Fire Research Note No 955

FIRE TESTS ON AN AIR-SUPPORTED STRUCTURE

by

J S Hopkinson

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FIRE
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SUMMARY

Concern over the stability of air-supported structures under fire conditions has been expressed by those involved with safety of persons in places of assembly and over the safety of contents by those concerned with insurance of property.

Tests have been conducted to investigate the behaviour of a structure with high and low level perforations, the effect of smoke and fires on escape, the characteristics of the fabric material and the fire fighting problems.

From these tests it was found that smoke is vented by any opening made in the structure, and normal exits may become smoke-logged when they are opened. The structure remains inflated with small fires even though the fabric is punctured, aided by the buoyance effect, but collapses quickly with a large fire. Fires can be put out from inside if they are small and from outside if the collapsed fabric lies flat on the ground.

KEY WORDS: Building air-supported; fire hazard; escape means; fire tests.

DEPARTMENT OF THE ENVIRONMENT AND FIRE OFFICES' COMMITTEE
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1. INTRODUCTION

A pneumatic structure has been defined[1] as one in which pressurized air stiffens or stabilizes a flexible material to form a structural shape. There are two types of pneumatic structures - air-supported structures where a single wall of material is inflated with air, maintained at a pressure slightly higher than atmospheric pressure, and air-inflated structures where walls or roofs of tubular or cellular construction are pressurized to develop structural stiffness.

A patent for an air-supported structure was first taken out in 1917 by Frederick William Lanchester[2,3] of Lewisham who had previously designed motor cars. It appears that the idea was not taken up until the forties when the need arose for a covering over radar antennae exposed to artic conditions. It was required that no metallic components be used in the protective structure and the concept of an inflated thin fabric was put forward. The structure used was heated from within to remove ice and snow, was stable in the artic winds due to the pressurization and it did not interfere with the radar waves. Many such 'radomes' were made for the US Air Force until the late fifties when an adaptation of the idea was made for use as a warehouse. The idea of a temporary warehouse providing a cheap and quick method of protecting goods from the elements appealed to industry. When the goods had been dispatched, the air-structure could be deflated and transported elsewhere for further use.

The concept of cheaply covering a large area was taken up quickly and by 1957 air-structures were being used for sports facilities[1,4], swimming pools, tennis courts and ice hockey stadiums. Greenhouses made with a transparent envelope are large enough to enable the users to operate conventional farm equipment inside. The temporary nature of the air-structure makes their use at exhibitions particularly attractive and this use has perhaps to date been the most popular application. Their use as coverings over sports facilities is becoming more widely accepted in the United Kingdom.

The fabric of an air-supported structure needs to have a substantial tensile strength because all of the static and dynamic stresses are of a tensile nature. This is achieved by using a reinforcing technique where for example a nylon matrix is coated on both sides with PVC. The perimeter of such structures has to be firmly anchored in order to avoid substantial leaks of the pressurized air and although pegged structures offer several advantages for temporary situations, a concrete ring beam foundation is recommended since it provides the necessary mass to fix the building firmly. The air inside the structure may be at a pressure of 10-30 mm w.g. above atmospheric and to avoid deflation by escaping air a special arrangement is made for access. The usual systems are revolving doors or two doors with an airlock arrangement. Bumper doors have proved unsuccessful[1] due to the quantity of air lost even from large structures. Air-curtains which counter the escape of air from the structure can also be used. The internal air pressure is maintained usually by electric fans with diesel power available in the event of electricity failure. The air inlets are located in the walls of the building and the functions of air conditioning and heating are sometimes combined with the supply of air for pressurization. The fabric may be translucent allowing adequate daylight into the interior but extra light may be provided by transparent panels. Light fittings are sometimes suspended from the walls, specially strengthened portions of fabric being provided to avoid any distortion.

The problem of collapse of these structures has been raised from the early days because of the absence of structural members in the accepted sense and also because of the dependence of the stability on the over-pressure of air. In the event of power failure to the fans, diesel generators would immediately come into operation. A fan failure will result in gradual deflation which in larger structures may take several hours[5] provided no intrusion is made via the doors or any puncturing of the fabric takes place. If, however, there are large numbers of people seeking an exit at the same time, the structure may not remain inflated very long and some additional method of maintaining height is sometimes provided by using steel cables suspended from poles located at the perimeter. This additional support is not in general provided and so the problem of collapse in the event of an emergency is important.

Since the air-structure has several advantages in situations normally fulfilled with more conventional structures, its use may well become more popular and this raises the question of its acceptance by Regulating Authorities.

Only limited information has been available on their performance under fire conditions on the basis of experiments carried out[6,7,8] in other countries. Under the particular conditions of these tests, the air-structure fabric did not appear to contribute to the spread of fire. Observers, although small in number, were able to escape satisfactorily. It also appeared possible that under the right conditions, heat of combustion could increase the buoyancy of the fabric sufficiently to resist deflation when the fabric became punctured. Confirmation of this work and further information of behaviour in fires was required as well as indications of the performance under phenomena leading to collapse of the structure, for example by the failure of the fan.

The insurance bodies have expressed concern[9] over the contents of an air-structure involved in fires because of the reluctance of the fire brigade to enter a damaged structure to extinguish the flames. Users of air-structures would benefit from information enabling them to reduce the hazard to structure and contents and the insurance companies could use data indicating the precise hazard.

In the meantime, due to the rising demand for these buildings, guidelines on the use and precautions to be taken have been prepared by the Regulating Authorities[10].

2. OBJECTIVES

There being no standard test method by which to determine the fire performance of the air-structure, tests of an ad hoc nature were proposed.

The objectives of the tests were to establish -

1. the pattern of smoke movement inside the structure when undamaged.
2. the effect of high and low level openings on the smoke movement
3. the effect of smoke movement on escape
4. the effect of fires on collapse of structure
5. the ignition and flammability characteristics of the fabric; and
6. to obtain information on fire fighting problems.

In addition, structural behaviour was investigated by the Structural Concrete Section of the Building Research Establishment[11] under the following headings:

1. Time for inflation.
2. Time to collapse under various conditions.

Time to collapse was defined as that time interval after the beginning of a test when the structure deflated to a height of 1.8 m (6 ft). Where relevant, mention is made of these tests in this report.

3. STRUCTURAL DETAILS

An air-structure was made available for structural and fire performance tests. The envelope had been fabricated in Sweden specially for the tests, and in terms of size was not typical of those used for warehousing or sports arenas. It would have perhaps been suitable for small exhibitions or swimming pools.

3.1. Size

The structure measured 19 m x 9 m and was 4 m high at the apex, of a semi-culindrical design with quarter sphere ends (Plate 1). The volume was approximately 480 m^3 (17000 ft^3) and the surface area 250 m^2 (2700 ft^2). On the site provided for the tests, the structure was orientated with major axis approximately east-west.

3.2. Fabric

The fabric forming the envelope of the structure was stated to have properties as given in Table 1.

Table 1. Technical description of fabric

Property	Warp direction	Weft direction
Fibre	Nylon	
Thread	840 denier	
Density of thread	12/13 threads per cm	
Coating	Soft PVC	
Tensile strength	400-450 kgf/5 cm	
Elongation at rupture	25%	35%
Tear resistance	65-100 kgf	
Weight	760 g/m^2	
Thickness	0.75 mm	

The anchorage of the fabric to the ground was achieved by filling the trough at the perimeter with water bags and sand. This provided the necessary weight to resist the tendency to lift but to avoid local displacement of the walls the fabric was secured with nylon rope to stakes driven into the ground. The building was erected on a layer of sand. A more permanent structure would have the perimeter secured to concrete foundations thus providing the necessary mass to resist vertical and lateral movement of the walls.

3.3. Door

Access to and from the air-structure was through an airlock measuring 1.8 m square on plan and situated on the east end. The height was 1.9 m with an apex of 2.3 m providing a sloping roof for drainage. Each door of the airlock measured 1.9 x 1.0 m and in opening outwards the over-pressure of air assisted their function. The main structure was joined to the airlock framework by a tunnel piece which was clamped to the framework (Plate 2). The stresses created in the envelope at the airlock were distributed along a 2 m steel bar inserted into a sleeve in the fabric above the head of the airlock. The ends of the bar were anchored to the ground by wire hawsers. In order to prevent the airlock lifting when the inner door was opened, it was necessary to peg the perimeter of the airlock to the ground.

3.4. Fan

The building was inflated and maintained in a pressurized condition by a single fan supplying air at a point 1.6 m from the ground and 5 m from the door along one wall. The air was supplied through a tube 0.53 m diameter and 3 m long which was fabricated from the same material as the main envelope. The tube was anchored to the wall by a circular plate having eight hinged louvred blades held open by the incoming air, and forming a non-return valve in the event of fan failure. The fan was mounted on a temporary frame at the far end of the supply tube and had the following specification:

Table 2. Specification of fan type PMCA1

Supplier	Thrige - Titan, Denmark
Cat. No.	MK 110 019-C
Manufacturer	AB Svenska Flaktfabriken, Stockholm, Sweden
Type	MT 80B 19-4
Power	0.75 kW
Speed	1410 rpm
Supply	380-420 V, three phase

According to the specification, the fan was capable of supplying 10,000 m^3/h of air into an over pressure of 13 mm wg and 7,000 m^3/h into an over pressure of 23 mm wg.

4. TEST METHOD

To study the effect of high and low level openings two removable vents were provided, each measuring 1 m square. One was situated at the apex and the other on one side with its centre 5 m from the wall of the door end (Fig. 1) and its lower edge 0.5 m from ground level. The vents were removable being fixed with "Velcro" fasteners. This enabled them to be taken off several times without the inconvenience of using adhesives. With the exception of tests 6 and 7 the side vent was not used because in terms of venting smoke, it behaved in a similar manner to the door. The door is thus referred to as the low level vent. The effect of venting smoke depended on the area of opening.

The performance of the structure was judged mainly by observation of the smoke movement, measurement of the smoke density and the collapse pattern.

4.1. Smoke tests

Experiments were carried out using both cool and hot smoke. This was produced at the centre of the structure and its movement observed. It has been found[12] that smouldering wood shavings and fibreboard produced smoke at 250°C but this behaved as cool smoke by the time dilution had occurred in the comparatively large volume assisted by the heat loss through the skin. Hot smoke was obtained by burning 1 litre of petrol in a tray (calorific value - 8,000 k cal) and in these instances, stratification occurred, whereas with the cooler smoke, no stratification was observed. Various combinations of door, fan and vent were used in the investigation on smoke movements. These are listed in Table 3.

Table 3. Smoke tests S_1-S_7

Test No.	Fan	Door	Apex Vent	Type of smoke
S_1	On	C	O	Cold
S_2	On	O	O	Hot
S_3	Off	C	C	Cold
S_4	Off	C	O	Cold
S_5	Off	O	C	Cold
S_6	On	O	C	Hot
S_7	On	O	C	Hot

(C - closed; O - open)

4.2. Fire tests

Three tests were carried out using timber cribs as fire load, details of which appear in Table 4. They were of increasing severity and were designed to investigate objectives Nos 4-6.

Table 4. Fire tests, F_1-F_3

Test No.	Crib size	Crib weights	Position of crib	Remarks
F_1	300 mm cube 1:1 spacing 25 mm sq. sticks	27 kg	250 mm from side wall	Plate 4
F_2	0.7 m x 0.7 m x 400 mm high	48 kg	Centrally, 1.2 m above ground level	Plate 5
F_3	0.5 m x 0.5 m x 10 m long	630 kg	Along major axis	Additionally 25 car tyres arranged at each end

Test F_1 was designed to investigate whether fire from a small source would spread along the fabric. The crib was arranged so that the flames played upon the internal surface.

Test F_2 was designed to investigate the effect of a larger fire on collapse of the structure. The fire was designed to puncture the apex but not to produce widespread damage.

The final fire test, F_3, subjected the structure to severe fire conditions to provide information of flame spread on the fabric under more severe conditions than tests F_1 and F_2 and the ability of the fire brigade to extinguish the burning contents by having members of the local fire brigade on the scene.

5. INSTRUMENTATION

Visual observations in the tests supplemented instrumentation and photographic records. Three posts to which the instrumentation was attached were adjusted to be 1.8 m above ground level. In addition to providing anchorage for instruments these provided reference points for judging the time to collapse, ie the time at which the structure deflated to 1.8 m. This was thought to be a relevant height when considering the escape of occupants.

The over pressure inside the structure produced by the fan was measured at 1.8 m above ground level on the instrument posts along the major axis[11] and was in the range 12 to 15 mm of water. The rate of pressure drop when the apex vent was opened is shown in Fig. 2 as a typical result.

5.2. Smoke

Optical density was measured in the smoke tests at four points as indicated in Table 5 below: (see also Fig. 1).

Table 5. Location of Smoke Meters

Smoke meter number	Location
1	Height 1.8 m. Distance from wall, 1 m. Distance from entrance door 5 m. This meter monitored smoke leaving the emergency exit (side vent).
2,3	Height 1.8 m, situated at the two third points on the major axis.
4	Height 1.8 m, situated between the doors of the airlock to monitor smoke leaving through the entrance.

The instrument used had been designed and built at the Fire Research Station and used the principle of attenuation of light falling on a photoconductive cell.

5.3. Air temperatures

Temperature of the interior air was measured with chromel-alumel thermocouples at ten positions (see Fig. 1) as listed in Table 6 below and recorded on a Honeywell potentiometric recorder.

Table 6. Location of thermocouples

Thermocouple numbers	Location
1 - 4	Two on each side wall 1.8 m high and at the third points along the length.
5 - 7	1.8 m high on the instrument poles.
8 - 10	300 mm from the roof at the quarter points along the major axis.

6. TEST RESULTS

Full details of observations made in each test are given in the Appendix and the temperatures and smoke conditions are shown in Figs. 2 to 9 and the appearance of the structure in various tests is shown in Plates 3 to 8.

6.1. Air and smoke movements inside undamaged structure

6.1.1. Anemometer measurements

The entrance of air from the fan at close proximity to the louvred flaps could be felt but measurements with a vane type anemometer showed no measurable air movement over the floor area at a height of 1.8 m presumably due to the flaps deflecting the incoming air downwards.

6.1.2. Cold smoke. (Tests S_1, S_3, S_4 and S_5)

Smoke generated from smouldering wood shavings and fibreboard diffused throughout the structure in 30 minutes. Observations showed that the smoke did not stratify.

There was no noticable difference in this behaviour whether the fan was running or not. (Tests S_1 and S_4). As smoke was generated, visibility became slowly reduced to 6 m after 30 minutes. (Test S_4). There was no temperature rise at the apex during these tests.

6.1.3. Hot smoke. (Tests S_2, S_6 and S_7)

Burning petrol produced hot black smoke which rose immediately to the apex of the envelope and stratified. As more smoke was produced, the layer quickly dropped until at about 1½ minutes it had reached 1.5 m from the floor. By 4 minutes the layer had virtually reached the floor. Temperatures at the apex rose to 100°C.

6.2. Effect of high and low level openings on smoke movement

It was apparent that when the building was smoke logged, venting produced a similar pattern of smoke movement with hot or cold smoke. The quantity of smoke produced by the medium and small cribs in the fire tests F_1 and F_2 was not sufficient to give information on smoke movement. Observers were able to remain in close proximity to these fires in both cases.

Data on the movement of smoke resulting from opening various combinations of high and low level vents are summarized in Table 7.

Table 7. Effect of opening high and low level vents on smoke movement

Test No.	Fan	Vents open	Collapse* time	Smoke movement
S_1	On	High level only	3 min 5 sec	Smoke forced through apex vent (Plate 3)
S_2	On	High level and door	55 sec	Smoke vented through both openings but more observed to leave through the doorway than apex vent
S_3	Off	Neither	20 min	Smoke leaked away slowly with escaping air
S_4	Off	High level only	2 min	Smoke forced through apex vent
S_5	Off	Door only	1 min	Smoke was pushed out through the door by the collapsing structure and the escaping over pressure
S_6 & 7	On	Door only	1 min	Smoke pushed through doorway leaving bottom 1.2 m relatively clear

*Collapse time is defined as the time for the structure to deflate to 1.8 m (6 ft).

6.3. Effect of smoke movement on escape

Tests conducted with hot smoke from burning petrol - (Nos. S_2, S_6 and S_7) gave an assessment of the effect of smoke movement on escape. In the other tests, the visibility was never low enough to cause the exit to be obscured.

In Test S_2, more smoke was forced through the doorway (having the larger area) than through the apex vent. Since the collapse time was only 55 seconds, escape may have been hazardous. The collapsing structure tended to lower the smoke level, causing an initial increase in smoke density near the ground (Fig. 3). As with Test S_4 (Fig. 5) the smoke density in the main hall momentarily increased when the apex vent was opened.

In Test S_6, the smoke was allowed to build up until even the fire was obscured. By just over 2 minutes, there was only 1.2 m (4 ft) height from the floor not obscured by smoke. The door was opened at 4 minutes for the observers to leave the structure but smoke was still escaping 1 minute later.

In Test S_7, the door was opened after 2 minutes and the structure had collapsed 1 minute later. Smoke was forced through the doorway but the lower 1.2 m (4 ft) was observed to be fairly clear. Observers inside the structure wearing breathing apparatus, noted that the building was smoke logged at this stage, to a height of 1.2 m (4 ft).

6.4. Results of fire tests

6.4.1. Small fire F_1

The first signs of the effect of heat on the fabric were scorching and smoking, observed from both internal and external surfaces. Scorching continued until small blisters were observed on the external surface. By this time, smoke was coming from an area approximately 900 x 400 mm. The number of blisters and the quantity of smoke increased until ignition took place on the internal surface. Puncturing of the fabric occurred at 7 min 35 sec forming at first a vertical slit, immediately widening to a hole 600 x 230 mm.(Plate 4). Although flames were being forced through the hole, it did not enlarge very quickly. The escaping air from the inflated structure forced smoke and flames through the hole. Although the hole increased in size the structure did not collapse - the fan supplying sufficient air to compensate for that lost through the hole and the fire supplying hot air to increase buoyancy.

When the doors were opened thus providing a larger area for air to escape, the air flow through the hole was reversed and the flames from the crib were drawn back inside through the hole. The flames were forced out again when the door was closed. The fire was extinguished and the structure did not deflate. The hole was repaired while the fan kept the building up.

6.4.2. Medium fire F_2

In this test the effect of a fire in the central area on the collapse pattern of the structure was examined. The fire was not large enough to cause large-scale damage to the fabric.

The flames caused a split in the fabric after 2 min which developed to a hole about 1 m square. Although the walls and roof flapped slightly in the wind, the structure did not collapse - the hot air from the fire imparting some buoyancy to the structure. (Plate 5).

The hole enlarged and the building deflated to 1200 mm above the crib by 10 min 30 sec. When the fire was extinguished after 15 min the crib was standing proud of the fabric (Plate 6). Once the fabric had collapsed below the crib height, no hot air was being supplied to the remaining volume, and complete collapse followed fairly quickly. Until that time the occupants within the structure could have made their escape.

6.4.3. Large fire F_3

This fire subjected the structure to severe conditions and was designed to produce complete collapse.

Five seconds after flames touched the ceiling, smoke was observed from the external surface above the crib. The fabric was penetrated by the flames at 45 sec and noticeable deflation was taking place less than 1 minute later. The building collapsed quickly as the flame built up and burnt back the fabric. The observers were forced to leave as the structure collapsed around the crib at 2 min. The bars holding the fabric clear of the ground near the door (see 3.3) permitted easy evacuation. The fabric burnt as soon as it fell on the burning crib until a hole the same size as the crib had been made.

The final size of the hole was not much larger than the area of the crib except where prevailing wind had caused flames to deflect towards one collapsed wall leading to sustained ignition until the fabric in that area was consumed.

6.5. Characteristics of the fabric

6.5.1. Small scale tests

The following is a summary of small scale tests carried out on the fabric to investigate its fire performance.

B.S. 2782 508C (semi-circular test).

The degree of flammability was found to be 9.5 mm ($\frac{3}{8}$ in). This could be compared with the requirements for PVC stretch plastic ceilings under the Building Regulations 1972 (E16). With this test the permissible degree of flammability for such ceilings is 75 mm (3 in).

BS. 2782 508D (alcohol cup test)

This test was not suitable for testing the fabric because severe distortion of the sample occurred when subjected to the heat.

BS. 3119 (vertical strip test)

The length of charred or burnt surface was 44-70 mm ($1\frac{3}{4}$-$2\frac{3}{4}$ in) classifying the fabric as "inherently flameproof".

BS. 476 Part 5 (Ignitability test)

The flame melted a hole through the sample. There was no ignition and therefore no flamespread. The material is therefore classified as "not easily ignitable".

BS. 476 Part 6 (Fire Propagation test)

The samples were tested with an air gap behind them and gave $i_1 = 11.01$ and $I = 17.83$. This shows that the fabric ignited and the heat content was released in the early stages. The result is typical of other flexible fabrics which have been examined.

6.5.2. Fire tests (see also 6.4.1)

The fabric performance is best seen in Test F_1 where the small fire caused blisters and smoke on the outer face. Ignition of the inner face occurred but soon ceased when further heat caused an aperture in the fabric. The hole had hardened edges and as the flames were pushed out by the air stream there was no further enlargement. There was similarly no spread of flame on the fabric in test F_2.

Ignition of the fabric was maintained in Test F_3 only because of the severity of the flames above the collapsed fabric. (Plate 7). There was no tendency to spread to other areas where there was no flaming in the vicinity.

6.6. Effect of deflation

6.6.1. Movement of occupants

Deflation of the smoke-filled structure lowered the level of the stratified smoke and thus introduced a hazard for the occupants. The rate of deflation depended on the total area of openings and whether the fan was operating. Thus with no apertures at all and the fan off a deflation time of 20 minutes was found.

With the fan off and all vents open, including the door giving a total opening of 3.5 m^2, the structure had collapsed after 30 seconds. In the structural tests on deflation[11], it was shown that the time to deflate was related to the area of venting up to a value of 1.5 m^2 after which it was independant of the area of venting.

The ability to escape depends on the distance to exits, obstructions in the escape routes, and visibility. In the smoke tests carried out smoke movement towards the openings was therefore a significant factor. This tendency was of greater importance in tests with open doors as these could become smoke logged. Shorter collapse times with a large number of open doors could make escape more hazardous.

6.6.2. Fire fighting problems

There is no evidence from the tests that the severity of fires was increased by venting of the flames and hot gases, eg test F_1 with the small fire near the wall.

In tests where deflation took several minutes, any further venting would have reduced the collapse time introducing problems for the fire fighters. For this reason the events in test F_3 are significant because fire fighting took place from the outside after deflation was complete. Under these conditions, there was no difficulty in reaching the burning timber and tyres by walking over the collapsed fabric and the fire was extinguished by approaching from the windward side (Plate 8).

The fire in test F_2 was extinguished from inside - the water supply having been laid on beforehand. The fire was put out before complete deflation and people were able to move around in a crouched position. At a slightly later stage, extinguishing could only have taken place from the outside since the structure collapsed leaving the timber crib standing proud of the fabric. (Plate 6).

7. CONCLUSIONS

A series of smoke and fire tests has been carried out on an air-supported structure 19 m x 9 m and 4 m high. A total of ten tests are reported, (three fire, seven smoke tests,) the final fire test resulting in the destruction of the building.

From this investigation, the following conclusions are drawn:

7.1. Smoke movement

1. Cold smoke diffuses over the whole volume as soon as it is produced (6.1.2). There is no evidence of smoke circulation being influenced by the fan.

2. Hot smoke rises and stratifies forming a thickening layer as more is produced (6.1.3). The stratified layer drops progressively causing a serious reduction in visibility.

3. Venting of the smoke takes place through any opening made in the structure. The escaping air causes the smoke to leave with it (6.2).

4. The quantity of smoke removed depends on the area of the opening. When both door and apex vents were opened, smoke escaped through both but more passed through the door because of its larger area. (6.2 Test S_2).

5. The opening of the door causes the smoke to leave that way leading to reduced visibility at eye level although there was a clearer section available near the ground (6.2 Test S_7).

6. The level of stratification lowers as the structure collapses (6.3).

7.2. Deflation of structure

1. Rate of deflation depends on the area of openings (up to a limiting size when it is independant of the size of the opening. The operation of the fan has some influence up to the limiting size[11]).

2. The secondary supporting bars to the door unit allowed the exit to remain accessible for a much longer time than would otherwise be the case (6.4.3).

3. Where the structure remained inflated for some time even though fires were in progress, collapse would nevertheless be quick once a large opening was made, for example by the opening of the door.

4. Small fires of the size used in tests F_1 and F_2 do not appear to be hazardous because hot gases give buoyancy to the structure. Although the flames punctured the fabric giving a hole of similar area as that used in the delfation tests, collapse took three times as long. The deflation of the fabric was also resisted by the fan supplying air.

5. With large fires, deflation is rapid as soon as the hole in the fabric increases in size at the rate observed in test F_3 (6.4.3).

7.3. Flame spread

There was no tendency for flame to spread along the underside of the fabric in the fire tests even though ignition of the inner surface took place. Once puncturing had occurred, the hole formed increased in area and the flames passed through drawing cool air from the inside past the edges of the aperture. These edges set hard and tearing did not take place. (6.4.1 and 2).

7.4. Fire fighting problems

1. If small fires are to be extinguished inside the punctured structure, apparatus would need to be available internally to avoid deflation when access is made. Normal fire-fighting techniques would probably require an exit to remain open for access and deflation would take place.

2. Large fires are best extinguished from outside when deflation has caused the fabric to lie along the ground (6.4.3). If the contents of the structure are such that upon deflation the fabric droops over them and does not lie on the ground, this may present different problems.

7.5. Escape of occupants

1. Time available for escape is dependent on collapse time which in turn depends on the size of the aperture made in the fabric.

2. The fabric around the door needs to be kept above head level by secondary supports (Test F_3).

3. Small fires imparted buoyancy to the structure delaying deflation even though the fabric was punctured. Occupants could freely move within the structure while the fires were burning (Tests F_1 and F_2).

4. Large fires causing quick collapse, present a hazard because time to collapse is short (Test F_3).

5. To delay deflation and to prevent the collapse of the fabric to the ground it may be necessary to provide some additional means of support. This would avoid collapse to below the 2 m level during the early stages of a fire.

8. RECOMMENDATIONS FOR FURTHER RESEARCH

Similar work to that described in this report needs to be carried out on a larger structure because the size of the structure may be an important factor.

Supplementary support to hold the structure above the ground should be tried out to obtain data for its design.

The use of doors with air curtains needs to be investigated to see the effect this type may have on escape provisions.

9. ACKNOWLEDGMENTS

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To Mr J A Kennington from the Department of the Environment for observations made during several tests, which have been incorporated in the Appendix.

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APPENDIX

TEST OBSERVATIONS

TEST S_1 — Cold smoke from FRS smoke generator
Fan on
Door closed
Apex vent ripped open during test
Side vent closed
Wind speed 1–4 m/s

Time	Observations
-32.00	Smoke generator ignited
00.00	Visibility 18 m (60 ft), smoke diffused throughout. Top vent ripped open. (Plate 3)
03.00	Distinctly cleared of smoke.
03.05	Fabric touching both 1.8 m (6 ft) poles, smoke cleared.

TEST S_2 (see also Fig 3)

Hot smoke generated from burning petrol

Fan on

Door open

Apex vent open

Side vent closed

Wind speed - zero

Time	Observations
00.00	Petrol fire ignited
03.00	Smoke layered to 1.8 m (6 ft)
04.00	Door and apex vent opened
	Doorway filled with smoke. Apex vent passing smoke also, but much less than through door
04.50	Fabric touched one of the 1.8 m poles
04.55	Fabric touching both poles

TEST S_3 (see also Fig 4)	Cold smoke from FRS smoke generator Fan off Door and vents closed Wind speed 3-6 m/s

Time	Observations
00.00	Smoke diffused throughout structure, fan off; smoke coming from fan tunnel; smoke ceases leaking from perimeter
03.00	South wall began to flap
05-06.00	Flapping of sides in many places
14.00	First touch at 1.8 m (6 ft). Visibility less than 6 m.
16.00	Observers not able to remain inside, visibility 'very low'
20.00	Fabric touching both 1.8 poles

TEST S_4 (See also Fig 5)	Cold smoke from FRS smoke generator Fan off Door closed Apex vent ripped open during test Side vent closed Wind speed 3-6 m/s

Time	Observations
00.00	Visibility about 6 m, apex vent ripped off Smoke escaping through apex vent
01.00	Fabric touched at one pole
02.00	Fabric touching both 1.8 m (6 ft) poles

TEST S_5 (see also Fig 6)

Cold smoke from FRS smoke generator
Fan off
Door open
Both vents closed
Wind speed 4-6 m/s

Time	Observations
00.00	Smoke diffused throughout structure, doors opened Smoke pushed out through door
01.00	Fabric touching both 1.8 m poles

TEST S_6 (see also Figs 7 & 8)

Hot smoke generated from burning petrol
Fan on
Door closed
Both vents closed
Observers wearing breathing apparatus

Time	Observations
00.00	Ignition of petrol
00.30	Smoke layered to 1.8 m (6 ft) from floor
01.00	Very dark-sunlight obscured
01.30	Smoke layered to 1.5 m (5 ft) from floor
02.15	Smoke layered to 1.2 m (4 ft) from floor. Far end of structure not visible
03.00	Fire almost obscured, still burning. Near 1.8 m pole obscured (5 m away)
04.00	Fire obscured, exit of observers
05.00	Smoke escaping through door

TEST S_7

Smoke generated from burning petrol
Fan on
Door opened at 2 min
Apex vents closed
Side vent opened at 5 min
Observers wearing breathing apparatus

Time	Observations
00.00	Petrol ignited
00.15	Smoke at ceiling and swirling
00.30	Smoke reached door end
01.30	Smoke stratified to 1.8 m (6 ft)
02.00	Door opened - smoke forced out but lower 1.2 m (4 ft) relatively clear (as seen from inside)
03.00	Building collapsed to 1.8 m (6 ft)
04.00	Remaining volume still full of smoke
05.00	Side vent half opened - $\frac{1}{2}$ m^2
06.00	Smoke clearing slightly
08.00	Side vent completely removed - 1 m^2
10.00	Smoke still clearing, visibility 18 m (60 ft)

FIRE TEST F_1 (see also Fig 9)

300 mm cube timber crib placed 250 mm from side wall
Fan on
Door and vents closed
Wind speed 4-6 m/s

Time	Observations
00.00	Ignition of the crib
04.00	Heat layer 1.5-1.8 m (5-6 ft)
05.00	External surface over flames too hot to touch but no visible change
05.20	Slight scorching and smoking from internal surface. Smoke on external surface from area approximately 300 mm dia.
06.55-07.20	Small blisters and more smoke from external surface
07.20	Ignition of internal surface
07.35	Hole formed in fabric - at first a vertical slit, widening immediately to a hole 600 x 250 mm
07.50	Escaping air pulling flames through hole. Hole not enlarging. (Plate 4)
08.45	Building not collapsing, visibility over 18 m
09.00	Hole increased to 760 x 250 mm
10.00	Flames projecting 600 mm
10.00-11.00	Doors opened, flames drawn back in - door closed, flames out again
16.00	Flames dying down, fire extinguished from inside

FIRE TEST F_2 (see also Fig 10)

58 kg timber crib placed centrally, 1200 mm above the ground
Fan on
Door and vents closed

Time	Observations
00.00	Ignition of crib by paraffin soaked sticks
01.30	Smoke from external surface of roof above fire. Flames licking ceiling occasionally
02.00	Ceiling scorching on inside
02.10	Split appeared in sealed fabric joint
02.20	Seam parted forming 1200 mm slit
02.40	Hole formed next to split, flames 1 m above fabric
02.45	Building falling, hole area $\sim \frac{3}{4}$ m^2
03.30	Wall and roof flapping slightly
07.30	Flames blown around hole as building blown by wind
08.10	Flames going out through hole (Plate 5)
09.35	Hole $\sim$ 1 m^2
10.30	Ceiling dropped to 1200 mm above crib
11.43	Ceiling and walls flapping in the wind
12.15	Ceiling 900 mm above crib, hole same size, flames 2 m above crib
13.30	Ceiling 600 mm above crib
14.00	Building collapsed to 1.8 m (6 ft), hole $\sim$ 1.5 m^2
14.30	Building collapsed around crib (Plate 6)
15.30	Fire extinguished from inside

TEST F_3 630 kg timber crib placed along the major axis and 25 rubber tyres at each end

Fan on until 1 min 35 sec

Door and vents closed

Time	Observations
00.00	Ignition of crib with paraffin soaked sticks
00.30	Flames reached ceiling
00.35	Smoke observed from outside coming from roof above crib
00.45	Hole developed in roof over crib
00.50	Flames through hole observed from outside
01.20	Flames from hole about 1 m high
01.25	Building deflating around crib
01.30	Flames about 2 m high above hole
01.35	Fan switched off, building collapsing
01.45	Large hole developed (~ 2 m dia), fabric above flames burnt away
02.00	Building collapsed around crib; observers leave through normal exit; material burning on south side of crib
02.15	Tyres ignited giving off black smoke; building totally collapsed
02.30	Material flaming on ground, south side. Ignition sustained by radiation from flames (Plate 7)
03.10	Hole over crib approximately 6 m x 3 m
03.15	Material not burning on north side (wind direction from north to south)
05.25	Fabric on south side burnt right to the edge of structure
08.30-11.00	Fire brigade putting out fire (Plate 8)

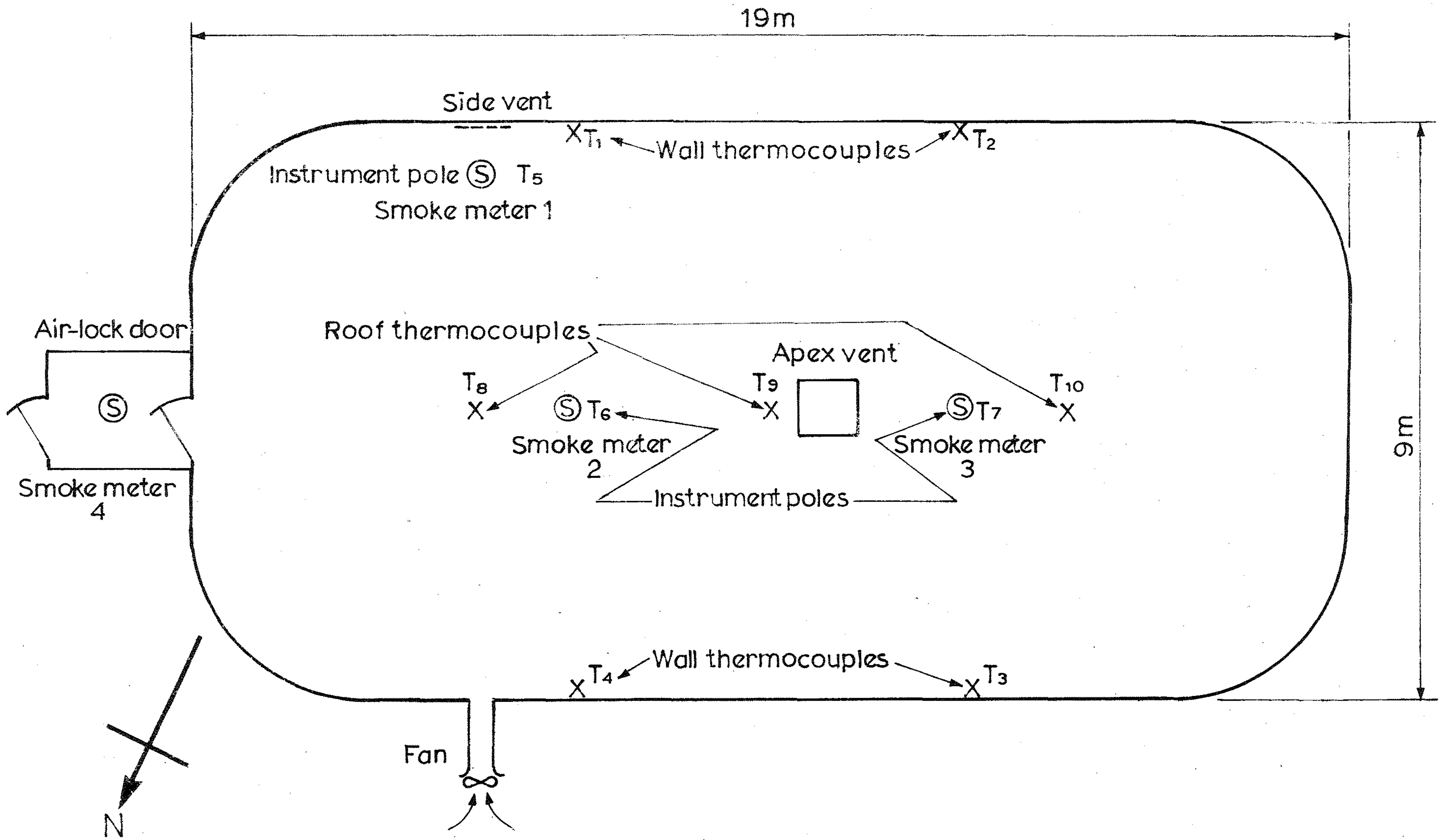

FIG.1 LOCATION OF INSTRUMENTATION IN AIR-SUPPORTED STRUCTURE

11 FR 955

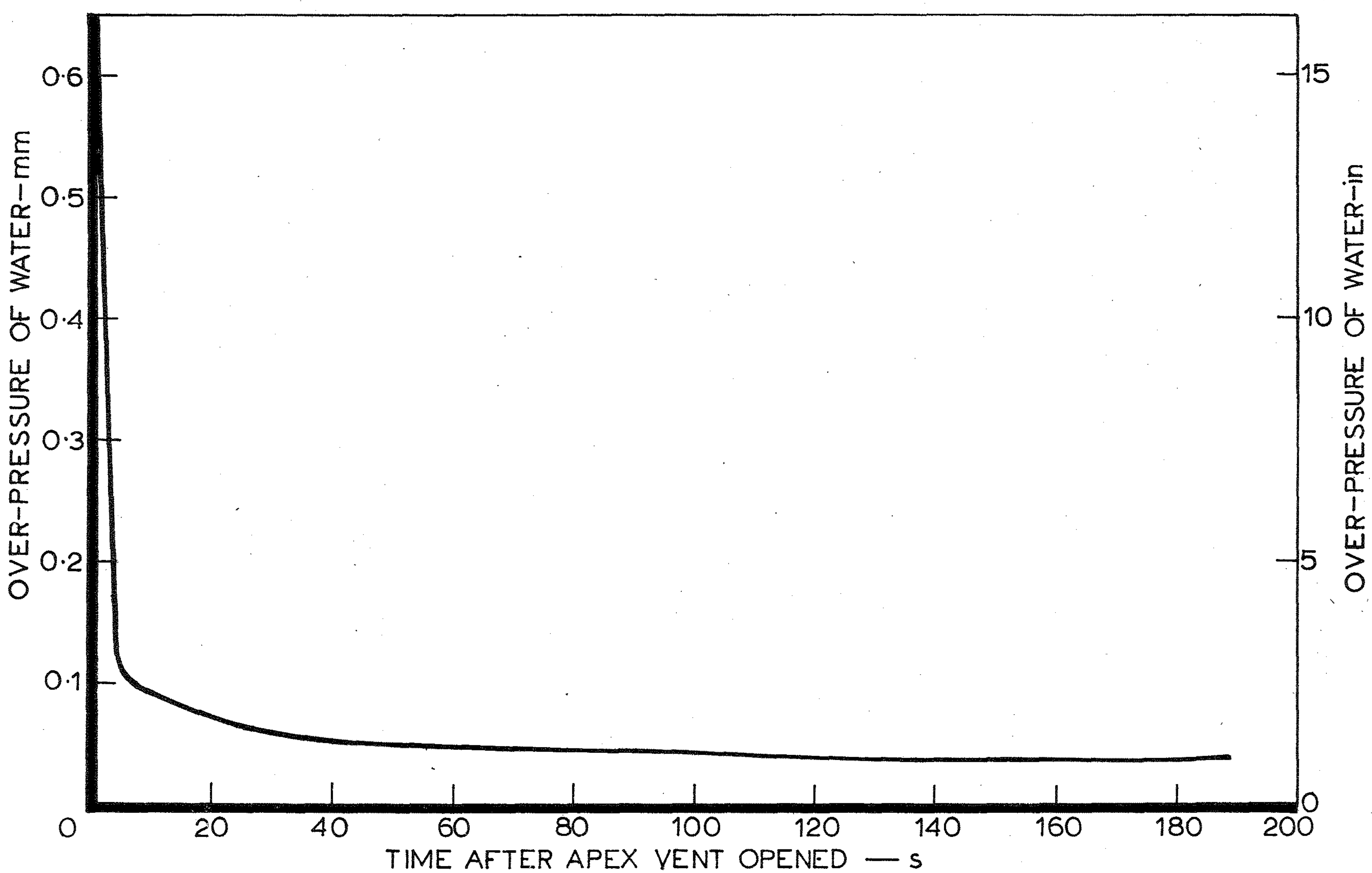

FIG. 2 PRESSURE DROP WITH APEX VENT OPENED

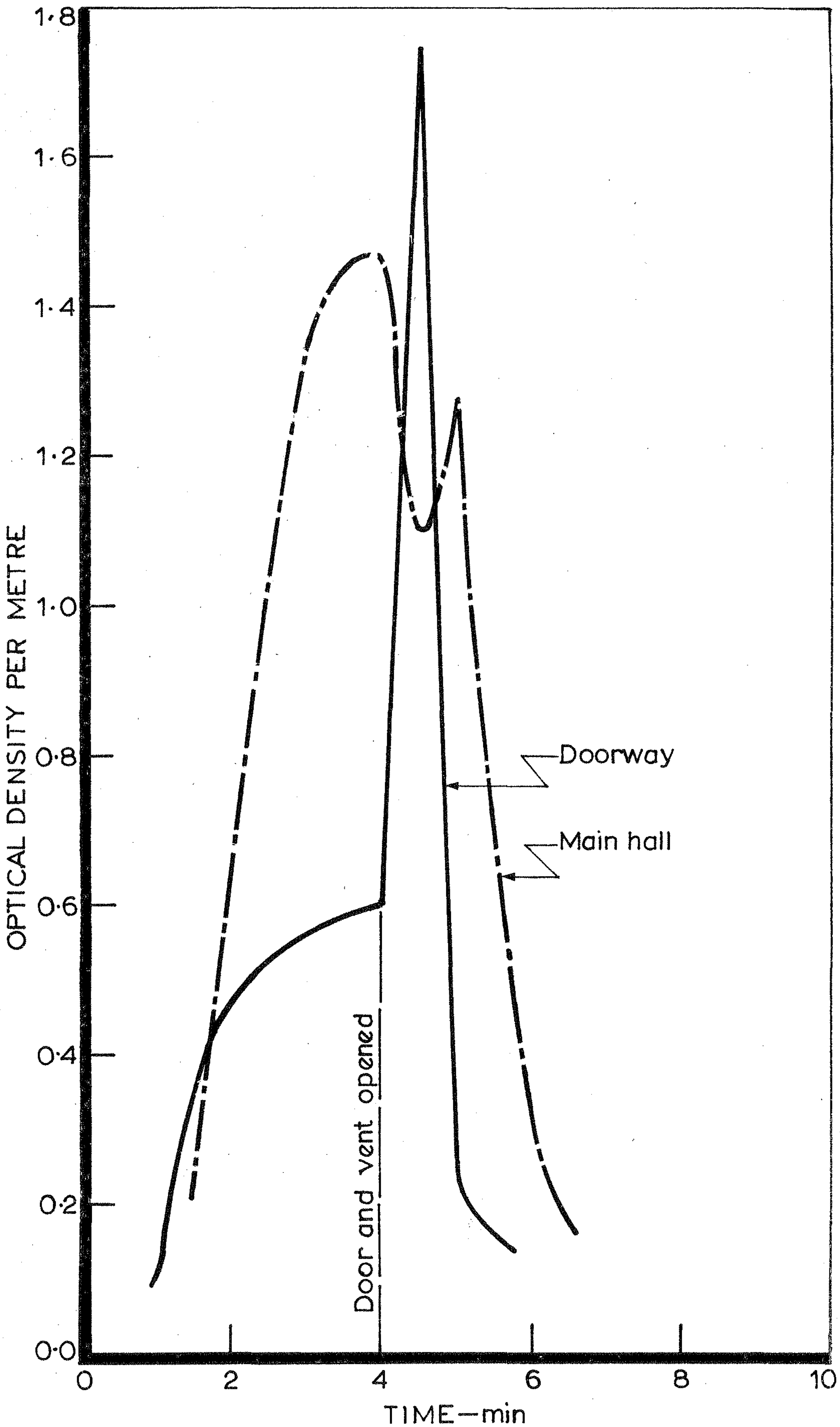

FIG. 3 TEST 2 SMOKE DENSITIES AT 1·8m (6ft)

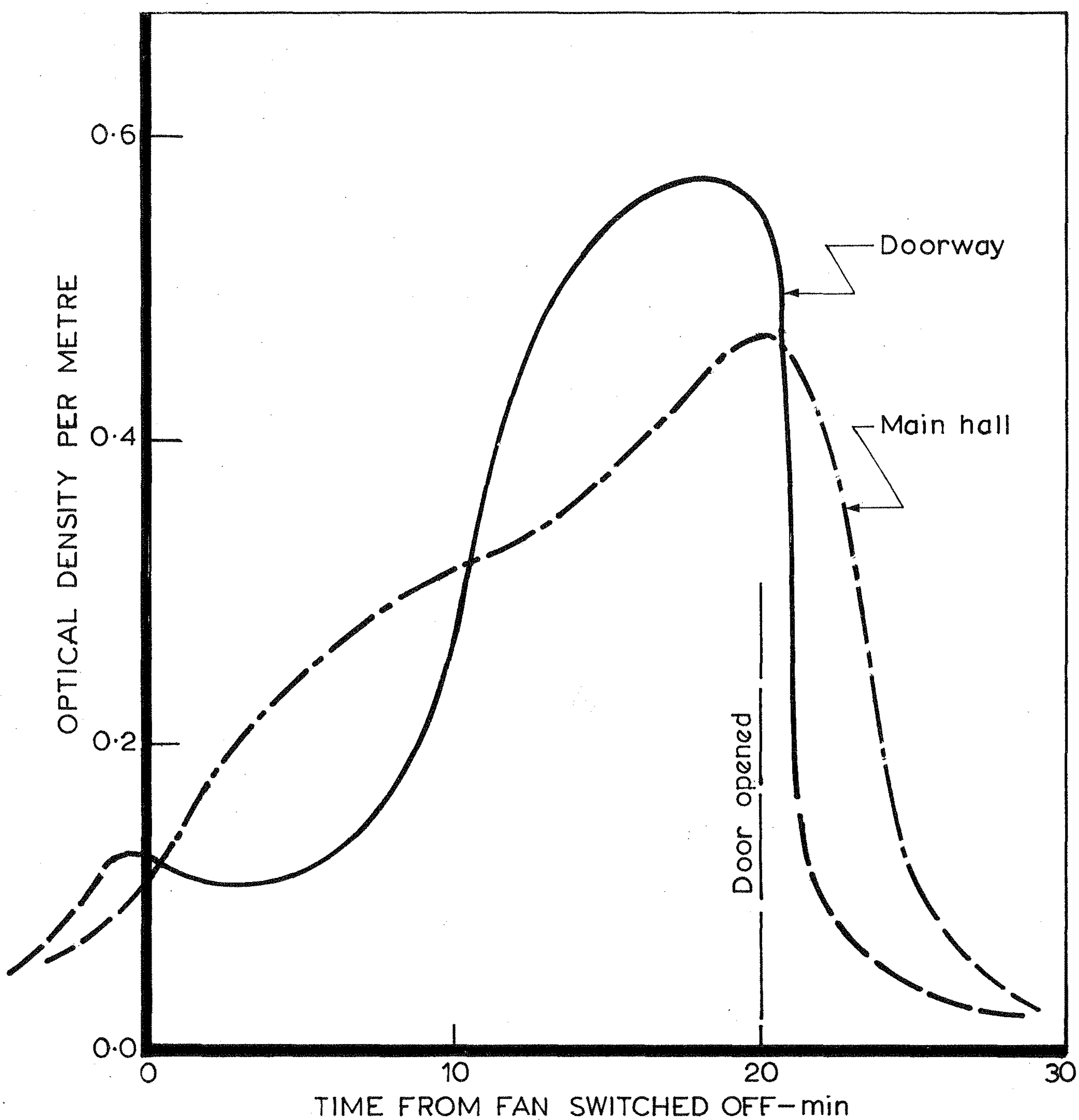

FIG.4 TEST 3 SMOKE DENSITIES AT 1·8m (6ft)

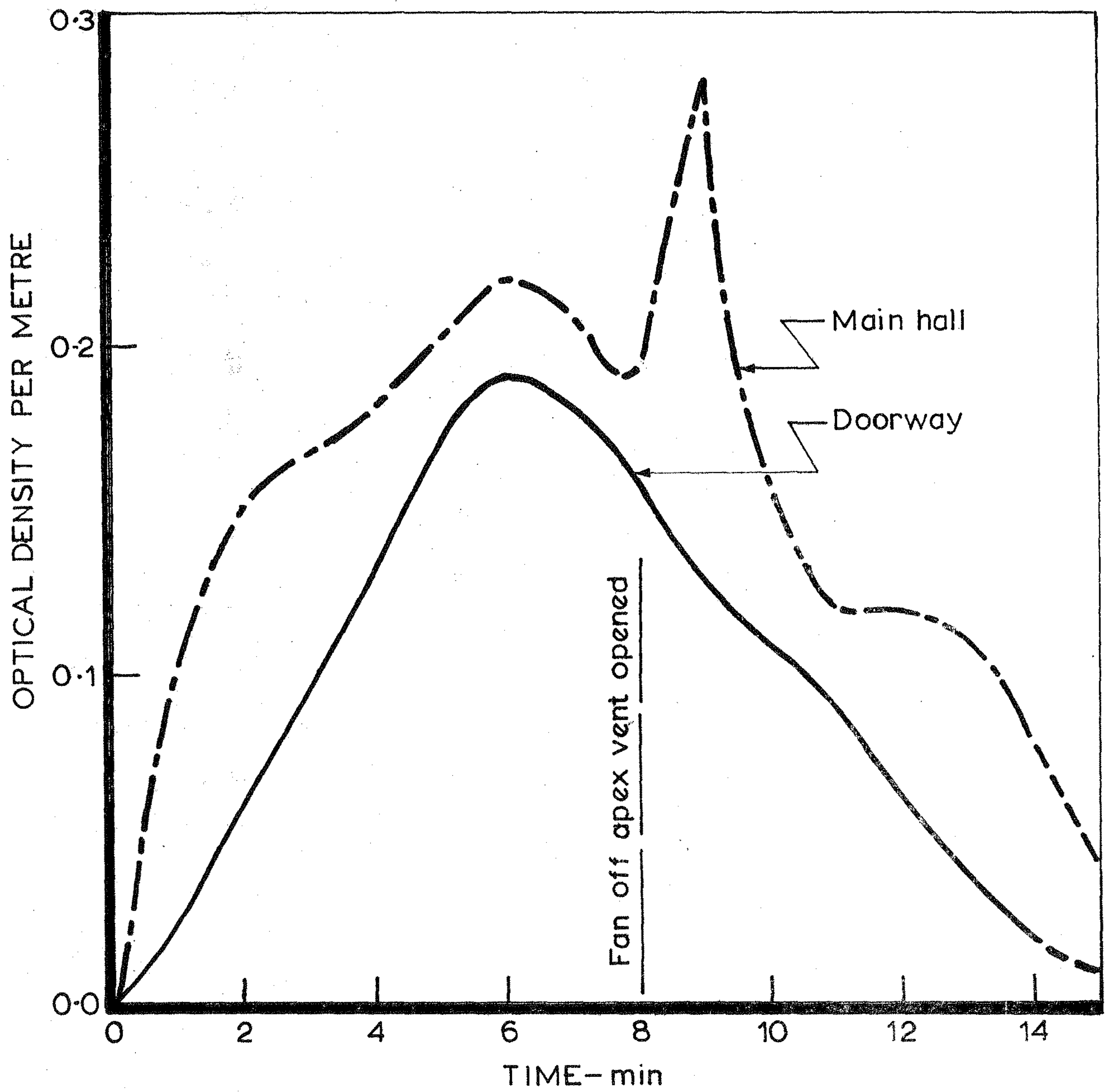

FIG. 5 TEST 4 SMOKE DENSITIES AT 1·8m (6ft)

FR056

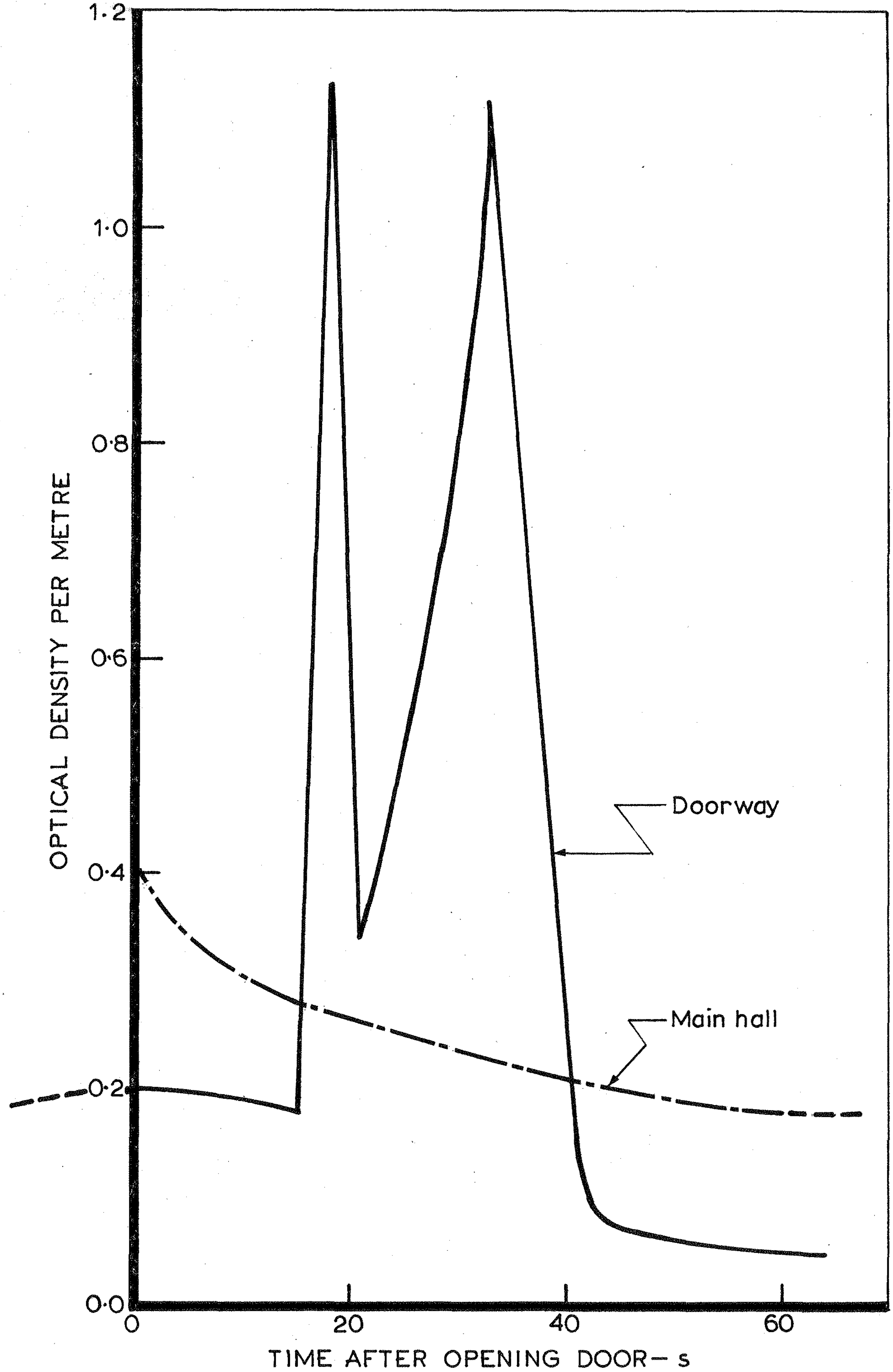

FIG.6 TEST 5 SMOKE DENSITIES AT 1·8m (6ft)

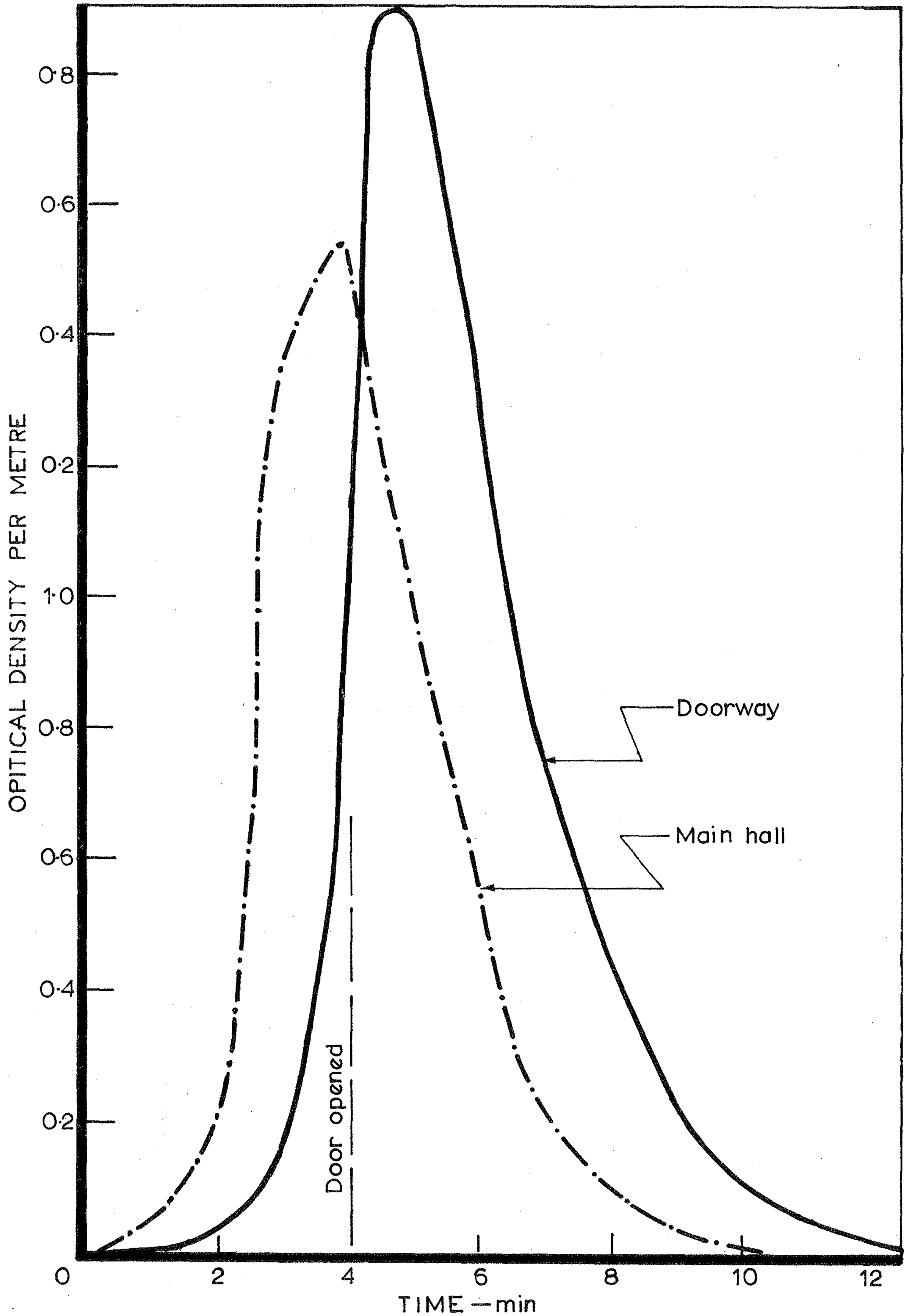

FIG 7 TEST 6 SMOKE DENSITIES AT 1·8m (6ft)

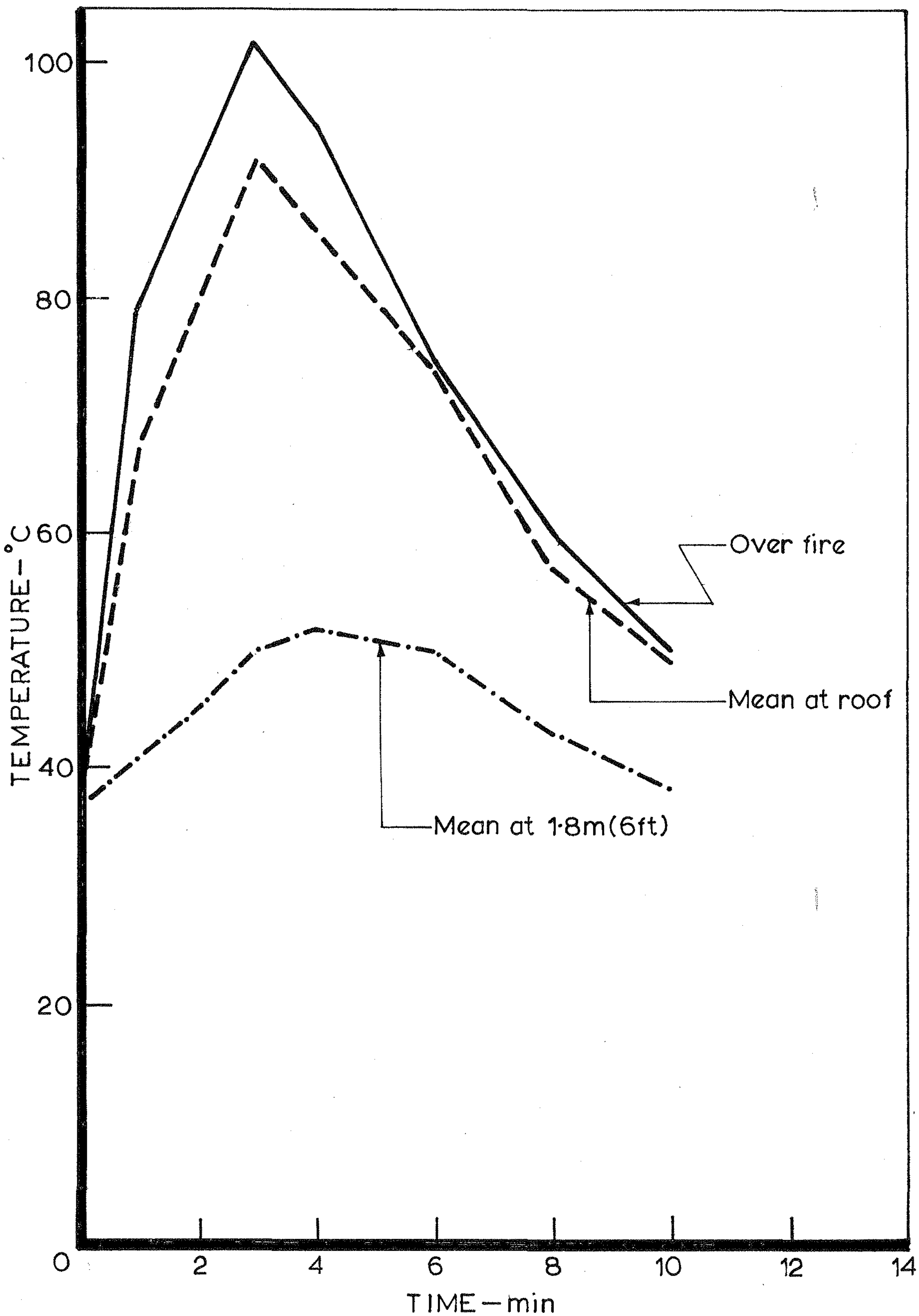

FIG. 8 TEST 6 AIR TEMPERATURES

FR 555

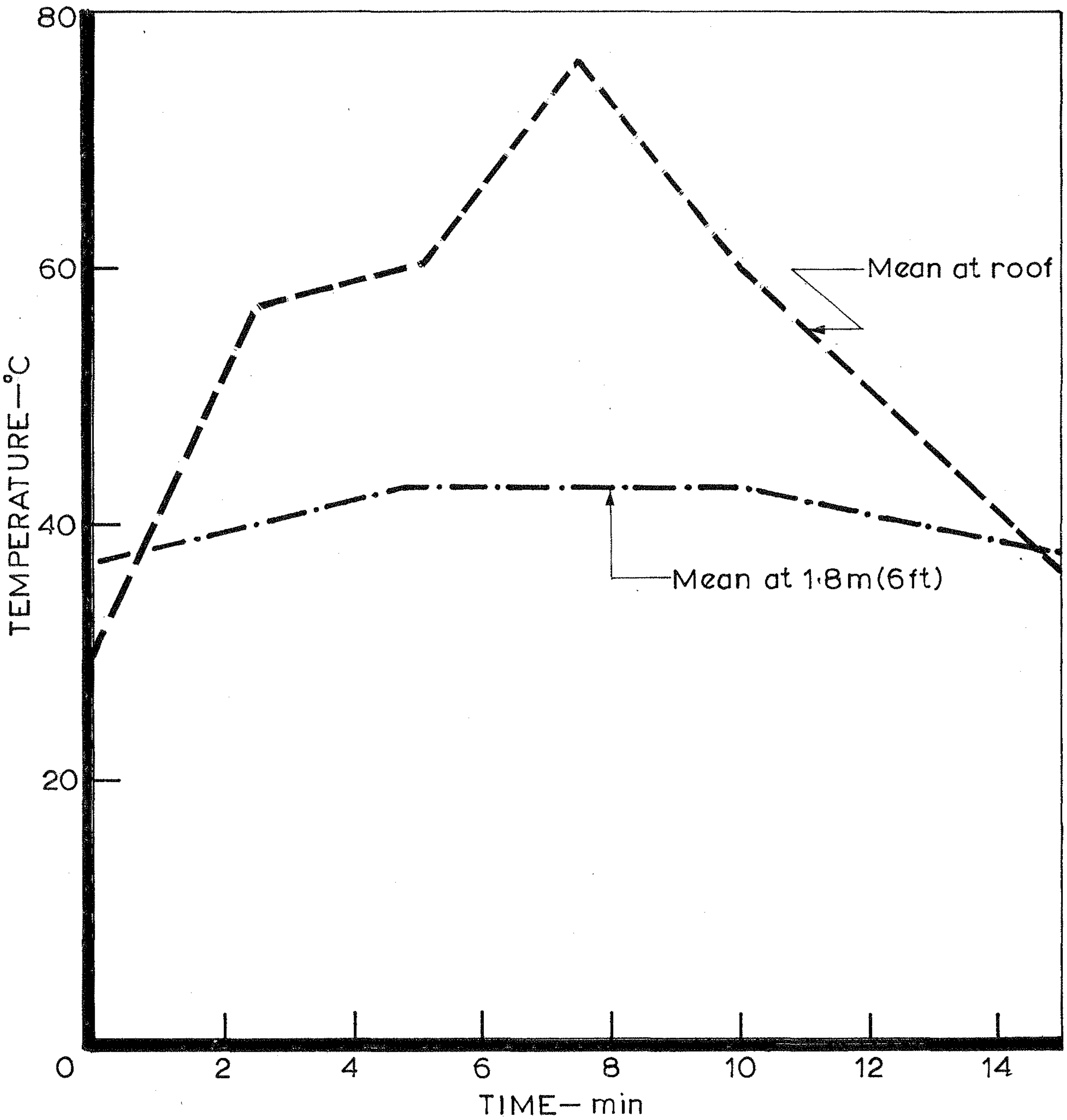

FIG.9 TEST F_1 AIR TEMPERATURES

916 FR955

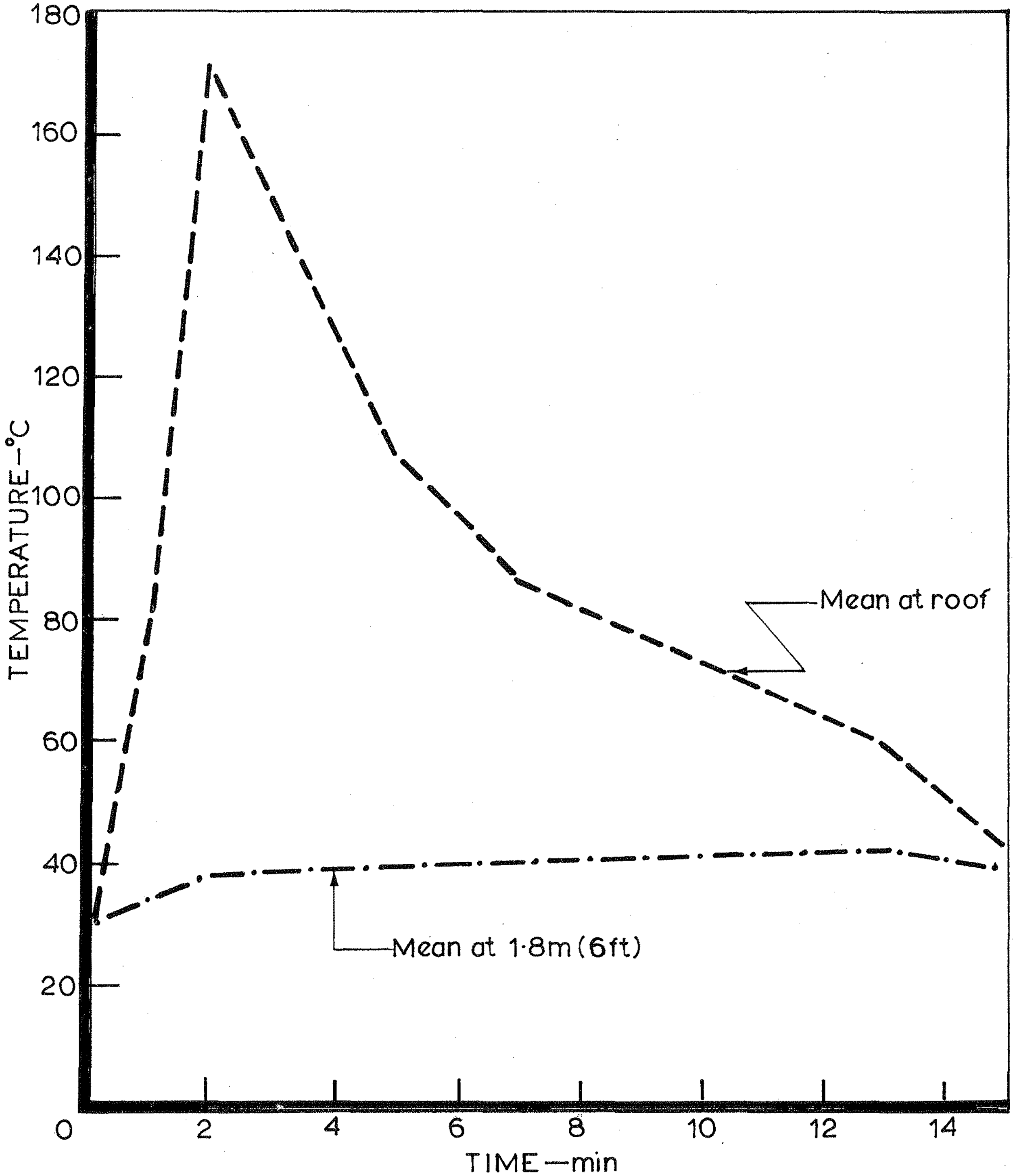

FIG.10 TEST F_2 AIR TEMPERATURES

916 FR 955

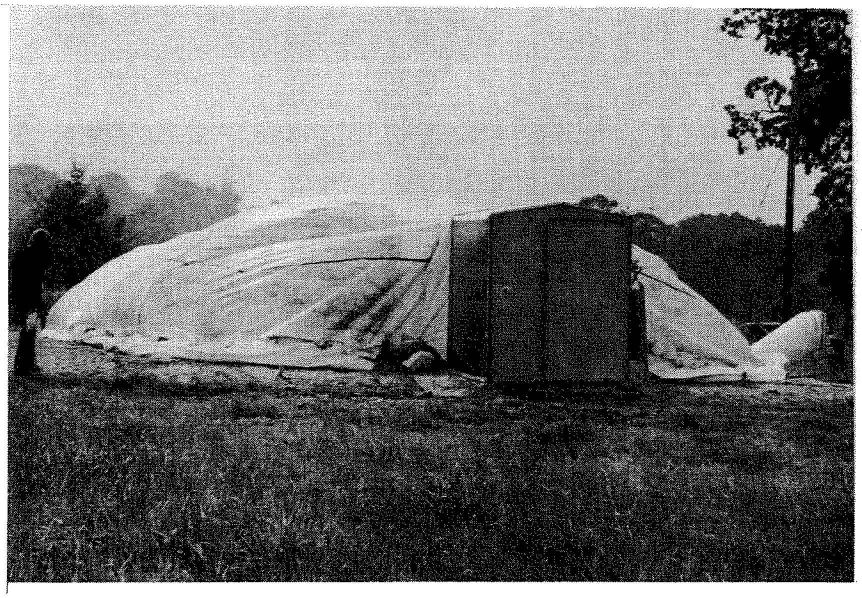

PLATE 1. INFLATION OF BUILDING

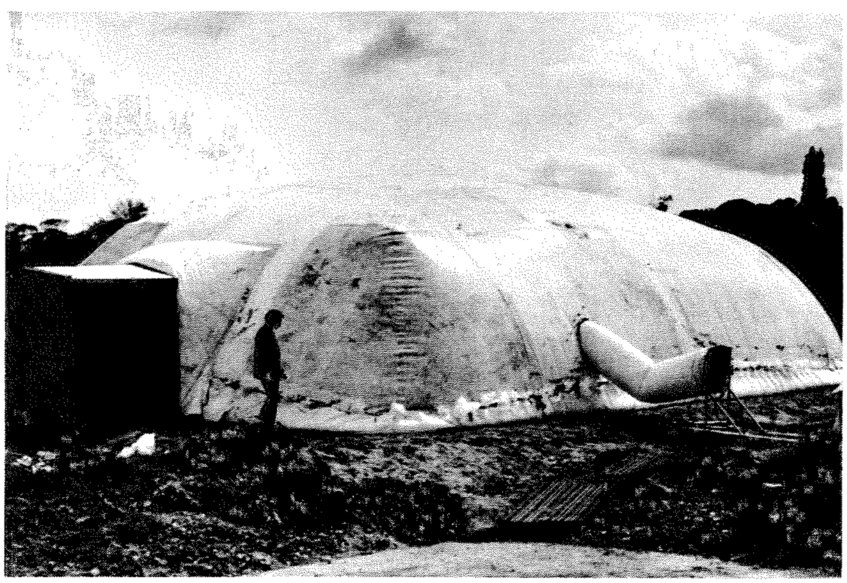

PLATE 2. STRUCTURE FULLY INFLATED

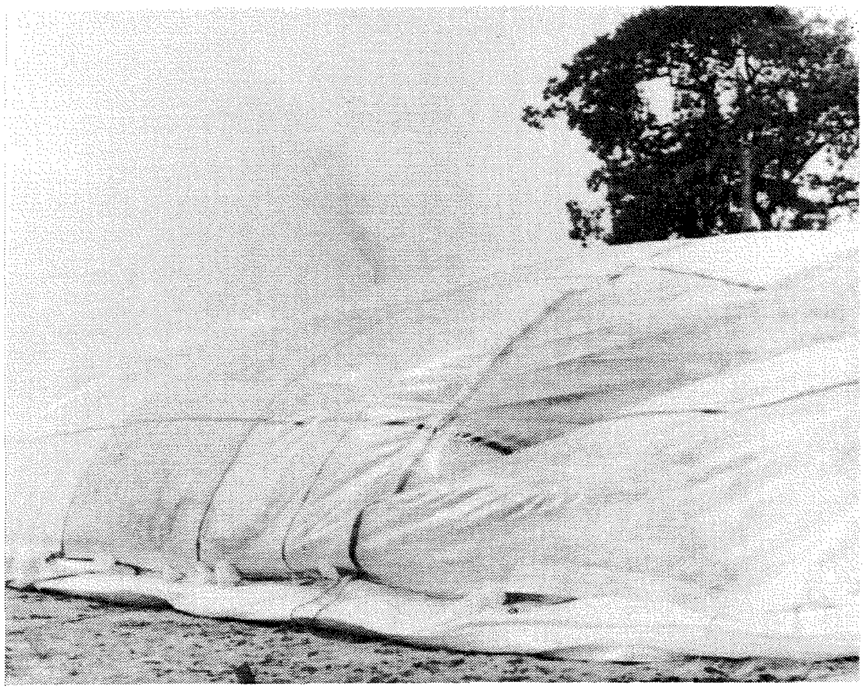

PLATE 3. SMOKE FORCED THROUGH OPEN VENT - TEST S1

PLATE 4. HOLE FORMED IN FABRIC AND FLAMES GOING THROUGH IT - TEST F1

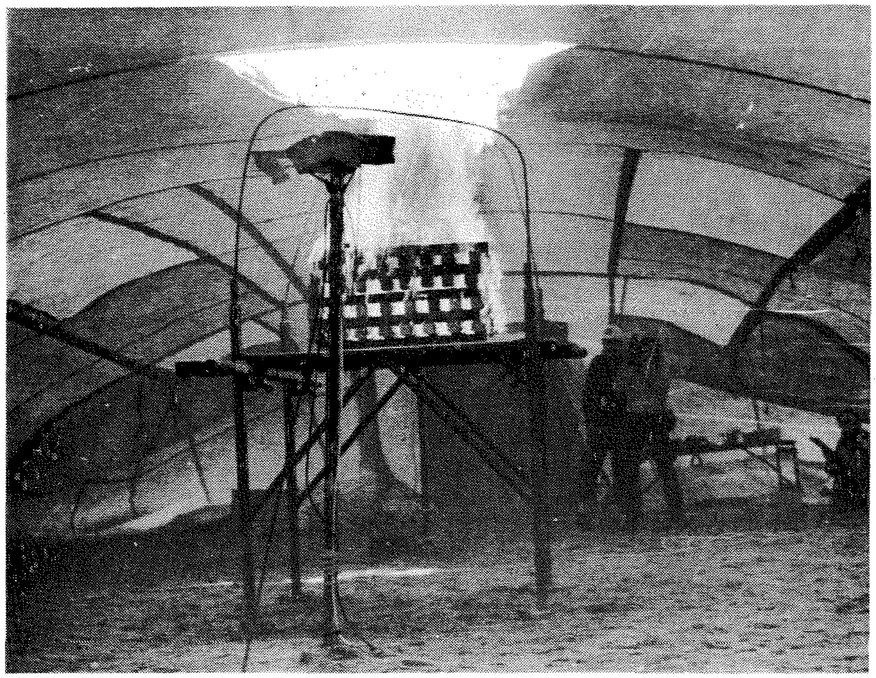

PLATE 5. HEAT FROM FIRE IMPARTING BUOYANCY TO STRUCTURE - TEST F2

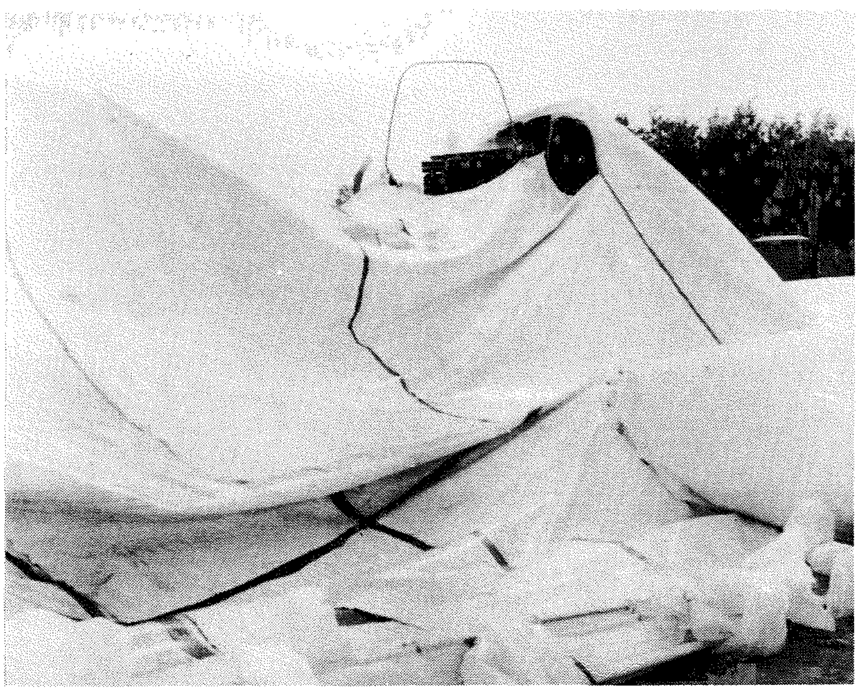

PLATE 6. STRUCTURE COLLAPSED AROUND CRIB - TEST F2

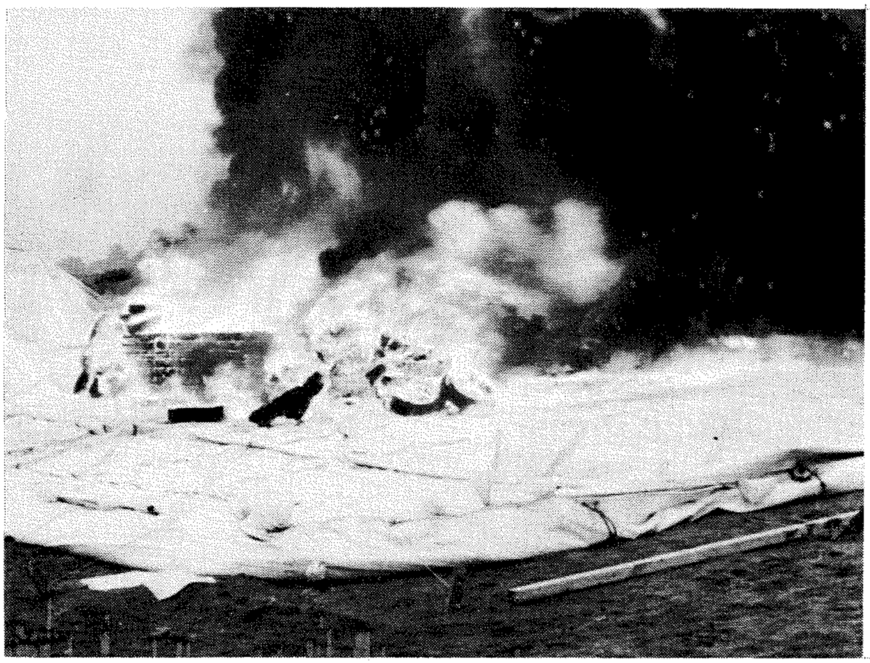

PLATE 7. FABRIC BURNING CAUSED BY RADIATION - TEST F3

PLATE 8. EXTINGUISHING OF FLAME AT END OF TEST F3