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# THE PROJECTION OF SPRAY FROM FIXED NOZZLES ON TO AN OUTDOOR RISK

by

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## SUMMARY

The projection of water spray on to an outdoor risk is most effective when the spray nozzles are placed as close as possible to the risk, without risk of damage to the nozzle system by a fire on the risk. The effect of wind on spray reaching the risk is also reduced by using nozzles delivering spray uniformly over the area covered. Nozzles with a hollow spray cover are less effective than nozzles with a peaked or uniform spray cover. Excessive wastage of water by projection beyond the risk being protected may be minimised by using spray nozzles of small cone angle.

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## INTRODUCTION

A note has been recently published on the extinction by water sprays of fires of oil pouring over a risk in the open air[1]. It was found that the rate of flow of spray reaching the risk controlled the ease with which extinction took place and that the spray should penetrate to all surfaces of the risk on which oil could burn. The present note describes the method for measuring rate of flow at the risk, and the effect of the nozzle type and disposition, and the prevailing wind conditions on this rate of flow.

## EXPERIMENTAL

### General

The site and equipment used for the tests are shown diagrammatically in Fig. 1. Water was supplied at the required pressure to the ring main R by pump E. The delivery of water to the spray nozzle manifold was controlled by the magnetic valves $V_1$ and $V_2$, operated remotely from the control hut N. Records of wind direction and speed during each test were taken in the control hut from instruments mounted 6 ft above ground level at the weather station P.

### Equipment

The spray manifold was arranged so that spray could be projected either vertically downwards, or at an angle, on to the risk. The risk, described in greater detail elsewhere[2], consisted of a bank of 21 tubes 1.9 in dia., of overall dimensions 1 ft 8 in wide, 4 ft 8 in long, and 7 ft high; (6 ft 6 in above the level of gravel in the trays B, Fig. 1), erected with the long side normal to the prevailing wind. (S.W.)

Spray was projected vertically downwards on to the risk from arrays of 1 to 12 nozzles, Fig. 2. Spray was projected at an angle on to the risk from nozzles supplied with water from 4 vertical pipes, Fig. 3.

The spray was produced by nozzles of differing characteristics, some of whose properties are given in Table 1, operated at pressures of 25, 50 and 90 lbf/in$^2$. The cones of spray produced at 50 lbf/in$^2$ by the nozzles used are shown in Plate 1 and the patterns of flow rate of spray 7 ft 6 in below the nozzles are given in Fig. 4. Further information on the nozzles and their properties is given elsewhere[3, 4].

### Measurement of Flow Rate

Measurements of flow rate were made on the tube rig without a fire. Spray reaching the risk was collected by the apparatus shown in Fig. 5. The top tray, $T_1$, caught spray that would reach the top of the risk. Spray that would reach the long and short sides was intercepted by the vertical sheet metal screens and caught in the trays $T_2$ and $T_3$ respectively. These trays were made wide enough, 6 in, to catch the splashes produced by the spray impinging on the vertical metal screens. They also caught the small amount of spray which could fall directly into them. For convenience, when sprays were projected vertically downwards, the spray was collected in trays $T_1$ and $T_2$ only. A few special tests, however, were made in which spray was collected in all trays. Spray was collected in all trays for the tests with spray projected at an angle on to the risk. The rate of flow was found from the amount of spray collected.

## RESULTS

### Spray Projected Vertically Downwards

Measurements were made of the rate of flow of sprays, projected vertically downwards from heights of 4 ft 6 in and 9 ft 6 in above the top of the risk.* The heights were chosen as representing some spacings used in fixed spray installations. The tests with nozzles 9 ft 6 in above the risk were usually made when the wind speed was of less than 5 ft/s, since it was found that at higher wind speeds the spray was often deflected so as to miss the risk. The rate of flow was usually measured over the top and the long sides of the risk (see footnote). The results for tests with spray caught on the top and all four sides of the risk are given in Table 2. The proportion by which the rates of flow, measured on the top and long sides only, have to be increased to give the flow rate to the top and all four sides of the risk can be estimated by the factors given in Table 2.

### Factors influencing flow rate at the risk

The factors which would be expected to affect the flow rate of spray at the risk were the number and disposition of the nozzles about the risk, the flow rate and properties of the spray produced, the operating pressure, and the direction, speed, and variation in speed of the prevailing wind. It was not possible to make an analysis on all these factors, since suitable numerical values could not be assigned to some of them. However, a limited analysis for nozzles in a single line above the risk showed that the effect of wind direction was not significant. The effects of significant factors are given below.

### Effect of Nozzle Array

The rate of flow of spray reaching the risk increased with increasing number of nozzles and decreased with increasing height of nozzles above the risk. This is shown in Fig. 6 for results of tests at the same wind speed with nozzles L and M at heights of 4 ft 6 in and 9 ft 6 in above the risk. The difference in rate of flow between these nozzle types was not significant, when they were mounted 9 ft 6 in above the risk, and the results at this height are therefore plotted as a single curve.

The amount of spray reaching the risk increased with increasing rate of flow from the nozzles and decreased with increasing cone angle. The degree of uniformity of spray cover, and extent to which the spray reached all surfaces of the risk on which oil could burn were not measured directly. It was observed however that at least four nozzles were needed to meet the latter requirement with all types of nozzle, and that this number of nozzles gave a fairly uniform cover.

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*In the extinction tests with these spray systems, the distance between spray nozzle and fire was taken as the distance between spray nozzle and the manifold from which the burning oil issued; this was 6 in below the top of the risk. Thus heights of 5 ft and 10 ft of application of spray to a fire are equivalent to heights of 4 ft 6 in and 9 ft 6 in above the top of the risk. The spray reaching the top of the risk was collected in a 6 in deep tray, the rim of which was thus 6 in above the top of the risk.

Footnote

The results of individual tests are not produced here. They may be obtained by interested parties on application.

The uniformity of spray cover in still air was estimated by calculating the distribution of spray over the sampling tray on top of the risk, from the information on the shape of the spray cone from Plate 1, and from the spray patterns given in Fig. 4, and the position of the plane of the rim of the top sampling tray, Fig. 5. From these data, and the disposition of the nozzles above the risk, the rates of flow per unit area in still air, to 4 in wide lateral strips of the sampling plane, were calculated. The results for 2 and 4 nozzles of types L and $L^1$ are shown as flow rate curves in Fig. 7.

Effect of Pressure

An increase in pressure at the nozzle produced an increase in the rate of flow of spray at the risk. The rates of flow for nozzles L and M are shown in Fig. 6; the increase in rate of flow is approximately proportional to the cube root of the pressure at the nozzle. The rate of delivery of spray from the nozzles, Table 1, is approximately proportional to the square root of the pressure at the nozzle, the theoretical relation. This difference is discussed later.

Effect of wind on flow rate and spray cover

The regression analysis showed that the rate of flow of spray at the risk decreased with increasing wind speed and increased with increasing coefficient of deviation of wind speed. (The coefficient of deviation, a measure of variation, is the standard deviation expressed as a proportion of the mean value of a given population). The latter effect was, however, small. The effect of wind speed on the rate of flow at the risk from some of the nozzle arrays mounted 4 ft 6 in above the risk is shown in Fig. 8. The relation for the directional nozzles could be plotted as a straight line up to wind speeds of about 15 ft/s; above this speed there was evidence of a more rapid reduction of rate of flow with increasing wind speed. The decrease in rate of flow with increasing wind speed was less for the nozzles giving a more uniform spray pattern. The rate of flow from arrays of the non-directional nozzles, however, decreased more rapidly than that of all the directional nozzles as wind speed increased from quite low values, the effect being most marked for the 12 nozzle array at 90 $lbf/in^2$. It was observed during these tests that only the highest wind speeds ($>$ 15 ft/s) appeared to deflect the spray from directional nozzles sufficiently to reduce markedly the amount of spray reaching the risks on the windward side, while spray from non-directional nozzles was easily deflected by winds of moderate speed.

When spray nozzles are operated close to each other a concentration of spray is produced by the mutual interference of the spray cones. This is called "pull-in". The effect of "pull-in" on the rate of flow at the top of the risk was examined by comparing the measured rate of flow extrapolated to zero wind speed, with that calculated by integrating the spray cone over the top of the risk as given in Fig. 7. Some of these measured and calculated rates of flow in still air for nozzles mounted 4 ft 6 in above the top of the risk are given in Table 3. These results show that, for all but one of the tabulated groups of nozzles, the measured rate of flow was greater than the calculated value. The amount of this excess became less for directional nozzles as the pressure was increased, while for the non-directional nozzle N, the excess became larger as the pressure increased.

Spray projected at an angle on to the risk

The effect of positioning of nozzles for projecting spray at an angle on to the risk was examined for spray projected downwards, horizontally and upwards. The positioning was selected with the object of ensuring that all surfaces on which oil could burn were reached by the spray. Two configurations of nozzles were tested and these are shown in Fig. 3. Nozzles mounted at plan position A, Fig. 3, gave rates of flow given in Table 4, tests 1 - 6. These positions resulted in some tubes at the centre of the risk being incompletely covered by spray, as they were shielded by the outer tubes. A more satisfactory spray cover was given by nozzles mounted at plan position B, Fig. 3, and rates of flow for nozzles mounted in these positions are given in Table 4, tests 7 - 21. In addition, since the rate of flow from 4 nozzles of type N was so small, a further test, No. 22, was made in which 12 nozzles N were used, four each spraying downwards, horizontally and upwards respectively.

Factors influencing rate of flow at risk

Insufficient tests were made with sprays projected at an angle to attempt an analysis of the influence of the various factors on the rate of flow at the risk. However, it is likely that the factors and their effects would be similar to those influencing rate of flow from sprays projected vertically downwards.

The direction which the spray was projected on to the risk had some effect on the rate of flow at the risk. On the average, horizontal projection gave a higher rate than either upward or downward projection of spray, the rates of flow from which were similar. The differences between the rates of flow with the three directions of projection were less for nozzles with larger cone angles.

It was observed during the tests of downward projected spray that a fairly strong wind ($>$ 8 ft/s) could cause sufficient deflection of the spray cones to reduce markedly the quantity of spray reaching the base of the risk on the windward side. The effect of deflection was much less for horizontal or upward projection.

## DISCUSSION

To ensure efficient protection of a risk, over which oil may burn, by a fixed array of spray nozzles, the essential requirement is that the spray must reach every surface on which oil can burn in sufficient quantity to extinguish or control the fire under all expected weather conditions. The required rate of flow to unit surface area of the risk may be estimated using data given elsewhere(1) from expected temperatures of the rig at the times when the spray would be applied after the start of a fire. The wastage of water would be a minimum when the spray reaches all surfaces of the risk at the required rate for extinguishing or controlling the fire, and the spray projected beyond the risk is the minimum necessary to extinguish spill fires.

With the present risk a sufficiently uniform cover was obtained with at least four nozzles mounted in line 4 ft 6 in above the risk; but it would also be possible to achieve such cover with nozzles mounted to spray at an angle on to the risk. Uniformity of spray cover would be best assured by the use of nozzles delivering a fairly uniform pattern of spray, and such cover would be much less affected by wind speed than that provided by nozzles with a peaked spray pattern. Though the actual differences in flow rate over a risk between spray nozzles of peaked or uniform pattern were not measured because of a time limit on the occupancy of the test site, they would be expected to be less marked than those shown in Fig. 7 c and d, since the variations in wind speed usually encountered would alter momentarily the position of the high and low rates of flow, and so make the flow rate more uniform over a period of time.

The calculation of spray cover to a surface of a risk from the spray pattern and cone angle of a nozzle produces an underestimate of the amount of spray reaching the surface (Table 3). The increase in the measured rates of flow over the calculated values are probably due to the "pull-in" of sprays, and to the destruction of momentum in meeting spray clouds.

The "pull-in" of sprays is occasioned by the drag of air on each droplet transferring momentum from the droplet, which rapidly reduces its velocity to the terminal velocity, and imparts velocity to the air. The air stream so produced by spray is maintained by air drawn into the sides of the spray stream, and this movement of air laterally into the spray stream deflects the spray drops inwards towards the axis of the stream. The effect is not confined to spray from a single nozzle but is also found for arrays of nozzles at a sufficient distance from the nozzles. The distribution of spray within the spray cone from a nozzle can affect the degree of "pull-in" occurring, and also, since an increase in the momentum of drops will reduce the deflection produced by the induced air, an increase in pressure at the nozzle will reduce "pull-in". Thus, the impinging jet directional nozzles, having substantially similar spray patterns at differing pressures, show a lesser decrease of "pull-in" with increasing pressure, than the swirl nozzles, for which the spray pattern becomes more peaked as pressure increases (Fig. 4).

The wide angle non-directional impinging jet nozzle N behaved quite differently from the directional nozzles, since the increase, above the calculated amount, of spray reaching the top of the risk increased with increasing pressure. Thus the effect of variations in operating pressure would be to cause even greater variation in the flow rate to the top of the risk. This difference in behaviour between the non-directional and the directional nozzles is probably associated with the hollow spray pattern of the non-directional nozzle. The spray therefore had little momentum in the downward direction, the bulk of the spray being projected laterally and hence producing lateral momentum. The mutual interference of sprays from adjacent nozzles would destroy this lateral momentum, and the spray would then fall downwards under gravity. The increase in the rate of flow at the risk with increasing pressure was probably due to increasing mutual interference of the laterally projected sprays as pressure increased.

Since this destruction of momentum is a separate effect from that of "pull-in", it can account also for the much larger increase in the measured rate of flow at the risk over the calculated values for sprays from non-directional nozzle N, which has large lateral momentum, as compared with the directional nozzles, which have small lateral momentum.

The "pull-in" of the spray cloud from an array of nozzles would also account for the relation found between rate of flow at the risk and nozzle pressure. For nozzles mounted at a given height above the risk, a linear trajectory of spray drops would lead to the relation that the amount of spray reaching the risk would be approximately proportional to the square root of pressure, instead of the cube root, as found. Also, if the drops followed a linear trajectory the rate of flow at the risk would be proportional to the inverse square of the distance of the nozzles from the risk. Thus, the flow rate at the risk for nozzles at 9 ft, would be expected to be 0.198 of that for nozzles at 4 ft above the risk. The actual proportion found for four nozzles L or M (Fig. 6) is approximately 0.33.

The cone angle of the spray nozzles affected the wastage of spray by projection beyond the risk. This is illustrated in Fig. 9 in which the percentage of the total rate of flow of spray actually reaching the top of the risk from four nozzles operated at 50 $lbf/in^2$ and 4 ft 6 in above the risk is plotted against the angle of the spray cone. Fig. 9 also gives support to the expectation that less spray would be lost from nozzles with a peaked spray pattern than from nozzles with a uniform spray pattern, and, further, suggests that the loss of spray from nozzles with a hollow spray pattern is of the same order as that from nozzles with a uniform pattern.

The above points show the way in which nozzles may be selected to obtain the most efficient distribution of spray over a risk, from a nozzle array projecting spray vertically downwards. The nozzles should be placed as close as possible to the risk commensurate with the spray nozzles being unimpaired by damage by fire, and the spray cone angle should be so chosen to minimize wastage of spray by projection beyond the risk. The flames in fire tests on the present risk[1] varied in height from 10 - 30 ft, but nozzles placed 4 ft 6 in above the risk did not have their performance impaired, although some nozzles with moving parts were slightly damaged by fire. In these tests, the nozzles were free from water until the spray was discharged. Nozzles sited to spray at an angle on to a risk and therefore not directly above any area supporting flames could be placed closer to the risk without the chance of their performance being impaired. The extent to which spray should extend beyond the risk will depend upon the expected wind speeds.

## Practical implications

The efficiency of a fixed water spray installation for the protection of a risk against running oil fires depends upon the spray being applied at a rate sufficient to control or extinguish the fire wherever it may occur; and upon the reduction of the quantity of spray projected beyond the risk to a minimum commensurate with provision of the desired cover to the risk under all expected wind conditions. The rate of spray application required will depend on whether control or extinction is needed, and on the expected time of burning before the spray is applied. A simple method of calculating the rate of application is given elsewhere(1).

The requirement that spray at the requisite rate must reach all surfaces of a risk where burning may take place can be met economically by mounting as few nozzles as possible directly above the risk, and arranging other nozzles to project spray at an angle on to the remaining unprotected surfaces of the risk. The nozzles should be mounted as close to the risk as the need for unimpaired operation will allow. The distance of nozzles from the risk will then depend on the material from which they are made, and the time for which the nozzles may be heated by flames.

The number and spacing of the nozzles used should be such as to give the desired spray cover under the worst expected wind conditions. The use of nozzles with a uniform spray pattern reduces to a minimum the effect of wind on the rate of application to a given surface, although the proportionate loss of spray is greater than with peaked spray nozzles. The spray protection at an edge of a risk separating a vertical and horizontal face should extend beyond the risk. In the present tests, directional nozzles of 50° cone angle, 4 to 5 ft above the nearest part of the risk, gave sufficient over-spray if they were mounted 8 inches outside the edge of the risk, for wind speeds of up to 15 ft/s.

The wastage of spray by projection beyond the risk can be minimised by using nozzles of small cone angle. The maximum size of cone angle that may be used efficiently will depend on the size of the risk and the distance of the nozzle from it; as the size of risk increases and the distance from the risk decreases, so the required cone angle of the nozzle increases.

The use of wide angle nozzles producing a hollow spray pattern is not desirable. Such nozzles may be sensitive to variations of operating pressure, and because of the low axial momentum of spray from such nozzles, the spray cloud is easily deflected by wind.

Subject to the provision of additional cover to allow for the effect of wind, the rate of application of spray to a risk may be calculated from the geometry of the system(5). In this way design data could be provided for each kind of nozzle to ensure its efficient use in a protective water spray system.

The extinction of fires of oil pouring over hot metal surfaces requires greater flow rates of spray than the extinction of pool, or spill, fires(1, 6). It is therefore important, for economy in the supply of water and pumping capacity, to design the spray cover separately for these risks so that the greater flow rates are used to protect the metal risk, and the lower flow rates to protect areas where pool or spill fires could occur.

## REFERENCES


(1) RASBASH, D. J. and STARK, G. W. V. F. R. Note No. 303.

(2) "A Test Rig for Reproducible fires of oil pouring over a Tube Bank", (in publication).

(3) RASBASH, D. J. and STARK, G. W. V. F. R. Note No. 445. "Some aerodynamic properties of Sprays".

(4) RASBASH, D. J. and STARK, G. W. V. "Control of distribution of spray to an area". J. Sci. Inst. 34 No. 2, 1957.

(5) "Water spray protection for oil cooled transformers". Factory Mutual Laboratories. Research Project No. 12549-S1, 1954.

(6) RASBASH, D. J. and ROGOWSKI, Z. W. "Extinction of fires in liquids by cooling with water sprays". Combustion and Flame 1957, No. 4. p. 453.

TABLE 1

PROPERTIES OF SPRAYS

| NOZZLE DATA | | | | PROPERTIES AT NOZZLE | | | PROPERTIES OF SPRAY | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | DOWNWARD FORCE IN SPRAY | | |
| Code | Type | Spray pattern | Pressure $lbf/in^2$ | Cone angle ° | Total flow rate Gal/min | Nozzle reaction per unit flow rate $lbf/gal/min^{-1}$ | Estimated mass median drop size mm | Measured at an obstruction $lbf/gal/min^{-1}$ (+) | Force in air current $lbf/gal/min^{-1}$ * | Drop velocity ft/s* |
| A | Swirl directional | Moderately peaked | 25 | 65 | 9.9 | 0.261 | 1.2 | 0.29 | 0.183 | 20.4 |
| | | | 50 | | 14.0 | 0.325 | 0.97 | 0.51 | 0.240 | 20.9 |
| | | | 90 | | 18.3 | 0.437 | 0.83 | 0.81 | 0.379 | 14.4 |
| B | " | Peaked | 25 | 48 | 10.7 | 0.251 | 1.2 | 0.41 | 0.167 | 19.8 |
| | | | 50 | | 15.5 | 0.363 | 0.99 | 0.51 | 0.244 | 26.9 |
| | | | 90 | | 20.0 | 0.514 | 0.85 | 0.59 | 0.418 | 19.8 |
| L | Impinging jet directional | " | 25 | 51 | 19.4 | 0.287 | 3.9 | 0.52 | 0.117 | 36.8 |
| | | | 50 | | 28.2 | 0.402 | 3.2 | 0.49 | 0.169 | 47.8 |
| | | | 90 | | 37.2 | 0.537 | 2.8 | 0.60 | 0.298 | 48.4 |
| M | " | " | 25 | 100 | 19.1 | 0.221 | 1.8 | 0.41 | 0.113 | 26.7 |
| | | | 50 | | 26.3 | 0.336 | 1.5 | 0.44 | 0.156 | 38.2 |
| | | | 90 | | 35.4 | 0.421 | 1.3 | 0.53 | 0.267 | 33.0 |
| L' | " | Uniform | 25 | 52 | 18.6 | 0.215 | 1.6 | 0.32 | 0.129 | 22.4 |
| | | | 50 | | 25.7 | 0.330 | 1.3 | 0.35 | 0.220 | 25.4 |
| | | | 90 | | 33.4 | 0.449 | 1.1 | 0.67 | 0.344 | 23.6 |
| M' | " | " | 25 | 98 | 17.7 | 0.157 | 0.84 | 0.18 | 0.102 | 18.4 |
| | | | 50 | | 24.1 | 0.224 | 0.68 | 0.49 | 0.175 | 15.9 |
| | | | 90 | | 31.1 | 0.318 | 0.59 | 0.49 | 0.278 | 12.8 |
| N | Impinging jet non-directional | Hollow | 25 | 140 | 17.1 | 0.071 | 0.91 | N.M. | 0.0201ø | 12.6φ |
| | | | 50 | | 22.4 | 0.105 | 0.74 | N.M. | - 0.0075ø | 9.6φ |
| | | | 90 | | 30.6 | 0.164 | 0.64 | N.M. | - 0.0227ø | 8.1φ |

N.M. = Too small to measure.
(+) = Force measured 7 ft 6 in below nozzle.
* = Measured 6 ft below nozzle.
ø = Force over central 9 ft diameter
φ = Sum of terminal velocity and velocity due to air current.

SYMBOLS

A = Swirl Nozzle, Wide Angle, Directional.
B = " " Narrow " "
L = Impinging Jet Nozzle, Narrow Angle, Directional, Peaked Pattern.
L' = " " " " " " Uniform "
M = " " " Wide " " Peaked "
M' = " " " " " " Uniform "
N = " " " " " Non-directional.

TABLE 2

CONTRIBUTION OF SMALL END TRAYS TO AMOUNT OF SPRAY COLLECTED AT RISK NOZZLE 4 ft 6 in ABOVE RISK (Fig. 5 refers)

| Nozzle | | Pressure lbf/in$^2$ | Spray collected Gal/min. | | Percentage of Spray Normally Collected | |
|---|---|---|---|---|---|---|
| Type | No. | | Top & long sides | Short sides | Increase contributed by short sides | Mean value |
| M' | 1 | 90 | 9.1 | 0.17 | 1.9 | 1.9 |
| M' | 2 | 90 | 16.1 | 1.00 | 6.2 | 4.9 |
| M' | 2 | 90 | 18.1 | 0.69 | 3.7 | |
| L | 4 | 25 | 39.2 | 7.23 | 18.4 | 11.5 |
| | | 25 | 34.8 | 4.00 | 11.5 | |
| M | 4 | 25 | 27.7 | 2.22 | 8.0 | |
| L' | 4 | 25 | 21.0 | 1.29 | 6.2 | |
| M' | 4 | 25 | 15.2 | 1.10 | 7.2 | |
| L | 4 | 50 | 53.4 | 6.47 | 12.1 | 10.9 |
| M | 4 | 50 | 30.0 | 3.57 | 11.9 | |
| L' | 4 | 50 | 37.5 | 3.34 | 8.9 | |
| M' | 4 | 50 | 16.0 | 1.54 | 9.6 | |
| L | 4 | 90 | 66.8 | 14.14 | 21.2 | 14.5 |
| | 4 | 90 | 60.5 | 9.57 | 15.8 | |
| M | 4 | 90 | 44.4 | 6.11 | 13.8 | |
| | 4 | 90 | 35.0 | 3.30 | 9.4 | |
| L' | 4 | 90 | 49.2 | 5.54 | 11.3 | |
| M' | 4 | 90 | 19.4 | 1.41 | 7.3 | |
| | 4 | 90 | 27.5 | 5.58 | 20.3 | |
| | 4 | 90 | 23.5 | 3.17 | 13.5 | |
| | 4 | 90 | 15.9 | 0.74 | 4.7 | |
| L | 7 | 25 | 67.0 | 6.70 | 10.0 | 9.3 |
| | 7 | 25 | 84.8 | 11.08 | 13.1 | |
| M | 7 | 25 | 64.7 | 4.24 | 6.6 | |
| L' | 7 | 25 | 63.0 | 3.94 | 6.3 | |
| L | 7 | 50 | 102.7 | 9.36 | 9.1 | 11.7 |
| | 7 | 50 | 107.9 | 13.72 | 12.7 | |
| M | 7 | 50 | 86.3 | 11.75 | 13.6 | |
| | 7 | 50 | 84.9 | 12.40 | 14.6 | |
| L' | 7 | 50 | 90.8 | 8.19 | 9.0 | |
| L | 7 | 90 | 114.5 | 17.36 | 15.2 | 14.2 |
| | 7 | 90 | 142.9 | 19.76 | 13.8 | |
| | 7 | 90 | 125.9 | 14.50 | 11.5 | |
| M | 7 | 90 | 89.2 | 17.70 | 19.9 | |
| | 7 | 90 | 114.7 | 14.10 | 12.3 | |
| L' | 12 | 90 | 121.8 | 14.30 | 11.7 | 11.7 |

**TABLE 3**

**Measured and Calculated Rates of Flow in Still Air**

**Spray projected vertically downwards**

| No. of Nozzles | | 2 | | 4 | | 7 | | 8 | | 12 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Rate of flow at top of risk, Gal/min. | | | | | | | | | |
| Type | Pressure Lbf/in$^2$ | Measured | Calculated | Measured | Calculated | Measured | Calculated | Measured | Calculated | Measured | Calculated |
| A | 25 | (14) | 5.90 | (14) | 7.95 | - | - | (20) | 9.81 | - | - |
| | 50 | (18) | 10.99 | (20) | 14.80 | - | - | (29) | 18.14 | - | - |
| | 90 | (21) | 19.57 | (24) | 25.46 | - | - | (34) | 26.60 | - | - |
| B | 25 | (18) | 6.74 | (24) | 9.20 | - | - | (29) | 12.03 | - | - |
| | 50 | (23) | 11.12 | (30) | 14.94 | - | - | (32) | 18.73 | - | - |
| | 90 | (32) | 24.97 | 34.1 | 32.20 | - | - | (38) | 32.49 | - | - |
| L | 25 | (34) | 28.66 | 39.4 | 31.95 | (82) | 49.87 | - | 22.27 | - | 54.22 |
| | 50 | (42) | 40.20 | 52.4 | 46.84 | (102) | 72.40 | - | 30.57 | - | 77.41 |
| | 90 | (55) | 47.07 | 60.7 | 55.37 | (134) | 86.03 | - | 39.55 | - | 94.91 |
| L' | 25 | (21) | 12.69 | 26.9 | 18.31 | (61) | 35.89 | - | 26.62 | - | 44.93 |
| | 50 | (33) | 21.33 | 38.4 | 29.52 | - | 58.15 | - | 36.44 | - | 65.96 |
| | 90 | (50) | 41.33 | 53.5 | 52.03 | - | 106.93 | - | 43.91 | (105) | 85.76 |
| M | 25 | (28) | 14.33 | 30.9 | 16.88 | (66) | 37.15 | - | 12.31 | - | 29.18 |
| | 50 | (32) | 23.91 | 37.6 | 28.27 | (83) | 62.16 | - | 21.27 | - | 49.51 |
| | 90 | (40) | 36.07 | 46.6 | 42.26 | (109) | 93.91 | - | 30.44 | - | 72.69 |
| M' | 25 | (10) | 5.77 | 10.9 | 9.20 | - | 17.38 | - | 16.27 | - | 25.27 |
| | 50 | (13) | 9.24 | 17.6 | 14.47 | - | 27.48 | - | 25.12 | - | 39.59 |
| | 90 | (18) | 16.72 | 26.0 | 24.40 | - | 47.89 | - | 37.26 | - | 61.74 |
| N | 25 | - | - | 6.2 | 2.57 | - | - | (12) | 5.30 | (25) | 7.87 |
| | 50 | - | - | 8.8 | 2.50 | - | - | (29) | 5.34 | 35.4 | 7.83 |
| | 90 | - | - | 9.5 | 3.36 | - | - | (32) | 7.38 | 67 | 10.74 |

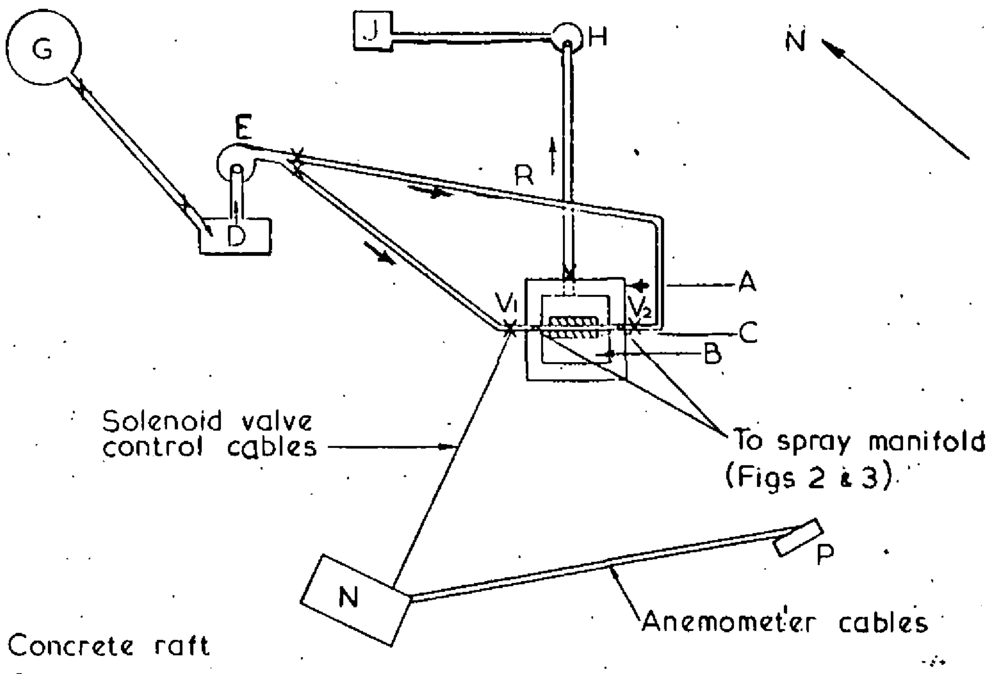
N.B. Measured flow rates are mean values from several tests. Where the number of tests was less than 4, the mean is shown in parenthesis.

TABLE 4

FLOW RATE OF SPRAY PROJECTED AT AN ANGLE TO THE RISK

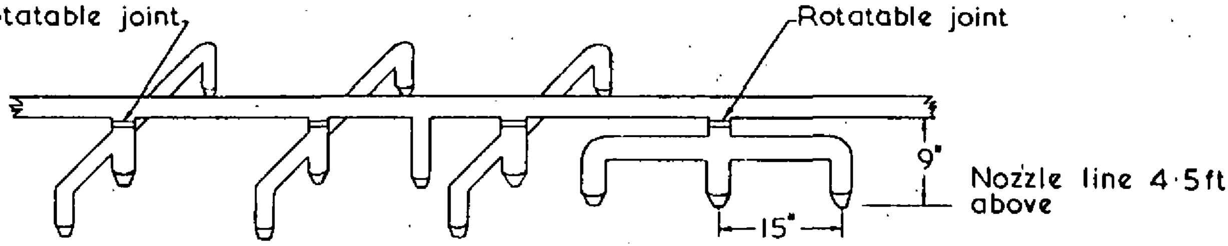
| Test No. | NOZZLE DATA | | | | WIND SPEED | | FLOW RATE AT RISK Gal/min. | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Type | Direction of Projection | ANGLE BETWEEN NOZZLE AXES AND | | Mean Value ft/s | Coefficient of variation | Top | Long sides | Short sides | Total |
| | | | (a) Vertical | (b) Long side of risk | | | | | | |
| 1 | M | Down | 50 | 50 | 9.7 | 0.10 | 8.3 | 18.8 | 15.8 | 42.9 |
| 2 | M | Horizontal | 95* | 50 | 8.2 | 0.09 | 0.0 | 26.3 | 20.2 | 46.5 |
| 3 | M | Up | 45 | 50 | 8.0 | 0.04 | 0.0 | 21.7 | 16.9 | 38.6 |
| 4 | M' | Down | 50 | 50 | 4.4 | 0.15 | 8.5 | 8.5 | 8.5 | 25.5 |
| 5 | M' | Horizontal | 95* | 50 | 7.3 | 0.17 | 0.0 | 10.5 | 12.5 | 23.0 |
| 6 | M' | Up | 45 | 50 | 6.9 | 0.07 | 0.0 | 13.2 | 15.0 | 28.2 |
| 7 | A | Down | 50 | 45 | 5.0 | 0.16 | 0.99 | 32.1 | 2.36 | 35.5 |
| 8 | A | Horizontal | 95* | 45 | 4.5 | 0.10 | 1.45 | 44.7 | 1.50 | 47.7 |
| 9 | A | Up | 45 | 45 | 5.0 | 0.11 | 0.99 | 31.9 | 0.63 | 33.5 |
| 10 | B | Down | 50 | 45 | 8.0 | 0.27 | 1.39 | 29.2 | 1.75 | 32.3 |
| 11 | B | Horizontal | 95* | 45 | 6.2 | 0.09 | 0.98 | 39.3 | 0.74 | 41.0 |
| 12 | B | Up | 45 | 45 | 12.4 | 0.06 | 2.38 | 37.1 | 0.48 | 40.0 |
| 13 | L' | Down | 50 | 45 | 6.3 | 0.13 | 1.21 | 51.3 | 3.27 | 55.8 |
| 14 | L' | Horizontal | 95* | 45 | 2.5 | 0.13 | 4.58 | 67.3 | 3.05 | 74.9 |
| 15 | L' | Up | 45 | 45 | 3.5 | 0.12 | 9.00 | 46.8 | 2.32 | 58.1 |
| 16 | M | Down | 50 | 45 | 5.0 | 0.05 | 3.78 | 57.9 | 2.30 | 64.0 |
| 17 | M | Horizontal | 95* | 45 | 3.6 | 0.07 | 1.97 | 53.8 | 2.05 | 57.8 |
| 18 | M | Up | 45 | 45 | 5.2 | 0.20 | 12.30 | 36.7 | 2.05 | 51.1 |
| 19 | N | Down | 50 | 45 | 8.6 | 0.19 | 2.58 | 4.79 | 0.37 | 7.7 |
| 20 | N | Horizontal | 95* | 45 | 7.5 | 0.10 | 1.22 | 4.96 | 0.76 | 6.9 |
| 21 | N | Up | 45 | 45 | 4.7 | 0.10 | 0.31 | 5.98 | 1.14 | 7.4 |
| 22 | N | (All three) (combined) | - | - | 8.1 | 0.21 | 1.71 | 11.0 | 1.68 | 14.4 |

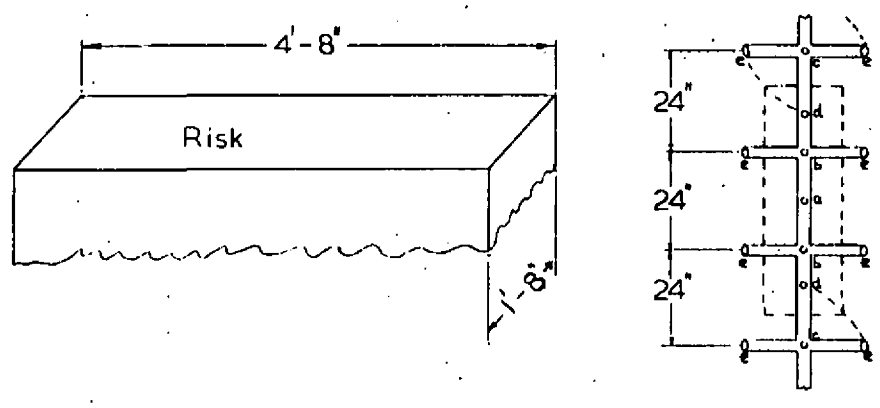
*Nozzles pointed up slightly so that spray core was horizontal at the risk.




A Concrete raft
B Gravel filled trays
C Tube rig, standing in B
D 1,000 gal water feed tank
E Water pump
G 10,000 gal water storage tank
H Drainage pump, gravel trays
J Oil separating tanks
N Control hut
P Weather station
R $2\frac{1}{2}$" water ring main
V Solenoid valves, ring main to spray manifold
X Control valves

FIG. 1. DIAGRAM OF SITE AND EQUIPMENT




| No. OF SPRAY NOZZLES | POSITIONS |
|---|---|
| 1 | a |
| 2 | b |
| 4 | b c |
| 7 | abcd |
| 8 | e |
| 12 | bce |

FIG. 2 NOZZLE DISPOSITIONS
(Spray projected vertically downward)

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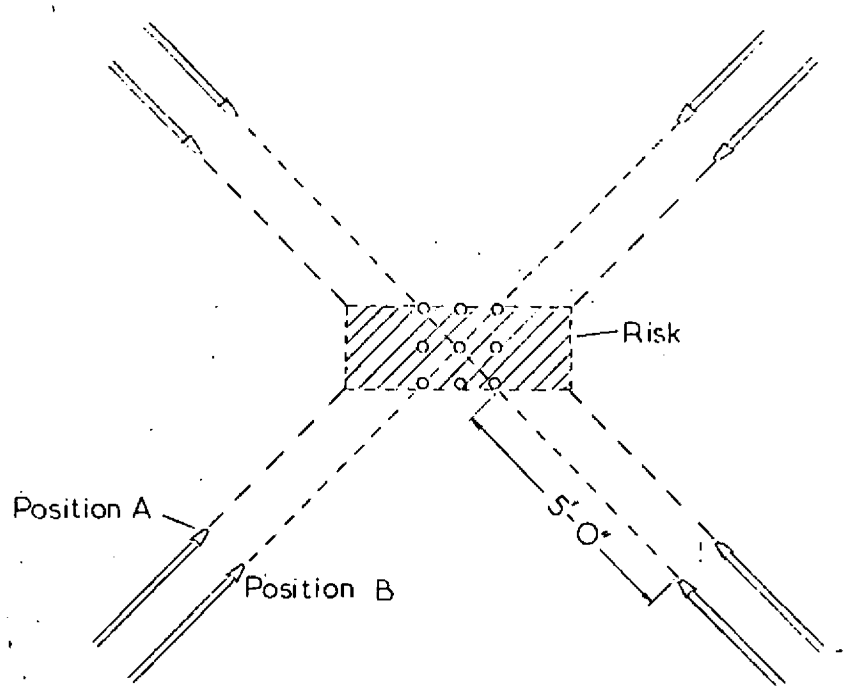
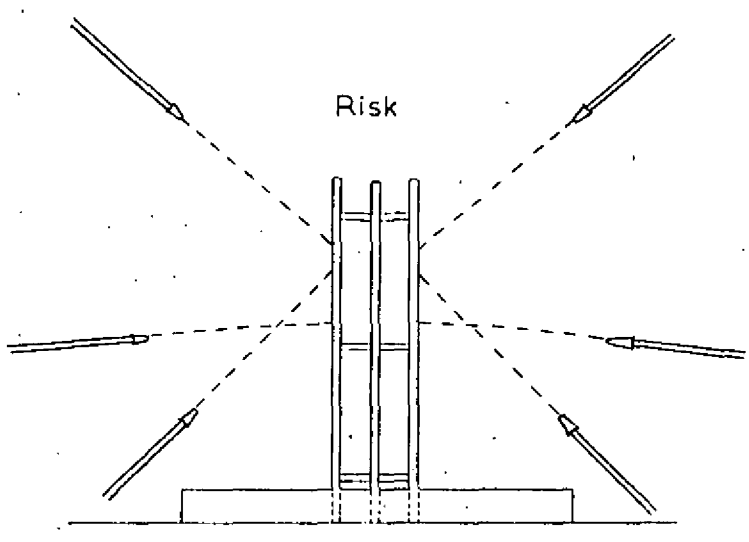



PLAN

Note. All nozzle mounting points not in use blanked off




ELEVATION

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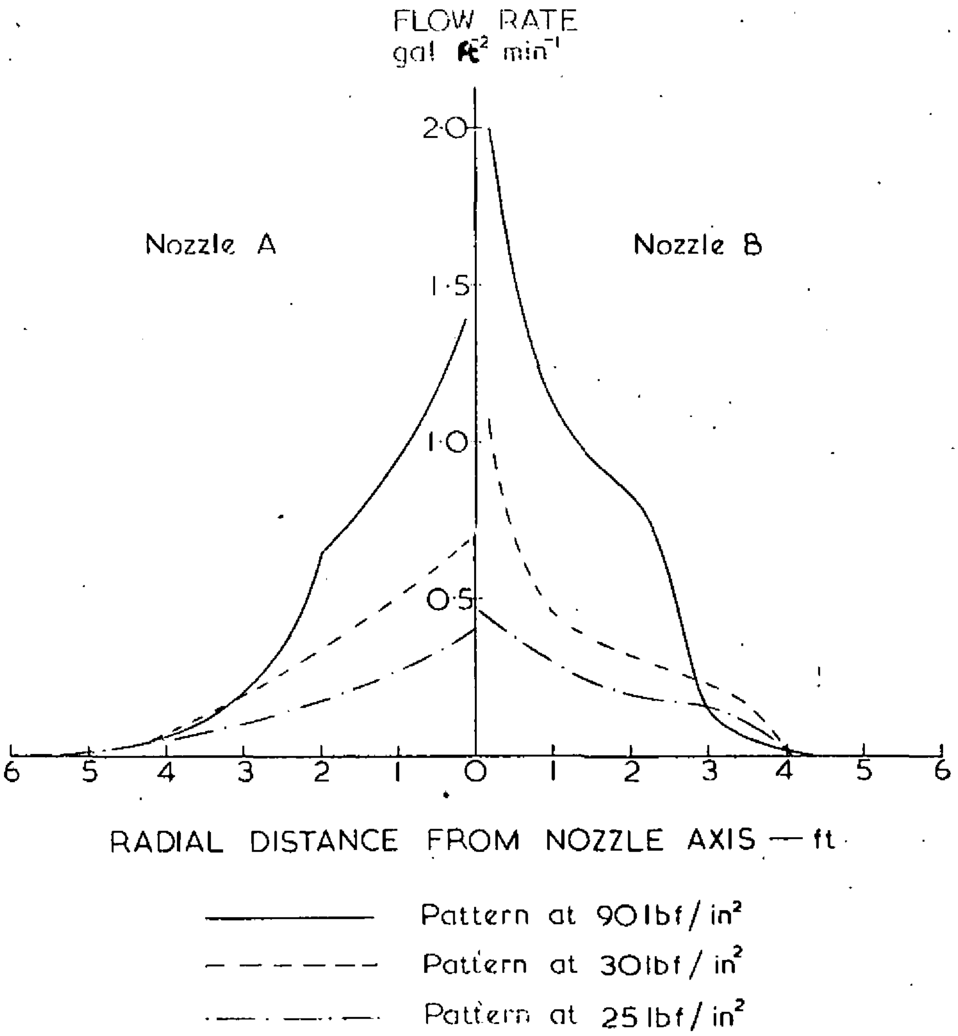
FIG. 3. NOZZLE MANIFOLD FOR PROJECTING SPRAY AT AN ANGLE ON TO THE RISK



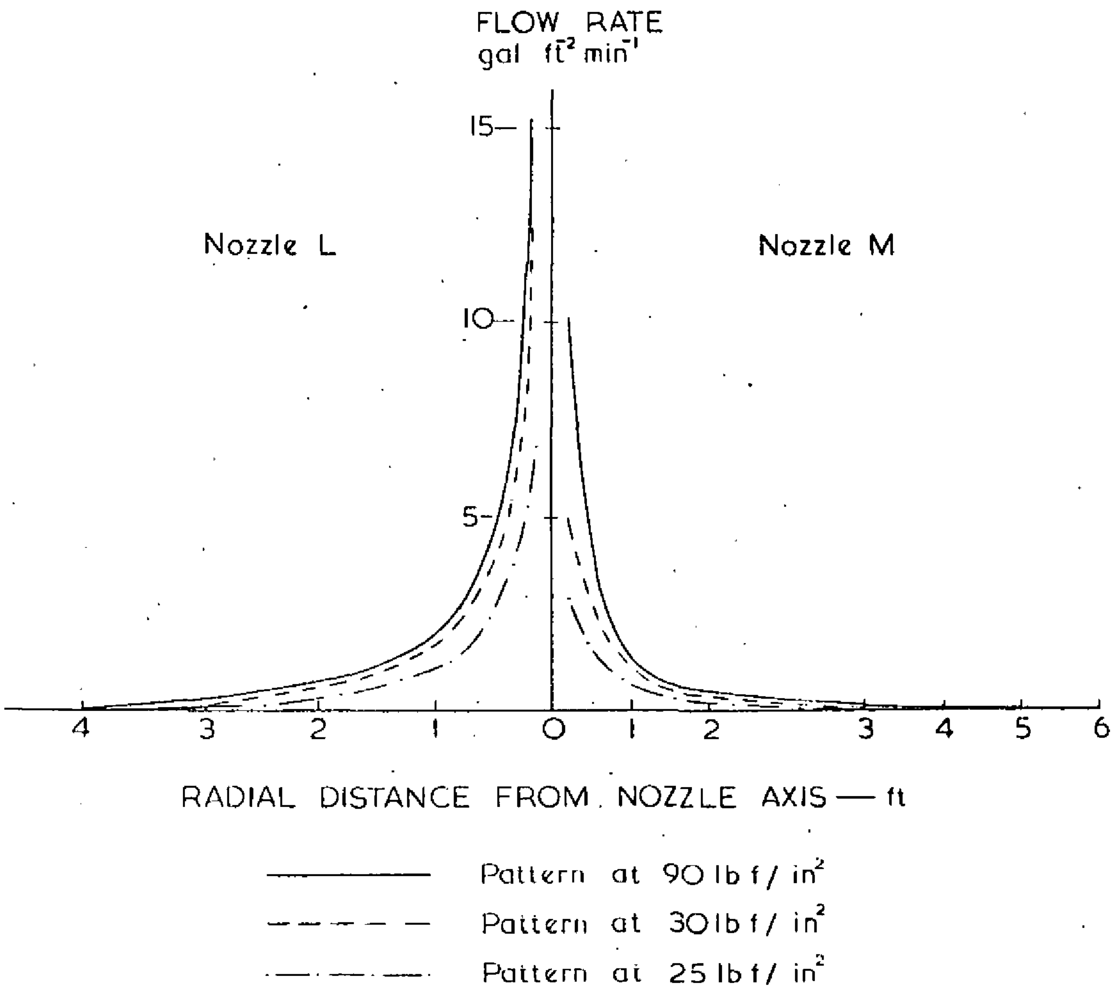




FIG. 4. SPRAY PATTERN, 7′-6″ BELOW NOZZLE

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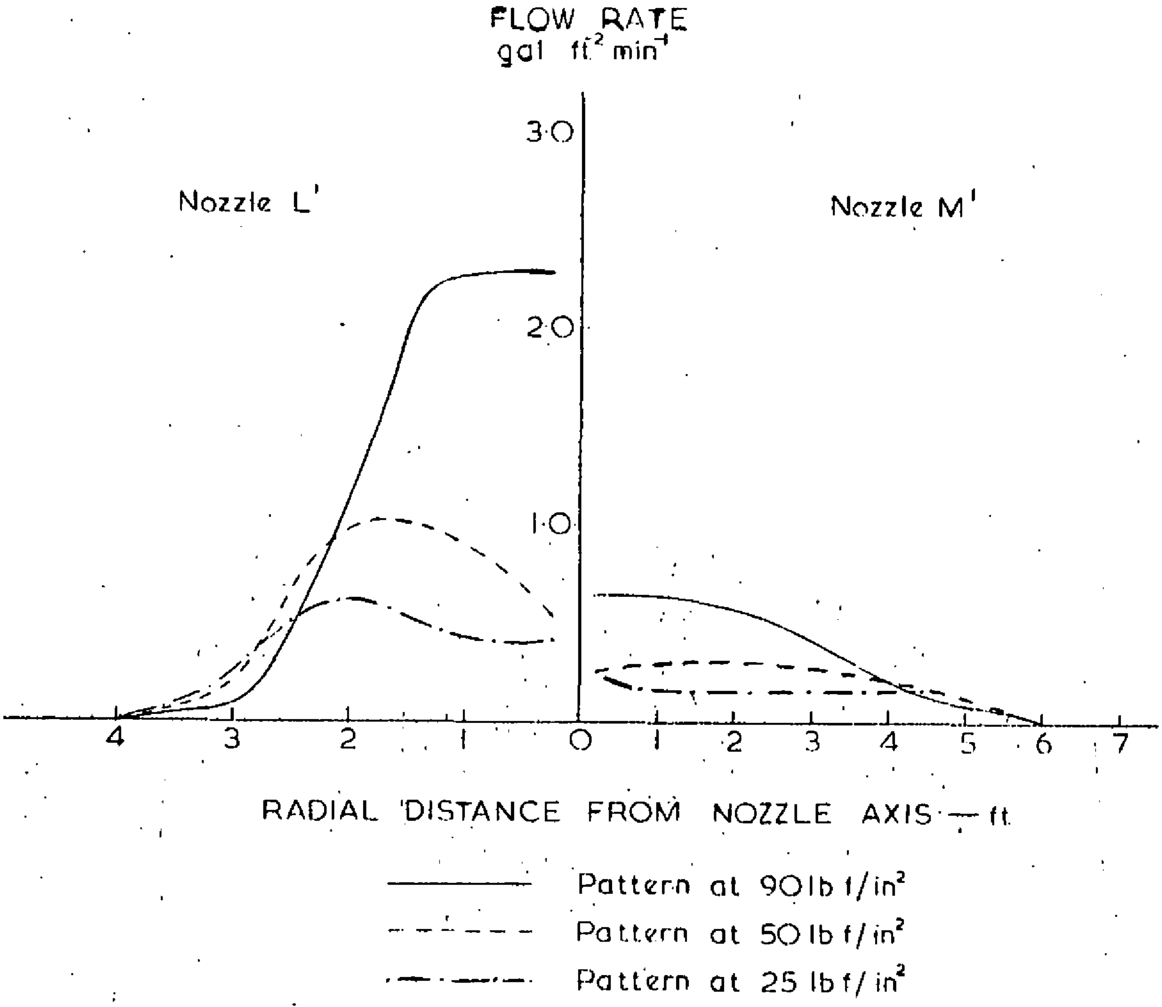


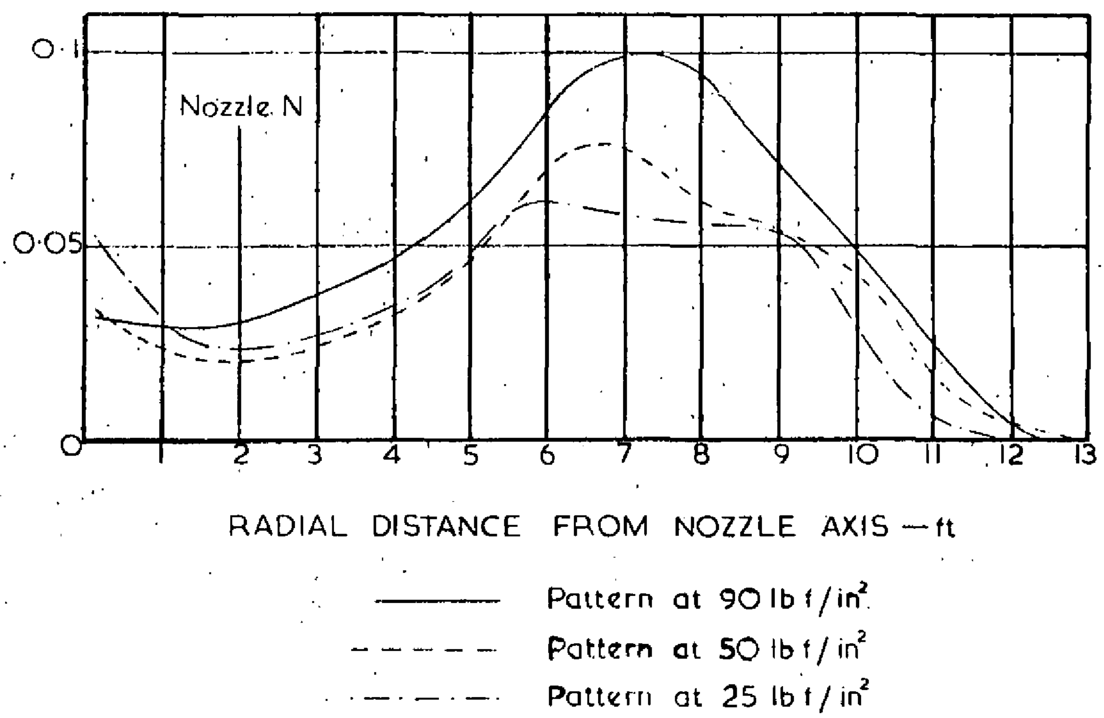


FIG.4.(CONTINUED) SPRAY PATTERN, 7'-6" BELLOW NOZZLE

FR.465

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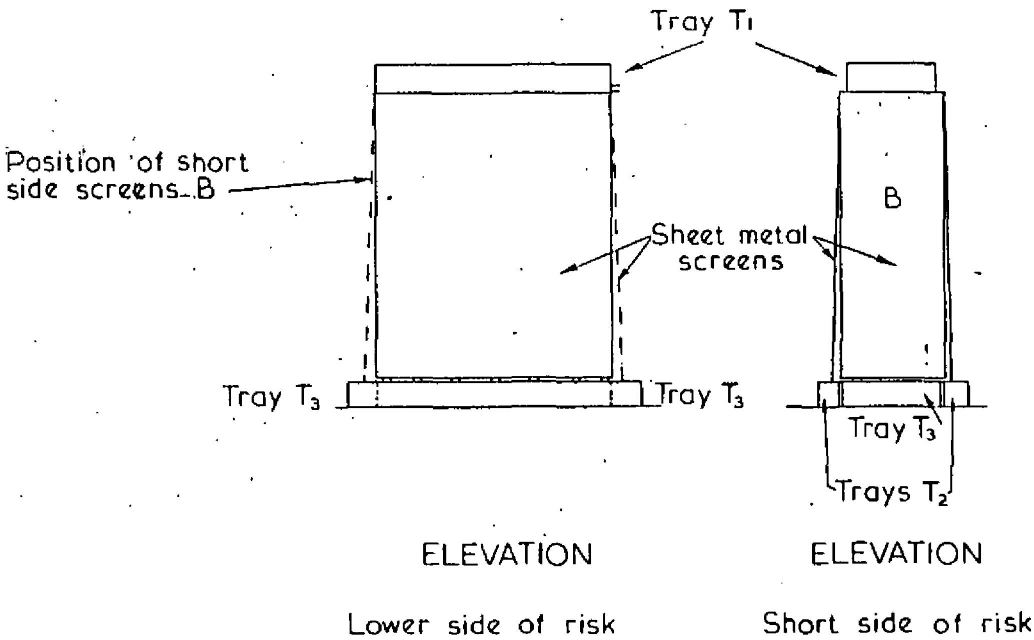


FIG. 5. APPARATUS FOR MEASUREMENT OF FLOW RATE

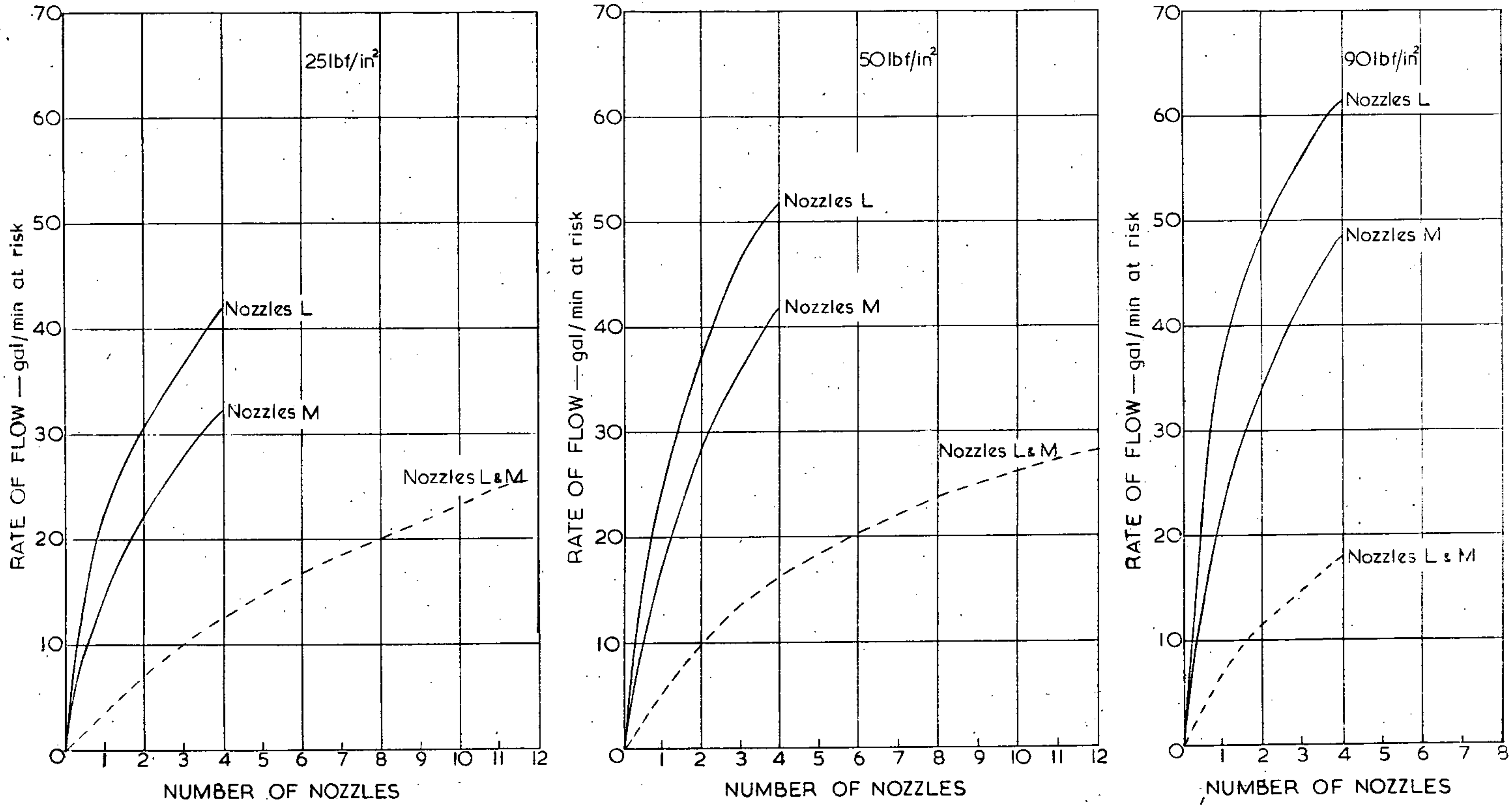


FIG. 6. EFFECT OF NUMBER OF NOZZLES

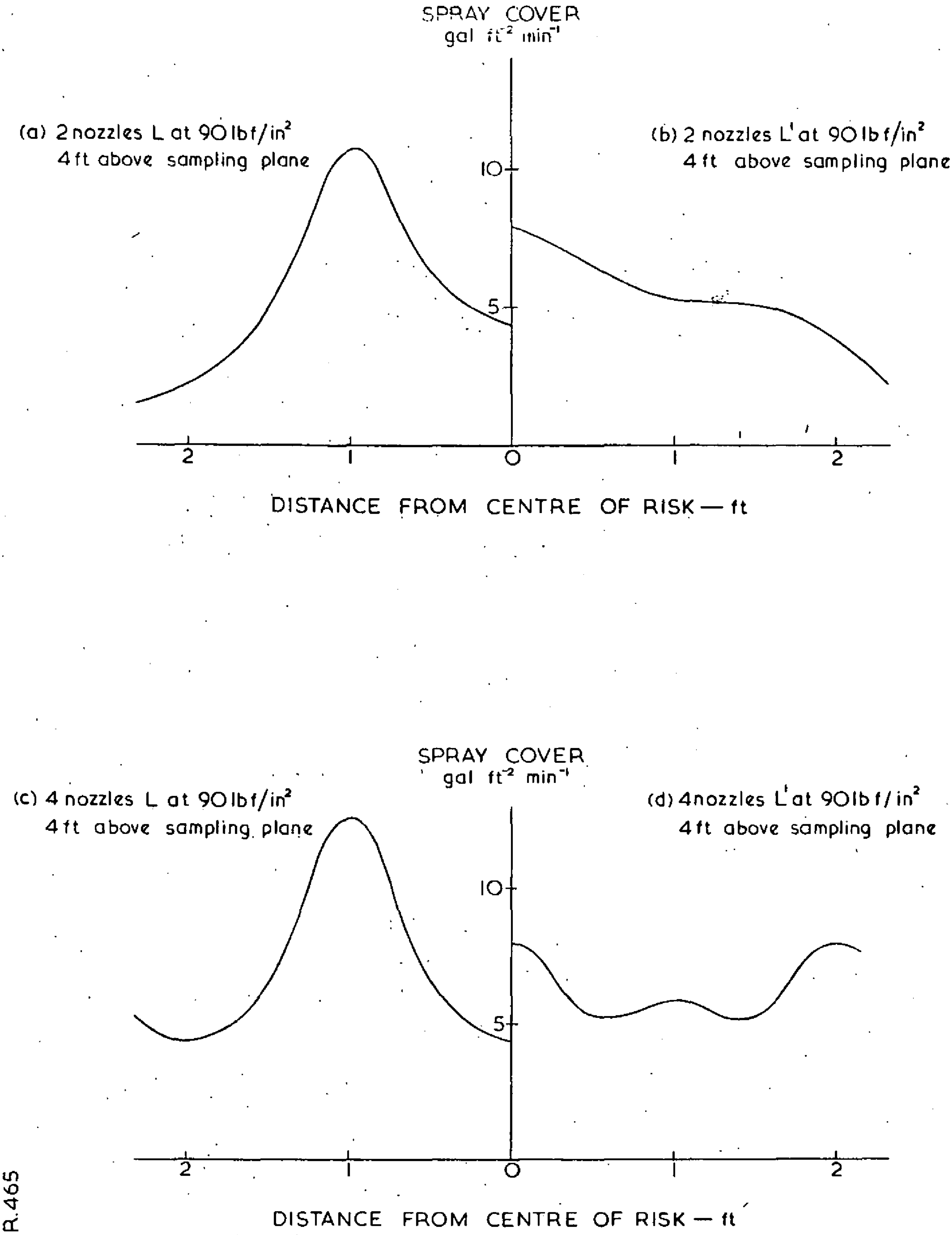


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FIG.7 SPRAY DISTRIBUTION AT TOP OF RISK

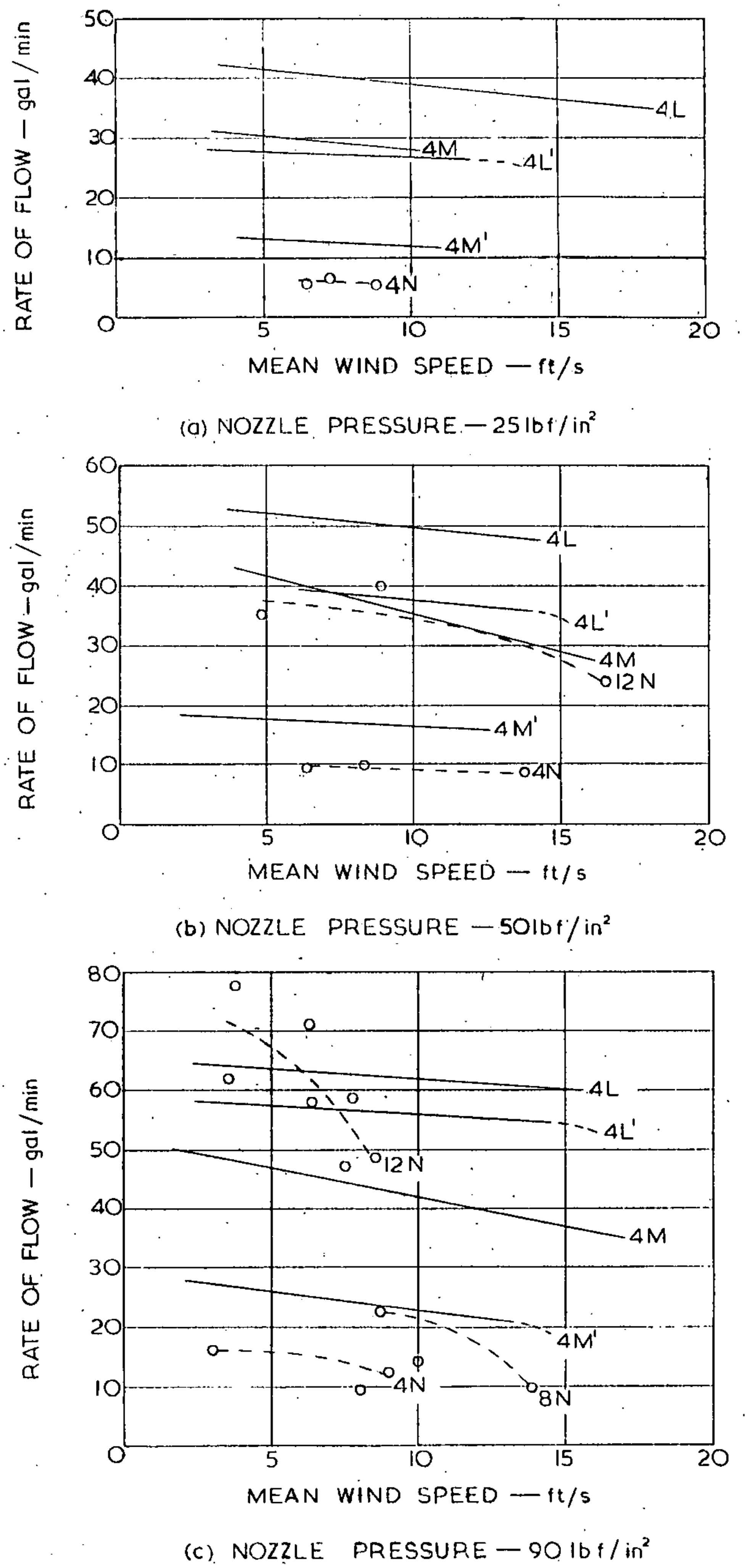


FIG. 8 EFFECT OF WIND SPEED ON RATE OF FLOW FROM VERTICAL NOZZLE ARRAYS

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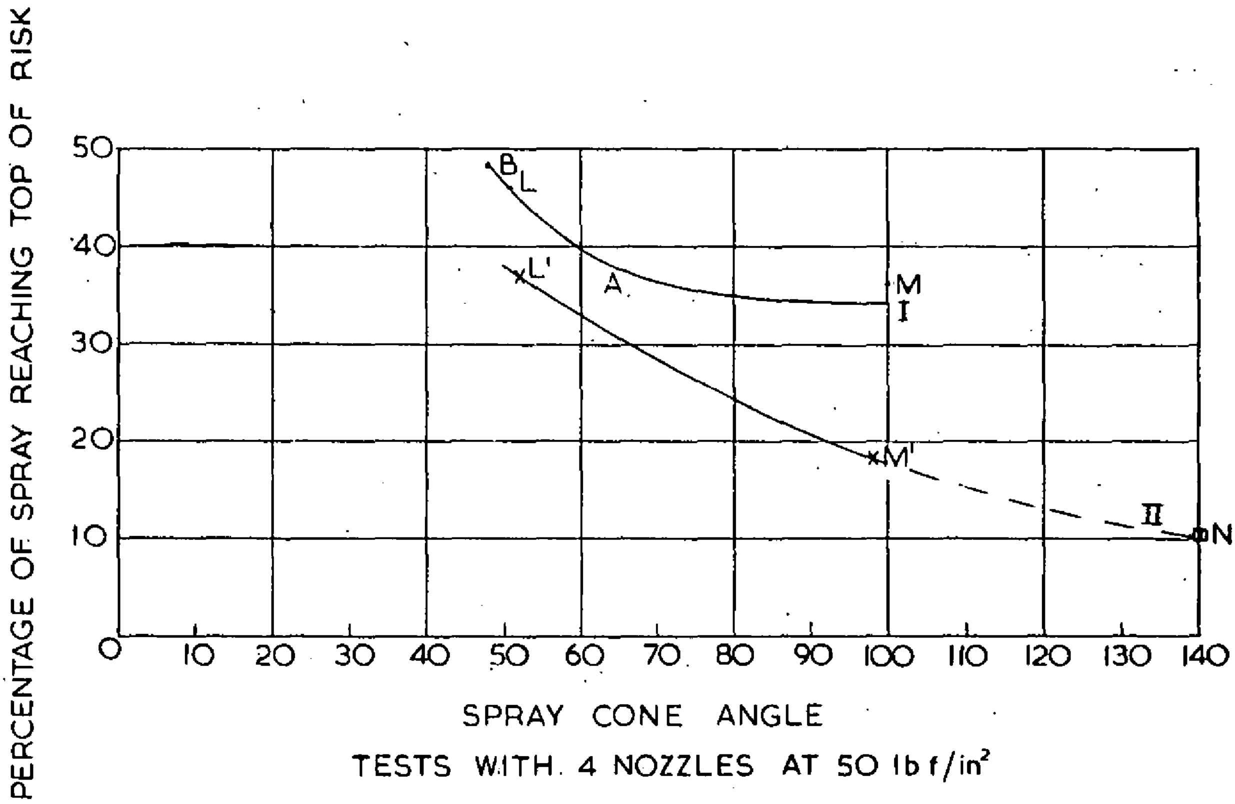
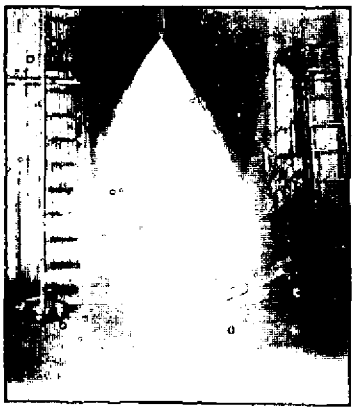



The letters refer to spray nozzle code (see table I)

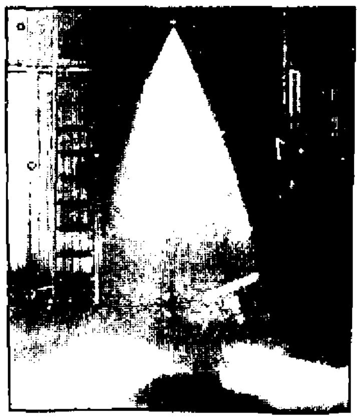
I Nozzles giving peaked spray pattern

II Nozzles giving uniform or hollow spray pattern

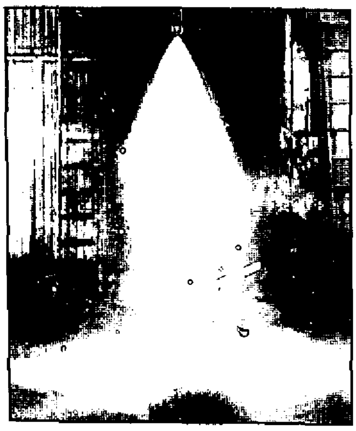
FIG. 9 PROPORTION OF SPRAY REACHING TOP OF RISK



Nozzle A

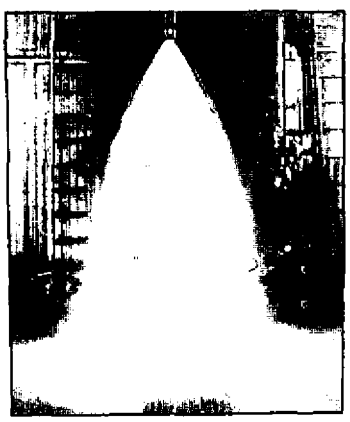


Nozzle B

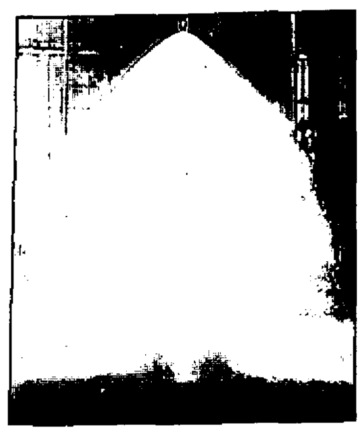


Nozzle L

Nozzle M



Nozzle $L^1$



Nozzle $M^1$

Nozzle N

PLATE. 1. SPRAYS PRODUCED BY NOZZLES OPERATING AT 50 $lb/in^2$