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THE APPLICATION OF HIGH EXPANSION AIR FOAM TO TWO TYPES OF FIRE

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SUMMARY

High expansion foam has been applied to two types of fire. The action of flames and radiated heat on the foam has been observed. Rates of foam application to enable the fires to be controlled, and eventually extinguished, have been measured. Critical foam application rates for each type of fire have been obtained.

The fires used in the experiments can be used as standard of their types for comparing the relative efficiencies of high expansion foam compounds.

Key Words: Foam High Expansion

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MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE
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INTRODUCTION

In recent years the fire fighting properties of high expansion foam have been investigated and as a result the foam has been used increasingly as a method of fighting fires. Fire brigades, equipped with generators, have employed this method successfully[1, 2].

It has become apparent that high expansion foam is more efficient in combating some types of fire than it is in dealing with others. It was thought that the foam could operate by three mechanisms in quenching fires namely, cooling, by virtue of the application of water to the burning materials, production of steam in the atmosphere thus inhibiting combustion and thirdly, acting as a blanket to prevent access of air to the fire. In view of this it is apparent that high expansion foam will vary in its fire fighting efficiency according to the type of fire, the rate of foam application to the fire and its expansion ratio in addition to its more fundamental properties.

The foaming properties of different foam concentrates vary[3] and thus their fire fighting properties will also vary. It was therefore thought necessary to be able to assess the fire fighting efficiencies of foam concentrates relative to an accepted standard of performance. In order to do this the types of fire used would be such that they could be readily reproduced and regarded as standard of their types.

With the above factors in mind two series of experiments were carried out, one using a flammable liquid fire in a tray on the ground and the other a similar fire in a tray at about 18 in below a ceiling. With the latter type of fire flames spread over a ceiling area and simulated a fire in a ceiling or burning material near a ceiling. In such fires the foam was subjected to radiated heat from above as it approached from floor level.

EXPERIMENTAL

Site

In the absence of a specially constructed building and large indoor accommodation not being available, both series of experiments were carried out in a relatively small brick and concrete structure, parts of the walls and ceiling of which formed some of the sides of the enclosures in which the fires were placed. The foam generator was situated outside the building and the foam was admitted to the enclosures through openings in one wall. Observations were made from outside the building through openings in the walls. The openings were covered with expanded metal screens of small aperture, to retain the foam. For the majority of ceiling type fires openings 0.75 m (2.5 ft) long and 0.15 m (0.5 ft) high, were made in three walls below the ceiling at fire level to ensure good ventilation and air supply to the fire. A few experiments were carried out without these openings. Fig. 1 is a diagram of the layout showing the positions and dimensions of the enclosures for both tray and ceiling type fires.

Tray fires

The dimensions of the steel tray used in these experiments were 1.4 m x 1.4 m x 0.15 m deep (4.5 ft x 4.5 ft x 0.5 ft). It was situated in the central part of the structure beneath an opening in the roof 2.2 m x 2.2 m (7 ft x 7 ft) and opposite a 0.9 m x 0.9 m (3 ft x 3 ft) opening in one wall through which the foam was applied. The enclosure around the tray was 4 m x 4.7 m x 1.5 m high (13 ft x 15.5 ft x 5 ft high), two sides of it being the wall of the building, the other two being fabricated with expanded metal screens and sheets of asbestos wood.

Ceiling fires

The conditions of a ceiling fire were simulated by burning liquid fuel in a tray 2.4 m x 0.76 m x 0.15 m (8 ft x 2.5 ft x 0.5 ft deep) situated about 0.45 m (1.5 ft) below the ceiling. Under these conditions the flames spread across the ceiling (Fig. 1) giving a relatively large area of flame.

The shape and dimensions of the enclosure was as shown in Fig. 1. A wire net screen was built at one end of the enclosure and, for the first six experiments, was at position A (Fig. 1); for all other experiments it was at position B (Fig. 1). In the latter position the screen did not reach the roof of the structure but was about 0.6 m (2 ft) higher than the ceiling below which the fire was situated (Fig. 1). This arrangement allowed gases and foam to escape from the enclosure and eliminated the possibility of any pressure build up in the fire enclosure which might possibly affect the output from the generator and the fire fighting properties of the foam.

Materials

The fuel was a commercially available petroleum product with a narrow boiling range of 62°C to 68°C.

The foaming agent was a proprietory brand. The half drainage time of a sample of foam 1.2 m (4 ft) high and 0.71 m (2 ft 4 in) in diameter was greater than 16 minutes which has been suggested as a standard[4].

The water used was that from the mains supply.

Foam Generator

The machine was a commercially available, portable type foam generator, designed to deliver 142 m^3 (5000 ft^3) of high expansion foam per minute. It consisted of a fan, mounted on the crankshaft of a single cylinder petrol engine, a plenum chamber, a band of four spray nozzles and a knitted nylon net on which the foam was formed.

Foam was produced by spraying a mixture of the foam concentrate and water onto the nylon net and then creating a constant airflow through the fabric by running the fan. The foam concentrate was drawn into the water stream through a metering orifice and was designed to give a solution containing 1.5 per cent concentrate.

It was found that by varying air speed and water flow the output of foam from the generator could be varied and the expansion remained at an acceptable value but fine adjustment of the controls was not possible.

It was important to minimise the amount of free air in the foam as this would feed the fires when it entered the enclosure. Presence of this air was indicated when the foam issuing from the generator did not appear as a "solid plug". Decreased fan speed increased the volume of foam produced since all the air was then converted into foam. This effect was most marked in cold weather.

During experiments it was required to be able to switch the flow of foam onto the fire area after the generator had started producing it. To facilitate this a hinged shutter in a housing of dimensions 0.9 m x 0.9 m x 1.2 m long (3 ft x 3 ft x 4 ft long) was constructed of wood and wood composition and fitted to the front of the generator. The shutter housing had two outlets, one at the front with full cross sectional area and one at the side with the same dimensions. The shutter was hand operated from outside the housing and foam could be delivered through either outlet as desired.

Thermocouples

These were of 28 S.W.G. chromel and alumel alloys.

Radiometers

The radiometers used in the work were of a Joint Fire Research Organization design5.

EXPERIMENTAL PROCEDURE

Tray fires

The procedure for applying the foam to tray fires was varied according to the rate at which it was required to apply the foam.

For the higher rates of application the full outlet from the machine was used in conjunction with variation in generator fan speed.

For the low rates of foam application the size of the entrance to the fire enclosure was reduced and only the required part of the foam output from the machine was admitted to the fire enclosure. The smallest aperture used was 23 cm x 60 cm (9 in x 24 in). To avoid forcing foam through these small apertures in such a way as to affect its properties, the generator was moved 1.5 m (5 ft) back from the aperture and screens 1 m (3.2 ft) high were positioned to form a funnel between the foam generator and the aperture. This provided a constant head of foam, the excess spilling over the sides of the funnel and this head provided the necessary pressure for foam to flow gently through the aperture at a constant rate.

To carry out an experiment, the procedure was firstly to select the appropriate size of opening to admit foam into the fire enclosure and then to fill the enclosure and measure the rate of filling in terms of height of foam in unit time. A foam sample of known volume was then taken and weighed from which data the expansion ratio was calculated. The foam in the enclosure was then dispersed with water spray and the enclosure cleared of foam. 45 litres (10 gallons) of fuel were then floated on water 5 cm (2 in) deep in the tray and ignited. After a preburn time of 30 sec. foam was applied to the fire, at the same rate as measured previously, until the desired height of foam above the extinguished fire was obtained. The height of foam built up above the extinguished fires was varied to ascertain if the foam would break down and permit re-ignition of the fuel without the application of an independent source of ignition.

During experiments, the output from the thermocouple 2.8 m (9 ft) above the fire was recorded automatically. The output from two radiometers connected in series 1.5 m (5 ft) from and 1.5 m (5 ft) above the fire was similarly recorded.

Ceiling Fires

For ceiling fires the rate of foam application and the volume of the enclosure were such that foam was applied direct from the generator at the required filling rate.

Thermocouples were used as indicators in this series of experiments, one situated 15 cm (6 in) below the ceiling in line with the generator and approximately in the centre of the compartment (see Fig. 1) and the other 7.5 cm (3 in) above the fuel surface in the centre of the tray. Radiation was measured by a radiometer 1.1 m (3.5 ft) below the ceiling, facing upwards and directly below the central thermocouple.

The operating procedure for this type of fire was similar to that for tray fires. Firstly, the rate of foam application to the enclosure was measured and a sample taken for expansion measurement. The remainder was then discarded. 112.5 litres (25 gals) of fuel were floated on 5 cm (2 in) of water in the tray and then ignited. The fire was allowed to burn for 3 min before foam was admitted to the enclosure. Application of foam was continued until the fire was extinguished, or until all the fuel had been burnt. After extinction the enclosure was cooled, the foam dispersed, using a water spray, and remaining fuel drained off.

Plate 1 shows a ceiling fire and Plate 2 shows foam approaching a ceiling fire.

RESULTS

Tray fires

For this type of fire, Fig. 2 shows the relationship between the rate of application of the foam, in terms of height of foam per unit time, and the time to obtain nine-tenths control of the fires as shown by the radiometer output recordings. The highest rate of foam application with which extinction of the fire was not achieved was 0.15 m/min (0.5 ft/min).

Table 1 lists three measurements for each fire which show the way in which control of the fires depended on the rate of foam application.

TABLE 1

Data from experiments with tray fires

Rate of Foam Input metres (height)/ min.	Mean Radiation before foam application watts/cm^2	Expansion	Time to cover fire s (observation)	Time for extinction s (observation)	Time for 9/10 control (radiometers) s
3.1	1.0	1100	4	8	5
3.1	1.1	1140	4	27	7
2.15	1.2	1100	5	20	6
2.15	0.9	1100	5	13	7
0.31	0.6	900	60	105	42
0.31	1.0	950	45	60	40
0.2	2.1	950	20	55	25
0.15	1.7	950	90	Not attained	87
0.08	1.0	950	Not attained	Not attained	Not attained

In this series of experiments the foam was allowed to build up to various heights between 0.3 m (1 ft) and 1.5 m (5 ft) after extinction had been achieved. In no case did the foam break down sufficiently quickly to permit re-ignition of the fuel without application of an independent source of ignition.

Ceiling fires

Wind strength and direction affected the intensity of these fires and the provision of vents in the brick walls at fire level enhanced this considerably. Before the vents were made, and afterwards when there was very little wind, the intensity of the fires was relatively low. After the vents were provided, and if there was a strong wind, the fires were intense with flames penetrating the leeward vents and the top portion of the screen which formed one side of the enclosure at position B, Fig. 1.

The results of this series of experiments and data calculated from them are given in Table 2.

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CORRIGENDA

The following amendments should be made to Table 2, page 7:

The values in column 2, lines 2, 3, 4 and 8 should read -

24, 36, 65 and 55 respectively.

The values in columns 5, 6, 7 and 9, line 8, should read -

760, 118, 221 and 1.1 respectively.

The values in columns 6 and 7, line 11, are for time period 163 seconds.

TABLE 2

Data from experiments with ceiling fires

1	2	3	4	5	6	7	8	9	10
Rate of foam application m(ht)/min	Time for foam to rise 1.5 m (X) s	Time for foam to reach fire s	Time to extinction (Y) s	Total radiation over time period (Y) J/cm^2	Total radiation prior to foam application for time period (X) J/cm^2	Total radiation during foam application for time period (X) J/cm^2	Rate of foam breakdown during period (Y) m(ht)/min	Expected foam breakdown rate due to radiation m(ht)/min	Measured Expansion
4.6	35	51	95	124	30.9	30.9	3.0	0.35	1130
4.6	50	70	100	98.2	54.8	37.6	3.0	0.26	1130
3.1	24	70	100	274	43.1	46.4	1.5	0.75	1030
2.15	36	220	285	412	39.7	44.3	1.6	0.37	960
1.8	65	not attained	not attained	*485	121	173	*1.3	0.52	920
1.2	173	606	630	824	191	166	1.2	0.34	1100
4.6	39	92	110	610	202	176	3.2	1.3	960
3.1	36	100	140	836	97	264	2.0	1.5	960
2.5	60	95	130	481	142	167	1.3	0.71	820
2.3	64	160	180	853	122	226	1.4	1.1	960
2.0	195	not attained	not attained	*1451	539	594	*1.8	0.53	820
1.8	52	120	165	280	64.4	70.6	0.9	0.38	960
1.5	72	145	200	456	99.9	120	0.7	0.51	960
1.5	60	236	355	627	58.9	71.2	1.1	0.40	960

* Based on the total time the foam was applied.

The highest rate of foam application with which extinction of the fire was not achieved was 2.0 m(ht)/min (6.5 ft(ht)/min).

The values for radiated heat from the fires were obtained by the application of the method of radiant interchange configuration factors[6] to measured experimental values for radiation at the centre of the enclosure and using the observed and automatically recorded times for the foam to rise over known distances in the enclosure.

The expected foam breakdown rate due to radiation (column 9, Table 2) was calculated on the basis of the radiation converting the water into steam. The breakdown rates were obtained by substituting the appropriate values in the following expression:-

$$\frac{0.6\ R_T E}{\Delta H\ t} \quad \text{metres (ht)/min}$$

where R_T = Total radiation to which the foam was exposed J/cm^2

E = Expansion

ΔH = Heat change in the system to vaporise the water J/cm^2 [7]

t = Time during which the foam was exposed to the heat - seconds.

The time taken for the foam to reach the fire was as indicated by the output of the thermocouple above the surface of the fuel and the time taken for the foam to reach a height of 1.5 m (5 ft) in the enclosure was that indicated by the output from the radiometer - both outputs having been automatically recorded.

The values for foam application rates and extinction times given in Table 2 are plotted in Fig. 3. For this purpose the results have been divided into two sections according to whether the radiation was less than, or greater than 2.5 watts/cm^2. Fig. 3 indicates that the critical rate of foam application was 1.2 and 2.0 m(ht)/min (4 and 6.5 ft(ht)/min) for low and high radiation intensity fires respectively.

Fig. 4 is the plot of columns 6 and 7 of Table 2 and shows the relationship between radiation before and after the application of foam for the time periods specified in the Table.

Fig. 5 is the plot of foam input rate and foam breakdown rate (columns 1 and 8, Table 2).

DISCUSSION

Because of the nature of the site and experimental conditions as described above, the fires were subjected to varying weather conditions and were influenced particularly by the direction and strength of the wind. These conditions affected the burning rate of the fuel and consequently accounted for the variation in radiation intensity from the fires and would therefore contribute to the degree of scatter in the graphs.

Low air temperatures affected foam production. This was particularly noticeable when the temperature fell below freezing and it was found necessary to lower the fan speed and thus the volume of foam produced, in order to maintain the required expansion. The water supply temperature was approximately 6°C and the foam concentrate was at 9–12°C due to being stored inside a heated building. Under freezing conditions waste foam outside the fire enclosure froze within minutes but the foam inside the enclosure was not affected in this way.

The results show that high expansion foam was more efficient as an extinguishing agent when applied to liquid fires at floor level (e.g. tray or spillage fires) where the flames are unimpeded and rise vertically, than when it was applied to fires in which it was subjected to much more radiated heat (from a ceiling fire).

Consequently, the critical foam application rate required to extinguish tray fires was less than that required to extinguish fires of similar intensity near a ceiling.

In both cases it was evident that once the foam was able to enter the trays it flowed across the surface of the fuel relatively quickly to effect extinction, chiefly by blanketing action.

In the experiments with ceiling fires the enclosure was filled with foam and then the foam supply was stopped. The heat from the ceiling continued to break down the foam which indicated that it would be necessary to apply foam and keep it in contact with a ceiling, after flaming ceased, to effect complete extinction.

Although the foam broke down at a fast rate as it rose towards ceiling fires (Fig. 5), in general there was no evidence that steam produced had any marked effect on the burning rate of the fuel. However, with some fires of relatively low intensity it was observed that when the foam rose to within a short distance of the fires, the latter became visibly subdued, which may have been an indication that they were being affected by the generation of steam from the foam.

The relative values of columns 8 and 9 in Table 2 suggests that on average only about one-third of the foam broken down vaporised - this would not be sufficient to produce a flame-extinguishing atmosphere above the foam.

In Fig. 4, radiation values prior to the application of foam are plotted against radiation values when filling the enclosure with foam to a height of 1.5 m (5 ft). The dotted line in Fig. 4 represents constant radiation values before and after application of the foam. Most of the points are in the vicinity of the line but in three cases only were values lower after the foam had been admitted to the enclosure. The increase in radiated heat obtained in some of the experiments after the application of foam may possibly have been due to the fire being fed with air liberated from the broken-down foam.

From the work described above it would appear that in both types of fire extinction was attained chiefly by the blanketing effect when the foam covered the surface of the liquid fuel. Further work is necessary to obtain information regarding the ability of high expansion foam to extinguish fires in solid materials and liquid fuel burning on hot metal surfaces.

CONCLUSIONS

1. In the experiments with liquid fuel fires (spillage type) at ground level the lowest rate of application of high expansion foam which extinguished the fires was 0.15 m (ht)/min (0.5 ft (ht)/min).
2. In experiments with fires in which the flames spread across a ceiling, the critical rates of foam application were 1.2 and 2.0 m(ht)/min (4.0 and 6.5 ft(ht)/min) for low and high radiation intensity fires respectively.
3. There was no rapid breakdown of the foam and re-ignition of the fuel when the foam was built up to a height of 0.31 m (1 ft) or more above the surface of the fuel after extinction of the tray fires on the ground.
4. The fires used in the experiments were easy to carry out and reasonably reproducible. They could be used as standard of their types for assessing the relative efficiencies of high expansion foaming agents but it would be desirable if the experiments were carried out away from the influence of wind.

ACKNOWLEDGMENTS

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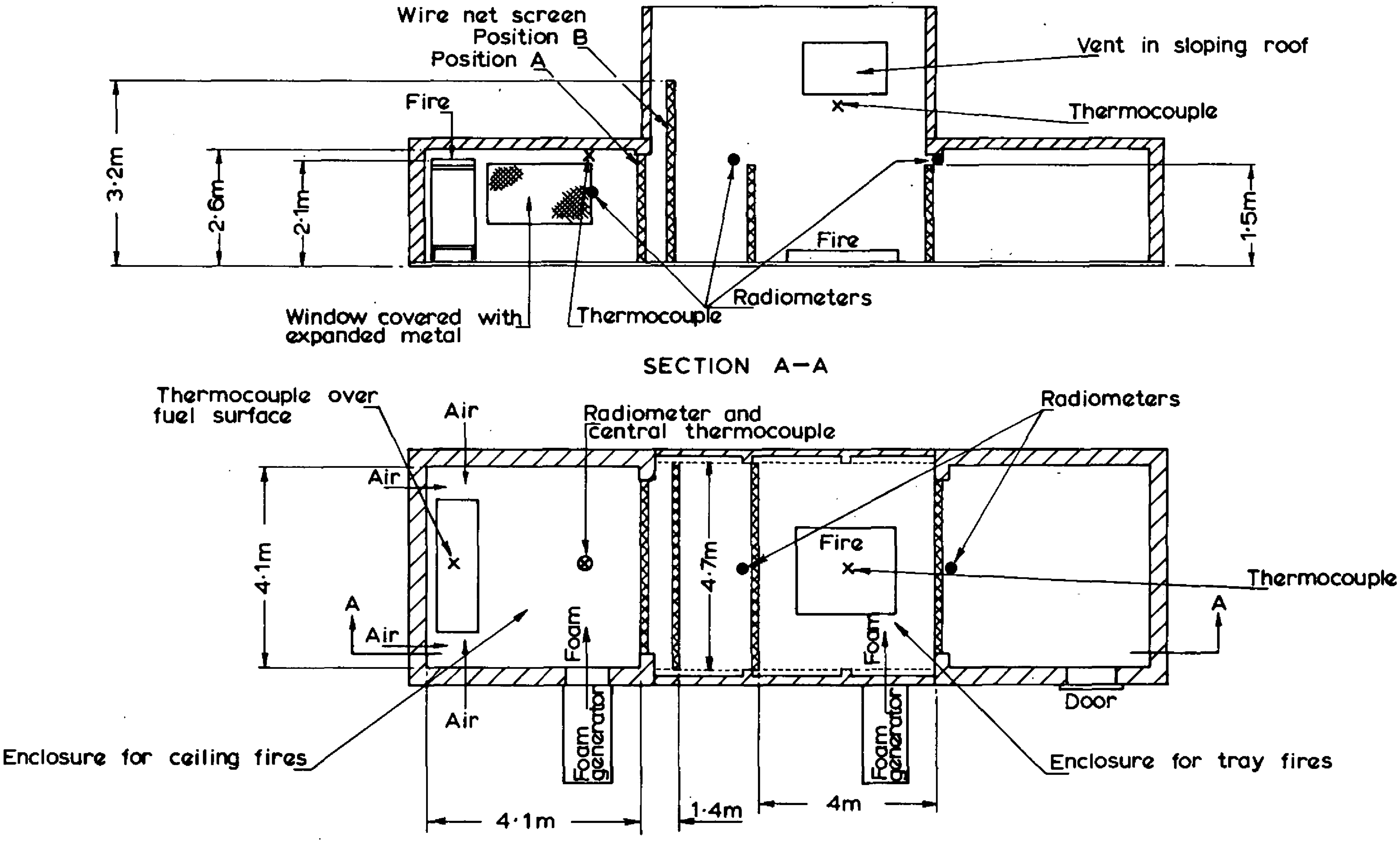
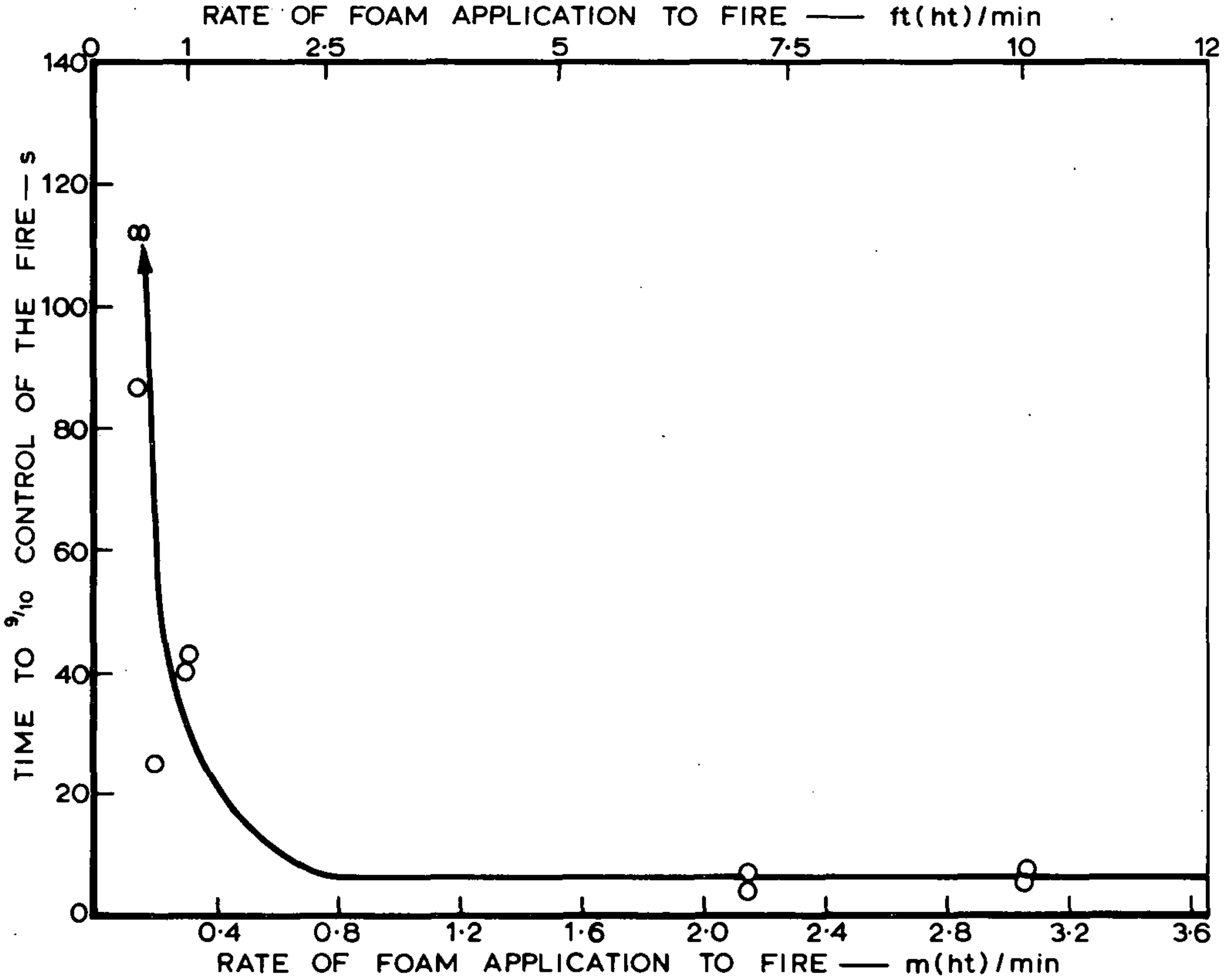


FIG. 1. EXPERIMENTAL LAYOUT FOR TRAY AND CEILING FIRES



Tray fires

FIG. 2. THE EFFECT OF FOAM APPLICATION RATE ON FIRE CONTROL TIME

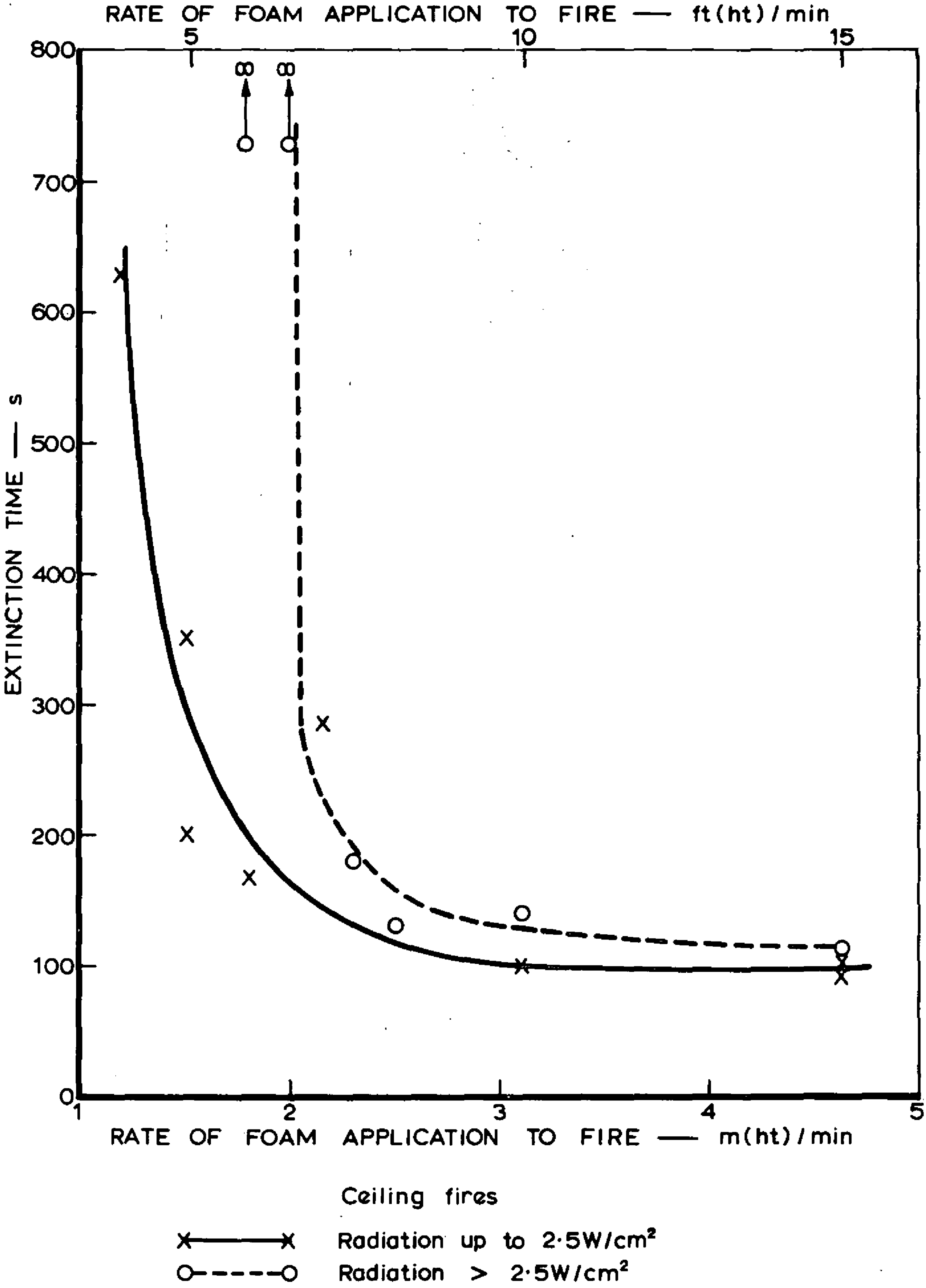


FIG. 3. EFFECT OF FOAM APPLICATION RATE ON EXTINCTION TIME

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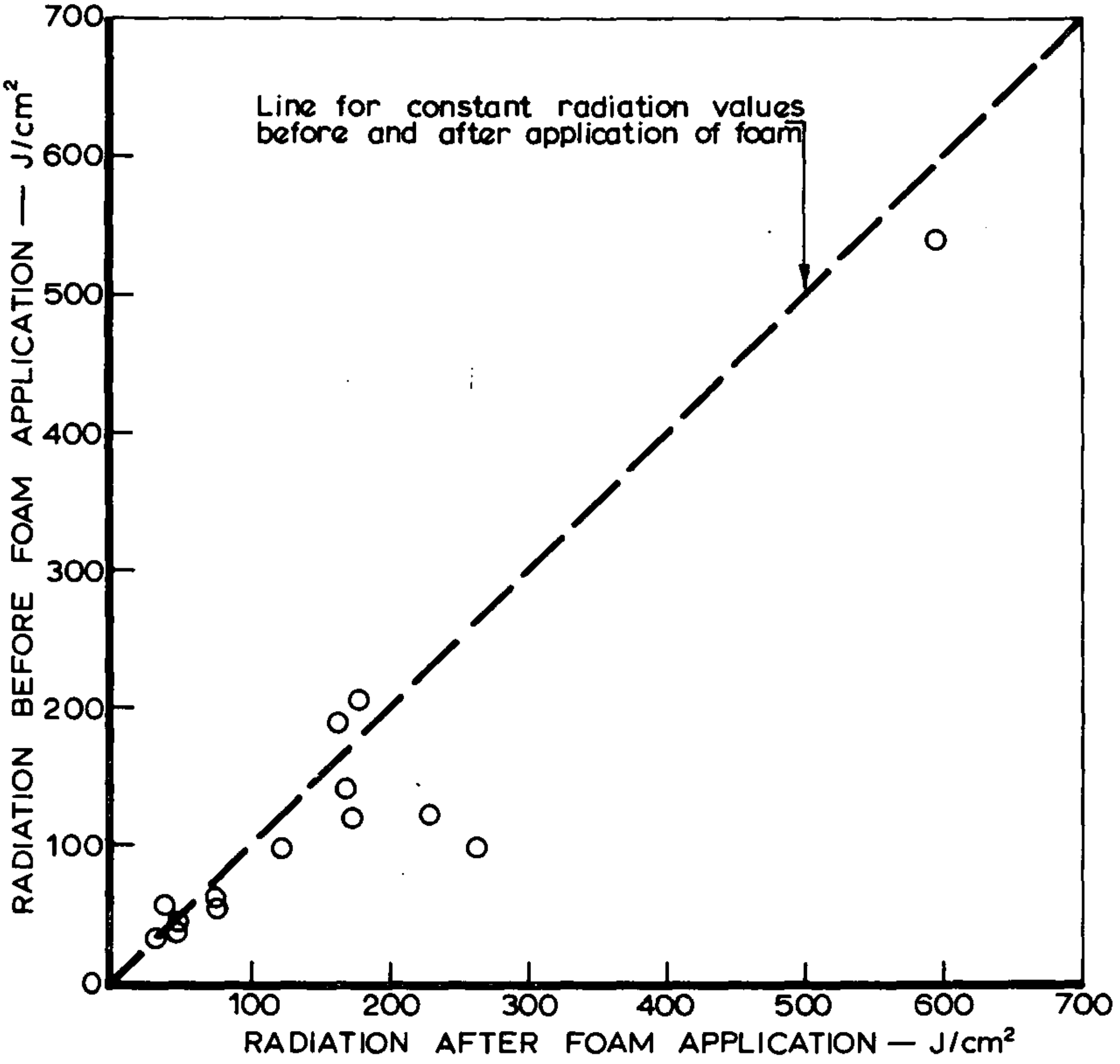

Ceiling fires

FIG. 4. RADIATION FROM FIRES BEFORE AND AFTER APPLICATION OF FOAM

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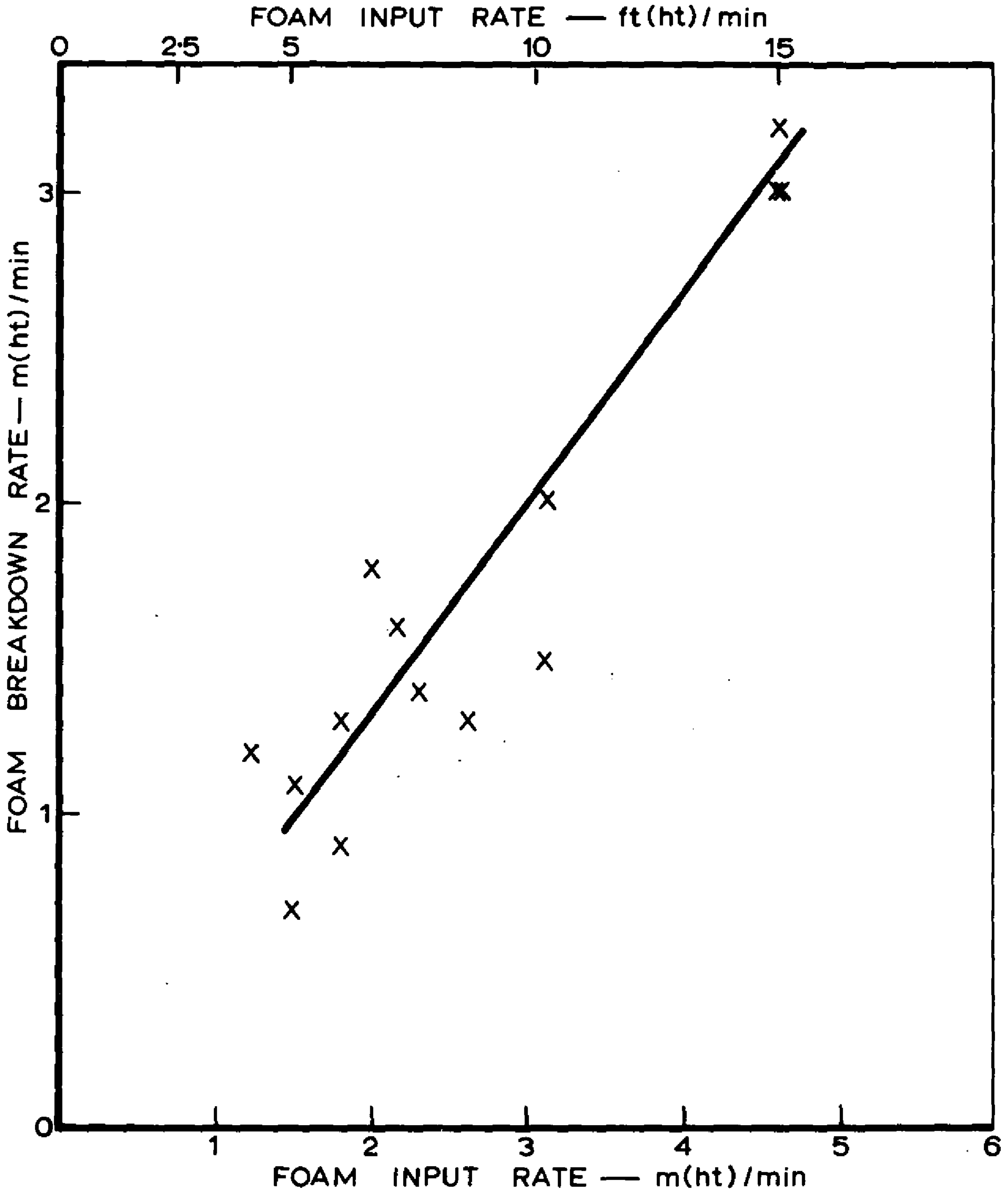

Ceiling fires

FIG. 5. VARIATION OF FOAM BREAKDOWN RATE WITH FOAM INPUT RATE

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PLATE 1. A CEILING FIRE

PLATE 2. FOAM APPROACHING A CEILING FIRE