Fire Research Note No. 916

EXPERIMENTS WITH SPRINKLERS IN HIGH RACKED STORAGES

(1) EXTINCTION WITH CENTRALLY MOUNTED SPRINKLERS

by

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SUMMARY

A series of experiments has been carried out to determine the effects of sprinklers mounted in the centre of a storage rack on fires propagating up the face of the stack.

The number of heads required to extinguish fires at various stages of development was found, and it was concluded that a satisfactory system would result from grouping sprinklers vertically and operating a group by means of a line detector.

When the pallets were $\frac{2}{3}$ full the fire moved from the face to the centre of the stack.

KEY WORDS: Fire spread; high-piled; sprinkler; storage.

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1. INTRODUCTION

A further series of experiments using sprinklers on high stacked goods has been carried out at Cardington. In the first series of experiments with the large racks[1], the sprinklers gave generally good control of the fires, but it was felt that an improvement would result from faster operation of the system. The experiments described in this note were therefore designed to find whether rapid control of a fire which had reached a specified degree of development, could be achieved if certain sprinkler heads were opened at this stage.

The earlier experiments had suggested that a fire starting on the face would generally progress up the face of the stack if each pallet were fully loaded, but that if each load was around two thirds of the maximum height, the fire would spread to the centre of the stack. An opportunity was taken to verify this during the experiments.

2. EXPERIMENTAL DETAILS

2.1. Racking

The racking used for previous experiments in the Models Laboratory at JFRO[2] was taken to Cardington and erected near the larger rack, in the airship hanger. The racking was of tubular steel, and was 4.88 m (16 ft) long, 2.95 m (8 ft 2 in) deep, and 5.68 m (18 ft $7\frac{1}{2}$ in) high. (Fig 1).

2.2. Loading

The rack contained thirty two standard wooden pallets, 1.02 m x 1.22 m (40 x 48 in), each loaded with cardboard cartons as used in the larger racks. Each carton contained three empty 5 gallon drums and some wood wool in the spaces between them.

For ten of the experiments, each pallet carried nine cartons, loaded as in the previous series of experiments, but in one experiment each pallet carried only six cartons, thus making the load 0.91 m (36 in) high instead of 1.37 m (54 in).

2.3. Sprinklers

Each of the four levels was provided with five sprinkler positions (Fig 1), the four distribution pipes being fed from one 50 mm (2 in) riser. The ends of the distribution pipes remote from the riser were used for connections to pressure gauges. The central positions were fitted with open or closed sprinklers, as required for each experiment. All other positions were fitted with 68°C (155°F) glass bulb sprinklers of conventional pattern.

The particular arrangement of sprinklers left open for each experiment was decided from the results of the previous experiment, as was the stage of development of the fire when water was applied. An algorithm shown in Fig 2 was used to assist in this decision. The first experiment used one open sprinkler in the bottom level represented by O.S. = A and water was applied to this when the flames reached the top of the first layer of pallet loads represented by F.H. = 1. If this controlled the fire, the next experiment would repeat the first, and assuming this was also successful, the third experiment open head (B) with water being applied when the flames reached $1\frac{1}{2}$ levels high. This is shown in the algorithm, using the YES exits from the first and second boxes.

If the first experiment was deemed unsuccessful, using the NO exit from the first box, the algorithm gives for the second experiment a flame height of $1\frac{1}{2}$ layers (loads) but with water applied to two open heads, A and B. A simple algorithm of this type cannot cover all the possible choices for succeeding experiments since there are several variables, and the final choice was made on past experience. Table 1 gives the details of which heads were open in each experiment, and the height of the flames when water was applied, for the first 10 experiments. The final experiment of the series used closed heads throughout, operating automatically, but the pallets were only two thirds filled.

2.4. Instrumentation

A thermocouple was fitted near each sprinkler head on the vertical centre line of the rack (i.e. near each head which was to be used open or closed as required). In addition, two thermocouples were positioned on the face of the stack at the top of the second and fourth levels, above the point of ignition of the fire.

Two radiometers were mounted at heights of 1.67 m (5.5 ft) and 4.4 m (14.5 ft) facing the stack, at a distance of 1 m from the vertical through the point of ignition, to give an estimate of the likelihood of an adjacent stack igniting by radiation.

A light source and photocell with a 1 m path length was mounted across the top of the centre of the stack to measure the obscuration produced by smoke.

All the above devices were connected to a U.V. recorder, giving a continuous trace for each parameter being measured.

Measurements were also made of the moisture content of the cardboard cartons.

3. TEST PROCEDURE

Each fire was lit with a match at a tear in the side of a box on the bottom layer, between the two centre pallets, near the face. At the same time, the U.V. Recorder and the clocks were started. The pump was operating and the supply hose was charged, up to a quick acting valve 2 m from the bottom of the rising main. The fire was allowed to burn until the flames reached the predetermined level, and the valve was then opened. The pressure was quickly adjusted to 7 bars (100 lbf/in^2) at the valve. In some cases, the sprinkler system extinguished the fire except for small amounts of deep seated burning. The water requirements for extinguishing these very small fires would have been excessive, and therefore these were extinguished as the goods were cleared from the stack, by the R.A.F. Fire Brigade.

3.1. Results

The sequence of events in each fire test is given in the Appendix. Figures 3, 4 and 5 show temperature, radiation and optical density measurements for Test 8, which was in many ways typical of experiments in which the vertical spread of fire was arrested by the sprinkler system.

The air temperature rise in the centre of the rack is not plotted as it did not exceed 60°C at any level. In no case where the fire spread was stopped did any thermocouple in the centre of the rack show a temperature increase of more than 20°C.

The radiation measurements given in Fig 4 show a maximum radiation intensity of 0.5 watts/sq cm at a distance of 1 m from the face. The maximum intensity recorded in this series of tests was 0.65 watts/sq cm which is less than 1/10th of the intensity required to ignite cardboard.

The smoke measurements made with the device in the most advantageous position for detection, show that with a detector set to operate at say, 5 per cent obscuration, detection would usually be made before the fire had spread beyond the level in which it originated. In Fig 5 it can be seen that detection would have occurred at about 2 min 15 sec after ignition, that is, when the flames were less than 1 m high in the pallet of origin.

In these experiments, with boxes almost filling each pallet space, the flame spread, from an ignition point near the front face of the stack, was mainly up the face of the stack, the flaming gradually moving into the centre of the rack as the flame height increased. This followed the findings of experiments made previously at Cardington[1].

To prevent the vertical spread of flames, which was far more rapid than the horizontal spread, it was found that a sprinkler had to operate in advance of the flames.

The height of the uppermost sprinkler above the flames tips necessary to arrest the vertical flame spread depended upon both the rate of flame spread and the number of levels of sprinklers operating simultaneously.

Thus it was found in Test 9 that with sprinklers operating at the 1st, 2nd and 3rd levels the vertical spread was arrested when the water was turned on with the uppermost sprinkler only a $\frac{1}{2}$ level in advance of the flame tip. In general, it was found that a single sprinkler needed to operate at least 1 full level in advance of the flames to be effective, as can be seen in Fig 7.

The growth of the fire in each test is shown in Fig 8, where the rate of increase of flame height is plotted against time. The time taken for the flames to reach the top of the first pallet load varied from 2 m 15 s to 5 m 40 s. This variation does not appear to be due to variation in the average moisture content, the relationship of which with time to reach 1st pallet level is shown in Fig 9.

There may be some relationship between moisture content of the cardboard boxes and the rate of growth of the fire, but if a relationship does exist, it is masked in these experiments by other factors such as variations in the filling of the box in which the fire started.

In the final experiment of the series where the pallets were loaded to only $\frac{2}{3}$ of their former height, the fire spread to the centre of the stack. The sprinklers were allowed to operate automatically, but did not prevent the upward spread of the fire before it had reached the top of the stack. This result was in accord with the work done at JFRO[2], and suggests that the mode of vertical fire spread is dependant upon the geometry of the racked goods.

4. CONCLUSIONS

4.1. The early operation of a sprinkler or sprinklers ahead of the fire is a dominant factor in the control of fires developing in racked storages.

4.2. A single head would often be sufficient to arrest the fire if it could be made to operate soon enough and were in a suitable position to do so.

4.3. Heads operated by the normal thermal devices are unlikely to operate soon enough to check the fire.

4.4. A zone or group of several heads operated together is a more certain means of controlling the fire than is a single head. The size of the zone would be a compromise depending on the combustibility of the goods, the tolerable amount of water damage, cost of installation and other factors, but the optimum number is likely to be small, in the range 2 to 6.

4.5. Line detector systems are needed which will operate heads, or zones of heads, considerably sooner than the present method of individual thermal devices. The design of these systems must be such as to eliminate the possibility of false alarms.

4.6. In an experiment with "two-thirds" loading of each cell, the fire was found to spread more rapidly into the centre of the stack than it would have done with full loading. It would therefore have activated a sprinkler system more rapidly than in the other case.

5. REFERENCES

1. NASH, P., BRIDGE, N. W. and YOUNG, R. A. "Some experimental studies of the control of developing fires in high-racked storages by a sprinkler system." Fire Research Note No. 866, April 1971.
2. YOUNG, R. A. "Fire tests with sprinkler on high piled stock," Fire Research Note No. 814, March 1970.

Table 1

Cardington tests - series 2

Test No.	Height of pallet load	Open sprinkler head-levels	Flame height at operation, in levels	Upward spread prevented	Comments
1	3 boxes	1	1	No	
2	" "	1	1	Yes	
3	" "	2	$1\frac{1}{2}$ intended (4 actual)	No	Delay in turning on water.
4	" "	1,2	$1\frac{1}{2}$	Yes	
5	" "	1,2	$1\frac{1}{2}$	Yes	
6	" "	2	$1\frac{1}{2}$	Yes	
7	" "	3	$2\frac{1}{2}$	No	
8	" "	3	2	Yes	
9	" "	1,2,3	$2\frac{1}{2}$	Yes	
10	" "	2,4	3	Yes	
11	2 boxes	No open sprinklers. 1 sprinkler operated on 3rd level, and 2 sprinklers operated on 4th level.	-	No	Fire allowed to take natural course.

Small rack, sprinklers at 4 levels, (1 per pair of pallets, including all heads)

APPENDIX - SEQUENCE OF EVENTS IN FIRE TESTS

Serial No. S 2/1

Time	Event
0.00	Ignition, on face
0.45	Re-lit
1.25	Flames to top of first box
2.00	Flames to top of second box
3.00	Burning round face of first box
3.05	Flames to top of third box
3.30	Flames 2 m high to 1st level sprinkler in centre of rack. WATER ON
4.00	Flames on 1st level subdued, but box caught alight in gap between pallets on 2nd level. Optical density 0.05 (approx. 10 per cent obscuration)
6.00	Flaming on 2nd level extinguished with hand line
7.30	WATER OFF. No reignition of boxes on 1st level.

Serial No. S 2/2

Time	Event
0.00	Ignition, centre of front face
0.30	Flames 1 box high
3.40	Flames to top of 2nd box
4.00	WATER ON. Flames to top of 3rd box, 1.6 m high
7.00	No fire spread to 2nd level, all flaming extinguished.
	WATER OFF.

Serial No. S 2/3

Time	Event
0.00	Ignition at centre of front face
0.10	Flames 1 box high
2.05	Flames 2 boxes high
2.50	Flames 3 boxes high
3.10	Flames 2 m high
3.50	Flames 3 m high in gap between pallet loads
4.20	WATER ON
4.30	Flames to top of rack, freely burning above operating sprinkler. Extinguished by hose reel jets.

Serial No. S 2/4

Time	Event
0.00	Ignition, at centre of front face.
0.35	Flames 1 box high
2.15	Flames 2 boxes high
2.55	Flames 3 boxes high
4.50	Flames burning through box in 2nd level
5.00	Optical density 0.05
5.20	Flames 3 m high in gap between pallet loads
	WATER ON.
5.30	Flames spreading up gap between pallets, no burning on face.
5.40	Third level boxes alight
5.45	Third level boxes extinguished
9.00	WATER OFF. Jet used to extinguish small pockets of flames on 1st level.

Serial No. S 2/5

Time	Event
0.00	Ignition, at centre of front face
0.30	Flames 1 box high
4.20	Flames 2 boxes high
5.15	Flames 3 boxes high
5.40	Flames 2 m high
5.45	Optical density 0.05
6.05	Flames 3 m high. WATER ON.
7.00	Top of flames beating under 3rd level pallets, flames being drawn into centre of rack over top of boxes.
11.00	Centre 2 pallets on 2nd level still burning well.
18.00	Flames extinguished by hose reel jet. WATER OFF.

Serial No. S 2/6

Time	Event
0.00	Ignition, at centre of front face.
1.35	Flames 2 boxes high
2.00	Flames 3 boxes high
2.08	Optical density 0.05
2.30	Flames licking under bottom of 2nd level pallets
	Flames 3 m high - WATER ON
3.30	Vertical spread of flames arrested
14.00	All flaming extinguished - WATER OFF. Fire damage to 2 pallets of the bottom level and 1 pallet on 2nd level.

Serial No. S 2/7

Time	Event
0.00	Ignition, at centre of front face
1.10	Flames 2 boxes high
1.55	Flames 3 boxes high
2.15	Flames reach 2nd pallet level
3.00	Optical density 0.05
3.45	Flames reach 3rd pallet level
3.55	Flames 5 m high - WATER ON
4.30	4th level boxes burning
5.00	Burning on face of pallets on 4th level
6.00	Top level burning well
7.15	Flaming on top level extinguished by hose reel
12.15	All flaming now extinguished by sprinklers, WATER OFF.

Serial No. S 2/8

Time	Event
0.00	Ignition, at centre of front face
0.25	Flames 1 box high
3.30	Flames 2 boxes high
4.00	Optical density 0.05
4.05	Flames 3 boxes high
5.05	Flames beating under 2nd level pallet
5.35	Flames beating under 3rd level pallet, WATER ON
6.00	All flaming extinguished above 2nd level
7.00	Large pieces of cardboard carried up to 30 m
11.00	Deep seated burning in bottom level
13.30	WATER OFF. A little deep seated burning extinguished with hose reel.

Serial No. S 2/9

Time	Event
0.00	Ignition, at centre of front face
1.30	Flames 2 boxes high
2.25	Flames 3 boxes high
2.35	Second level pallet alight
3.20	Flames licking bottom of 3rd level pallet
3.50	Flames $2\frac{1}{2}$ pallet levels high, WATER ON
4.00	All flaming on 3rd level extinguished
7.30	All flaming on bottom level extinguished
11.30	WATER OFF. Some persistent flaming on 2nd level.

Serial No. S 2/10

Time	Event
0.00	Ignition, at centre of front face
1.05	Flames 1 box high
2.40	Flames 2 boxes high
3.15	Flames 3 boxes high
3.40	Flames touching bottom of 2nd level pallet
4.00	Flames touching bottom of 3rd level pallet
4.08	Optical density 0.05
5.10	Flames reach top of racking, WATER ON
8.00	WATER OFF. All major flaming extinguished.

Serial No. S 2/11

Time	Event
0.00	Ignition, at centre of front face
0.55	Flames 1 box high
2.00	Flames 2 boxes high
3.30	Flames moving into centre of stack, 0.3 m from front face.
4.00	Flames at bottom of 2nd level
5.00	Boxes on 2nd level ignited
5.05	Flames at bottom of 3rd level pallet and reached centre of stack at 2nd level.
6.40	Top layer of boxes burning
8.00	First sprinkler, operated at centre of 3rd level
19.00	Sprinkler at 4th level operated
20.00	All major flaming extinguished
20.00	WATER OFF.

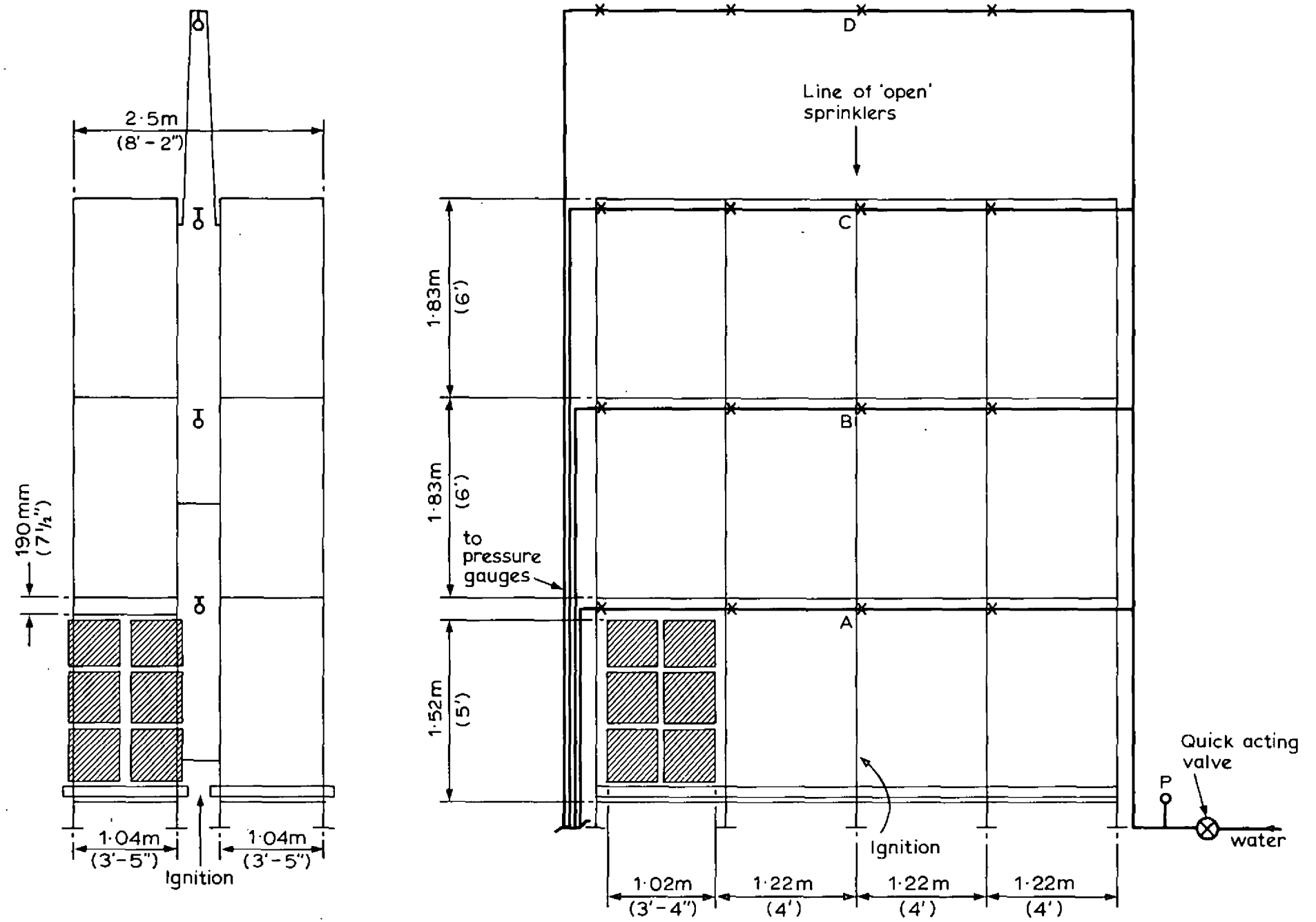

FIG. 1 ARRANGEMENT OF RACKING AND SPRINKLERS

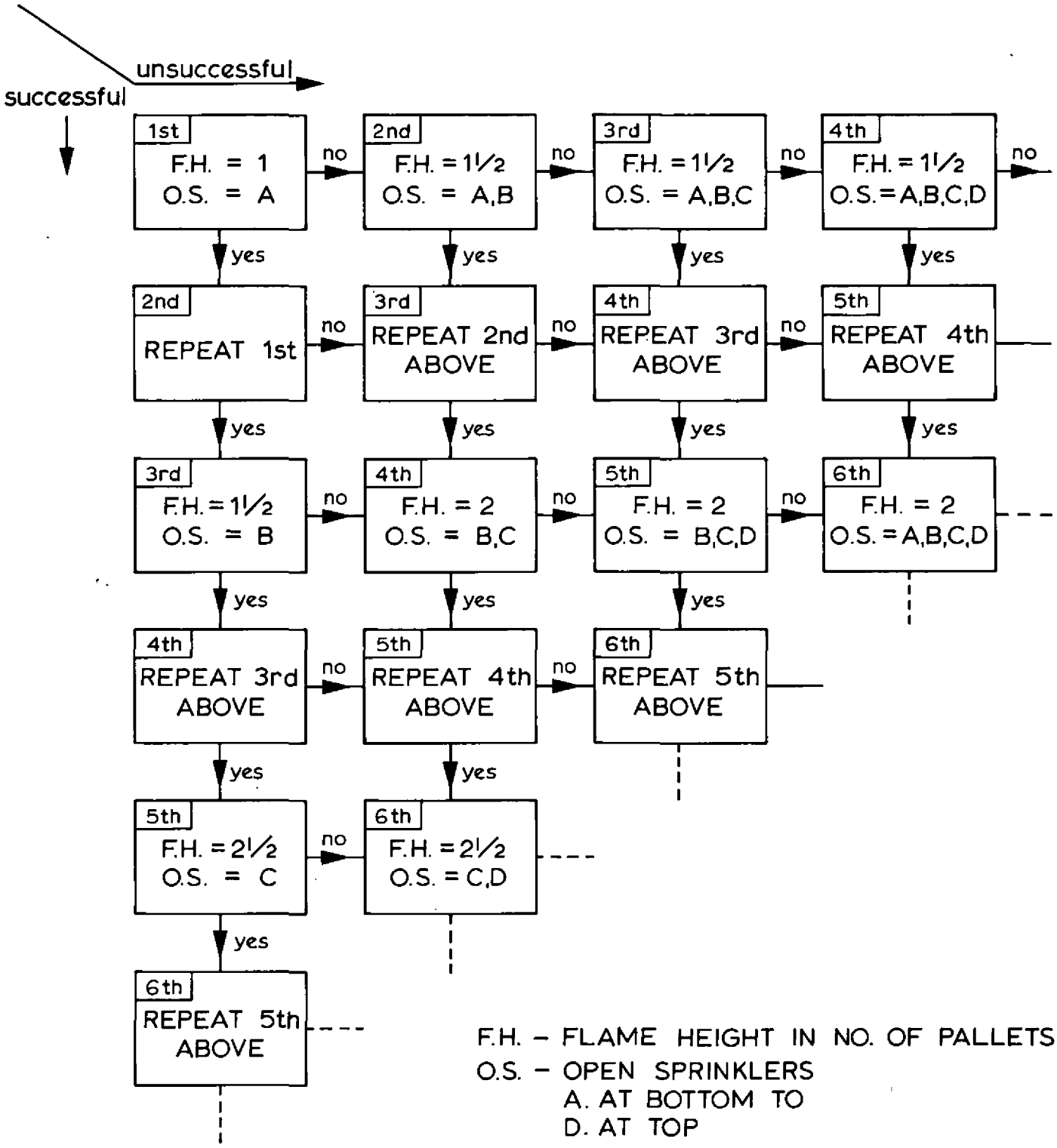

FIG. 2 TEST PROGRAMME, CARDINGTON 2nd SERIES
SIX TESTS
JOHN LEWIS RACK

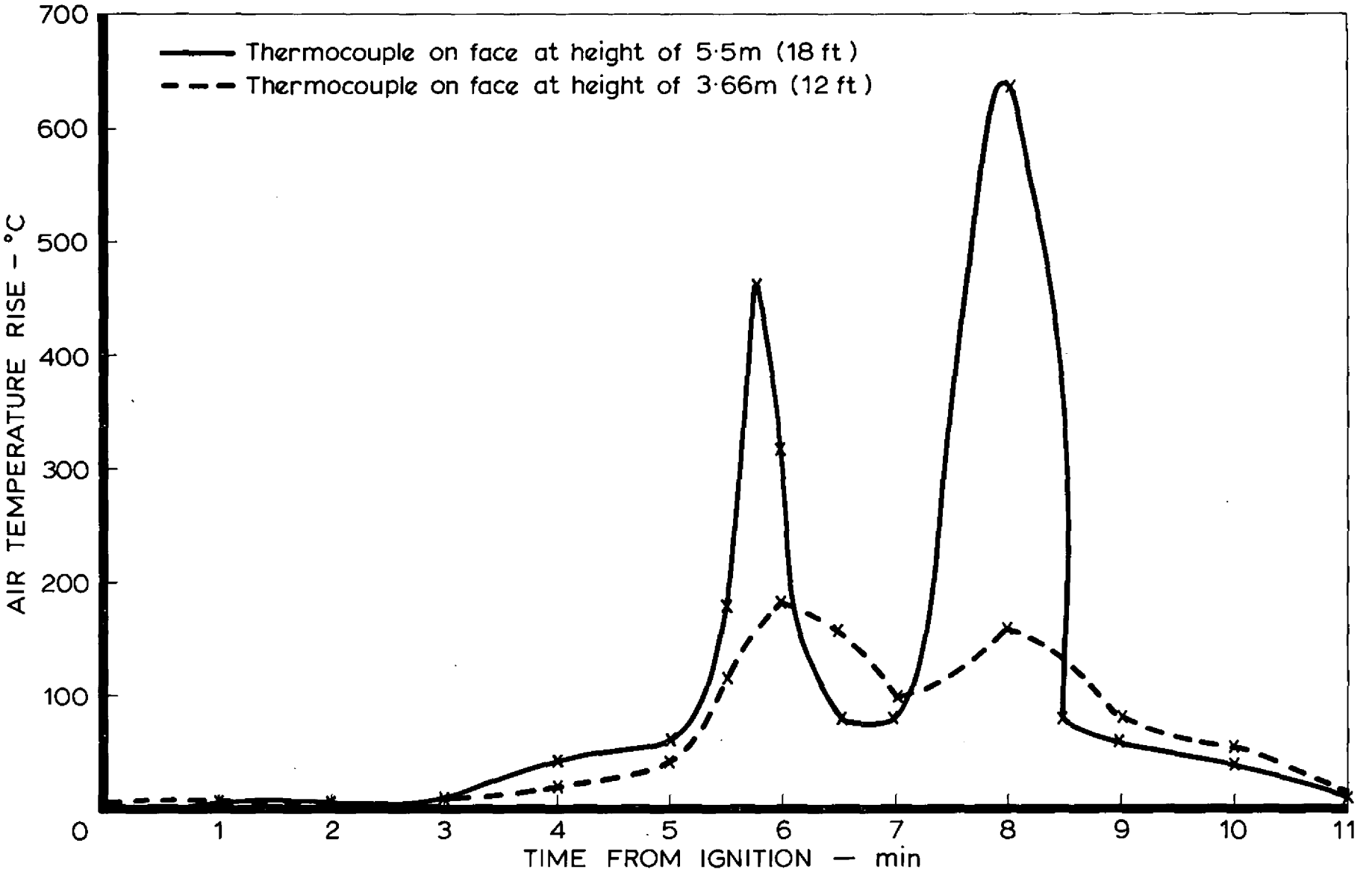

FIG. 3 AIR TEMPERATURE RISE EXPERIMENT 8

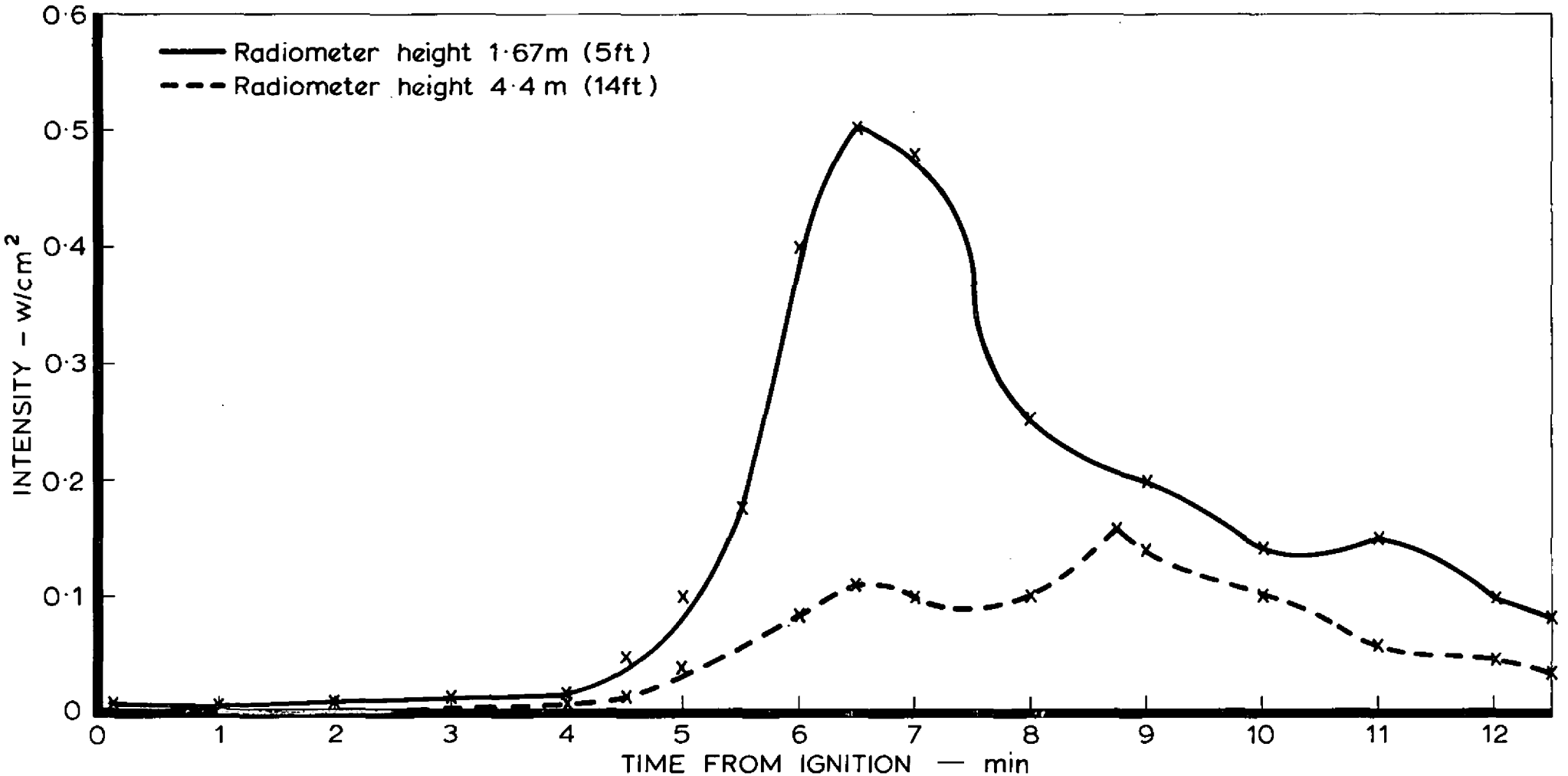

FIG. 4 RADIANT INTENSITY AT 1m FROM FACE EXPERIMENT 8

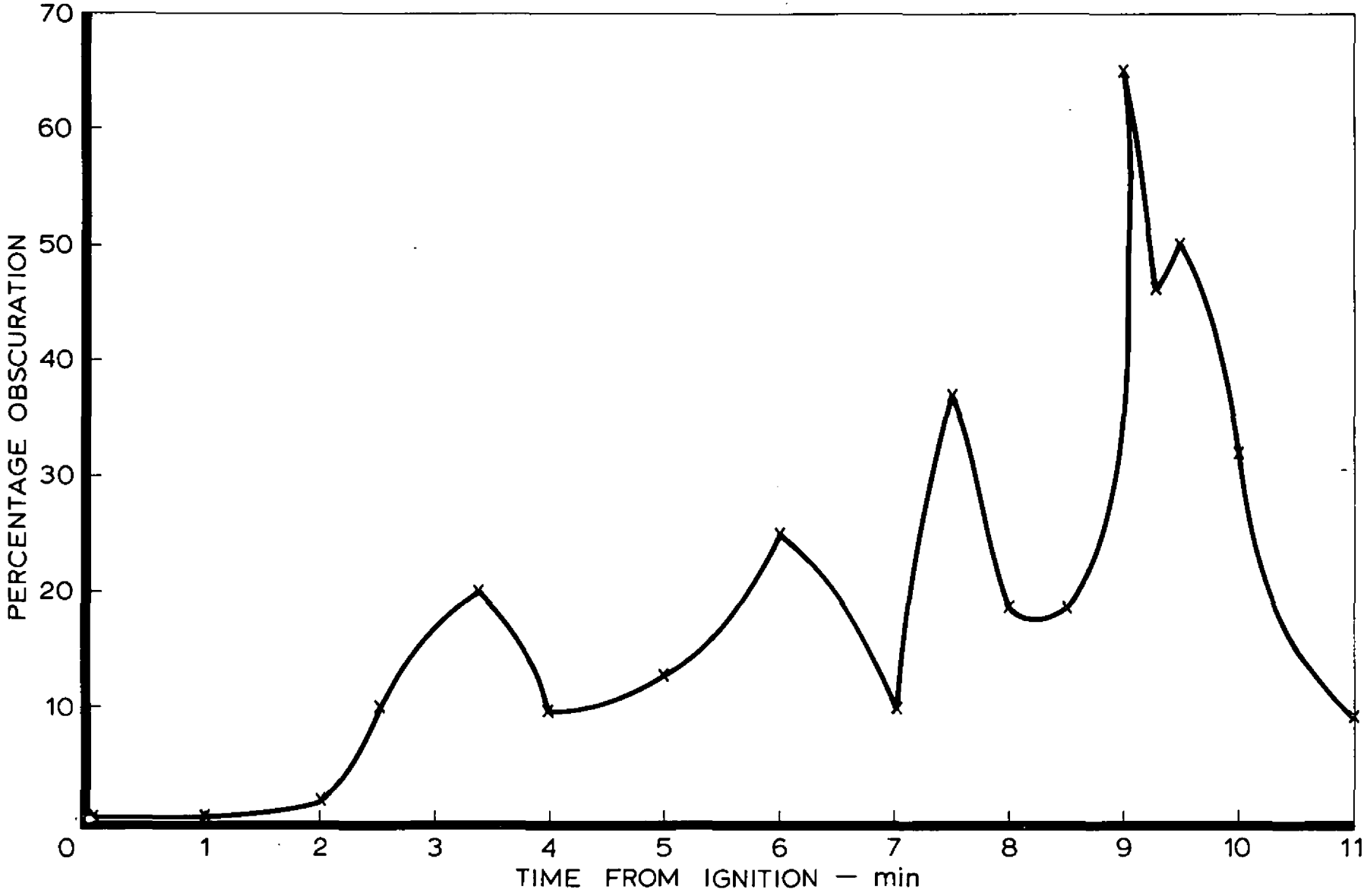

FIG. 5 SMOKE DENSITY AT TOP OF STACK EXPERIMENT 8

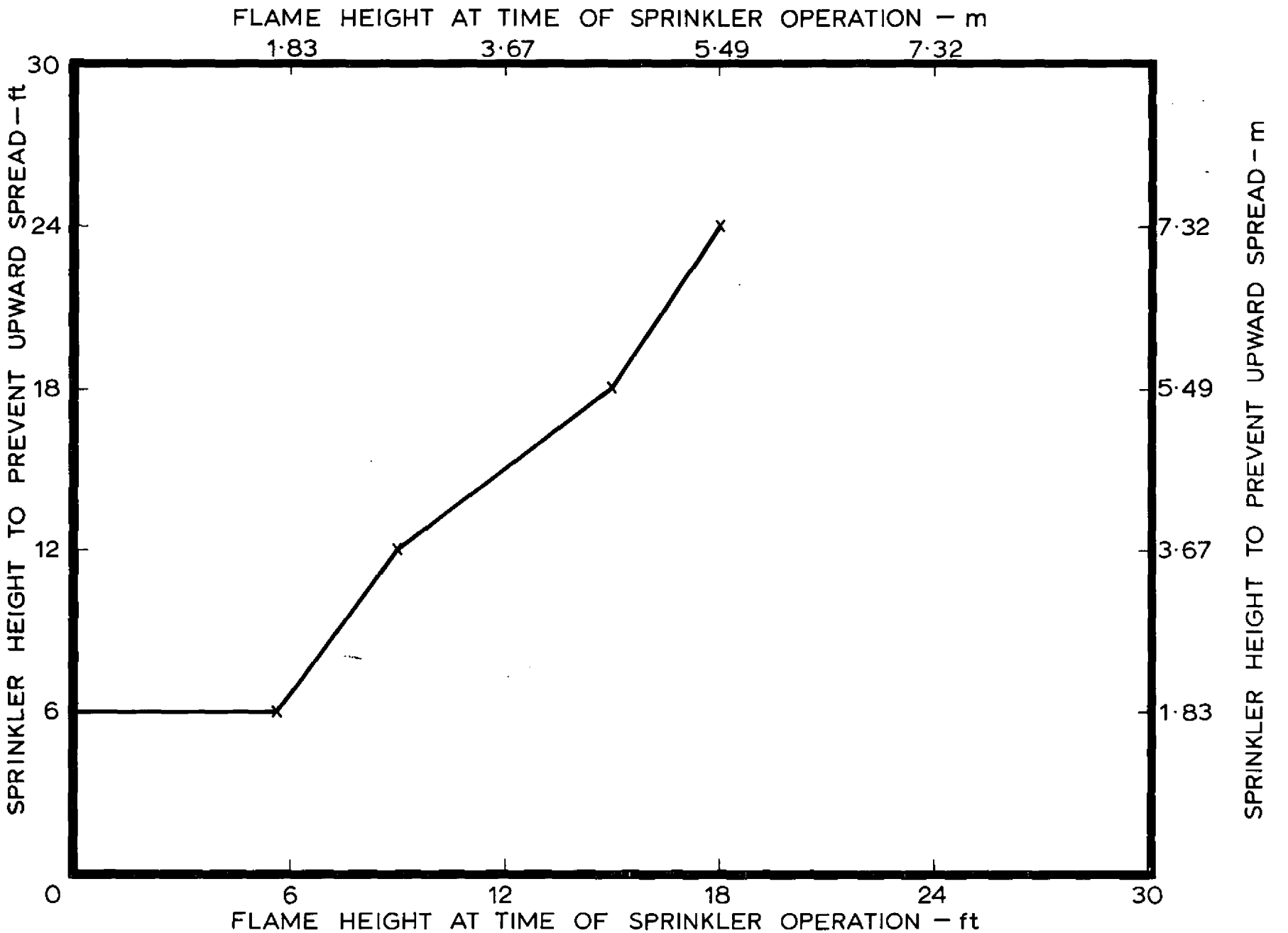

FIG. 6 FLAME HEIGHT AT TIME OF SPRINKLER OPERATION – SUCCESSFUL TESTS

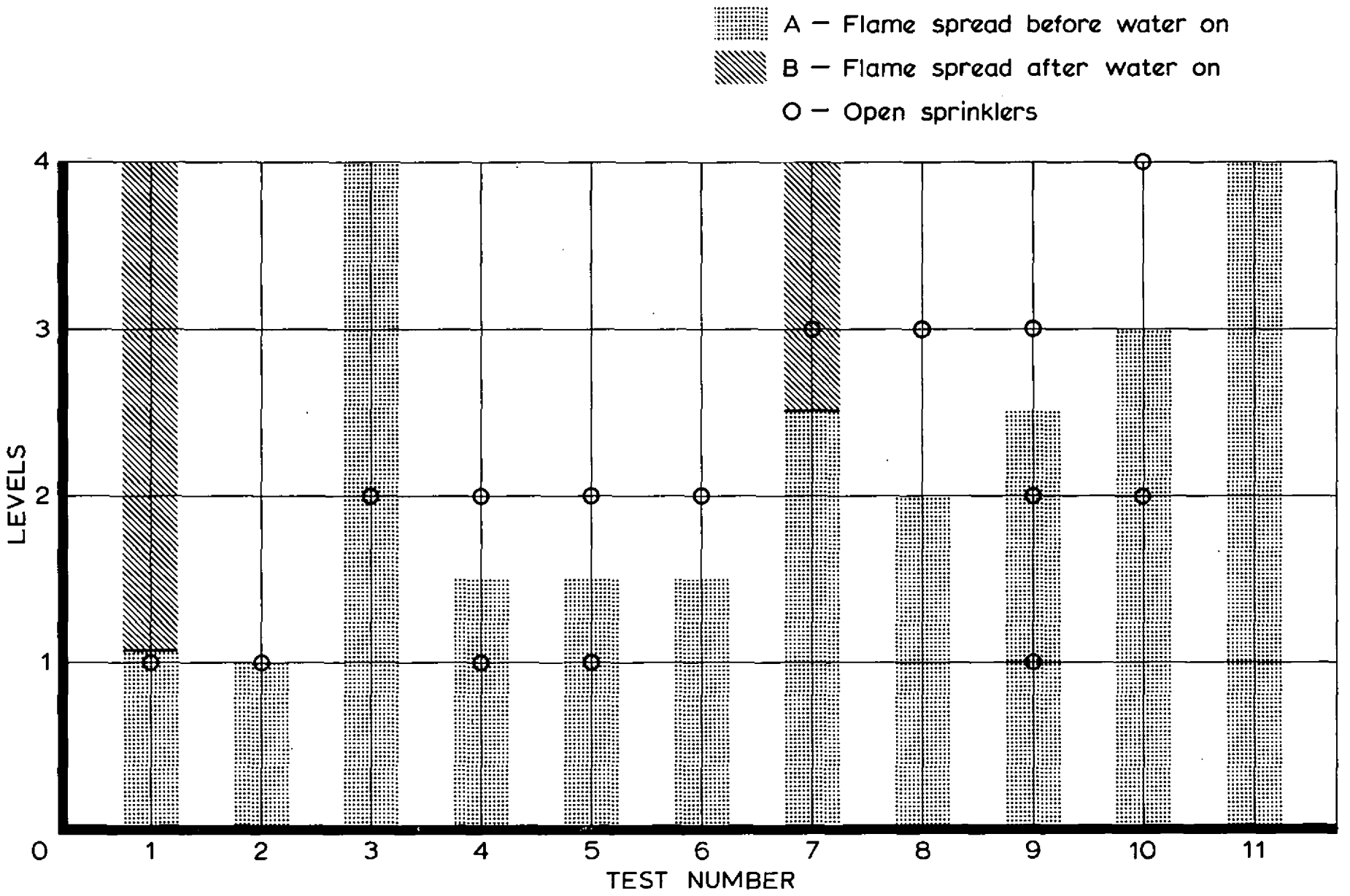

FIG. 7 DIAGRAM SHOWING TEST RESULTS

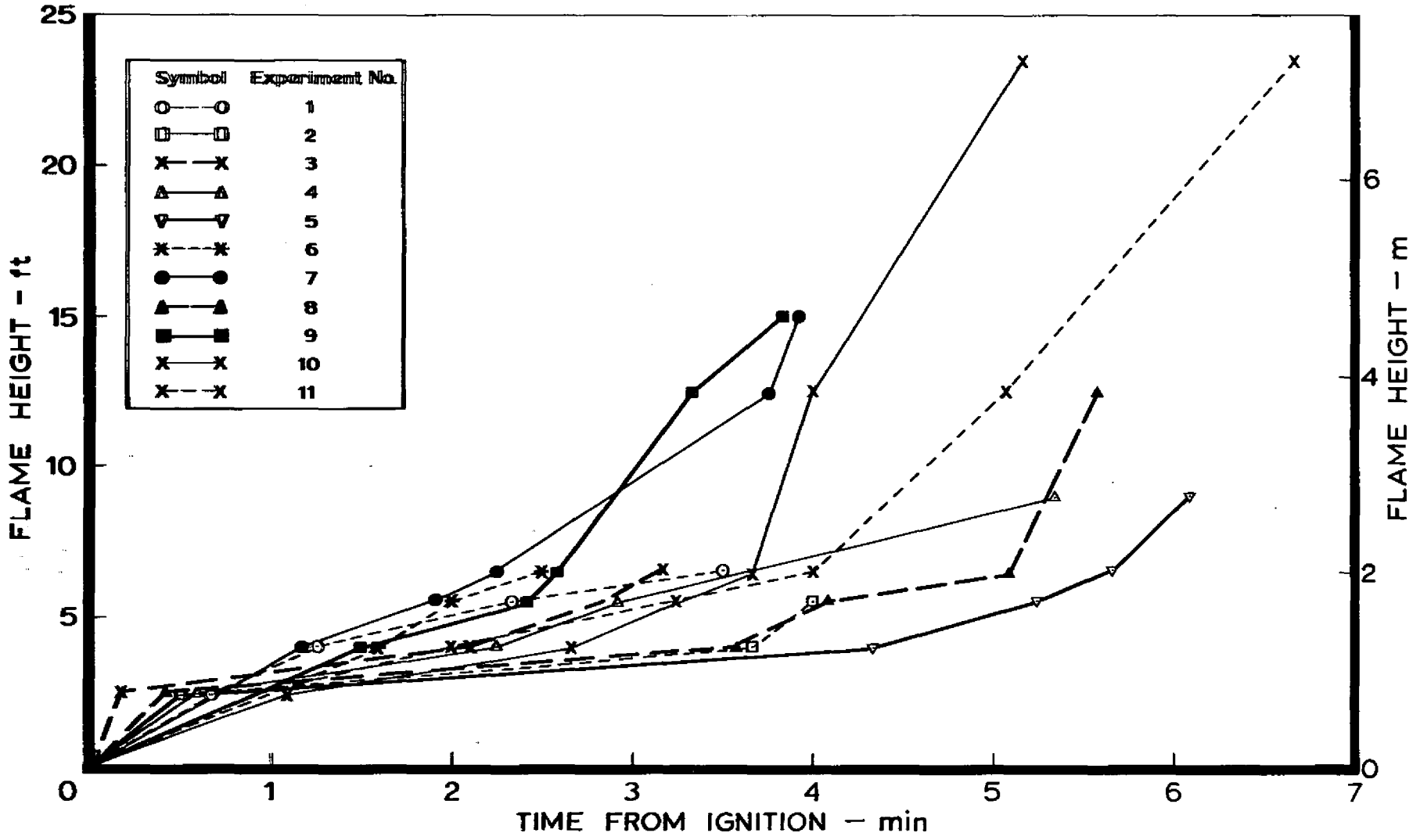

FIG. 8 RATE OF FLAME DEVELOPMENT

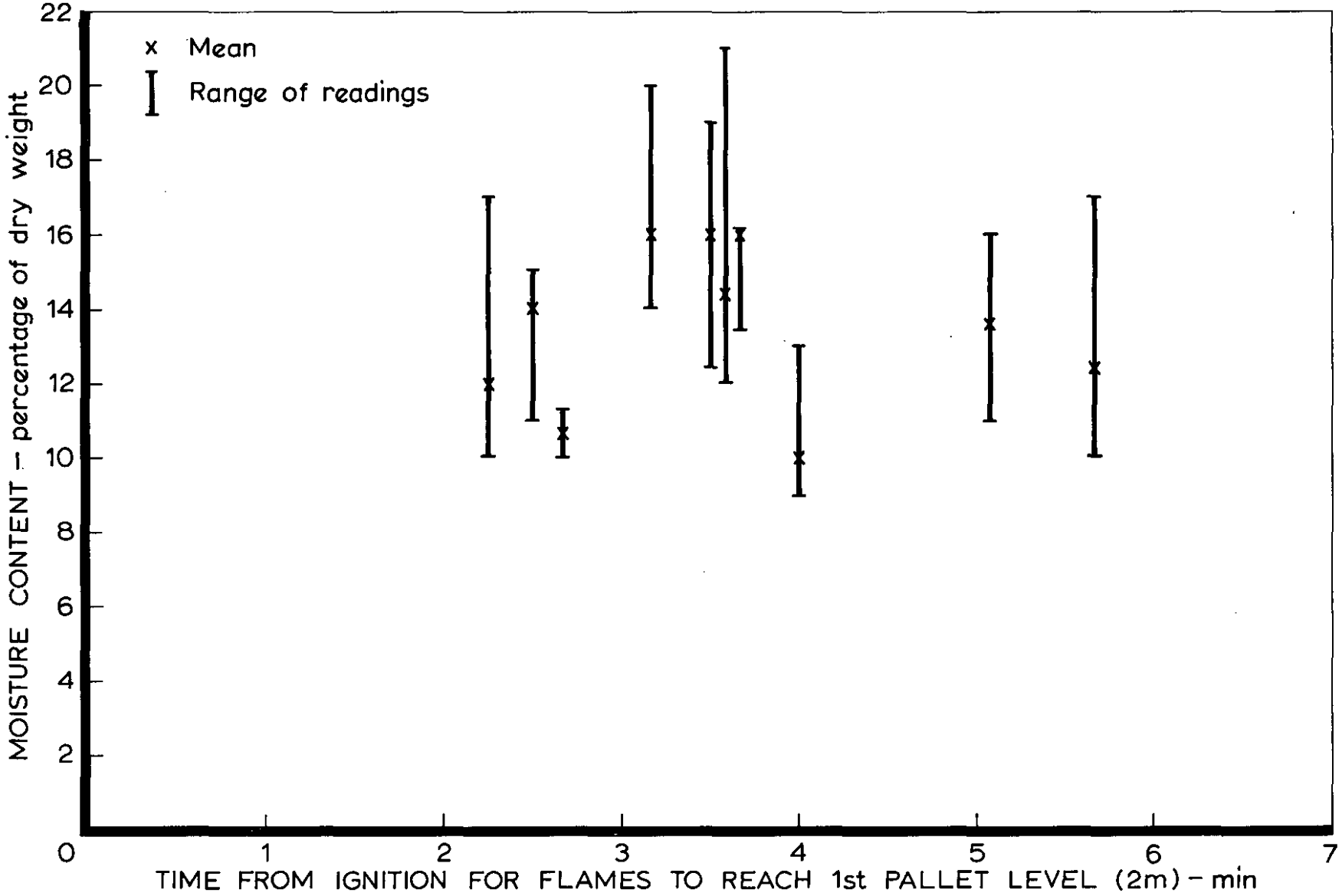

FIG. 9 RELATIONSHIP BETWEEN MOISTURE CONTENT AND RATE OF FLAME DEVELOPMENT