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MEASUREMENTS OF THE TRANSMISSION OF RADIATION THROUGH WATER SPRAYS

by

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SUMMARY

This report describes measurements of the transmission of radiation through water sprays from two types of nozzle. The transmission for a nozzle water pressure of 50 lb in^{-2} was appreciably lower than that for a pressure of 6.5 lb in^{-2} even for comparable water flows. A comparison of the results with those of Seekamp(4) and Schuler(5) suggests that transmission depends markedly on nozzle design and that with certain nozzles a water curtain of low transmission could be produced for water flows comparable with those of sprinkler installations.

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Introduction

In the consideration of water curtains as a possible means of preventing spread of fire within buildings it is necessary to know among other things the amount of thermal radiation which would be transmitted through such curtains. Measurements have accordingly been made of this transmission for the spray from a sprinkler head, and from a small nozzle giving a fan-shaped spray. The results are compared with data published for other nozzles.

Flat spray

The transmission through the spray from a nozzle consisting of a Bray 266/5 burner (Intended for use as a bat's wing burner) was measured by means of a radiometer (1) receiving radiation from a Schwank gas radiant panel either directly, or after passage through the spray (See Fig. 1). The radiometer was 19 cm below the nozzle which pointed vertically downwards and produced a flat spray increasing in width from 5 to 8 cm at the radiometer height as pressure increased from 1.1 to 2.6 lb in^{-2} (0.07 to 0.18 Atmospheres) and nozzle flow increased from 9.7 to 16 ml/s. The hot refractory surface of the panel measured about 12 cm wide and 17 cm high, and ran at 800-850°C. This temperature was high enough to produce a wavelength-intensity distribution comparable with that from large fires. The effect of increasing the source temperature to 1000°C (probably nearer the temperature of large fires) is shown in the section on "Scattering of radiation". The results are given in Table 1.

TABLE 1

RESULTS WITH FLAT SPRAY

Number of nozzles	Water pressure		Radiation transmission per cent
	cm Hg	lb in^{-2}	
1	6	1.1	95
	9.5	1.8	93
	12	2.3	90
	13	2.5	88
	13.5	2.6	88
3	12	2.3	74

Sprinkler Spray

The sprinkler was a spray-type sprinkler, pendent version, mounted 2.75 m (9 ft) from the floor, and operated at pressures of 50 and 6.5 lb in^{-2}

(3.4 and 0.4 atmospheres). A Schwank gas radiant panel was used as a radiation source. The panel was viewed by a Land total-radiation narrow-angle pyrometer type RNF 50/69 with an arsenic-trisulphide lens giving substantially constant and high transmission to 9 microns and some transmissions to 11 microns. The radiant panel and pyrometer were set up 1.4 m above the floor on opposite sides of the sprinkler spray (See Fig. 2).

The pyrometer was aligned to view the panel and readings were taken of the pyrometer output before, during and after operation of the sprinkler spray. Measurements were made with the line joining pyrometer and panel intersecting a vertical line passing through the sprinkler head and also with the pyrometer moved to one side so that the transmission through outer parts of the spray could be determined (See Fig. 2).

The sprinkler spray induced considerable air movement in the laboratory and the panel was cooled slightly. The radiation from the panel was therefore monitored by a radiometer and corrections were made for the cooling of the panel. Values obtained for transmission are given in Table 2.

TABLE 2

RESULTS WITH SPRINKLER SPRAY

Water pressure at sprinkler head $lb\ in^{-2}$	Distance of radiation path from vertical line from sprinkler head m	Transmission of radiation Per cent	Qd $g\ cm^{-1}\ s^{-1}$
50	0	9,10*	12.3
	0.52	8,14*	8.8
	1.01	46	4.9
	1.59	78	2.9
6.5	0	55	6.4
	0.52	72	5.5
	1.01	84	3.3
	1.59	95	1.2

*Repeat experiments

J.F.R.O. results

The transmission (T) of unit intensity of radiation incident on a layer of totally absorbing particles can be expressed (2) as the Lambert-Beer law:-

$$T = \exp(-qNd) \qquad (1)$$

where q is the extinction cross-section of a single particle

N is the number of particles per unit volume

and d is the layer thickness

For a pencil of radiation

$$q = \pi r^2$$

where r is the drop radius.

Also if all particles are the same size

$$N = \frac{Q}{v} \frac{3}{4 \pi r^3}$$

where Q is the volume flow rate through unit horizontal area

and v is the downward component of drop velocity.

Therefore

$$T = \exp \left(- \frac{3Qd}{4 v r} \right) \qquad (2)$$

Neither the downward velocity component nor the size distribution of the drops is known for the sprinkler head, so that the results cannot be correlated in terms of equation (2). However if v and r were constant for all drops from both jets then

$$T = \exp (- A Q d) \qquad (3)$$

where A is approximately constant for a given spray operating at a given nozzle pressure. In most real sprays A is not quite constant for all radiation paths since v and r are not the same in all parts of the spray. A should vary with water pressure at the nozzle since higher pressures will give smaller drops. The factor Qd has a considerable practical importance since it is the total rate of flow of water in the spray for unit width. Approximate values of Qd for the sprinkler spray were obtained by conversion of the water distribution measured in the standard Joint Fire Research Organization sprinkler tests to the distribution at the height of measurement (1.4 m).

The fraction of the total water output from the sprinkler head falling within a given radius at a pressure of 50 lb in^{-2} was very similar to that at a pressure of 5 lb in^{-2}. The distribution for a pressure of 6.5 lb in^{-2} could therefore be found since sprinkler output is nearly proportional to (Pressure)$^{\frac{1}{2}}$.

In Fig. 3 log T has been plotted against the factor Qd. The sprinkler spray transmission for a pressure of 50 lb in^{-2} is lower than that for a pressure of $6\frac{1}{2}$ lb in^{-2}, presumably because the higher pressure produces smaller drops which, according to equation (2), give a spray of lower transmission. The best lines through the points do not pass through the origin, probably because the drop size distribution is not the same for the radiation paths through different parts of the spray.

The transmission values obtained with the flat jet are high presumably because the drops are large. At the low pressures used the jet produced a small sheet of water breaking up into drops.

<u>Scattering of radiation</u> (Sprinkler spray experiments)

Before the pyrometer readings can be taken to measure the transmission of the spray it is necessary to know whether scattering of radiation by the spray is important. The scattering can be estimated if the droplet size is known.

The product (νr) can be obtained from the slope of the Beer Law relation (Equation 2, as plotted in Fig. 3). Since the downward momentum of the water spray is largely destroyed by the deflector plate, an upper limit to downward component of velocity is that due to free fall under gravity, which, neglecting air drag, is 525 cm s^{-1} for a drop falling 1.4 m from rest. From the value of νr we can now obtain a lower limit for the average drop radius of 0.0075 cm for the 50 lb in^{-2} spray.

This radius is comparable with those of drops from various nozzles used by Rasbash and Rogowski (3). They obtained mass median drop radii between 0.015 and 0.15 cm.

The fraction absorbed of a narrow beam of radiation incident on a single drop of radius 0.0075 cm can be found from the relation given by Thomas (2). For a source at 800°C a value for k, the absorption index, of 120 cm^{-1} was calculated, giving a fraction of incident radiation absorbed of 0.75 and this would be even higher for the actual drops which are in fact larger. The remaining 25 per cent is reflected and transmitted, but not in the direction of the incident beam. Thus, in the sprinkler spray experiments some radiation which was received by the pyrometer before the spray was turned on is scattered outside the field of view of the pyrometer, but may still penetrate the spray. The effective transmission of radiation from an extended source to an extended receiver is therefore under-estimated by the pyrometer. Table 3 gives the estimated transmission of radiation from an extended source for two source temperatures assuming that

(a) in these experiments none of the scattered radiation was received by the pyrometer and

(b) in the case of the extended source all the scattered radiation is scattered in a forward direction, and penetrates the spray. No account has been taken of the increase in extinction area of the drop as the source becomes larger, from πr^2 for a narrow beam of radiation to $2\pi r^2$ for an infinite source. The transmission for an extended source is therefore likely to be smaller than the values given in Table 3 and the absorption larger.

Results of other workers

Seekamp (4) and Schuler (5) measured the transmission of radiation from an extended source through water curtains formed from a number of spray heads mounted at short distances apart on pipes. Seekamp used only one water pressure ($2\frac{1}{2}$ atmospheres). Schuler varied water flow independently of pressure by increasing the number of pipes. In this case Q d can be taken as the rate of volume flow of water per unit length of curtain. Schuler measured radiation transmission, drop size distribution and drop velocity of water curtains and has presented his transmission values as a function of the dimensionless variables of equation 2, extended to sum in steps a range of drop sizes. His results, simplified to the form of equation (3) are plotted in Figs. 4 and 5. In Fig. 4 are shown the only transmissions he quotes where the flow of water was varied independently of pressure. Smart (6) measured radiation transmitted by water sprays from various nozzles for various pressures using a pyrometer and a 3 ft square radiant panel as radiation source. He found that the radiation transmission could be as low as 5% for 100 lb/in^2, but it is difficult to compare his results with those quoted ~~have~~ because of differences in geometry. The radiation path was horizontal, through horizontally directed sprays and in the direction of the sprays and it is difficult to calculate values for Qd.

Evaporation of drops

For low values of Q d and high intensities of radiation evaporation of a substantial fraction of the spray can take place. The fractional absorption by the drops in the lower portions of the spray is then less than for lower radiation intensities since from equation (1) as q becomes smaller, T becomes larger even if no drops are completely evaporated. Since the air in the spray is unheated one would expect condensation to form clouds of very small droplets which would scatter radiation rather than absorb it. Water vapour would also absorb some radiation. These aspects have not been studied yet.

TABLE 3

ESTIMATED EQUIVALENT TRANSMISSION FROM AN EXTENDED SOURCE
WATER PRESSURE 50 lb in^{-2}

Absorption index (k) cm^{-1}		Absorption of narrow beam incident on a single drop per cent		Transmission that would be measured by the pyrometer per cent	Estimated equivalent transmission from an extended source per cent	
800°C Source	1000°C Source	800°C Source	1000°C Source	800°C Source	800°C Source	1000°C Source
				5	29	38
				10	33	42
120	93	75	65	25	44	51
				50	63	67
				90	92	93

If we consider a square radiation source of height and breadth 10 ft and intensity 4 cal cm^{-2} s^{-1} the total radiant heat emitted $= 10 \times 10 \times 144 \times 2.54^2 \times 4 = 370,000$ cal s^{-1}. The maximum possible heat absorption by water at 20°C converted to steam at 100°C is 620 cal g^{-1} so that the minimum amount of water necessary for complete absorption of the radiation $= \frac{370,000}{620} \times \frac{60}{454} \times \frac{1}{10} = 8$ gal min^{-1}. Thus the substantial fractional absorption that is possible by sprays producing 10-30 gal min^{-1} over a 10 ft length, as do sprinklers would be expected to evaporate a correspondingly substantial part of the flow but still leave a significant quantity of water reaching the floor for extinguishing or suppressing fire.

General discussion

In Figs. 3 and 4 it can be seen that for any given nozzle and water pressure, transmission falls as the rate of flow of water in the radiation path increases, but the results are not sufficient to indicate the exact form of the relation. For any given nozzle transmission falls as water pressure increases, even when the rate of flow does not alter (Fig. 4). This is to be expected from equation (2) since higher pressures will tend to produce smaller drops and the value of $3/(4\rho r)$ will therefore increase.

Fig. 5 indicates that there are wide differences in the ability of different nozzles to absorb radiation even with comparable water flows, some nozzles being quite unsuitable.

Conclusions

The results suggest that provided a high pressure was used a water curtain produced by a water flow of 3 gal $min^{-1} ft^{-1}$ could absorb at least 50-55 per cent of incident radiation from sources at 800-1000°C, and a curtain produced by a flow of 4-5 gal min^{-1} ft^{-1} could absorb at least 60-70 per cent of incident radiation. Further experiments are desirable, and attention should be given to nozzle design since this appears to be critical.

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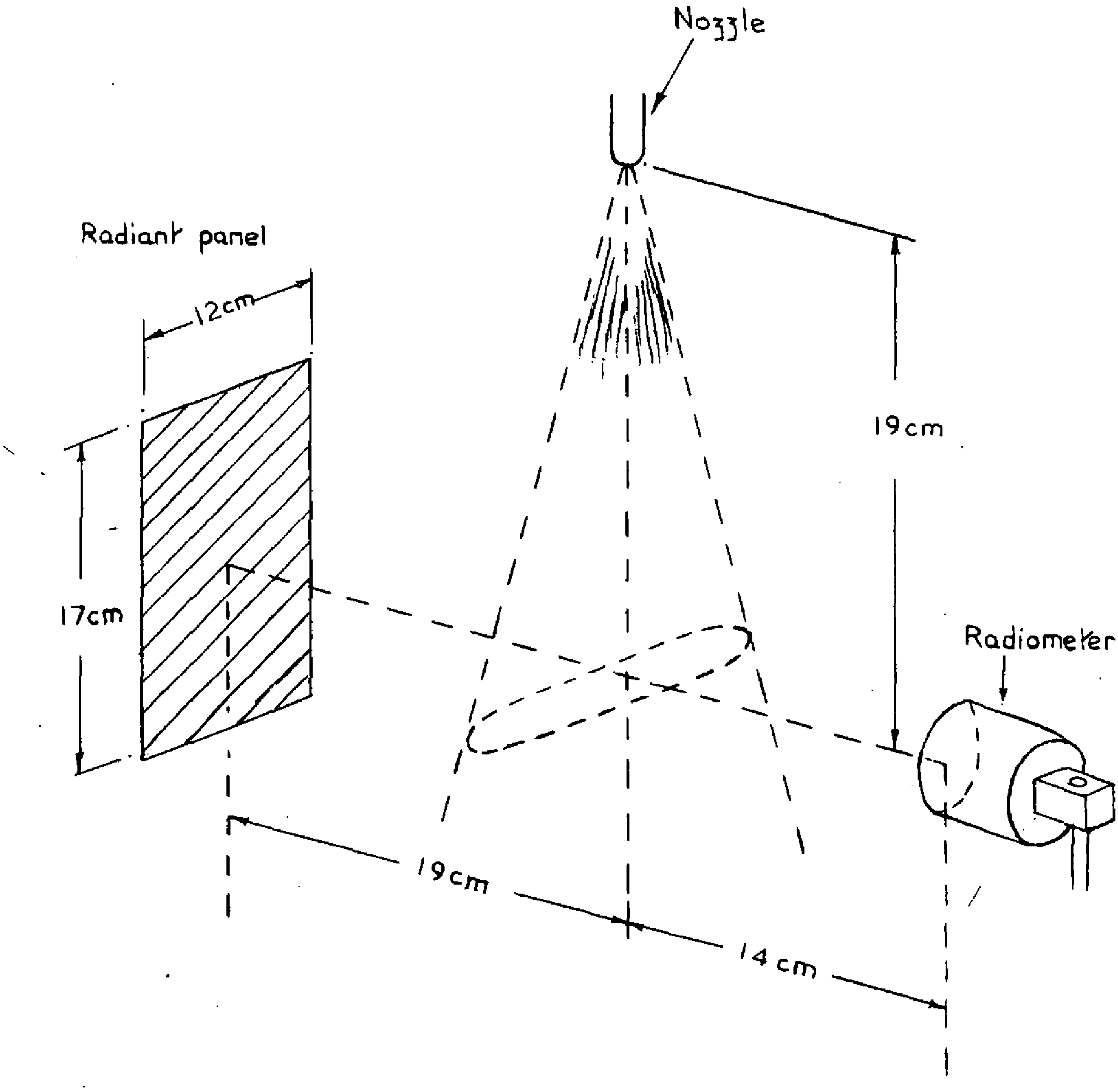

FIG. 1. LAYOUT OF APPARATUS FOR FLAT SPRAY MEASUREMENTS

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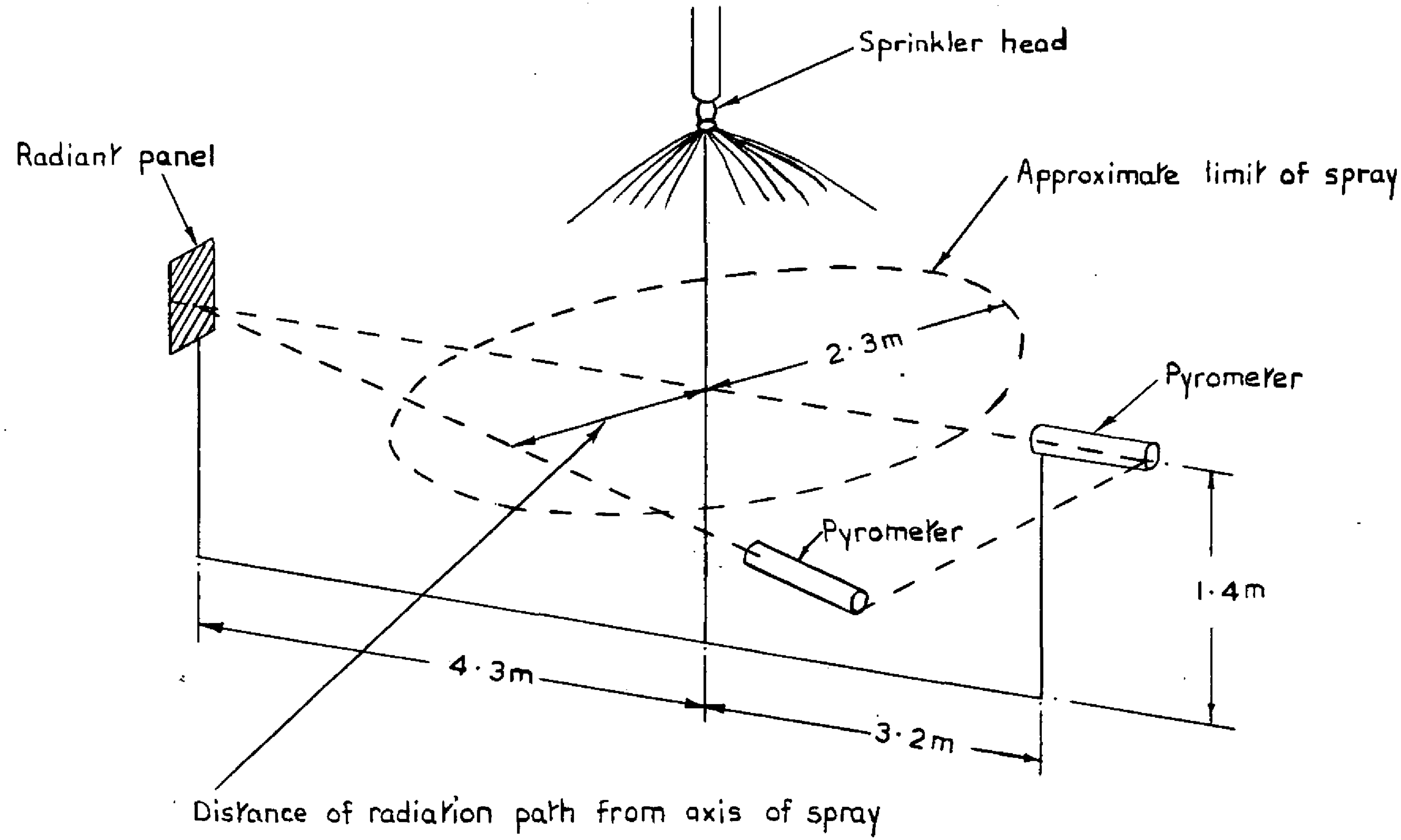

FIG.2. LAYOUT OF APPARATUS FOR SPRINKLER SPRAY MEASUREMENTS

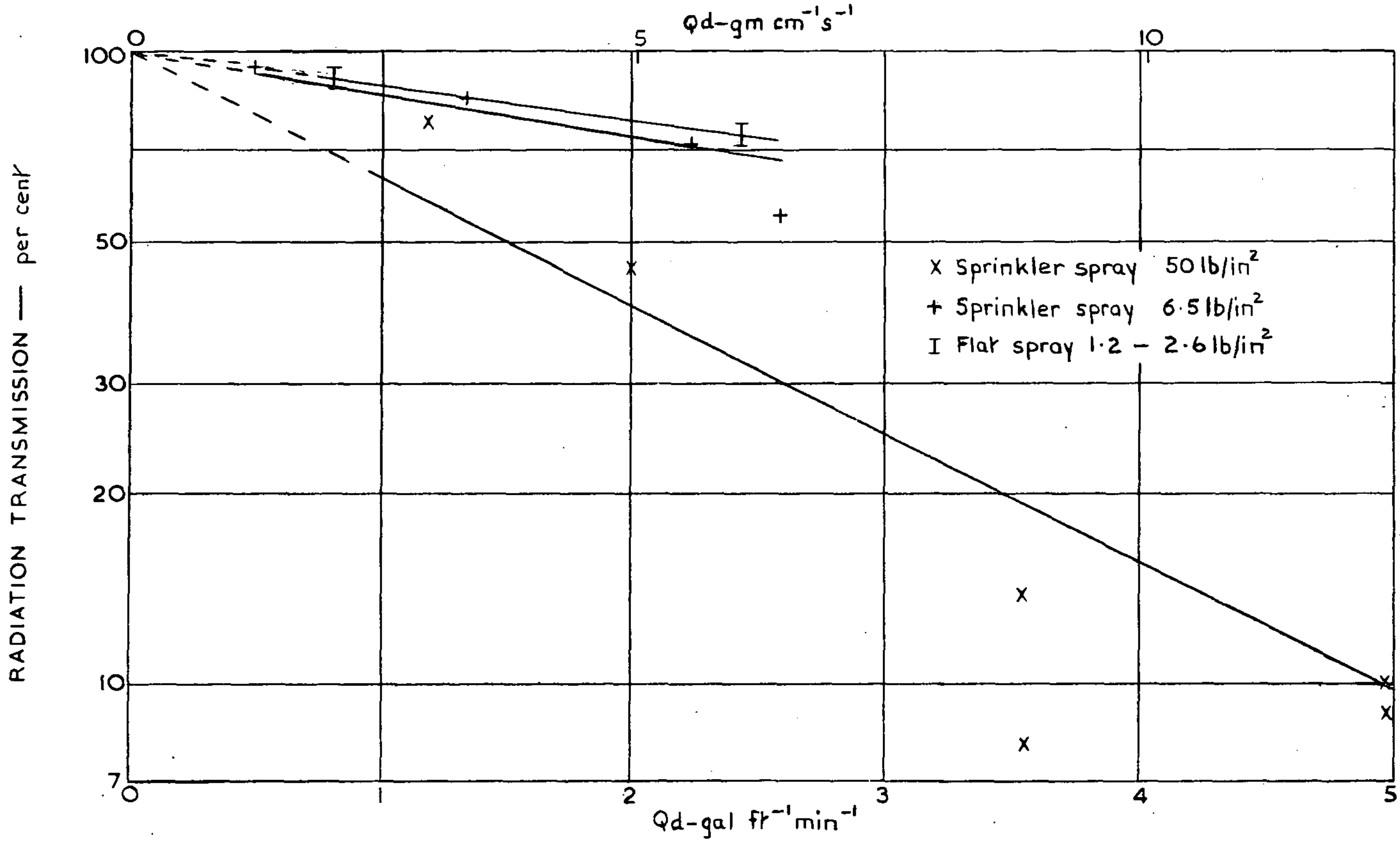

FIG.3. EFFECT OF FACTOR Qd ON TRANSMISSION (J.F.R.O. RESULTS)

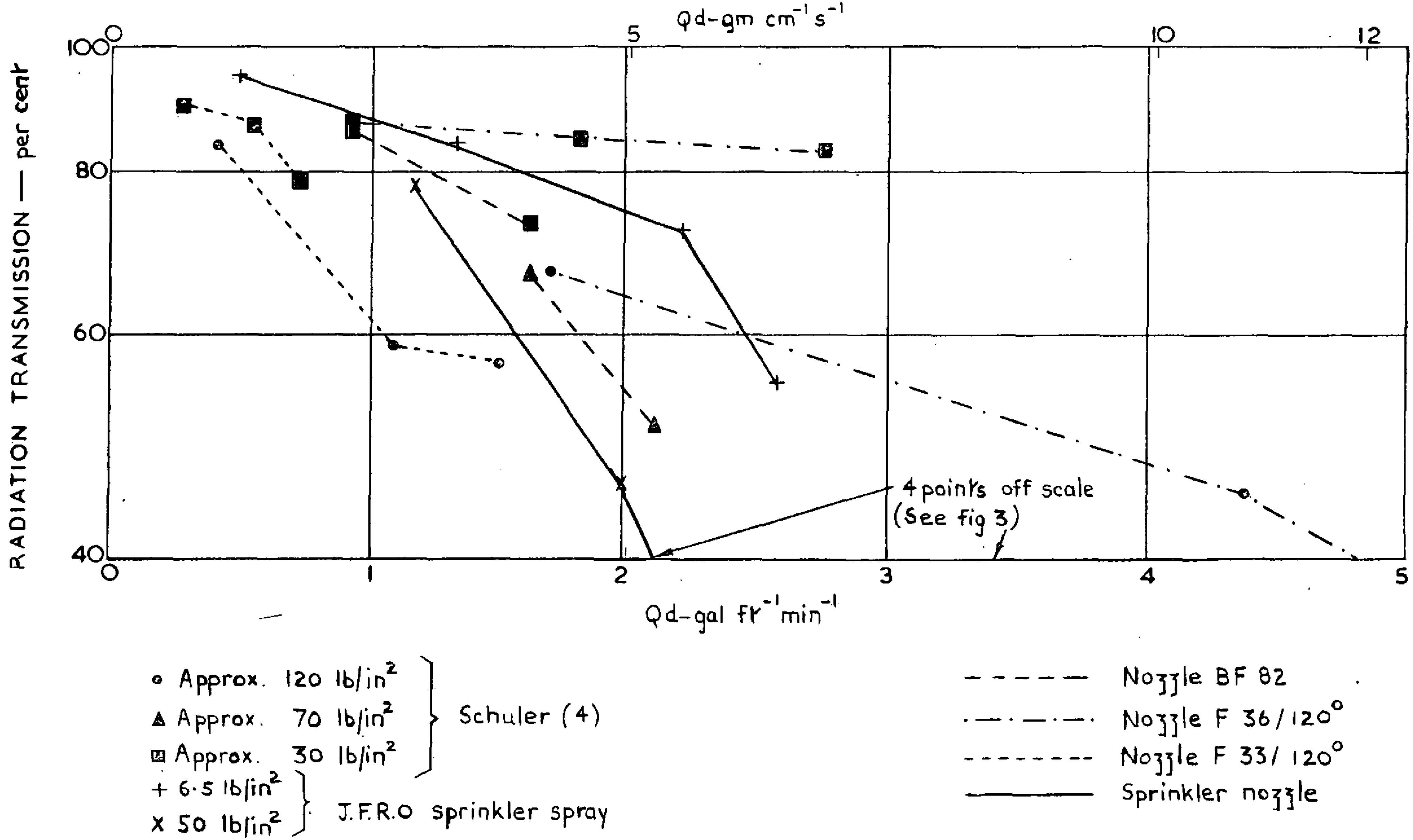

FIG.4. EFFECT OF PRESSURE ON ABSORPTION RELATION

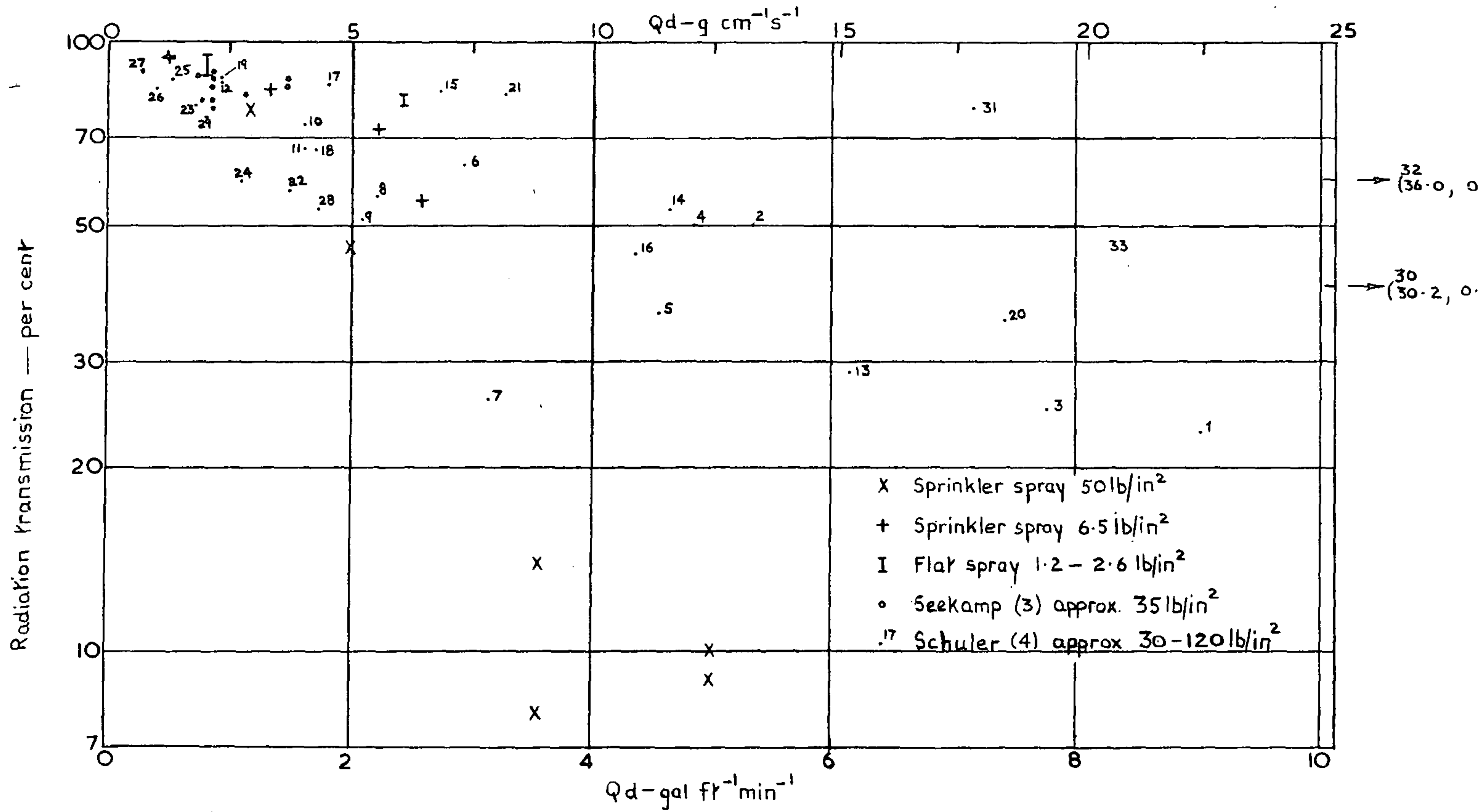

FIG. 5. RESULTS OF ALL WORKERS