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EXPERIMENTS ON SMOKE DETECTION:

PART 2: FIRES IN WOOD CRIBS, RUBBER CRIBS, POLYVINYL CHLORIDE POWDER AND PETROL

by

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SUMMARY

Experiments are described on the measurement and detection of smoke in a room 2.46 m (8ft 1in) high, having a volume of 153 m^3 (5400 ft^3). The fires were in wood cribs, rubber cribs, petrol and polyvinyl chloride powder, which were sited at a range of horizontal distances up to 6.10 m (20 ft) from the measuring and detecting equipment. Measurements were made of the optical density of the smoke, the rise in air temperature, and the response times of two types of proprietary smoke detector.

KEY WORDS: Investigation; Smoke; Detector, Fire; Solids, Flammable liquid.

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EXPERIMENTS ON SMOKE DETECTION: PART 2: FIRES IN WOOD CRIBS, RUBBER CRIBS, POLYVINYL CHLORIDE POWDER AND PETROL

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1. Introduction

The work described in this note is a continuation of that described in Part 1, in which small flammable liquid fires of benzene-in-alcohol were used. The experiments were performed to examine the effect of smoke produced from fires in wood, rubber, polyvinyl chloride powder and petrol. The same room was used as that used for Part I of the programme, which had a volume of 153 m^3 (5400 ft^3) and was made draught-free. Continuous measurements were made of the optical density of the smoke during the course of the fire with the fire at various distances from the measuring position. The response times of an ionisation chamber detector (detector A) and an optical scattering detector (detector B) were recorded, together with the air temperature rise adjacent to the detectors.

2. Experimental

The experimental procedure was identical to that described in Part 1. The fires used in the experiments were as follows:-

(1) Wood crib

This was constructed of 25.4 mm (1 in) square sticks each 305 mm (1 ft) long. The crib had a 305 mm (1 ft) square base and consisted of 6 layers of sticks, with 6 sticks in each layer so as to have a uniform spacing of 30.5 mm (1.2 in). The crib was ignited by burning 10 cm^3 of industrial methylated spirits in a 50.8 mm (2 in) diameter tray placed at the centre of its base.

(2) Rubber crib

The crib was constructed of strips cut from 6.4 mm ($\frac{1}{4}$ in) thick black rubber sheet, each strip being 152 mm (6 in) long and 25.4 mm (1 in) wide. The crib had a 152 mm (6 in) square base, and was made up of 6 layers of strips, with 4 uniformly spaced strips in 5 of the layers and two strips in the top layer. The weight of rubber in each crib was 0.45 kg (1 lb). Ignition was effected by 50 cm^3 of methylated spirit in a small tray placed at the centre of the base.

2. Experimental (continued)

(3) Polyvinyl chloride powder

The powder was placed in a rectangular tray, measuring 305 mm (1 ft) by 76.2 mm (3 in) and 15.9 mm ($\frac{5}{8}$ in) deep, and levelled off. The tray was placed with its base at 25.4 mm (1 in) above a 1 kW electrical heating element, and the ignition time was measured from the time of switching on the current to the element.

(4) Petrol

Regular grade leaded petrol was used, and 500 cm^3 was ignited in a 152 mm (6 in) diameter tray for each test.

Three replications were made for the wood crib fires for each position of the fire in relation to the smoke detecting and measuring equipment, and two replications, in general, for the other types of fire. In some cases extra experiments were carried out where these were considered necessary. The operating times for the two detectors are given in Table 1.

3. Optical density measurements

(a) Type of fire

(1) Wood crib

The optical density showed large random variations with time, and there was generally no characteristic type of curve, with the exception of the measurements made at 6.10 m (20 ft) from the fire. There were short term fluctuations in optical density for the measurements made directly above the fire at a frequency of approximately 10 - 15 c/min, and for some of those made at 1.52 m (5 ft) from the fire. In general, these are absent for distances of 3.05 m (10 ft) and more from the fire. The short term fluctuations are characteristic of conditions in or near to the rising plume of hot gases and smoke from the fire. The random nature of the smoke emission is characteristic of wood crib fires in their early stages of fire development, the smoke being emitted in an unsteady manner with 'puffs' of high density and of varying duration.

There was a time lag before any appreciable measure of smoke was recorded, which increased with the distance from the fire, ranging from a mean value of about 1 min above the fire to a mean of about 4 min at 6.10 m (20 ft). All the results showed a general increase of optical density with time, but only those at 6.10 m (20 ft) from the fire showed a consistent form, with a very rapid increase in optical density following a time lag ranging from $1\frac{3}{4}$ to $6\frac{1}{2}$ min.

3. Optical density measurements (continued)

(2) Rubber crib

The increase in optical density with time was generally similar for all the experiments, showing a rapid initial increase with the curve passing through a point of inflexion to a maximum value after a time varying from 5 to 9 min. Some typical results are shown in Figure 1. There was generally a delay of up to $2\frac{1}{2}$ min before any measureable smoke concentration was recorded. The measurements made immediately above the fire showed fluctuations of optical density about the mean curve at approximately 20 c/min, but at 1.52 m (5 ft) and more from the fire there was a fairly steady build up in density.

(3) Petrol

The increase in optical density with time showed a consistent pattern which is similar to that obtained with the benzene-in-alcohol fires in the experiments described in Part 1. The optical density showed a practically linear increase with time after a rapid initial increase, followed by a flattening out to a plateau value after about 20 to 30 min from the start of the fire. (Figure 2) The smoke density built up rapidly with no appreciable time lag and showed a fairly steady increase, except for the measurements immediately above the fire for which there were fluctuations about the mean curve at a frequency of about 25 c/min.

(4) Polyvinyl chloride powder

These fires were initiated by electrical heating and there was generally no measureable change in optical density for at least 3 min, ranging up to 5 min for measurements at 6.10 m (20 ft) from the fire. In general, there was a rapid rise in optical density to a plateau value which was achieved in times ranging from 5 to 9 min. (Figure 3). These times represent a range of approcimately $2\frac{3}{4}$ to 5 min from the first measurable evolution of smoke. The maximum value of the optical density was about 0.1, with the exception of the measurements immediately over the fire which ranged up to values of 0.23. These maximum values are low when compared with the optical densities recorded for other materials. As with the other fires there were short term fluctuations about the mean curve for measurements made immediately over the fire and at 1.52 m (5 ft) away, with a frequency of about 10 - 12 c/min.

3. Optical density measurements (continued)

(b) Distance from fire

The effect of distance from the fire on the optical density was consistent for all the fires with the exception of the wood crib fires which showed large and random variations of optical density with time. For the rubber, petrol and polyvinyl chloride powder fires there was a reduction in optical density as the distance from the fire increased, with a maximum immediately above the fire. Beyond 3.05 m (10 ft) from the fire there was a relatively slow decrease in optical density up to 6.10 m (20 ft), and in some cases there was little or no reduction beyond 3.05 m (10 ft). Some typical results are shown in Figure 4.

4. Effect of horizontal distance on detector operating time

(1) Wood cribs

The operatime time of the detectors increased linearly for both types of detectors, from a mean value of approximately 2 min immediately above the fire to approximately 6 min at 6.10 m (20 ft) away. The mean operating times are plotted in Figure 5. Detector A was generally more rapid in response near the fire (about 1 min faster above the fire), but the difference became progressively smaller with increasing horizontal distance until at 6.10 m (20 ft) from the fire the response times were about equal.

(2) Rubber crib

The results for detector B indicate the effect of distance as being relatively small, with a linear increase in operating time varying from 4.3 to 5.2 min over the range of 0 to 6.10 m (20 ft) in horizontal distance (Figure 6). For detector A the response time rose from 47 s above the fire to a value ranging from $2\frac{3}{4}$ to $3\frac{1}{2}$ min over the range 1.52 to 6.10 m (5 to 20 ft), so that beyond 1.52 m (5 ft) the effect of distance was relatively small. Detector A was more rapid in response at all distances from the fire, and was particularly sensitive close to the fire.

(3) Petrol

Detector A was very rapid in its response to this fire, with a maximum response time of 46 s. The effect of distance was not marked and of little practical significance beyond 1.52 m (5 ft); above the fire the response was only 19 s (Figure 7). Detector B was much slower in its response to the fire with times ranging from

4. Effect of horizontal distance on detector operating time (continued)

(3) Petrol (continued)

$2\frac{1}{4}$ min above the fire to 14 min at 6.10 m (20 ft) away. Again, over the range 1.52 to 6.10 m (5 to 20 ft), the response times ranged from 12.6 min to 14 min, so the effect of distance was not marked.

(4) Polyvinyl chloride powder

Detector A responded to this fire when it was situated immediately above it (5.1 min), but no response was obtained in any of the experiments at 1.52 m (5 ft) and more from the fire. Detector B responded to the fire at all distances up to 6.10 m (20 ft), showing a linear increase in operating time with horizontal distance from 4.8 to 7.2 min over the range examined. (Figure 8).

5. Effect of type of fire on detector operating time

The response times for both detectors are plotted in Figure 9 for the four types of fire used in the experiments, so that the relative speeds of response can be easily compared. The response times for wood fires were comparable, with detector A being generally more rapid in response. For rubber fires detector A was much faster over the fire, and was generally faster in response, although the difference between the detectors was less pronounced at 1.52 m and more from the fire. The graph shows clearly the very high sensitivity of detector A to petrol fires, and the slow response of detector B at distances of 1.52 m and over from the fire. The single result for which a comparison can be made for the polyvinyl chloride fires shows that the two detectors were approximately equally sensitive when sited over the fire.

Table 2 is a summary of detector operating times at 3.10 m (10 ft) from the fire which gives a convenient comparison of detector performance. The limits chosen for speed of response are arbitrary, but the table provides a relative measure of detector performance for the types of fire used in the experiments, including the fires used in Part I of the experiments.

6. Air temperature rise

In all the experiments, for all the types of fire, it was found that the air temperature rise was small when the smoke was detected. In general the rise in air temperature was below 5 deg C (9 deg F), even when the fire was positioned directly below the detectors.

7. Optical density at detector operation

The optical densities recorded at operation of the two detectors are shown in Figure 10, which enables a comparison between the detectors to be made.

For the wood fires both detectors operated at values of optical density which were similar, except over the fire, when detector A operated at a relatively low value. At 6.10 m the recorded values were high, and this was due to one very high value in the three replications made at this distance; if this figure is taken as unrepresentative, then a value is obtained which is comparable with those obtained at 1.52 and 3.10 m.

The results for the rubber fires show that detector A operated at considerably lower optical densities than detector B, and at a very low value over the fire. The values for detector B, however, show operation at a relatively constant optical density, whereas those for detector A cover a wider range of values.

For the petrol fires the optical densities were low for detector A and practically constant at all distances from the fire. The values for detector B were comparable with those recorded for the rubber fires, and showed a greater variation than the figures obtained for detector A.

The only comparison possible for the polyvinyl chloride powder fires was for detection immediately over the fire, since this was the only position for which detector A operated. The detectors operated at approximately equal optical densities, which were relatively large in comparison with most of the other results.

Figure 11 is given for the benzene-in-alcohol fires (described in Part 1 of this report), and shows the optical densities at operation of detector A. A comparison with the values given in Figure 10, show that the detector responded to these fires at relatively low values of optical density.

8. Conclusions

The fires all showed characteristic increases in the optical density of the smoke with time, with the exception of the wood crib fires, for which there were large and random variations.

The optical density of the smoke at any particular time during the fire decreased with horizontal distance from the fire from a maximum immediately over the fire. Beyond a distance of 3.05 m (10 ft) there was a relatively slow decrease in optical density up to 6.10 m (20 ft).

The operating times of the detectors increased with horizontal distance from the fire. For the petrol fires, and for detector A in response to the rubber crib fires, there was a rapid increase in response time over the first 1.52 m (5 ft) from the fire, followed by a relatively small range of

8. Conclusions (continued)

response times from 1.52 m (5 ft) to 6.10 m (20 ft). For the wood crib fires, and for detector B in response to the rubber crib and polyvinyl chloride powder fires, there was a linear increase in response time with distance from the fire.

A comparison of detector performance showed that both had good sensitivity to smoke from wood and rubber crib fires. For the wood crib fire detector A was generally more rapid in response, although the difference was not marked, particularly at some distance from the fire. For the rubber cribs, detector A was considerably more rapid in response near the fire, but beyond 1.52 m (5 ft) the difference was less marked. For the petrol fires detector A had a very rapid response, and detector B a relatively slow response, particularly at 1.52 m (5 ft) and more from the fire. For the polyvinyl chloride powder fires detector A operated only when sited immediately over the fire; detector B however, operated up to 6.10 m (20 ft) from the fire in times similar to those recorded for the other solid fuel fires.

Table 1. Operating times of detectors A and B

Distance from fire m (ft)	Operating time (min - s)							
	Wood crib fire		Rubber crib fire		Petrol fire		Polyvinyl chloride powder fire	
	A	B	A	B	A	B	A	B
0	1-39 1-32 1-26	2-04 1-50 3-23	-(1) 0-45 0-48	4-21 4-30 4-00	0-18 0-10	3-30 1-05	5-28 4-54	4-46 4-56
1.52(5)	1-50 0-59 5-45	2-12 2-38 5-18	3-50 3-09	4-15 4-54	0-49 0-42	15-41 10-18	-(1) -(1) -(1) -(1)	5-00 5-15 7-30 3-33
3.05(10)	3.45 1.56 5-10	4-11 3-52 4-21	2-42 2-49	4-38 4-30	0-41 0-26	9-58 15-09	-(1) -(1)	5-55 5-10
6.10(20)	4-50 7-26 7-05	4-52 7-18 6-54	3-22 3-15 3-00	-(1) 5-30 5-16	0-39 0-34	16-24 14-50	-(1) -(1)	8-20 7-10

(1) No detector operation during the experiment

Table 2. Comparison of detection times at 3.10 m (10 ft) from fire

This table is a general guide to the rapidity of detector response observed during the experiments, and gives the ranges of time in which the detector responded at 3.10 m (10 ft) from the fire.

Type of fire	Detector response times	
	Detector A	Detector B
Wood crib	$2\frac{1}{2}$-5 min	$2\frac{1}{2}$-5 min
Rubber crib	$2\frac{1}{2}$-5 min	$2\frac{1}{2}$-5 min
Petrol	0-$2\frac{1}{2}$ min	$12\frac{1}{2}$-15 min
Polyvinyl chloride	No response	5-$7\frac{1}{2}$ min
Benzene-in-alcohol		
(i) 5 per cent benzene	No response	No response
(ii) 10 per cent benzene	$>$15 min	Inconsistent response ($>$15 min)
(iii) 15 per cent benzene	$2\frac{1}{2}$-5 min	No response
(iv) 20 per cent benzene	0-$2\frac{1}{2}$ min	Inconsistent response ($>$15 min)

1/7953 INT NOTE 301 + F.R. 788

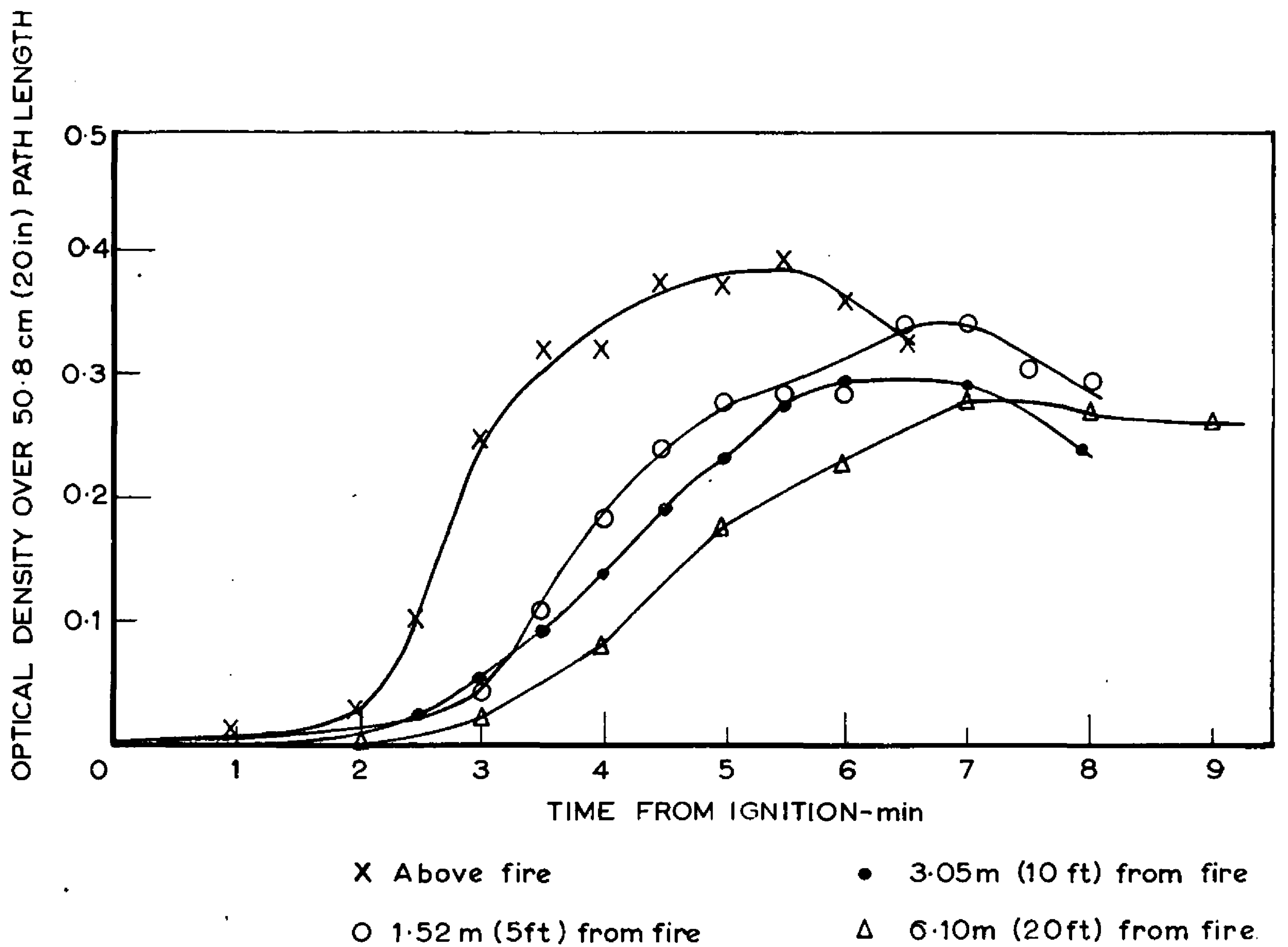


FIG. 1. VARIATION OF OPTICAL DENSITY OF SMOKE WITH TIME FOR RUBBER CRIB FIRES

1/7054

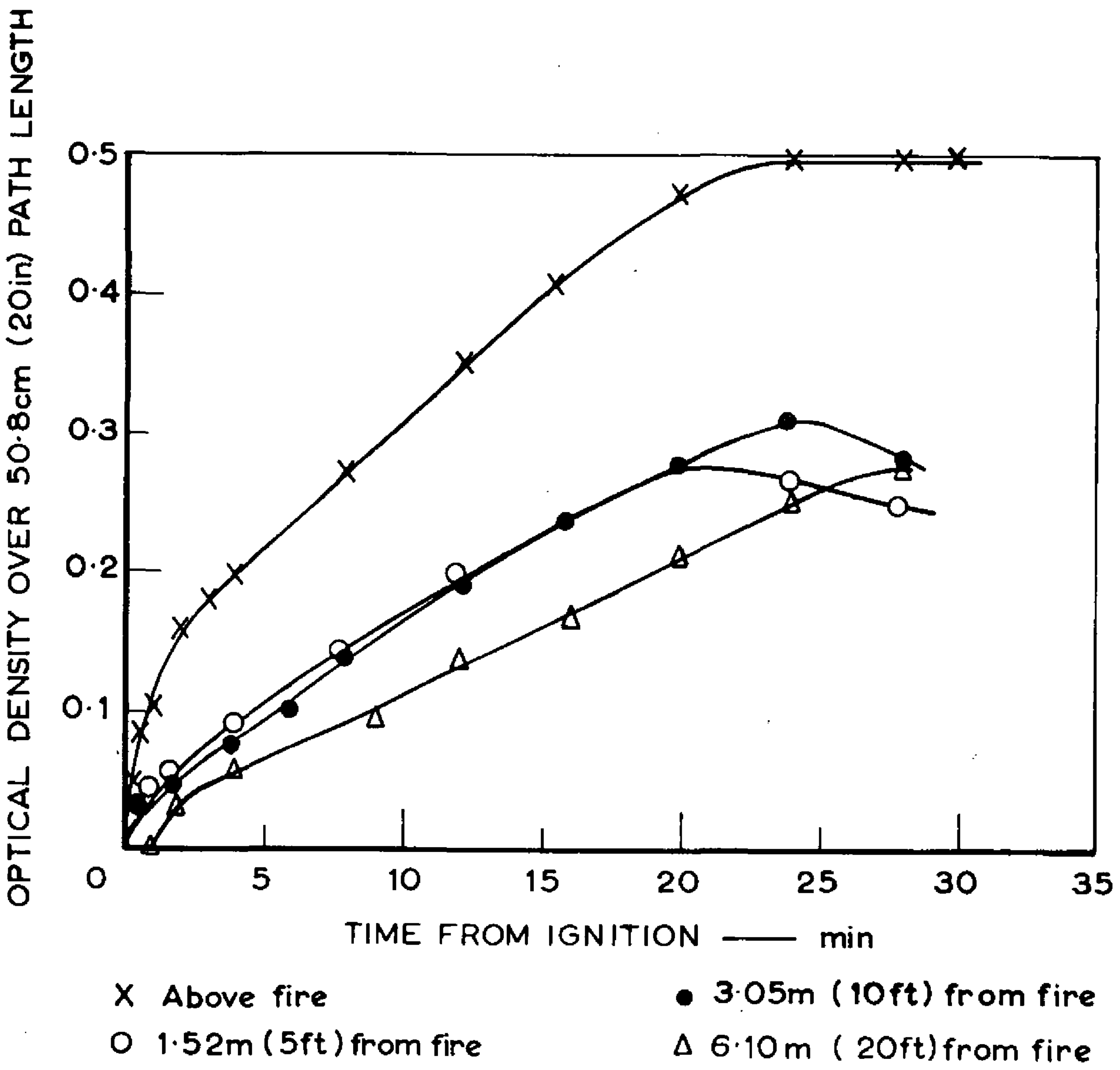


FIG.2. VARIATION OF OPTICAL DENSITY OF SMOKE WITH TIME FOR PETROL FIRES

1/79.55 INT NOTE 301 + F.R. 780

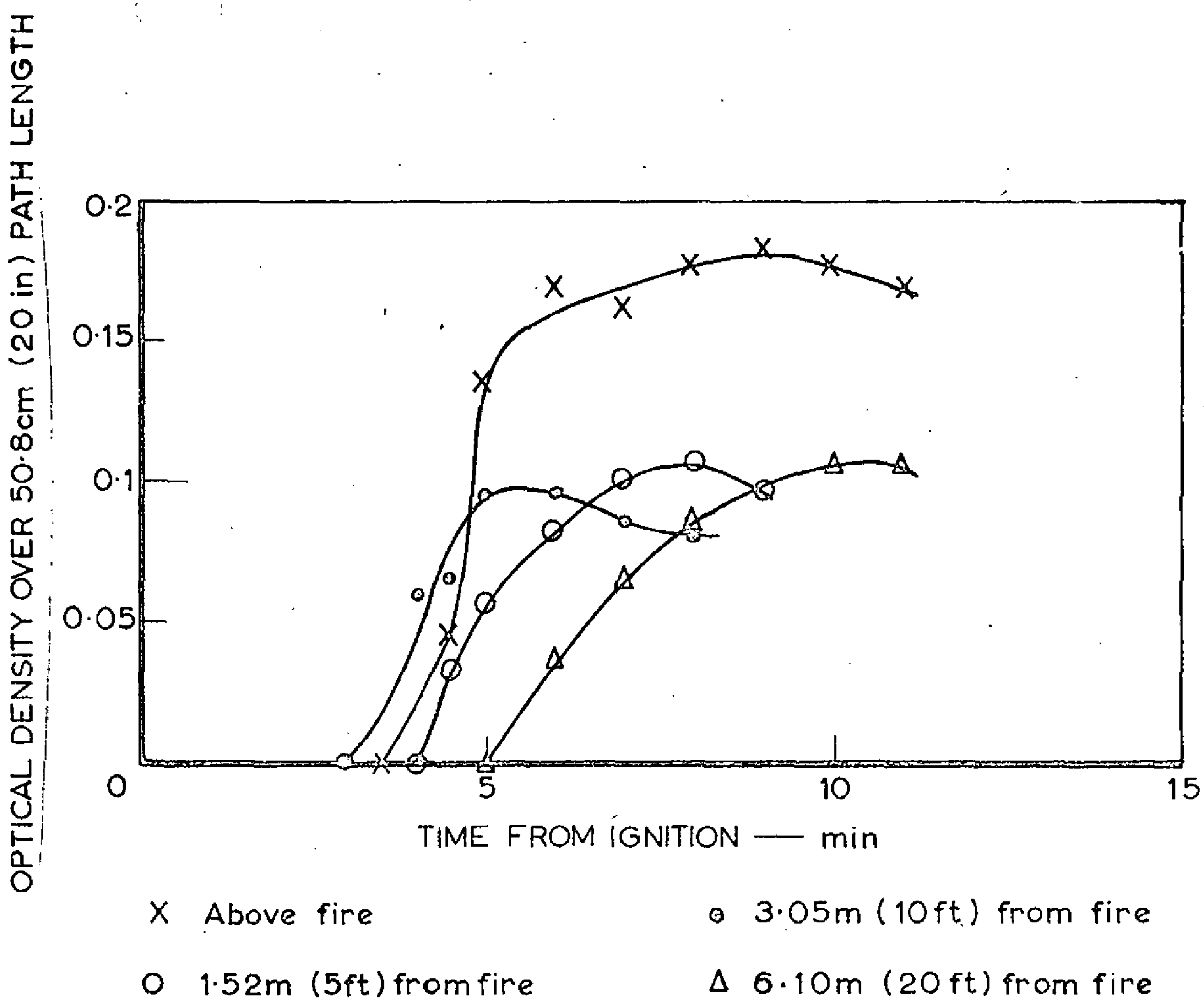


FIG. 3. VARIATION OF OPTICAL DENSITY OF SMOKE WITH TIME FOR POLYVINYL CHLORIDE POWDER FIRES

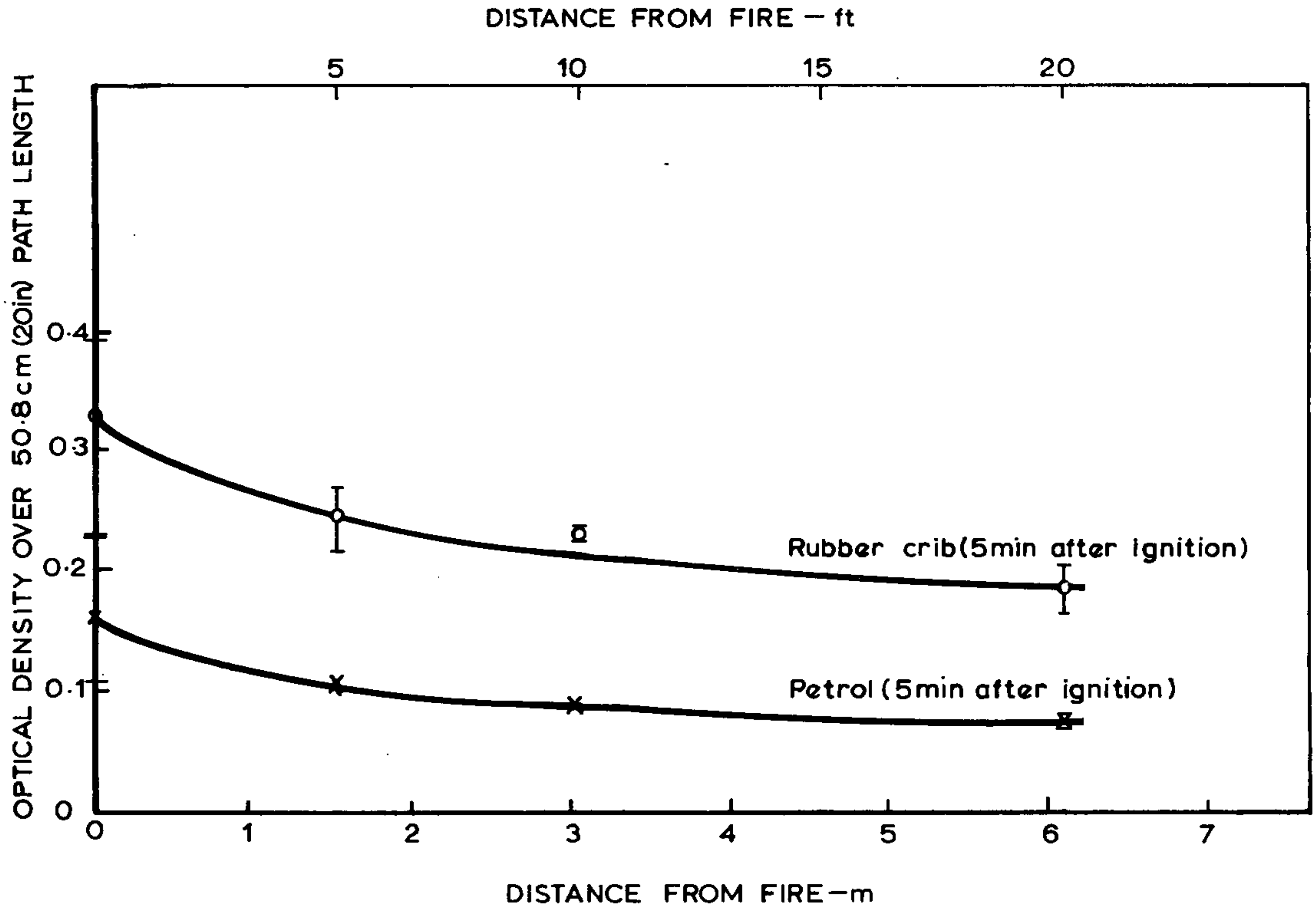


FIG. 4. VARIATION OF OPTICAL DENSITY OF SMOKE WITH DISTANCE FROM FIRE

1/79.57 INT NOTE 301 + F.R. 780

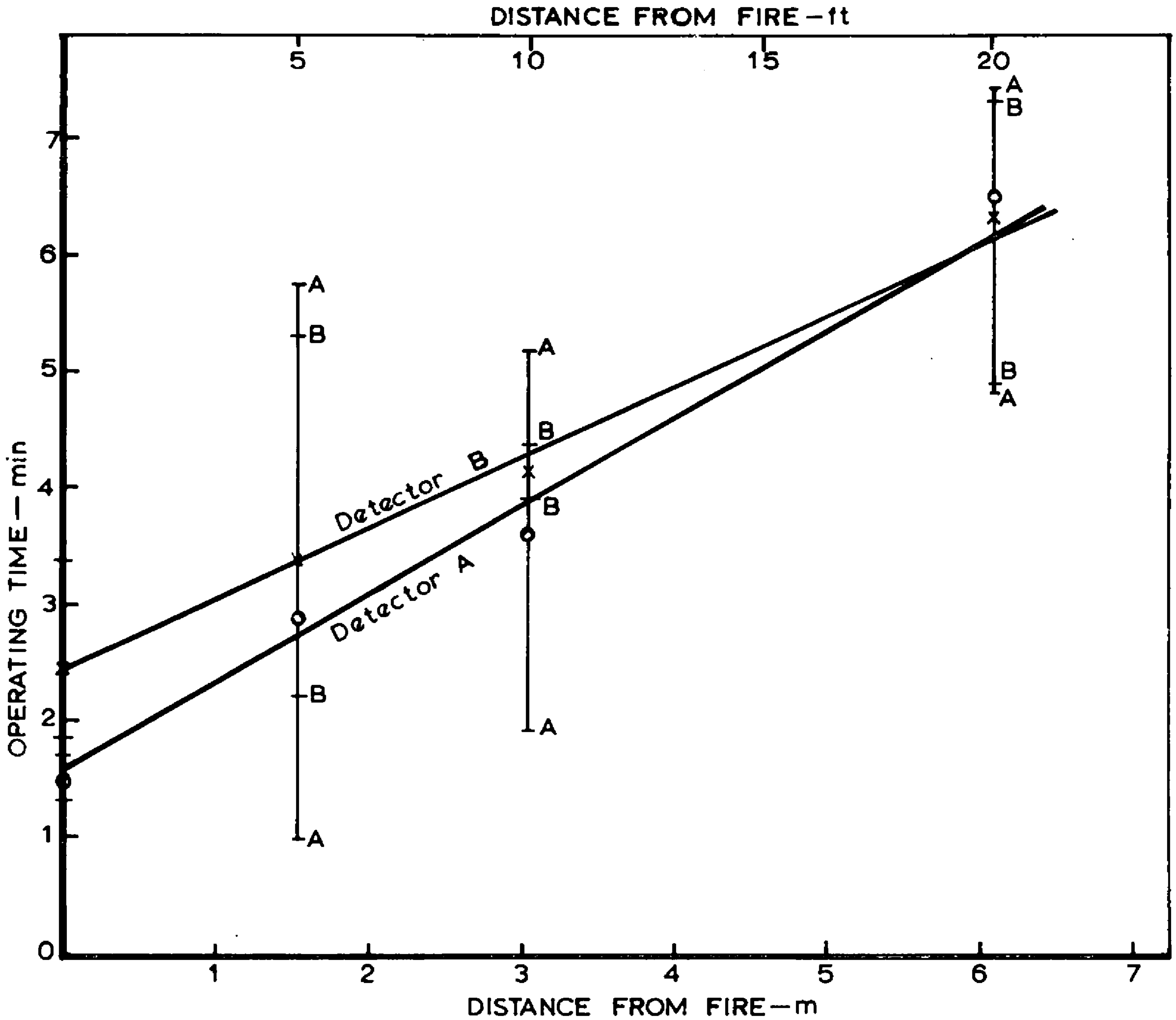


FIG.5. VARIATION IN DETECTOR OPERATING TIME WITH DISTANCE FOR WOOD CRIB FIRES

1/7958 INT NOTE 301 F.R.

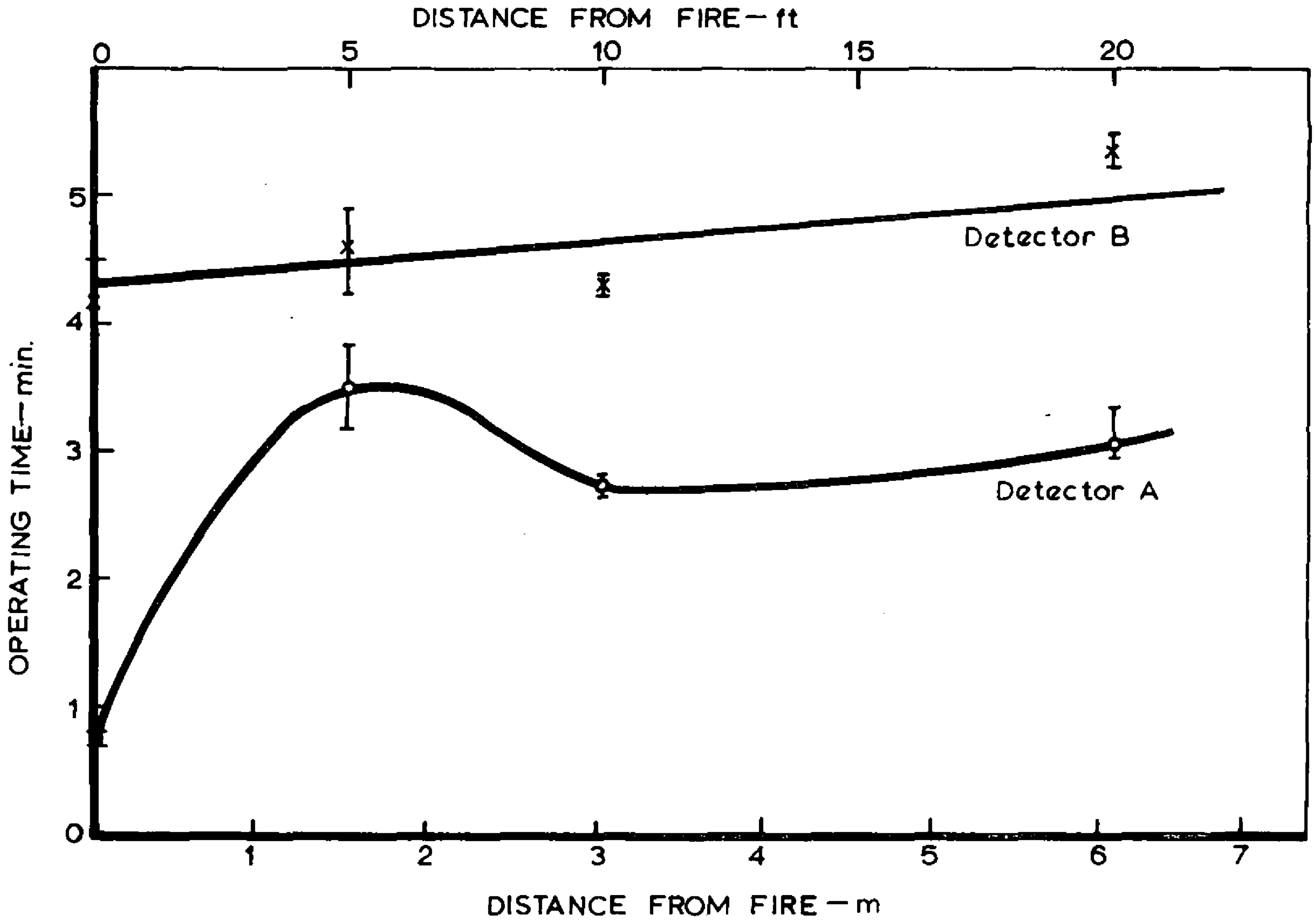


FIG. 6. VARIATION IN DETECTOR OPERATING TIME WITH DISTANCE FOR RUBBER CRIB FIRES

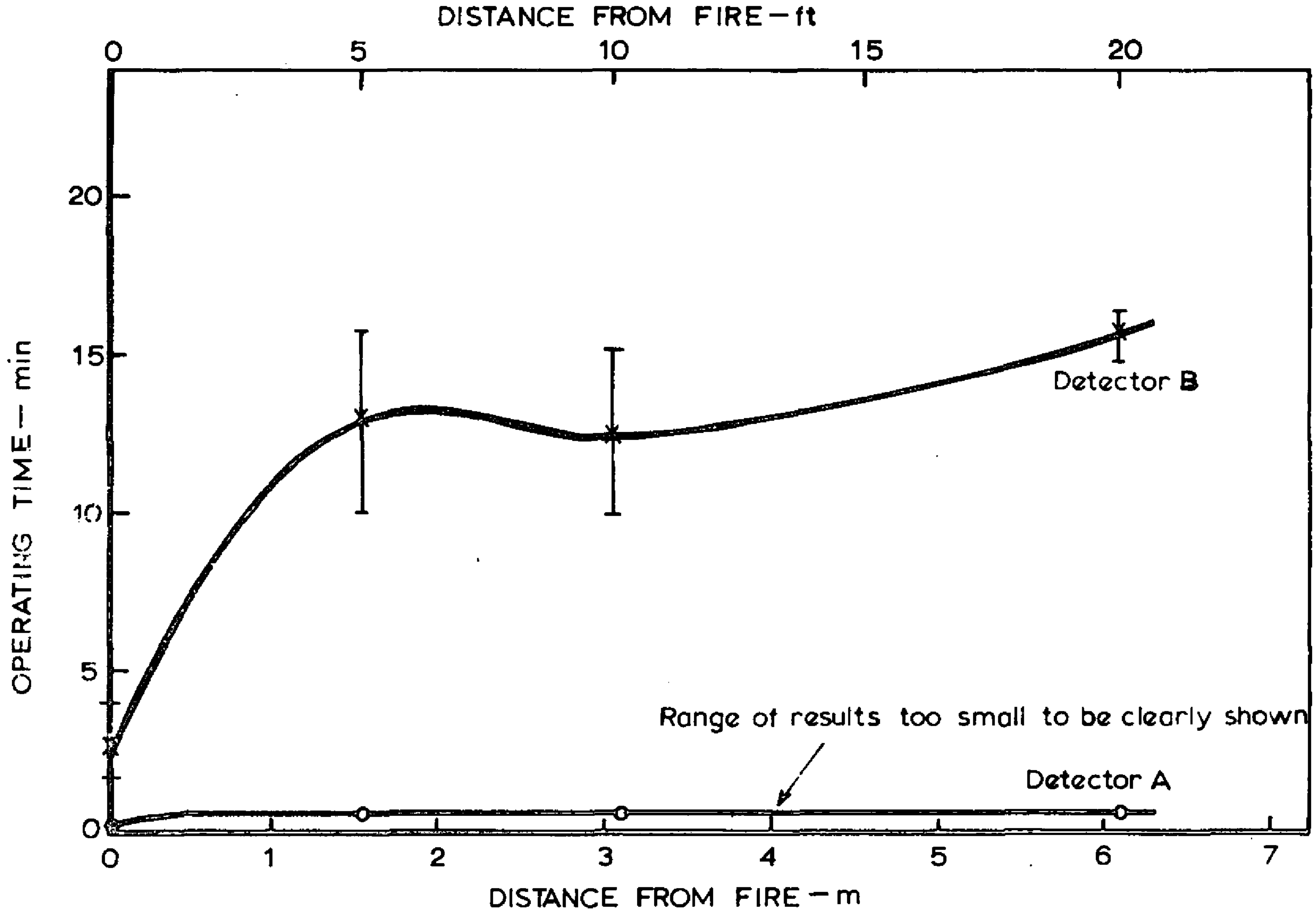


FIG.7 VARIATION IN DETECTOR OPERATING TIME WITH DISTANCE FOR PETROL FIRES

1179060 INT NOTE 301 + F.R. 780

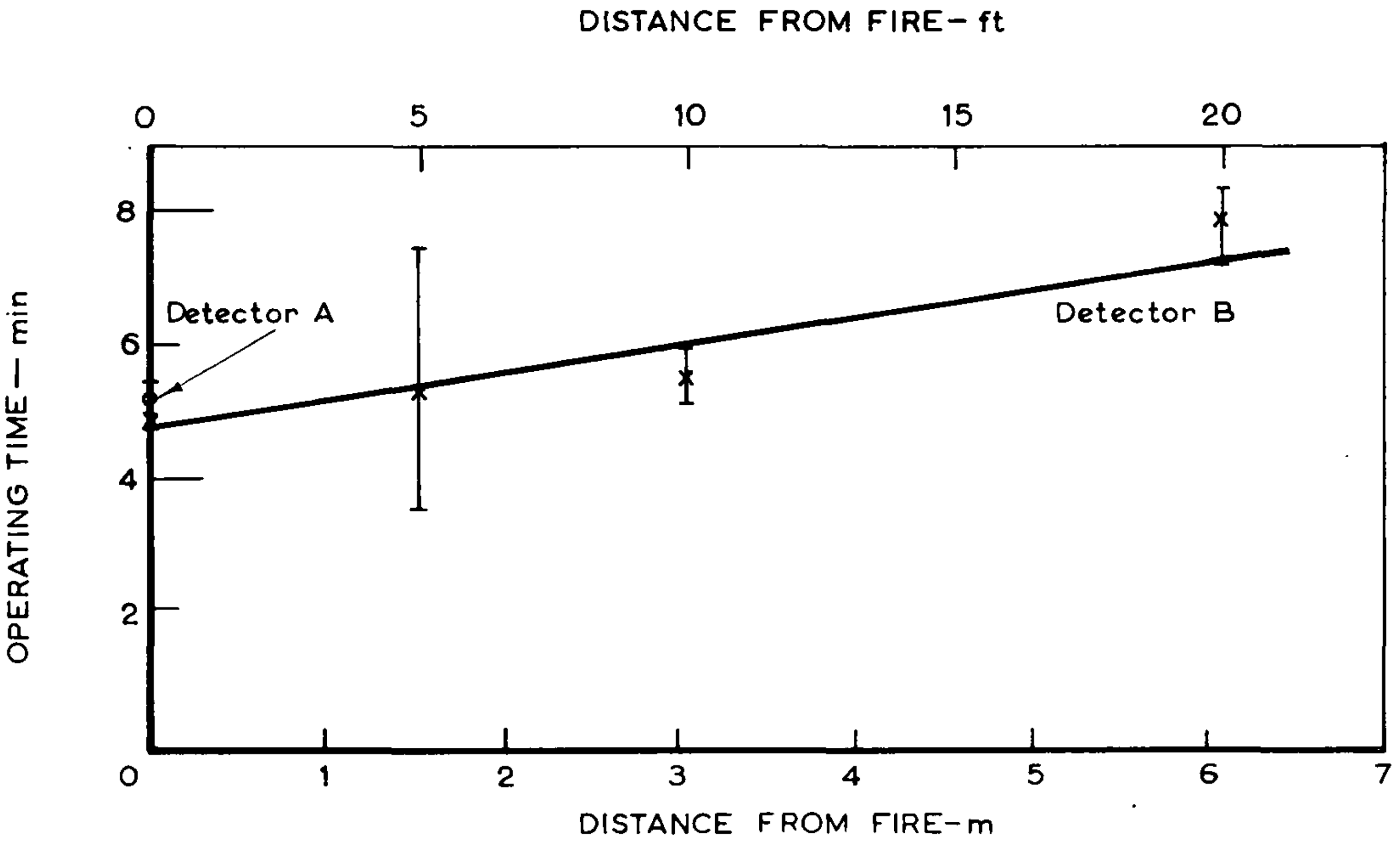


FIG.8. VARIATION IN DETECTOR OPERATING TIME WITH DISTANCE FOR POLYVINYL CHLORIDE POWDER FIRES

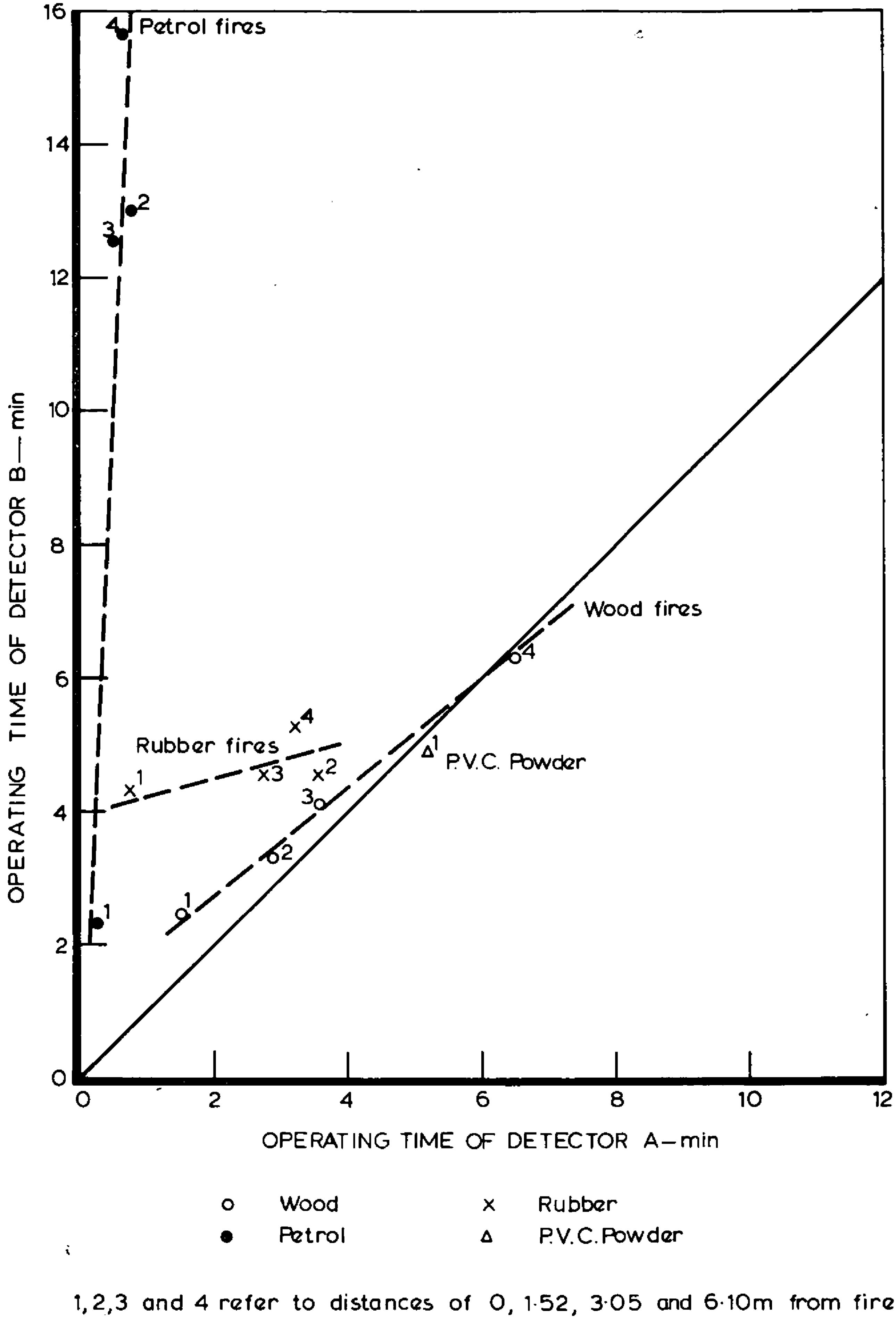
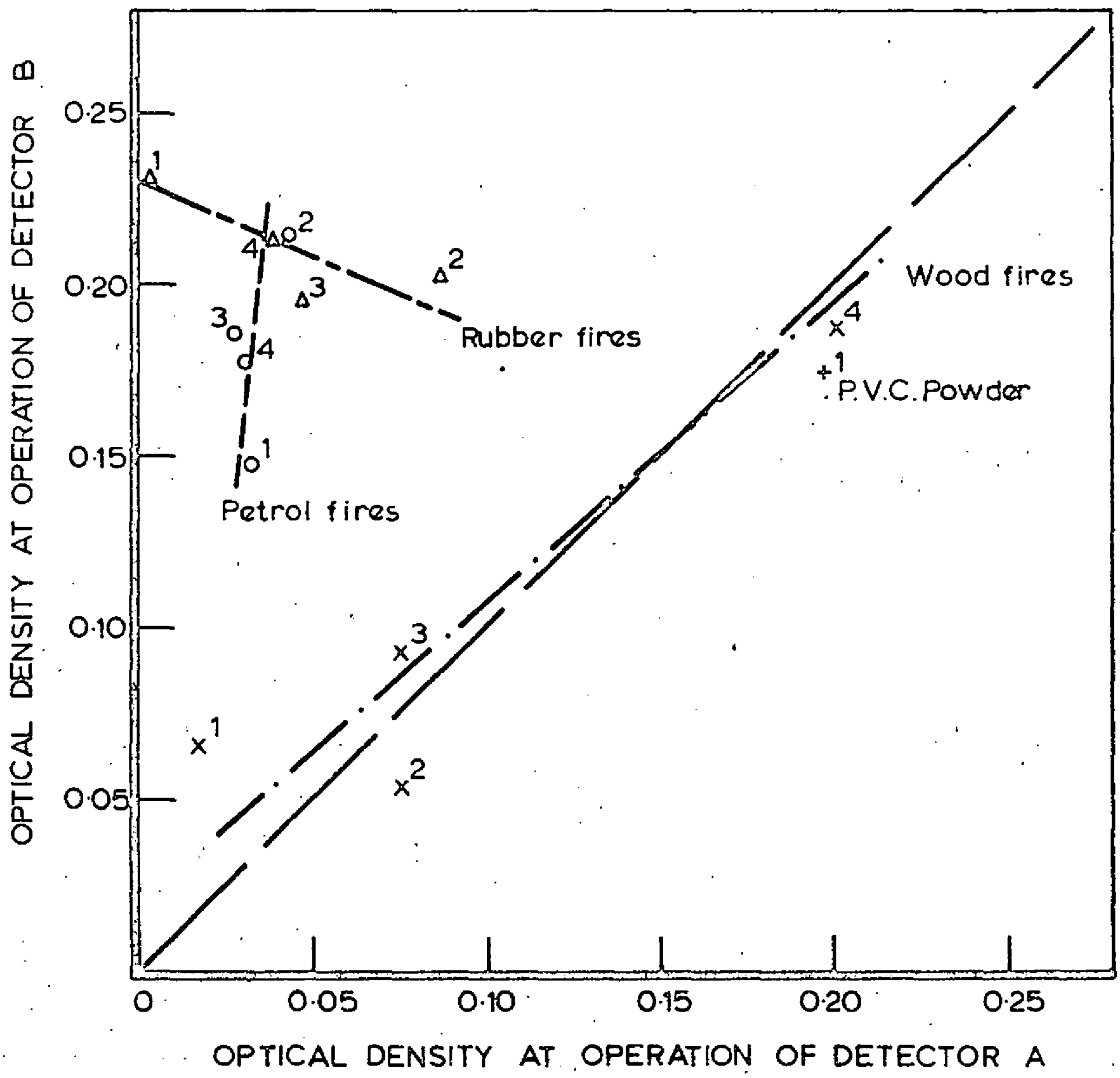


FIG.9. OPERATING TIMES OF THE TWO TYPES OF DETECTOR

9186 F.R. 780.



1, 2, 3 and 4 refer to distances of 0, 1·52, 3·05 and 6·10m from fire

Optical path length = 50·8 cm (20 in)

FIG. 10. OPTICAL DENSITY AT OPERATION FOR THE TWO TYPES OF DETECTOR

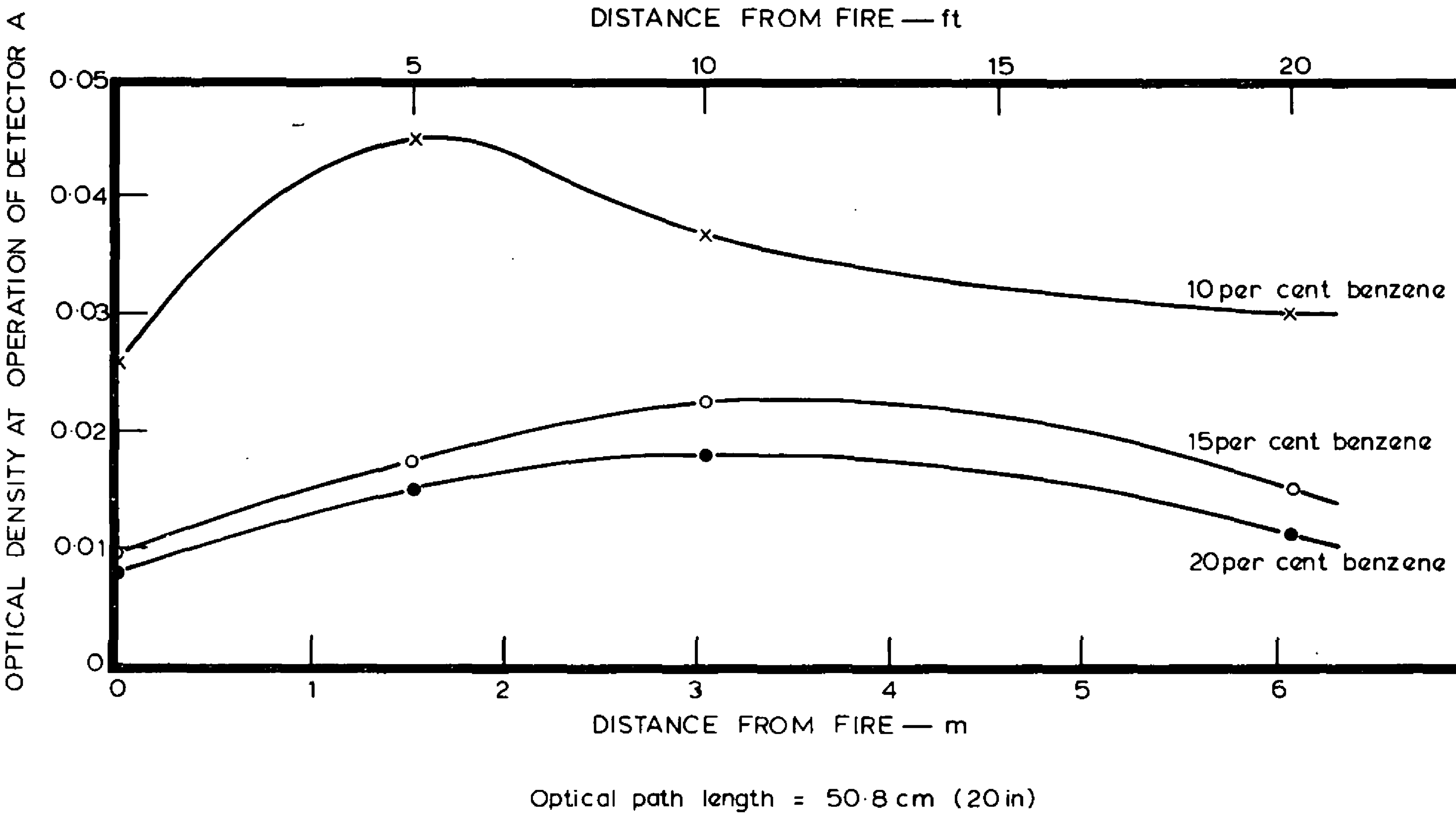


FIG. 11. OPTICAL DENSITY AT DETECTOR OPERATION FOR BENZENE IN ALCOHOL FIRES