F.R. Note No. 152/1955
Research Programme
Objective C3/2(C)

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

THE PRACTICAL APPLICATION OF CHLOROBROMOMETHANE TO PETROL FIRES

by

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Summary

The Ministry of Supply asked the Joint Fire Research Organization for advice on the method of applying chlorobromomethane to petrol fires.

Experiments were made with petrol fires ranging between 11 in. diameter and 10 ft. square and also on aircraft fires. Comparisons were made with chlorobromomethane applied as plain jets, cone sprays, and different types of flat sprays, and comparisons were also made between chlorobromomethane and carbon tetrachloride.

Flat sprays were superior to plain jets or cone sprays, and the lateral spread of the spray was the controlling factor in the efficiency of the nozzle, provided that the rate of delivery per unit of area was above a minimum value, which in these trials was about 0·01 gal/sq ft/min

Some measurements were made of the decomposition products in the atmosphere near to the fire.

January, 1955.

File No. F.1031/1/7

Fire Research Station,
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Introduction

Following a decision of the Air Ministry Fire Service to use chlorobromomethane as an auxiliary agent to foam in the heavy crash tender, the Ministry of Supply asked for advice on the method and rate of application of the agent in relation to the size of fire with which it was expected to deal. In some earlier full-scale tests (1) on the application of chlorobromomethane to aircraft crash fires, the agent had been applied using a pair of proprietary cone spray nozzles delivering 6 gal/min each, but there was reason to believe that further study might lead to greater economy in the use of the agent, and to greater efficiency of the appliance. The present report therefore describes a systematic study of the application of chlorobromomethane to petrol fires in open vessels up to 10 ft. square, and in simulated aircraft crash fires. During this work a detailed comparison was also made between chlorobromomethane and carbon tetrachloride, and some measurements were made of the concentrations of noxious gases produced.

The programme of experiments was divided into three parts: firstly, a preliminary small-scale investigation to decide the best way of applying the extinguishing agent to a fire: secondly, trials with medium scale fires to discover the effect of spray pattern, drop size, and rate of application of the agent on the efficiency of extinction, and also to compare the efficiencies of chlorobromomethane and carbon tetrachloride: and finally, large-scale trials, including fires involving aircraft, to test the performance of the best type of applicator under conditions simulating those expected in the field.

EXPERIMENTAL

Materials

Chlorobromomethane - The chlorobromomethane was supplied to a Ministry of Supply specification (Appendix) and was stated to contain 80 per cent chlorobromomethane, the remainder being methylene chloride and methylene bromide. Previous tests made at the Joint Fire Research Organization (2) had shown that the difference in extinguishing efficiency between the pure material and a grade of 70 per cent purity was not of practical significance.

Carbon tetrachloride - The carbon tetrachloride was a technical grade, and no measurements were made of its purity.

Petrol - The fuel used for the small fires was a standard grade of unleaded petrol. For the purpose of these tests the combustion characteristics of this are not significantly different from those of high octane fuel. The fuel used in the large-scale tests was contaminated petrol from Royal Air Force Stations but it was not considered that the impurities would materially affect the results.

Method of test

Site - All the tests were carried out in the open air. The small-scale trials were made at the Joint Fire Research Organization. This site was unsuitable for the large-scale tests which were therefore made at the Royal Air Force Station, Kenley.

Fires - In the preliminary trials, a $\frac{1}{4}$ in. layer of petrol was floated on water in circular trays, 5 in. deep, and 11, 14, and 24 in. diameter, with an ullage of $\frac{3}{4}$ in. The trays were placed on a concrete raft. In the medium-scale trials, a $\frac{1}{2}$ in. layer of petrol, without water, was used in circular trays, 1 in. deep, and 24 and 48 in. diameter, embedded to the rim in a sanded area about 10 ft diameter.

The large-scale trials were made (a) in 10 ft square bunds with walls 9 in. high. The exterior was built to a 45° slope with sand and clay. They contained 25 gallons of petrol floated on water, with an ullage of $4\frac{1}{2}$ in., and (b) in 10 ft square areas, covered unevenly with damp sand surrounded by a 3 to 4 in. high wall of wet clay; 15 gallons of petrol were used. For the fires involving aircraft a Spitfire, without engine or wheels was collapsed on to the tarmac, and three steel trays, each 7 ft x $3\frac{1}{2}$ ft were arranged under the forward bulkhead to give a fire area 7 ft x 11 ft. These contained a total of 15 gallons of petrol, and additional petrol was allowed to run down the bulkhead, at about 3 gal/min into the centre tray during the fire. The aircraft was pointed into the wind.

Before attacking the fires, they were allowed to attain maximum intensity. The preburn times were 15 seconds in the trials at Joint Fire Research Organization, with fires from 11 in. to 48 in. diameter, 20 to 25 seconds for the 10 ft square fires on water, 45 seconds for the 10 ft square fires on sand, and 60 seconds for the aircraft fires. All these fires would have burnt at maximum intensity for not less than 3 minutes if no extinguishing agent had been applied.

Nozzles

Table 1 lists the characteristics of the nozzles used in the trials. There were three main types:-

(a) plain nozzles as used in carbon tetrachloride hand extinguishers. These have a slight constriction in the bore so that a broken stream is projected.

(b) Cone spray nozzles producing a conical pattern of spray. The nozzles used all gave a solid cone of spray. Two forms of proprietary nozzle, referred to as Mk I and Mk II, were used. They were said to have the same characteristics, but the Mk II nozzle was fitted with a positive shut-off cock. The Mk I nozzle was used in the previous trials at Kenley [1]. Both were set so as to deliver 6 gal/min of chlorobromomethane, when used with a tank pressure of 100 lb/in^2. This gave a pressure of 35 lb/in^2 at the nozzle. The spray was delivered as a cone of about 60° angle, and, at the angle of operation, had a forward throw of between 10 and 12 ft. and a lateral spread of about 8 ft.

(c) Flat spray nozzles giving a flat plate of spray, produced either by two jets impinging one on the other, by one jet impinging on a flat plate ("fan spray"), or by an array of batswing type gas burners. The delivery rate of spray at a given pressure was varied by fitting jets or batswing burners of different sizes. The batswing spray applicator (Fig. 5) consisted of an array of 3 or 7 batswing burners arranged regularly on an arc of 112°. The three burners of the small applicator were arranged on an arc of radius $3\frac{3}{4}$ in. and the seven of the larger applicator on arc of 7 in. radius. The applicators were used on a 6 ft long boom incorporating a filter and shut-off cock.

The plain impinging jets, fan, spray, and the four small cone spray nozzles, were used in the preliminary investigation. The fan spray nozzles and the small batswing applicator were used in the medium-scale trials and the proprietary cone spray nozzles and the batswing applicators were used in the large-scale trials.

TABLE 1

Characteristics of nozzles used in tests

NOZZLE		PRESSURE 30 Lb/in.^{2}												PRESSURE 60 Lb/in.^{2}										
			CHLOROBROMOMETHANE					CARBON TETRACHLORIDE						CHLOROBROMOMETHANE					CARBON TETRACHLORIDE				
			Spray pattern			Delivery rate		Spray pattern			Delivery rate			Spray pattern			Delivery rate		Spray pattern			Delivery rate	
Description	No. of nozzles	Drop size mm	Lateral spread ft	Throw ft	Area ft	Gal/ft^2/min	Total gal/min	Lateral spread ft	Throw ft	Area ft	Gal/ft^2/min	Total gal/min	Drop size mm	Lateral spread ft	Throw ft	Area ft^2	Gal/ft^2/min	Total gal/min	Lateral spread ft	Throw ft	Area ft^2	Gal/ft^2/min	Total gal/min
Plain jet 0.032" dia.	1		NOT	DETERMINED			0.09	NOT	DETERMINED			0.10		NOT	DETERMINED			0.12	NOT	DETERMINED			0.14
0.052" "	1		"	"			0.21	"	"			0.24		"	"			0.30	"	"			0.34
0.093" "	1		"	"			0.36	"	"			0.42		"	"			0.51	"	"			0.59
Impinging jets 1/32" dia.	1	-	NOT	DETERMINED			0.14	NOT	DETERMINED			0.16		NOT	DETERMINED			0.20	NOT	DETERMINED			0.23
3/64" dia.	1	-	"	"			0.31	"	"			0.36		"	"			0.44	"	"			0.51
1/16" dia.	1	-	"	"			0.57	"	"			0.66		"	"			0.81	"	"			0.93
Fan spray 1/32" dia.	1	0.38	1.25	1.9	1.5	0.060	0.09	1.25	1.9	1.5	0.067	0.10	0.47	2.0	2.1	2.9	0.041	0.12	2.0	2.1	2.9	0.048	0.14
" "	2	0.38	1.25	3.0	2.5	0.072	0.18	1.25	3.0	2.5	0.080	0.20	1.47	2.5	3.5	6.2	0.039	0.24	2.5	3.5	6.2	0.045	0.28
3/64" "	1	0.31	3.0	3.5	6.3	0.025	0.16	3.0	3.5	6.3	0.030	0.19	0.29	2.75	3.75	8.2	0.029	0.23	2.75	3.75	8.2	0.032	0.26
" "	2	0.31	3.0	3.5	7.8	0.041	0.32	3.0	3.5	7.8	0.049	0.38	0.29	3.25	4.0	8.6	0.053	0.46	3.25	4.0	8.6	0.061	0.52
1/16" "	1	0.25	2.75	4.0	7.9	0.039	0.32	2.75	4.0	7.9	0.047	0.37	0.21	3.25	4.5	9.0	0.048	0.43	3.25	4.5	9.0	0.054	0.49
" "	2	0.25	3.0	3.5	7.0	0.089	0.64	3.0	3.5	7.0	0.106	0.74	0.21	3.0	4.0	8.5	0.101	0.86	3.0	4.0	8.5	0.115	0.98
3/32" "	1	0.32	3.25	4.5	10.5	0.054	0.58	3.25	4.5	10.5	0.064	0.67	0.23	3.5	4.5	13.5	0.061	0.82	3.5	4.5	13.5	0.070	0.94
" "	2	0.32	3.25	3.5	8.0	0.143	1.16	3.25	3.5	8.0	0.168	1.34	0.23	5.0	5.5	19.0	0.086	1.64	5.0	5.5	19.0	0.099	1.88
1/8" "	1	1.0	6.0	7.0	30.0	0.039	1.16	6.0	7.0	30.0	0.043	1.30		NOT	DETERMINED			1.64	NOT	DETERMINED			1.84
Cone spray No. 1	1	-	1.0	2.35	1.5	0.037	0.055	1.0	2.35	1.5	0.042	0.063	-	1.0	2.5	1.8	0.043	0.078	1.0	2.5	1.8	0.049	0.089
No. 2	1	-	1.0	7.0	5.0	0.018	0.092	1.0	7.0	5.0	0.021	0.106	-	1.4	6.5	5.6	0.023	0.13	1.4	6.5	5.6	0.027	0.15
No. 3	1	-	NOT	DETERMINED			0.21	NOT	DETERMINED			0.24		NOT	DETERMINED			0.30	NOT	DETERMINED			0.34
No. 4	1	-	3.6	4.7	10.0	0.039	0.39	3.6	4.7	10.0	0.045	0.45	-	3.6	6.5	13.8	0.040	0.55	3.6	6.5	13.8	0.046	0.64
Proprietary	1	2.0 (approx.)	8	10-12	55	0.109	6	The solid angle subtended was about 60°. 35 lb/in.^{2} was the nozzle pressure obtained with a tank pressure of 100 Lb/in.^{2}															
Batswing (No. 000)	3		NOT	DETERMINED				NOT	DETERMINED					4.5	4.0	14.6	0.012	0.18	NOT	DETERMINED			
(No. 00)	3		"	"				"	"					5.0	4.0	17.5	0.021	0.36	"	"			
(on 112° of 3¾ in. circle except where shown otherwise) (No. 0)	3		"	"				"	"					6.0	5.0	26.3	0.021	0.54	"	"			
(No. 1)	3		"	"				"	"					6.0	4.0	20.1	0.034	0.69	"	"			
(No. 2)	3		"	"				"	"					6.0	5.0	26.3	0.033	0.87	"	"			
(No. 4)	3	0.1/0.2	9.0	4.9	38.0	0.024	0.90	9.0	4.9	38.0	0.027	1.01	0.1/0.2	10.0	5.5	47.9	0.026	1.26	10.0	5.5	47.9	0.029	1.41
(No. 7)	3	- " -	NOT	DETERMINED				NOT	DETERMINED					11.0	6.0	57.0	0.031	1.77	NOT	DETERMINED			
(No. 000)*	3	- " -	"	"				"	"					6.0	3.0	14.7	0.012	0.18	"	"			
(No. 000)†	7	- " -	"	"				"	"					6.0	3.0	14.7	0.029	0.42	"	"			
4 No. 4) 3 No. 7) †	7	- " -	"	"				"	"					16.0	8.0	12.2	0.028	3.41	"	"			
No. 7 †	7		"	"				"	"					16.0	8.0	12.2	0.034	4.13	"	"			

*3 nozzles spaced symmetrically on 112° of 7 in. radius circle.
†7 " " " " " " " "

Application of agent - With the smaller fires in order to avoid the effect of variation in the competence of operators, it was decided to use a machine to apply the agent. The machine projected the agent downwards at an angle of about 10° to the horizontal and oscillated with a horizontal sweep of 60° and 10° vertical sweep. The mean line of projection was along the wind direction at the start of the test. As the tests were made in the open, the wind was not steady, and the inability of the machine to orient itself with the wind introduced variations about three times greater than those due to the competence of different operators. Once the technique of application had been learned the difference between operators largely disappeared.

The tests were therefore made with three operators, using manually controlled appliances, and the fires were attacked with the wind.

Characteristics of nozzles - The spray pattern, i.e. the effective area covered by the spray produced by the nozzles was estimated by projecting dyed agent for about 3 seconds on to a sheet of absorbent material, and measuring the area completely covered by the spray. The nozzle was held in the position in which it would be used in practice. The spray patterns obtained are given in Fig. 3.

The mass median drop size of the sprays was calculated from the number and size of stains produced by the drops of dyed agent collected on smooth absorbent paper. The diameters of stains were corrected to true drop diameter from a graph of the relationship between the diameter of the stain and of the drop producing it. Single drops of known size were produced by a micro-burette.

The total rate of flow, measured by collecting the amount of agent delivered in a given time, when divided by the area of the spray pattern, gave the mean rate of flow per unit area.

The pressure at the nozzle was adjusted to the required value by adjustment of the reservoir pressure. With the proprietary cone spray nozzle, when it was used as recommended by the manufacturers at a tank pressure of 100 lb/in^2 the nozzle pressure was 35 lb/in^2.

Containers and delivery hose

The containers for the agent were steel or copper vessels, those used in the preliminary and medium-scale trials containing about 2 pints, and 2 gallons, and those for the large-scale trials 12 gallons of agent. The hose lines were of flexible bronze tubing for the smaller-scale trials and of reinforced tubing of chlorobromomethane-resistant rubber for the large-scale trials. In the medium and large-scale trials the experimental nozzles were connected to the hose line by 6 ft long applicators incorporating a control cock and a filter, but the proprietary cone spray nozzle, was connected directly to the hose line. The agent containers in the smaller-scale trials were pressurised by an air compressor and a pressure reservoir, and in the large-scale trials by either this system or by a small nitrogen cylinder, the dead space in the tank, about half its volume, acting as the pressure reservoir.

RESULTS AND DISCUSSION

Preliminary trials

In order to conserve the chlorobromomethane, carbon tetrachloride was used as the extinguishing agent in these trials.

Effect of type of nozzle - Trials were made with an 11 in. diameter fire of petrol floating on water, the agent being applied at a nozzle pressure of 30 lb/in^2, and three types of nozzles were examined.

Figures 1a and 1b show the relationships between delivery rate, quantity of agent used for extinction, and extinction time for different nozzles.

Figure 1a shows that as the delivery rate was increased, the quantity of agent used for extinction decreased with cone and flat sprays, but increased with plain jet nozzles. Figure 1b shows that, with all of the nozzles, the extinction time was decreased as the delivery rate increased. The effect was however more marked with the cone and flat sprays than with the plain jets.

The trials showed that flat spray nozzles were superior to the cone sprays and the plain jets and subsequent tests were made only with flat sprays produced by one jet impinging on a metal plate. These are referred to as fan sprays in order to distinguish them from other flat sprays produced by two impinging jets, or as described later, by batswing gas burners.

In these experiments the impinging jet spray was difficult to maintain because of the necessity to re-align the nozzles when they were changed. The subsequent experiments were therefore made with the simpler fan spray.

Effect of rate of delivery - The effects of delivery rate were examined with fan sprays on fires of 11 in., 14 in. and 24 in. diameter with petrol floating on water. The ratios of the areas of these fires were 1 : 1·6 : 4·8. The results are shown in Figure 2a. The small 2 pint agent vessel used for these trials did not contain sufficient carbon tetrachloride for complete extinction of the 24 in. fires at delivery rates of 0·1 and 0·18 gal/min. Sufficient control was obtained, however, before the supply of agent was exhausted, to permit a rough estimate to be made of the probable time for extinction. The estimated curve for the 24 in. fire is shown as a dotted line.

The curves show that increase in delivery rate decreased the extinction time, but the relationship was not linear. Below a certain rate there was no extinction, and very great increases in rate were necessary to achieve extinctions in less than 5 to 10 seconds.

Effect of size of fire - The relation between the size of fire and extinction time is shown in Figure 2b. With any given rate of flow the extinction time increased with the size of the fire, and the average ratios of extinction times were greater than the ratios of the areas of the fires. The reason for this appeared to be related to the pattern of the spray and will be discussed later in this report.

The preliminary experiments showed that in order to obtain results which could be related to practical conditions it would be necessary to increase the sizes of the fires and experiments were therefore made with 24 in. and 48 in. diameter fires. A 48 in. diameter fire was the largest that could be accommodated on the site available.

Effect of water layer - It was found in the early trials where water was used that some of the agent was rendered ineffective because it passed through the layer of burning petrol and sank beneath the water.

Medium-scale trials. 24 in. and 48 in. fires

Because of the effects produced by floating petrol on water, the medium-scale trials were made with petrol alone.

Fan spray nozzles - The results are given in Table 2. Both carbon tetrachloride and chlorobromomethane were used.

TABLE 2

The effect of rate of flow, drop size and pressure, on extinction time

SIZE of FIRE	AGENT												
		Pressure lb/in.$^{-2}$	30					60				30	60
		Nozzle bore in.	1/16		3/32		1/8	1/16		3/32		3/64	3/64
		Drop size mm	0.25		0.32		1.0	0.21		0.23		0.31	0.29
		No. of nozzles	1	2	1	2	1	1	2	1	2	2	2
2 ft. diameter (3.14 sq.ft. area)	CARBON TETRACHLORIDE	Rate of flow gal./min.	0.37	0.73	0.67	1.33		0.49	0.98	0.94	1.87	0.37	0.52
		Extinction time sec.	143	68	52	7		63	29	65	3	65	4
		Volume of agent used gal.	0.881	0.828	0.581	0.155		0.514	0.473	1.019	0.094	0.401	0.035
		Wind speed	*H	H	H	H		H	H	H	H	H	H
	CHLOROBROMOMETHANE	Rate of flow gal./min.	0.32	0.64	0.58	1.16		0.43	0.86	0.82	1.63	0.32	0.45
		Extinction time sec.	23	3	33	8		6	14	9	16	32	6
		Volume of agent used gal.	0.123	0.032	0.319	0.154		0.043	0.201	0.123	0.434	0.170	0.045
		Wind speed	H	L	H	H		L	H	L	H	H	H
4 ft. diameter (12.56 sq.ft. area)	CHLOROBROMOMETHANE	Rate of flow gal/min.	0.32	0.64	0.58	1.16	1.16	0.43	0.86	0.82	1.63	0.32	0.45
		Extinction time sec.	62	16	62	13	8	52	8	7	8	96	94
		Volume of agent used gal.	0.331	0.171	0.599	0.251	0.155	0.373	0.115	0.096	0.217	0.512	0.705
		Wind speed	H	H	H	H	H	L	H	L	L	H	H

*H indicates wind speeds greater than 7 m.p.h. and L indicates winds below this speed.

Nozzles of $^3/_{64}$ in., $^1/_{16}$ in. and $^3/_{32}$ in. bore were used at 30 and 60 lb/in. pressure. The range of drop sizes was between 0·21 mm and 0·31 mm diameter. The rates of flow were between 0·37 and 1·87 gal/min for carbon tetrachloride, and 0·32 and 1·63 gal/min for chlorobromomethane. A $\frac{1}{8}$ in. bore nozzle was also used at 30 lb/in^2. This gave a drop size of about 1 mm diameter, and its delivery rate was 1·16 gal/min of chlorobromomethane.

Effect of rate of delivery - When the delivery rate was increased either by increasing the number or bore of the nozzles, or by increasing the pressure, the extinction times on the 24 in. fires were, on the whole, decreased with both carbon tetrachloride and chlorobromomethane. The effects were more marked in the tests with carbon tetrachloride, than with chlorobromomethane.

The 48 in. fire was not extinguished with carbon tetrachloride. In tests with $^3/_{32}$ in. bore nozzles, the fire was often swept from the tray, but while the persistent fire beyond the tray was being attacked it flashed back and re-ignited the petrol in the tray. Extinctions were obtained in all the trials with 48 in. fires when chlorobromomethane was used, the effect of delivery rate on extinction being similar to that observed for the 24 in. fire with carbon tetrachloride.

Effect of drop size - The effect of drop size can be seen by comparing the results of tests at the same pressure of 2 x $^3/_{64}$ in. and 1 x $^1/_{16}$ in., of 2 x $^1/_{16}$ in. and 1 x $^3/_{32}$ in., and of 2 x $^3/_{32}$ in. and 1 x $\frac{1}{8}$ in. nozzles. It did not appear that the drop size, in the range used in these experiments, produced any significant differences of extinction time.

The effect of wind - During the trials it was observed that the behaviour of the fires varied with the wind speed. At low speeds the flames rose straight up but as the speed increased the plume of flames was bent towards the ground. At this stage hot petrol vapour was carried forward along the ground and it burned at some distance away. With a 4 ft tray and 10 m.p.h. wind this distance was about 6 ft.

Extinction times were longer in higher wind speeds. During the experiments air was entrained with the spray and was carried into the fire. The amount of entrained air was greatest with high rates of delivery at high pressures, the effect was seen as an intensification of the fire along the line where the spray met the flames.

In these experiments the effects of wind and entrained air were not sufficient to prevent extinction, but the results of some experiments with batswing burner nozzles showed that they may affect extinction times.

Effect of size of fire

Comparing the extinctions with chlorobromomethane on the 2 ft. and 4 ft. diameter trays, the extinction times were, generally, increased. The ratio of extinction times for the two sizes of fire was similar to the ratios of the diameters of the fires. This point is discussed later in this report.

Comparison of carbon tetrachloride and chlorobromomethane

Table 2 gives the quantities of agent used and the times of extinction on 2 ft. and 4 ft. trays.

The 4 ft. fire was extinguished at all rates of delivery with chlorobromomethane but in no case with carbon tetrachloride. On the 2 ft. fires chlorobromomethane was, about, three times better than carbon tetrachloride whether the criterion was time of extinction or on quantity of agent used.

Spray pattern

The experiments showed the importance of the spray pattern and the necessity for covering as wide an area as possible. Measurements were made of the spray patterns produced by the nozzles used. These patterns are shown in Figure 3. It was seen that the superior performance of the 3/32 in. nozzle either alone or as a pair could be related to the spray pattern as it gave a wider spray than the other nozzles.

Spray applicators were therefore constructed from batswing gas burners arranged as in Figure 5. The spray pattern is given in Figure 3.

Batswing burner nozzles

The batswing burner nozzles produced a thinner plate of spray than the flat impinging jet sprays and fan spray nozzles, and thus covered a larger area for a given rate of flow. The delivery rate of the agent could be varied either by varying the nozzle pressure, or by varying the burner size. A few trials were made on the effect on extinction of varying the delivery rate of chlorobromomethane on a 48 in. diameter petrol fire. The delivery rate was varied in one series by varying the nozzle pressure of a three burner applicator fitted with size No. 4 burners, and in another series the burner size was varied and the pressure maintained at 60 lb/in.^{2}. The agent was applied for a maximum time of 1 minute. The results of the trials are given in Table 3 and the data are plotted in Figure 6.

Table 3

The effect of nozzle characteristics on extinction time and quantity of agent used. 4 ft. diameter petrol fires attacked with chlorobromomethane after 15 seconds preburn. Applicator with 3 burners on 112° arc of $3\frac{3}{4}$ in. radius
(except tests No. 2 and No. 3)

Result No.	Wind speed	Characteristics of nozzles							Extinction time	Quantity of agent used
		Burner	Nozzle pressure	Spray pattern			Delivery rate			
				Lateral spread	Throw	Area	Gal/sq.ft./min.	Total		
	m.p.h.	Size No.	Lb./in.^{2}	ft.	ft.	sq.ft.		gal./min.	sec.	pints
1*	4	000	60	4·5	4	14·6	0·012	0·18	Not extinguished	
2†	2	000	60	6	3	14·7	0·012	0·18	"	"
3ø	2	000	60	6	3	14·7	0·029	0·42	11	0·62
4	2	00	60	5	4	17·5	0·021	0·36	20	0·96
5	1	0	60	6	5	26·3	0·021	0·54	13	0·94
6	$2\frac{1}{2}$	1	60	6	4	20·1	0·034	0·69	12	0·55
7	3	2	60	6	5	26·3	0·033	0·87	8	0·94
8‡	9	4	60	10	5·5	50	0·025	1·26	3	0·50
9	9	4	30	9	4·9	38	0·025	0·90	4	0·48
10	9	4	4	8	4	30	0·011	0·32	6	0·36
11	9	4	2	7	3·5	23	0·010	0·23	8	[illegible]
12	4	7	60	11	6	57	0·031	1·77	5	[illegible]

*Mean of two tests
†3 burners arranged on 112° arc of 7 in. radius circle
ø7 " " " " " " " " "
‡Mean of four tests.

Test No.	FIRE				Wind speed m.p.h.	NOZZLES		DELIVERY RATE		SPRAY PATTERN		Extinction time secs	Volume of agent used gal	COMMENTS
	Dimensions ft	Volume of petrol gal	Conditions	Preburn time secs		Type	Nozzle pressure $lb/in.^2$	$Gal/ft.^2 min.$	Total gal/min	Spread ft	Throw ft			All fires attacked with the wind. All tray fires attacked along diagonals.
1	10 x 10	25	Petrol on water	22	Wind speed varied from 6·0 to 8·25 m.p.h.	Large batswing burner (7 nozzles)	60	0·028	3·41	16	8	9·5	0·57	Easy progressive extinction, after first extinguishing flame at windward wall of tank.
2	10 x 10	25	" " "	22		" " "	55	0·028	3·41	16	8	12·0	0·65	Extinction made by inexperienced operator given verbal instruction just before attacking fire.
3	10 x 10	25	" " "	24		Proprietary cone MKI.	35	0·109	6	8	10–12	39·5	3·95	Attack made difficult by limited area covered by spray. Extinction finally achieved mainly by dilution.
4	10 x 10	25	" " "	22		Small batswing burner (3 nozzles)	60	0·026	1·26	10	5·5	No extinction	-	Attacked for about 1 minute but cover insufficient to extinguish, although flames largely removed from petrol.
5	10 x 10	25	" " "	22		" " "	60	0·027	1·77	12	6	No extinction	-	Comment as Test 4
6	10 x 10	25	" " "	22		2 small batswing burner (3 nozzles each)	60	-	3·54	EACH NOZZLE 12	6	11·0	0·7	Comment as for large batswing above. (Test 1)
7	10 x 10	25	" " "	22	15·8	Large batswing burner	60	0·034	4·13	16	8	20	1·44	Fire more difficult to extinguish than earlier ones due to high wind.

2nd PART

TABLE 4

Results of large scale trials using proprietary cone sprays and batswing burner applicators

8	10 x 10	10-15	" " "	22	15·8	Proprietary cone MkII.	35	0·109	6	8	10-12	16·5	1·65	Fuel of lesser quantity and higher volatility than other trials. On extinction remaining fuel, (one or two gallons only), pushed to within a foot of far corner of bund, and difficult to re-ignite.
9	10 x 10	25	" " "	22	15·8	" " "	35	0·109	6	8	10-12	38	3·80	Similar to earlier test (No. 3) with same quantity of fuel. Petrol failed to re-ignite after extinction.
10	10 x 10	15	Petrol on sand	45	15·5	" " "	35	0·109	6	8	10-12	14·0	1·40	Fire readily extinguished by moving nozzle to cover fire area.
11	10 x 10	15	" " "	45	15·5	Large batswing burner	60	0·034	4·13	16	8	8.5	0·60	Fire readily extinguished by advancing spray across fire area.
12	11 x 7	15 gal. petrol in 3 trays, combined size 11 ft. x 7 ft. with aircraft over tray, with running petrol fire of about 3 gal./min. x		60	8·8	Proprietary cone MkI. and MkII.	35	-	6-12	EACH NOZZLE 8	10-12	55	9·5	2nd nozzle brought into use 15 secs after starting attack. Extinguished in 39 secs, followed by flash back and further 16 secs fighting.
13	11 x 7			60	11·9	2 large batswing burner	60	-	4·13 -8·26	EACH NOZZLE 16	8	47	4·96	2nd nozzle was put into use 22 secs after starting. Several seconds spent after flames extinguished in applying agent to air intake and engine cooler radiator.

x No. 13 fire was more intense than No. 12. (see note in text).

The drop size from the batswing burners was not measured because it was below the range of the method available. The drops however seemed much smaller than 0·2 mm diameter.

Effect of rate of delivery - The minimum rate of flow for extinction in the trials with the No. 4 burner and variation of pressure was somewhat less than 0·010 gal./sq.ft./min. when the pressure was low (Figure 6 Curve A), and was between 0.012 and 0·021 gal./sq.ft./min. when the pressure was 60 lb./in.^{2} and the burner size was varied (Figure 6 Curve B).

When the fire was not extinguished (Tests 1 and 2 Table 3) the tray fire was cleared rapidly, but the fire beyond could not be extinguished in spite of the lateral spread being sufficient to cover the fire. A similar effect was observed with a test made using carbon tetrachloride at 0·029 gal./sq.ft./min. at 60 lb./in.^{2}. Thus it would appear that a rate of 0·029 gal./sq.ft./min. was insufficient to produce extinction.

In Test No. 11 with 0·010 gal./sq.ft./min. of chlorobromomethane at 2 lb./in.^{2} the fire was extinguished in 8 seconds. The different behaviour in Tests 1 and 2, and Test 11 is possibly due to the effect of entrained air, which would be more at the higher pressure. This point is discussed later when the mechanism of extinction is considered.

The batswing nozzles were more efficient than the fan spray nozzles, in that the fires could be extinguished in a shorter time, with the use of less agent (c.f. Tables 2 and 3). The batswing burner applicators were used in large-scale trials (Table 4). Although the results given in Table 3 are few in number, there were sufficient to indicate that the minimum rate of delivery necessary for extinction was sufficiently below the rate it was proposed to use, and that an adequate margin was available to allow for variations in the intensity of the fire.

In order to establish firmly the minimum conditions required for extinction it would be necessary to carry out a much more extensive series of experiments.

Large-scale trials

A series of tests on 10 ft. square petrol fires and petrol fires involving aircraft was made at the Royal Air Force Station, Kenley, and comparisons were made of batswing burner applicators and proprietary cone spray nozzles. The results are given in Table 4.

Trials with open fires - Tests with the 10 ft. sq. fires on water were made on different days with different wind conditions. The first series was made with winds between 6 and 8¼ m.p.h., on the second day the wind speed varied between 9 and 16 m.p.h. One small batswing applicator using 1·77 gal. agent did not extinguish the fire, but with two applicators it was extinguished in 11 seconds with 0·65 gallons. One large applicator extinguished the fire in an average of 11 seconds with 0·62 gallons in the low wind, and in 20 seconds using 1·44 gallons in the high wind. Different arrangements of batswing burners were used in the first and second tests.

The Mk. I cone spray extinguished the fire in 39 seconds using 3·9 gallons in the low wind, and the Mk. II spray in the high wind extinguished the fire in 38 seconds using 3·8 gallons. After these extinctions the fires were difficult to re-ignite. It was noticed that the cone sprays moved the floating petrol across the surface of the water, and the extinctions were thus due partly to this clearance of the fire area. The effect is shown in Plate 1 taken from the cine record of the trials. The result of one test (No. 8) made with the Mk. II nozzle was disregarded as it was found that insufficient fuel had been used.

The fires on the sanded areas were less intense than when the fuel burned from a free surface, and extinction was much easier. The flat spray extinguished the fire in 8 seconds with 0·6 gallons of agent and the cone spray in 14 seconds with 1·4 gallons. The difference between extinction times for the flat spray and the cone nozzle are less than for petrol on water fires. This was probably because the times were of a similar order to the minimum times taken to traverse the area with the nozzle. More agent was used by the cone spray than by the batswing applicator.

The direction of the wind in all of the tests with open fires was diagonal to the side of the bund and since the attacks were made down wind, the maximum width to be controlled was about 14 ft.

The extinction of a petrol fire may be achieved by adding sufficient agent as vapour to the flame zone, or by diluting the petrol with agent so that the vapour evolved is not flammable. When 10 ft. square fires of petrol on water were extinguished with the commercial cone nozzle the petrol was difficult to re-ignite and it is considered that these extinctions occurred largely by dilution of petrol by the agent. This conclusion is supported by the similarity in extinction times under differing wind conditions, since earlier trials had shown that a high gusty wind adversely affected extinctions occurring principally in the vapour phase.

<u>Trials with aircraft</u> - Two trials were made with the aircraft in winds of 9 and 12 m.p.h. In these trials the fire was considered to be extinguished when it would have been safe for rescue personnel to have reached the cockpit. Small fires of hydraulic liquid and hose connections persisted after the main fire had been extinguished.

The first test was made with proprietary cone sprays. The attack was started with one spray and a second was used at 15 seconds. At 39 seconds the fire appeared to be extinguished, but it re-ignited from a fire concealed under the engine bulkhead. Both nozzles were used to attack the re-ignition. Extinction was considered complete at 55 seconds, although there was still a small fire behind the bulkhead and inside the engine compartment which was extinguished much later with water. 9·5 gallons of agent were used. The appearance of the fire just before attacking is shown in Plate 2.

During the extinction of the persistent fire in the previous test the area surrounding the aircraft became flooded with water and also, the fuselage was damaged. When petrol for the second fire was applied it floated on the water and produced a fire about 12 ft. wide and 16 to 20 ft. long. The flames extended well down the fuselage and over half the aircraft was involved. The second fire was therefore more intense and extensive than the first fire (Plate 3). It was attacked for 22 seconds with one large flat spray and then a second spray was used. The fire was finally extinguished at 47 seconds and approximately 5 gallons of agent were used.

Both of the aircraft fires were more intense than in the previous trials with aircraft at Kenley [1].

In the present series of trials the two operators worked side by side so as to cover as wide an area as possible, and as far as they could, advanced together. The attack was made low down and as near to the ground as possible. When the area fire had been substantially cleared, the fire from the running petrol was attacked by one man, and the pair then advanced again until the fire was extinguished.

Relative performance of nozzles

The batswing nozzles used less agent and extinguished the fires, whether on flat surfaces as on water, or damp sand, or whether obstructions such as an aircraft were present, in a shorter time than the proprietary cone nozzle.

DECOMPOSITION PRODUCTS

When either carbon tetrachloride or chlorobromomethane was applied to the fires the volume of smoke was increased and the smoke became very acrid. The smoke and fumes were denser with longer periods of attack. Samples of the vapours and fumes were taken from three fires on which $^1/16$ in. fan spray nozzles were used. The sampling apparatus was a ¼ in.-bore copper tube, connected by a short length of rubber tubing to a 5 litre vessel. Ten seconds after the application of agent to the fire, the open end of the tube was held in the smoke 5 ft. on the lee side of the tray and 5 ft. above the ground, and the fumes were drawn through the vessel at about 30 litres/min. The sample was taken for 10 seconds and so represented an average composition over a ten second period. The analyses are given in Table 5.

Table 5

Analyses of decomposition products from petrol fires

Agent	Type of spray	Rate of delivery gal./min.	Diameter of fire ft.	Analysis (per cent) by volume	
				Acid gases	Undecomposed agent
Carbon tetrachloride	Fan	0·32	2	0·043	0·0029
" "	"	0·32	2	0·244	0·0095
Chlorobromomethane	"	0·31	4	0·015	0·0015

The amounts of acid gases found both with carbon tetrachloride and chlorobromomethane were of a similar order to the concentrations found with chlorobromomethane in the cockpit of the aircraft at the Kenley trials (1). They were higher with carbon tetrachloride than with chlorobromomethane.

Carbon dioxide, carbon monoxide and oxygen were measured in two tests (Nos. 1 and 2) but the amounts of carbon dioxide and carbon monoxide found were very low, (0·1 and 0·7 per cent CO_2 and 0·1 and 0·2 per cent CO) and the oxygen was not depleted to a hazardous extent (20·4 and 19·5 per cent O_2).

As with the earlier Kenley trials, the main danger would be from hydrogen halide gases. The concentrations could not be considered innocuous except for very short exposure periods, and in Test 2 with carbon tetrachloride they were lethal for short periods of exposure.

The figures given should be treated with caution since the analyses are of samples taken over a relatively short period at one particular point.

General discussion

The mode of extinction - As already mentioned when discussing the effect of wind, hot petrol vapour was carried along the ground and produced a fire extending some distance from the tray and down wind. The first operation was to clear the tray of flame, and the next was to project the agent across the tray and on to the extended fire area to prevent flashing back (Plate 4 and Plate 5).

The first operation was made in a very short time for both 24 in. and 48 in. fires, but the second operation took longer. The times for both operations were longer at higher wind speeds. Similar effects were observed with the 10 ft. square fires.

There was thus a minimum time in which extinction could be produced in one sequence of operations, and this time, in the experiments on 24 in. and 48 in. fires was between 3 and 10 seconds depending on the weather. With a gusty wind, or with one which veered rapidly, the fire in the extended area was more liable to flash back and re-ignite the petrol in the tray, and the whole sequence of operations had to be performed again.

It is considered that with the 2 ft. fire the extinctions with chlorobromomethane were all made in or near the minimum time and that variations of extinction time were influenced more by changes of weather than by changes of delivery rate, and the rates used were therefore sufficient to produce an extinction under all weather conditions.

Mechanism of extinction

Relative efficiency of chlorobromomethane and carbon tetrachloride - The average superiority of chlorobromomethane over carbon tetrachloride in the fan spray trials on the 24 in. diameter fire was three times. On the 48 in. fires chlorobromomethane at 0·012 gal./sq.ft./min. and carbon tetrachloride at 0·029 gal./sq.ft./min. both failed to produce complete extinction although the flames were cleared from the tray. These rates of flow are in a similar ratio, 2·4, to the ratio of the superiority of chlorobromomethane over carbon tetrachloride when extinctions were achieved.

This "improvement factor" of 3 is greater than would be expected from considerations of the peak values of the agents which are 6·35 per cent for chlorobromomethane and 9·9 per cent for carbon tetrachloride, the ratio between which is about 1·5. The difference between the ratios of 1·5 and 3 may be explained by considering the conditions in which the agents operate.

Richness of petrol/air mixture - The atmosphere immediately above the surface of petrol is rich in fuel, and will burn only when induced air has reduced it to the upper limit. Further away in the extended area, although weaker, it is still rich as is shown by the smoky flame.

The effects of chlorobromomethane and carbon tetrachloride on the flammable limits of n-hexane, (a combustible similar to petrol) are shown in Figure 4. The addition of 0·5 per cent of agent reduces the upper limit of hexane from 6·7 per cent to 5·0 per cent with chlorobromomethane but only to 6·5 per cent with carbon tetrachloride, and in order to reduce the limit to 5·0 per cent it would be necessary to add 5·2 per cent carbon tetrachloride; also, with either of the agents the change of the lower limit with a small addition of agent is negligible. The marked superiority of chlorobromomethane may be due to the low concentration required to reduce a rich mixture to an inert condition.

It would also appear that the agent is applied with the greatest advantage just above the liquid surface to that part of the flame closest to the rich non-flammable vapour zone so as to maintain the vapours in a non-flammable condition even when air is diffusing into them.

Air entrainment - It is well known that the droplets of a spray entrain air during their passage, the amount entrained depending upon the velocity, which is related to the nozzle pressure. If much air were entrained, the flammable mixture could be diluted to such an extent that the composition of the combustible/air/agent mixture would be brought to a position where the effectiveness of the agent was low. The same effect would be produced by a high wind.

The inability to achieve extinction in Tests 1 and 2 - Table 3 may well have been due to the entrained air having diluted the petrol/air mixture to a point where the existing concentration of agent vapour was not capable of producing a non-flammable mixture.

The spray of agent should therefore be delivered at a pressure as low as possible commensurate with the retention of other necessary attributes.

Efficiency of flat spray - The investigation has shown that a flat spray produced by any suitable method is superior to any of the cone sprays examined. Consideration of the mechanism believed to operate indicates that its superiority is due to it concentrating the agent in that part of the fire where it is more effective, whereas the cone spray, by reason of its vertical spread is not so economical of agent.

There appears to be a minimum requirement of chlorobromomethane, which in these trials, was of the order of 0·01 gal./ft.^{2}/min. but this low rate of delivery would be insufficient to allow for variations such as could be introduced for instance by weather conditions, and the rate of 0·034 gal./sq.ft./min. used on the 10 ft. sq. fires and the aircraft fire allows a reasonable margin.

In addition to a minimum rate per unit of area, the lateral spread must be commensurate with the size of the fire and should be greater than the width of the fire.

Decomposition products

The gases from the fires contained appreciable quantities of hydrogen halides and the concentration could not be considered innocuous except for very short exposure periods.

General observations on the use of chlorobromomethane

Chlorobromomethane has a high degree of solvent action on materials such as rubber, grease and some plastics. Some difficulty was experienced with the apparatus using it. Rubber gaskets and jointing washers could not be used, nor was it possible to use ordinary jointing compounds for pipe joints since all were attacked rapidly and dissolved. Flexible metal delivery tubing was used where possible and joints were made with cellulose/aluminium lacquer or with shellac.

It was found that scale and rust from steel or iron was loosened and detached by the chlorobromomethane and it was therefore necessary to use filters to prevent the nozzles from becoming blocked.

CONCLUSIONS

The results of the experiments on the application of chlorobromomethane to petrol fires showed that flat sprays were superior to either cone sprays or plain jets, and that the lateral spread of the spray should be wider than the fire. An applicator made from batswing burners, which produced a very thin flat spray, was economical with the agent and gave short extinction times.

When the lateral spread was sufficient, the minimum rate of delivery of agent appeared to be of the order of 0·010 gal./sq.ft./min. but it is suggested that the rate for practical application should be higher in order to provide a safety margin. A petrol fire involving an aircraft was extinguished with two applicators each with a lateral spread of 16 ft. and a delivery of 0·034 gal./sq.ft./min. of chlorobromomethane.

The nozzle pressure should be as low as possible in order to reduce the amount of air entrained with the spray.

Chlorobromomethane was much superior to carbon tetrachloride and it is considered that the superiority is due to the effect of small additions to rich mixtures. From this it is concluded that chlorobromomethane is most effective when applied low down at the base of the flames.

The decomposition products from some fires were analysed, and the concentrations of hydrogen halides could not be considered innocuous except for very short exposure periods.

Chlorobromomethane has a high degree of solvent action on many organic materials, and also appears to loosen scale or rust from steel components. Care is therefore necessary in the selection of materials for gaskets and washers, and filters should be provided to prevent nozzles becoming blocked.

Acknowledgements

Mr. P. S. Tonkin and Mr. M. D. Perry assisted with the experimental work.

REFERENCES

(1) F. E. T. Kingman and P. Nash.
A comparison of dry powder and chlorobromomethane for first aid application to aircraft fires. F.R. Note No. 99R/1954 Joint Fire Research Organization March, 1954.

(2) Fire Research. 1952 p. 12. Her Majesty's Stationery Office.

PC.

APPENDIX

Specification of chlorobromomethane

Ministry of Supply. Specification for chlorobromomethane. 13th August, 1954

Formula	CH_2ClBr	
Synonyms	Bromochloromethane, C.B.	
Physical form	Colourless volatile liquid	
Typical analysis	Contains at least 80 per cent chlorobromomethane, the residue being a variable mixture of methylene chloride and methylene bromide.	
	Boiling range	60-85°C
	Specific gravity	1·88-2·00
	Water content	0·1 per cent
Constants (of pure C.B.)	Molecular weight	129·4
	Melting point	below -70°C
	Boiling "	69°C @ 760 mm Hg
	Density	d^{25}_{25} 1·93.

United States Air Force Specification No. MIL-B-4394-A .

Characteristics - clear colorless liquid with a sweet odour	
Boiling range @ 760 mm/Hg 5/95 per cent	66-68°C
Freezing point	below -65°C
Specific gravity $\frac{25°C}{25°C}$	1·910/1·940
lb./gal. 25°C	15·98
Flash point	None
Fire "	"
Mol weight	129·4
Solubility per 100 gm water 25°C	2·4 gm
Solubility in common organic solvents	infinite
Cloud point (moisture)	below 3°C.

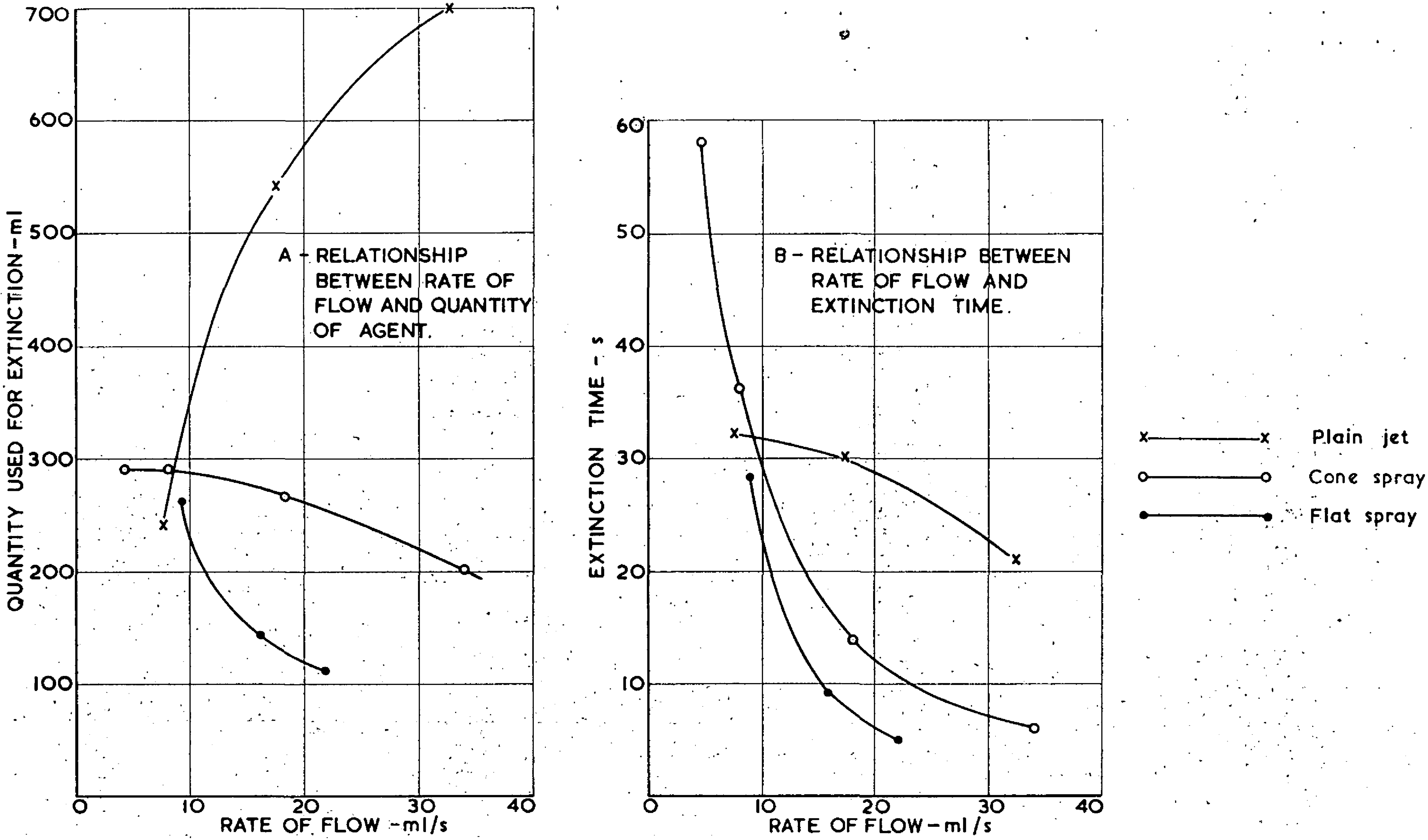

FIG. I. COMPARISON OF PLAIN JETS, CONE SPRAYS AND FLAT SPRAYS.
11" PETROL FIRE ATTACKED WITH CARBON TETRACHLORIDE

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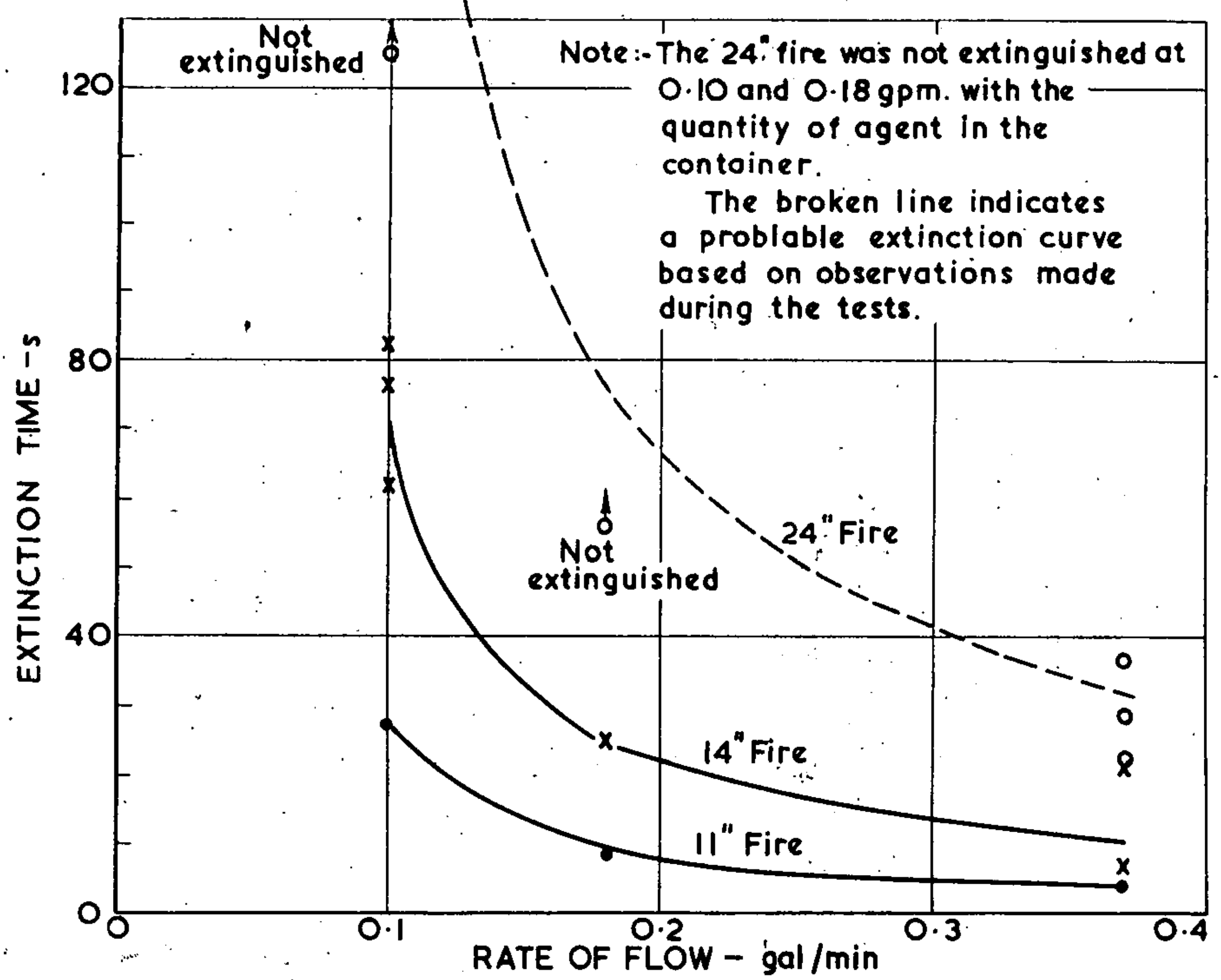
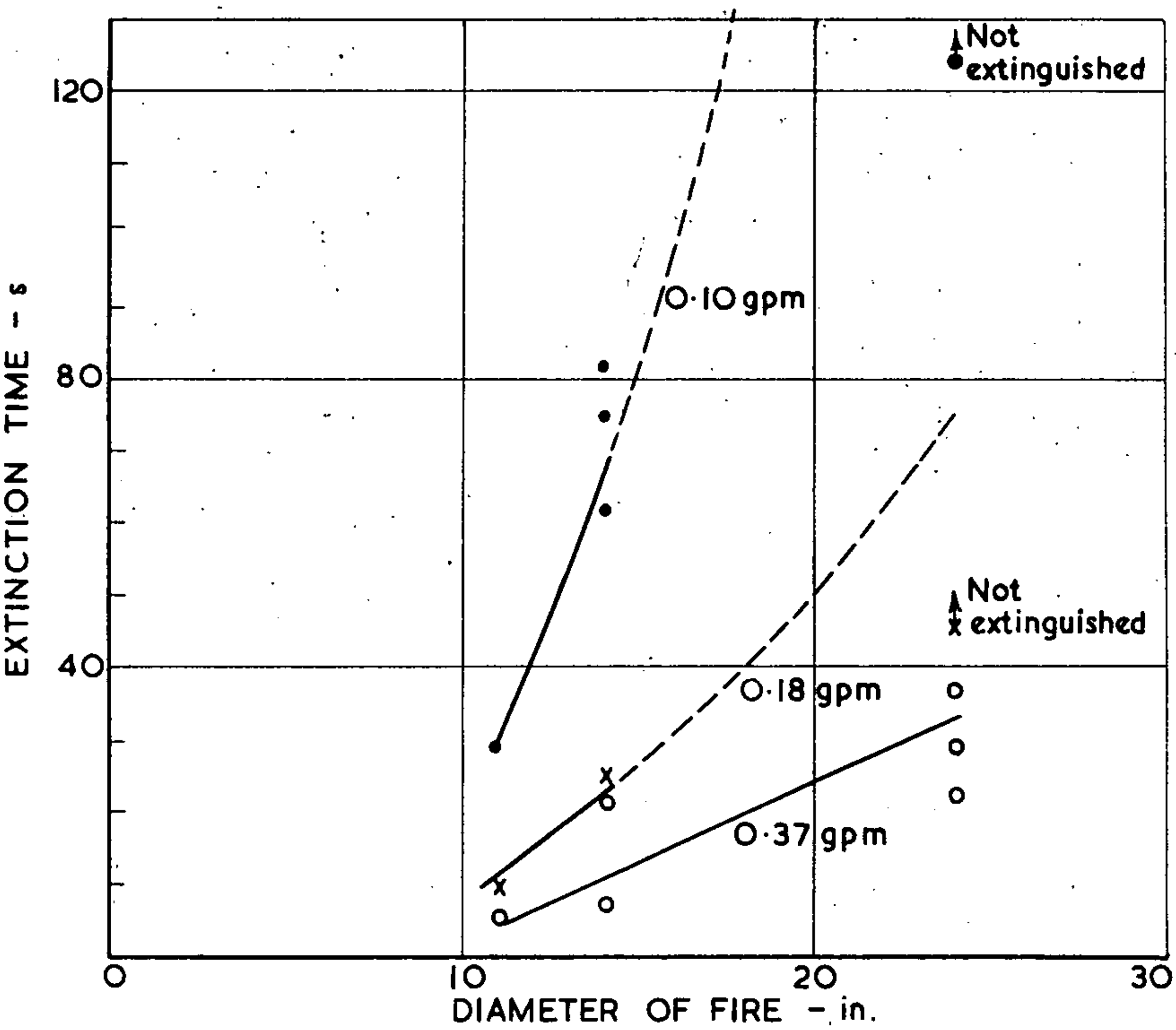


A – THE EFFECT OF RATE OF FLOW



B – THE EFFECT OF SIZE OF FIRE

FIG.2. THE EFFECTS OF RATE OF FLOW AND SIZE OF FIRE ON EXTINCTION TIME

F.R. 152

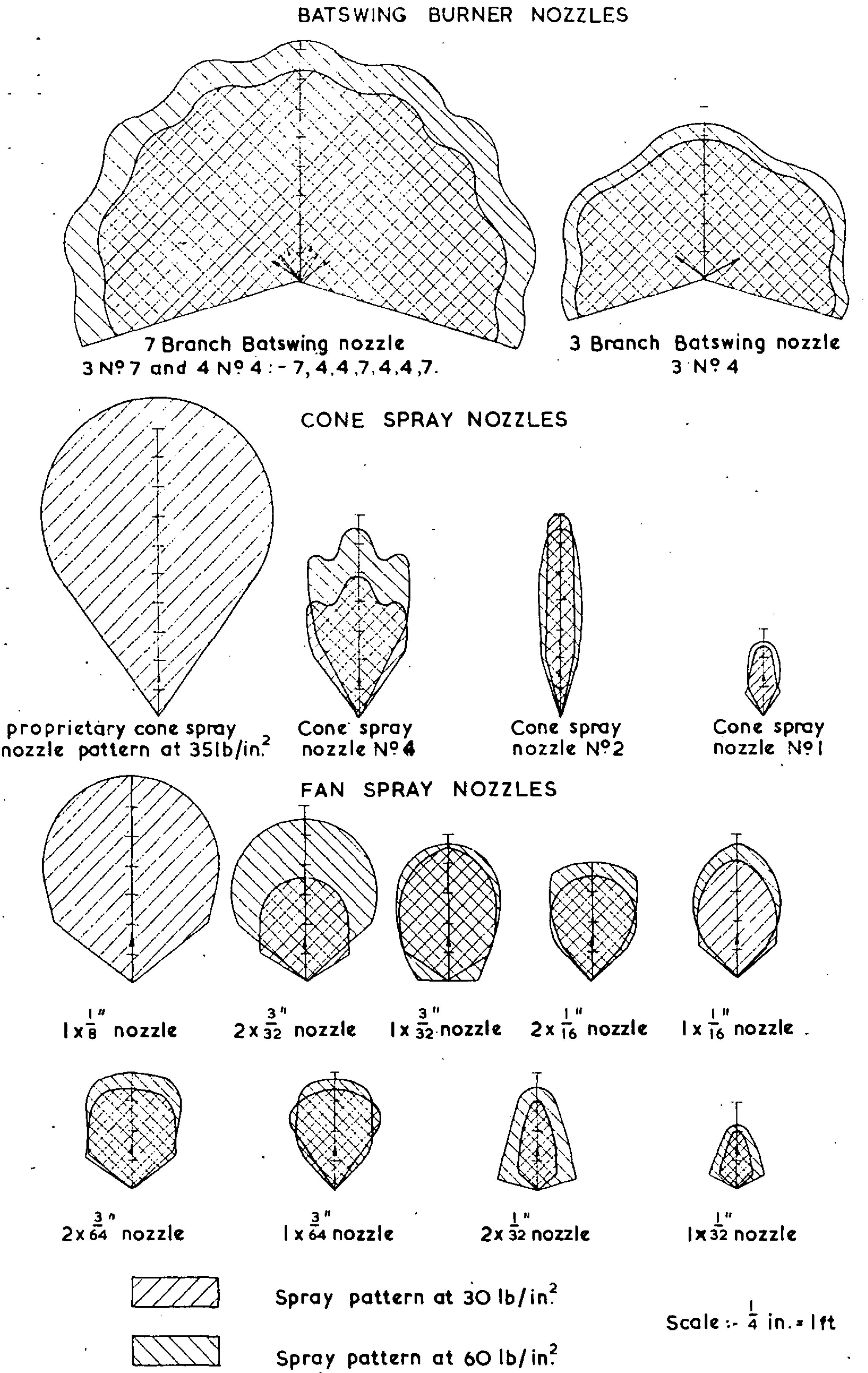


FIG. 3. SPRAY PATTERNS PRODUCED BY BATSWING, CONE AND FAN SPRAY NOZZLES.

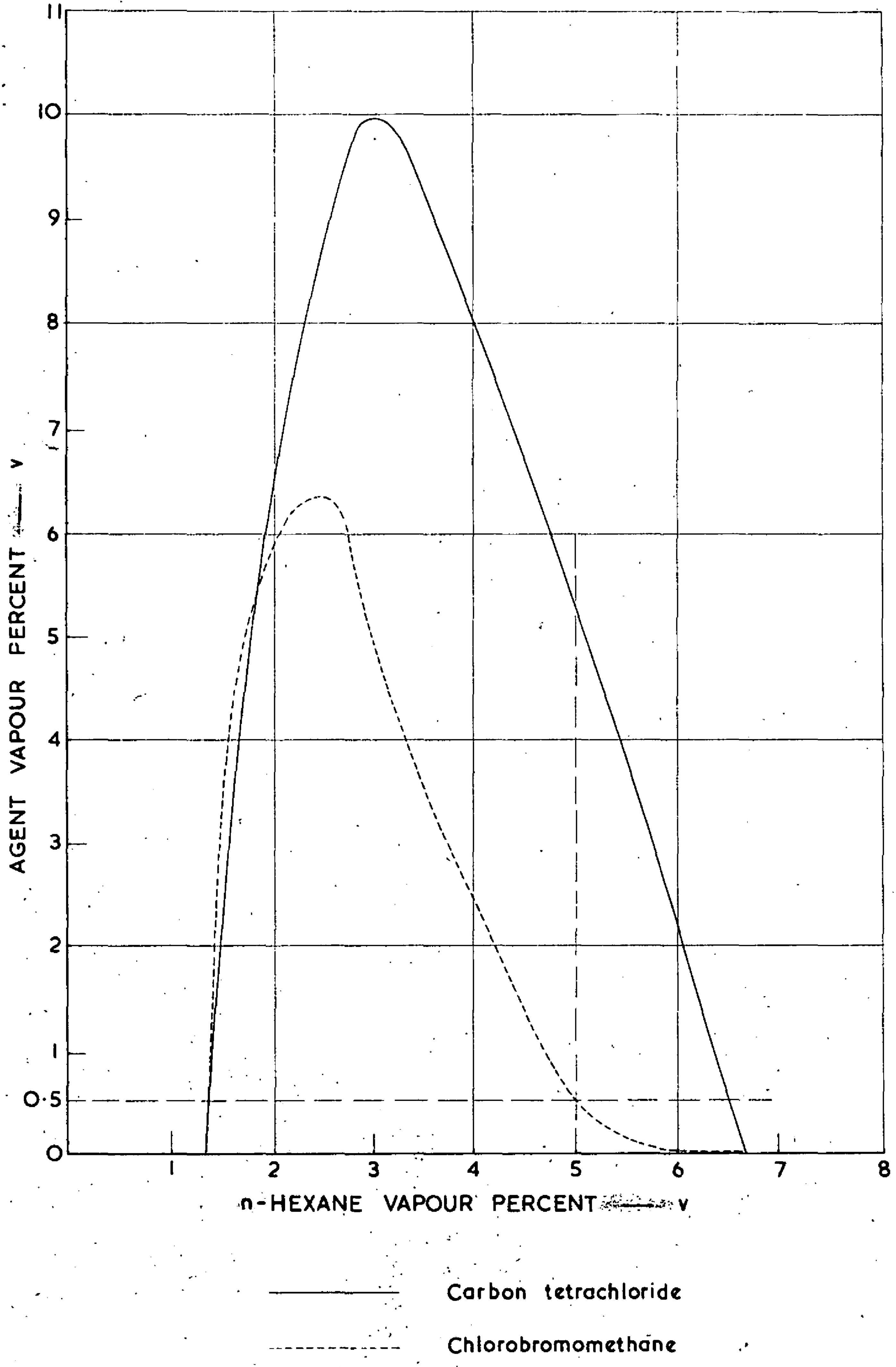
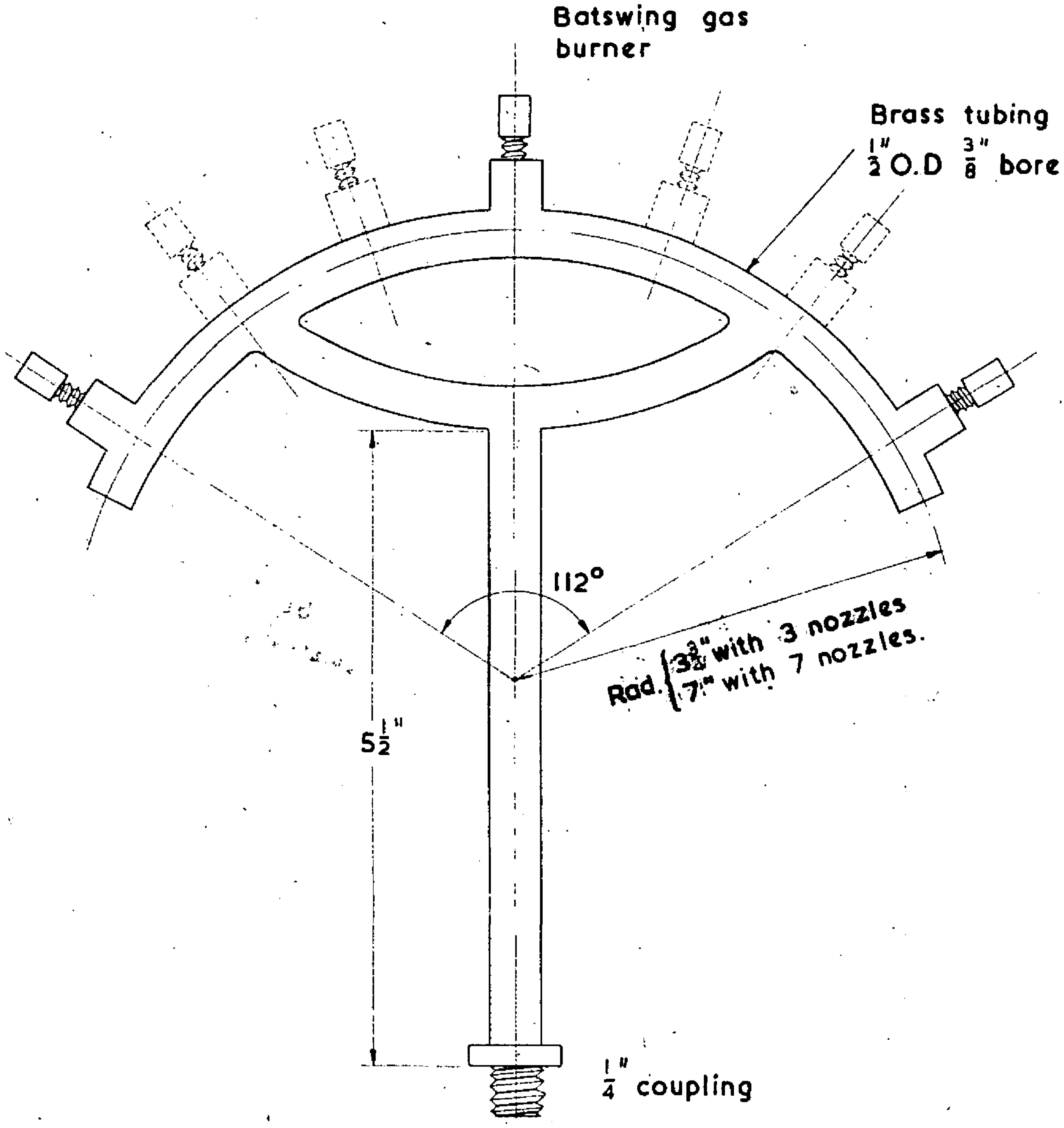


FIG. 4. FLAMMABILITY LIMITS OF n-HEXANE IN AIR WITH CARBON TETRACHLORIDE AND CHLOROBROMOMETHANE



Positions of burners for 3 nozzle applicators shown solid, and positions of additional burners for 7 nozzles shown dotted.

FIG. 5. SPRAY APPLICATORS WITH BATSWING BURNERS AS NOZZLES

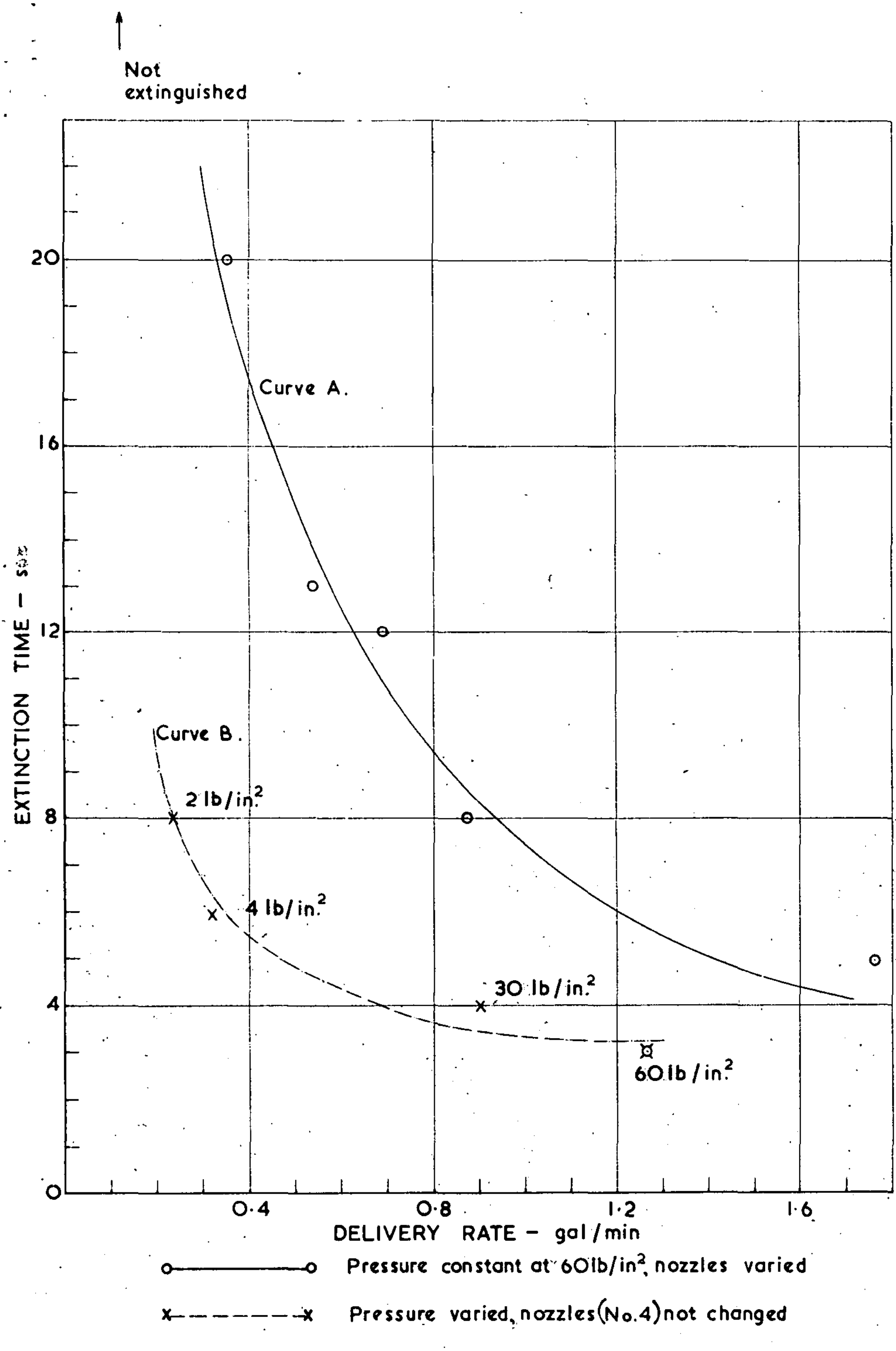
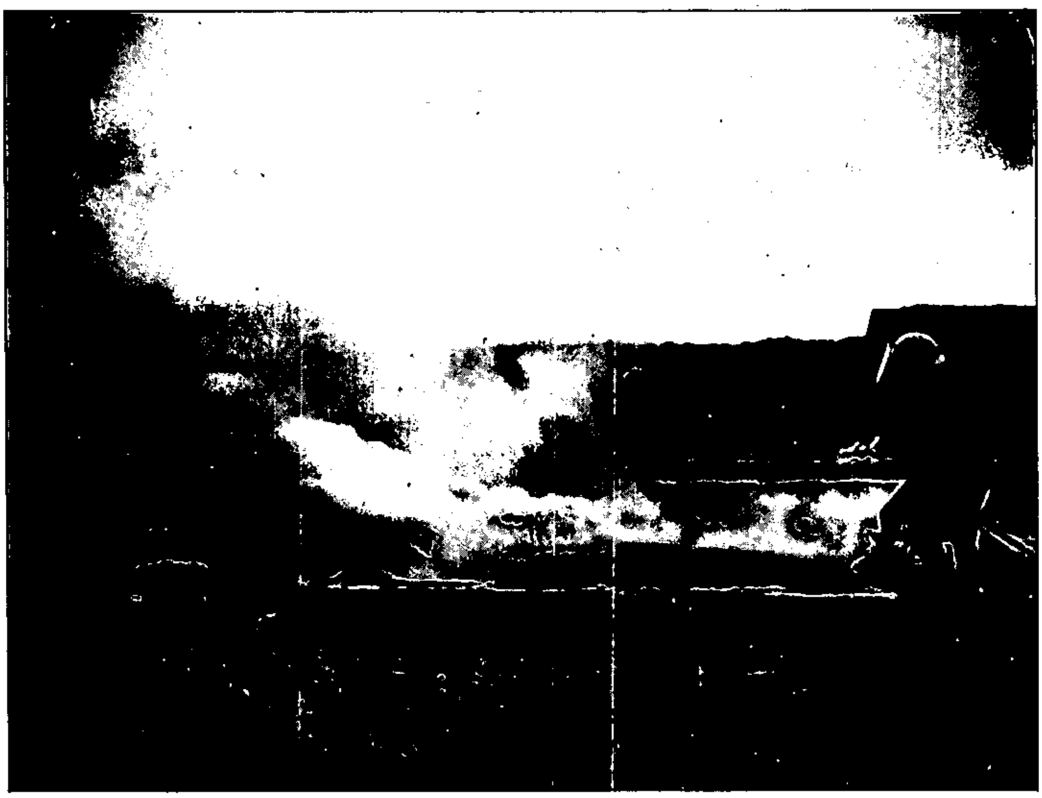
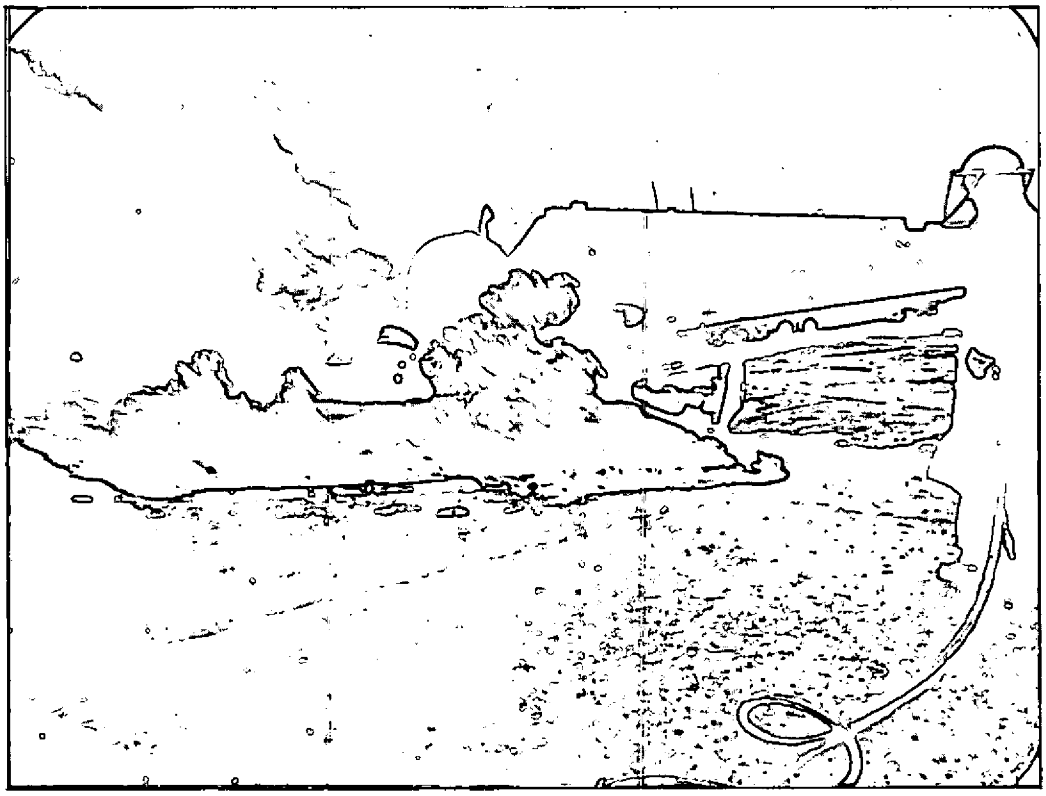


FIG. 6. EFFECT OF DELIVERY RATE ON EXTINCTION TIME 4 FT DIA FIRE ATTACKED WITH CHLOROBROMOMETHANE USING BATSWING BURNER NOZZLES.



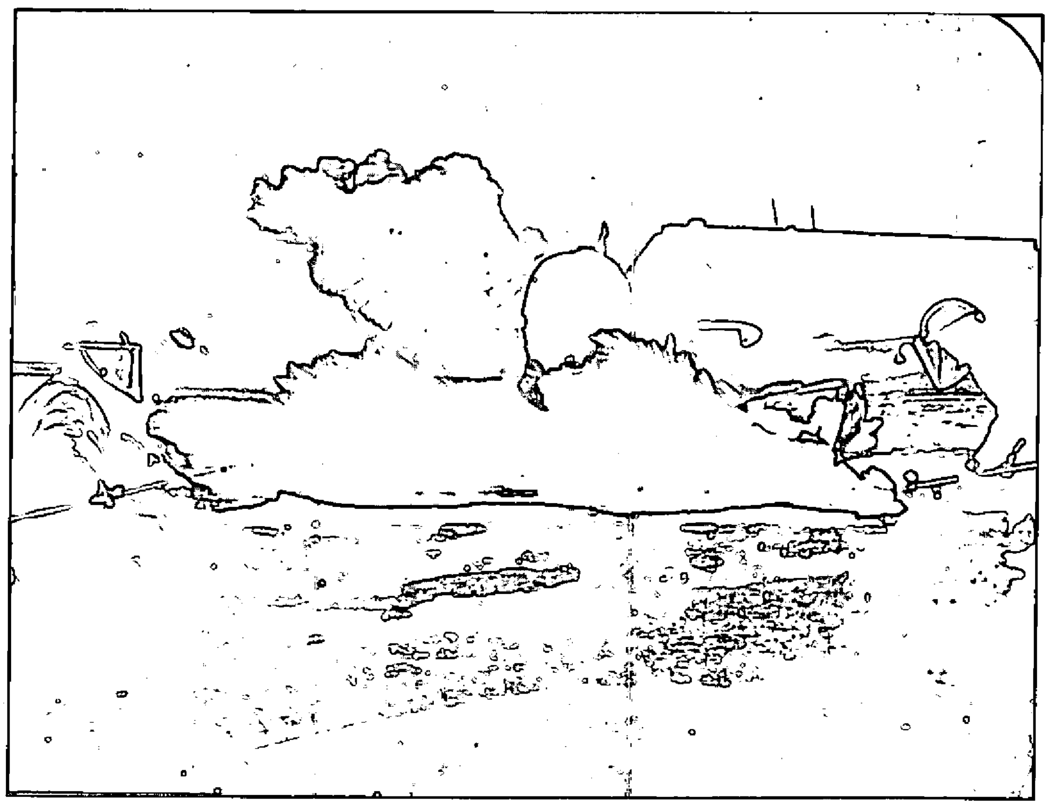
Movement, caused by cone spray, of petrol floating on water in 10ft. sq. bund.

PLATE I.



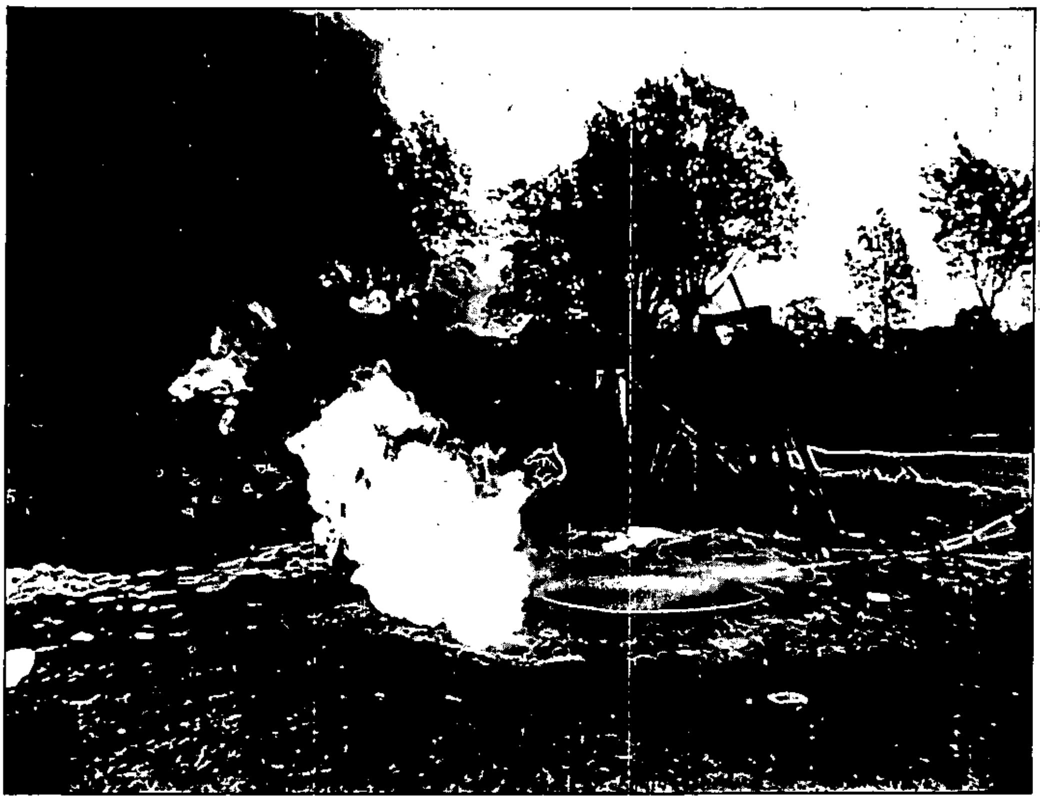
Aircraft fire immediately before attack with cone spray nozzles.

PLATE 2.



Aircraft fire immediately before attack with batswing burner nozzles.

PLATE 3.



Mode of extinction with flat sprays. 48 in. diameter petrol fire.

First stage. Fire cleared from tray.

PLATE 4.

Mode of extinction with flat sprays. 48 in. diameter fire.

Second stage. Extinction of fire in extended area.

PLATE 5.

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F.R NOTE 151

NOT ISSUED