MINISTRY OF TECHNOLOGY

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FIRE RESEARCH NOTE

NO.566

MOVEMENT OF SMOKE IN ESCAPE ROUTES AND EFFECT OF PRESSURIZATION

RESULTS OF SOME TESTS PERFORMED IN A NEW DEPARTMENTAL STORE

by

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F.R. Note No. 566

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
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SUMMARY

An investigation is being made of the feasibility of keeping escape routes in buildings free of smoke in case of fire by maintaining these areas at higher pressures than the other parts of the building, thus reducing the risk of entry of smoke through connecting doors.

This note describes the results of tests conducted in a 3-storey enclosed staircase and provides some preliminary data for the design of a suitable system. The pressurization system may be continuously in use or may be brought into operation in case of a fire either manually or automatically by smoke sensitive devices The latter appears to offer advantages.

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INTRODUCTION

The escape of occupants from a building in case of a fire is dependent upon the adequacy of the escape provisions which have as one objective to keep the escape areas free of smoke and other products of combustion. This concept is of particular importance when dealing with high buildings intended for occupancies such as hotels, offices and flats. The existing requirements are based on assumptions which have not been proved by experimental evidence and a research programme is in hand to investigate various aspects of this problem.

The usual arrangement for means of escape is the provision of enclosed staircases and lobbies, their exact design depending upon a number of factors, isolated from the accommodation by means of fire check doors, i.e. doors which should be capable of preventing undue penetration of smoke through the normal gaps between the door panel and its frame. In addition measures are adopted to prevent the lobbies from becoming smoke logged by providing facilities for evacuation of smoke. Permanent natural ventilation has been used for this purpose in certain buildings with a single staircase but this has led to objections on grounds of discomfort. Means of ventilation can also be provided which are brought into operation at the time of fire by manual operation of removable glazing or by shutters operated by smoke detectors. The effectiveness of these measures has not yet been proved.

Recently a great deal of interest has been shown in another approach to this problem, which is based on generating higher pressure conditions in the escape area than in the rest of the building which can either be a permanent feature and would prevent the entry of smoke into these areas or which can be

brought into use in case of a fire by smoke detectors or by manual operation.

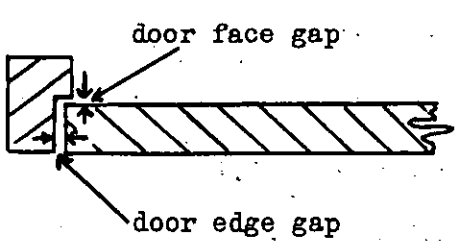
PURPOSE OF THE INVESTIGATION

As previously remarked an extensive research programme on the movement of smoke in escape routes is in hand and one of the factors to be investigated is the pressurization of escape routes. These tests are being conducted in specially built rooms attached to a four storey test building which can simulate a small part of a building. Through the courtesy of Messrs. Marks and Spencer a new store at Peterborough was made available to supplement the research with full scale tests. It was decided that the opportunity should be taken to obtain preliminary data on the effect of pressurization of staircase enclosures on the movement of smoke under various conditions of smoke logging.

DESCRIPTION OF THE TESTS

The tests were conducted in a two storey staircase built along one wall of the store as shown in Figures 1 and 2. The enclosed stairs led from the ground floor to the first floor where a landing was formed by a partition having a double swing double leaf door leading to offices at one end and a flush hinged door at the rear connecting to the stock room. From the rear door the stairs continued to the second floor canteen and staff room and were enclosed at the top by a temporary partition with an access door. A temporary natural ventilation duct, provided with a damper, had been installed at this level.

Door No.1 at ground floor opened into the store and was fitted into a timber frame with ½ in. rebates. The rear landing door (No.3) on the first floor was similar. The double leaf double swing door (No.2) was 64 in. wide and was provided with a floor mounted self closing device. The door clearances were measured between door edge and frame and door face and stop (as in sketch overleaf). The effective net gap is shown below calculated from the lesser of these two clearances.



Effective net area of gap between door and frame

	Upper half of door perimeter	Total
Door No. 1	10.5 in^2	23.0 in^2
Door No. 2	14.1 in^2	42.3 in^2
Door No. 3	0 in^2	6.0 in^2

Smoke was produced by two smoke generators, specially developed for investigations on the movement of smoke in which controlled combustion of known types and quantities of cellulosic material produces smoke of the type experienced in fires. The generators do not produce smoke in a quantity or at a temperature normally associated with fires. They do, however, provide a consistent source of warm smoke forming a useful tool for experiments and simulating smoke conditions in the early stage of a fire. Suitable enclosures were provided, both on the ground floor and the first floor, to house the smoke generators so that the smoke produced would tend to enter the staircase rather than disperse into the store.

The smoke density was measured by special meters located at a height of 63 in from the floor in positions adjacent to the doors as shown in Figures 1 and 2.

The pressurization facilities were provided by the Building Research Station who cooperated in this investigation. A centrifugal fan of 3000 c.f.m. capacity was located on the second floor, feeding air into the enclosure near the floor level. The fan was fitted with a damper to control the supply of air, and hence the pressure in the staircase. The pressure differential across each door was measured at about mid height by means of pressure tubes connected to an electronic indicator through multiport valves.

Visual records to supplement instrumental data were made by observers stationed at various points inside the enclosure who were able to move out when the smoke conditions became unbearable.

TEST RESULTS

Four tests were made, two with the smoke generators on the ground floor and two with the generators sited on the first floor. In each situation one test was performed without pressurization of the stairs as a control and one test with pressurization.

The logs of the tests are given in Appendix A and the smoke conditions as measured by various smoke density meters are shown in Figures 3 to 6 together with the pressure differential measurements across the appropriate door.

Test No. 1. In this test the smoke generators were at ground floor and by 4 minutes light density smoke was visible near door No. 1. There was very little smoke on the first floor landing until 12 minutes, though by this time the lower stairs were nearly filled with dense smoke. The movement of smoke up the stairs was slow, there were no signs of stratification, and the smoke was moving up as a solid plug. As the building was new and had not been completely dried it is probable that the smoke lost heat to the walls and quickly cooled to ambient conditions thus preventing any appreciable stratification. When the ground floor door was opened at 20 minutes the inrush of smoke quickly filled the landing and the upper stairs with appreciable amounts of smoke penetrating the door No. 2 (Meter No. 3 Fig. 3). The opening of the vent at the top of the stairs at 28 minutes did not appear to have any significant effect on the clearance of smoke. At 40 minutes the staircase was still smoke logged and could be cleared only by opening of doors 4 and 1 at the top and bottom of stairs.

Test No. 2. The smoke generators were placed in position as shown in Figure 1 near the door No. 2 on the first floor. The sectional area of the landing was twice that of the ground floor staircase and this was partly responsible for the slower rate at which it filled with smoke. By 30 minutes the conditions on the landing were becoming unbearable and it was only possible to move across it from door No. 3 to the door No. 2 with great difficulty. The smoke conditions on the first floor stairs were slightly worse at all times than on the landing itself at corresponding times. It is interesting to note that at all times very little smoke percolated down the stairs to ground floor.

Test No. 3. The smoke generators were on the ground floor and after 4 minutes the fan was switched on at full flow. The light smoke near the ceiling on the landing and in the ground floor staircase was quickly cleared. When the flow was reduced at 10 minutes the smoke began to penetrate through the ground floor door No. 1. The pressure differential across this door was then increased in steps; a value of 0.020 in. wg. was found to be sufficient to prevent the

penetration of smoke.

The double swing doors on first floor were opened five times to simulate the passage of people and this had no significant effect on the smoke conditions in the stair case nor did holding of one leaf at 45° for one minute.

The opening of the ground floor door at 25 minutes resulted in a sudden in-rush of smoke up the stairs at high level with the fresh air from the fan flowing at low level in the opposite direction. When the door was again closed after two minutes although there was medium density smoke at high level, approximately 4 to 5 feet from the floor the air was comparatively clear enabling one to walk along the stairs and the first floor landing in a slightly crouched position. The clearance of smoke after the closing of the ground floor door was not rapid until the flow was increased to the maximum when within five minutes the whole area was effectively cleared.

Opening the ground floor with the maximum flow conditions in the staircase did not prevent the entry of large quantities of smoke. Stopping the fan resulted in the almost complete smoke logging of the staircase in 30 seconds. Switching the fan on, with the ground floor door open, resulted in gradual clearance of smoke first starting at floor level so that within 8 minutes a space 4 to 5 feet above the floor on the landing was relatively clear of smoke. The smoke at high level was being pushed back more slowly in a wedge shape by the fresh air stream. Closing the bottom door resulted in a more rapid clearance of smoke at all levels.

Test No. 4. In this test the smoke generators were placed on the first floor and as noted in test No. 2 the emission of smoke into the landing was at a slow rate. After the fan was switched on at 10 minutes with reduced flow giving a pressure of only 0.003 in. wg. there was no reduction in the flow of smoke through the gaps of door No. 2. The pressure was increased in steps to determine the minimum value which would stop the flow of smoke through the door; this occurred with a pressure of 0.027 in. wg. When the pressure was increased to 0.084 in. wg. the light smoke in the lobby was rapidly pushed down the stairs and through the ground floor door.

Opening the ground floor door for a period of 1 minute had no effect on the smoke conditions in the lobby. However the opening of one leaf of door No. 2 with

the fan on resulted in a sudden rush of smoke into the lobby at high level, with 3 to 4 feet from the floor which was below the level of the smoke meters, reasonably clear of smoke. When the fan was stopped the whole of the lobby and the upper stairs were smoke logged, but the ground floor stairs remained almost clear.

At 40 minutes the door No. 2 was closed and the fan started at full flow. There was immediate clearance of smoke starting from the top stairs down and within 2 minutes it was possible to enter the first floor landing through the back door and as before a clear zone near the floor was observed. It took only five minutes to clear the lobby of most of smoke which was pushed down the ground floor stairs resulting in very light smoke conditions near door No. 1. In another 10 minutes the entire stairway was completely cleared.

The pressure was gradually decreased until it was found that 0.028 in. wg. was just sufficient to prevent the passage of smoke through the gaps in door No. 2.

DISCUSSION OF RESULTS

The series of tests conducted on the 2 storey stair enclosure in the Marks and Spencer store has provided an opportunity to obtain useful data on the value of pressurization of enclosures as a means of keeping them smoke free. Although the arrangement of stairs and the landing was not representative of either a block of flats or an office type of building the tests have been of value in indicating the relative importance of various factors which should form a basis for future work on this subject.

The tests without pressurization have shown that with normal types of smoke stop doors in the closed position sufficient quantities of smoke can penetrate through the gaps to render the escape area untenable in anything up to 20 minutes from the start of a fire. It is not unknown for fires to remain undiscovered for this length of time; on the other hand if the doors are partially or fully open the smoke penetration is at a greatly increased rate.

With a pressurization system as used in these experiments the passage of smoke through the door gaps was prevented. When however, the door leading to the fire area was open the maximum air flow rates which were used in this

investigation were unable to completely prevent the inflow of smoke, although a sufficiently clear zone close to the floor was maintained to permit movement along the staircase in a crouched position.

The opening of doors, other than that leading to the fire, for short periods for the passage of people did not appear to have any significant effect on the overall effectiveness of the pressurization system.

There are two possible ways of pressurization that may be used in practice: both pressurize the escape routes by the supply of fresh air, one on a continuous basis and the other as required if a fire occurs. Considering the first method the pressure differentials of the order of 0.028 in. wg. seemed adequate to prevent the entry of smoke through the normal door gaps. To counteract any deterioration in the performance of doors due to buckling under heat conditions or to cope with doors not fitted to a high standard it would seem desirable that pressures of the order of 0.050 in. wg. should be employed.

It would be difficult to promote this method in buildings with mechanical ventilation systems because comfort requirements demand the introduction of the conditioned air firstly to the occupied regions. The general airflow direction in these buildings is towards the corridors and stairways which is the reverse of that required to keep these areas clear of smoke. For this reason the alternate method will be the more attractive for office and flat buildings provided with ventilation systems.

With the second method higher pressures would be required as it is not only necessary to prevent the entry of smoke but also to clear the smoke already in the enclosure. Air flows providing a pressure of the order of 0.075 in. wg. appears to be necessary to clear the smoke which may have percolated into the enclosure and to safeguard against slight buckling or deformation of doors.

The sizing of such a system is discussed in Appendix B, which shows that for multistorey buildings, consisting of 30 or more units, the smoke clearance parameter for the stairways will be numerically about 4 or 5. This means that when the air volume flow per minute is the same as the volume of the stairway, the clearance time is 4 to 5 minutes. For different flow rates on a given stairway the smoke clearance times are pro rata.

In the present tests on a stairway which can be divided into three sections, the fan capacity was 3000 c.f.m. and the stairway volume was approximately 6000 ft^3 and the curve in Figure 7 gives a smoke clearance time of about 4 minutes. In practice effective smoke clearance was achieved in about 6 minutes in test 3 and 7 minutes in test 4. The difference between the predicted and the test values is believed to be due to the excessive leakage which occurred through the temporary partitioning adjacent to the fan installation on the 2nd floor.

The important point to note from the analysis is the rapid reduction in smoke clearance parameters when the stairway consists of very few sections. In the extreme, when only one section appears the smoke would clear in 1 minute for a flow rate of one section volume per minute; alternatively clearance in 5 minutes could be achieved with only $^1/_5$ of this air flow. This suggests that considerable reductions can be achieved in the size of fans for tall blocks if the air is introduced at each section, rather than one end of the stairway.

It is important to note that upon pressurization of an enclosure the smoke produced in a fire would travel to other parts of the building which are under lower pressure conditions and it may be necessary to channel its flow into safe zones to prevent entry into parts of the building where its presence would be objectionable. It was noticed in the tests that when the staircase was effectively pressurized, the smoke from the generator was able to enter other parts of the building through all available gaps and openings; it was even able to get behind the suspended ceiling in large quantities.

Further tests are necessary to determine the necessary air flow rates to establish the pressure conditions for different arrangements of stairs, in particular for high buildings. There is still lack of information on the air flow conditions in vertical staircase enclosures in tall buildings and the compatability of normal ventilation requirements with those necessary under conditions of a fire at various levels in the buildings.

CONCLUSIONS

The series of tests on the movement of smoke and the effect of

pressurization conducted in the two storey stair enclosure as described in this report enable the following tentative conclusions to be drawn.

1. A properly designed system to pressurize the stair enclosures either continuously or as required is capable of keeping the area clear of smoke if the doors are kept closed.

2. With continuous pressurization air flows to produce pressure conditions of the order of 0.050 in. wg. are capable of preventing entry of smoke through the normal door gaps.

3. With pressurization systems coming into operation on demand air flows of the order of stairwell volume per minute would be required to clear the existing smoke in about 5 minutes. Introduction of fresh air at more than one point is likely to result in a reduction of this time.

4. Short duration opening of doors for the passage of people has no adverse effect on the smoke conditions in the enclosure.

5. If the door leading to the fire is fully or partially open even the air flows specified may not be able to prevent the entry of smoke, but escape may still be possible in the early stages as a clear zone may exist close to the floor.

6. To minimize the loss of pressure the escape routes utilizing the pressurization system should be well sealed particularly when demountable partitions and ceilings are used.

ACKNOWLEDGMENTS

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APPENDIX A

LOG OF TESTS

Test No. 1. - Smoke generators on ground floor - No pressurization

Time	Observation
00	Smoke generators in operation
01	Visible emission of smoke round door No. 1.
04	Light smoke in the vicinity of smoke meter No. 1.
12	Smoke density in ground floor stairs medium light smoke on 1st floor landing.
16	Smoke on the stairs becoming dense.
20	Door No. 1 opened - stairs and landing filling very quickly with dense smoke.
28	Vent opened at top - smoke clearance negligible.
30	Door to smoke chamber on ground floor opened to clear smoke. End of test.
40	Stairs still smoke logged.

Test No. 2. - Smoke generator on 1st floor on corridor side of double doors - No pressurization.

Time	Log of test
00	Smoke generators in operation.
02	Whiffs of smoke from the top edge of No.2. door.
04	Smoke emission from the vertical gaps.
05	Smoke collecting near the ceiling of the landing, emission of smoke from the gaps in the upper part of the door continues.
10	Smoke density on the landing still light, presumably because of the large area to be filled
21	Rear door of the smoke chamber adjusted to increase ventilation, emission of smoke into the lobby slightly increased.
30	More smoke in the lobby - it is just possible to walk down from the 2nd to the 1st floor.
36	Just possible to walk from door No.3 to door No. 2 in the landing.
44	Vent in the duct at the top of the stair opened - smoke emission small.
57	End of test.

Test No. 3. - Smoke generators on ground floor

Time	Observation
00	Smoke generators in operation.
02	Light whiffs of smoke from the edges of the ground floor door.
03	Slight smoke in the whole of the staircase.
04	Fan switched On - full pressure.
06	First floor landing completely cleared of smoke.
07	Only light smoke near the bottom of the staircase.
10	Pressure reduced to 0.009" wg. smoke penetrating through the gaps in door No.1.
13	Smoke continues to come through the door in small amounts.
14	Pressure increased to 0.015" wg. - some smoke still penetrating.
15	Pressure increased to 0.020 - noticeable decrease in smoke penetration.
20	Double swing door No.2. on 1st floor opened 5 times to simulate passage of people (40 second operation) no noticeable effect on smoke conditions.
21½	One leaf of the double swing door opened 45° slight pressure drop across door No.1. Door No.2 closed at 23½ min.
25	Door No.1 opened, the air in the staircase tending to push the smoke back but smoke density increasing rapidly, 4-5 feet height from the floor level clear and dense layer along the ceiling.
27	Door No. 1 closed. Some turbulent mixing of smoke with clear air.
30	Smoke conditions on the landing not bearable.
31	Pressure increased to full. (0.084" wg.)
33	Top stairs clear of smoke, light smoke on 1st floor landing.
34½	Bottom stairs nearly clear.
36	Door No. 1 opened again.
37	Fan output reduced.

Test No. 3. continued

Time	Observation
38	Fan stopped - staircase filling with smoke very quickly.
39	Fan switched on, door No. 1. open.
42	Top stairs completely clear, 1st floor landing half clear, bottom stair still smoke logged - visible movement of smoke down the stairs.
45	On the first floor landing smoke seen to be coming up at high level and going down at low level, the flow reversal occurring near the rear landing door No.3.
47	Door No. 1. closed - smoke flow in one direction now on first floor landing at the rate of approximately 1 ft/sec towards ground floor stairs. The wedge of smoke being gradually pushed down the stairs.
50	End of test.

Test No. 4. - Smoke generators first floor

Time	Observation
00	Smoke generators in operation.
03	Light whiffs of smoke from the door gaps.
06	Only light smoke in the lobby.
10	Fan started, light smoke in the lobby.
11	Pressure across door No. 2. .003 in.wg. no visible effect on smoke.
13	Slight increase in the density of smoke.
16	More smoke in the lobby - pressure increased to 0.01" no pronounced effect.
18½	Pressure increased to 0.028" ; smoke emission from double doors stopped - There has been no smoke on 1st floor stairs for last 5 minutes.
20	Clearance of smoke from the lobby, some of the smoke being pushed down towards No.1.
24	Pressure increased to max. (0.084" wg.), lobby cleared of smoke in 30 seconds no smoke on ground floor stairs either.
30	Door No. 1. opened, no emission of smoke from door No. 2.
31	No. 1 door closed.
35	Door No. 2. one leaf opened, layer of dense smoke near the ceiling.
37	Top of lobby filled with smoke, fresh air flow at low level, 3 - 4 ft from floor reasonably clear. Fan stopped.
38	Lobby and top stairs gradually filling with dense smoke, smoke density less at low level.
40	Door No. 2 closed, fan started when the lobby is filled with smoke.
41	Top stairs getting cleared of smoke, Door No. 3. near landing reasonably clear, other parts of landing still filled with dense smoke.

Test No. 4. continued.

Time	Observations
42	Visible movement of smoke in the lobby toward the ground floor stairs, smoke still dense in ground floor stairs, no emission of smoke from door No. 2.
45	Only very light smoke in the lobby and ground floor staircase.
50	Lobby stays clear of smoke.
53	Pressure adjusted to determine the minimum necessary to prevent penetration of smoke through the door gaps.
56½	With pressure at 0.028" wg. no emission of smoke from the door gaps.
60	End of test.

Appendix B

Smoke Clearance from a Multi-level Stairway

A simple analysis for systems using presurrisation techniques

In general, continuous stairways in tall buildings can be divided into two groups:

(1) Those with the centre of the well sealed from floor to floor.

(2) Those with the well completely open, with the stairs and landings in a spiral round the edge.

Considering the first group, the design ensures that air can only pass from floor to floor via the stair space, making the air passage similar to a helically coiled tube. To examine the air flow it is convenient to unwind this coil so that we have one long corridor. In this analysis the following assumptions have been made:

(1) The doors are uniformly spaced in a corridor of uniform cross section.

(2) The leakage areas and pressure differentials across each door are identical.

The fresh air supplied does not mix with the smoke already in the stairway.

If the stairway is made up of n units, each consisting of one door with leakage area A, and a length of corridor, l , of cross sectional area, a, then:-

Total volume of stairwell, $C = l.\ a.\ n.$

Total area of leakage $= n.A$

Fan air flow V c.f.m.

With the fan installed at one end of the corridor

the time to clear the smoke to the 1st door is determined by:-

Volume flow in corridor $= V$

Volume of corridor to 1st door $= l.\ a.$

$\therefore$ Clearance time $= \frac{l.\ a.}{V} = \frac{l.\ a.\ n.}{V.n.} = \frac{C}{V.n.}$

Similarly to clear from 1st to 2nd door:-

Volume flow 1st to end door $= V\frac{v}{n} = V\left(1 - \frac{1}{n}\right) = V\left(\frac{n-1}{n}\right)$

Volume from 1st to 2nd door = l.a.

$\therefore$ Clearance time 1st to 2nd door $= \dfrac{l.a.}{V\left(\frac{n-1}{n}\right)}$

$$= \frac{l.a.n.}{V(n-1)} = \frac{C}{V(n-1)}$$

$\therefore$ Total time to clear to 2nd floor

$$= \frac{C}{Vn} + \frac{C}{V(n-1)}$$

$$= \frac{C}{V}\left(\frac{1}{n} + \frac{1}{n-1}\right)$$

Similarly from 2nd to 3rd door

Volume flow $= V - \dfrac{2V}{n} = V\left(\dfrac{n-2}{n}\right)$

and the total time to clear to 3rd door

$$= \frac{C}{V}\left(\frac{1}{n} + \frac{1}{n-1} + \frac{1}{n-2}\right)$$

For the nth door, by extension, the total time

$$T = \frac{C}{V}\left(\frac{1}{n} + \frac{1}{n-1} + \frac{1}{n-2} + \frac{1}{n-3} + \text{----} + \frac{1}{3} + \frac{1}{2} + 1\right)$$

$$= \frac{C}{V}\left(1 + \frac{1}{2} + \frac{1}{3} \text{----} + \frac{1}{n-2} + \frac{1}{n-1} + \frac{1}{n}\right)$$

or rearranging:

$$\frac{TV}{C} = 1 + \frac{1}{2} + \frac{1}{3} \text{---} + \frac{1}{n-2} + \frac{1}{n-1} + \frac{1}{n}$$

This smoke clearance parameter, $\frac{TV}{C}$, relating clearance time, stairway volume air supply rate, is seen to be a function only of the numbers of sections in the stairway. This function is shown in Fig.7 where up to 40 sections are considered.

For stairways of 30 or more units it is seen that the smoke clearance parameter tends to a value between 4 and 5. In fact, this means that when the air supply rate is equal to the volume of the stairway per minute, the clearance time is 4 to 5 minutes. For a given stairway this time is inversely proportional to the air supply rate.

The graph also indicates that when the air from one inlet supplies only one or two doors the smoke clearance parameter is much reduced. The

advantage of this is that either the smoke can be cleared much more rapidly than on multi-sectioned stairways or a reduced quantity of air will suffice to clear the space in the same time. It follows that it may be preferable on a tall block to introduce that air at many points along the stairway and so reduce the size of fan required. This will entail the installation of ducting which would need to be designed to ensure an even distribution of air in the stairway; these distribution points should be sited midway between the doors to prevent the formation of smoke pockets in these regions.

This theory is not applicable to open stairways because thermal buoyancy effects cannot be controlled and these will cause mixing of the fresh air and the smoke. However, once the stairway has been pressurised there will be no further entry of smoke; any particularly warm pockets of gas will rise towards the top of the stairway. The solution given for this condition assumes complete mixing of the fresh air supplied and the smoke already present.

Consider a stairway of total volume C at time T, let the proportion of smoke be x and let the fresh air supply rate be V

Then in time dT,

Volume of smoke discharged $= x\,V\,dT$

$$\therefore \quad dx = \frac{-x\,V\,dT}{C}$$

$$\therefore \quad \frac{dx}{x} = \frac{-V\,dT}{C}$$

Integration gives:

$$\log x = \frac{-V\,T}{C} + K$$

where K is a constant

rearranging: $x = e^{\frac{-V\,T}{C} + K}$

The limits of the problem are:

at $T = 0$, $x = 1$. i.e. the staircase is initially fully smoke logged

$$\therefore \quad K = 0.$$

$$\therefore \quad x = e^{\frac{-VT}{C}}$$

and the proportion of smoke clearance

$$(1 - x) = 1 - e^{\frac{-V\,T}{C}}$$

This curve is plotted in Fig. 8 and is seen to have an exponential form. Visibility in a staircase would be unimpaired for escape purposes with a 95 per cent clearance and this figure indicates a smoke clearance parameter value of 3. This figure is independent of the number of sections on the stairway.

It is interesting to note the similarity between the values obtained in these theories for both open and sealed stairways. For both designs it is shown that the introduction of fresh air at rates of the order of stairway volume per minute should ensure clearance of smoke in less than 5 minutes.

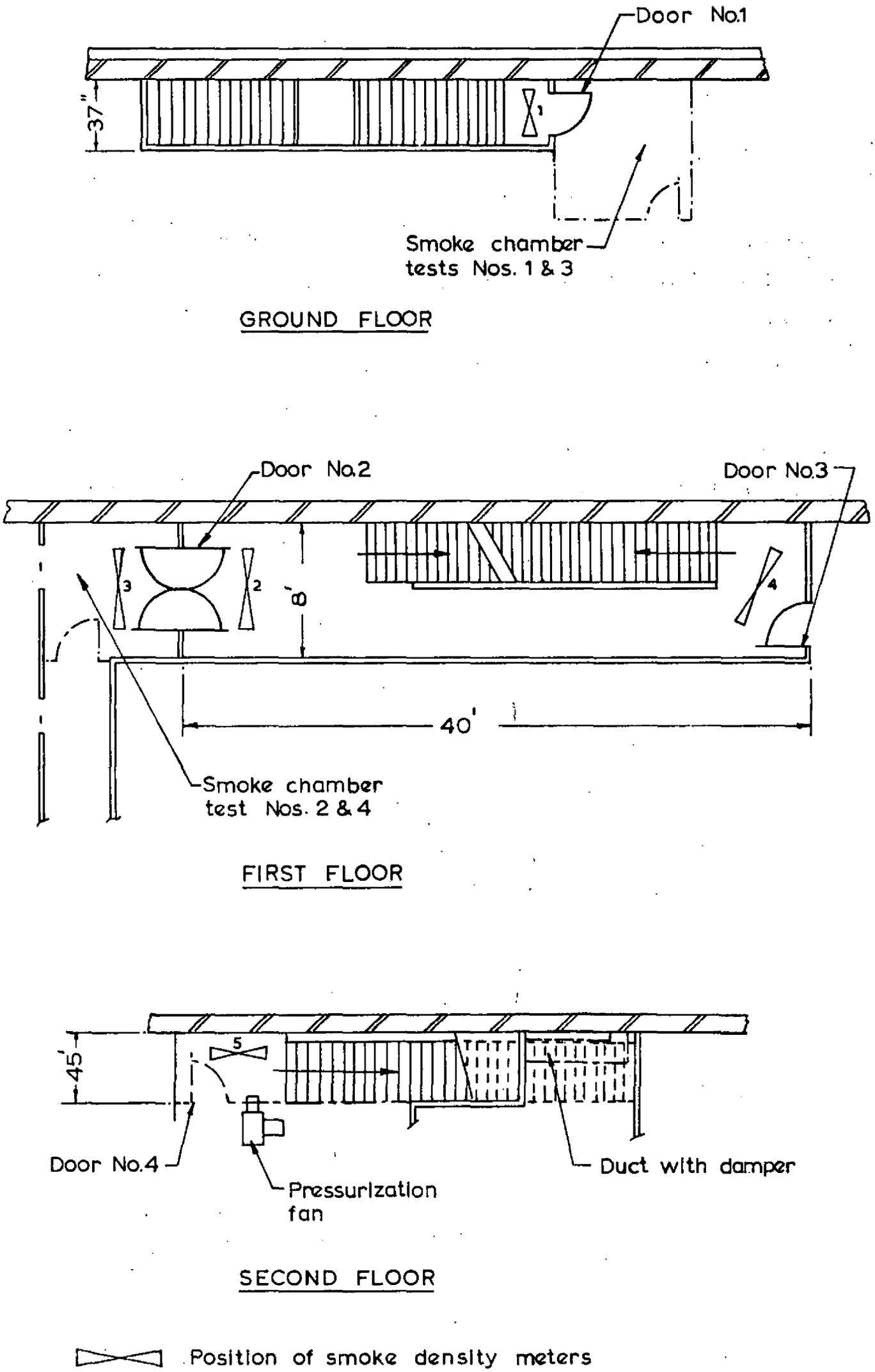

FIG.1. EXPERIMENTAL STAIRCASE
MARKS AND SPENCER
PETERBOROUGH

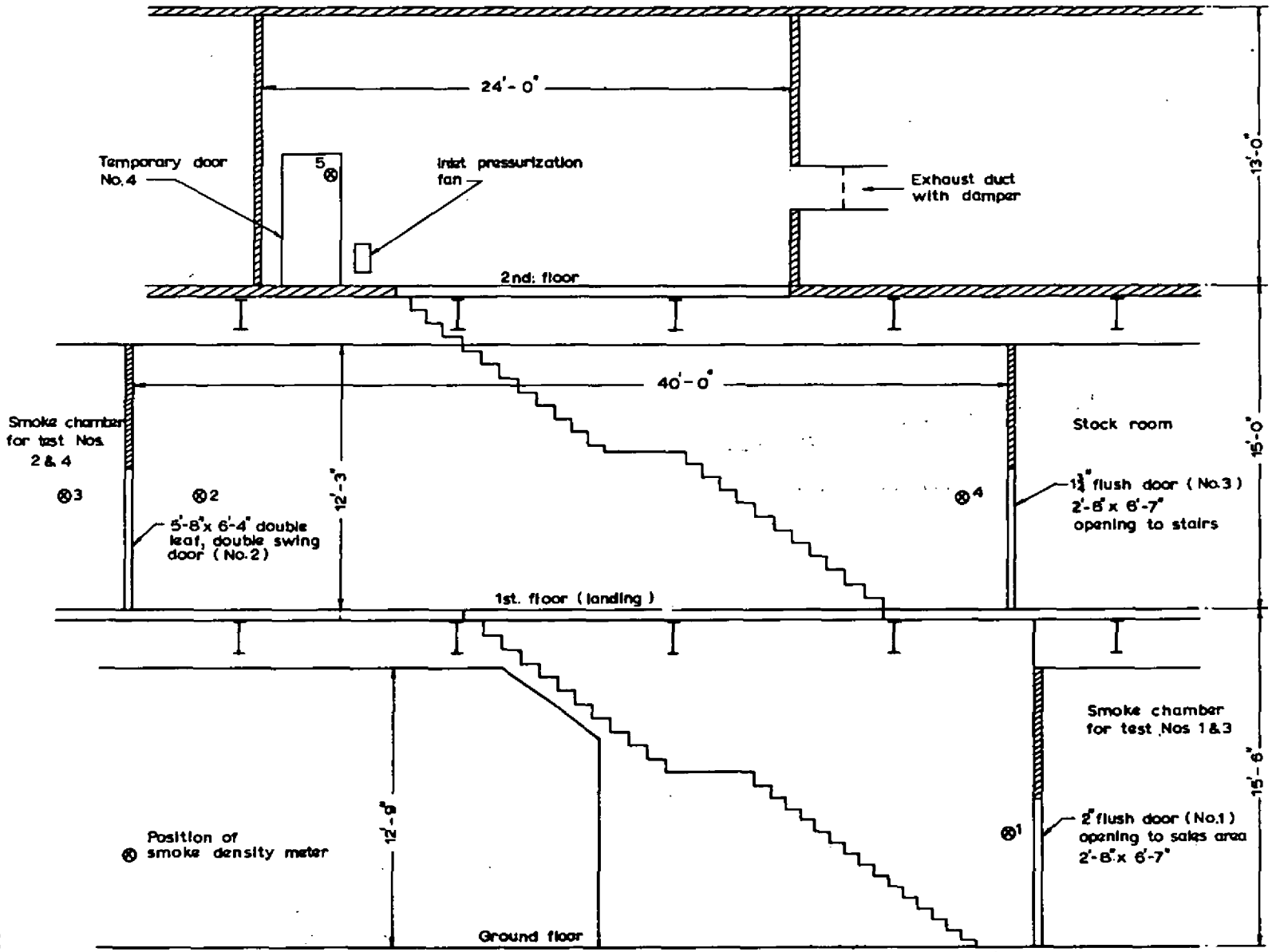

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FIG. 2. SECTIONAL ELEVATION OF STAIRCASE. (MARKS & SPENCER PETERBOROUGH)

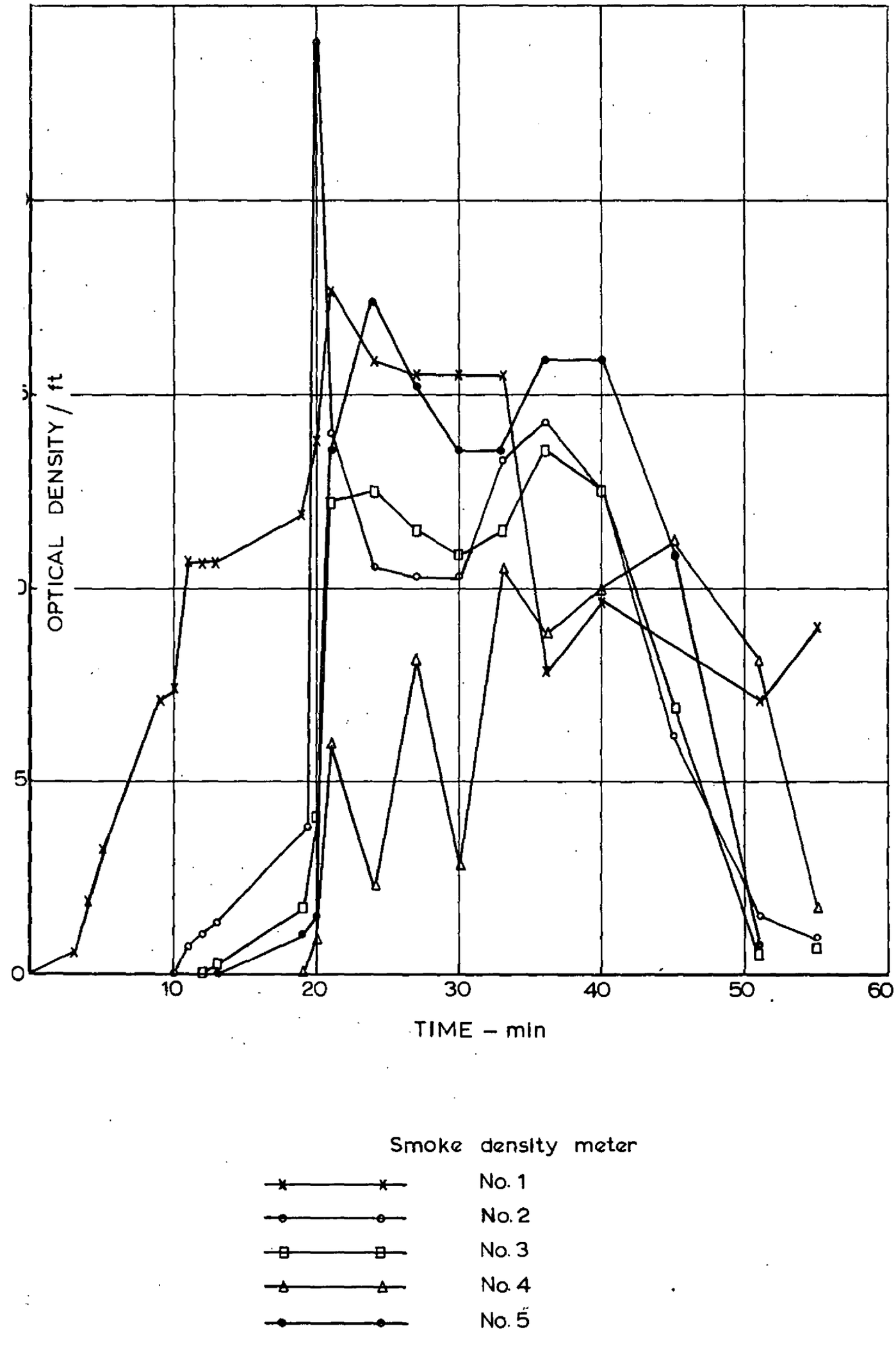


FIG. 3. SMOKE DENSITY CURVES TEST No.1

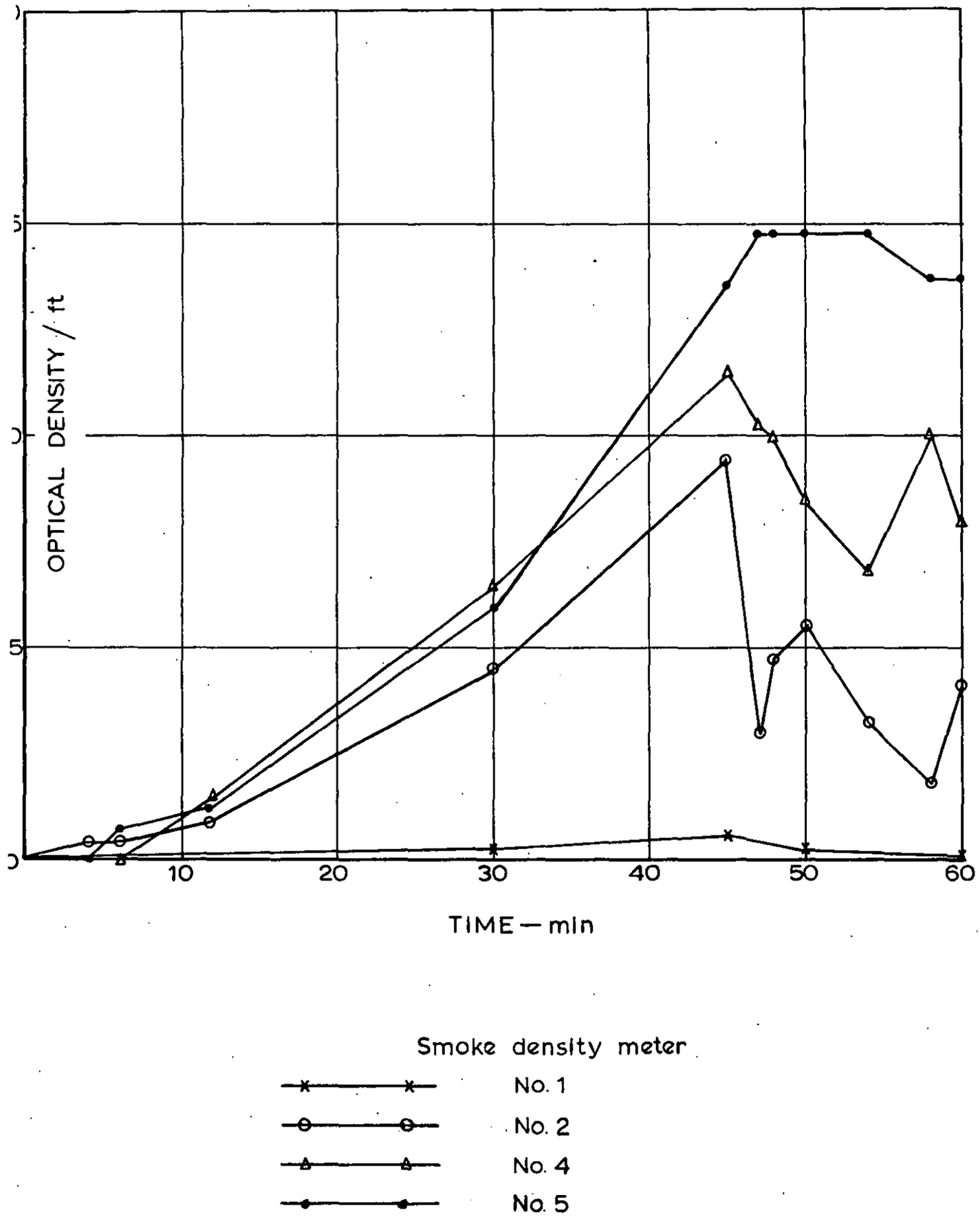


FIG.4. SMOKE DENSITY CURVES TEST No.2

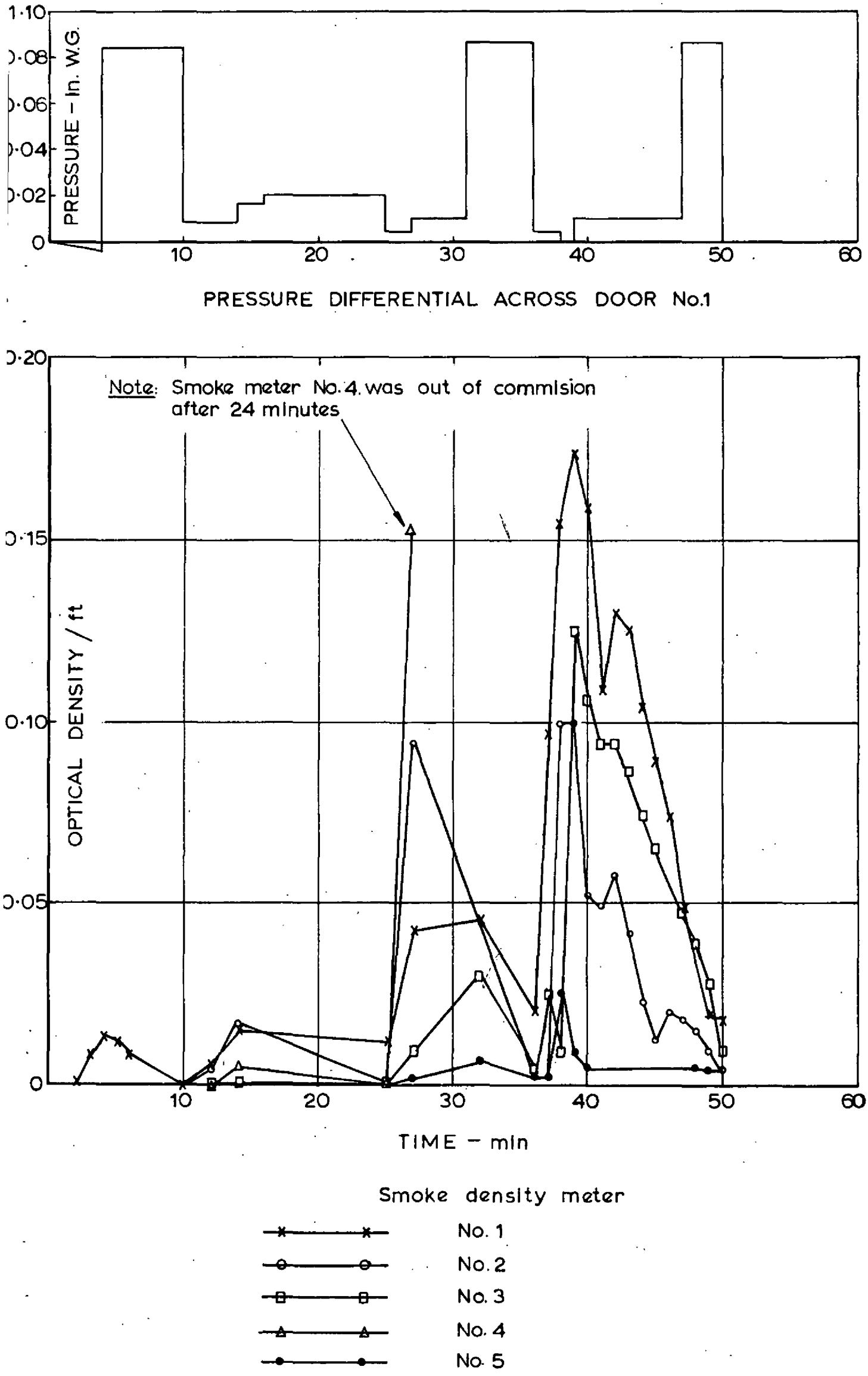
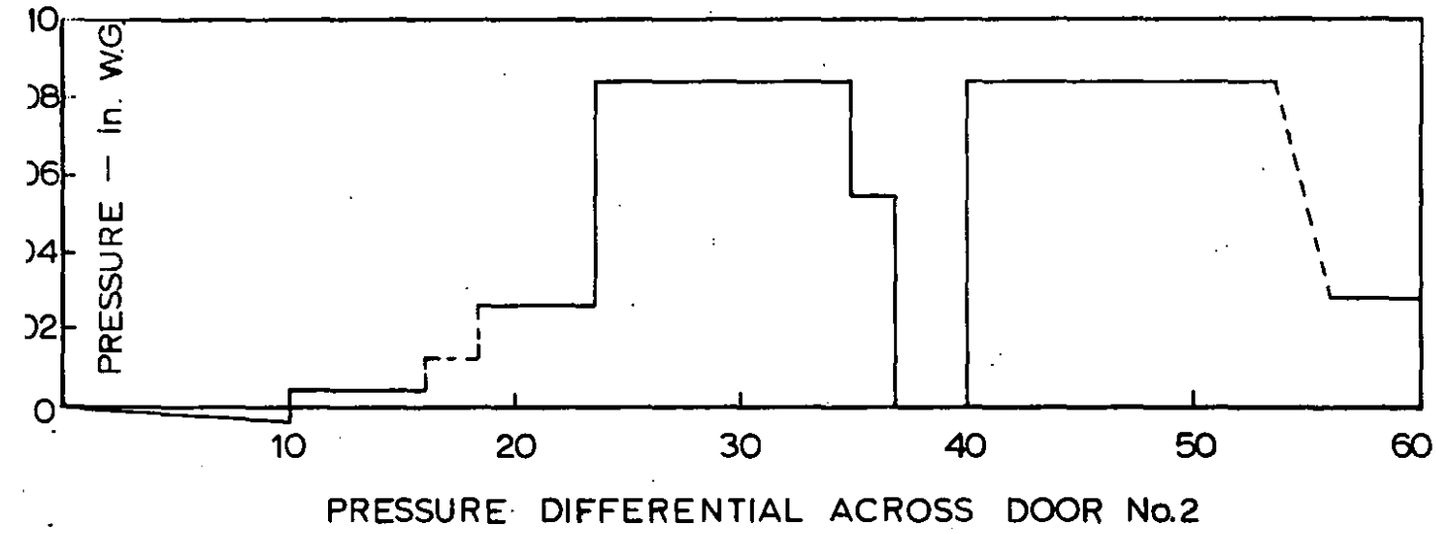
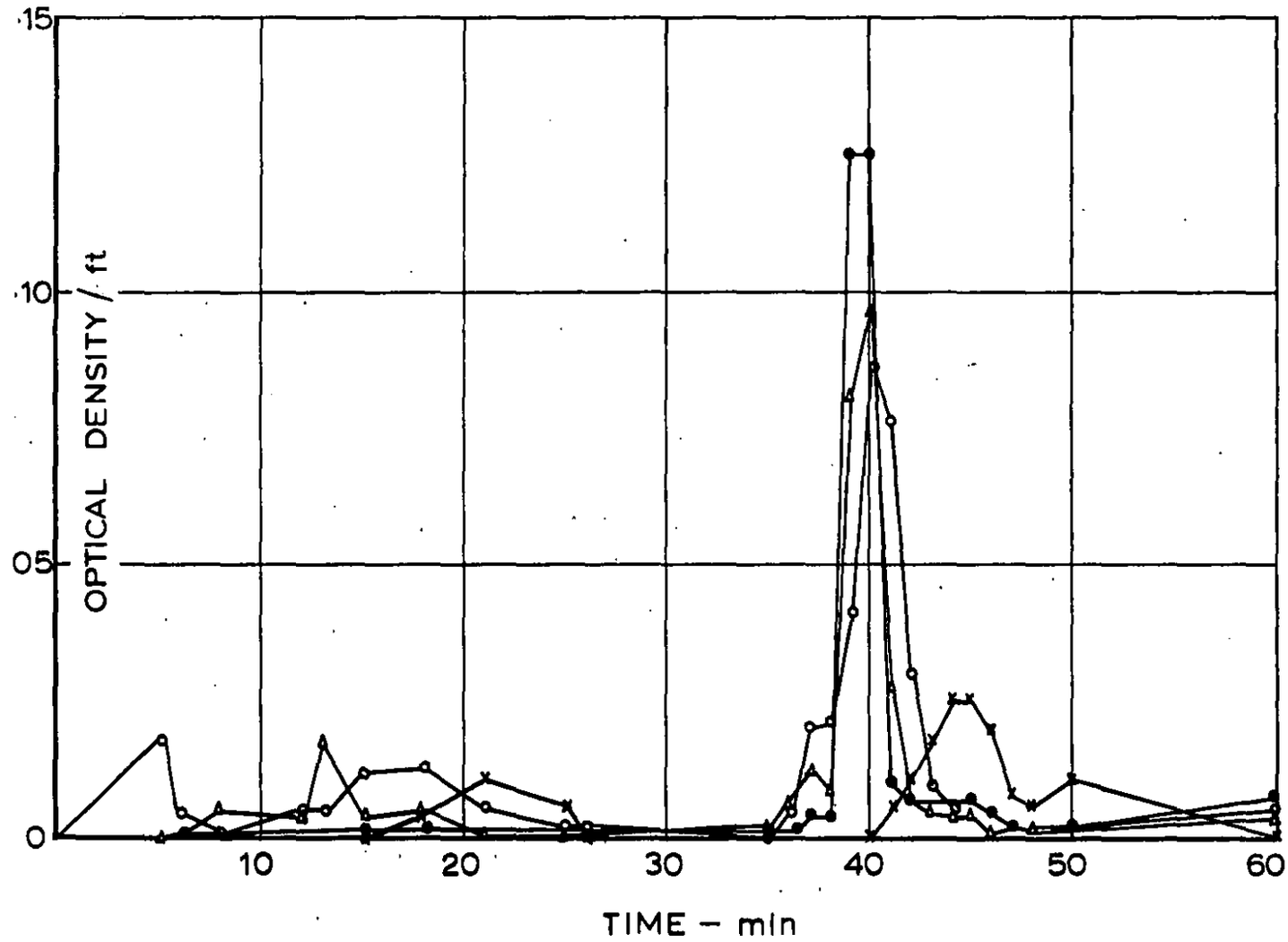


FIG. 5. SMOKE DENSITY AND PRESSURE CURVES TEST No. 3





Smoke density meter

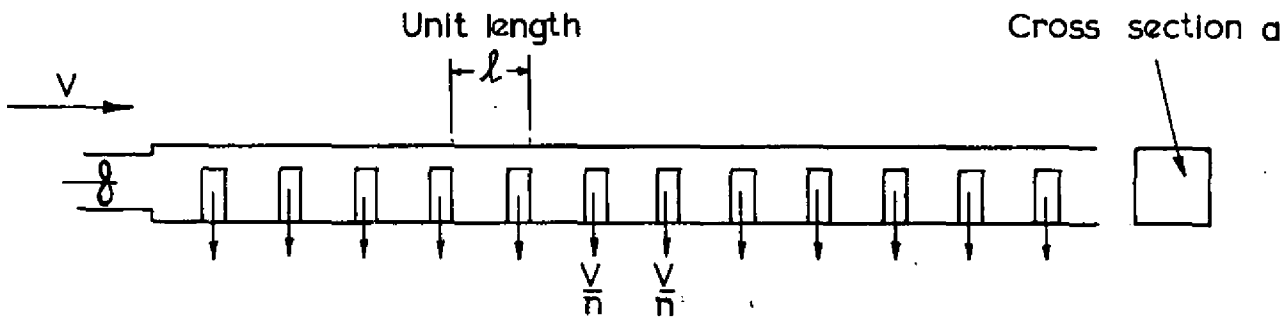
No. 1

No. 2

No. 4

No. 5

FIG. 6. SMOKE DENSITY AND PRESSURE CURVES
TEST No. 4



CORRIDOR OF n UNITS, TOTAL VOLUME, C = ℓa.n.

V Rate of introduction of fresh air

T Time to clear smoke

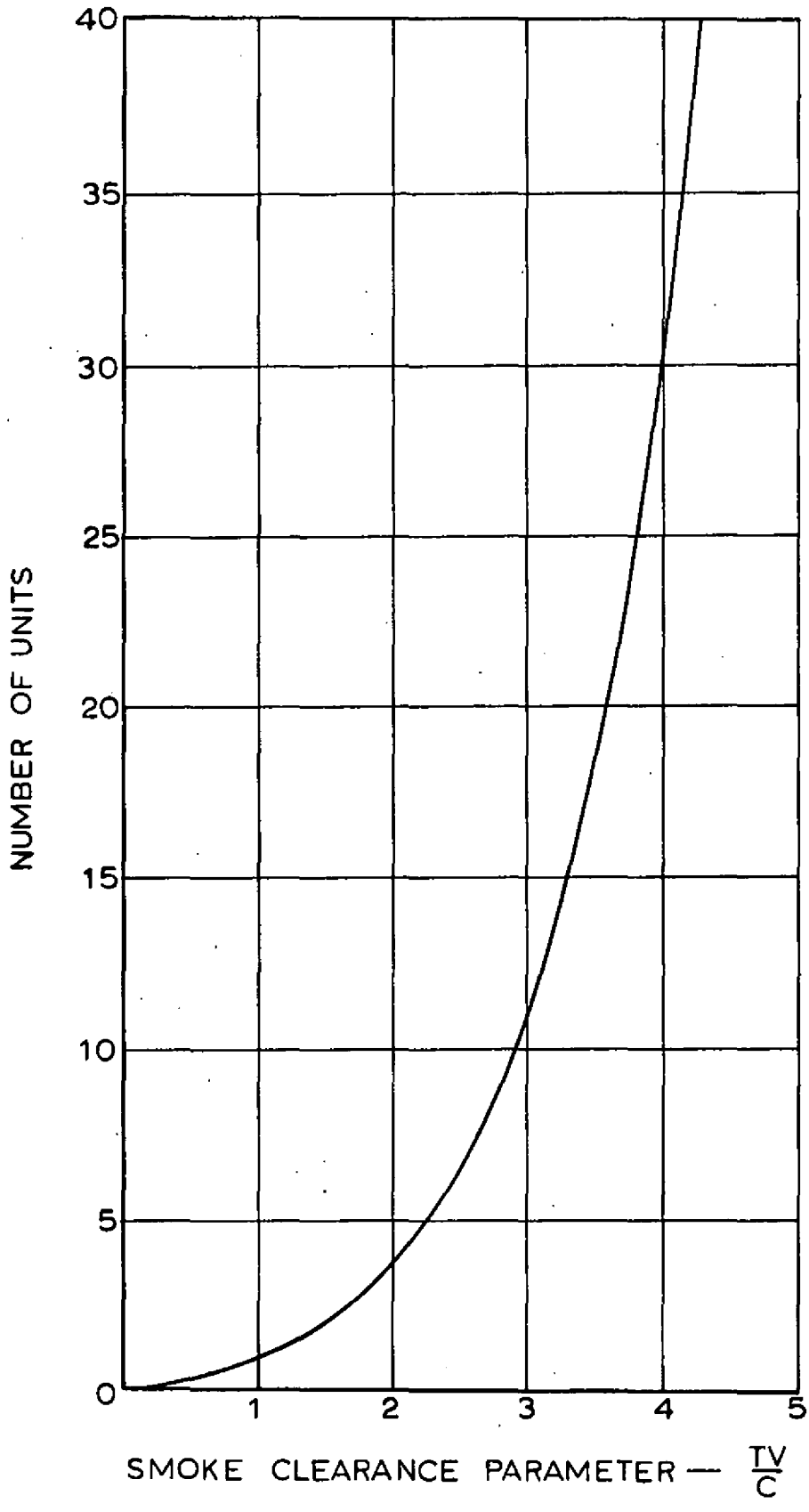
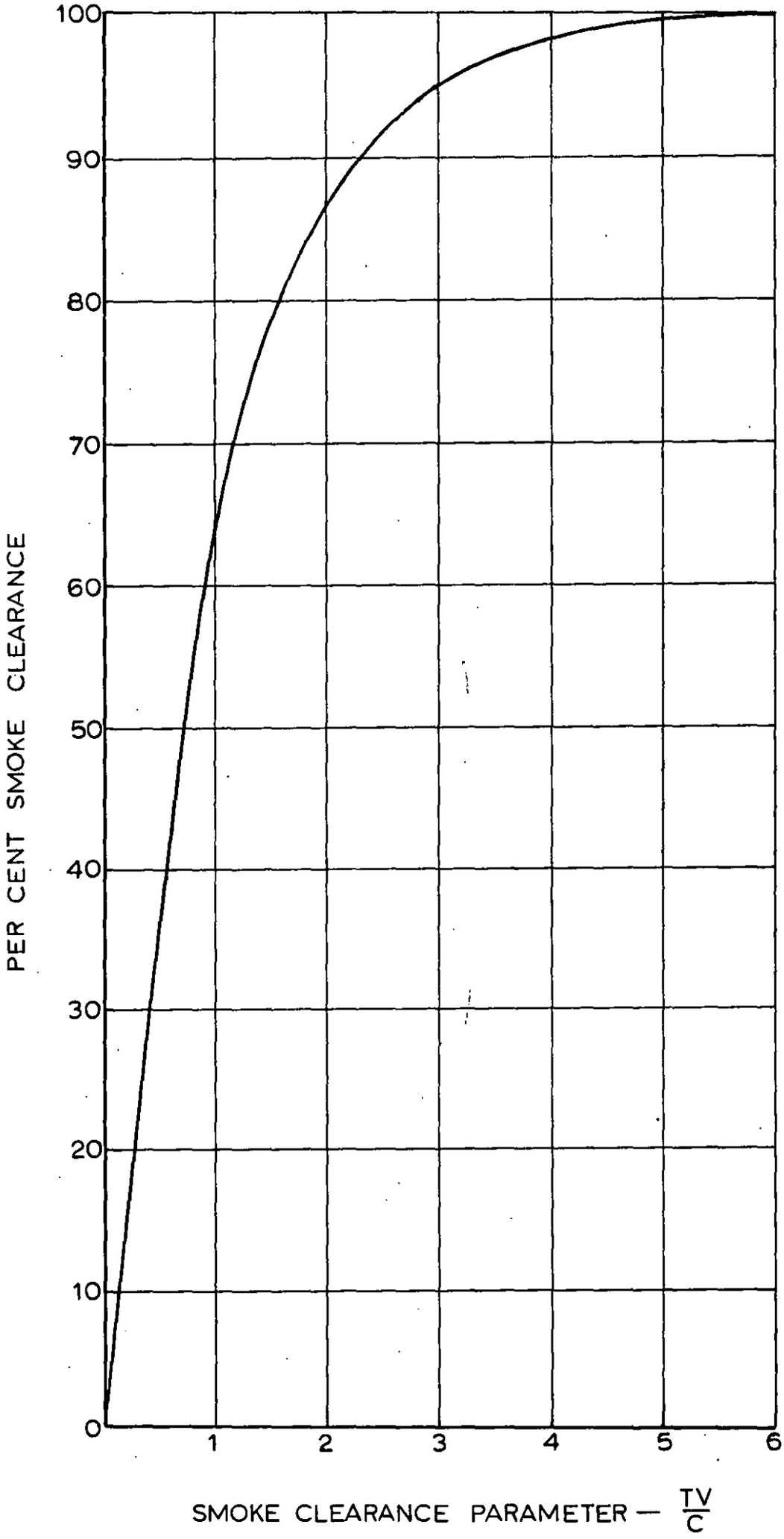


FIG.7 SMOKE CLEARANCE FROM A SEALED STAIRWAY



T Time to clear smoke

V Rate of introduction of fresh air

C Total volume of stairway

FIG.8. SMOKE CLEARANCE FROM AN OPEN STAIRWAY

FIG. 9 DOOR No. 1 ON GROUND FLOOR

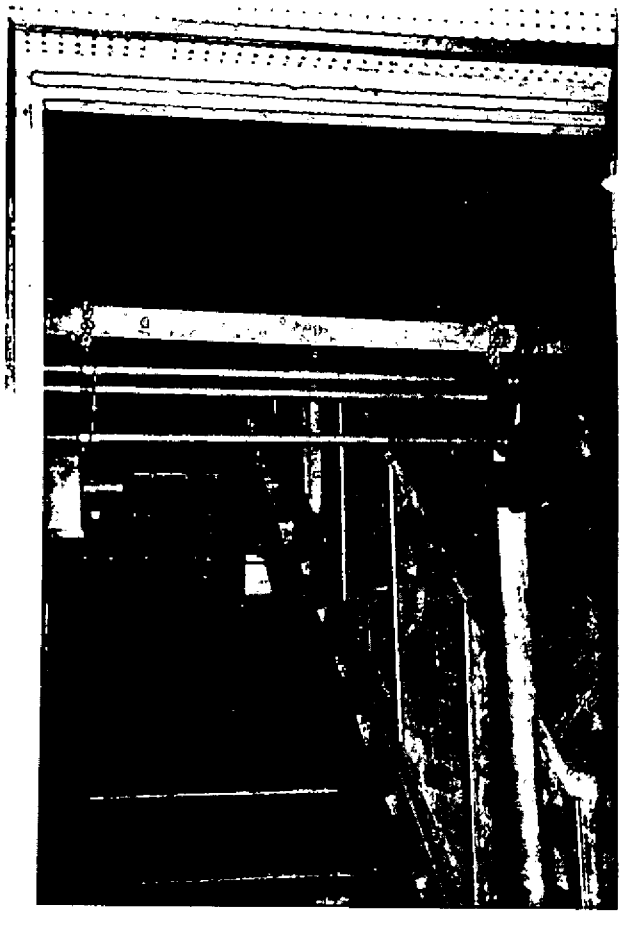


FIG. 8 LOOKING UP WITH DOOR OPEN, SHOWING SMOKE METER IN POSITION

FIG. 11 ADJUSTMENT OF SMOKE METER NO. 2
IN FRONT OF DOUBLE LEAF DOOR ON 1st FLOOR LANDING

FIG. 12 MEASUREMENT OF SMOKE DENSITY (LEFT) AND
PRESSURE CONDITIONS (RIGHT)