# Fire Research Note
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## FIRE PROBLEMS OF PEDESTRIAN PRECINCTS
## PART 1. THE SMOKE PRODUCTION OF VARIOUS MATERIALS

by

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## SUMMARY

The experimental full-scale section of a pedestrian shopping mall at the Fire Research Station is described and results given of the first test series, designed to measure the smoke production in vision-obscuring terms of a number of materials burnt under well-ventilated large fire conditions. The amount of smoke produced is given as $D_s$, the optical density per metre produced by burning 1 gram of the material in a stirred volume of 1 cubic metre, and $D_s$ can be used to obtain the visibility in other situations. Remarkably little of any of the fuels needs to be burnt to produce low visibilities in an enclosed, though large, volume.

The worst materials gave an optical density per gram 7-9 times that of the best material.

For wood and polyurethane agreement with data from small scale tests is reasonably satisfactory, but for polystyrene much more smoke was produced than in a test employing the fire propagation test apparatus, possibly because of a different mode of combustion.

KEY WORDS: Smoke, shopping mall, visibility, smoke test, fire propagation test

This report has not been published and should be considered as confidential advance information. No reference should be made to it in any publication without the written consent of the Director of Fire Research.

DEPARTMENT OF THE ENVIRONMENT AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

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## PART 1. THE SMOKE PRODUCTION OF VARIOUS MATERIALS

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## 1. INTRODUCTION

Fires in pedestrian precincts of town centre developments are potentially dangerous because of the action of the confining building in enhancing smoke and fire spread. This report describes the initial stages of a research programme to devise measures to protect the safety of occupants.

A full-scale mock-up of a section of a pedestrian precinct has been constructed at the Fire Research Station and studies of the spread of smoke and fire and means of reducing this spread are now being made with it.

This first series of experiments was concerned with testing the instrumentation and data processing arrangements and measuring the smoke production of various materials. These included kerosine because smoke spread over long distances has been studied using kerosine fuel in a disused railway tunnel in Glasgow[1,2], representing a shopping mall, and in order that the results of these tests could be applied more universally it was necessary to compare the smoke production of kerosine with that of materials that might be found inside shops.

Little quantitative information is available on the production of smoke by various materials particularly under large fire conditions. Values for some materials are given by Gross et al[3], who developed a small scale test method, and Bowes and Field[4] who developed a smoke test based on the fire propagation test. Saito[5] has also made measurements of smoke production for plywood and studied the effect of temperature on smoke production. The main emphasis in this report is on the measurement of smoke production of various materials and its correlation with small scale testing.

## 2. EXPERIMENTAL BUILDING

The experimental building (Fig.1) was housed within a corrugated-steel shed 23.8 m (78 ft) long, 9 m (30 ft) wide and 7.6 m (25 ft) high, placed between two existing two-storey brick buildings which had each been designed and used for other fire tests. Within the shed a mock-up pedestrian mall was formed by inserting a ceiling 3 m (10 ft) above the ground and joined to walls A 6 m (20 ft) apart (Fig.1) continuing the line of the walls of the brick building. The lower rooms of the brick buildings represented open fronted shops opening on to the mall. A wall B (Fig.1) closed one end of the mall, the other end was fitted with doors occupying the full width, which were fully open during the tests.

The ceiling and walls A and B were constructed of 40 mm (1.5 in) thick wood wool slabs set into a slotted angle-steel framework. These were used because they were cheap and light - the loading which could be put on the shed was limited. The top surface of the ceiling was sealed with a paste of Perlite powder and silicate paint to render it less porous and the joints between the wood wool slabs and the framework were caulked with mineral wool strips.

An area of the ceiling 4 m wide and 5 m long immediately in front of the fire compartment was constructed of 6 mm ($\frac{1}{4}$ in) asbestos wood covered on the exposed lower side with 6 mm ($\frac{1}{4}$ in) thick refractory-fibre felt treated with a rigidiser. This would bear the brunt of the thermal attack from the hot gas and flames emerging from the fire compartment. The exposed surface of the slotted angle steel was similarly protected immediately in front of the fire compartment, and outside this area was protected by means of mineral wool felt for about half the length of the mall.

The fire compartment, representing a shop, measured 3.8 m wide, 7.7 m deep and 2.85 m high (12.5, 25 and 9.5 ft) respectively and communicated with the arcade by means of an opening 3 m (10 ft) wide and 2.5 m (8 ft) high (see Fig.2). A sliding door at the rear was provided to enable fuel to be brought in by means of a fork-lift truck and to allow structures representing a rear escape from a shop to be set up. The floor sloped down to a drain which was connected to a large tank buried near the building and the opening onto the mall had a sill so that water from sprinklers could be rapidly disposed of and would not flow into the pedestrian mall.

## 3. INSTRUMENTATION

At 5 points (I,J,K,L,M, Fig 3) down the centre of the mall a column of thermocouples was installed from floor to ceiling, spaced 300 mm apart. There were also eight thermocouples in a column in the centre of the plane of the opening of the fire compartment and eight thermocouples attached to the ceiling between the two brick buildings.

A foil heat-flux meter[6] was set flush with the ceiling and facing downwards close to each of the columns of thermocouples in the mall. A field radiometer[7] was mounted 1.5 m below the ceiling, facing upwards, close to each column of thermocouples.

Two types of smoke meter were used to measure the opacity of the smoke. Both of these measured the absorption by the smoke of a beam of light. For dense smoke a meter was used similar to that described by Malhotra[8] but with a lamp base sealed against smoke entry, a lower power lamp bulb (5 W), and with the compensating circuit dismantled and the output from each photocell measured separately. 'Everclean' windows[9] were installed to prevent sooting up of the lamp and photocell window and the lamp and photocell chambers were protected with thermal insulation. The length of the optical path through the smoke was 0.5 or 0.25 m. These smoke meters were installed at 0.3 and 0.9 m below the ceiling close to positions J and L.

For thin smoke a meter was developed with a horizontal beam of light which was thrown the full width of the arcade. The lamp on one side and the receiving photocell on the other were both on the far side of the wood wool wall and were thus protected from the hot gases travelling along the mall. Fig.4 shows the essential features of the meter. A tungsten-iodine car spot lamp produced a beam of light which, after passage through an 'Everclean' window, was thrown across the mall on to a photocell* at the end of a long blackened tube which reduced the effects of stray light and prevented deposition of soot on the photocell. A perspex light guide lead a little of the light from the lamp to a photocell monitoring changes in output.

These were installed to scan the width of the arcade at 0.5, 1.1 and 1.7 m below the ceiling, close to positions K and M, and 1.7 m below the ceiling close to position L.

The reading of the long path length instrument was influenced only by smoke and not by beam deflections caused by refractive index gradients due to temperature gradients in the hot gases. This is presumably because the beam of light reaching the far side of the arcade was wide enough to be capable of a slight deflection without appreciable change in the illumination at the photocell, unlike a laser beam which is very narrow and whose small deflection can be made to operate an alarm system[10]. Burning a large tray of industrial methylated spirit in the arcade produced no perceptible change in reading of the smoke meter.

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* Selenium barrier layer type

Air velocity was measured at 5 points by means of electronic vane anemometer heads. These were connected through a specially developed switching unit to a counting circuit which took as input the pulses caused by the change in capacity of an electrode as the vanes passed close to it and gave as output a voltage which was recorded on a chart recorder. A reading from each head was obtained every 60 s.

Three heads were placed in the centre of the arcade at position K (Fig.3) at heights of 0.30 m, 0.90 m and 1.50 m from the ground and two were placed centrally in the plane of the opening between the arcade and the fire compartment, at heights of 0.30 and 0.90 m above the top of the sill. It would have been desirable to measure the velocity in the hot gases but the heads could not withstand elevated temperatures.

A weighing platform was provided in the fire compartment, consisting of a heavy welded-steel frame covered with 10 mm thick asbestos millboard and supported on load cells which were protected against heat by a thick layer of insulation and aluminium foil.

The signals from most of the instruments were recorded on punched tape by a data logger, and processed by means of a computer.

## 4. FUELS

The following fuels or fuel arrangements were separately burned:

(1) 22 litres (5 gals) kerosine burned on a layer of cool water in a tray approximately 1.2 m square.

(2) As (1) but with a 2.4 m square 'spreader' of thin steel sheet placed on a frame 0.6 m above the tray.

(3) A crib of wood 0.6 m x 1.8 m and 0.15 m high and weighing 22 kg, made from sticks of Baltic Redwood (Pinus sylvestris) 25 mm thick placed with an air gap of 75 mm.

(4) 7.4 kg of polyurethane foam cushions (from old'bus seats).

(5) 1.4 kg of expanded polystyrene pieces, burned in a tray on a balance between two trays of industrial methylated spirit (i.m.s.). Normal grade, density about 40 kg/$m^3$.

(6) 3.2 kg of foam rubber offcuts (from old'bus seats) burned on a balance between two trays of i.m.s.

(7) As (6) but with 1.8 kg of foam rubber offcuts.

These were all lit in such a way as to get the whole of the fuel flaming quickly. The computations for the standard optical density (next section) were made from data recorded when the rate of burning of the smoke-producing fuel had reached a fairly steady value, and when the depth of the layer of smoke-laden gases flowing along the mall was constant.

We are primarily concerned here with the problems arising when large quantities of smoke-laden gases are produced by a rapidly developing fire and are ejected into a pedestrian mall. The experiments described relate to well ventilated fires with flaming combustion and this would be appropriate for open shop fronts, as may be found in fully-enclosed and heated malls. No studies have yet been made of the smoke produced from fires with restricted ventilation, e.g. a shop with a closed-in front with some window glass removed by the fire, where although optically denser smoke may be produced the total rate of production may be much less.

## 5. RESULTS

In order that the data obtained can be used in other situations the results for a given material have been expressed as a 'standard optical density', taken as the optical density for a 1 metre path length after burning 1 gram of the material in a stirred volume of 1 $m^3$. These have been calculated from the optical density at K, obtained by an interpolation of the measurements at J and L.

The rate of flow of hot gases was obtained by two methods:-

> Method 1 assumed that the mass flow of effluent smoke-laden gas travelling along under the ceiling was equal to the mass flow of air along the arcade underneath this layer, i.e. it was assumed that the building was not leaky. The mass air flow was obtained from the anemometer readings, the total flow being obtained by integrating the area under a graph of velocity versus height. The upper boundary of the inflowing layer of air was obtainable from the readings of the thermocouples which showed that there was a fairly sharp change in temperature with height between the hot gas layer and the cool air underneath. The volume of gas passing the smoke meter was then obtained from its temperature.
>
> The rate of burning of the fuel was usually obtained by measuring its loss in weight. For fuels (1), (3) and (4) the fuel was placed directly on the weighing platform. For fuel condition (2) no weighing was possible as the spreader rested partly on the platform, but the rate of burning was derivable from that for (1) with a small adjustment due to a difference in the duration of the fire. Fuels 5, 6 and 7 were weighed on a spring balance observed through a small window in the door at the back of the fire compartment.

Method 2 obtained the flow of gases past the smoke measuring point from the rate of burning of the fuel, its calorific value, the heat loss up to the measuring point, and the temperature of the gases at the measuring point.

If only a small quantity of smoke-producing material was burnt the layer of smoke-laden gases formed was thin and the layer was optically dense, so that the obscuration of the beam of light in the smoke meter was nearly complete and no accurate reading of the optical density could be made. In these cases (Polystyrene and foam rubber) a small quantity of fuel (a few kilogrammes) was burnt between two trays of methylated spirit of total area 1.4 $m^2$. The alcohol fuel produced no detectable smoke, and the large volume of hot gases produced gave a deep layer of less dense smoke whose optical density could be measured more satisfactorily. Also the air inflow was of course greater and could be measured more accurately.

The standard optical densities found are given in Table 1. Some results quoted by Gross et al[3,11], Bowes and Field[4] and Gaskill and Veith[12] using bench or small scale apparatus are also included. All these are with a pilot flame.

Table 1. Standard optical density of smoke from various materials
(Well ventilated fires, flaming combustion)

| Material | Standard optical density [a] | | | | | |
|---|---|---|---|---|---|---|
| | Experiments in mock-up pedestrian mall | | Measurements by Gross et al. | | Measurements using fire propagation test apparatus (Mean) | Measurements by Gaskill and Veith[12] |
| | Gas flow from anemometer measurements | Gas flow from temperature measurements | Ref (3) | Ref (11) | | |
| Wood | $0.1_0$[b] | $0.1_0$[b] | 0.05[c]<br>0.04[j] | - | 0.05[d,l] | 0.04[h] to 0.05[h],0.03[i] |
| Polyurethane foam | $0.1_2$ | $0.1_5$ | 0.05 | 0.06 to 0.19 | 0.19[l] | - |
| Kerosine(spreader) | $0.2_8$ | $0.3_8$ | - | - | - | - |
| Kerosine(no spreader) | $0.4_4$ | $0.7_0$ | - | - | - | - |
| Foam rubber | $0.5_1$[e] | $0.6_3$[e],$0.5_5$[e] | $>$ 0.35 | - | - | - |
| Polystyrene | $0.6_6$[f] | $0.8_7$[f] | $>$ 0.10[g] | - | 0.18[m] | 0.41 to 4.1[k] |

a - the optical density per metre produced by burning 1 gram of material in a stirred volume of 1 cubic metre ($D_s$)

b - crib of Baltic Redwood

c - spruce board

d - birch plywood

e - with alcohol fire(in one of the foam rubber fires by accident no air flow measurements were made)

f - expanded polystyrene,with alcohol fire(normal grade)

g - solid polystyrene

h - limits for coniferous woods (boards)

i - Douglas Fir Plywood

j - Douglas Fir Plywood (exterior)

k - 'Polystyrene foam FR' - see page 9

l - Measurements by Bowes and Field[4]

m - Measurement by Mrs.R.Ramaprasad (Private communication)

## 6. DISCUSSION

Except for kerosine fuel there is reasonable agreement between the standard optical densities obtained from the two estimates of gas flow in the arcade tests and since these estimates are obtained by quite different and very simple methods this gives one some confidence in the values obtained. However previous experiments[2] show that a high precision cannot be achieved inthis kind of measurement.

The data for kerosine show more difference between standard optical densities given by the two methods, possibly because the radiant heat loss from the flames of kerosine is larger than the value of 25 per cent assumed, owing to the flames being especially emissive. Similar, though smaller, differences were found in experiments in a disused railway tunnel in Glasgow[2] between measurements of optical density based on a gas flow obtained from direct observation of the travel of the smoke 'nose' and on a gas flow derived from the temperature of the smoke layer.

The small-scale measurements of $D_s$ for woods are in the region of $\frac{1}{2}$ of those for the large-scale measurements and this might be a real difference between the smoke produced from small heated specimens and that produced in larger fires, due perhaps to a more rapid mixing of air into a smaller flame. It is not likely to be due to differences in the wood species since all the small-scale data, obtained from various coniferous woods and also birch, are similar. However in terms of standard optical density the difference between small and large scale data is not very large compared with the whole range of standard optical density given by all materials ($\sim$ 0.1 to 0.9).

For polyurethane foam the small scale values are less consistent, yet bracket the large scale values. Some of the variation may be due to a difference in smoke production between thevarious types of urethane foam or perhaps to the presence or absence of flame retardants; the data in reference 11 show that 'polyester urethane' gives higher smoke density values than the 'polyether urethane'. However even if this is not the explanation for the differences, as with the values for wood fuel they are not important in relation to the whole range of $D_s$ given by various materials.

For foam rubber and polystyrene such thick smoke was obtained by Gross et al[3], that only a lower limit could be set for the optical density which, because different weights of specimen were exposed, led to different lower limits for $D_s$. Gaskill and Veith[12] report a test with polystyrene foam but do not give density data to enable the weight of the specimen to be obtained. However, the density of polystyrene foam is almost certain to be between 10 and 100 kg/m$^3$ (0.6 to 6 lb/ft$^3$) and if these values are inserted for a 75 mm (3 in) square specimen, 6 mm ($\frac{1}{4}$ in) thick, we find that $D_s$ lies between 4.1 and 0.41 for 'polystyrene foam FR'.

Bowes and Field[4] tested a specimen of expanded polystyrene but the specimen melted and gave no measurable smoke.

In view of the present interest in test methods for smoke production it seemed advisable to explore further the smoke-producing properties of expanded polystyrene and accordingly some small scale experiments were also made with this material. These have highlighted the considerable difficulty in setting up meaningful tests for smoke production of some lining materials.

In the first experiments a 25 mm thick sample of expanded polystyrene (standard grade, density 17 kg/m$^3$) was exposed in the fire propagation test apparatus[13]. The test was carried out in the standard way except that asbestos paper was placed round the rear and sides of the specimen to ensure that molten material could not run down into the bottom of the specimen holder and escape burning. Fourteen grammes of polystyrene were consumed - virtually the whole sample.

The test apparatus was itself placed in a closed chamber of volume 19 m$^3$ equipped with two fans which stirred up the smoke produced and distributed it throughout the chamber. The transmission and hence the optical density of the smoke was measured by means of a smoke meter. Little smoke was produced, the optical density rising to only 0.07 for a path length of 0.56 m after about 10 min, and this leads to a value for $D_s$ of 0.18 per g

Next, 20 g quantities of expanded polystyrene were burned in the same chamber in a thin metal tray 260 mm in diameter. Twenty grammes of standard grade polystyrene (not self extinguishing) were taken first, broken into several pieces, piled in the tray and ignited by lighting a few mls of alcohol poured over the pile.

The polystyrene ignited readily and burned up quickly producing black smoke. It rapidly melted and the molten material was contained by the tray so that all but about 1 g (obtained by weighing) was consumed. The optical density per metre rose to 0.8 in 3 min, when the burning was completed (Fig.5) and then slowly decreased, presumably as the smoke particles fell out of suspension. After the test the floor of the chamber was strewn with large black smoke particles. This gives $D_s = 0.8/g$, close to the arcade test value.

The test was repeated with the same weight of self extinguishing grade expanded polystyrene with a very similar result (Fig.5).

Some difficulty was experienced in getting the self-extinguishing grade polystyrene to ignite. Although flames some 0.2 m high were produced when the alcohol poured over the pile was lit the fire rapidly went out, leaving beads of molten polystyrene in the tray. A further addition of alcohol also gave no ignition. This was eventually achieved, with the same sample, by heating the tray over a low gas ring and when vapour could be seen to be evolved, lighting with a match. A small flame flickered at first and then spread rapidly over the molten pool which then burned well producing black smoke and leaving virtually no residue in the tray, so that about 20 g of material was burnt in all. This gives $D_s = 0.9/g$.

A self extinguishing grade of polystyrene can burn if it is exposedto a high enough heat flux; this could occur for example in a fire if other combustible materials were present in sufficient quantity.

The optical densities obtained were a little higher than for the normal grade material but it is doubtful whether this difference is significant - it was possibly caused by more stratification due to the greater heat release required to ignite the self extinguishing grade polystyrene.

These results show that when polystyrene burns under conditions approximating to those of a well-ventilated fire, much more smoke per gram is produced than in the fire propagation test,- a test appropriate for linings. This difference in smoke production must be due to the apparatus itself or some feature of how the specimen burnt in the apparatus rather than to the method of smoke collection. It is clear that the high value obtained in the full scale arcade test was not due to the freshness of the smoke - Fig 5 shows that the optical density of polystyrene smoke decays quite slowly.

The overall average value of $D_s$ for kerosine ($0.4_5$) is very close to the average obtained from the experiments in the Glasgow railway tunnel ($0.4_7$) and the scatter of the values is similar, whilst the gas temperature in the layer (Table 2) was higher than in most of the railway tunnel experiments, because the experimental mall was not so tall as the tunnel and less air was entrained into the rising plume above the fire.

It is now seen to be very unlikely that kerosine smoke is affected by the gas temperature over the range of the experiments so far (45 - 190°C rise), for example by condensation, agglomeration, etc.

With regard to the other materials it can be said that the measurement was made at points far enough away from the fire compartment for the opacity of the smoke to represent realistically the opacity in the real situation where the fire might be larger, but we would need to estimate visibility for a longer distance of travel of the smoke. In any case table 2 shows that at this point the gases were in nearly all cases substantially cooled. One of the tests with foam rubber had a temperature rise of 140°C at the measuring point, but the standard optical density given by this test was close to that in a repeat test with a smaller quantity of rubber where the temperature rise was only 85°C.

Turning now to the differences between materials it is seen that there are very considerable differences in the standard optical density and hence in the visibility of the smoke produced by different materials. The conversion from optical density to visibility can be made by means of the relation given by Rasbash[14]. Table 3 gives the quantities of various materials needed to produce a standard visibility (4.5 m or 15 ft) in a volume representing a small shopping mall and shows that only very small quantities of materials need to be burnt to produce this high level of smoke logging.

Table 2

| Material | Peak gas temperature rise at point of measurement of smoke density<br>deg C |
|---|---|
| Wood | 80 |
| Polyurethane foam | 50 |
| Kerosine (spreader) | 190 |
| Kerosine (no spreader) | 170 |
| Foam rubber | 140, 85 |
| Polystyrene | 65 |

Table 3. Comparison of materials in terms of visibility of smoke produced

| Material | Value taken for standard optical density (Table 1) | Mass of material to give 4.5 m (15 ft) visibility in volume of 540 m$^3$ (20,000 ft$^3$) | | Equivalent volume of material |
|---|---|---|---|---|
| | | (kg) | (lb) | |
| Wood | 0.10 | 1.2 | 2.6 | 2,500 cm$^3$(0.09 ft$^3$) |
| Polyurethane foam | 0.13 | 0.91 | 2.0 | 22,000 cm$^3$(0.8 ft$^3$) |
| Kerosine | 0.5 | 0.24 | $0.5_3$ | 310 cm$^3$(½ pint) |
| Foam rubber | 0.55 | 0.22 | $0.4_9$ | 1,100 cm$^3$(0.04 ft$^3$) |
| Expanded polystyrene | 0.76 | 0.16 | 0.35 | 12,000 cm$^3$(0.43 ft$^3$) |

The third, fourth and fifth columns give the quantity of material required to produce a visibility of 4.5 m (15 ft) in a stirred volume of 6 m x 3 m x 30 m (20 ft x 10 ft x 100 ft) i.e. 540 m$^3$ (20,000 ft$^3$).

Following a suggestion by Dr D J Rasbash, estimates have been made for the various fuels (Table 4) of the fraction of the mass of the fuel which becomes converted into smoke, assuming that a concentration of suspended material of 0.33 g/m$^3$ would be required to produce unit optical density in a path 1 m long. This value derives from tests on smoke produced by domestic heating appliances[15].

Table 4. Estimates of the fraction of the mass of fuel converted into smoke

| Material | Value taken for standard optical density (Table 1) | Fraction of the mass of fuel converted into smoke (per cent) |
|---|---|---|
| Wood | 0.10 | 3 |
| Polyurethane foam | 0.13 | 4 |
| Kerosine | 0.5 | 17 |
| Foam rubber | 0.55 | 18 |
| Expanded polystyrene | 0.76 | 25 |

As with the previous measurements in a disused railway tunnel[2] no high precision can be claimed for these measurements, although they are probably accurate enough for the intended purpose. What can be claimed for them is that these are quantitative and objective measurements made under conditions approximating to those of real fires.

## 7. CONCLUSIONS

1. Quantitative values are given for the smoke production in vision-obscuring terms of 5 materials, including some especially bad smoke producers, under well-ventilated large-fire conditions, the smoke measurement being made at a point where the smoke has cooled substantially, though not completely.
2. The worst materials gave an optical density per gram 7-9 times that of the best material. This is equivalent to saying that to produce the same level of visibility in a given volume the worst materials would require only $^1/_7$ to $^1/_9$ of the mass for the best material.
3. Very small quantities of most materials can produce a surprising amount of smoke, even when burning with a flame, for example to give a visibility of 4.5 m (15 ft) in a volume of 6 x 3 x 30 m (20 x 10 x 100 ft) requires only 1.2 kg (2.6 lb) wood, or 0.16 kg (0.35 lb) of polystyrene.
4. Apart from the experiments with kerosine there is reasonable agreement in the values of standard optical density ($D_s$) obtained using two methods for estimating the gas flow rate in the smoke layer. The differences in these estimates given by the kerosine fuel may be due to an error in the radiation loss term.
5. For wood and polyurethane foam the differences in $D_s$ between small-scale or bench tests and the large scale tests are small compared with the overall range of $D_s$ from various materials and are therefore not very important.
6. For expanded polystyrene the non-standard tests described in this report give values of $D_s$ much higher than other available results. This is unlikely to be due to the effect of scale but could be due to differences in the mode of combustion.
7. Wood in the form of an open crib is the best of the materials tested so that it is not the most suitable fuel material to use in experimental fires when smoke opacity is crucial.
8. Kerosine is a bad but by no means the worst smoke producer.

## 8. ACKNOWLEDGMENTS

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Mr.H.Wraight was responsible for most of the instrumentation and data recording arrangements; Mr.C.Theobald developed the long-path smoke meter and the switching unit for the anemometers.

Messrs P. Collinson, J.Leake, J.Haselwood and S.Fink carried out the experimental work and the computations for this report.

Mr.North developed computer programs for the processing of the data tapes obtained, and arranged for the regular processing of the tape.

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## ADDENDUM

Since writing this note another paper with measurements of the smoke production from various materials has come to hand ('Smoke development in polymers during pyrolysis or combustion', J. R. Gaskill, J. Fire and Flammability, 1, (July 1970), p.183). Apparatus and methods similar to those of Gross et al[3] were employed and a value for the standard optical density of solid polystyrene of 0.07 per g (Flaming combustion) can be derived from the data quoted. Data are also given for various types of urethane.

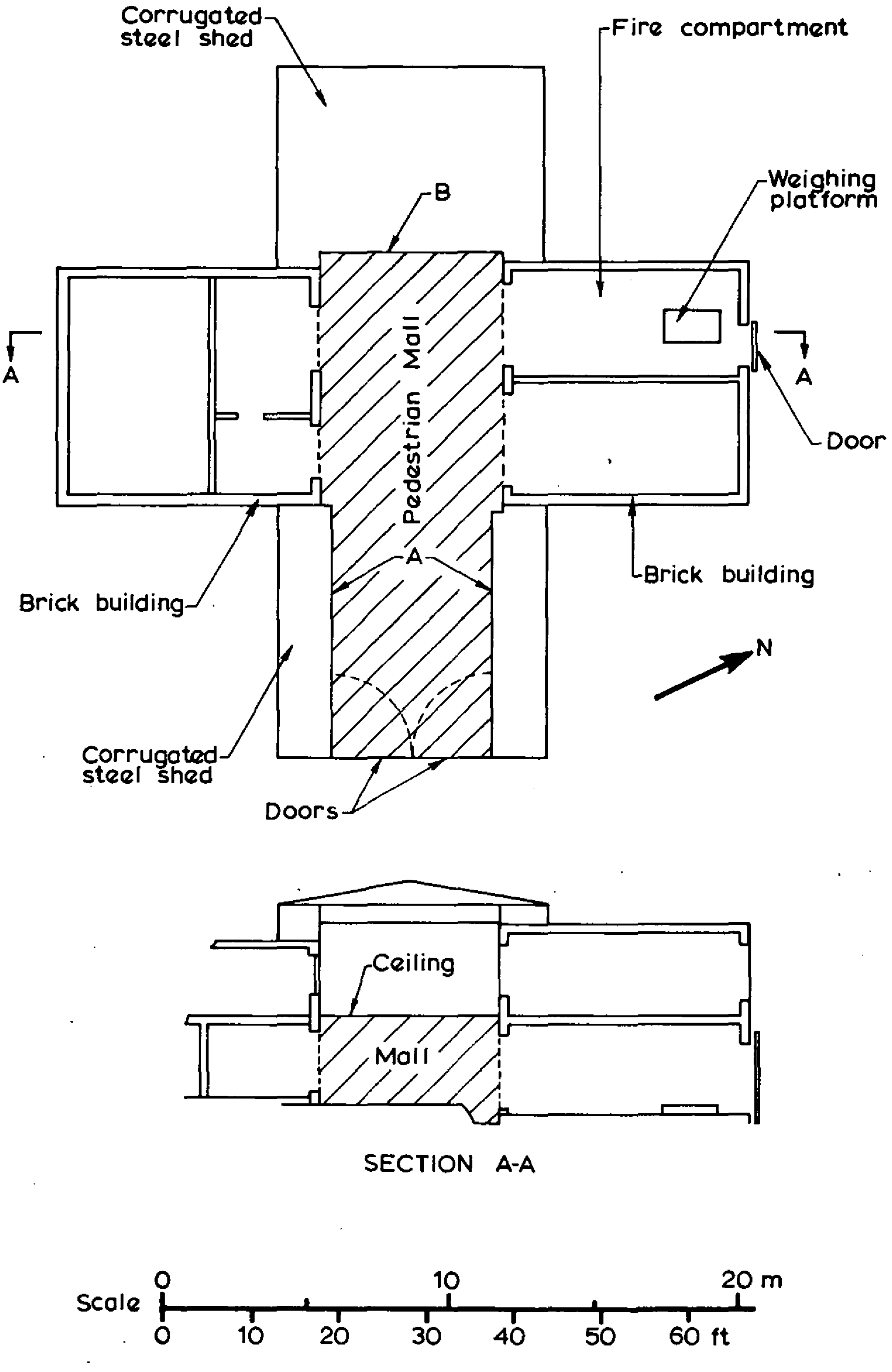

FIG. 1. PLAN AND SECTION OF EXPERIMENTAL BUILDING

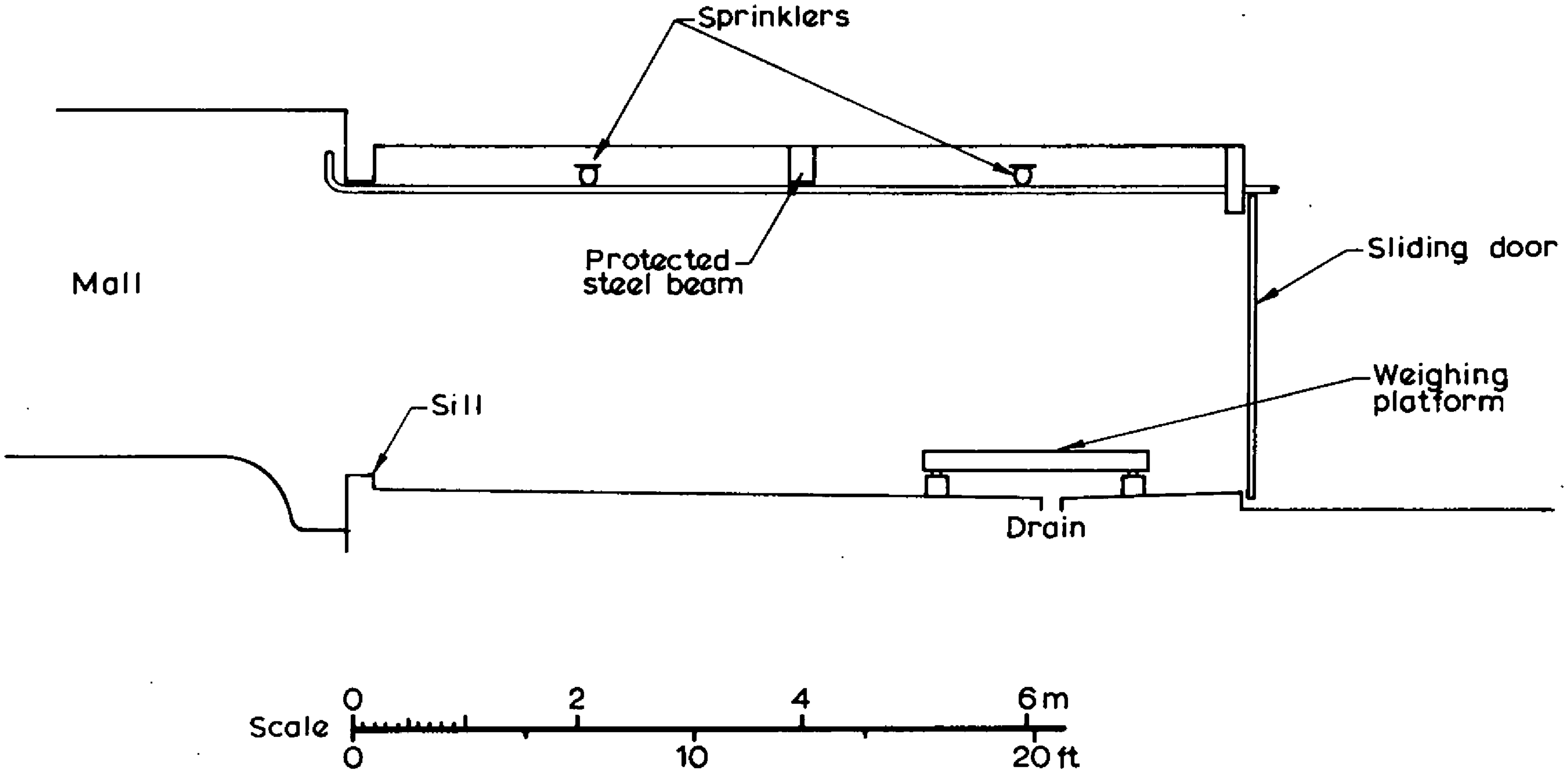

FIG. 2. SECTION THROUGH FIRE COMPARTMENT AND MALL

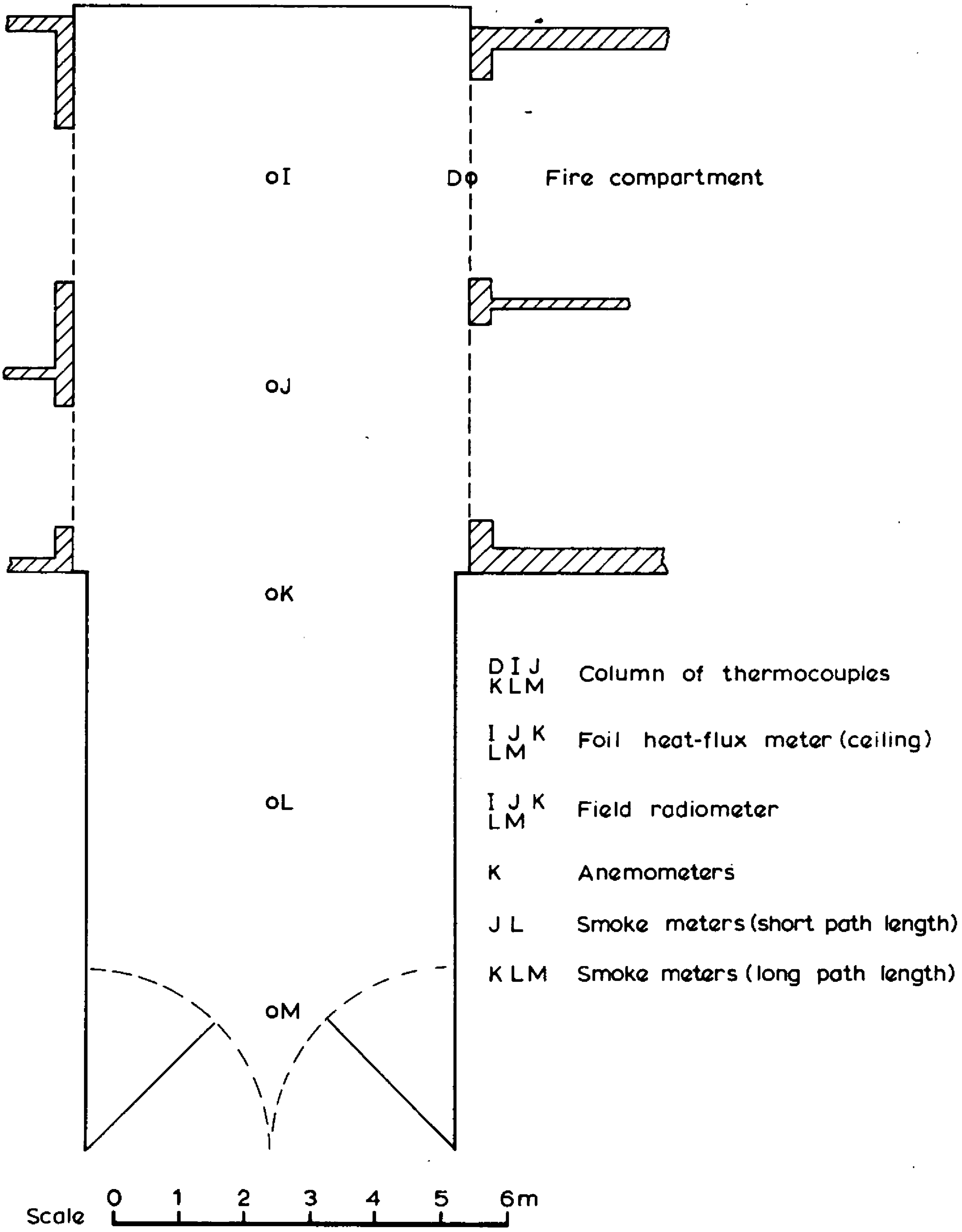

FIG. 3. PLAN OF MALL SHOWING POSITIONS OF INSTRUMENTATION

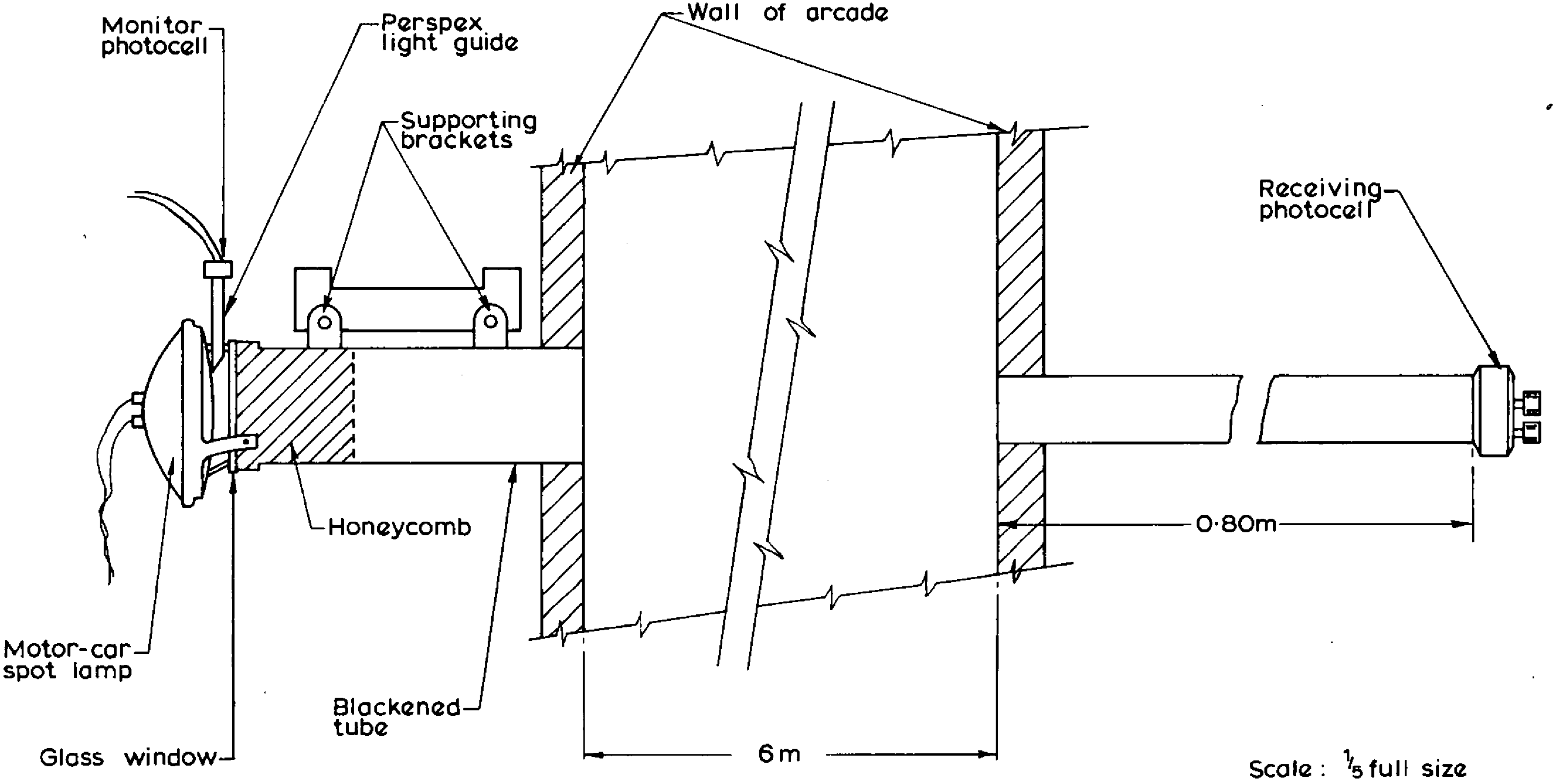

FIG. 4. SMOKE METER FOR THIN SMOKE

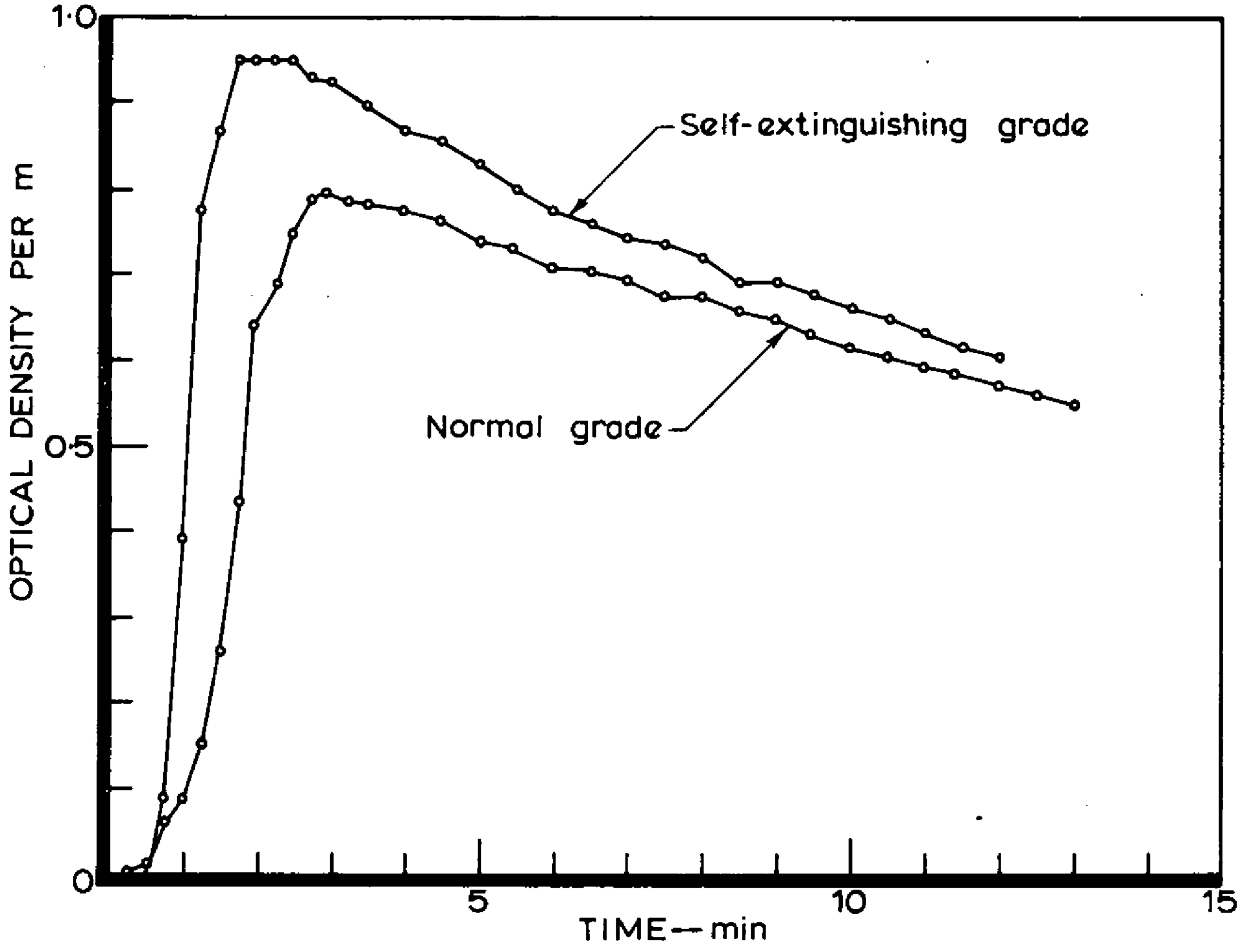

FIG. 5. TESTS WITH POLYSTYRENE BURNT IN A 19m$^3$ CHAMBER