Fire Research Note

No. 814

FIRE TESTS WITH SPRINKLERS ON HIGH PILED STOCK

by

R. A. YOUNG

March 1970

FIRE RESEARCH STATION

F.R.Note No 814
March 1970

FIRE TESTS WITH SPRINKLERS ON HIGH PILED STOCK

by

R. A. Young

SUMMARY

A recent development in the industrial field is the introduction of high-stacked storages of heights ranging from 6 m (20 ft) up to as much as 30 m (100 ft) or more. These storages create a high fire hazard both in their configuration and and in the immense value of the goods in them. The detection and extinction of fires in them is of paramount importance.

This note describes an investigation of the efficacy of a conventional sprinkler system, combined with the latest means of fire detection in controlling fires developing in a palletised storage of height 7.3 m (24 ft), consisting of two rows of back-to-back pallets at four levels.

The main avenues of fire spread were found to be up the vertical gaps between the goods, rather than up the outer face of the stack, and it was found that sprinklers installed on the longitudinal axis of the rack to cover each gap at alternate levels controlled the fires, without the fires ever reaching serious proportions.

It was also found that the detection systems gave a warning of fire from 3 to 7 min before the first sprinkler operated.

KEY WORDS: Detector, fire, Extinguishing, Fire spread, High-piled, Sprinkler, Storage.

MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

F.R.Note No 814
March 1970

FIRE TESTS WITH SPRINKLERS ON HIGH PILED STOCK

by

R. A. Young

INTRODUCTION

A major problem in modern fire protection is the design of protective installations for automated high rack storage. One of the methods by which this may be accomplished is to provide the sprinklers within the racks. However, a factor which might have a large effect on this method is the initial movement of the flame in the stacks. Thus, if flames move up an aisle, then sprinklers within the racks may not be affected before the flames become large. However, if flames move within the rack, then sprinklers installed in the rack would operate quickly.

The main purpose of the tests described in this note was to obtain information on this point, particularly with regard to a sprinkler system that was being planned for a specific automated high rack warehouse. However, the opportunity was also taken to obtain information on a number of other factors which are also of considerable importance in this problem. These factors included the effectiveness of different arrangements of sprinklers, the gain that might be achieved by the installation of low temperature sprinklers and rapidly acting fire detecting systems, the extent to which smoke-logging occurred and the way it could be alleviated by roof venting, and the influence of different combustible materials in the stack.

2. EXPERIMENTAL DETAILS

2.1. The Racking

The racking used (Fig.1) was designed to simulate palletised storage conditions in a high bay warehouse. It was constructed of tubular steel and was 4.88 m (16 ft) long, 2.95 m (8ft 2in) deep, and 5.68 m (18ft 7½in) high. Racking for warehouses of above about 10 m (32 ft) will normally be constructed of structural steel of at least 100 mm (4 in) section. It was not considered that the difference in racking was likely to affect the course of the fire, but where sprinkler distribution might be affected by cross beams, a steel baffle was inserted, as shown in Plate 1.

The racking provided storage space for 32 pallet loads of goods (Plate 2). Pallet loads were placed back-to-back at each level in the racking. The pallets were 1.22 m x 1.02 m (48 in x 40 in) in size, and their front edges were aligned with the front edges of the racking, leaving

a 51 mm (2 in) gap in the centre of the racking. The racking was installed in a laboratory measuring 12 m high x 15 m wide x 45 m long (40 ft x 50 ft x 150 ft).

To simulate the effect of a rack, a scaffold with cardboard facings (Plate 3), equivalent in frontal area to the loaded pallets, was positioned parallel to the racking 1.47 m (4ft 10in).

2.2. The sprinkler system

Sprinklers were mounted within the racking and on the ceiling. The positions of the sprinklers within the racking for tests 1, 2and 3 are shown in Fig.1. Sprinklers were fitted above the 1st 2nd and 3rd pallet. The arrangement for test 4 is shown in Fig.2; sprinklers were fitted above the 2nd and 4th layers.

Rules for the installation of sprinkler systems have been published by the Fire Offices' Committee[1]. These rules stipulated that siting of sprinklers within the racking should depend on the nature (category) of the commodities stored. If the commodities used in these tests are considered to come within category 1, then tests 1, 2 and 3 were carried out with a higher concentration of sprinklers than are called for in the rules, but if the commodities are considered as coming in category 3 then test 4 represents a lower density that is required by the rules. However, these tests were not designed primarily to test the efficiency of the rules since a much larger stack would be needed for this purpose.

In tests 1 and 2 the sprinklers were mounted in the upright position, and for tests 3 and 4 the pendent position, but in each case the deflector plate of each sprinkler was in the same position, relative to the racking.

The temperature rating for the sprinklers within the racking was 68°C (155°F) in all tests, and the ceiling sprinklers were rated at 141°C (286°F). In the first three tests a 57°C (135°F) sprinkler was fixed near to each 68°C sprinkler, but not connected to the water supply.

Preliminary tests showed that the conventional type of deflector plate was the most suitable of the three types available (marine and spray being the other types), and conventional sprinklers were used throughout the tests.

2.3. Pallets

Goods were stacked on ordinary wooden pallets, to a maximum height of 1.52 m (5 ft). These pallets were then placed in the racking by a fork lift truck, where possible. In each case they were put on top of a flat wooden board, 1.02 m x 1.22 m and 51 mm (2 in) thick.

2.4. Goods

About 15 per cent of the goods were similar to those found in a mixed automated warehouse and included books, magazines, aerosoles, anti-freeze, plastic goods, rubber mats, wooden rolling pins and for Test 4, cases of lard. These goods were either made up into pallet loads in their own boxes or packed in suitable cardboard cartons. The remaining 80 - 90 per cent of each load was made up of cardboard boxes filled with wooden blocks, wood-wool, paper, cardboard and bricks. In each test 1 or 2 pallets were loaded with baled compressed cardboard.

As far as was possible, each pallet load were made up of boxes with a common filling in order to simulate warehouse practice.

2.5. Fire detection

Two rapid response detector systems were used, one based on infra-red detection and the other on smoke detection using smoke detectors of the ionisation chamber type.

A scanning infra-red detector was fixed to the ceiling above the aisle and a fixed infra-red detector viewing along the aisle and 8 m (26 ft) from the centre of the racking. The smoke detectors were arranged in two zones separated by a horizontal distance of 2 m (6 ft 6 in) on the ceiling above the racking.

2.6. Roof venting

A section of the roof in the laboratory was opened to between 3 and 10 per cent of the floor area. The details of the venting arrangements for each test are given in Section 4.

2.7. Measurements

Chromel Alumel thermocouples were positioned near each sprinkler head, on the front face of the racking and on the ceiling above the racking, as shown in Fig.3. Radiometers were positioned in front of the centre of the racking at heights of 2 m (6 ft 6 in) and 3 m (10 ft) at a distance of 1.5 m (5 ft) from the face of the stack. The thermocouples and radiometers were connected to a data logger; each measuring position was monitored every 15 s.

Visual assessments of fire spread and sprinkler operating times were made, and are recorded in Section 4.

3. TEST PROCEDURE

3.1. General - Common for all test

In all tests the stack was ignited on the aisle face of pallet B. The method of ignition was varied from test to test in order to investigate the possibility of flames travelling up the aisle in the initial stages of the fire.

The sprinkler system was pressurized and all doors in the building closed. Temperature measurements were made from the start of tests and the growth of the fire was observed and noted by a number of observers. The time of operation of the sprinklers was recorded visually and also observed from the change in pressure of the sprinkler system. The total flow of water to the sprinkler system was measured.

The operation of the detectors was indicated audibly and the times of operation were recorded.

A photographic record was made of each test, and Plates 4a to 4h show this record for Test 1.

3.2. Test 1

The sprinklers were arranged as shown in Fig.1 with the sprinklers in the pendent position, and the pressure at the control valves of the sprinkler system was maintained at 2.8 b (40 lbf/in^2).

Sprinklers of 57°C rating were fixed next to the 68°C sprinklers and weights attached by wires to these bulbs of these sprinklers so that their operation could be observed.

A torn cardboard box in the bottom layer on pallet B 450 mm (1ft 6in) from the joint edge in the B/C gap was ignited by match. The sequence of events is given in section 4.1.

3.3 Test 2

The loading of the stack and the sprinkler system arrangements were as for Test 1. In Test 1, the fire had spread away from the aisle, moving rapidly up the narrow chimneys in the centre of the racking.

In Test 2, 5 l of 120° proof spirit was poured over the face of the lower half of pallet F and the face of pallet B, (plate 5a) to try to encourage burning up the aisle face of the stack. The spirit was ignited with a match.

Other details were the same as for test 1, and the sequence of events is shown in section 4.2, and plates 5b,c and d show the development of the fire.

3.4. Test 3

The position of the sprinklers was as shown in Fig.1, but the sprinklers were mounted in the upright position, the sprinkler deflector plate being in the same position as in tests 1 and 2. The 57°C sprinklers were installed as in the previous tests.

The water pressure was maintained throughout this test at a pressure of .38 b measured in the centre range of sprinklers.

In order to get a slower initial spread of fire in this test, an electric element was inserted in a bottom layer box in the front face of pallet B (Plate 6). This failed and eventually the edge of the box was lit as in test 1. The sequence of events is given in section 4.3.

3.5. Test 4

The sprinklers were installed in the upright position in the places shown in Fig.2. The water pressure was maintained at .38 b, measured at the top level of sprinklers.

The arrangement of goods in the racking was similar to that of the previous 3 tests with the addition of a number of cases of lard, most of which were placed on the bottom layer of pallet F.

The fire was started by igniting the edge of a box with a match, the box being in the same position as in Test 3.

4. RESULTS

The sequence of events in each test is shown in Tables 1a, 2a, 3a, and 4a, and the times of operation of sprinklers are shown in Tables 1b, 2b, 3b and 4b, and of the operation of the detectors in Tables 1c, 2c, 3c and 4c. Figures 4, 5, 6 and 7 show the air temperature rise on the central vertical axis of the stack at heights of 24ft and 39ft for each of the four tests.

4.1.1 Sequence of events. Test 1

Table 1a

TIME min. s	EVENT
0	Contents of box in pallet B lit with a match.
25	Flames 0.3 m (1 ft) high on first box.
1.00	Flames 0.6 m (2 ft) high in B/C gap to a distance of 0.3 m from front face.
2.25	Flames 1 m (3 ft) high to a distance of 0.6 m from front face.
2.30	First detector operated (smoke).
3.00	Flames 1.2 m (4 ft) high in gap, spreading round front face of pallet B.
4.00	Flames 2 m high in B gap to a distance of 1 m from front face.
4.30	Pallet B well alight.
5.00	Fire spread to pallet C in B/C gap. Flames 2 m high, nearly to centre of stack.
5.15	Flames 3 m (10 ft) high in central chimney.
5.25	Flames 7.5 m (25 ft) high in central chimney.
5.30	Sprinkler 7 operated.
5.50	Sprinkler 2 operated, total water flow to the two sprinklers 45 gal/min. Intensity of flaming reduced in chimney.
6.10	Sprinkler 4 operated
6.40	Flaming in pallet B almost extinguished, considerable smoke. Flaming in pallets B,C,F and J on front face.
7.18	Sprinkler 6 operated.
8.40	Considerable smoke logging, flaming generally much reduced. Some flaming visible in pallet 1.
10.00	Fire well under control. Small flames occasionally visible in several places.
12.00	Roof opening to 10 per cent (5 min taken to reach this) Main door opened. No appreciable effect in smoke logging, but draught re-kindled fire in several places.
13.00	Main door closed.
17.20	Water off to sprinklers, very little flaming. Hose reels used to damp down.

Most damage caused in pallet B . Between 5 and 10 per cent of goods on the front face damaged. No fire damage to goods on rear face or on top layer.

4.1.2 Sprinkler operating times

Table 1b

Sprinkler position	Operating time 135°F(57°C)	Operating time 155°F(68°C)
	min sec	min sec
1	N.O*	N.O
2	5 35	5 50
3	N.O	N.O
4	4 30	6 10
5	N.O	N.O
6	5 45	7 18
7	4 30	5 30
8	N.O	N.O

*N.O sprinkler did not operate

4.1.3 Detector operating times

Table 1c

Detector	Operating time
Smoke	Zone 1, 2 min 30 sec, Zone 2, 2 min 35 sec
Infra-red	Infrastat 3 min 20 sec, Infrascan 3 min 30 sec

4.2.1. Sequence of events Test 2

Table 2a

TIME	EVENT
min sec	5 l 120° proof spirit poured over face of pallet B and bottom 0.6 m (2 ft) of pallet F
0	Spirit lit with match.
18	First detector operated (infra-red).
20	Flash fire on face of pallet B.
50	Fire mainly burning spirit. Smoke detector operated.
2 . 00	Flames 2.4 m (8 ft) high from face of pallet B - not spreading vertically.
3 . 15	Pallet B collapsing - fire spreading down B/C gap, Pallet C alight on gap face.
4 . . 00	Flames almost spread to centre in B/C gap.

Table 2a

TIME	EVENT
min sec	
5 . 00	Flames 2.4 m high in centre of stack.
5 . 15	Flames 6 m (20 ft) high in centre of stack, only 2 m high on front face of pallet B.
5 . 30	Sprinkler 7 operated, flow 23 gal/min.
7 . 00	Flaming on top of stack in pallets M and N, roof started to open to 5 per cent.
8 . 00	Sprinkler 4 operated.
	Sprinklers 1, 2 and 3 being wetted from above, considerable flaming in B and C.
	Flaming 2 m above goods on top of stack.
10 . 30	Pallet B almost burnt out, considerable flaming on top layer.
14 . 00	Flames 3 m above goods on top layer in pallets behind O and P. Considerable smoke logging, visibility very poor.
15 . 30	Ceiling sprinkler operated, flow 12 gal/min, flaming spreading in bottom layer to pallet A.
17 . 30	Main door opened to help clear smoke, but flaming increased in pallets A and B.
20 . 30	Door closed.
21 . 30	Flaming in pallets A, B and C.
27 . 00	Fire well contained but extinguishment in bottom layer delayed due to non-operation of the lower sprinklers.
28 . 30	Only flaming in bottom layer and in pallet behind pallet M in top layer.
37 . 00	Water off to sprinklers.

A ceiling sprinkler operated and controlled the fire on the top level of the racking, but the considerable delay in operation, due to distance of sprinklers above racking and the use of 141°C sprinklers allowed a considerable amount of fire damage.

Fire damage was also extensive in the bottom layer, where sprinklers did not operate due to water running over them from the sprinklers above.

About 30 per cent of goods were damaged by fire.

4.2.2. Sprinkler operating times

Table 2b

Sprinkler position	Operating time 57°C (135°F)		Operating time 68°C (153°F)	
	min	sec	min	sec
1	N.O		N.O	
2	N.O		N.O	
3	N.O		N.O	
4	7	55	8	00
5	N.O		N.O	
6	N.O		N.O	
7	5	30	5	30
8	N.O		N.O	

N.B. 1 ceiling sprinkler operated at 15 min 30 s

4.2.3. Detector operating times

Table 2c

Detector	Operating time
Smoke	Zone 1, 50 sec, Zone 2, 1 min 12 sec
Infra-red	Infrastat 18 sec, Infrascan 20 sec

4.3.1. Sequence of events Test 3

Table 3a

TIME		EVENT
min	sec	
	0	100 volts applied to heater.
3	0	Smoke appearing.
4	30	Flame within box.
6	00	Heater shorted - smoke issuing from box.
7	00	Edge of box lit with match.
7	28	Detector operated (Infra-red).
8	00	Flames 1 m high on front face of pallet B.
8	30	Flames 2 m high on front face of pallet B.
10	00	Flames only 1.5 m high on front face of pallet B.
11	00	Flames moving round edge of pallet B into B/C gap.
11	40	Boxes falling from pallet B. Flame height 2 m.
14	00	Flames reaching centre in A/B gap.
		Flames almost reached centre of stack in B/C gap.
14	30	Flames spreading up central chimney 2.5 m high.
		Sprinkler 4 operated.
14	45	Flames 8 m (26 ft) high in centre of stack.
15	00	Sprinkler 7 operated, roof started to open 3 per cent and opening of same area made at ground level.
15	10	Sprinkler 2 operated.
16	00	Flaming noticeably subdued, visible in pallets B C F G J K O.
22	00	No flaming more than 2 ft in height, pallets C K N O still alight.
23	30	Boxes falling from pallet A. Smoke logging considerably less than in previous tests.
25	30	Flaming remaining in pallet M.
35	00	Water off to sprinklers, occasional flaming seen in P N and K.
		No fire damage to rear half of stack.
		Total flow rate to the 3 operating sprinklers 27 gal/min.
		Very little smoke remaining in laboratory.

4.3.2. Sprinkler operating times

Table 3b

Sprinkler position	Operating time 57°C (135°F)		Operating time 68°C (155°F)	
	min	sec	min	sec
1	N.0		N.0	
2	15	00	15	10
3	N.0		N.0	
4	14	45	14	30
5	N.0		N.0	
6	N.0		N.0	
7	15	00	15	00
8	N.0		N.0	

4.3.3. Detector operating times

Table 3c

Detector	Operating time
Smoke	Zone 1, 8 min 1 sec, Zone 2, 8 min 25 sec
Infra-red	Infrastat 8 min 13 sec, Infrascan 8 min 13 sec

4.4.1. Sequence of events Test 4

Table 4a

TIME		EVENT
min	sec	
0	00	Contents of box X lit with match.
1	00	Flames 0.6 m high.
1	05	First detector operated (Infra-red).
1	30	Flames 1 m high.
2	05	Flames 2 m high.
2	35	Flames 2 m high.
4	00	Flames spreading sideways to pallet B/C gap
5	10	Flames moving slowly into centre of stack in B/C gap.
6	00	Flames moving up both sides of pallet F, total height 2.5 m.
	20	Flames 6 m high in central chimney, pallet F alight on both sides.
6	35	SPRINKLER 1 OPERATING.
8	00	Flames spreading to B.2 across centre of stack, ROOF OPENING to 3 per cent with ground level openings of same area.
10	00	Main burning in B, and up centre chimney.
11	25	Pallet J alight, flames 6 m high in C/D gap.
11	30	SPRINKLER 2 OPERATING
13	00	SPRINKLER 4 OPERATING
14	30	Flaming 2 m high above pallet N.
15	00	Flaming in all 3rd layer pallets on front face.
16	00	SPRINKLER 3 OPERATING
17	30	Flaming on top of N 2. Very little smoke logging, smoke level 6 m above floor.
20	00	Little burning on 1st and 2nd levels, considerable flaming involving all 3rd level pallets.
22	00	Flaming molten plastic dripping from 02 - not igniting any goods below.
25	00	Front face of 3rd level nearly burnt out, L2 burning well.
25	45	SPRINKLER 5 OPERATING
28	00	Pallets N, O and P burning well.
30	00	Little flaming in N.2 and I, most other flaming out.
37	00	Water pressure increased. Smoke increasing, level dropping.
42	00	Water off - only flaming remaining in J2.

A far higher proportion of goods were destroyed by fire in this test than in the previous three tests. For the first time in this series of tests the fire spread was not averted before all the goods on the 3rd layer were consumed.

4.4.2. Sprinkler operating times

Table 4b

Sprinkler position	Operating time 68°C (155°F)	
	min	sec
1	6	35
2	11	30
3	16	00
4	13	00
5	25	45

4.4.3. Detector operating times

Table 4c

Detector	Operating time
Smoke	Zone 1. 2 min 10 sec, Zone 2, 2 min 20 sec
Infra-red	Infrastat 1 min 5 sec, Infrascan 1 min 30 sec

5. Discussion of results

5.1. Method of flame travel

Although in all tests the fire was ignited in the aisle in none of the tests did the fire in the initial stages proceed upwards in the aisle beyond the top of the bottom pallet. The dominant method of flame travel was therefore in the chimneys in the stack, and once flame reached these chimneys upward spread was rapid through the centre of the stack.

The siting of sprinklers in the chimneys in the centre of the stack is therefore a viable method of providing protection for stacks of this kind.

5.2. Nature of goods

As would be expected, there was a variation in the duration and intensity of the flaming between pallet loads made up of different goods, or different box fillings. In general, plastic bowls etc. burnt with considerable intensity until water reached them, but were then easily extinguished. Cardboard boxes filled with wood wool also burnt with considerable intensity and proved to be more difficult to extinguish, smouldering for some time after sprinkler operation.

Cardboard boxes filled with tinned goods, antifreeze aerosoles etc. only burnt reluctantly, no aerosoles exploded in fully filled boxes. Cases of lard also burnt very reluctantly, the lard not being involved in the fire.

5.3. Aisle width

Cardboard squares hung parallel to the main stack and 1.5 m (4 ft 10 in) distant were not ignited in the tests. Radiation measurements (maximum of 0.8 w/cm^2) show that the intensity at that point was less than $1/10$ of that necessary to ignite the cardboard, but calculation shows that without the operation of sprinklers and with only 1 pallet fully involved it would be possible to transmit radiation of 10 times the necessary value for ignition across an aisle of width 1.5 m (5 ft).

5.4. Detectors

Both the infra-red and the smoke detectors operated in all tests, in times given in Tables 1c, 2c, 3c and 4c. The average time advantage of the 1st detector to operate over the 1st sprinkler was 5 min 11 sec, the average time advantage of the infra-red type detectors over the 1st sprinkler was 4 min 59 sec, and for the smoke detectors 4 min 34 sec, as shown in Table 6.

5.5. The Sprinklers

5.5.1. Sprinkler mounting position

There was no obvious difference in the water distribution from the sprinklers when mounted in pendent (Tests 1 and 2) and upright (Tests. 3 and 4) positions.

5.5.2. Sprinkler spacing

In tests 1, 2 and 3 sprinklers were situated on each level within the racking, each sprinkler covering 4 pallet spaces. In the fourth test sprinklers were positioned at alternate levels, one row above the second level of goods and another row above the fourth level of goods.

The difference between the two systems is shown by comparing tests 3 and 4, where in each case the water flow rate was maintained at about 9 gal/min to each sprinkler. (For an area of 5.6 m^2 (60 ft^2) this is equivalent to a density of water application of 7.5 mm/min) In test 4, the goods on the levels directly beneath the rows of sprinklers received little fire damage, but goods on the first and third levels were completely burnt out. All 5 sprinklers operated.

In test 3, only 3 sprinklers operated and 15 per cent of goods were damaged by fire.

5.5.3. Sprinkler temperature rating

The average difference in operating time between the 57°C (135°F) rated sprinklers and the 68°C (155°F) rated sprinklers was about 30 seconds. The differences ranged from -15 seconds (where the 57°C rated sprinkler operated after the 68°C), to +100 seconds. In two cases the operating times were the same and in six cases the 57°C rated sprinkler operated first.

In no case did the 57°C rated sprinkler operate without the 68°C rated sprinkler in the same position operating.

5.5.4. Water pressure and flow rate

In tests 1 and 2, approximately 22 gal/min was delivered from each sprinkler head within the racking, and in tests 3 and 4 approximately 9 gal/min.

The most noticeable effect of a reduction of water pressure was that the smoke logging was much less severe. At the end of test 4, the water pressure was increased to give a flow of approximately 22 gal/min for a period of 5 mins, and there was a marked increase in smoke logging, although the ventilation arrangements were unchanged.

The total volume of water used in each test was calculated and is shown in Table 5 below.

Table 5

Test number	Number of sprinklers operating (racking)	Ceiling sprinkler operating	Total volume of water used (gals)
1	4 at 22 gal/min	-	860
2	2 at 22 gal/min	1 at 12 gal/min	1580
3	3 at 9 gal/min	-	540
4	5 at 9 gal/min	-	1500

The water was turned off when it was considered that there was nothing to be gained by continuing the test, so the total volume of water used in each test may not be strictly comparable. Comparison of tests 1 and 3 would suggest, however, that nothing was gained by using the higher rate of discharge.

Table 6

Comparison of operation time of first sprinkler and detectors

Test	Operating times						Best time advantage	
	Infra-red		Smoke		Sprinkler			
	min	sec	min	sec	min	sec	min	sec
1	3	20	2	30	5	30	3	0
2		18		50	5	30	5	12
3	7	28	8	1	14	30	7	2
4	1	5	2	10	6	35	5	30

5.6. Smoke logging

The tests indicated that smoke logging might be a serious problem when sprinklers are used. In the first two tests, visibility at ground level was very poor after the sprinklers had been in operation for 5 min. In the third test where the roof ventilation was supplimented with ground level ventilation of the same area, (3 per cent of floor area of laboratory) smoke logging was much reduced. This was probably due to a number of factors in addition to the actual area of venting, including earlier opening of vents and the lower water pressure of the sprinkler system.

The early opening of vents prevented a deep smoke layer becoming established, and the lower pressure had a smaller cooling effect on the smoke. The more important of these effects would appear to be the reduced water pressure, for in test 4, when the water pressure was increased to shorten the test, the smoke level then dropped from about 6 m (20 ft) to ground level.

6. CONCLUSIONS

6.1. General

In the stack tested, fire spread up the centre of the stack and not up the aisle face, even when the means of ignition was designed to encourage fire spread in the aisle. Thus it is considered that for this type of stacking that sprinklers are best situated at levels in the centre of the racking.

It is mainly the surface of the cardboard boxes that burns in the early stages of the fire, in which detection and control should occur. If the fire is not controlled, or if control is delayed or only partial, the nature of the goods will be important. An efficient detection/extinction system should aim at complete control, and preferably extinction, in not more than 10 minutes.

6.2. Sprinklers

6.2.1. Sprinklers should be installed at each level in the racking.

6.2.2. There should not be less than one sprinkler per four (2 x 2) pallet positions.

6.2.3. Successive levels of sprinklers, mounted on the longitudinal axis of the racks, should be staggered by one pallet position per level.

6.2.4. Sprinklers should be sited in the vertical chimneys within the racking, and must be protected from water falling from above by a plate of the minimum necessary area.

6.2.5. The sprinklers appeared to be just as effective in controlling the fire at the lower flow rate (9 gal/min per sprinkler), as at the higher rate (22 gal/min/sprinkler), provided that the above conditions are complied with.

6.2.6. Spr inklers can be mounted in either upright or pendent positions without a significant change in their response.

6.2.7. Sprinklers will operate slightly earlier if 57°C rating bulbs are fitted, instead of 68°C bulbs. The average time advantage was found to be about 30 seconds.

6.3. Detection

Smoke and/or infra-red detectors will give a significant time advantage over the sprinklers in the detection of the fire. The average time advantage was approximately 5 minutes.

Thus, detectors used in conjunction with a sprinkler system might enable personnel in the vicinity to extinguish the fire before the sprinklers operate, provided that suitable extinguishers are readily available. The alarm from the detectors could also be used as a signal to call the local fire brigade, open roof vents etc.

6.4. Smoke logging

Smoke logging of a serious nature could result from the action of sprinklers on this type of fire, preventing the fire brigade from entering and locating the seat of the fire for a considerable time. In these tests smoke logging was significantly less serious when the lower water pressure was used.

7. ACKNOWLEDGEMENTS

Thanks are due to the following firms for the provision of equipment and materials and their help in the conduct of the tests:-

Mather and Platt Limited, for the design, supply and erection of the sprinkler system.

The John Lewis Partnership, for the supply of the racking, pallets and goods.

Minerva Fire Defence Limited, for the supply of Ionisation chamber type smoke detectors.

The A.F.A. Group, for the supply of Infra-scan and Infra-stat detectors.

8. REFERENCES

1. Rules for automatic sprinkler installations, 29th edition, issued by the Fire Offices' Committee, December, 1968.

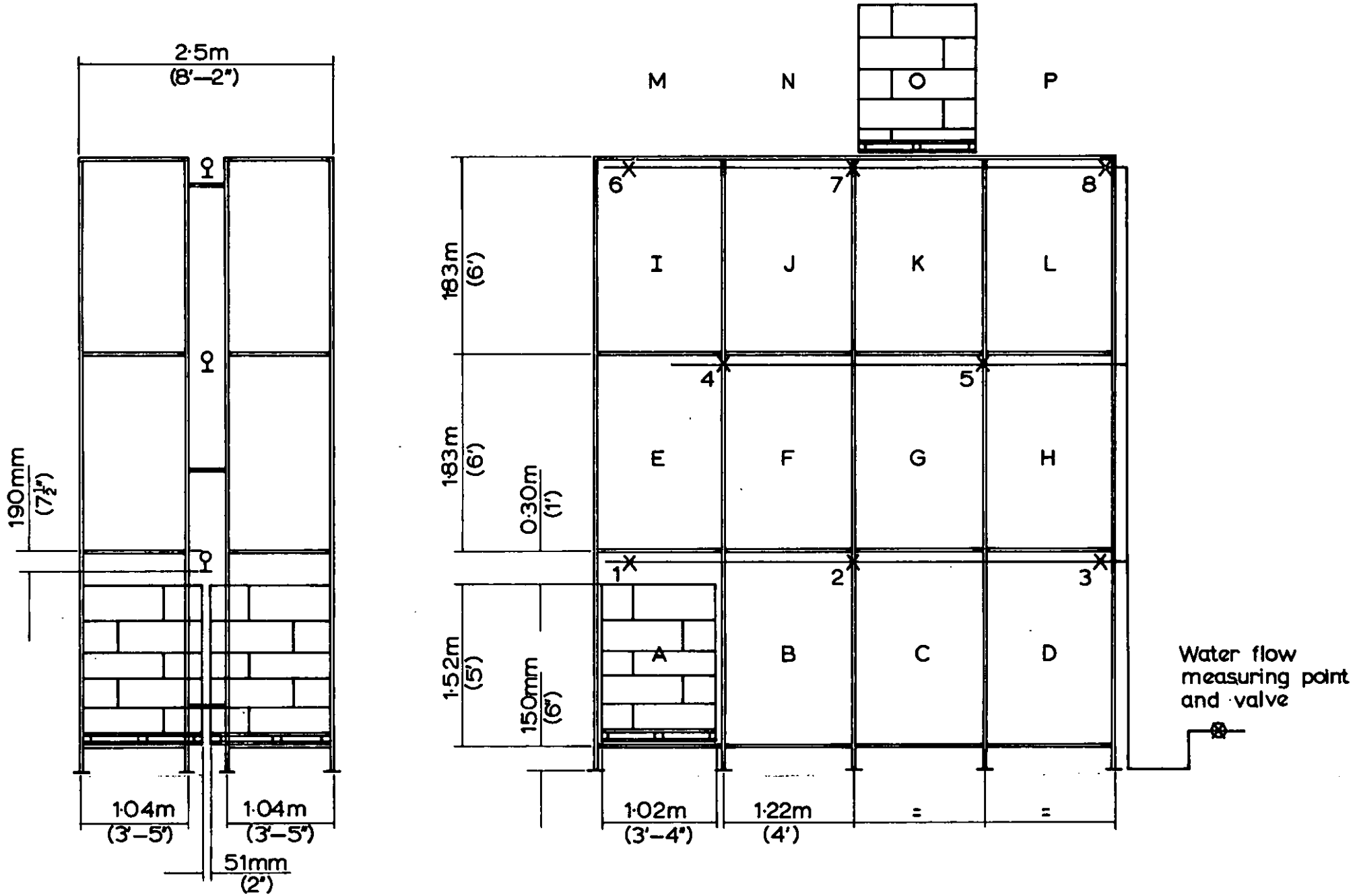


FIG. 1. RACKING, SHOWING SPRINKLER POSITIONS FOR TESTS 1, 2 AND 3

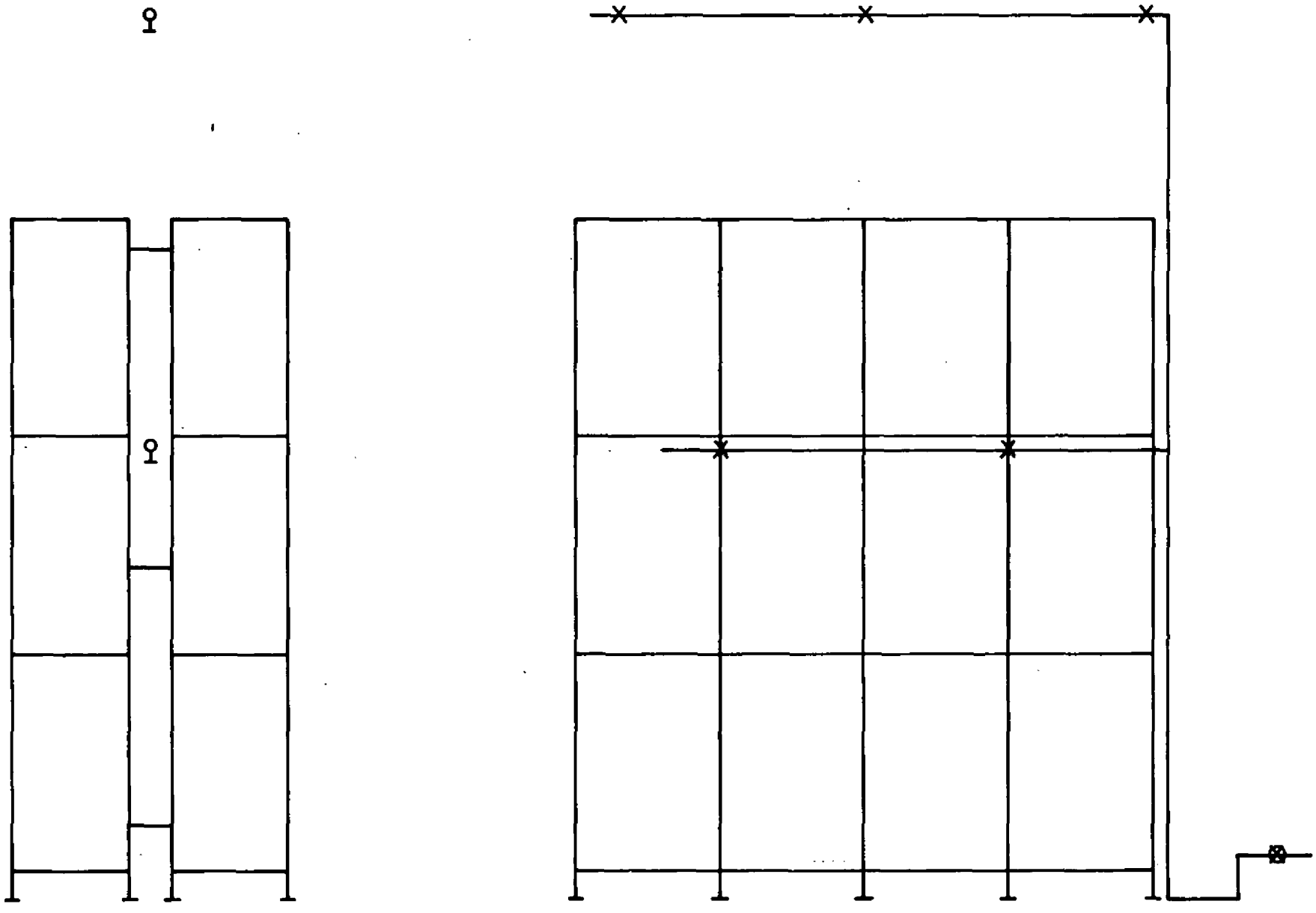


FIG. 2. RACKING, SHOWING SPRINKLER POSITIONS — TEST 4

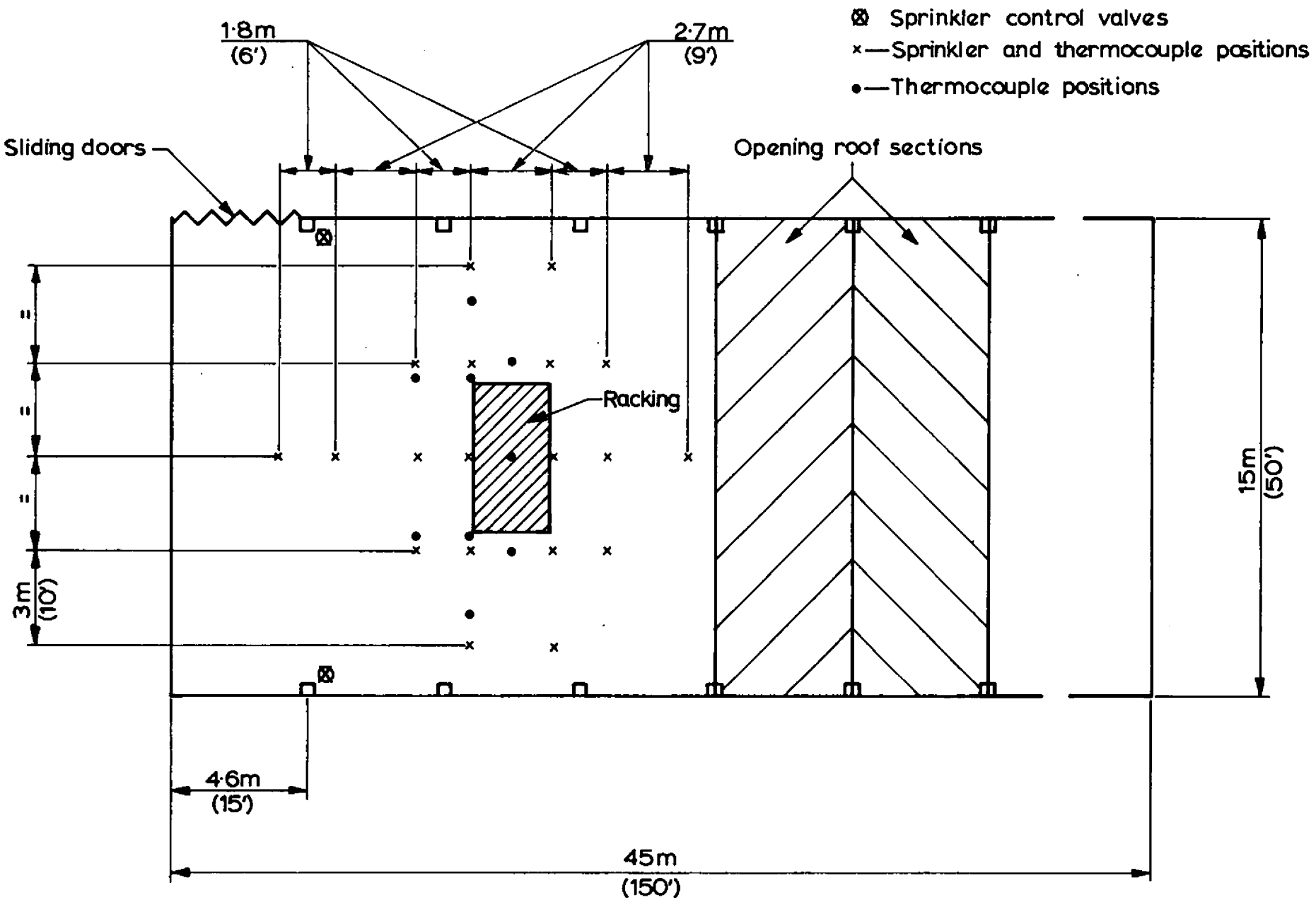


FIG. 3. POSITION OF CEILING SPRINKLERS AND THERMOCOUPLES

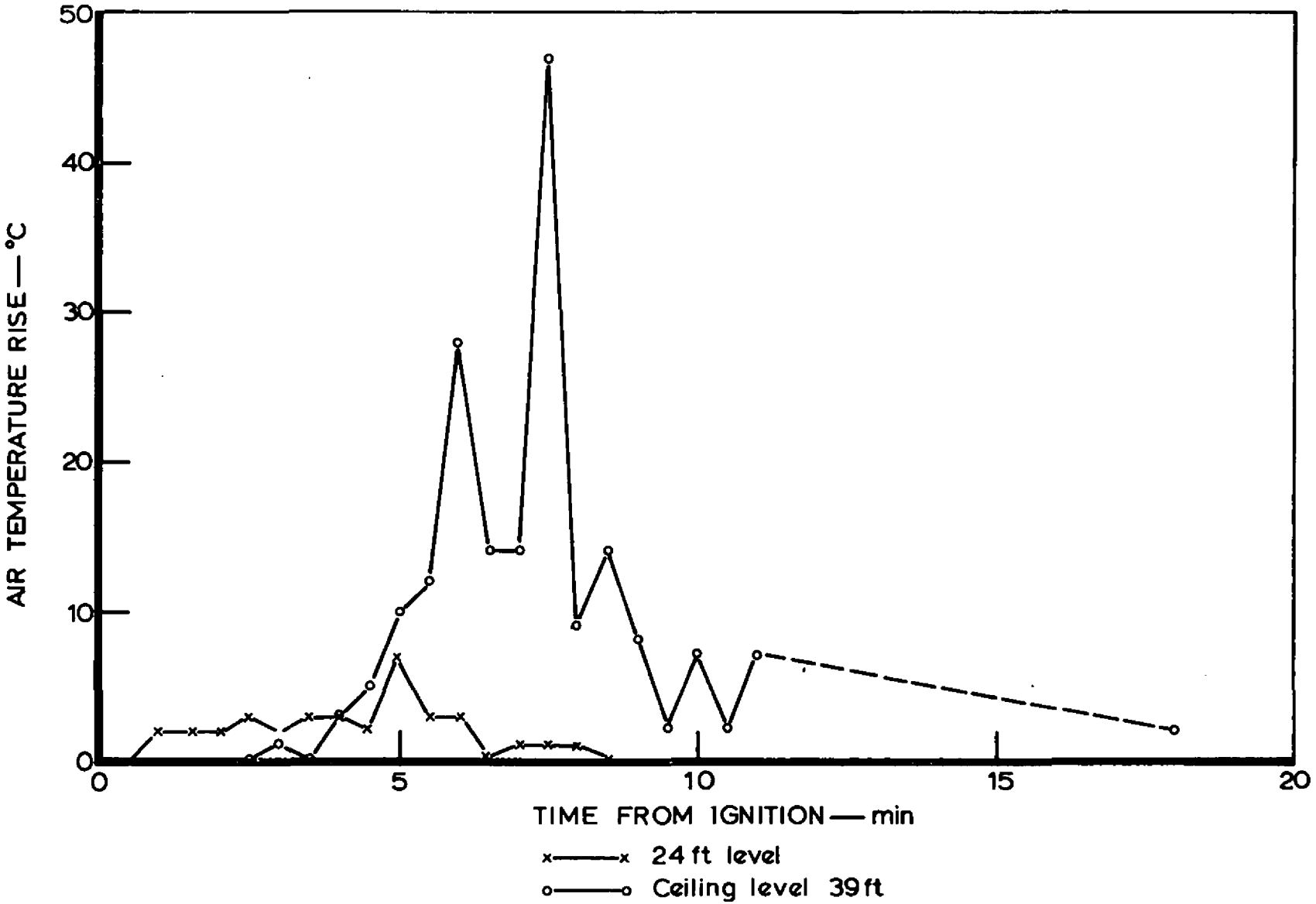


FIG. 4. AIR TEMPERATURE RISE AT CEILING LEVEL AND 24 FT, TEST 1 (ABOVE CENTRE OF RACKING)

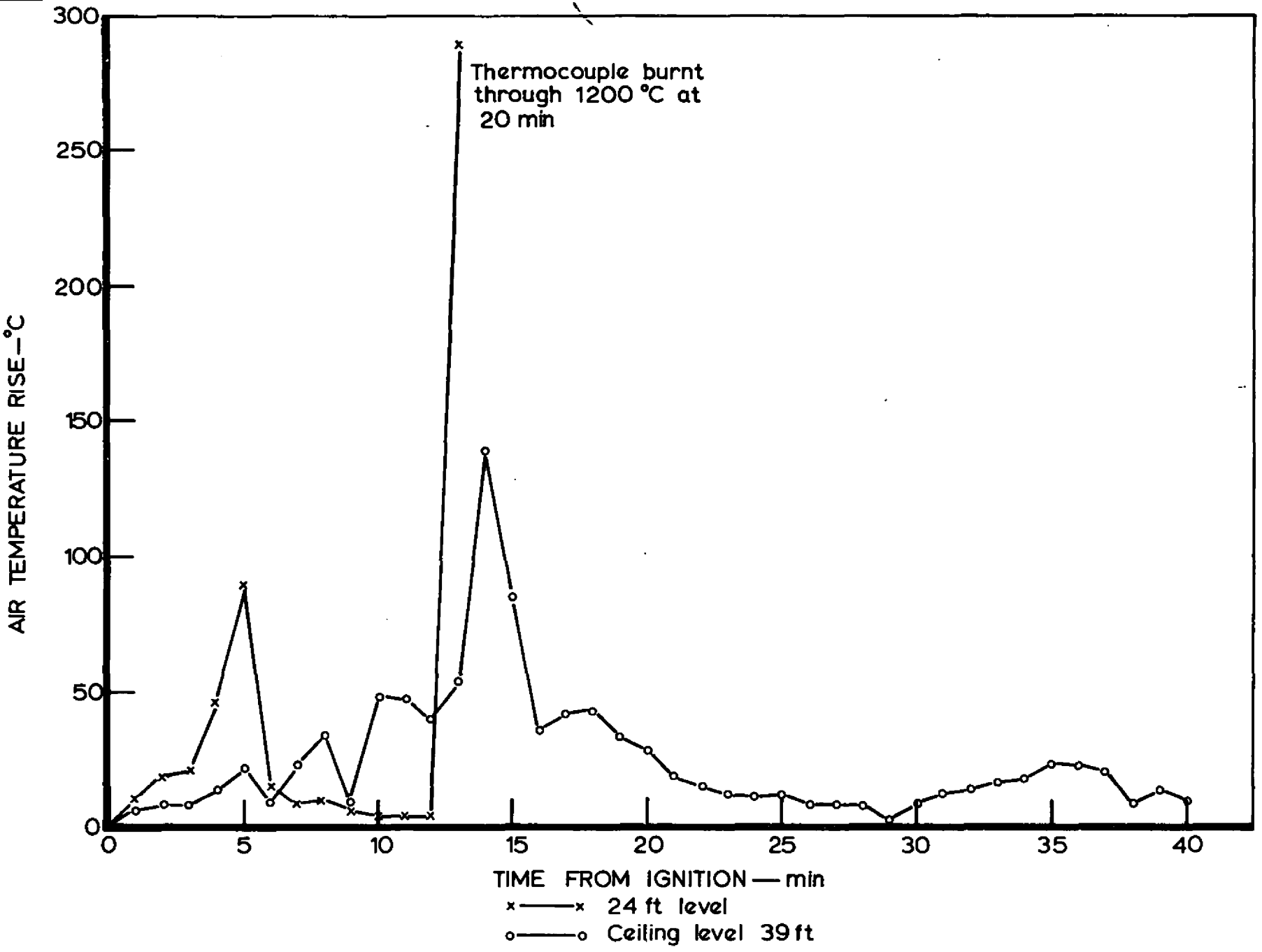


FIG. 5. AIR TEMPERATURE RISE AT CEILING LEVEL 39 FT, AND 24 FT, TEST 2 (ABOVE CENTRE OF RACKING)

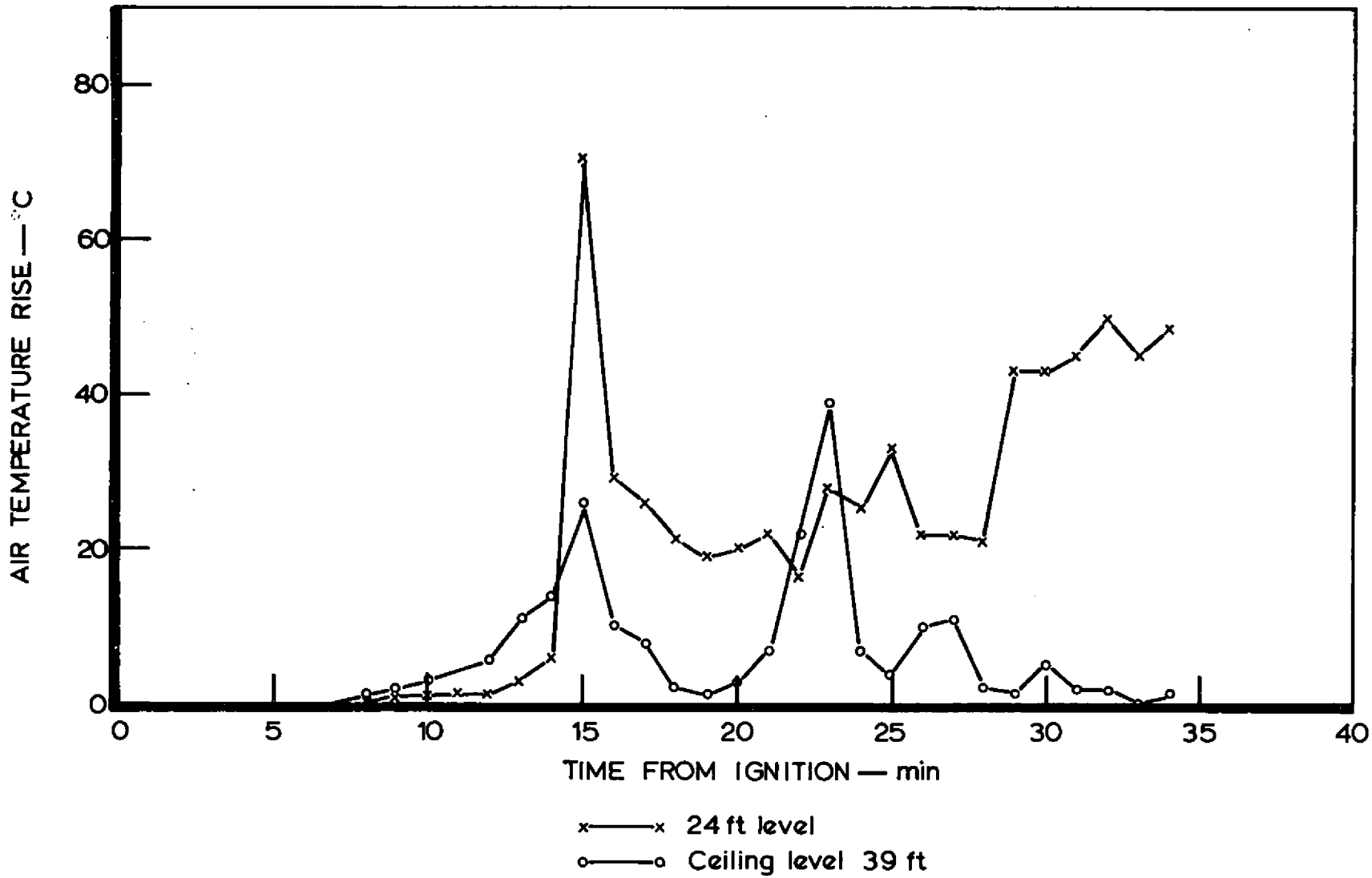


FIG. 6. AIR TEMPERATURE RISE AT CEILING LEVEL AND 24 FT, TEST 3 (ABOVE CENTRE OF STACK)

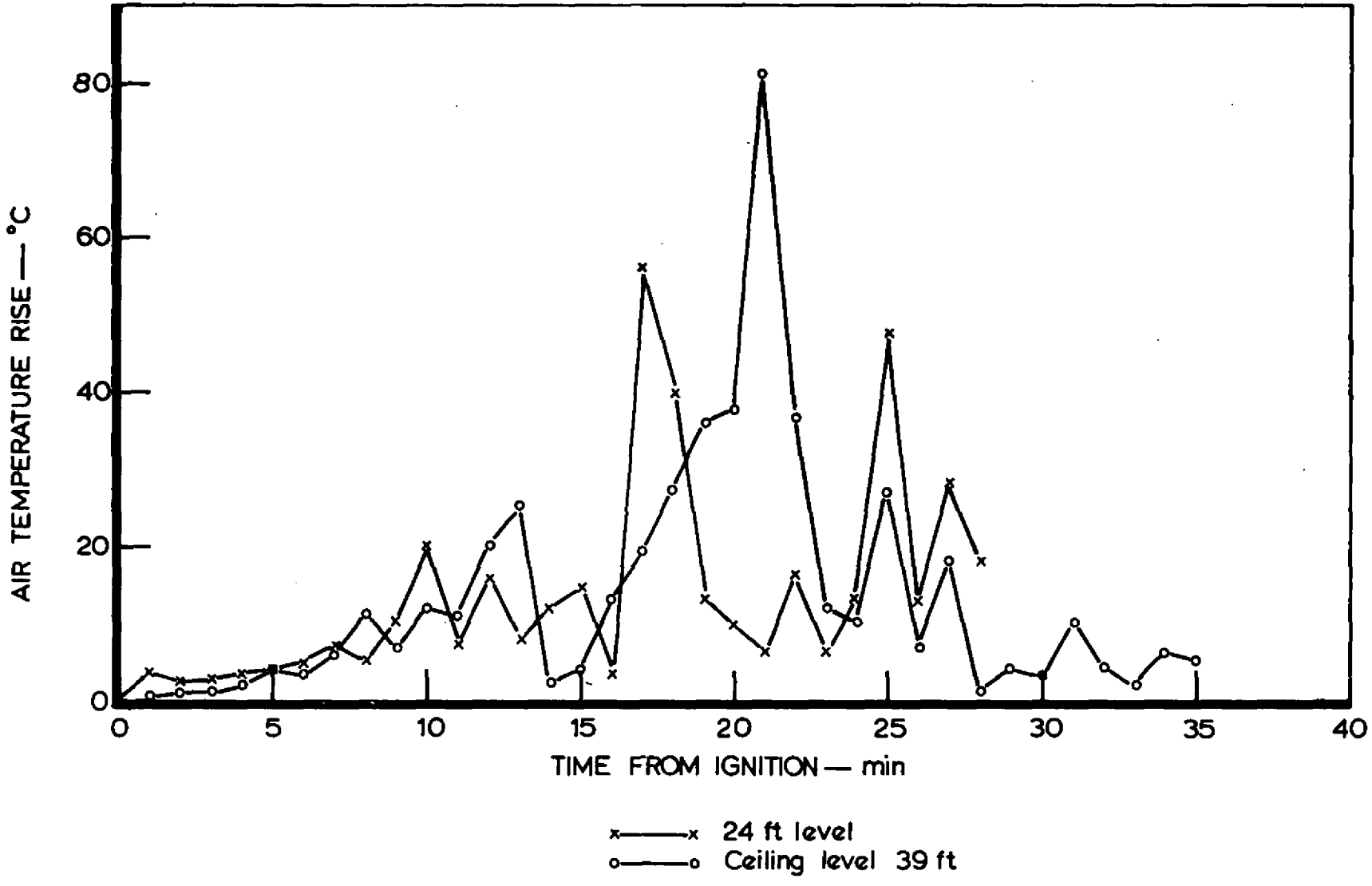
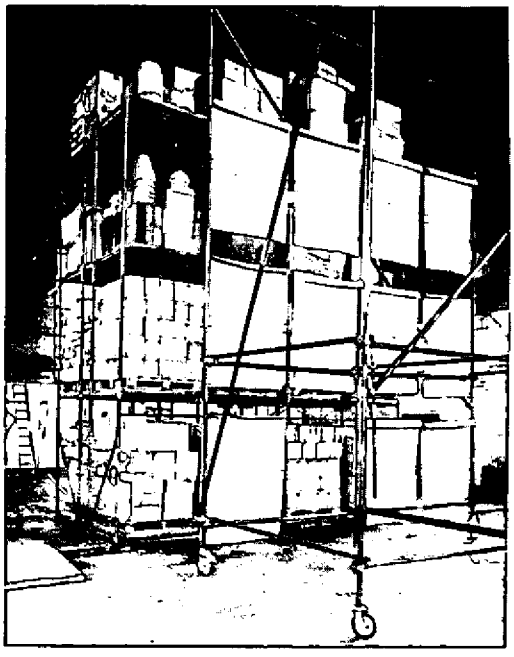


FIG.7. AIR TEMPERATURE RISE AT CEILING LEVEL AND 24 FT, TEST 4 (ABOVE CENTRE OF RACKING)

Sprinkler and baffle
PLATE 1

Racking and goods
PLATE 2



Scaffold with cardboard facings
PLATE 3

a. 20 s after ignition

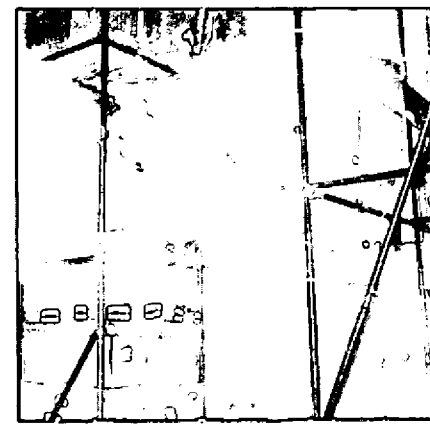
b. 4 min 50 s after ignition

c. 5 min 20 s after ignition

d. 5 min 30 s after ignition

PLATE 4. TEST 1

e. 5 min 55 s after ignition



f. 7 min 7 s after ignition

g. 7 min 37 s after ignition

h. 10 min after test completed

PLATE 4. TEST 1

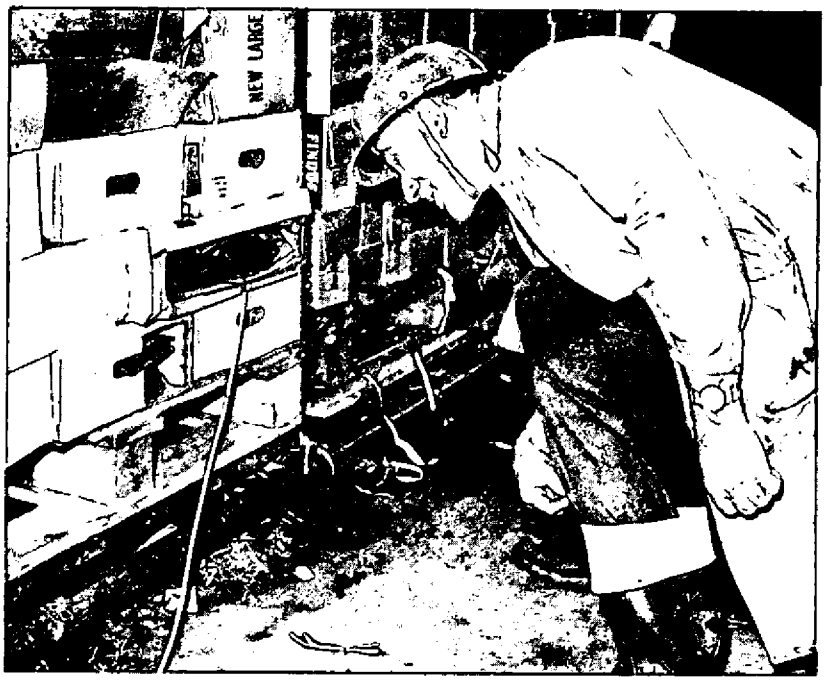
a. Boxes wetted with alcohol

b. 40 s after ignition

c. 4 min after ignition

d. 5 min 50 s after ignition

PLATE 5. TEST 2



Electric element in cardboard box

PLATE 6