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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

A COMPARISON OF THE CONVENTIONAL AND THE "WIDE-COVER" TYPE OF SPRINKLER

by

P. H. Thomas and P. Nash

SUMMARY

This report describes tests comparing the performance of the "wide-cover" type of sprinkler developed by the Factory-Mutual Laboratories of the United States of America, and sprinklers of conventional design. The tests included measurements of water distribution, and of ability to control a spreading fire beneath both plain and joisted ceilings.

While reports of tests on fires in high stacks of materials have shown a superiority of the "wide-cover" type of sprinkler in extinguishing the fire, the tests reported here showed them to be scarcely the equal of conventional-type sprinklers in dealing with a fire at ground level when operating at the minimum acceptable water pressure. The "wide-cover" type, used singly, was not so effective in controlling a fire directly beneath it, and in one case it is doubtful whether the sprinkler could be deemed to give adequate cover in this respect.

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1. Introduction

An automatic sprinkler combines the roles of a fire alarm and a water nozzle. While there are many makes of conventional sprinkler, they are all designed to discharge a spray of water over an area of about 100 sq.ft. at a flow of order 40 gal/min. when operating at a pressure of 50 lb/sq.in. In 1953 the Factory-Mutual Laboratories in the United States of America announced (1) the development of a new type of sprinkler, differing from the conventional sprinkler in the design of its deflector. Two versions of this type were introduced, one for upright and the other for pendent use. In passing it is worth pointing out that the description of this sprinkler as a "spray sprinkler" is misleading in that all types of sprinkler discharge water in the form of spray. There is no fundamental departure from any accepted principle, the difference from conventional sprinklers being a matter of degree only, and this new type will be subsequently referred to in this report as the "wide-cover" sprinkler.

The effect of the different deflector is to increase the area over which water is discharged. This has two consequences. Firstly, the delivery per unit floor area from a single sprinkler is reduced, though if more than one sprinkler opens the average delivery per unit area under an array of open sprinklers is unaffected, for the water discharged further by one sprinkler augments the smaller amount discharged under a neighbouring sprinkler. Secondly, at points between sprinklers, the water is discharged higher, as shown in Figure (1).

Clearly if burning material were present in the region between the sprinklers and were piled to within a few feet of the ceiling, the wide-cover sprinkler would be bound to show a superiority in controlling the fire, since in the shaded regions of Figure (1) the conventional sprinkler discharges no water at all. This was clearly demonstrated by the tests of the Factory-Mutual Laboratories (2), in which a burning crib was within 3 ft. of the ceiling at least 5 ft. horizontally from the sprinkler. A concluding note to the report by N. J. Thompson, Director of the Factory-Mutual Laboratories states that "Spray sprinklers show to particular advantage over regular * sprinklers when good distribution at the higher levels is needed. The difference in performance when the fire is at floor level, is directly under the regular sprinklers, or is more shielded will not be as great as the difference shown under the test conditions".

It was because of these factors that, when the Joint Fire Research Organization received a request from the Fire Offices' Committee to compare the merits of the two types of sprinkler, the test fire was chosen to be at floor level. In an actual fire, there are usually obstacles which prevent the sprinklers from wetting completely the area within their range, thereby permitting the fire to spread. There are often vertical surfaces which promote the growth of flames sufficiently high to affect the ceiling, and which permit the persistence of flaming in their shadow. The design of the test fire was intended to give a reproducible fire, while taking these factors into account (Section 2.4.). Information was sought by the Fire Offices' Committee on the effect of the spacing of the sprinklers, difference between using sprinklers in the upright and pendent position and the difference in sprinkler behaviour beneath flat and open-joisted ceilings. The pressure of the water supply was chosen as being about the lowest permitted by the Fire Offices' Committee rules. Moreover, the sprinklers would be giving a poor distribution as they are normally designed to work at a much higher pressure.

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* i.e. conventional sprinklers.

2. Description of test arrangements

2.1. Ceiling

A 20 ft. square joisted ceiling was supported on brick pillars at a height of 10 ft. at one end of the Joint Fire Research Organization test building. The underside of the ceiling was close-boarded in the first series of tests. The boards were removed during the second series for tests, leaving the joists open.

2.2. Water supply

The water was supplied from a static tank at a height sufficient to give a running pressure of $6\frac{1}{2}$ lb/sq.in. at the sprinklers. The water level in the tank was kept constant throughout each test.

2.3. Sprinklers and their arrangement

The sprinklers are described in Table 1.

TABLE 1

Types of sprinklers tested

Sprinkler reference	Type	Temperature rating	Bore	Operation
A (Star)	Wide-cover approved by F-M for upright use.	165°F	$\frac{1}{2}$ in.	Fusible-link cantilever.
B (Globe)	Ditto - for pendent use.	165°F	7/16 in.	Only used open in these tests.
C (Atlas)	Conventional - approved by Fire Offices' Committee for upright and pendent use.	155°F	$\frac{1}{2}$ in.	Fusible-link cantilever.

The deflectors of the sprinklers were $4\frac{1}{2}$ in. below the ceiling (or the soffit of the open joists) when used upright, and 7 in. when used pendent. The fusible links were thus at the same height within $\frac{1}{4}$ in. for both positions.

The arrangement of the sprinklers is shown in Figure 2.

2.4. Construction of test fire

A photograph of the combustible material is shown in Figure 3. The egg-box structure was a $\frac{3}{8}$ in. thick fibreboard lattice enclosing 25 (5 x 5) squares each of side approximately 3 ft. 3 in. and the whole lattice extended over a square of 19 ft. 8 in. sides i.e. over the whole floor area beneath the ceiling: each small box contained $6\frac{1}{2}$ lb of straw. A second series of tests was conducted with one sprinkler mounted centrally over a smaller lattice, 10 ft. square, of nine (3 x 3) boxes each containing 10 lb of straw. The fibreboard lattice was supported at a height of 3 in. above floor level to increase the ventilation of the fire.

2.5. Instrumentation

A continuous record of the temperature at various points 2 in. below the ceiling was obtained by means of 40 S.W.G. thermocouples, shown at positions "T" in Figure 2. Other thermocouples, not shown in the figure, were mounted adjacent to the sprinkler positions or were peened into the sprinkler links. The radiation from the fires was also measured by four radiometers, adjacent to the corners of the square.

3. Test procedure

3.1. Fire tests

TABLE 2

Programme of tests

Test No.	No. of sprinklers	Ceiling	Upright or pendent	Type of sprinkler	Spacing ft.
1 (Trial)	4	Flat	Pendent	C	10
2	4	"	"	C	10
3	4	"	"	C	15
4	4	"	"	A	15
5	4	"	"	A	10
6	4	"	Upright	A	10
7	4	"	"	C	10
8	4	"	"	A	15
9	4	"	"	C	15
10 (Trial)	1	Flat	Upright	A	-
11	1	"	"	A	-
12	1	"	"	C	-
13	1	"	Pendent	C	-
14	1	"	"	B	-
15	1	Open joist	"	C	-
16	1	" "	"	B	-
17	1	" "	Upright	C	-
18	1	" "	"	A	-
19	4	" "	"	C	10

In tests 2-9 and test 19 the straw in the centre box was ignited and the fire was allowed to spread and to cause the sprinklers to open. In tests 11-18 the straw in all nine boxes was ignited within 5 seconds, the fire was allowed to develop for a further 50 seconds, and the water supply was then turned on. The increase in fuel in each box (Section 3.1.) in these second tests was thought desirable from experience gained in the first series, particularly as the boxes were to be lighted simultaneously.

3.2. Water distribution tests

The distribution of water from each sprinkler was measured in the conditions in which it was used in these tests.

4. Test results and discussion

4.1. Fire tests

The photographic and temperature records were found to give similar but more detailed information than the radiation records, and the results are therefore illustrated by the former, rather than the latter, except where corroborative information is required. The average reading of the five central thermocouples (see Figure 2) was taken as giving a good indication of the severity of the fire and the likelihood of the ceiling being damaged, and is used to illustrate these points. Figure 6 shows the development and control of one of the spreading fires (Test 3) and the opening times of the sprinklers with this type of fire are shown in Table 3.

TABLE 3

Results of tests with fire ignited centrally between 4 sprinklers

Test No.	Sprinkler	Spacing (ft)	Position	Times of sprinklers opening (sec)	No. of sprinkler opening	Time to reduce temperature 2 in. below central portion of ceiling to 100°C - (sec)
2	C	10	Pendent	100	4 together	< 10
3	C	15	"	110	"	100
4	A	15	"	100	"	42
5	A	10	"	60	1 only	<10
6	A	10	Upright	170	4 together	<10
7	C	10	"	230	2 "	<10
8	A	15	"	2 @ 210, 1 @ 325	2 " and one later	25* and 140*
9	C	15	"	160, 175, 265 and 272	4 at intervals	20* and 285*
19	C	10	Pendent	140	2	<10 secs

*These fires were not controlled by the first sprinklers opening.

10 foot spacing

In comparing ceiling temperatures (Figure 4) in tests 2, 7, with conventional sprinklers and in tests 5, 6 with wide-cover sprinklers, it may be seen that at 10 foot spacing these two types were equally effective in reducing the ceiling temperatures to 100°C or less in 10 seconds. The sprinklers opened shortly after the fire had spread from the central box to the four flanking boxes and control was achieved easily with both types of sprinkler whether upright or pendent. Even in test 5 where, by chance, only one wide-cover sprinkler opened, the fire was prevented from spreading outside the range of the sprinkler and was eventually extinguished by it almost as easily as with two or more sprinklers operating. In test 19, the only test with a spreading fire beneath a joisted ceiling, the rate of control of the fire was not significantly different from that in the other tests.

15 foot spacing

In comparing ceiling temperatures (Figure 4) in tests 3, 9 for conventional sprinklers and in tests 4, 8 for wide-cover sprinklers, it may be seen that at this spacing, the wide-cover type sprinkler restricted the spread more readily than the conventional sprinkler although ceiling temperatures remained high (Figure 4). In test 3 with the conventional sprinklers pendent, the fire continued to grow despite the fact that all four sprinklers opened (Figures 4 and 5) and it is possible that, left to itself, the fire might have spread between the sprinklers. In test 4, with the wide-cover sprinklers pendent, control was achieved more quickly than in test 3. Tests 8 and 9 were not comparable with the other tests, as by chance, the fire spread to one side, opening the two sprinklers on this side first. It was noted that the fire grew more rapidly at this stage with conventional than with wide-cover sprinklers. Finally, when sprinklers on the other side of the square opened, the fire was reduced more rapidly by the three wide-cover sprinklers which opened, than by the four conventional sprinklers.

Single sprinkler central over fire

From the temperature records of tests 11-18 (Figure 7) it is apparent that in only one test of four (test 18) did the wide-cover sprinklers approach the speed of control of the fire exhibited by the conventional sprinklers. While the latter reduced ceiling temperatures to 100°C in 15-20 seconds, the wide-cover sprinklers (except test 18) required 110-135 seconds to do so. This difference was seen to lie in the capacity of the sprinklers to control the centre of the fire, as can best be seen from a comparison of temperatures 60 seconds after application of water. A further comparison may be drawn between pendent and upright wide-cover sprinklers. The pendent sprinkler B (tests 14 and 16) was much less effective than the upright sprinkler A (test 18), although sprinkler A was not so effective in test 11 as it allowed the fire to grow again temporarily after a fairly rapid initial reduction. Although the fire developed more rapidly under the open-joisted ceiling (tests 15-18), there was no significant difference in rate of control of the fire due to the type of ceiling.

4.2. Water distribution tests

The mean radial water distributions of the sprinklers are shown in Figures 8-10. In considering the significance of "hollows" and gaps in the water distribution, it was noticed in the course of the tests that if at any place flames did not reach the ceiling and were surrounded by a curtain of water, they did not, in general, endanger the ceiling. With the ventilated straw fire used, flames from a 3 ft. 3 in. box were nearly 10 feet in height (Figure 6-ii); as these were proportionately higher than with other types of fire it was therefore considered that no "hollow" or gap should exceed 3 feet diameter.

Water necessary to control fire

In Table 4, the mean flow of water per unit area to a 4 foot diameter circle is shown in Column 2, being approximately the rate of application per unit area to the centre box of the lattice, the flame from which will affect the five central thermocouples most. This flow (Column 2) is seen

TABLE 4

Water delivered to fire

Test No.	Flow to centre box x 100	Temperature 1 min. after water applied	Mean flow over whole fire area x 100	Water to reduce radiation to 1/5th x 100
11	gal/sq.ft./min. 4.85	°C 150	gal/sq.ft./min. 3.9	gal/sq.ft. 1.5
12	10.4	< 10	7.35	1.1
13	8.2	< 10	5.2	1.0

TABLE 4 (Contd.)

Test No.	Flow to centre box x 100	Temperature °C 1 min. after water applied	Mean flow over whole fire area x 100	Water to reduce radiation to 1/5th x 100
	gal/sq.ft./min.		gal/sq.ft./min.	gal/sq.ft.
14	1.33	250	4.65	0.9
15	8.2	20	5.2	0.8
16	1.33	250	4.65	1.5
17	10.4	< 30	7.35	1.8
18	4.85	35	3.9	0.8

to relate closely with the temperature just below the ceiling after application of water for 1 minute (Column 3). While an average delivery of 0·08-0·10 gal/sq.ft./min. could rapidly reduce the temperatures just below the ceiling (tests 12, 13, 15, 17), a delivery of 0·013 was insufficient to reduce the temperature below 250°C in 1 minute (tests 14 and 16). An average delivery of 0·05 gal/sq.ft./min. appeared to be the minimum sufficient to reduce the temperature of the ceiling in 1 minute to the known safe value of 100°C (tests 11 and 18). By comparison, a sprinkler operating at 50 lb/sq.in. delivers water on average at more than three times this rate. It is of interest to note that the delivery to Boxes X-X, test 3, (Figure 6), was about 0·09 gal/sq.ft./min., approximately twice the average delivery necessary to control the fire, yet this did not extinguish the fire, due to the shelter afforded by the vertical sides. In addition to the criterion of ceiling temperature, the radiation from the fire may be considered as a general measure of the magnitude of the fire. The total amount of water used in reducing the radiation to 1/5 its initial value may be calculated, and is shown in Column 5. This is seen to be between 0·8 and 1·8 x 10^{-2} gal/sq.ft., corresponding to an average depth of water on the floor of 1/50th inch.

The effect of pressure and spacing on water distribution

In Figures 8-10, the mean delivery at each radius is plotted, both for a pressure of $6\frac{1}{2}$ lb/sq.in., and for an effective pressure of 17 lb/sq.in.* The distributions at the two pressures are similar in form, except that a peak appears with Sprinkler C (pendent) with a pressure of 17 lb/sq.in. The peaks in the distribution of Sprinkler A (pendent) and Sprinkler C (upright) were found to move further from the sprinkler with increasing pressure, the effect being greater for Sprinkler A. Where peaks are present, at distances of markedly less than 5 feet from the sprinkler they will not be affected when a sprinkler lattice of 10 feet spacing is considered. If on the other hand the peaks occur in the range 5 feet-7 feet the peaks will be reinforced by the co-operating sprinklers.

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*The flow from a pressure of 17 lb/sq.in. on a $\frac{1}{2}$ in. diameter orifice is equal to that from a $\frac{1}{2}$ in. diameter open pipe with a pressure 50 lb/sq.in., 10 feet along the pipe.

The likely delivery of water to any point on the floor under a square array of sprinklers at $6\frac{1}{2}$ lb/sq.in. pressure may be computed from Figures 8-10, for spacings from 10-15 feet. This is best considered in terms of the distribution along the diagonal of the square with sprinklers at the corners. Figures 11-13 show the effect of increasing the spacing from 10 to 15 feet on the distribution of sprinklers A, B and C respectively. Figures 14-17 compare the distributions of sprinklers A, B and C at the five spacings 10, 11, 12, 13 and 15 feet. From these curves it may be seen that the distribution from sprinkler A at spacings up to 11 feet, is everywhere above the 0·05 gal/sq.ft./min. known to be sufficient to control a fire of this type. On the other hand it falls below this value close to the sprinkler at 12 foot spacing. There is inadequate cover beneath Sprinkler B at all the spacings tested. Sprinkler C gives adequate cover at all positions up to 12 feet spacing, but the central cover is marginal at 13 feet, being approximately half that at 10 feet. The cover afforded by the three sprinklers is compared in Figures 14-18 for the five spacings.

4.3. Opening time of sprinklers

In Column 5, Table 3, the opening times of sprinklers in tests 2-9 and 19 are shown. Although the links of all the sprinklers for both pendent and upright positions were the same distance below the flat ceiling, the opening times for the upright position were approximately twice as long as those for the pendent position at similar spacings. By comparison, in a single test (19) the opening time of the pendent sprinkler beneath the open-joisted ceiling was about 50 per cent longer than under a flat ceiling. There was no significant difference between the opening times of conventional and wide-cover type sprinklers under the same conditions of mounting and spacing.

The difference in the opening times of sprinklers mounted upright and pendent cannot be explained completely by the shielding effect of the water pipes, since the heating of the fusible link is by convection from the gas stream moving horizontally as well as by direct radiation from the fire. A possible explanation is that with the upright sprinkler, the hot gases are moving horizontally between two cooling surfaces, the ceiling and the pipes, whereas pendent sprinklers are outside the two cooling surfaces which have a lesser total effect in reducing the gas temperature. If this were true the extent of the delay would depend upon whether the path of the gases coincided with the direction of the pipeline. This was not able to be checked in the present series of experiments as only one arrangement of pipes was used (Figure 2).

The effect of an increase of spacing on the opening time of the sprinklers is shown in Table 3 to be small, and this is explained by the rapidly-spreading nature of the fire at the time the sprinklers were opening (Figure 19).

5. Conclusions

(1) For a fire of the type discussed in this report, a density of water distribution of 3 gal/sq.ft./hour. (0·05 gal/sq.ft./min.) would be adequate to reduce the ceiling temperatures to 100°C in 1 minute, and this is considered safe.

(2) The conventional type sprinkler gives a better performance than the "wide-cover" type sprinklers at floor-level, although the same may not have been found to be true for high-stacked fire loads, as shown by Factory-Mutual Laboratories. The following conclusions regarding the performance, at different spacings, of the three sprinklers tested, refer to a water pressure of $6\frac{1}{2}$ lb/sq.in. at the sprinkler. Bearing in mind that the sprinklers are designed to operate at 50 lb/sq.in., their performance should normally be better than that described.

(3) The "wide-cover" Sprinkler A would provide the necessary density of 3 gal/sq.ft./hour for spacings up to 12 feet.

(4) The "wide-cover" Sprinkler B would not provide this cover at any of the spacings tested, including 10 feet.

(5) The conventional Sprinkler C would provide this cover for spacings up to 13 feet.

(6) The type of ceiling did not significantly affect the ability of a sprinkler to extinguish the fire in these tests, despite the more rapid growth of fire beneath the open-joisted ceiling.

(7) Upright sprinklers, of both conventional and "wide-cover" types, took approximately twice as long as pendent sprinklers to open, in these tests.

(8) The time to open of a pendent sprinkler was approximately 50 per cent greater under an open-joisted ceiling than under a flat ceiling.

(9) There was no significant difference in the opening times of conventional and "wide-cover" sprinklers under similar conditions.

(10) The time for a sprinkler to open was not, in general, significantly increased by an increase in sprinkler spacing, probably because of the rapidly-spreading nature of the fire used in these experiments.

6. Acknowledgments

The authors would like to acknowledge the assistance of D. I. Lawson regarding suggestions for the form of test fire used. The experimental work was performed by Mr. Gordon, Mr. French and Mr. Hinkley.

7. References

(1) Factory-Mutual Record, May, 1953.

(2) N. J. Thompson. National Fire Protection Association Quarterly, January, 1954. "Proving spray sprinkler efficiency".

(3) P. C. Bowes. "Ignition of wood by steam pipes". To be published.

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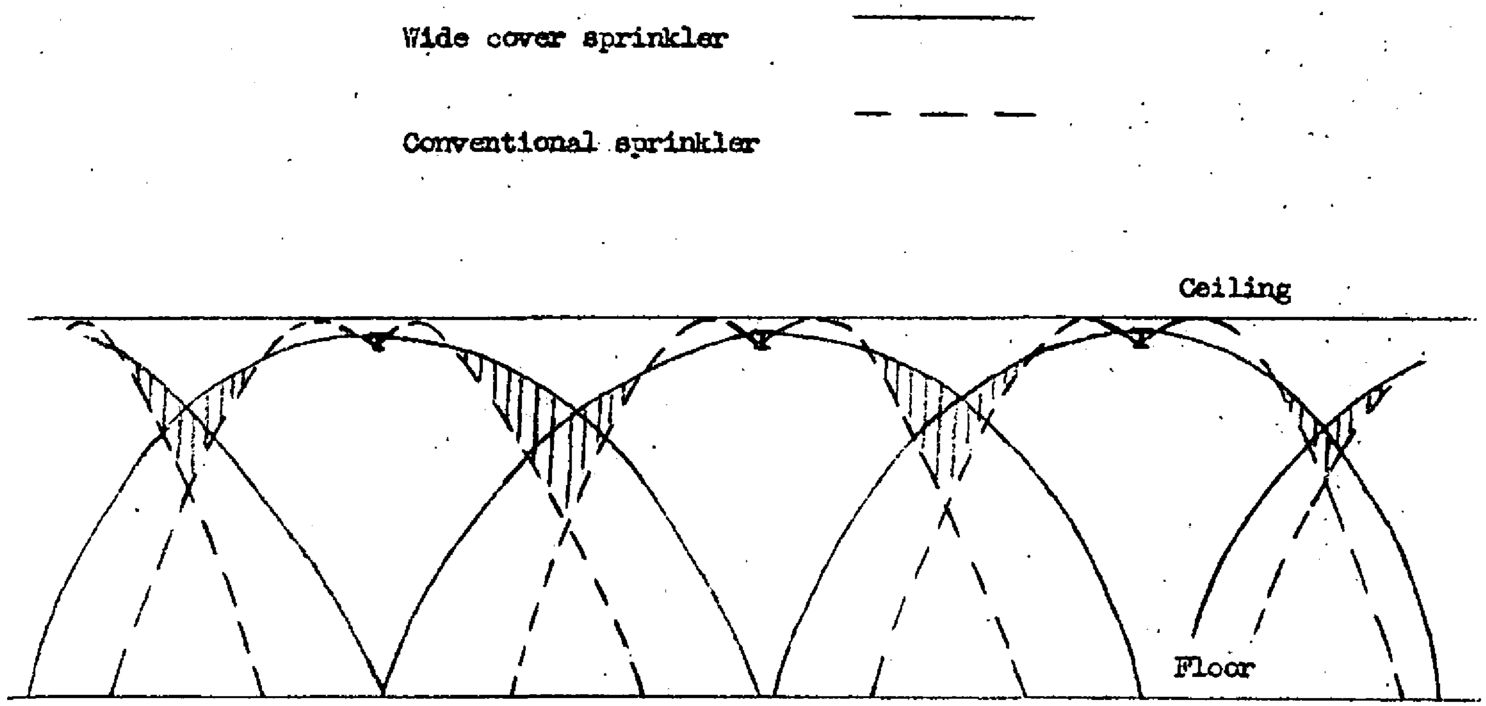
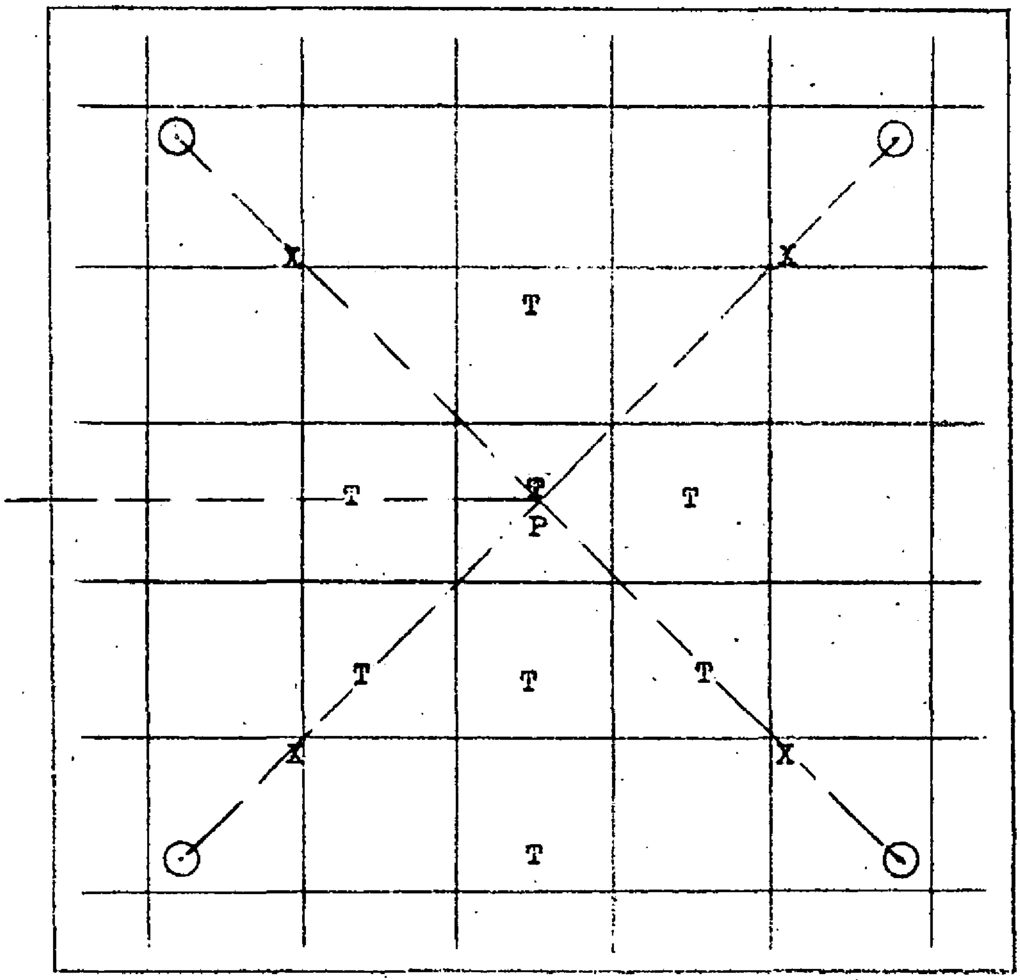


FIG. 1 - REPRESENTATION OF SPRINKLER DISCHARGE IN VERTICAL PLANE



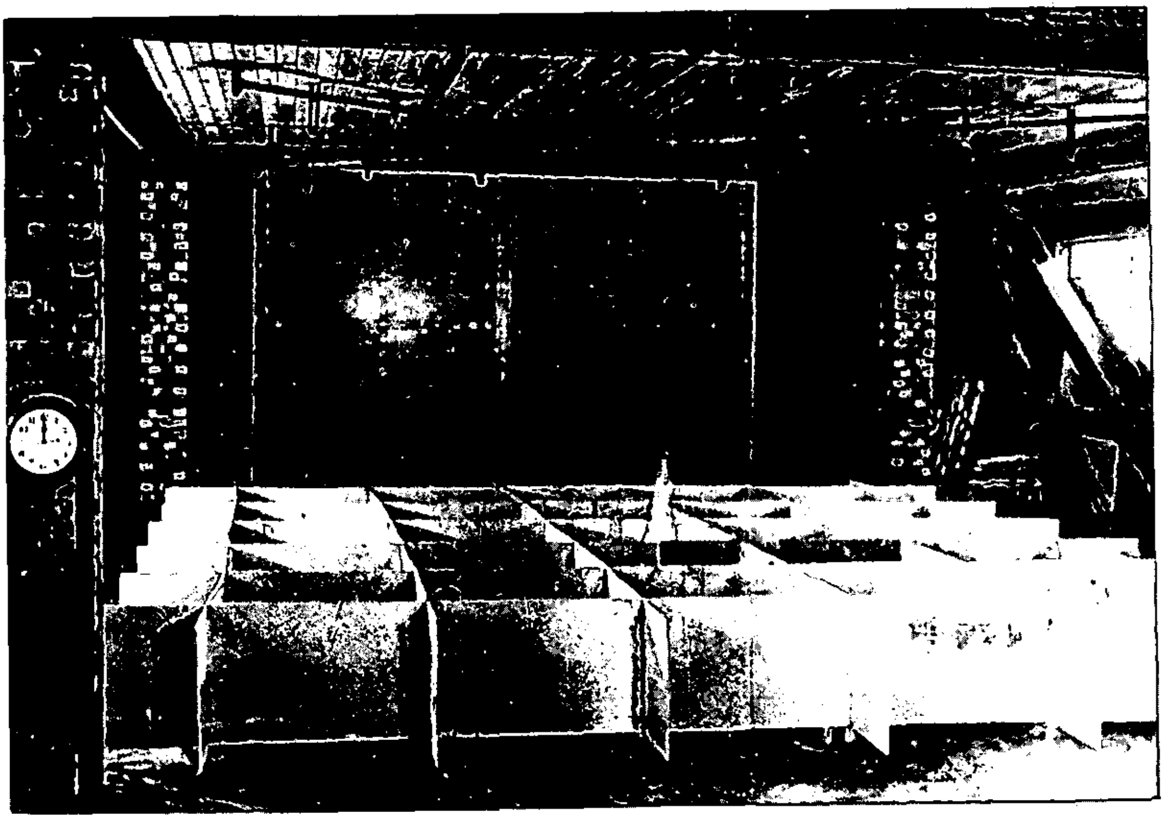
Scale 1 in. = 4 ft.

Sprinklers at ⊙ 15 ft. apart
Sprinklers at X 10 ft. apart
Sprinkler at P for test with fire involving nine (3 x 3) boxes only.

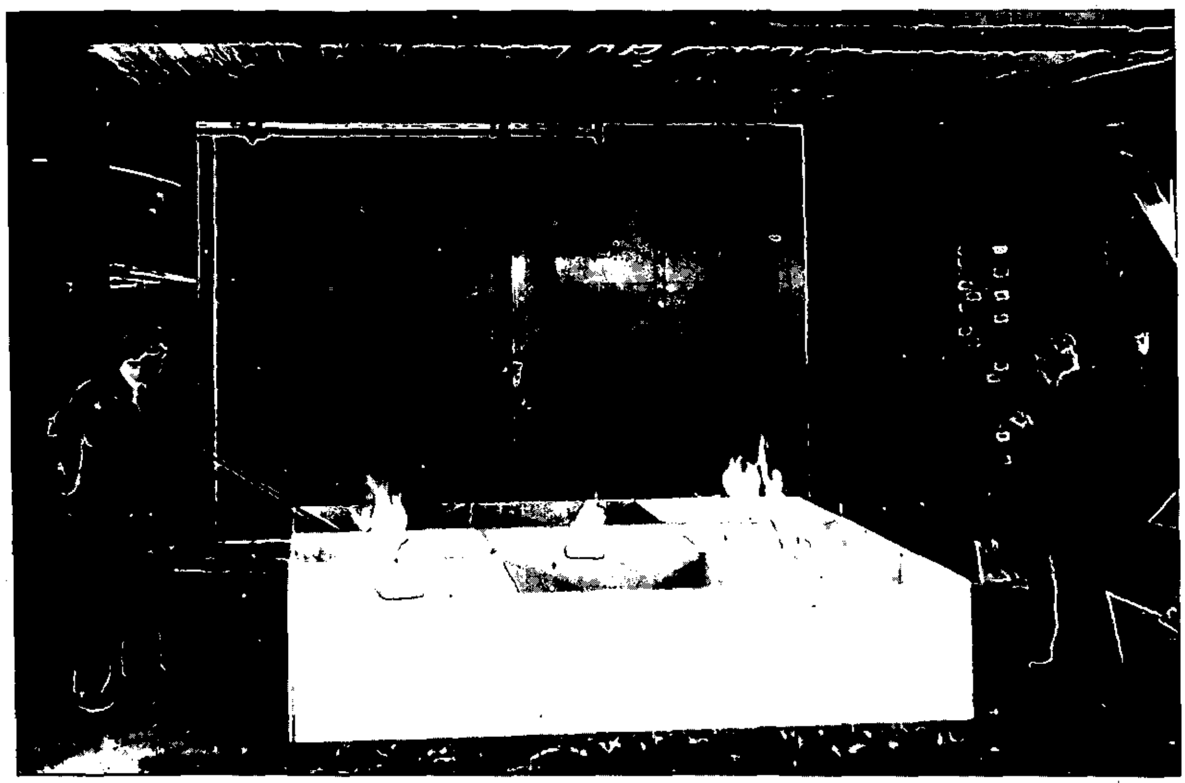
Pipework — — — — —

T - position of thermocouples other than those next to sprinklers.

Fig. 2. ARRANGEMENT OF SPRINKLERS AND THERMOCOUPLES



(a) Tests 2 – 9 & 19.



(b) Tests 11 – 18

FIG. 3. ARRANGEMENT OF TEST FIRE.

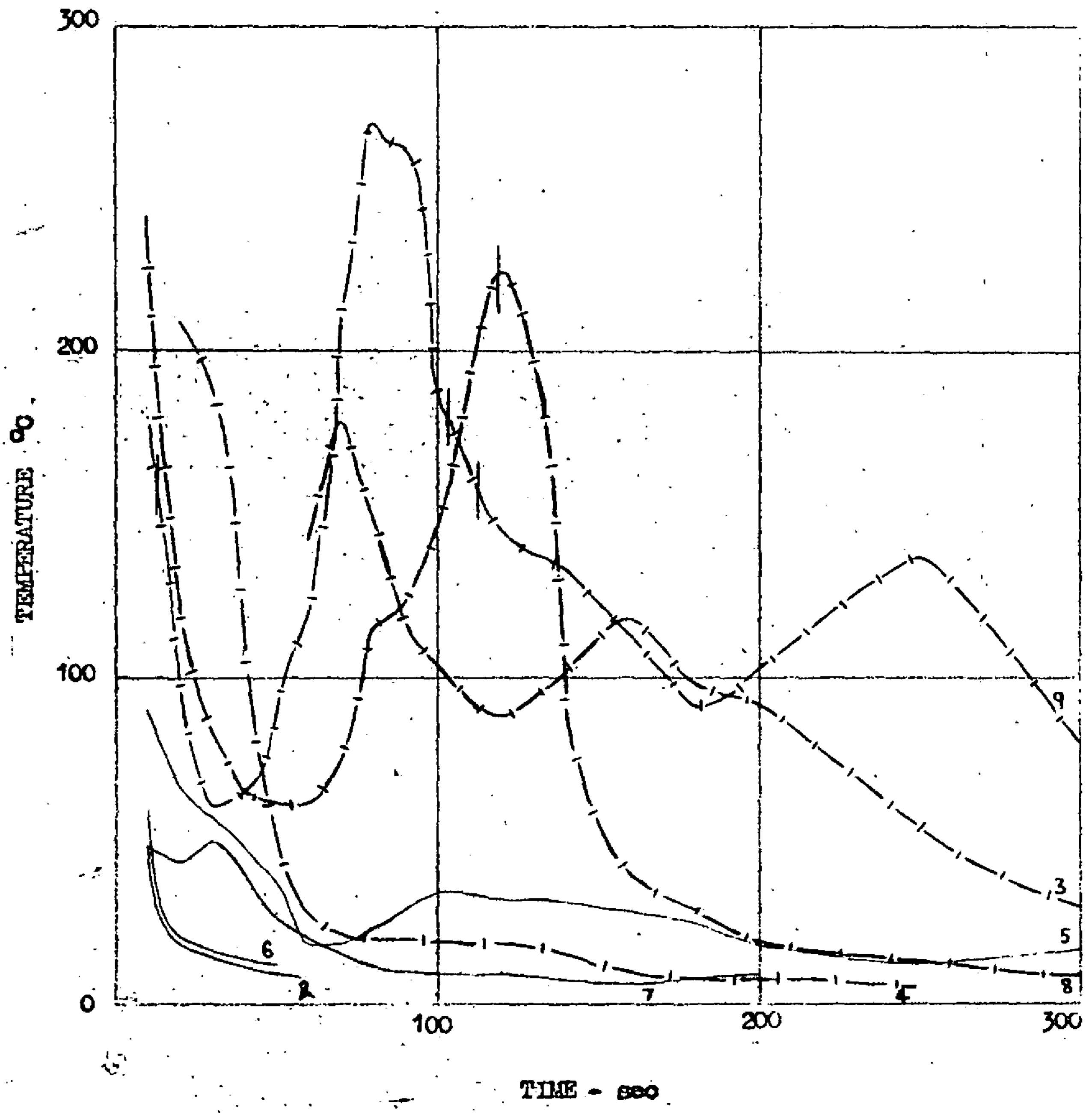


FIG. 4 - TEMPERATURE 2 IN. BELOW CEILING (TESTS 2-9)
AFTER OPENING OF FIRST SPRINKLER

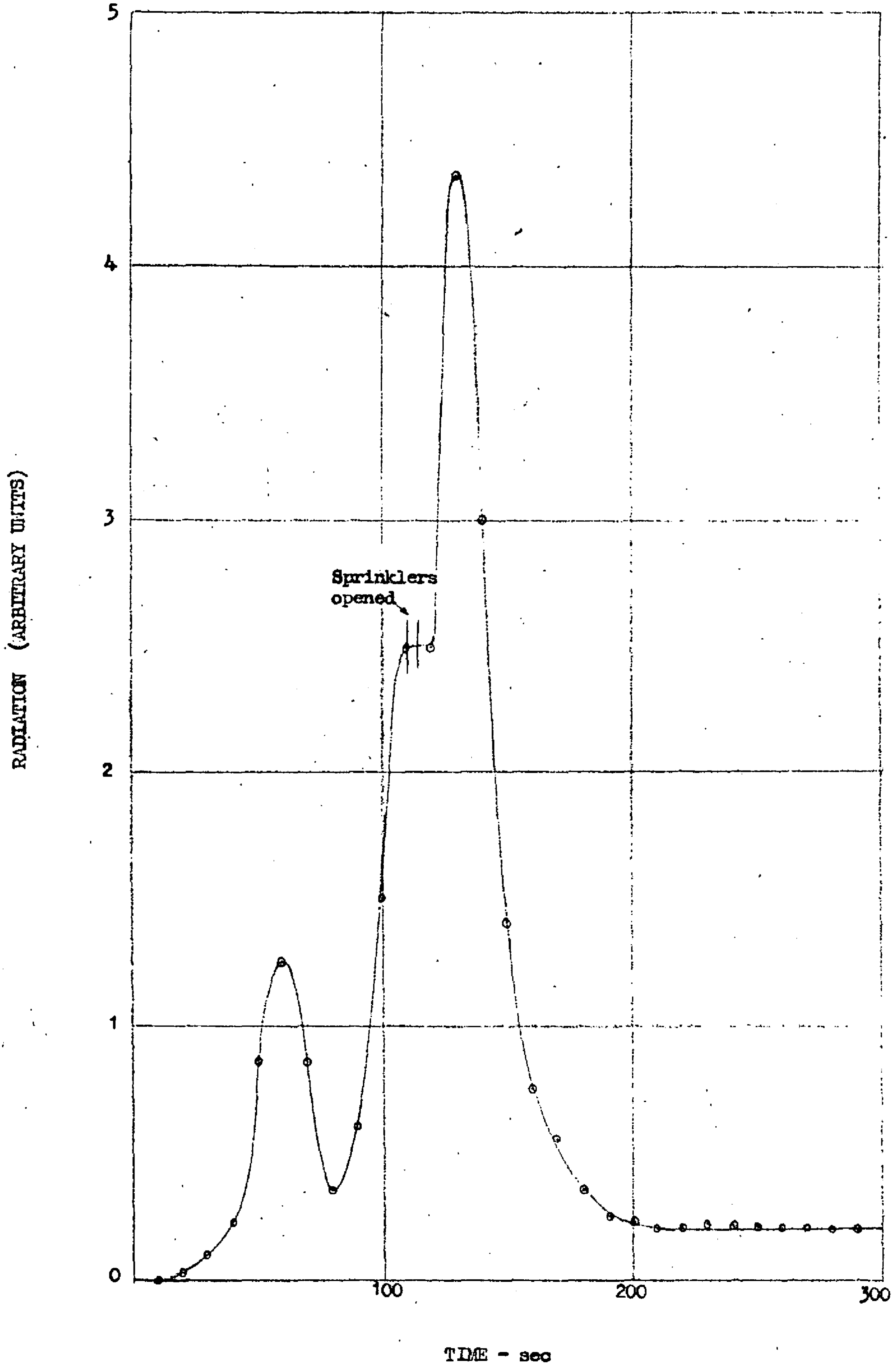
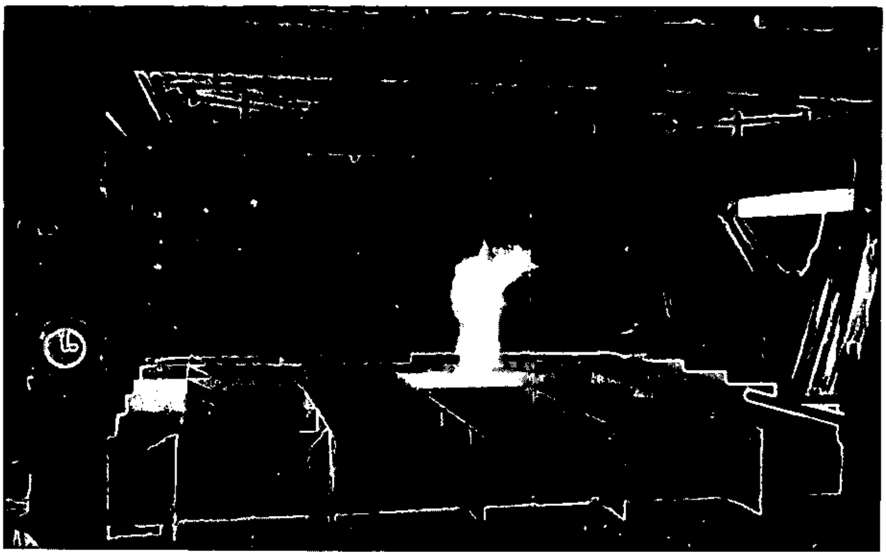
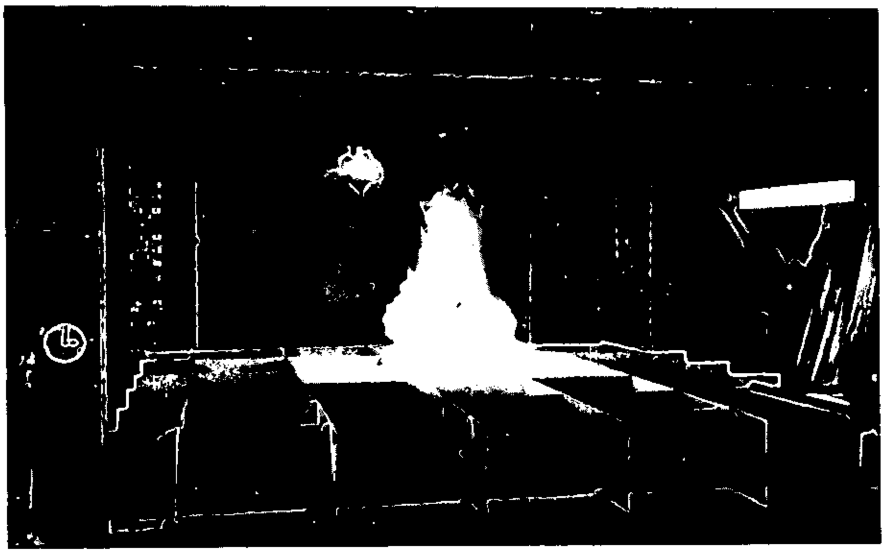


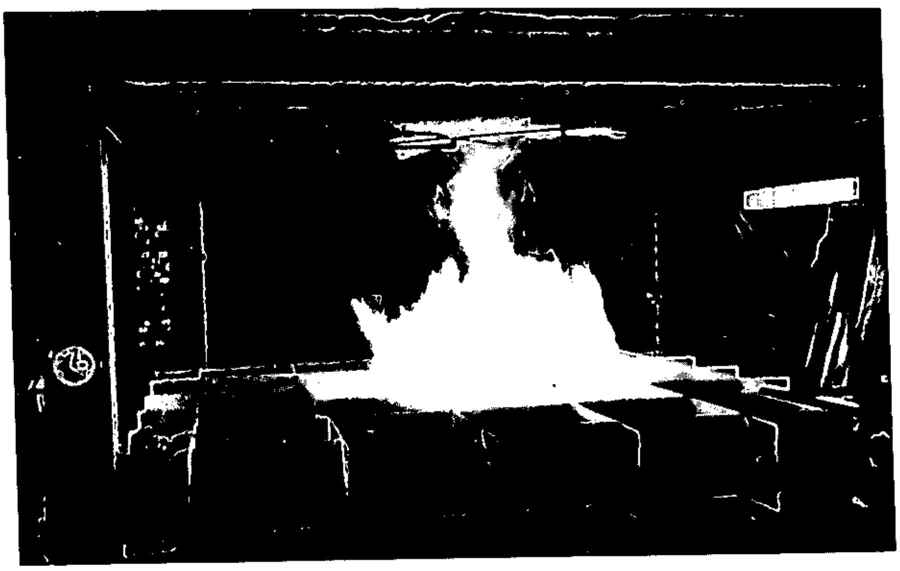
FIG. 5 RADIANT INTENSITY FROM THE FIRE IN TEST 3.



30s after lighting.

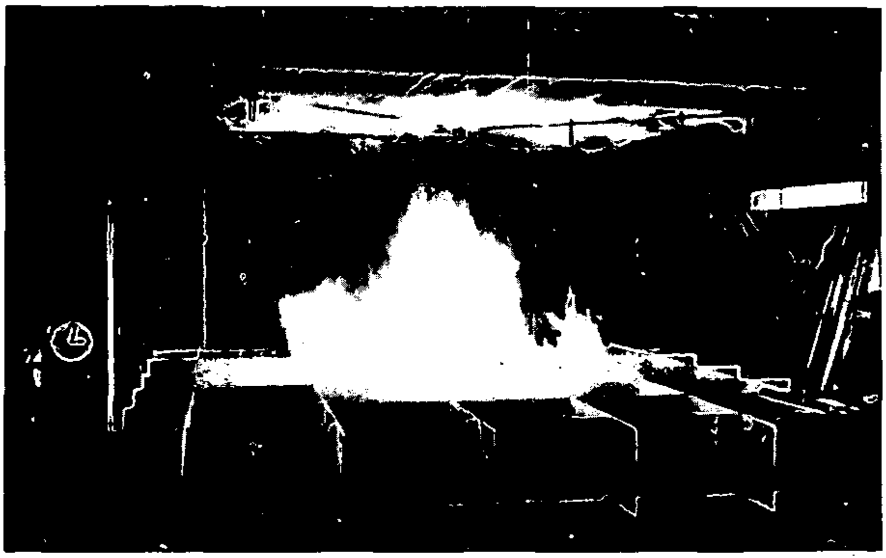


60s after lighting.

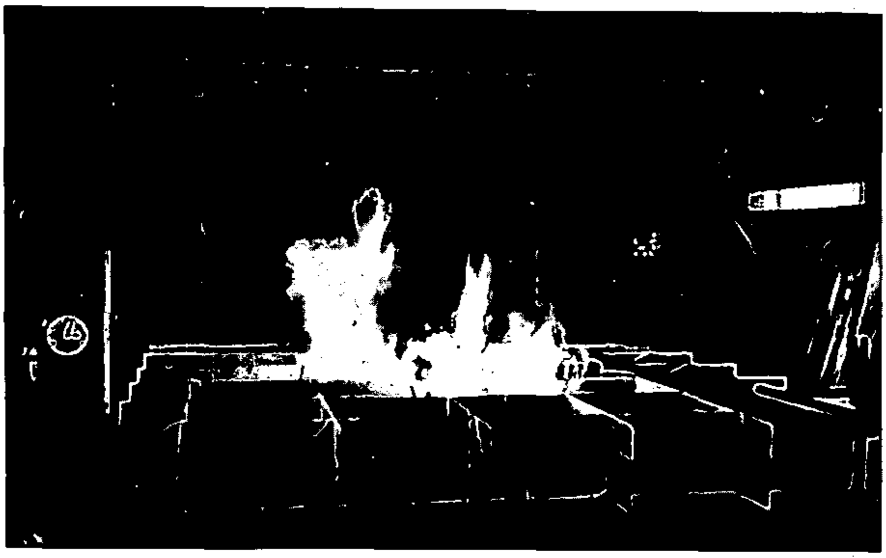


110s after ignition. Near right sprinkler has just opened.

FIG. 6. TYPICAL PROGRESS OF SPREADING FIRE (TEST 3).



20s after opening of first sprinkler.



50s after opening of first sprinkler.

210s after opening of first sprinkler.

FIG. 6. (cont.) TYPICAL PROGRESS OF SPREADING FIRE (TEST 3)

DS884-46/1/125 60 4/55 CL

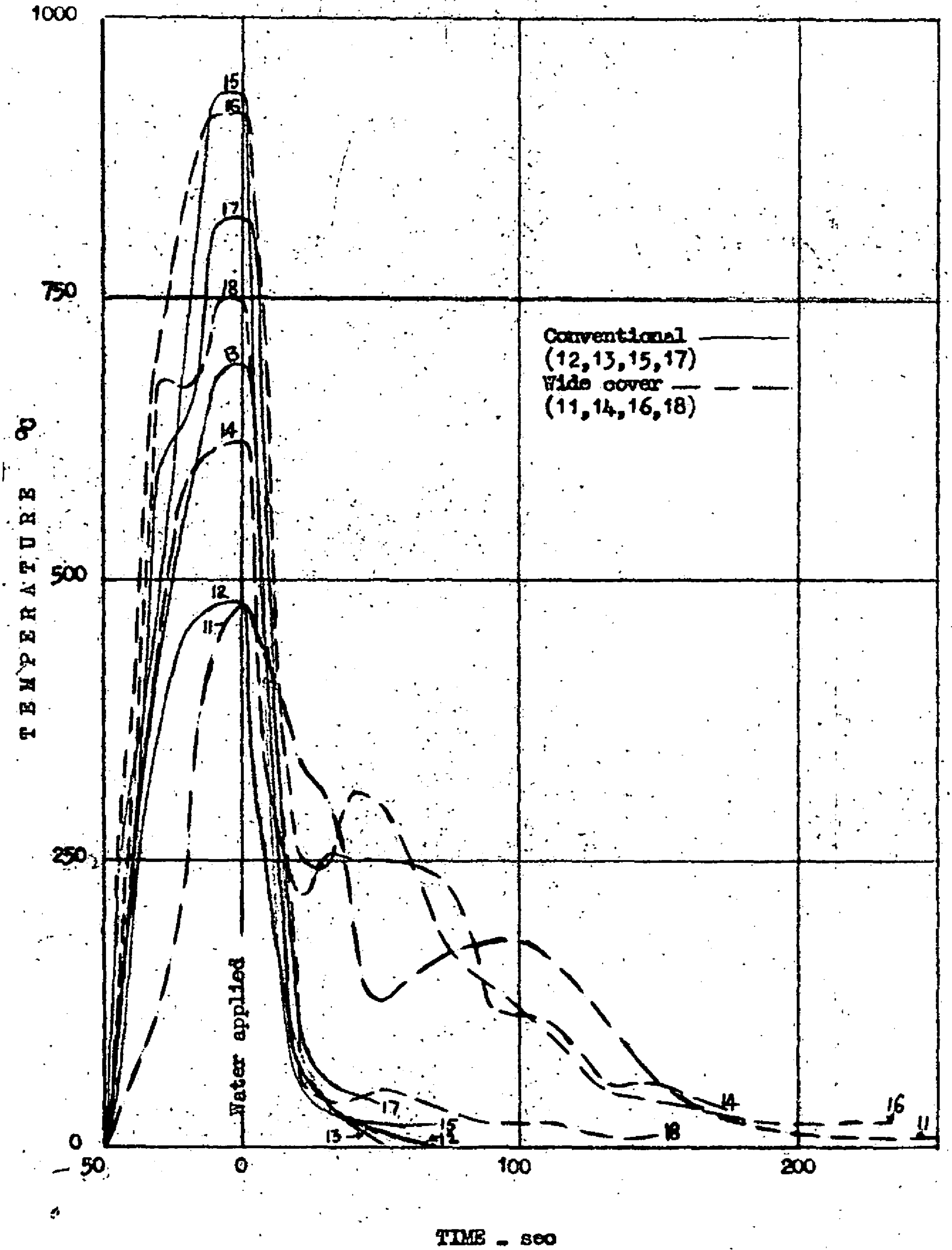


FIG. 7 TEMPERATURES 2 IN. BELOW CEILING (TESTS 11-18)

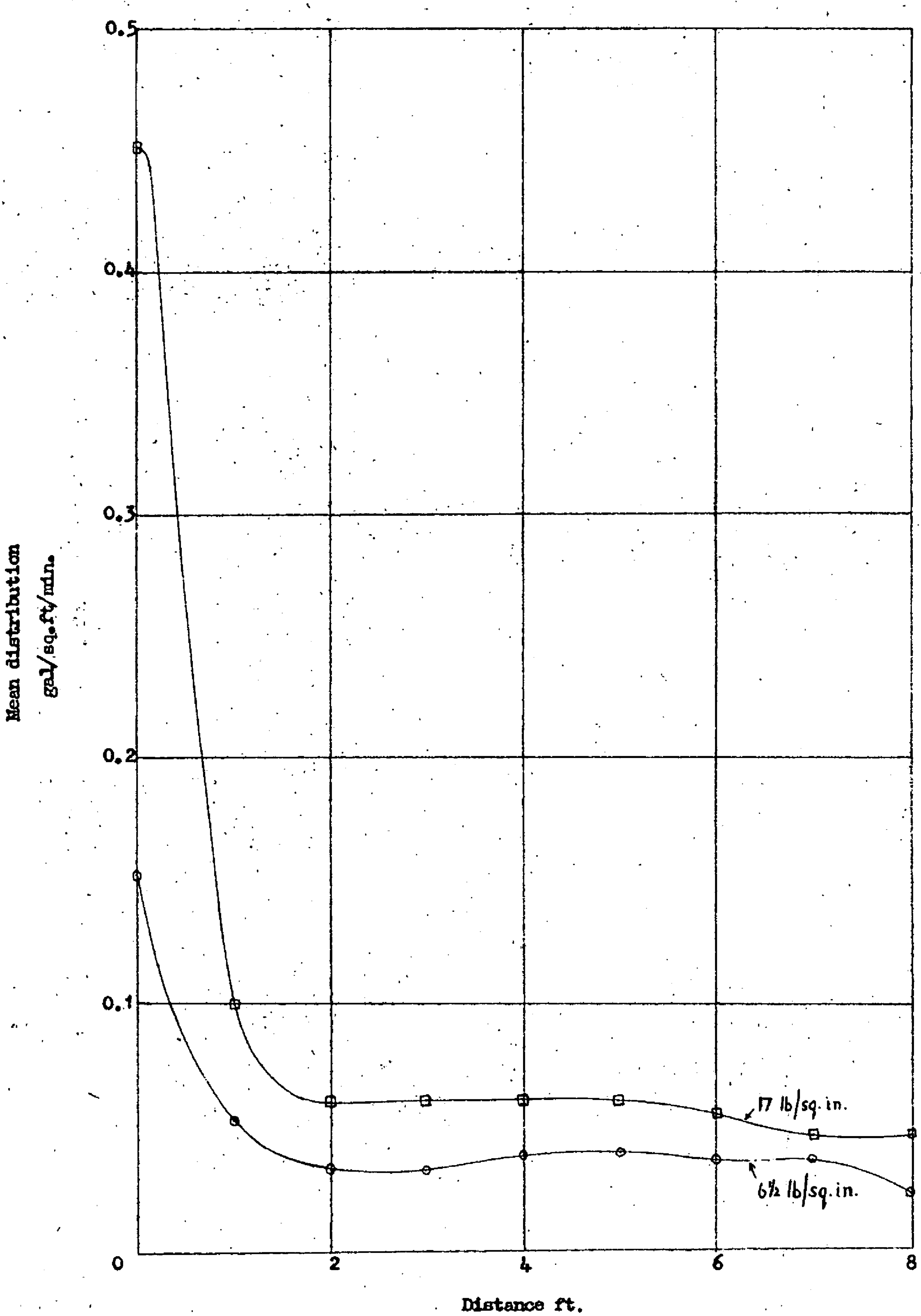


FIG. 8 - MEAN RADIAL WATER DISTRIBUTION - SPRINKLER "A" UPRIGHT

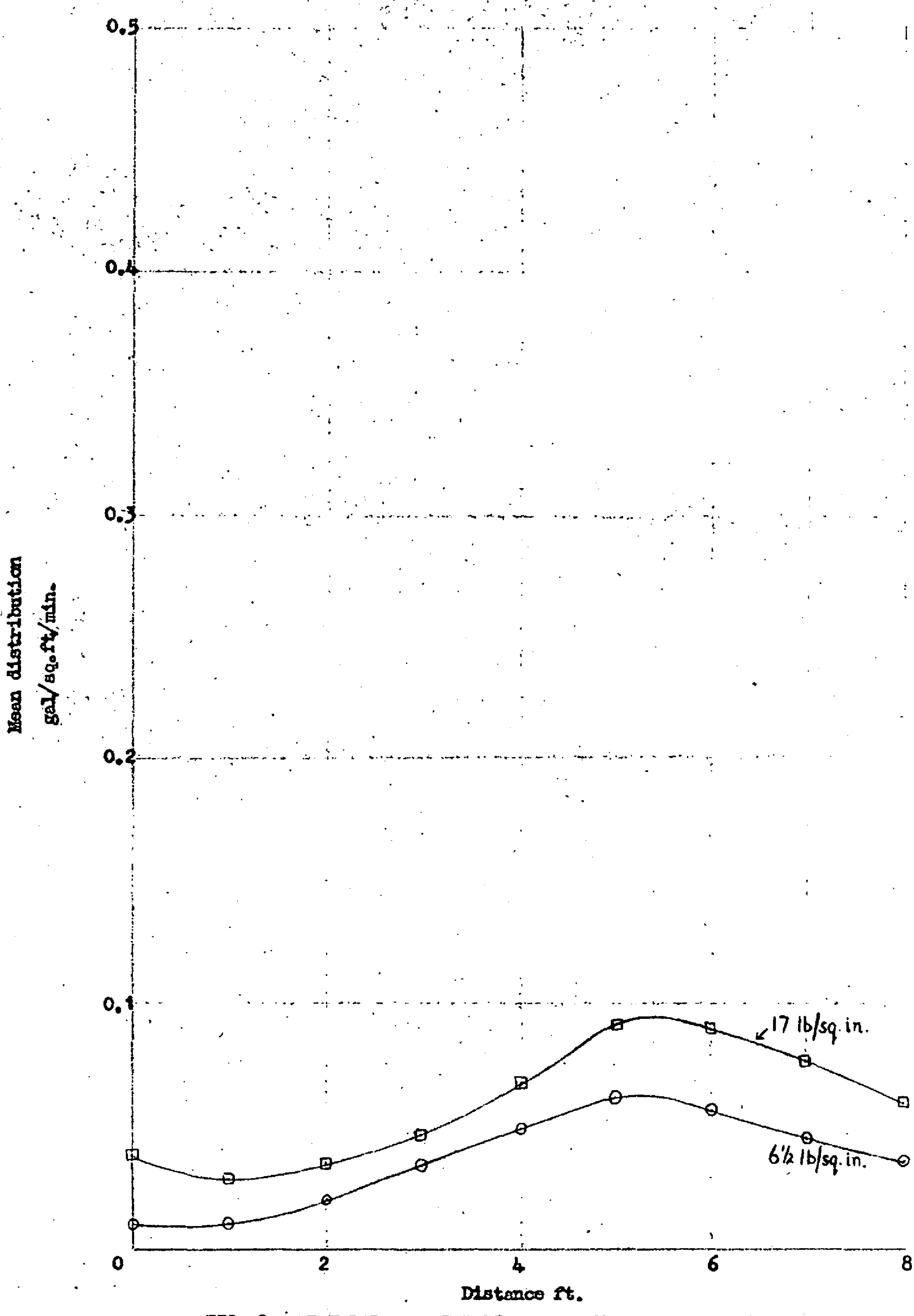


FIG. 9 - MEAN RADIAL WATER DISTRIBUTION - SPRINKLER "B" PENDENT

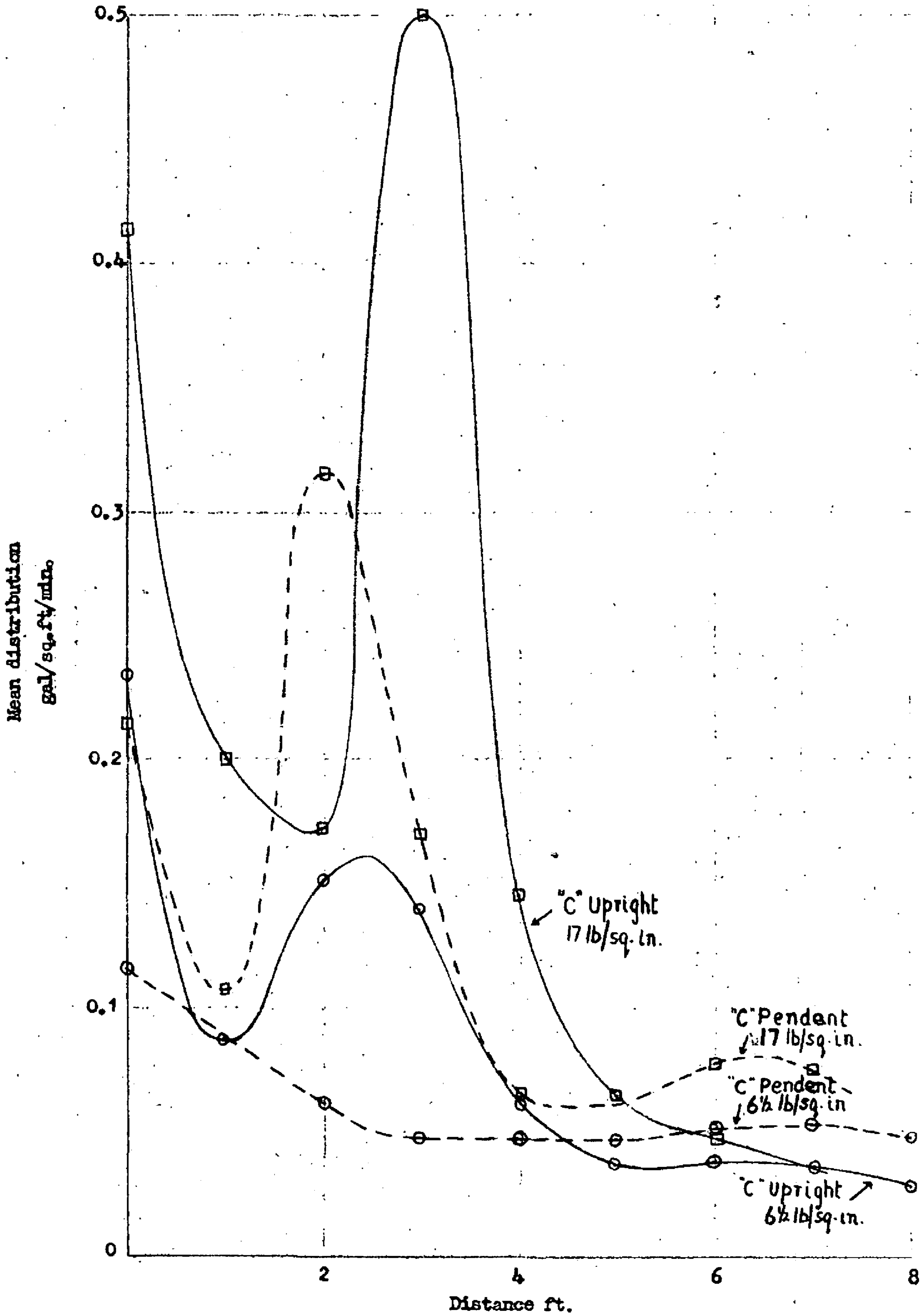


FIG. 10 - MEAN RADIAL WATER DISTRIBUTION - SPRINKLER "C"

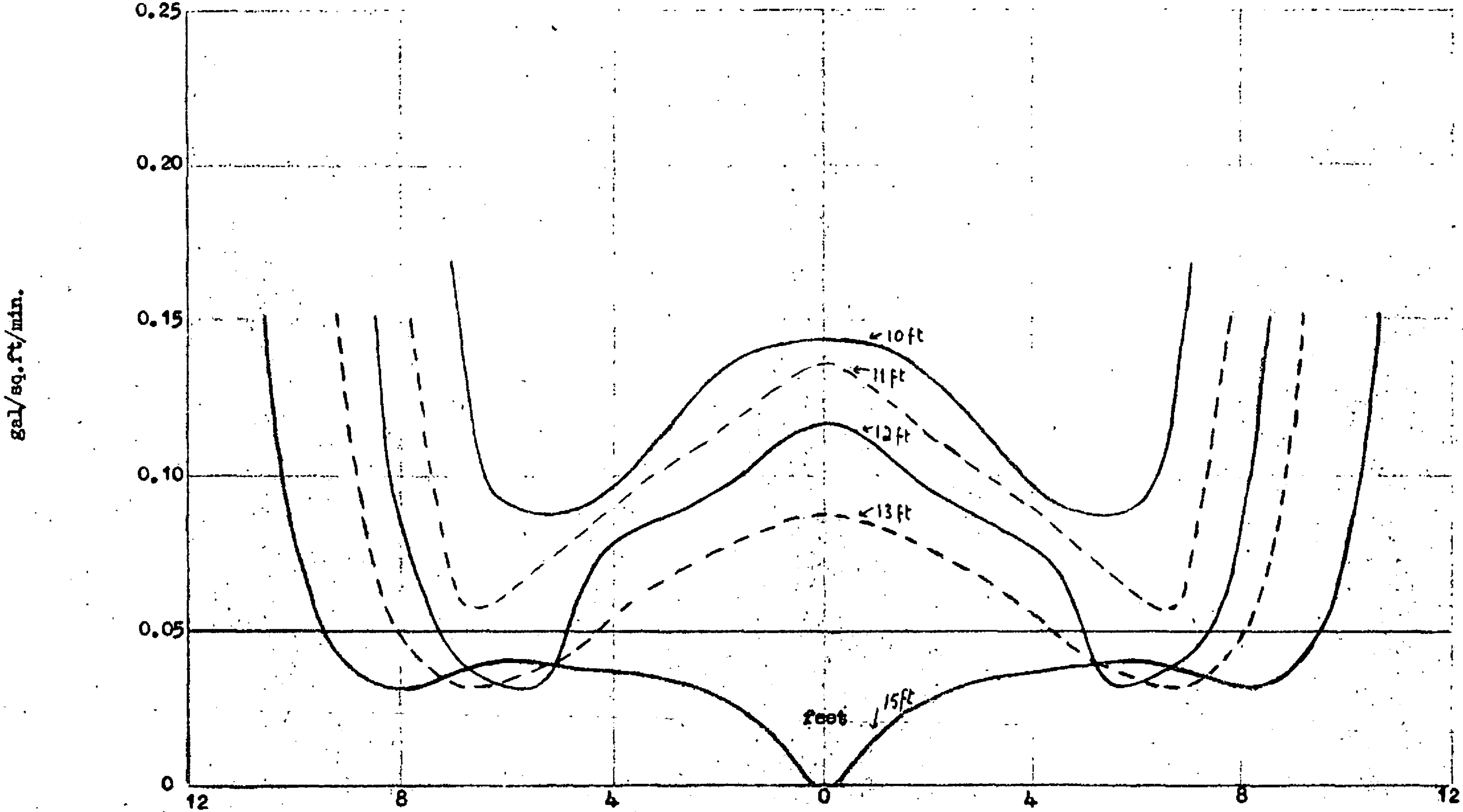


FIG. 11 - WATER DISTRIBUTION FROM 10,11,12,13 and 15 ft.square ARRAYS OF SPRINKLER "A" UPRIGHT

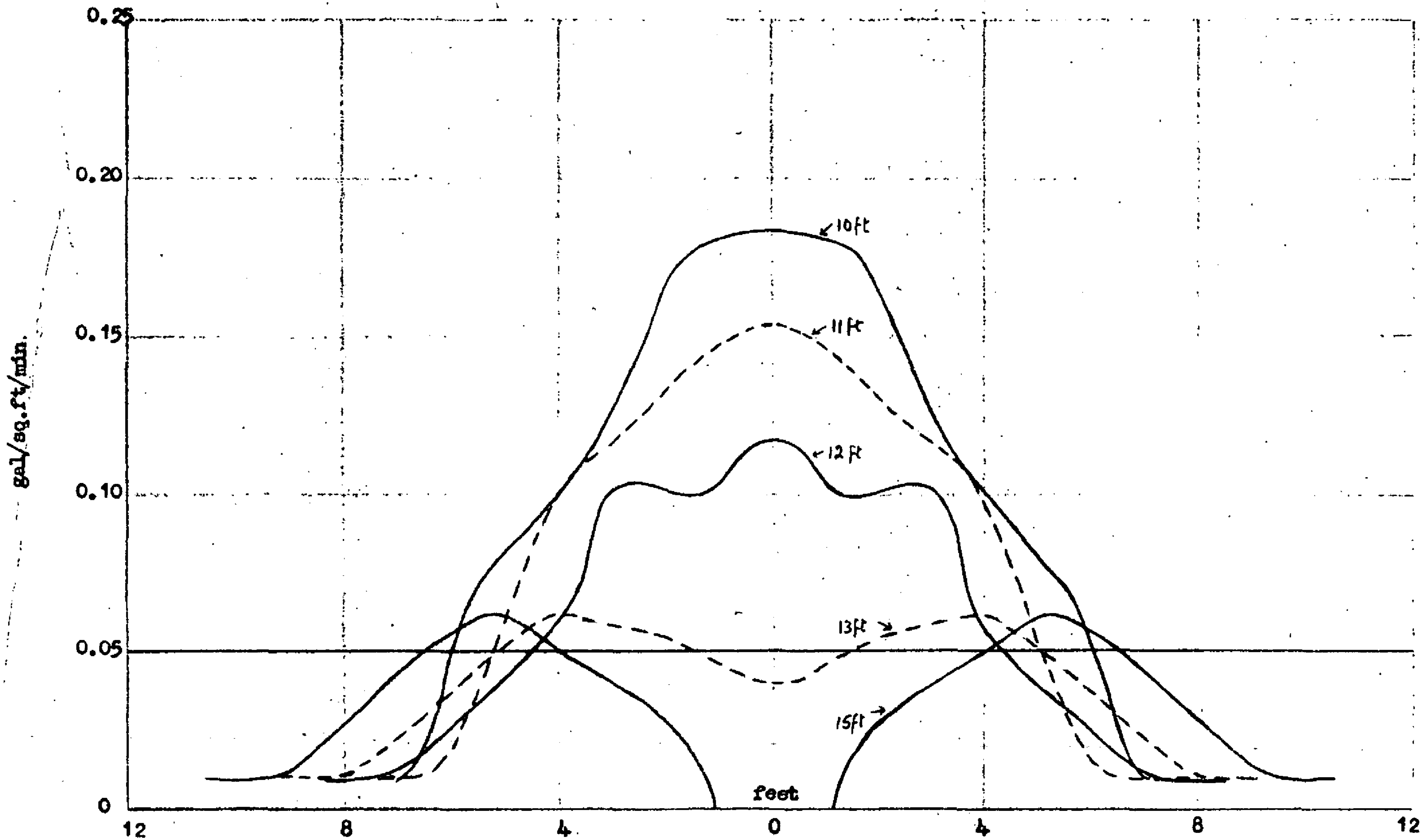


FIG. 12 - WATER DISTRIBUTION FROM 10,11,12,13 AND 15 FT. SQUARE ARRAYS OF SPRINKLER "B" PENDENT

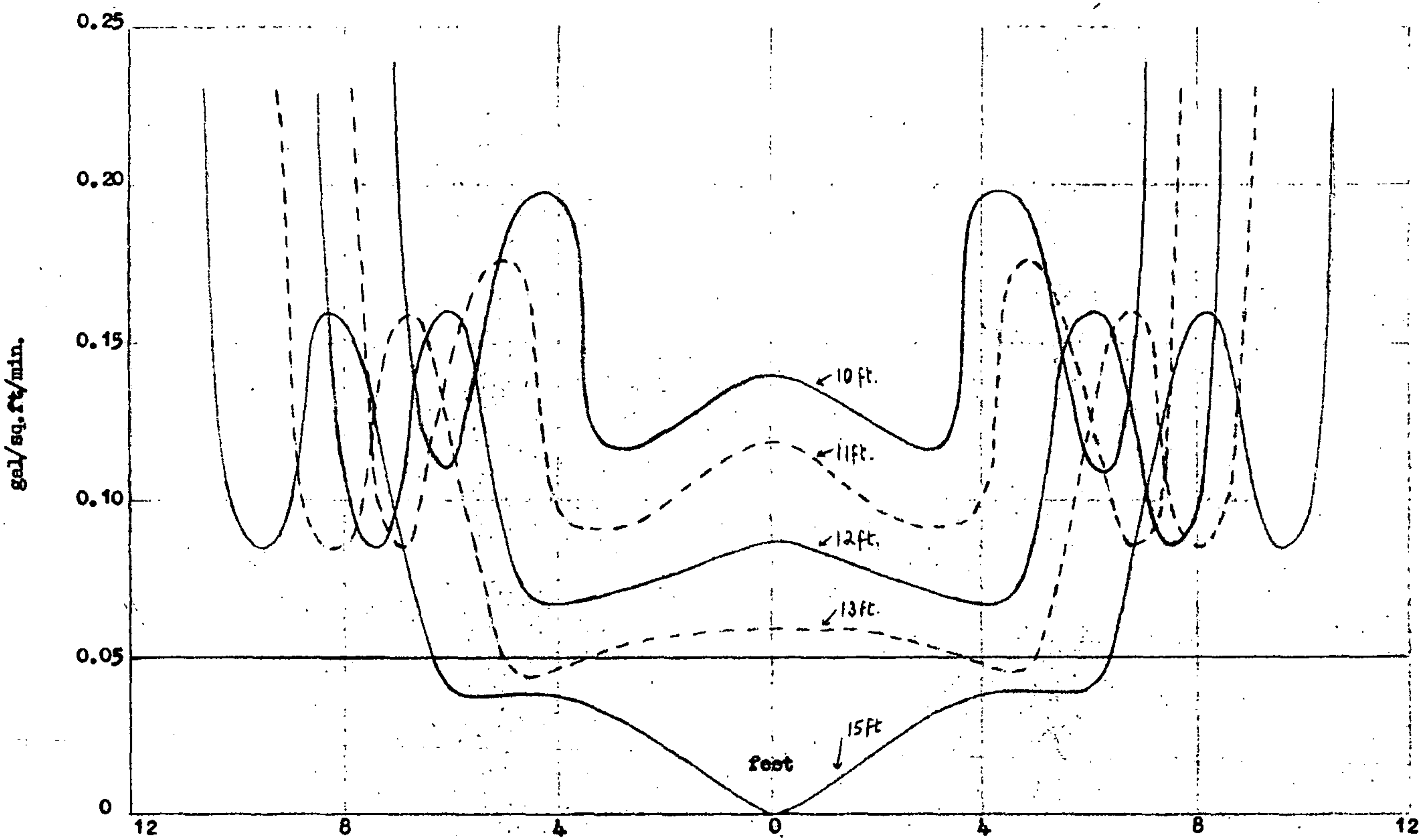


FIG. 13 - WATER DISTRIBUTION FROM 10,11,12,13 AND 15 FT.SQUARE ARRAYS OF SPRINKLER "C" UPRIGHT

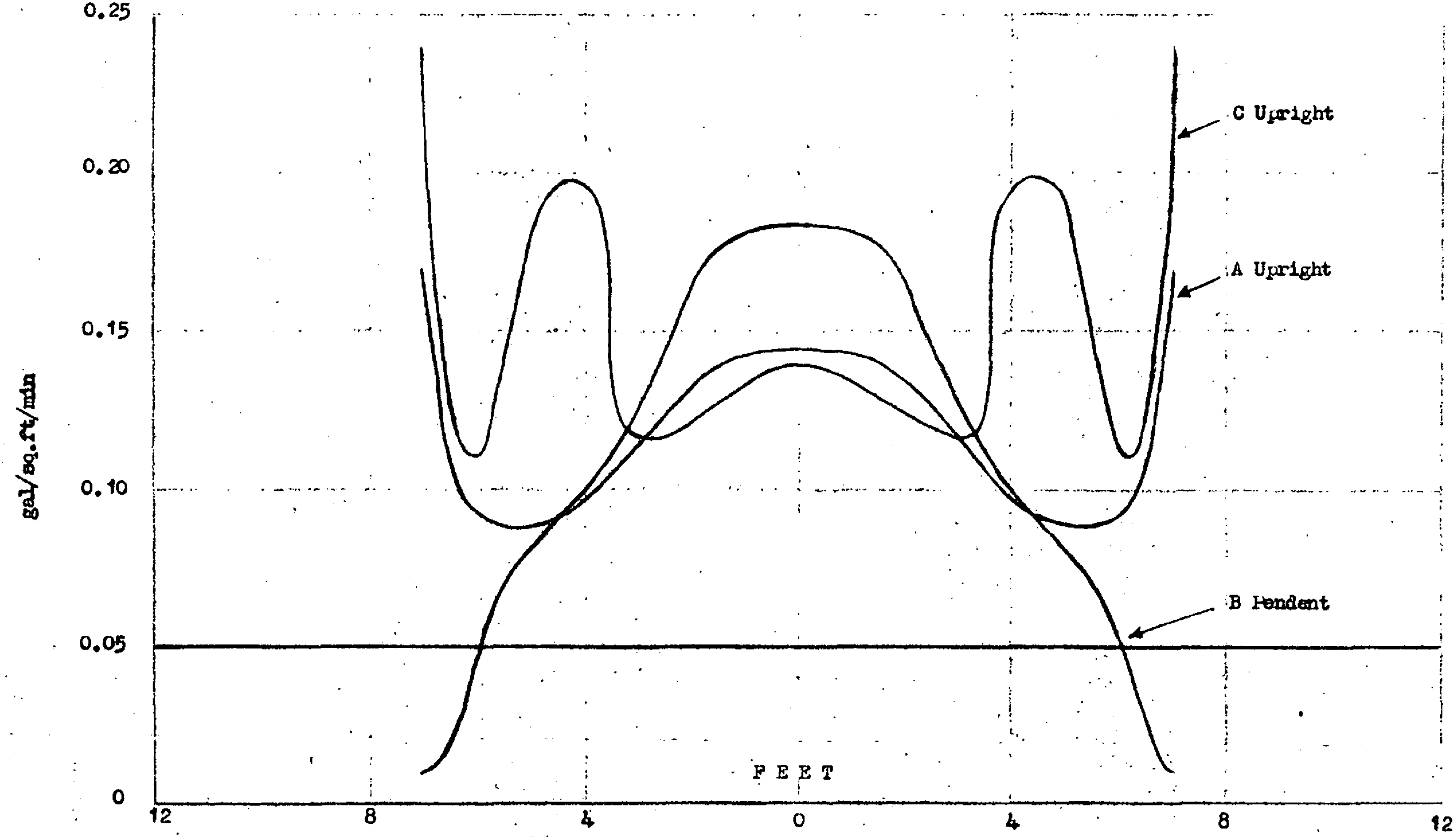


FIG. 14 - WATER DISTRIBUTION FROM 10 FT. SQUARE ARRAY

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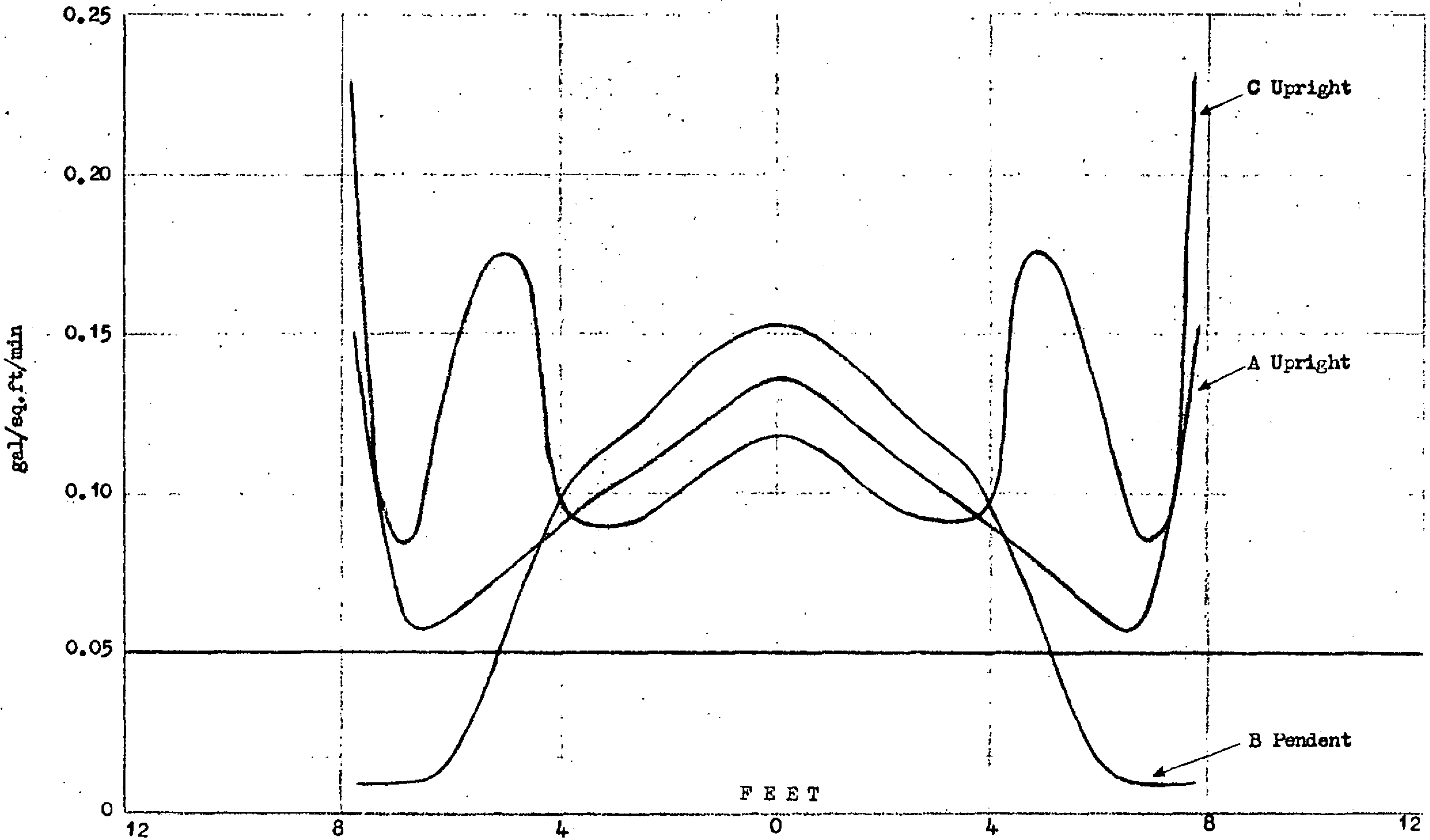

FIG. 15 - WATER DISTRIBUTION FROM 11 FT. SQUARE ARRAY

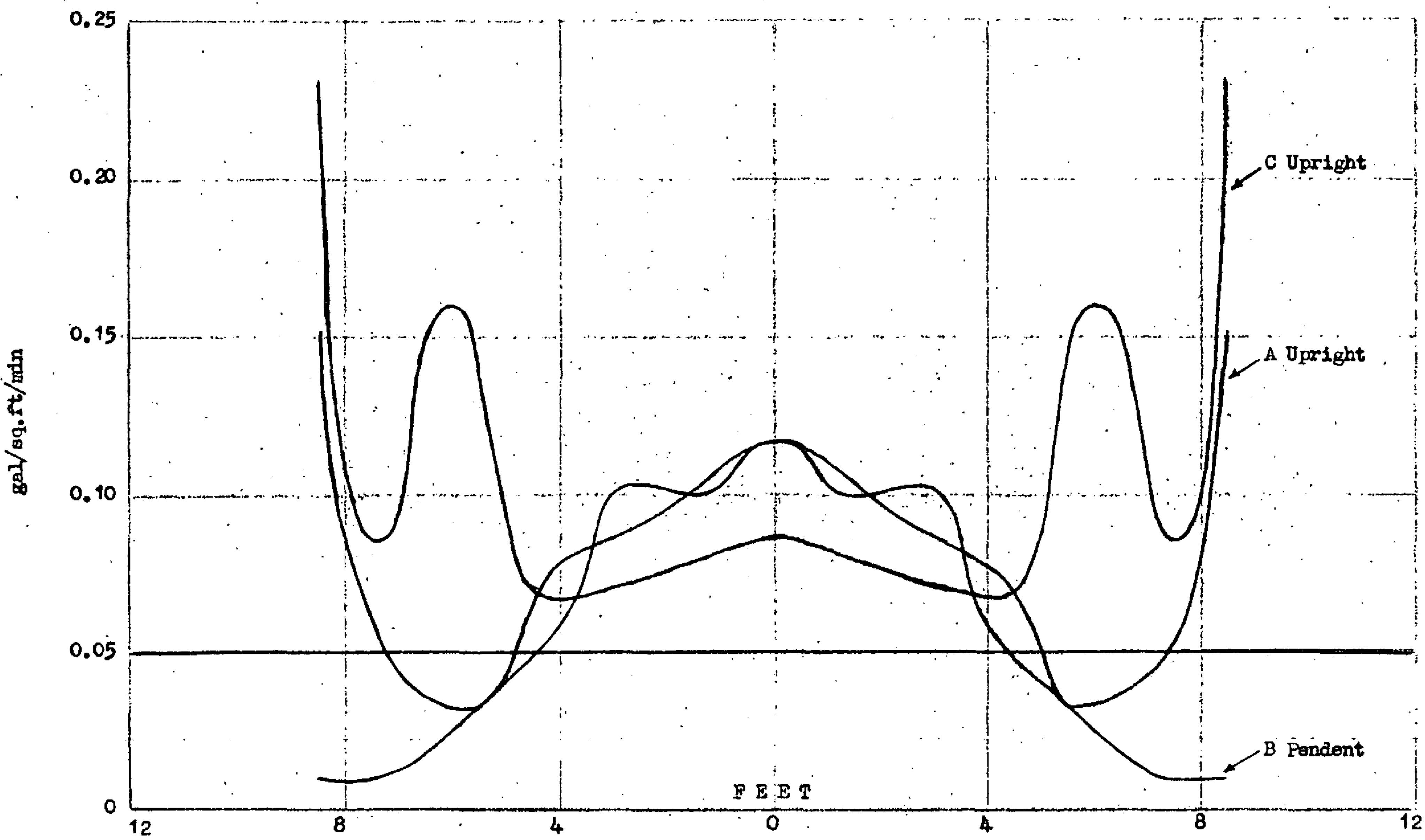

FIG. 16 - WATER DISTRIBUTION FROM 12 FT. SQUARE ARRAY

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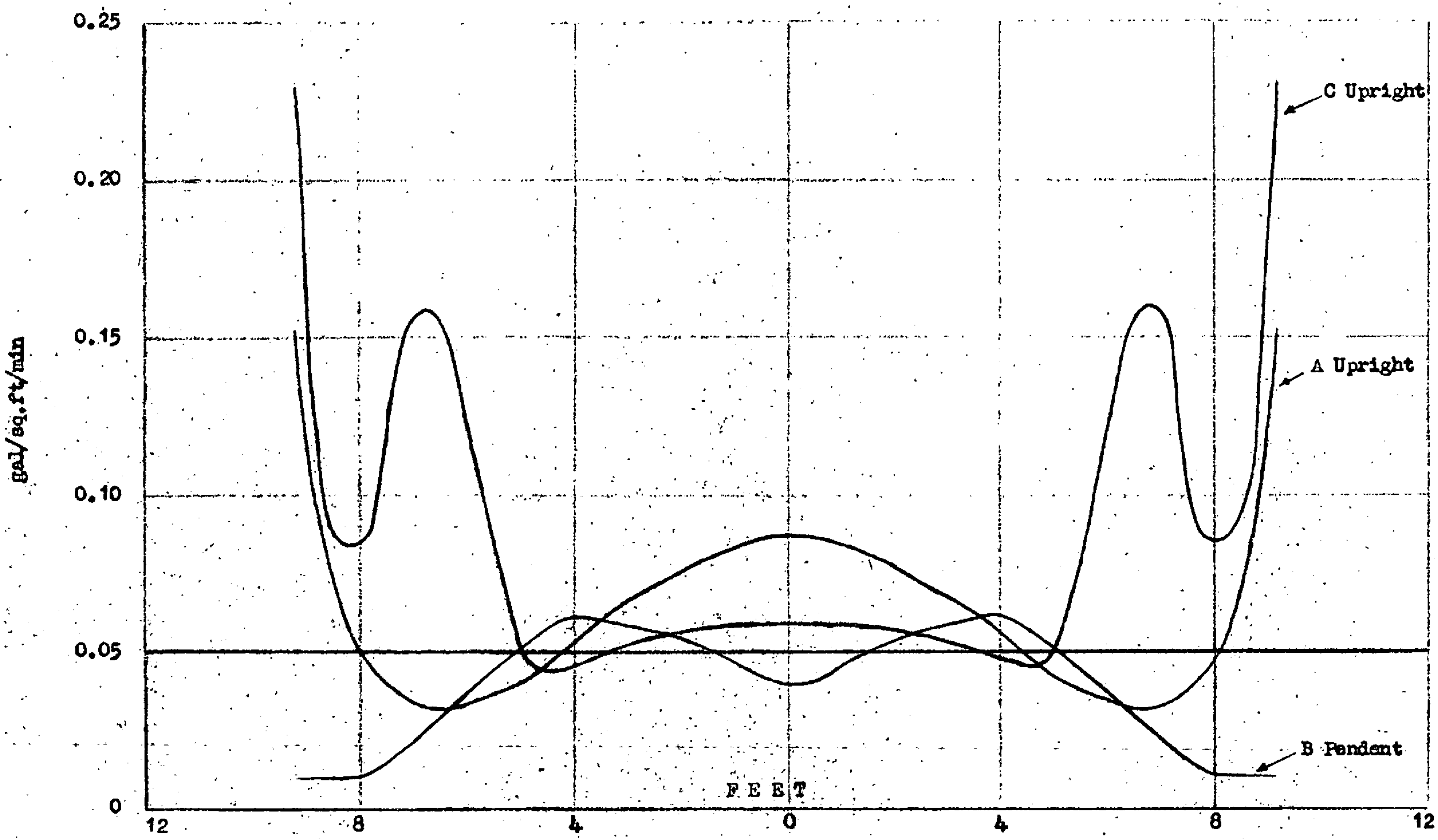

FIG. 17 - WATER DISTRIBUTION FROM 13 FT. SQUARE ARRAY

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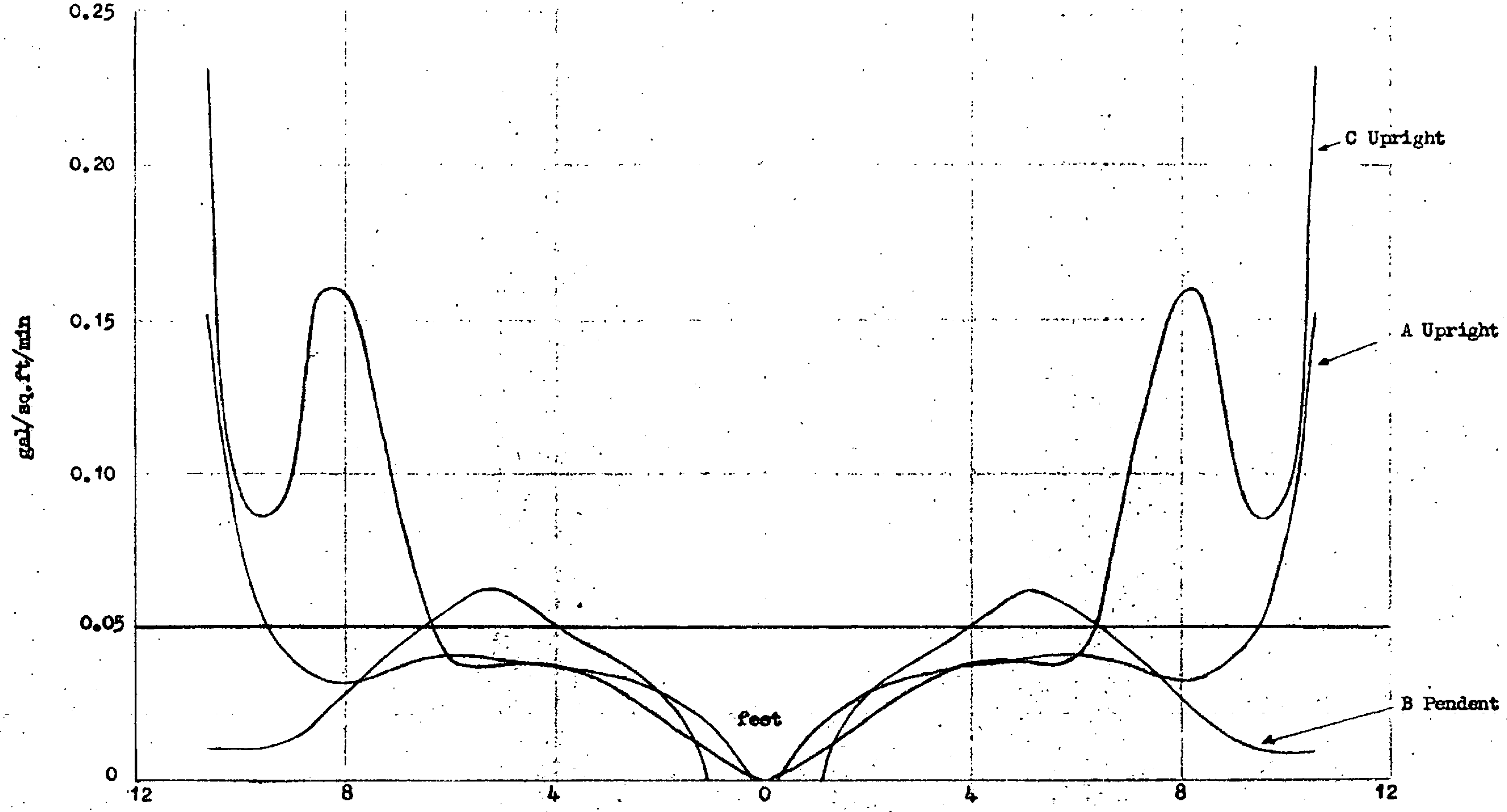

FIG. 18 - WATER DISTRIBUTION FROM 15 FT. SQUARE ARRAY

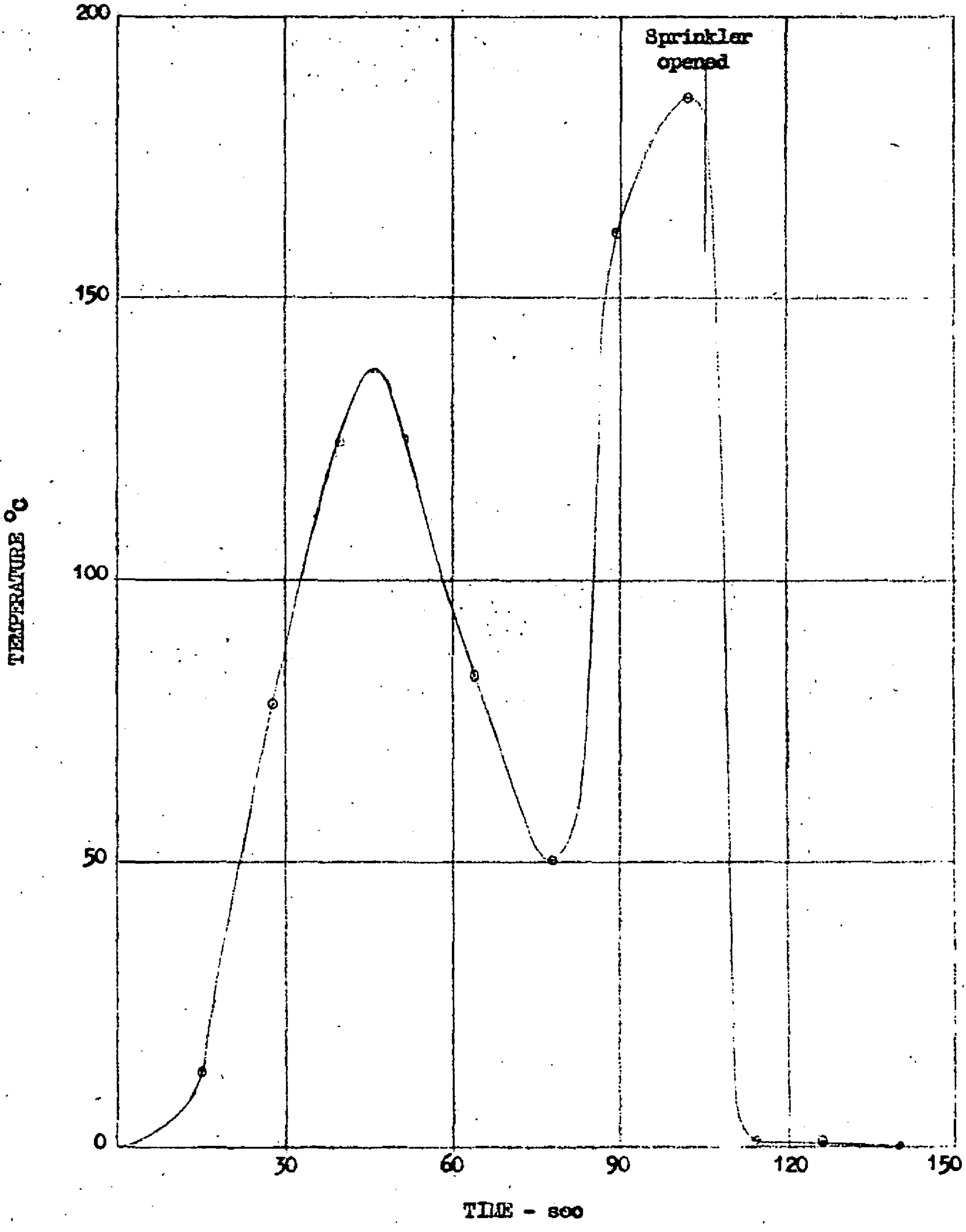

FIG. 19 - TYPICAL TEMPERATURE-TIME CURVE OF FIRE UP TO OPENING OF FIRST SPRINKLER