Fire Research Note No. 857

THE EXTINCTION OF FIRES IN STORAGES OF RACKED GOODS USING HIGH EXPANSION FOAM

by

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SUMMARY

A major problem in fire protection is the design of protective installations for single-storey warehouses of more than 6 m (20 ft) in height. The need to make maximum use of available floor area has led to the introduction of many such high stacked storages with differing degrees of automation and of heights up to 30 m (100 ft). These present a high fire hazard in both their configuration, which assists rapid fire growth, and in the high value of goods stored.

This note describes an investigation of the effectiveness of high expansion foam, combined with different types of fire detection equipment, in controlling fires developing in a palletized storage of height 7.3 m (24 ft), consisting of two rows of back-to-back pallets at four levels.

The high expansion foam was found to be effective in controlling the fires with the range of fill rates and application times employed.

It was found that early application of the foam was necessary to prevent the fire from reaching ceiling level and that the foam cover might need to be maintained for some hours to ensure complete extinction of the fire.

KEY WORDS: Detector, fire, foam, high-expansion, storage.

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

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1. INTRODUCTION

This report describes a co-operative investigation made jointly by The Walter Kidde Co.Ltd and the Joint Fire Research Organization, of the extinction of fires in storages of racked goods by the application of high expansion foam. The increasing use of such storages in the United Kingdom and other countries makes the problem of fire detection and extinction of paramount importance. A successful extinction system must aim not only at rapid control of the fire, but also at the minimum of fire, smoke and agent damage to the goods. One possible method of fire control is by the use of high expansion foam which will fill the volume of the warehouse, or, at least, that part of it in which a fire exists. The use of high expansion foam is essentially a total flooding system. It is therefore important to know the effect of the following factors on the rapidity of fire control:

a) Rate of increase of depth of foam above floor level, described hereafter as 'rate of fill'.

b) Time interval between ignition of the fire and application of the foam.

c) Duration of foam cover necessary to ensure complete extinction.

The above factors will affect not only the control of the fire but also the degree of damage to the goods by fire, smoke and the extinguishing agent.

2. EXPERIMENTAL

Six experimental fires were made using the same racking as was used in a previous series of experiments in which the fire control was by a sprinkler system[1].

The experiments were made in the Models Laboratory of the Joint Fire Research Organization, a building of dimensions 12 m high x 15 m wide x 40 m long (40 ft x 50 ft x 130 ft). An area of the full width of the building and of length 9.1 m (30 ft) was screened off at one end of the building by a polythene curtain fixed right across the laboratory to provide an experimental area in which the foam could be confined (figs 1 and 2). The racking with the goods was positioned centrally within this area.

Details of the arrangements are given in the following paragraphs:

2.1. Curtain

The curtain was of 1000 gauge polythene sheet, fixed across the laboratory to a height of 10.4 m (34 ft). For experiments 3 - 6, a hessian sheet was hung on the exposed side of the polythene curtain down to about 4 m (13 ft) from the ground. This hessian was wetted by water from sidewall sprinklers during each experiment.

2.2. Ventilation

In experiments 3 - 6, at the commencement of foam application, the sliding roof section of the laboratory was opened in a time of 2 minutes to an area equal to 3 per cent of the floor area of the whole laboratory, corresponding to 13 per cent of the floor area being used for the experiment.

2.3. Racking

The tubular steel structure, (fig.3) was of dimensions 4.9 m x 2.6 m x 9.1 m (16 ft x 8 ft 6 in x 30 ft) and supported a false ceiling of asbestos boards 7.3 m x 4.9 m (24 ft x 16 ft) at a height of 9.1 m (30 ft) above floor level. Four storage levels were provided, at 0.45 m (1 ft 6 in), 2.3 m (7 ft 6 in), 4.1 m (13 ft 6 in) and 5.9 m (19 ft 6 in). Each level carried 8 wooden pallets of dimensions 1016 mm x 1220 mm $(40 \times 48 \text{ in})^2$.

2.4. Combustibles

In each experiment the fire load was composed of corrugated cardboard boxes filled with woodwool. Each pallet was stacked to a height of about 1.5 m (5 ft) except for the top layer, where the height of the pallet loads was restricted to 1.2 m (4 ft). It was considered that this type of fire load would simulate the worst conditions to be found in storages with regard to the speed of fire spread, and the likelihood of having deep-seated fires that would prove to be difficult to extinguish.

2.5. Foam Generation

Four generators, each designed to deliver 142 m^3 (5000 ft^3) per min of 1000:1 expansion foam, were fixed on top of scaffolding at a height of 9.75 m (32 ft). In Experiment 1, the generators were installed within the building, but for the remainder of the experiments they were positioned outside the building as shown in Fig.2.

The generators used were standard Walter Kidde P 500 units, driven by petrol motor. (In an actual installation, the manufacturers stated that the generators would have been powered by electricity or by the water supply). The generators were each fitted with a door at the front, to allow the motors to be run without affecting the air conditions in the laboratory. (See Section 3).

2.6. Fire detection and temperature measurements

Three different detectors and one 'fusible link' were installed for each experiment in the positions shown in Fig.2. and Table 2.

The detectors used were the Walter Kidde Firesaver, Fyr-index and Fire Alert types, the first two being 'rate of rise' thermal detectors and the third an ionisation chamber smoke detector. The 'fusible link' was operated by the breaking of a glass bulb rated at 68°C (155°F). The operating times of the detectors are given in Table 3, Section 4.6.

Chromel-alumel thermocouples were positioned as shown in Fig.4, each position being scanned at 15 s. intervals by a data-logger.

3. EXPERIMENTAL PROCEDURE

The following experiments were made:

Table 1 - Experimental detail

Experimental Number	Foam generation rate (theoretical)		Start of foam application		Flame height at foam application	
	m^3/min	ft^3/min	after ignition	after detection	m	ft
1	566	20,000	2min 16s	30s	1.2	4
2	566	20,000	3min 27s	60s	3.0	10
3	566	20,000	4min 15s	6s*	2.3	7½
4	425	15,000	3min 40s	1min51s	2.3	7½
5	425	15,000	4min 0s	2min20s	4.2	14
6	283	10,000	1min 50s	30s	1.8	6

Note: *Before detection

In Experiment 1, the foam generators were inside the laboratory (Plate 2), between the rack and the roof vent. After producing good quality foam for about 1 min they began to 'breathe' smoke. This caused the motors to slow down, and poor quality foam was produced. There was also severe leakage of foam at the edges of the curtain and the foam level could not be maintained without flooding other parts of the building.

The generators were moved outside the building for the remaining experiments (Plate 3), and the sealing arrangements were modified to prevent leakage.

The motors were started before the fire was lit, so that foam production could begin within seconds of the signal for foam to be applied. In Experiment 2 it was noted that the draught from the generator motors affected the initial stages of the fire and deflected the rising smoke plume away from the detectors, so doors were fitted to the front of the generators for the remaining experiments.

In each experiment the stack was ignited by lighting a torn cardboard box in the bottom layer of boxes on pallet C, at a position in the gap between pallets B and C, at a distance of 0.3 m (1 ft) from the front of the stack (see Fig.3). The vertical fire spread and the increase of depth of foam with time are shown in Figs 4-7 for Experiments 3, 4, 5 and 6.

The initial intention was to commence foam application at predetermined intervals after the fire had been detected by the smoke detector, and this procedure was followed in Experiments 1, 2 and 6. Because of the delay in operation of the detector due to draughts in Experiment 2, it was decided to commence foam application when the flames reached predetermined heights in the next three experiments, in order to avoid adding to the number of variables. Table 1 at the beginning of this section gives the time of the start of foam application in relation to both flame height and detection time.

The original delay of 30 s after detection was suggested as a typical time for evacuation of personnel from an actual building at risk. Where stacker cranes are manually operated, the required delay time between detection and start of foam application might need to be considerably longer.

The numbers of generators used, the rates of filling with foam and the filling times to a height of 9.1 m (30 ft) are given in Table 2 in Section 4.

The foam was maintained at the level of the false ceiling for some time after each experiment, by generating more foam at intervals, as described in Section 4.

Measurements of the expansion ratio of the foam at four levels were made in each experiment by an electrical resistance method. Fig.8 shows the variation in this measurement with time for Experiment 4.

4. RESULTS

No results are included for Experiment 1 as foam generation was reduced to about 10 per cent of its expected value by the inhalation of smoke. This reduction in the foam output was due to both the slower running speed of the petrol-engined fans and the poorer quality of the foam made with hot, smoke laden combustion products from the fire. Work elsewhere[3] indicates that the first of these factors is the more important, and it was found that with electrically driven generators, a reduction of foam output to some 80-90 per cent of its expected value occurred with contaminated air.

It is clearly essential to operate engine-driven generators in clean air.

No results are included for Experiment 2, where radiation from the fire caused the polythene sheet to melt in several places, reducing the maximum level to which foam could be contained to about 5 m (16 ft).

Table 2 - Rate of foam application

Test number	Number of generators	Total filling time min	sec	Average rate of filling m/min	ft/min
3	4	3	12	2.86	9.4
4	3	3	48	2.40	7.9
5	3	3	42	2.43	8.1
6	2	6	02	1.52	5.0

The sequences of events in Experiments 3 to 6 are detailed below. The flame heights given were measured from the floor to the tip of the flames, and the foam depths recorded were measured at the corner vertical tube of the rack by pallet A (Fig.3).

4.1. Sequence of events, Experiment 3

Time min.	s	Event
0	00	Box in pallet C lit with match
2	00	Flames 1 m (3 ft 3 in) high in B/C gap
3	54	Flames 2 m (6 ft 6 in) high on face of pallet C in B/C gap
4	00	Flames on face of pallet B in B/C gap
4	15	Flames 2.3 m (7 ft 6 in) high, FOAM ON. Roof started opening
4	21	Smoke detector operated
4	51	Foam 1 m deep, flames 3.4 m (11 ft) high
		Heat detector (X) operated
5	12	Foam 2 m deep, flames 4.1 m (13 ft 6 in) high
5	22	Heat detector (Y) operated
5	41	Flames out (maximum flame height reached 5.3 m (17 ft 6 in))
		Foam 3.5 m (11 ft 6 in) deep
7	30	Foam depth 9.1 m (30 ft) FOAM OFF

The foam level was maintained at 9.1 m for 3 hours, by topping up at 30 min. intervals. Smoke issued from the top of the foam for 2 hrs.30 minutes. Damage was restricted to pallets C and G, 30 per cent of pallet C and 10 per cent of pallet G being damaged by fire. Plates 4, 5 and 6 show the early stages of the fire. The 'fusible link' detector did not operate in this experiment.

4.2. Sequence of events - Experiment 4

Time min.	s	Event
0	00	Box in pallet C lit with match
1	00	Flames 1.2 m (4 ft) high on face of pallet C in B/C gap
1	49	Smoke detector operated
2	05	Flames 2 m (6 ft 6 in) high on side of pallet C
3	15	Flames beating under pallet G
3	40	Flames 2.3 m (7 ft 6 in) high in B/C gap; side of pallet B ignited. FOAM ON
4	00	Flames 2.6 m (8 ft 6 in) high, foam 0.45 m (1 ft 6 in) deep
4	01	Heat detector (X) operated
4	15	Second layer of boxes ignited, foam 1 m deep
4	35	Third layer of boxes ignited, foam 2 m deep
4	50	Fourth layer of boxes ignited, foam 2.3 m deep
5	00	Flames touching false ceiling 9.1 m (30 ft) high
5	32	Fusible link operated
5	33	Heat detector (Y) operated
6	00	All pallets on top layer burning, foam 5.5 m (18 ft) deep
6	35	Flame intensity decreasing, foam depth 7.1 m (23 ft 6 in)
7	00	Flaming extinguished, foam 8 m (26 ft 6 in) deep
7	32	Foam reached false ceiling, 9.1 m deep. FOAM OFF

The foam level was maintained at 9.1 m for 4 hr 30 min by topping up with 1 generator at 15 min. intervals. Smoke continued to issue from the top of the foam for the whole of this period. When the foam was broken down deep-seated smouldering was found in pallets P and M, and ignition occurred shortly after the foam cover was removed. The base boards of these two pallets were burnt through.

4.3. Sequence of events - Experiment 5

Time min.	s	Event
0	00	Box in pallet C lit with match
0	30	Flames 0.8 m (2 ft 9 in) high on face of pallet C in B/C gap
1	40	Flames 1.6 m (5 ft 3 in) high in B/C gap
		Smoke detector operated
2	30	Flames 2 m (6 ft 6 in) high
3	05	Flames ignited pallet B in B/C gap, flames 2.4 m (7 ft 9 in) high
4	00	FOAM ON. Flames 4.2 m (14 ft) high
4	08	Heat detector (X) operated
4	09	Heat detector (Y) operated
4	15	Flames 5.3 m (17 ft 6 in) high, foam 0.45 m (1 ft 6 in) deep
4	45	Flames touching false ceiling 9.1 m (30 ft) high, foam 0.45 m (1 ft 6 in) deep
4	50	'Fusible link' operated
5	30	Foam 4.4 m (14 ft 6 in) deep
6	00	Foam 5.8 m (19 ft) deep, considerable flaming on top layer
6	40	All flaming extinguished, foam 7.4 m (24 ft) deep
7	45	Foam depth 9.1 m
8	00	FOAM OFF. Continuous emission of smoke

Topping up by 2 generators for 30s each, every 15 mins. maintained the level at 11 m (36 ft). The foam was broken down with centrifugal fans after the stack had been covered for 4 hours 10 minutes. The fire was found to be out.

About 50 per cent of the materials on the top layer were consumed by fire (Plate 7), and the same proportion in pallets B, C, F, G, J and K on the 'curtain' face of the stack. No pallet loads were damaged on the other side of the stack, except on the top layer.

4.4. Sequence of events, Experiment 6

Time		Event
min.	s	
0	00	Box in pallet C lit with match
1	00	Flames 1.1 m (3 ft 8 in) high
1	20	Smoke detector operated
1	50	FOAM ON from 2 generators. Flame height 1.82 m (6 ft)
3	00	Flames 2.3 m (7 ft 6 in) high, foam 1.2 m (4 ft) deep
3	30	Flames 2.3 m foam 2 m (6 ft 6 in) deep
3	42	All flaming extinguished, foam 2.3 m (7 ft 6 in) deep
7	54	Foam 9.1 m (30 ft) deep. FOAM OFF
		Foam depth maintained for 2 hours, no smoke emission after 1 hr. 30 mins. Damage restricted to pallets B and C.

4.5. Temperature measurements

In Experiments 3 and 6, the temperature recorded at the centre of the ceiling increased by a maximum of 70 deg C and 40 deg C respectively.

In Experiments 4 and 5, where the fire spread to the top layer of goods, the maximum temperature reached at the centre of the false ceiling was about 850 °C and in both experiments the ceiling temperature remained above 600°C for about 2 minutes. A graph of temperature rise at ceiling level and at detector position 2 is shown in Fig.9

4.6. Detection

The detectors usually operated in the order:

Smoke detector; heat detector (X); heat detector (Y); fusible link.

The smoke detector operated 1 m 42 s (on average) before heat detector X, when both were within the racking.

The smoke detectors were set to operate at an optical density of about 0.2 per cent per metre.

This setting is more sensitive than could normally be considered practicable, but no false alarms were given when a smoke detector was installed in the ceiling of the laboratory for a period of 3 weeks after the experiments had been conducted. It is estimated that if the smoke detector had been set to operate at a more usual obscuration of 2 per cent per metre, it would have operated some 30 s to 1 min, later.

Table 3 - Detector Response Times

Experiment No	Detector			
	Heat X	Heat Y	Smoke	Fusible Link
	min s	min s	min s	min s
1	2 25[1]	3 07[1]	1 46[1]	3 45[1]
2*	3 55[1]	4 54[1]	2 27[1]	5 28[2]
3	4 51[2]	5 22[2]	4 21[3]	N.O [2]
4	4 01[2]	5 33[2]	1 49[1]	5 32[2]
5	4 08[2]	4 09[2]	1 40[1] 2 36[3]	4 50[2]
6	N.O [2]	N.O [2]	1 20[1]	N.O [2]

(1) - Detector on false ceiling

(2) - Detector 1.2 m (4 ft) below false ceiling

(3) - Detector on curtain

(*) - Air velocity at the detectors of 61 m/min (200 ft/min) caused by fans of foam generators

N.O - Detector did not operate

4.7. Water damage to goods

After immersion in the foam for the duration of the tests, the outer surface of the cartons at all levels appeared to be thoroughly wetted. The printing on the side of the cartons was not affected by immersion in the foam and the cartons dried out, without distortion, in about 12 hours.

Cartons in the interior of the pallet loads were unaffected by water draining from the foam, and were found to be completely unmarked when examined at the end of each test.

5. DISCUSSION

5.1. Fire growth

It may be seen from Figs 4, 5, 6 that the increase in flame height with time usually proceeded in two stages, a slow early development followed by a rapid rate of increase of flame height. In Fig 4 the flames were "intercepted" by the foam, that is, the foam level came sufficiently close to the flame tips to quell the fire before it increased to the top of the stack. This is clearly the best situation to achieve as it will result in less fire damage to the goods and ceiling. By plotting the difference in the height of the flame tips and the foam level, as taken from Figs. 4, 5, 6, 7 in Fig.10, we see the general requirement for "interception" to occur.

Thus in Exp. 3, the fire came within 2.4 m ($7\frac{3}{4}$ ft) of the flame tips and slowed down the development sufficiently to complete an interception at a gap of 1.8 m (6 ft). In Exp. 6 the foam came within 1.8 m (6 ft) of the flame tips and slowed the fire development gradually to zero. In Exp. 4, the foam came within 2.1 m ($6\frac{3}{4}$ ft) of the flame tips but the rate of application was not great enough to consolidate the interception, and the flame accelerated away from the foam. If we assume a maximum gap of not more than 1.5 m (5 feet) between foam level and flame tips for the interception to take place, we can draw a formalised graph of fire development (Fig.11) in which a slow first stage of development occurs at a typical rate of 0.84 m/min. (2.75 ft/min) for 4 minutes, followed by a rapid development at 6.1 m/min (20 ft/min) until the flames reach the ceiling. This curve is therefore the lower limiting envelope of fire development of interception if interception is just not to occur for the combination of fill rates and times of starting of foam application shown by the lines P, Q, R, S.

Thus for a given rate of fire development, it is probable that interception can be achieved by certain demonstrable values of fill rate, each combined with its own "starting time" of foam application. A slow fill rate can be offset, within limits, by an earlier starting time, and vice versa.

The general equation of the lines P, Q, R, and S is given by

$$t_o = a - \frac{b}{m}$$

where t_o = time of start of foam application

m = rate of fill in m/min

a, b = co-ordinates of critical point 'A', where a is in minutes and b in m.

Thus in Fig.11 this equation reduces to

$$t_o = 4 - \frac{1.8}{m}$$

It should be noted that, if the fire occurs by chance at a high level in the stack, the opportunity for the foam to "intercept" it is greatly reduced and may be non-existent, since the foam has to fill from floor level upwards.

6. CONCLUSIONS

6.1. The growing fire in the high-rack storage experiment was controlled by the application of high expansion foam to the area in which the racks were situated.

6.2. For rapid control it was necessary to apply the foam at a fill rate which was adequately high to ensure that the foam 'intercepted' the fire on its upward path. If this were not done, the upper layers of goods and the ceiling would be likely to be subjected to high temperatures for the period necessary for the foam to cover the top level of goods.

6.3. No less important than the fill rate was the delay between start of the fire and foam application. A rapid detection and start of application of foam could mitigate to some extent, a relatively slow fill rate. Similarly, a slow detection and start of application could be offset to some extent by a high fill rate.

An approximate relation between the latest time of commencement of foam application (t_o) after ignition, and the rate of fill in m/min (m) is given by the equation

$$t_o = 4 - \frac{1.8}{m}$$

for this type and configuration of goods, when ignition takes place near to floor level.

6.4. It may be necessary to keep the racked goods covered with foam for some considerable time to ensure that all smouldering material has cooled below ignition temperature. Periodic topping up may be necessary.

6.5. The use of high-expansion foam tends to give a clean-burning fire with little smoke production, but this advantage must be offset against increased temperatures and flame damage. (c.f. F.R.Note No. 814).

6.6. It would possibly be an advantage to use a combined system in which the rising foam level is aided by a low density water spray from above, or possibly by the application of high expansion foam over the top of the goods. This type of development should be considered.

7. ACKNOWLEDGMENTS

Thanks are due to The Walter Kidde Co.Ltd for their close co-operation and assistance throughout the series of experiments.

8. LIST OF TABLES, FIGURES AND PLATES

Table 1 Page 3 List of Experiments

Table 2 Page 5 Rate of foam application

Table 3 Page 9 Detector response times

Figure 1 Plan view of Laboratory

Figure 2 View of racking showing detector positions

Figure 3 Racking, showing pallet and thermocouple positions

Figure 4 Exp. 3 Flame height and foam depth

Figure 5 Exp. 4 "

Figure 6 Exp. 5 "

Figure 7 Exp. 6 "

Figure 8 Foam expansion at 4 levels

Figure 9 Air temperature measurements, Exp. 4

Figure 10 Distance between flame tip and foam surface

Figure 11 Formalised flame development curve

Plate 1 General view of racking and goods

Plate 2 Foam generators and polythene screen Exp. 1

Plate 3 View of foam generators, Exps. 3-6

Plate 4 Exp. 3, 3 min 42 s after ignition

Plate 5 Exp. 3, 4 min 36 s "

Plate 6 Exp. 3, 4 min 54 s "

Plate 7 Exp. 5, Top layer of boxes, after foam removed

9. REFERENCES

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3) Fixed High Expansion Foam installation for large aircraft hangar. Fire International, July 1969.

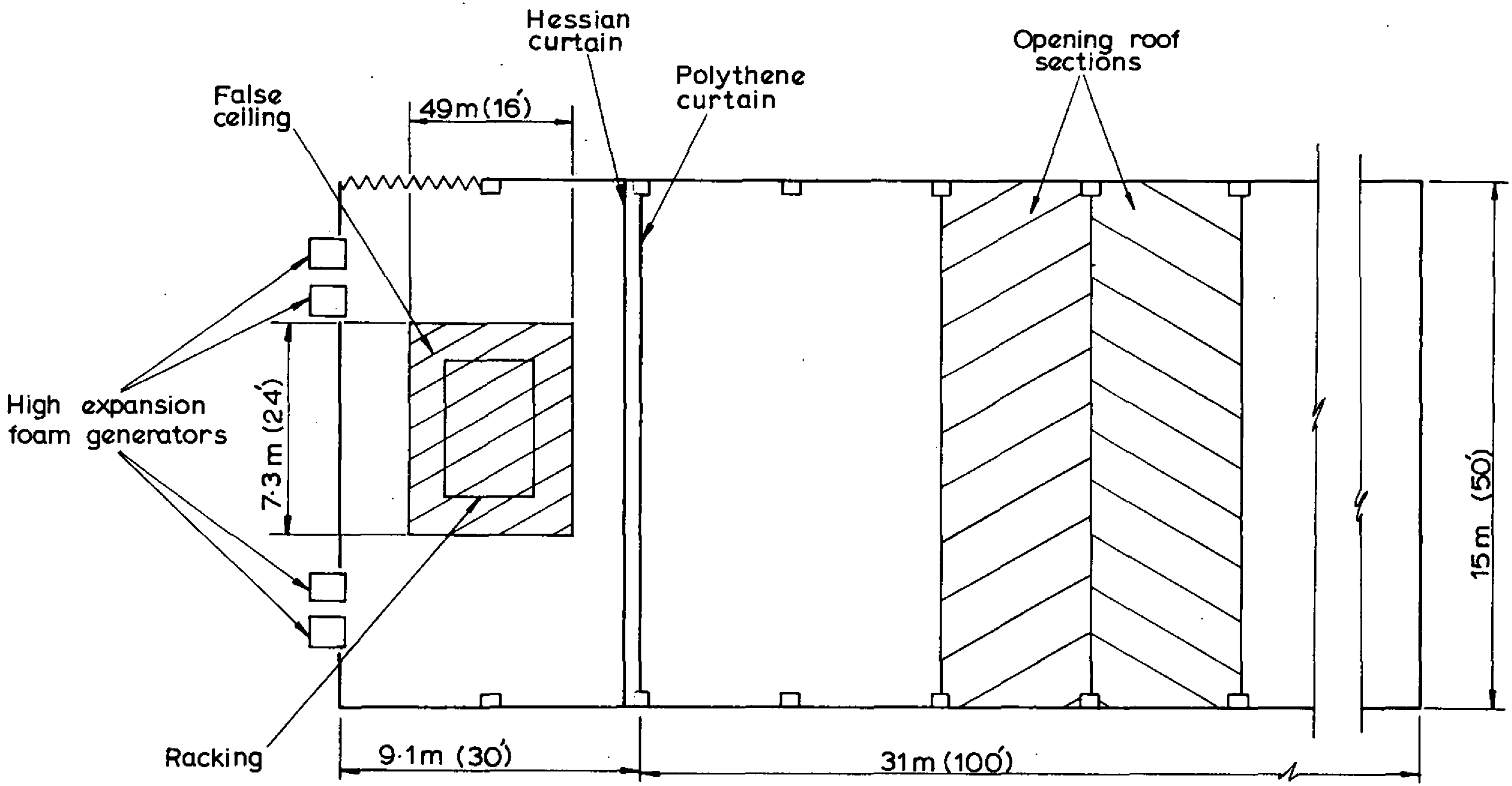

FIG. 1. PLAN VIEW OF LABORATORY RACKING AND GENERATORS

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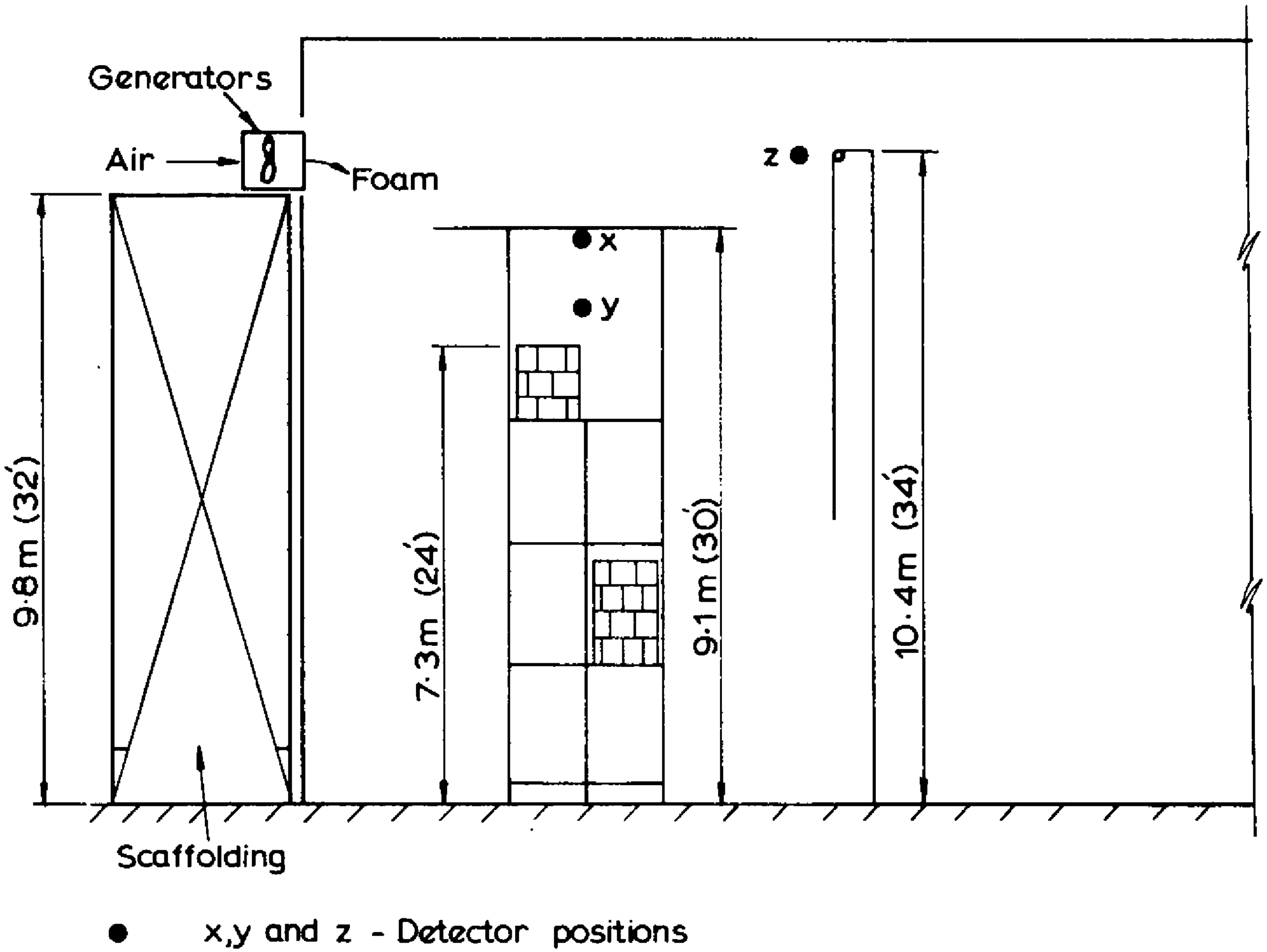

FIG. 2. END VIEW OF LABORATORY, RACKING AND GENERATORS

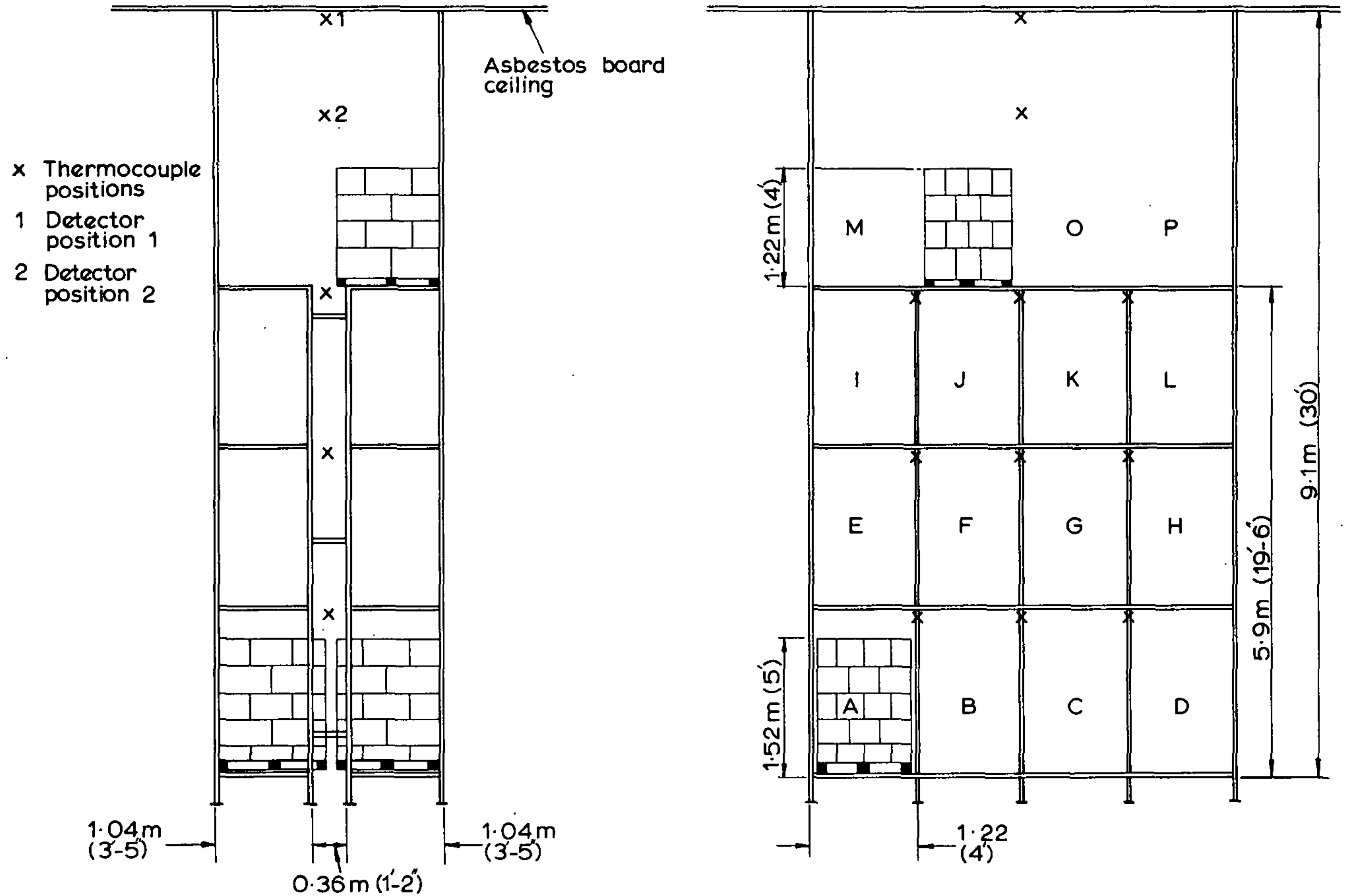

FIG. 3. RACKING SHOWING PALLET AND THERMOCOUPLE POSITIONS

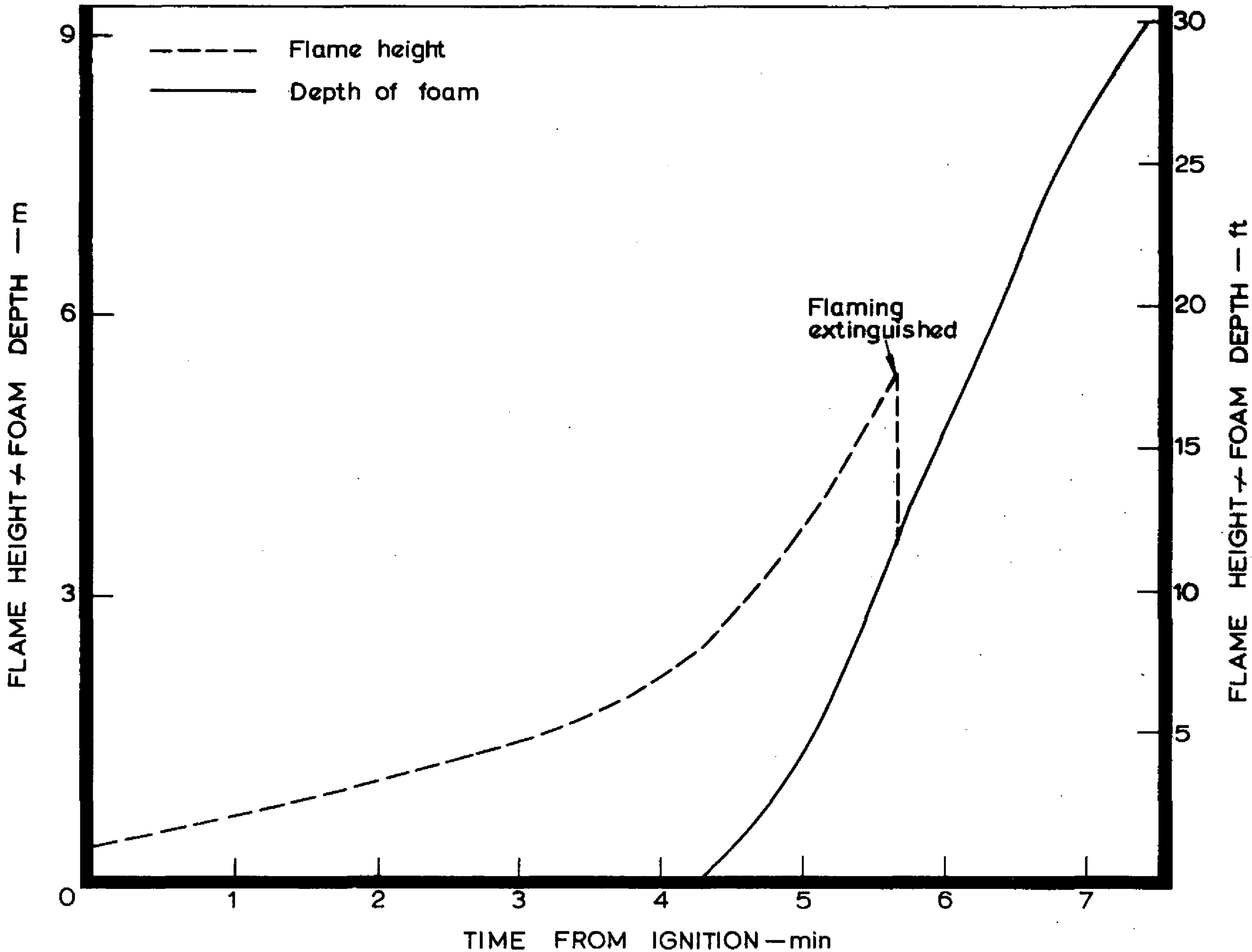

FIG. 4. TEST 3 FLAME HEIGHT AND FOAM DEPTH

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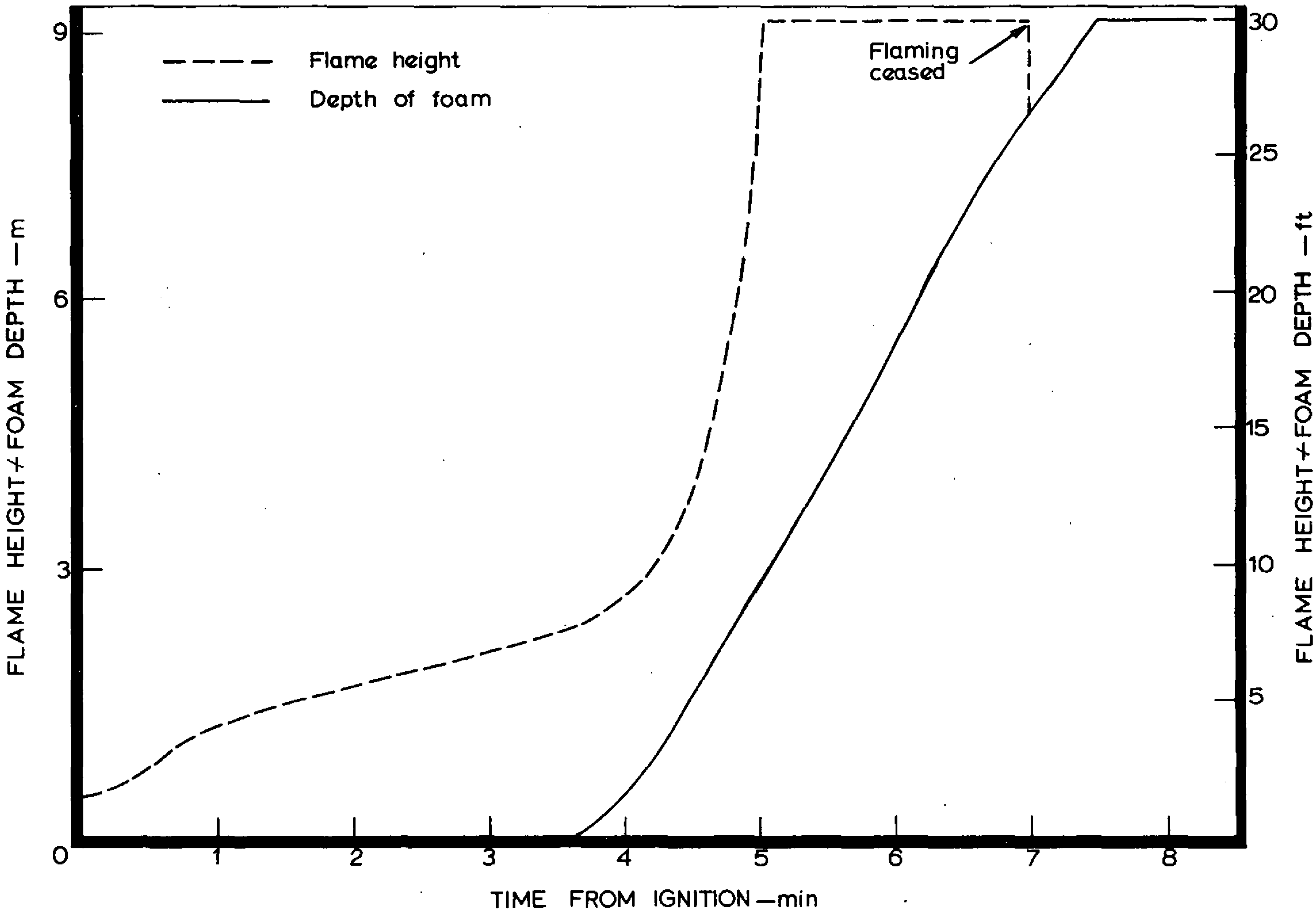

FIG. 5. TEST 4 FLAME HEIGHT AND FOAM DEPTH

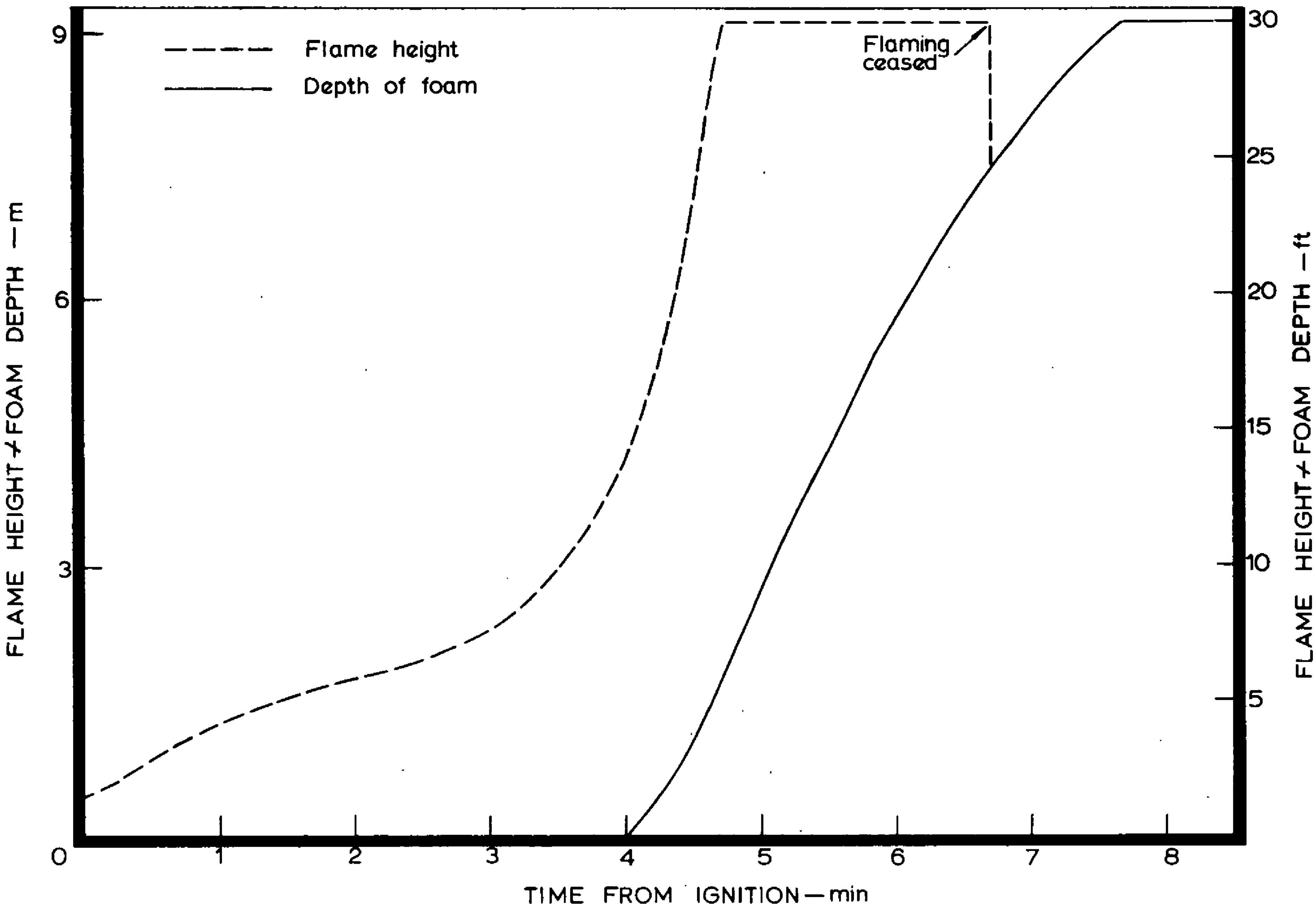

FIG. 6. TEST 5 FLAME HEIGHT AND FOAM DEPTH

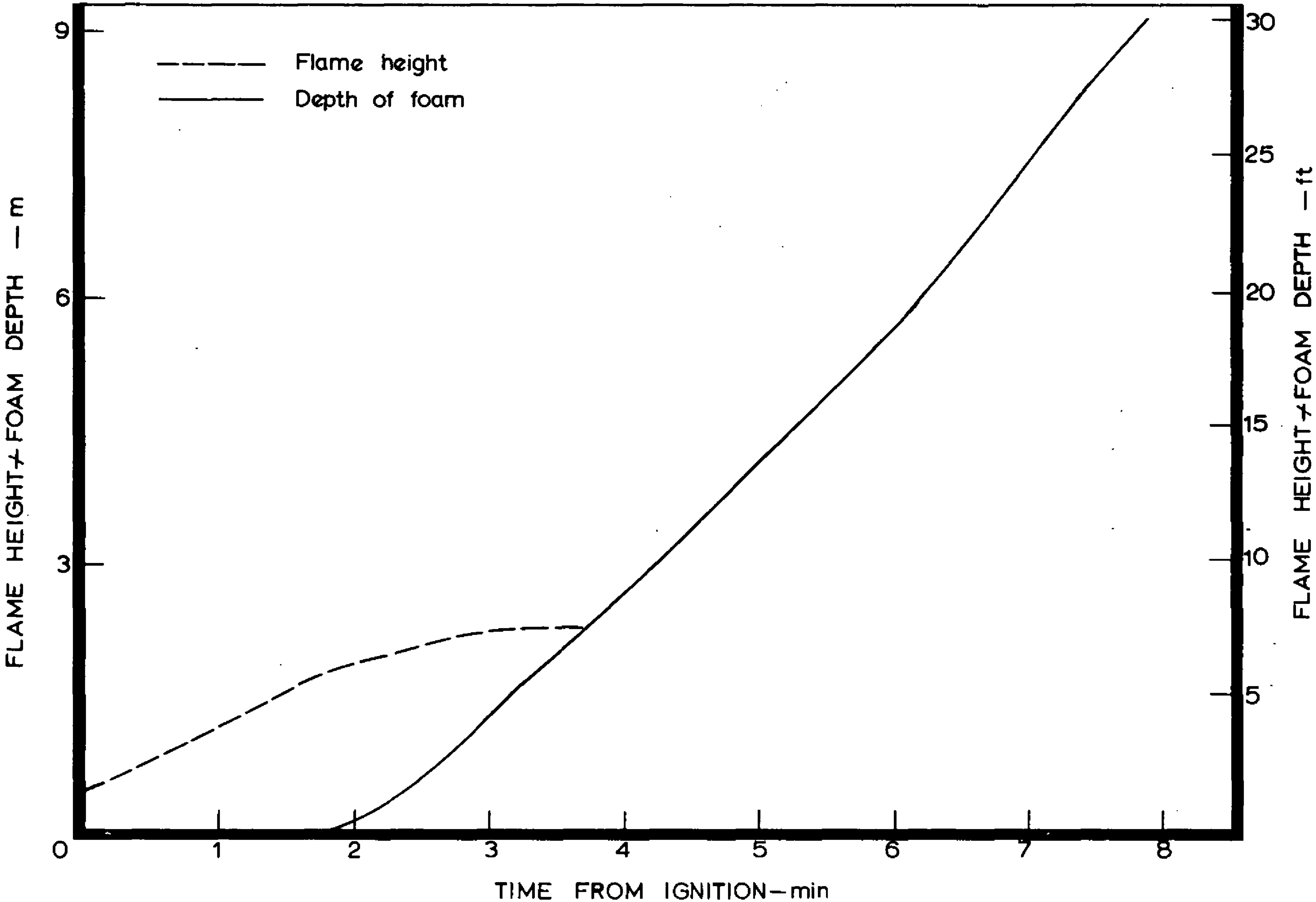

FIG. 7. TEST 6 FLAME HEIGHT AND FOAM DEPTH

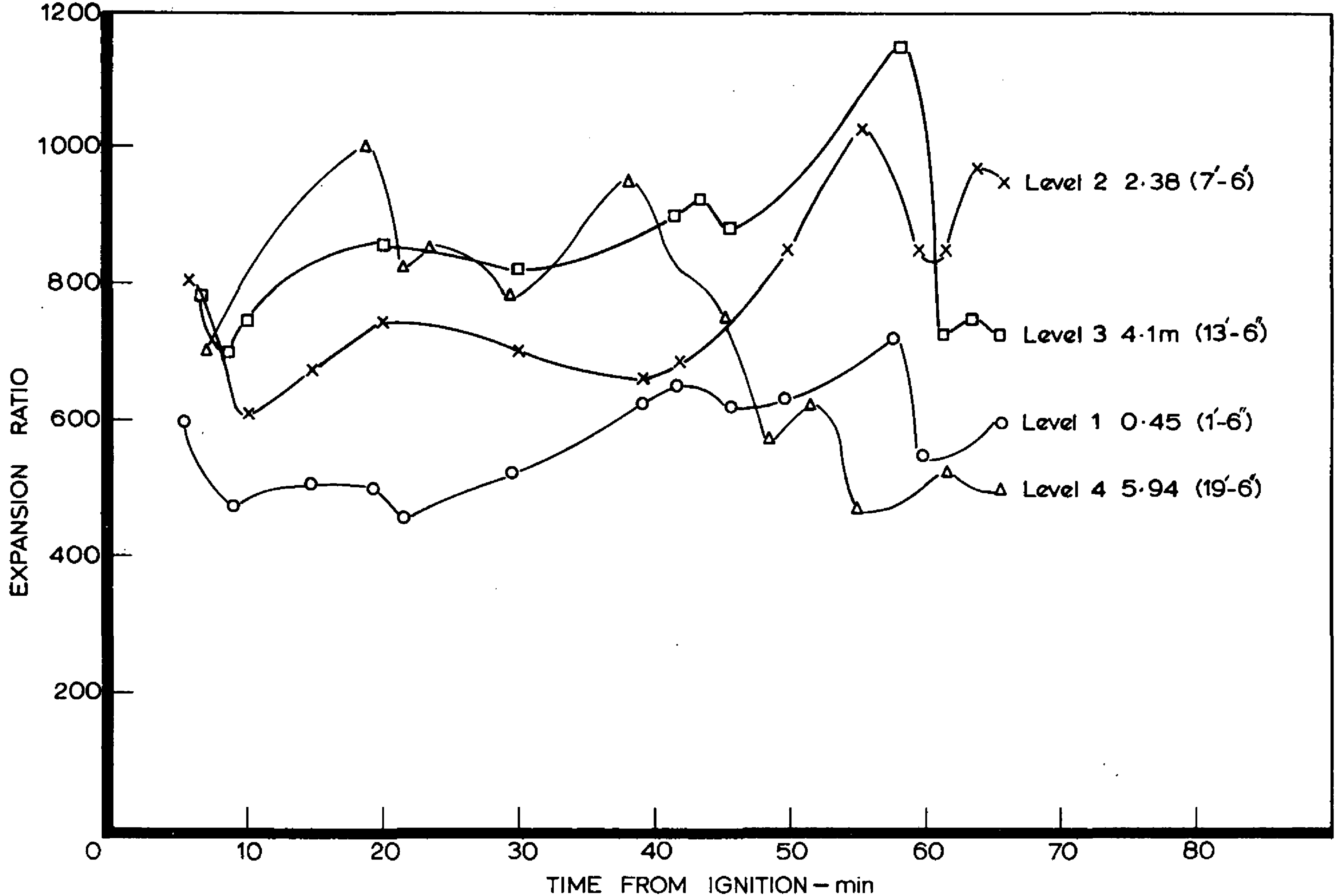

FIG. 8. FOAM EXPANSION AT FOUR LEVELS. TEST 4. AS MEASURED BY ELECTRICAL RESISTANCE

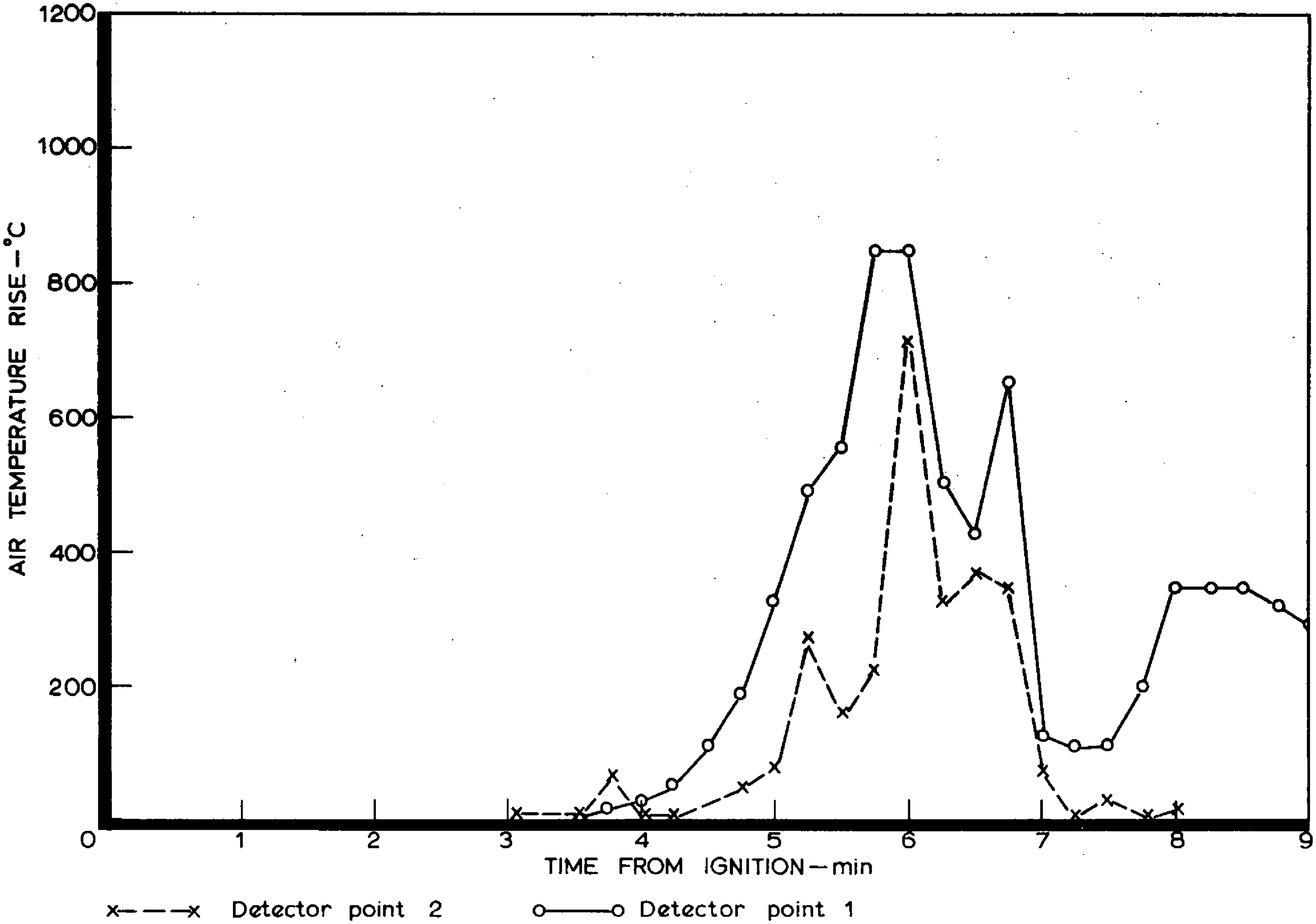

FIG. 9. AIR TEMPERATURE MEASUREMENTS TEST 4

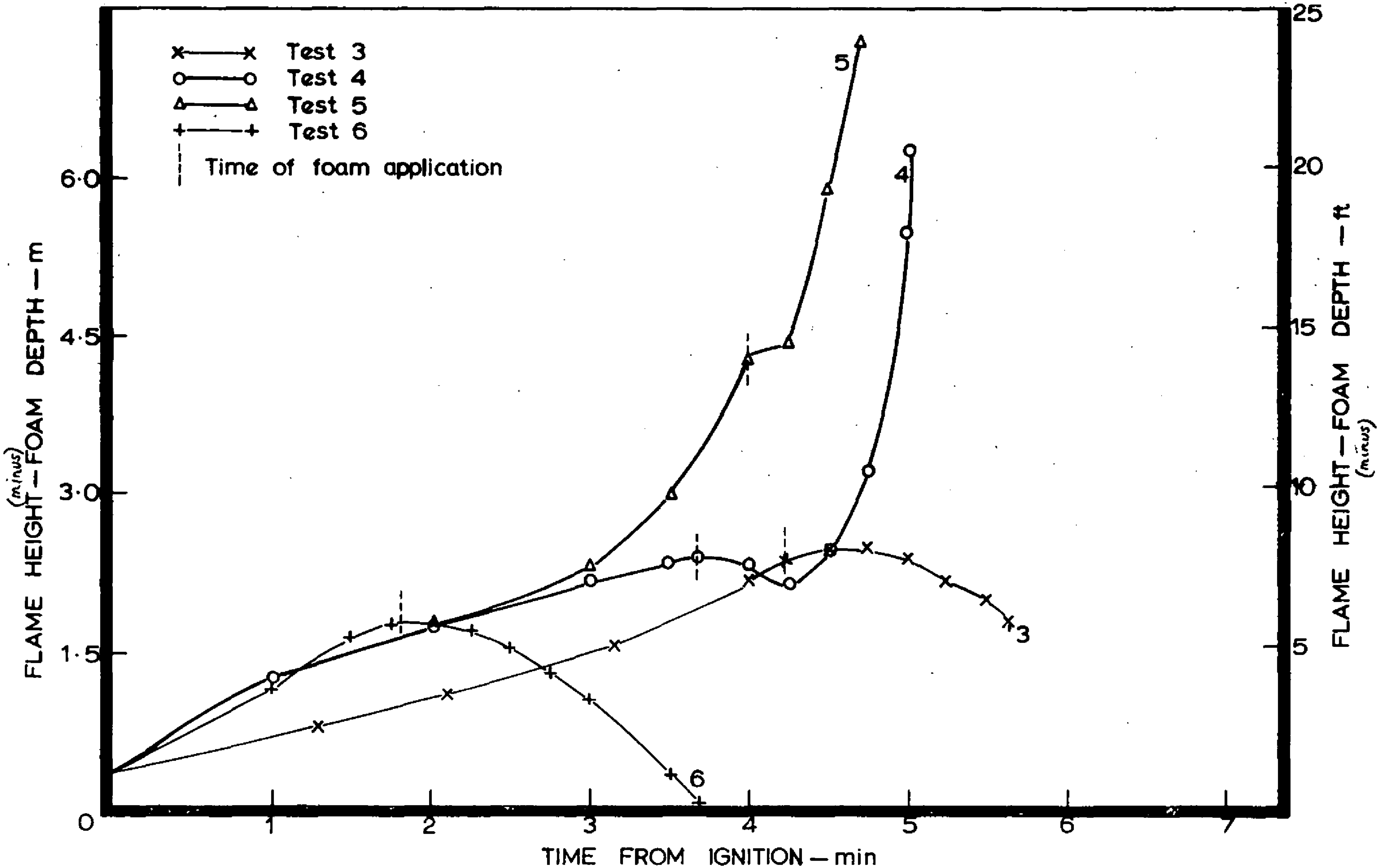

FIG. 10. DISTANCE BETWEEN FLAME TIPS AND FOAM SURFACE

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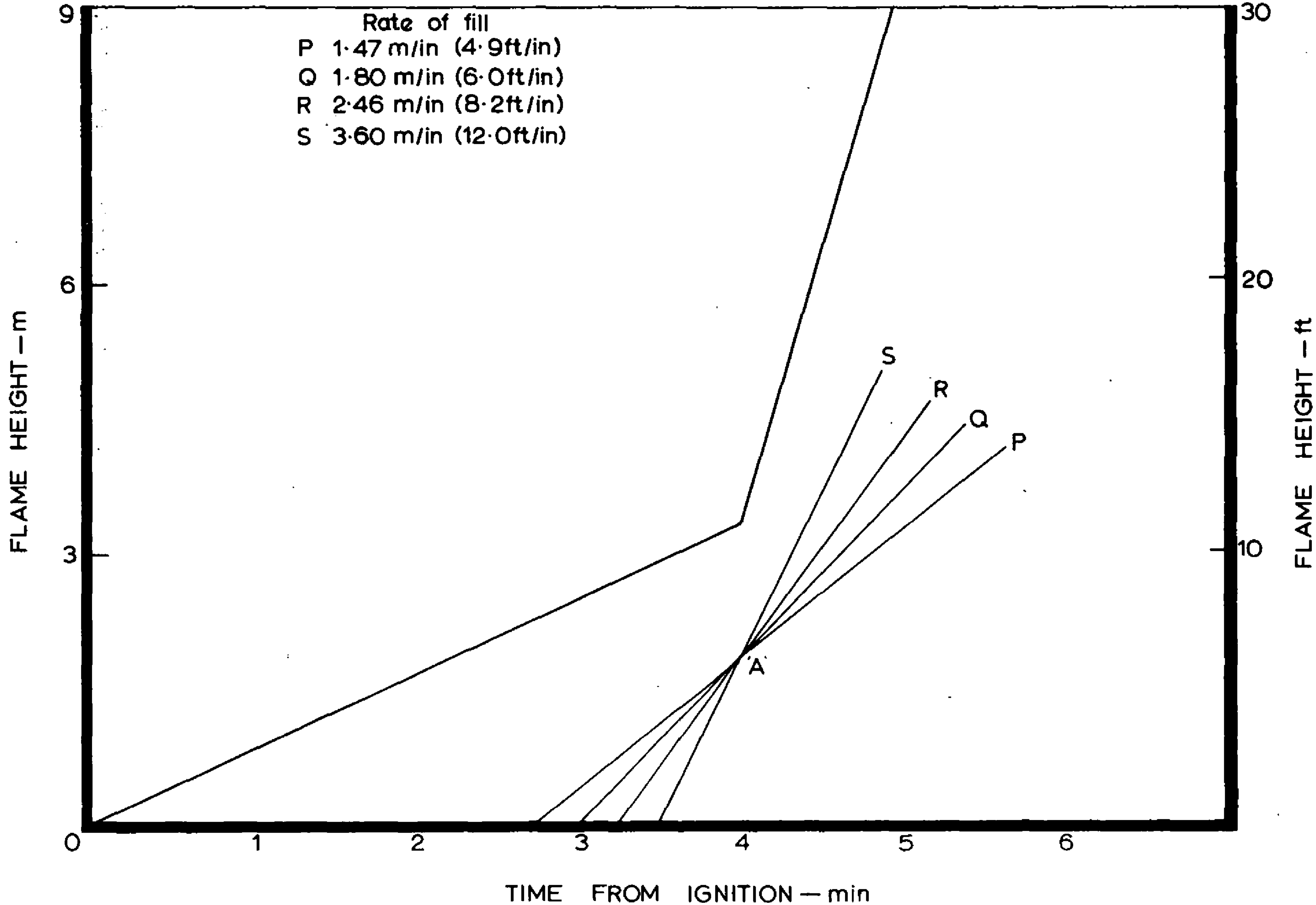
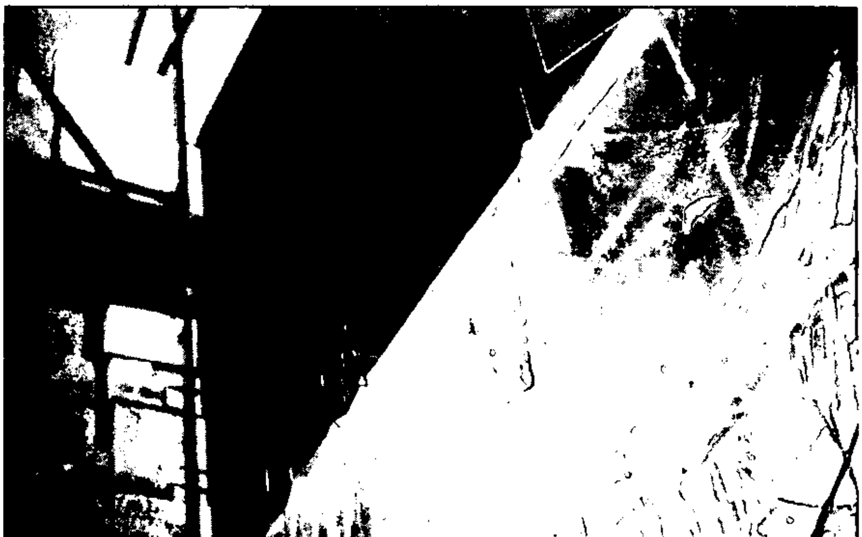
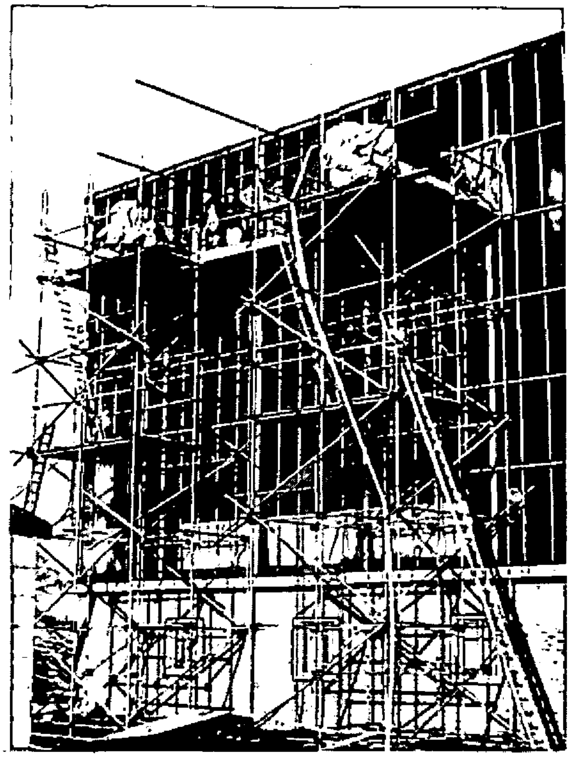


FIG. 11. FORMALISED FLAME DEVELOPMENT CURVE

GENERAL VIEW OF RACKING AND GOODS
PLATE 1

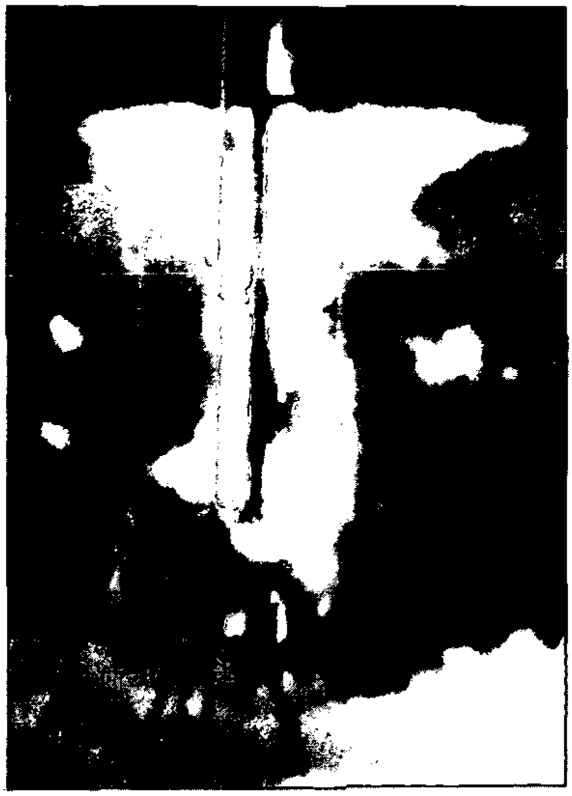


FOAM GENERATORS AND POLYTHENE SCREEN, TEST 1
PLATE 2

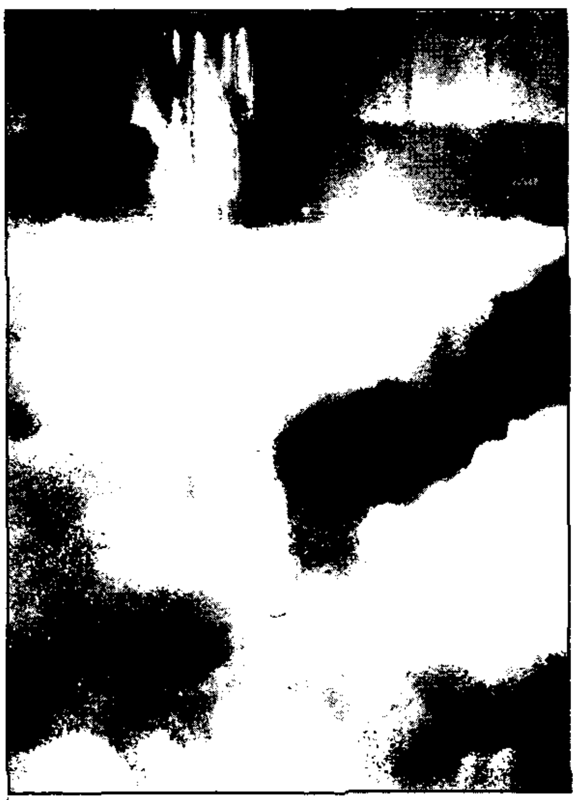


VIEW OF FOAM GENERATORS, TESTS 2-6
PLATE 3

TEST 3, 3 min 42s AFTER IGNITION
PLATE 4



TEST 3, 4 min 36s AFTER IGNITION
PLATE 5



TEST 3, 4 min 54s AFTER IGNITION
PLATE 6

TEST 5, TOP LAYER, AFTER FOAM REMOVED
PLATE 7