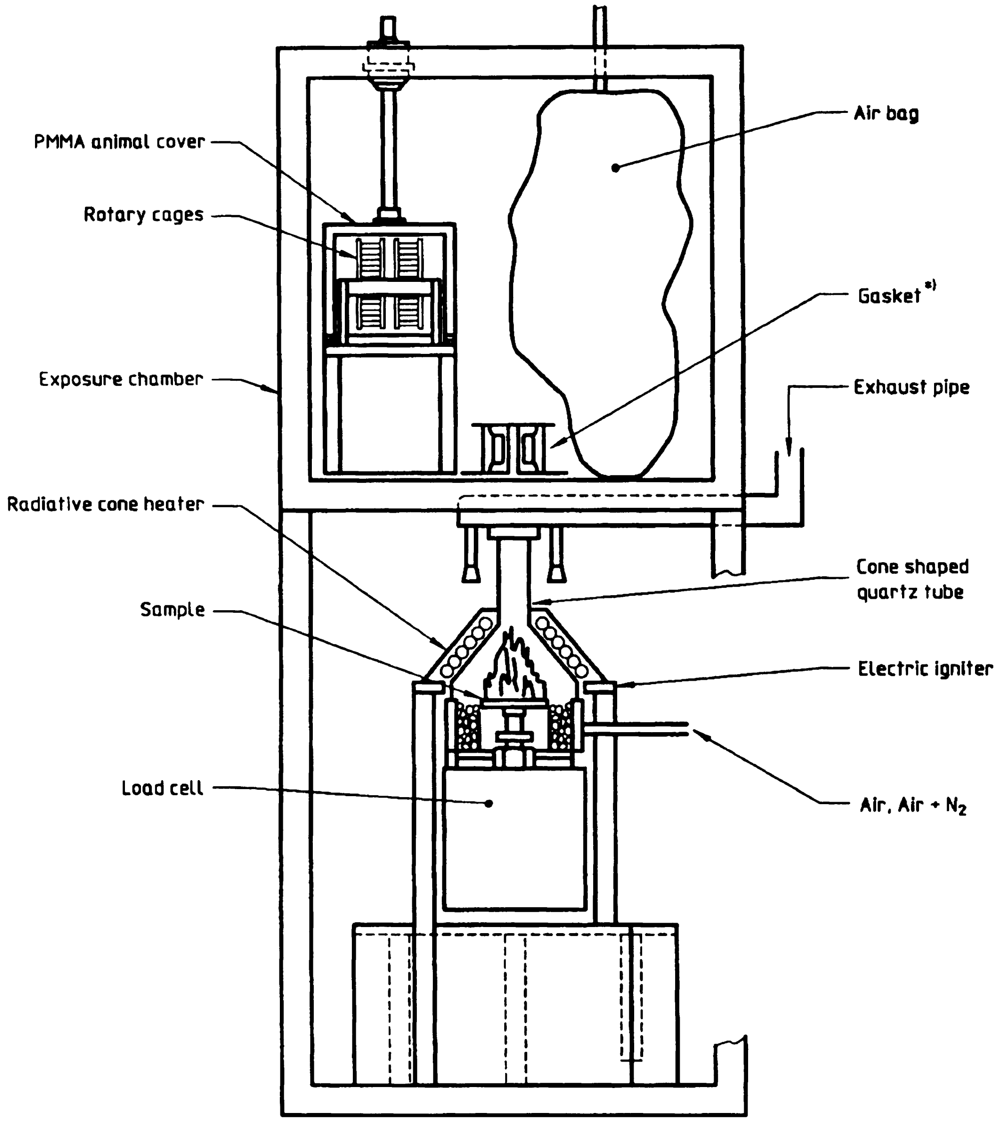


Figure 7 — Cone calorimeter



*) To control the time to introduce products.

Figure 8 — BRI smoke toxicity apparatus including cone furnace

The BRI cone furnace appears to satisfy most of the criteria and is quite flexible in being able to accommodate a range of controlled ventilation conditions. The data reported so far indicate its use mainly to simulate the well-developed, ventilation-limited fire. Two laboratories have the apparatus and reproducibility studies are in progress. The major problems are associated with the insufficient documentation.

4.3.3.2 *RIPT (Research Institute for Polymers and Textiles) cone furnace*

Another combustion device using a cone-type radiant furnace was developed at RIPT (see Figure 9)[29]. In the RIPT test method, the combustion device is a cone furnace somewhat smaller than the ISO 5657 cone heater. It is enclosed in a box of 91 cm × 91 cm × 61 cm.

Data obtained from the RIPT cone furnace indicate its use mainly to simulate the well-developed, ventilation-limited fire. It would seem, however, to be quite capable of also modelling a freely-ventilated fire as well. The combustion device appears to satisfy most of the criteria except for its limited documentation.

4.3.4 *Japanese Ministry of Construction model*

A test method for combustion gas toxicity was added in 1976 to the Ordinance of the Ministry of Construction (see Figure 10)[30]. The test apparatus uses a combustion furnace based on BS 476, Part 6, with which the surface of a specimen (18 cm × 18 cm) is heated both by radiation from an electric heater of 1,5 kW and by a propane gas flame contacting the bottom of the specimen. For 3 min from the start of testing, the specimen is heated by only the propane gas flame, and after 3 min, radiation is applied in addition. After 6 min from the start of testing, the radiant heating and the supply of air/propane are both terminated.

Since the test has been used more than 10 years for regulative purposes, considerable data have been obtained. Data produced from the combustion of several varieties of wood show CO_2/CO ratios under 10. Thus, this fire model would appear to represent the ventilation-limited fire. There is no capability to continuously monitor sample mass so a major disadvantage of the system is in quantifying the exposure dose of smoke.

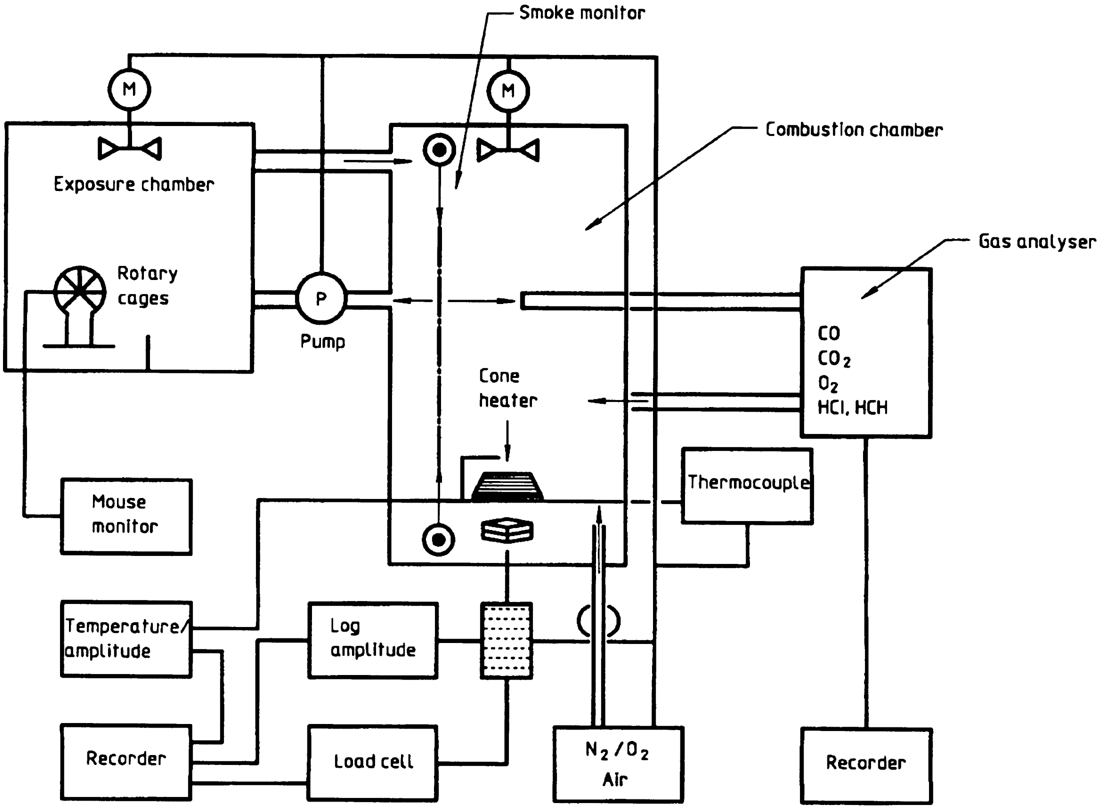


Figure 9 — RIPT smoke toxicity apparatus including cone furnace

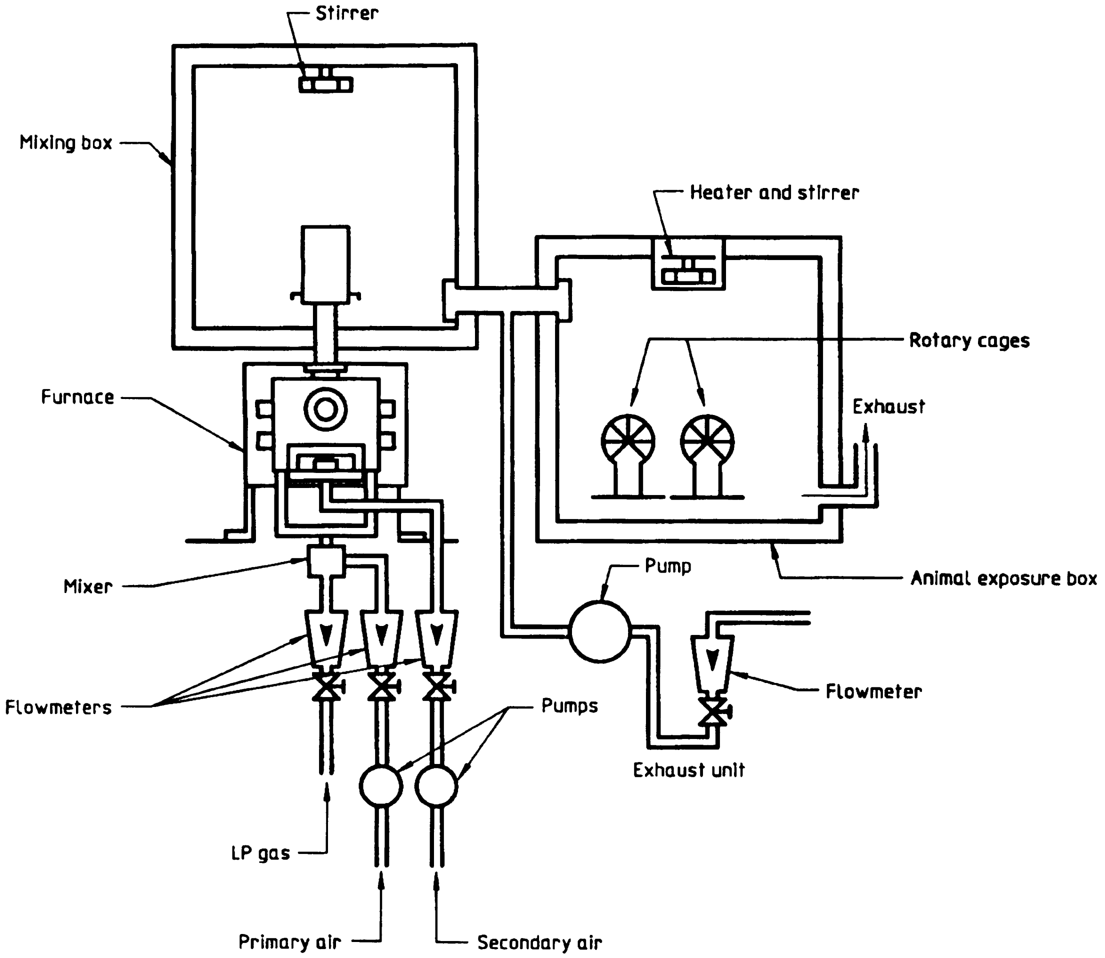


Figure 10 — Japanese Ministry of Construction smoke toxicity apparatus including furnace

5 Selection of a fire model

A model, by definition, is a surrogate. The accuracy of any model is represented by how closely it approximates the reality it is intended to simulate. The proper use of a model, on the other hand, depends on how well the user of the model understands, and honours, the accuracy limitations of the model. The selection of a valid model therefore becomes an exercise in assessing the model's limitations relative to accuracy followed by proper use which does not violate those limitations.

There has been long debate over the adequacy and validity of fire models. Participants in that debate have expressed varying levels of discomfort with the degree to which models depart from the reality of fire in full scale (i.e. the accuracy factor), or with the possibility that the models could, through misuse, lead to inappropriate decisions regarding a product's hazard if involved in a real fire (i.e. the proper use factor).

There is no fire model that replicates or simulates all the features of fire. Furthermore, there is no consensus that any model currently available is superior to all others in representing even a minimal set of conditions representative of real fire. The solution to selection of an appropriate fire model must, therefore, be found by matching a model's range of application to its recognized limits in representing the fire stages and conditions of interest.

The toxic potency of any fire effluent atmosphere is related to the very conditions of the fire model. Therefore, it must be clear as to which stage of fire it is relevant. Criteria involve the CO_2/CO ratio, residual oxygen in the fire plume and temperatures and/or heat fluxes involved. Since the amount of toxic products strongly depends on the air/fuel ratio, knowledge of this parameter is also highly desirable. These data all indicate in which area of the broad scale of possible fires a model may be valid.

In the final analysis, the choice of a fire model must be consistent with a good understanding of the characteristics of the real fire which is to be simulated.

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