Fire Research Note
No. 762

THE USE OF 'LIGHT WATER' FOR MAJOR AIRCRAFT FIRES

by

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SUMMARY

Major aircraft fires must be controlled extremely rapidly if lives are to be saved, and since all fire-fighting material has to be carried to the fire, such fires demand a fire-fighting agent of high weight effectiveness.

This note describes an investigation of the performance of light-water, a synthetic perfluorinated surface active foaming agent, on the extinction of simulated aircraft fires of areas up to 325 m^2 (3500 ft^2) burning AVTUR (JP1) and AVTAG (JP4) fuels. It compares this performance with that of regular protein foam, and that of a "fortified" protein foam containing synthetic surface-active agents.

It shows that the "light water" is up to twice as effective as regular protein foam, in terms of weight of foaming solution to control the fire, and that the fortified protein foam is about 25% more effective than regular protein foam. The light water foam only showed about one third the resistance of the protein foam to the re-establishment of flame over the area, once a fairly large area of fire was re-opened.

KEY WORDS: Light water, perfluorinated surface active agent, protein foams.

MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE
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1. Introduction

The size of airline passenger-carrying aircraft is increasing year by year and in the 1970's, aircraft carrying up to 500 passengers will be in use. An accident to one of these aircraft involving fire would place a heavy responsibility on fire fighters, and it is essential that the most effective materials and methods are available to control these potentially large fires. During 1965, the optimum physical characteristics for protein-based foams for use on aircraft fires[1] were determined, and the results of this research have influenced the design of recent foam-making vehicles in the United Kingdom. The search for more efficient fire-extinguishing materials giving more rapid fire control is continuous, and when a new material becomes commercially available its fire performance has to be assessed and compared with that of existing materials. 'Light water' is a comparatively new material intended as a potential replacement for protein foam in aircraft fire fighting. Like protein foam, it controls the fire by forming an enduring blanket over its surface. This vapour-sealing blanket on the fuel surface reduces the fire to a level where rescue operations may safely proceed, and prevents its rapid re-establishment. Small-scale research with this material[2] has shown that its fire performance is about twice as good as that of protein foam on certain flammable liquids, measured in terms of the quantity of foaming solution to control the fire.

This note describes a programme of large-scale simulated aircraft fire experiments designed to compare the performance of 'light water' and protein foams, on a realistic scale. Some experiments with a fluorinated protein foam were also made. The programme, planned by the Fire Research Station, was carried through with the co-operation of other establishments of the Ministry of Technology, Ministry of Defence, Board of Trade, Ministry of Public Building & Works and the British Airports Authority. The experimental work was done during the summer and autumn of 1968 at the Fire Service Central Training Establishment, Royal Air Force, Manston, Kent.

2. Experimental

2.1 Test fires and fuels

The experimental fires were conducted in three bunded areas of dimensions shown in Table 1, which also gives details of the fuels used. These areas were bounded by low fire-brick walls, and were filled to within about 50 mm (2 in) of the top of the walls with clean brick aggregate. The bunds were filled with water to a depth of 13 mm ($\frac{1}{2}$ in) below that of the brick aggregate, and were topped up with the appropriate fuel (AVTUR or AVTAG) just to the level of the aggregate. A cylindrical steel tube was used to represent the aircraft fuselage, and steel drums at each side represented the mainplane/nacelle configuration. The arrangement is shown in Fig. 1.

2.2 Foam properties

The aqueous solution strengths and physical characteristics of the protein and 'light water' foams made in the different foam generators used is shown in Table 2. In the experiments, the protein foams produced by Turfogen, the gas-turbine foam generator, had critical shear stress values of 400 to 550 dyn/cm^2, the "optimum" value found for aircraft fires[1]. Compared with protein foam, the critical shear stress of 'light water' foam was found to be very low, and accurate measurement of this property was difficult. Some values have been included in Table 2 and the approximate relation between critical shear stress and 25 per cent drainage time for 'light water' is shown in Figure 2.

Foaming solution rates of application to the fires varied between 2.28 l/s and 30.4 l/s (30 and 400 gal/min), that is, between 0.016 and 0.18 $l m^{-2} s^{-1}$ (0.02 and 0.23 gal $ft^{-2} min^{-1}$), depending on fire size.

2.3 Experimental method

The "standard" method of conducting a test was as follows - The fire was allowed to burn freely for about 60 s after ignition before foam application commenced from a position upwind and facing one of the four corners of the bund (Figure 1). Four radiometers spaced symmetrically around the fire gave a continuous record of radiant intensity during the experiment. To conserve the foaming agent, foam application was generally stopped shortly after gaining "9/10 control" of the fire, that is, after reducing the radiant intensity to one-tenth of its initial maximum value. This value is selected as representing a stage at which the heat radiation from the residual fire is small, so that in an actual incident, life-saving operations could proceed in relative safety.

2. Experimental (continued)

2.3 Experimental method (continued)

In many of the experiments, two or three observers made independent assessments of 9/10 control time. Most of the experiments were made when the wind speed was less than 4.6 m/s (15 ft/s).

A number of preliminary trials was made to give the experimental staff and the monitor operator, a trained fireman, experience with the test fire.

Tests 2, 3 and 4 differed from "standard" in that foam was applied down the centre line of the bund in Test 2, the preburn time was 3 minutes in Test 3, and a 12 per cent solution was used in Test 4.

In small-scale experiments[2], it had been found that the performance of protein foam could be impaired when used in equipment in which 'light water' had previously been used. In this programme, therefore, 'light water' was not used in the equipment until the protein foam tests had been completed.

For the main part of the programme, the gas-turbine operated foam generator (TURFOGEN) was used, but Mk 6 and Mk 7 fire crash tenders were also used for certain experiments to give an estimate of the comparison of these agents in existing operational equipment, and to enable a comparison of jet and spray application to be made.

3. Experimental results

The experimental results are given in Tables 3 to 7 inclusive as follows:

Table 3 9/10 control times for regular protein foam (all fires at all rates)

Table 4 9/10 control times for 'light water' and fortified protein foam (all fires at all rates).

Table 5 Comparison of 9/10 and 5/10 control times for 81 m^2 (875 ft^2) fire at .048 $lm^{-2}s^{-1}$ (0.06 gal $ft^{-2}min^{-1}$) from TURFOGEN.

Table 6 Typical "burn-back" times for regular protein and 'light water' foams on 81 m^2 (875 ft^2) and 325 m^2 (3500 ft^2) fires.

Table 7 Comparison of jet and spray application of protein and 'light water' foams on 208 m^2 (2240 ft^2) fire using AVTUR fuel and Mk 7 generator at .072 $lm^{-2}s^{-1}$ (0.09 gal $ft^{-2}min^{-1}$)

In most of the experiments there was good agreement between the observers' estimates and the recorded values of 9/10 control time. Average values shown in Tables 3 and 4 are therefore used for drawing conclusions.

3. Experimental results (continued)

3.1. Protein foam results

In tests 1 to 5, protein foam was applied by jet from Turfogen at a solution rate of 0.048 $lm^{-2}s^{-1}$ (0.06 gal $ft^{-2}min^{-1}$) to the 81 m^2 (875 ft^2) AVTUR fire. Under the standard test conditions described in Section 2 - Experimental the 9/10 control time was 47 seconds (Table 3, Test 1). In Test 2, where foam was applied along the centre line of the fire bund, the control time was 41 seconds. In Test 3 where additional fuel gave a free burning time before application of 3 minutes, the control time was 39 seconds.

Increasing the strength of the foaming solution from 6 to 12 per cent while maintaining the same values of foam properties did not appear to improve the fire performance of the foam (Test 4) as had been suggested by a foam liquid manufacturer.

It was thought that fire in AVTAG (JP4) might be more difficult to control with protein foam than fire in AVTUR (JP1) but no evidence of this effect was found between Tests 1 and 5.

In tests 8 and 9 in which foam was applied at a solution rate of 0.048 $lm^{-2}s^{-1}$ (0.06 gal $ft^{-2}min^{-1}$) to the larger AVTUR fires, 9/10 control was achieved in 80 and 78 seconds respectively, showing a scale effect between these fires and the 81 m^2 (875 ft^2) fire. The main reason for this effect, which was found to occur with both protein and 'light water' foams, appeared to be due to fluctuations in wind speed and direction which made it difficult to place the foam accurately over the greater distances involved with the two larger fires. In tests under the same conditions, the 9/10 control times on the 208 m^2 (2240 ft^2) fire were just over $1\frac{1}{2}$ times those on the 81 m^2 (875 ft^2) fire, a similar ratio applying on the 325 m^2 (3500 ft^2) fire (Table 3).

Control times on the 81 m^2 (875 ft^2) fire were found to be generally less than those in earlier tests with protein foam carried out in 1964/65[1]. The control times in the present programme were about 60 per cent of those in the earlier work. It is thought that the presence of water under the fuel tends to accelerate foam breakdown during application, by causing more fuel to be retained in the foam layer. It is likely that the broken bricks used in the bund in the present experiments, reduced this effect by reducing agitation of the water base, as compared with the earlier work.

3. Experimental results (continued)

3.1 Protein foam results (continued)

The critical rate of application for the protein foam was found to be about 0.016 $lm^{-2}s^{-1}$ (0.02 gal $ft^{-2}min^{-1}$) on the 81 m^2 (875 ft^2) fire. On the larger fires the number of results at low rates were not sufficient to enable the critical rates to be estimated, but there is no reason to suppose that they were different from the above.

3.2 'Light water' results

In experiments 17 to 25 inclusive (Table 4), Turfogen was used to make and eject a jet of 'light water' foam at a solution rate of application of 0.048 $lm^{-2}s^{-1}$ (0.06 gal $ft^{-2}min^{-1}$) to the 81 m^2 (875 ft^2) AVTUR fire. Expansion and 25 per cent drainage time in these experiments was varied between 7.7 and 20, and 1.0 and 5.7 minutes respectively. Changes in expansion in the range 7.7 to 14.3 did not appear to affect the "average" 9/10 control times, but 'light water' foam of expansion 20 appeared to be marginally better, with control times of about 29 s, compared with an average of about 31 s for the lower expansion foams. Changes in 25 per cent drainage time between 1.7 and 5.7 minutes had no appreciable effect on fire control, but when the drainage time was reduced to 1 minute, the control time increased to 40 s. Increasing the pre-burn period from 1 to 3 minutes did not reduce the effectiveness of 'light water'.

There was little difference in the fire performance of 'light water' on both AVTUR and AVTAG (Figure 4), the critical rate of application to each fuel being about 0.016 $lm^{-2}s^{-1}$ (0.02 gal $ft^{-2}min^{-1}$).

At a constant rate of application of 0.048 $lm^{-2}s^{-1}$ (0.06 gal $ft^{-2}min^{-1}$) the average control times on the 208 m^2 (2240 ft^2) fire (Tests 27, 28, and 29) and on the 325 m^2 (3500 ft^2) fire (Test 30) were 52 s and 45 s respectively, showing a similar scale effect, when compared with the 81 m^2 (875 ft^2) fire, as that found with protein foam.

4. Comparison of performance of 'light water' and protein foams

4.1 9/10 fire control

Fig. 5 shows the relation between 9/10 control time and rate of application of foaming solution, for 'light water', regular protein foam and fortified protein foam. The curves are based on a variable number of results of tests on the 81 m^2 (875 ft^2) AVTUR fire, except that the curve for fortified protein foam is estimated from the results of Tests 46 and 47 on the 208 m^2 (2240 ft^2) fire. At an application rate of 0.048 $lm^{-2}s^{-1}$ (0.06 gal $ft^{-2}min^{-1}$), the 'light water' gave an average control time of 30 s in the seven tests 17, 19-24 inclusive.

4. Comparison of performance of 'light water' and protein foams (contd)

4.1 9/10 fire control (contd)

The control time with protein foam was about 1.6 times greater, that is, 47 s (Test 1). On the 208 m^2 (2240 ft^2) and 325 m^2 (3500 ft^2) fires the ratios were 1.55 and 1.75 respectively. In comparative tests on the largest fire, using 6 per cent concentration of 'light water' in a Mk 6 foam-making vehicle, the ratio was over 3 to 1 in favour of 'light water' (Tests 10 and 31). When the 'light water' solution strength was reduced to 4 per cent (Test 32), the ratio fell from 3 to about 1.6.

4.2 Reduction of radiant intensity

One of the most important factors in extending the survival time of the occupants of an aircraft in a fire is the rapid reduction of radiant intensity to a level where it no longer provides a threat to the fuselage.

In the opinion of observers, including a number of experienced fire officers who viewed the experiments, a reduction on the radiant intensity of the fire appeared to occur almost immediately after the commencement of 'light water' foam application, but with protein foam, there seemed to be a delay of a few seconds before any discernible reduction in radiant intensity occurred.

This subjective assessment can be checked by the radiation records. The reduction of initial radiant intensity may be gauged by comparing the 5/10 and 9/10 control times in different experiments. In Fig. 6 these times are shown for a number of experiments in which TURFOGEN was used to apply foam at a solution rate of 0.048 $l m^{-2} s^{-1}$ (0.06 gal $ft^{-2} min^{-1}$) to the 81 m^2 (875 ft^2) fire. The ratio of 9/10 control to 5/10 control for protein foam varies from 1.48 to 1.95, with an average value of 1.61. For light water, the ratio ranges from 1.29 to 3.28 with an average value of 1.78. Thus, apart from giving shorter 9/10 control times, 'light water' also gave, on average, proportionately shorter 5/10 control times. Its variability was, however, greater than that of protein foam. At one end of the range it was proportionately worse, and at the other end proportionately much better, than protein foam. This variability may partly be explained by the "bad" results of Tests 17 and 21, in which the 5/10 control times were relatively slow although the 9/10 control times were well up to the standard of other tests.

The radiation records of Tests 1, 20 and 21 are shown in Fig. 6, and they illustrate the difference between 'light water' and protein foams during the initial stages of application.

4. Comparison of performance of 'light water' and protein foams (contd)

4.2 Reduction of radiant intensity (contd)

In Tests 20 and 21 the radiation began to reduce, after the commencement of foam application, in a similar manner in each test, but in Test 21 the radiation 'levelled' off after 5 or 6 seconds for a further 7 or 8 seconds before reduction continued. It is probable that during this intermediate period, the monitor operator concentrated on controlling one small area instead of playing the foam jet over the whole fire area. With light water, coverage of the whole area systematically appears to give the most effective results.

Fig. 7 shows a comparison of 'light water' and protein foams when applied to the 81 m^2 (875 ft^2) AVTUR fire at a rate of 0.048 $lm^{-2}s^{-1}$ (0.06 gal $ft^{-2}min^{-1}$), the curves being a mean of 4-5 experiments in each case. Fig. 8 shows the same two curves, with an additional (dotted) curve in which the protein foams curve has been scaled to give the same 9/10 control time. The difference between the 'light water' curve and the adjusted protein foam curve illustrates the proportionately more rapid reduction of the fire in its early stages by the 'light water'. Notwithstanding this "average" behaviour, individual results varied on both sides of the mean, sometimes giving a reversal of the general pattern, as illustrated in Fig. 9 which compares the fire control at two different rates giving about the same 9/10 control time.

4.3 Extinction

Extinction times were variable, as might be expected in large-scale outdoor fire experiments, and did not show any obvious difference between the performance of protein and 'light water' foams. For example, at the application rate of 0.048 $lm^{-2}s^{-1}$ (0.06 gal $ft^{-2}min^{-1}$) to the 81 m^2 (875 ft^2) fire, (Tests 2 to 5 inclusive, and Tests 18 and 20 to 24 inclusive) the extinction times varied between 60 and 120 s with both types of foam and statistical tests showed no significant difference between the foams.

With foam, the primary agent for controlling aircraft fires, complete fire extinction is desirable but not essential. Any small pockets of flame remaining after control of the main fire may be dealt with by other agents, such as dry powder, vaporizing liquid and carbon dioxide. The essential requirement is that control of the fire is gained as rapidly as possible to allow rescue operations to proceed.

4. Comparison of performance of 'light water' and protein foams (contd)

4.4 Resistance to burning back

This type of experimental fire, with an obstructed surface, is not ideal for making comparisons of the resistance of the foam layer to burning back, since the fire left uncontrolled may be separated into discrete areas in different ways. No special technique was therefore used to assess "burn-back" or rate of destruction of the foam layer by radiant heat. Approximate "burn-back" times were measured in some of the experiments, however, and these are shown in Table 6. In Tests 1 and 10 with protein foam on the 81 m^2 (875 ft^2) and 325 m^2 (3500 ft^2) bunds respectively, the residual fires at the end of foam application had estimated areas of 2.8 m^2 (30 ft^2) and 32.5 to 37.2 m^2 (350 to 400 ft^2) respectively, and the time for the fires to regain 50 per cent of the maximum value was over 10 minutes in each case. The "burn-back" times with 'light water' ranged between 2 and 5.7 minutes, and in each case the fire area at the start of the "burn-back" measurement was less than that in the comparable protein foam test. On average, the "50 per cent burn-back" time with protein foams was generally at least three times as great as that with 'light water' foams.

4.5 General

The more rapid fire control and superior re-sealing effect of 'light water', when compared with protein foam, appears to be mainly due to its greater fluidity and ability to flow more readily over fuel surfaces. In most of the experiments, a 'light water' foam layer of from 13 - 25 mm ($\frac{1}{2}$ - 1 inch) depth appeared to be sufficient to seal in the flammable vapour given off by the fuel. With protein foam, a depth of 25 - 50 mm (1 to 2 inches) was usually required.

4.6 Performance of a "fortified" protein foam.

A "fortified" protein foam, containing a fluoro-carbon additive, was also tested during the programme. When used in the Mk 7 generator, it produced foams having the following properties:

Table 8.

"Fortified" protein foam properties

Pre-mixed solution strength (per cent)	Expansion	25 per cent drainage time (min)	Critical shear stress (dyn/cm^2)
4	9	7.9	240
About 5	-	17.0	350

4. Comparison of performance of 'light water' and protein foams (contd)

4.6 Performance of a "fortified" protein foam (contd)

The average 9/10 control time when the fortified foam was sprayed onto the 208 m^2 (2240 ft^2) fire at a rate of 0.072 $l m^{-2} s^{-1}$ (0.09 gal $ft^{-2} min^{-1}$) was 40 s. (Tests 46 and 47). The control time ranges with the protein and 'light water' foams, under similar test conditions, were 48 to 54 s and 25 to 32 s, respectively.

4.7 Comparison of jet and spray application

Experiments to compare methods of application were carried out on the 208 m^2 (2240 ft^2) bund, using AVTUR fuel. The Mk 7 foam-making vehicle was used to make and eject the foam through its jet/spray nozzle. The spray pattern with both types of foam extended to about 15 m (50 ft) from the nozzle and had a width of about 9 m (30 ft). Solution throughput was 15 l/s (200 gal/min) giving a rate of application to the fire of 0.072 $l m^{-2} s^{-1}$ (0.09 gal $ft^{-2} min^{-1}$). The foam properties are shown with the 9/10 control times in Table 7. With protein foam, there was found to be no difference in control times between either method of application, but with 'light water', spray application was found to give better results than jet application, the overall control times being 29 s and 37 s respectively. Control times with protein foam were, therefore, about 1.8 times as great as those with sprayed 'light water' foam, and with the "fortified" foam the factor was 1.3 times.

5. Use of 'light water' in standard equipment

Satisfactory foams were produced from 6 per cent pre-mixed solutions of 'light water' in both the Mk 6 and Mk 7 foam-making vehicles. In the tests with 'light water' listed in Table 7, the agent was induced in the normal manner, and the resulting solution strength was between 5 and 6 per cent. The ambient temperature at that time was 7-8°C. With Turfogen and the Mk 6 and Mk 7 foam generators, the 'light water' foam jet began to break up into small flakes shortly after leaving the monitor and the resulting throw was less than that with protein foam.

When a 6 per cent pre-mixed solution of 'light water' was used in the standard branch pipe of the Ministry of Defence specification for foam liquid[3], the resulting foams had the following properties, the corresponding protein foam values being shown in brackets:

5. Use of 'light water' in standard equipment (continued)

Table 9.

Properties of 'light water' foams made in standard branch pipe

Pressure at branch pipe kg/m²	lb/in²	Expansion	Critical shear stress (dyn/cm²)	25 per cent drainage time (min)
4220	60	12.5	30 to 35	2.2
5630	80	11.3	40	2.6
7030	100	11.0 (8 to 11)	45 (150 to 300)	2.9 (3 to 5)
8440	120	10.6	45	2.9

6. Comparison of cost of agents

The cost of the 'light water' agent, to Government purchasers, in 1968 was about 20 times that of protein foam liquid. Its use in 6 per cent concentration, compared with the more usual 4 per cent for protein foam, gives a cost factor of 30 to 1 for foam-making solutions. With its twofold increase in effectiveness on fire the cost of fire control with 'light water' is, therefore, about 15 times that with protein foam, or 10 times if a 6 per cent solution of protein foam is used.

When compared with normal protein foam the fire performance of the "fortified" protein foam was found to be about 25 per cent better, and its cost is approximately 4 times as great. Its effective cost is therefore about 3 times that of regular protein foam.

7. Overall cost of fire protection

The cost of any new fire fighting agent is likely to be high when compared with conventional, well-proven, agents which have been in use for many years. As the agent gradually comes into greater use, however, its price may possibly reduce until it reaches a more comparable level. The cost of the extinguishing agent is not the only criterion to be considered in relation to aircraft fire fighting. The effectiveness of the agent in obtaining rapid fire control, the cost of vehicles and equipment, and the

7. Overall cost of fire protection (continued)

man-power required for their most effective use must also be considered. It is not intended to discuss the economics of aircraft fire protection in this note but there seem to be two alternatives available if the new, more effective agent is to be used. The first would be to maintain the present numbers of aircraft fire-fighting vehicles and crews, and to use 'light water' with its greater potential for saving life and property, but at extra cost. With the arrival of very large passenger aircraft in the early 1970's, use of the most efficient agent available, even though its cost be high, may become essential if the airfield fire services are to compete with the increased risk. The second alternative would be to use the more expensive 'light water' but to reduce the present numbers of foam-making vehicles to about half, thus maintaining the same degree of effective fire protection as at present. It is thought that this would be a retrograde step in view of the heavier responsibilities on aircraft fire-fighters in the future.

A preliminary assessment of the overall cost of using 'light water' as against protein foam, i.e. inclusive of savings in appliances and manpower, has already been made by the Service departments. This assessment shows that present costs are likely to be increased by an overall factor of about seven, for the same overall level of protection.

8. Conclusions

8.1 In comparison with regular protein foam, 'light water' foam was generally up to twice as effective in controlling major aircraft fires, i.e. it required about half the weight of fire-fighting solution to control the same fire, when both agents were applied at their most economic rate.

8.2 Similarly, a "fortified" protein based foam was about 25 per cent more effective than regular protein foam.

8.3 Light water was in general found to be proportionately more effective than protein foam in achieving a rapid initial reduction of heat radiation from the fire, although there were notable exceptions to this, possibly due to defective exploitation of its potential.

8.4 The resistance of light water to the re-establishment of the fire, once a sizeable area of flame has been re-opened, was only about one third that of protein based foams. This could be of importance where backing-up equipment is not available e.g. far from fire-fighting base facilities.

8. Conclusions (continued)

8.5 Light water can be used in certain unmodified protein foam-making equipment, but minor modifications may be necessary to suit its higher viscosity.

8.6 The performances of both protein-based and light water foams were unaffected by the use of AVTUR or AVTAG fuels, for both of which the above conclusions therefore apply.

8.7 A longer "preburn" time for the fire, in the range 1 to 3 minutes, did not materially affect the performance of either type of foam.

9. Acknowledgments

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10. References

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(2) FITTES, D.W. and NASH, P. 'Light water'. Research into its effectiveness compared with protein foam. Fire. Sept. 1968, 61, (759), 170-171, 195.

(3) Foam Liquid, fire extinguishing. Ministry of Defence/Ministry of Technology (Aviation Group) specification DEF STAN 42 - 3/Issue 1.

Table 1

Fire bund dimensions

Bund dimensions		Bund area		Dimensions of simulated aircraft					Fuel quantity (AVTUR or AVTAG)	
				Fuselage				Engine nacelles (No. of drums)		
				Length		Diameter				
m	ft	m^2	ft^2	m	ft	m	ft		litre	gal
10.7 x 7.6	35 x 25	81	875	6.1	20	1.5	5.0	4	1136	250
17.1 x 12.2	56 x 40	208	2240	9.8	32	2.6	8.5	8	2955	650
21.3 x 15.2	70 x 50	325	3500	12.2	40	2.75	9.0	8	4546	1000

Table 2

Foam properties

Type of foam	Foam generator	Pre-mixed solution strength per cent	Expansion	25 per cent drainage time (min)	Critical shear stress (dyn/cm^2)
Protein	Turfogen	6	12 to 16	25 to 35	410 to 550
Protein	Turfogen	12	15.5	26	440
Protein	Mk 6	About 4*	15	25	540
Protein	Mk 7	About 4*	15 to 15.6	About 35	600 to 640
'Light water'	Turfogen	6	7.5 to 21.2	1.0 to 6.8	Approx. 20 to 100
'Light water'	Mk 6	6	13.8	6.5	95
'Light water'	Mk 6	4	10.0	3.3	65
'Light water'	Mk 7	6	13.5 to 14	4.1 to 5.1	60
'Light water'	Mk 7	5 to 6*	14.0	6.4	-

*Not pre-mixed

Table 3

PROTEIN FOAM

Expansion Range 12 to 16
25 per cent drainage time range 25 to 35 min.

Test No	Foam Appliance	Applicator (Jet or Spray)	Fire size $m^2(ft^2)$	Fuel	Solution rate $1m^{-2}s^{-1}$ ($gal\ ft^{-2}min^{-1}$)	9/10 control time (S) Observer 1	Observer 2	Observer 3	Recorder	9/10 control time Average of previous columns S	Extinction time S	Remarks
1	Turfogen	Jet	81.0(875)	AVTUR	0.048(0.06)	45	50	-	47	47	-	
2	"	"	"	"	0.048(0.06)	40	42	-	41	41	60	'Centre-line' application
3	"	"	"	"	0.048(0.06)	-	-	-	39	39	75	Long pre-burn (3 min)
4	"	"	"	"	0.048(0.06)	56	54	-	50	53	85	12 per cent solution
5	"	"	"	AVTAG	0.048(0.06)	35	40	-	41	39	120	
6	"	"	"	AVTUR	0.11 (0.14)	27	-	-	29	28	-	
7	"	"	"	"	0.18 (0.23)	14	-	-	18	16	-	
8	"	"	208.0(2240)	"	0.048(0.06)	70	85	-	85	80	-	
9	"	"	325 (3500)	"	0.048(0.06)	70	80	-	85	78	-	
10	Mk 6	"	"	"	0.048(0.06)	120	80	-	⅔ control 115	> 100	-	Application from fixed position
11	Mk 7	"	208.0(2240)	"	0.072(0.09)	50	44	55	-	50	-	
12	"	"	"	"	"	54	48	50	-	51	-	
13	"	Spray	"	"	"	55	-	-	52	54	-	
14	"	"	"	"	"	50	50	54	-	51	-	
15	"	"	"	"	"	48	48	-	-	48	-	
16	"	"	325 (3500)	"	0.088(0.11)	120	120	-	-	120	-	Appliance moved parallel with bund during test.

Table 4

'Light water' foam

Test No.	Foam appliance	Applicator (jet or spray)	Fire size m^2 (ft^2)	Fuel	Solution rate $l\ m^{-2}s^{-1}$ (gal $ft^{-2}min^{-1}$)	Expansion	25% drainage time (min)	9/10 control time (s) Observer 1	Observer 2	Observer 3	Recorder	9/10 control time average value of previous columns (s)	Extinction time (s)	Remarks
17	TURFOGEN	Jet	81.0(875)	AVTUR	0.048(0.06)	7.7	3.3	29	29	-	32	30	-	
18	"	"	" "	"	" "	8.5	1.0	38	-	-	41	40	65	
19	"	"	" "	"	" "	13.0	3.0	28	32	-	-	30	-	
20	"	"	" "	"	" "	13.8	1.7	30	-	-	36	33	75	
21	"	"	" "	"	" "	"	"	28	-	-	31	30	60	
22	"	"	" "	"	" "	14.3	5.5	32	33	-	34	33	Estimated 100 to 120	
23	"	"	" "	"	" "	20	5.7	28	30	-	28	29	85	
24	"	"	" "	"	" "	"	"	27	-	-	28	28	Estimated 60	
25	"	"	" "	"	" "	"	"	24	27	-	28	26	-	Long pre-burn (3 min)
26	"	"	" "	AVTAG	" "	13.0	3.0	25	28	-	28	27	-	
27	"	"	208.0(2240)	AVTUR	" "	14.8	4.7	-	55	-	57	56	Estimated 150	
28	"	"	" "	"	" "	"	"	65	45	-	-	55	-	
29	"	"	" "	"	" "	"	"	45	40	-	48	44	Estimated 60	
30	"	"	325 (3500)	"	" "	13	4.6	38	49	-	48	45	-	
31	MK 6	"	" "	"	" "	13.8	6.5	30	-	-	33	32	-	Application from fixed position
32	"	"	" "	"	" "	10	3.3	65	39	-	85	63	-	Application from fixed position 4% solution
33	TURFOGEN	"	81.0(875)	"	0.18 (0.23)	12.3	4.4	8	-		9	9	20 to 30 V	
34	"	"	" "	"	0.11 (0.14)	14	"	14	-	-	17	16	40 V	
35	"	"	" "	AVTAG	0.18 (0.23)	12.3	"	9	-	-	18	14	30 V	
36	"	"	" "	AVTUR	0.028(0.035)	19	3.6	60	44	-	55	53	-	
37	"	"	" "	"	" "	7.4	4.0	40	-	-	44	42	-	
38	"	"	" "	AVTAG	" "	19	3.6	43	47	-	42	44	-	
39	"	"	208 (2240)	AVTUR	0.016(0.02)	20	5.7	160	-	-	118	139	180	
40	MK 7	"	325 (3500)	"	0.088(0.11)	13.5	4.1	48	-	-	54	51	-	
41	"	"	208 (2240)	"	0.072(0.09)	14	5.1	38	42	37	-	39	-	
42	"	"	" "	"	" "	"	"	36	35	34	-	35	-	
43	TURFOGEN	Spray	81.0(875)	"	0.048(0.06)	21.2	6.8	26	28	-	28	27	50 V	
44	MK 7	"	208 (2240)	"	0.072(0.09)	14	5.1	33	-	31	-	32	-	
45	"	"	" "	"	" "	"	"	26	24	25	-	25	-	
46	"	"	" "	"	" "	9	7.9	42	38	-	-	40	-	*'Fortified' foam, 4 per cent solution
47	"	"	" "	"	" "	-	17.0	-	40	40	-	40	-	* " " 5 " " "

V Virtually extinguished

* Protein based foam 'fortified' with fluorocarbons.

Table 5

Comparison of control times for 81 m^2 (875 ft^2) fire by light water and protein foams

Rate of application of solution:- 0.048 $lm^{-2}s^{-1}$ (0.06 gal $ft^{-2}min^{-1}$)

Generator: Turfogen

Application: Jet

(Control times from radiation records)

Test No.	Fuel	Control times		Ratio
		5/10	9/10	9/10/5/10
1	AVTUR	24	47	1.95
2	"	28	41	1.48
3	"	25	39	1.58
5	AVTAG	27	41	1.52
	Averages	26	42	1.61
17	AVTUR	23	32	1.39
20	"	11	36	3.28
21	"	24	31	1.29
22	"	15	34	2.26
23	"	12	28	2.34
24	"	19	28	1.48
25	"	16	28	1.76
26	AVTAG	19	28	1.48
	Averages	17½	30½	1.78

$$\text{Ratio} \quad \frac{9/10 \text{ Control, Protein (average)}}{9/10 \text{ Control, 'Light water' (average)}} = 1.38$$

$$\text{Ratio} \quad \frac{5/10 \text{ Control, Protein (average)}}{5/10 \text{ Control, 'Light water' (average)}} = 1.48$$

Table 6

Typical "burn-back" times for protein and 'light water' foams

Test No.	Fire bund size m^2 (ft^2)	Approximate fire area at "foam off" m^2 (ft^2)	Type of foam	25 per cent drainage time (min)	Time to regain 50 per cent of maximum fire area. Measured after "foam off" (min)
1	81 (875)	2.7 (30)	Protein	25 to 35	10
17	81 (875)	1.35 (15)	'Light water'	3.3	2.0
26	81 (875)	0.9 (10)	do	3.0	3.0
20	81 (875)	0.18 to 0.27 (2 to 3*)	do	1.7	3.3
22	81 (875)	1.08 (12)	do	5.5	4.5
24	81 (875)	0.45 (5)	do	5.7	5.7
10	325 (3500)	31.5 to 36.0 (350 to 400)	Protein	25	10
31	325 (3500)	13.5 (150)	'Light water'	6.5	2.0
30	325 (3500)	9.0 (100)	do	4.6	2.5

* Re-ignited after clearing area of foam

Table 7

Comparison of Jet and Spray application of protein and 'light-water' foam

Fire size 208 m^2 (2240 ft^2)
Fuel AVTUR
Foam appliance Mk 7

Foam Properties	Protein (concentration about 4 per cent)	Expansion	15 to 15.6
		25 per cent drainage time (min)	About 35
	'Light water' (Concentration 5 to 6 per cent)	Expansion	14
		25 per cent drainage time (min)	About 6.4

Rate of application of solution 15 l/s (0.072 $lm^{-2}s^{-1}$)
(200 gal/min (0.09 gal $ft^{-2}min^{-1}$)

Test No.	Foam	Applicator (Jet or Spray)	9/10 control time - (s) Observer 1	2	3	Recorder	Average value of previous columns (S)	Overall average 9/10 control time (S)	Remarks
11	Protein	Jet	50	44	55	-	50	51	
12	"	"	54	48	50	-	51		
13	"	Spray	55	-	-	52	54	51	
14	"	"	50	50	54	-	51		
15	"	"	48	48	-	-	48		
41	Light-water	Jet	38	42	37	-	39	37	
42	"	"	36	35	34	-	35		
44	"	Spray	33	-	31	-	32	29	
45	"	"	26	24	25	-	25		
46	Fortified* protein	"	42	38	-	-	40	40	4% solution
47	Fortified* protein	"	-	40	40	-	40		5% solution

*Protein based foam 'fortified' with surface active material

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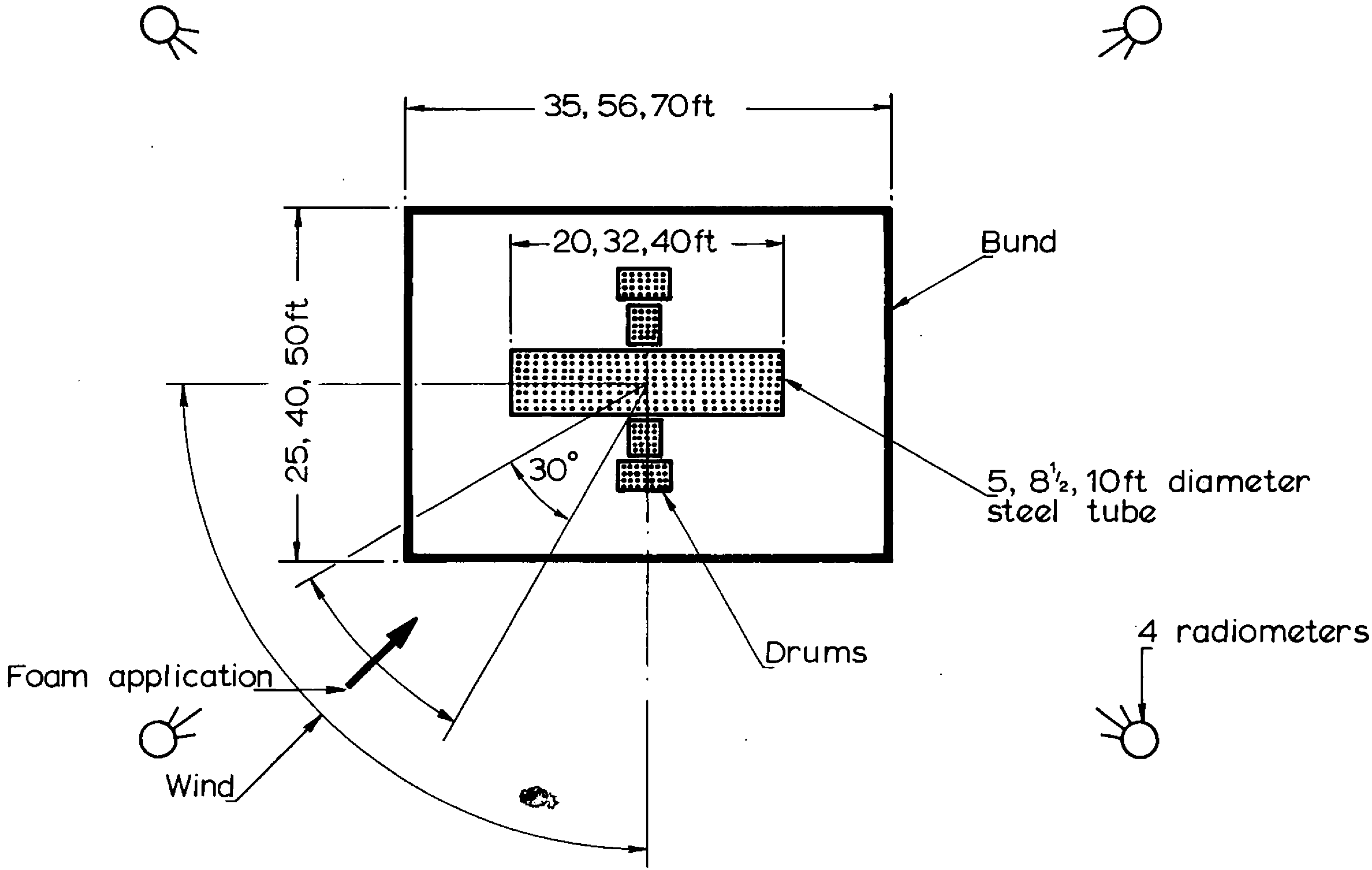

FIG. 1. AIRCRAFT FIRE TEST ARRANGEMENT

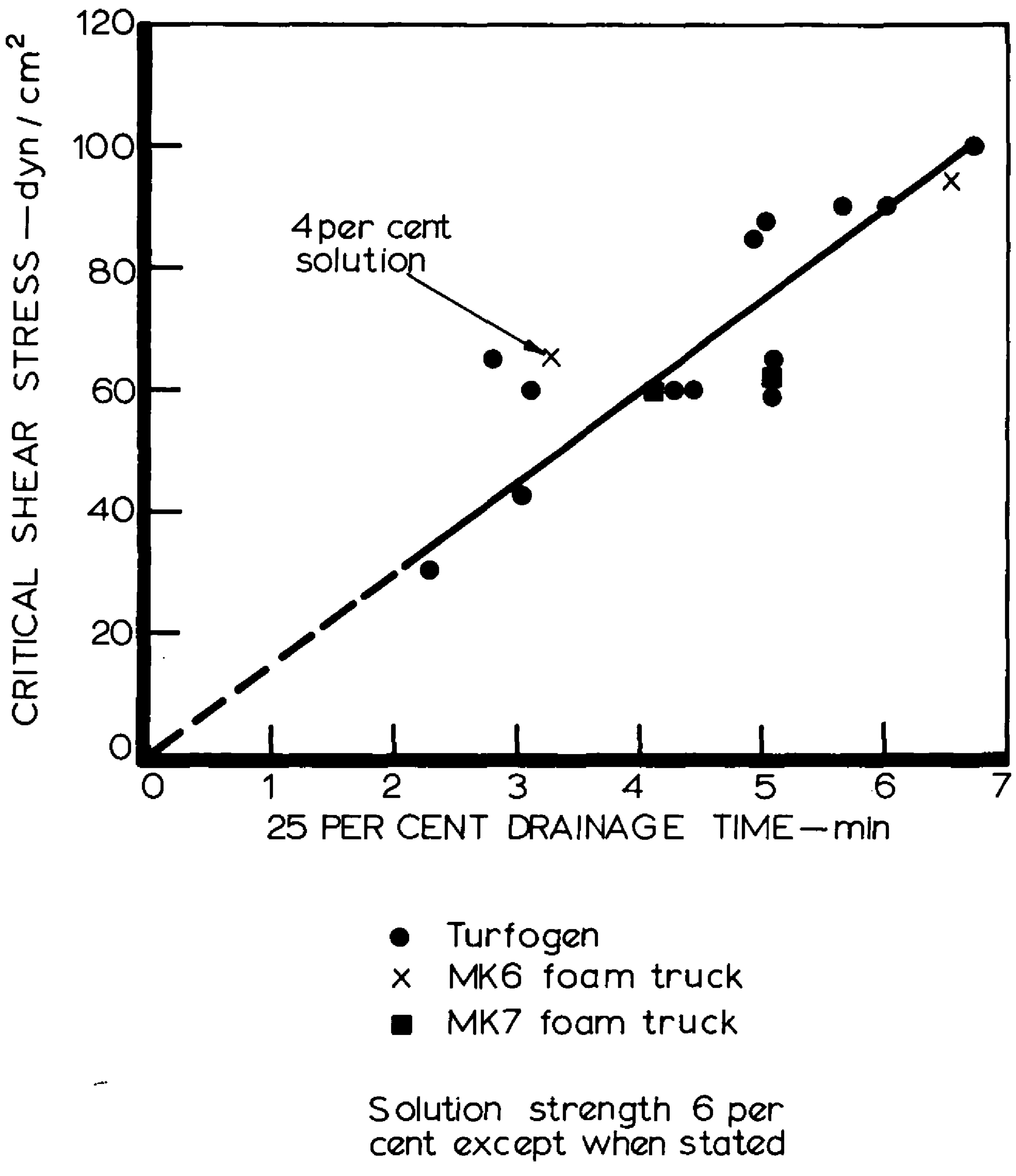

FIG. 2. SHEAR STRESS AND DRAINAGE OF 'LIGHT WATER' FOAM

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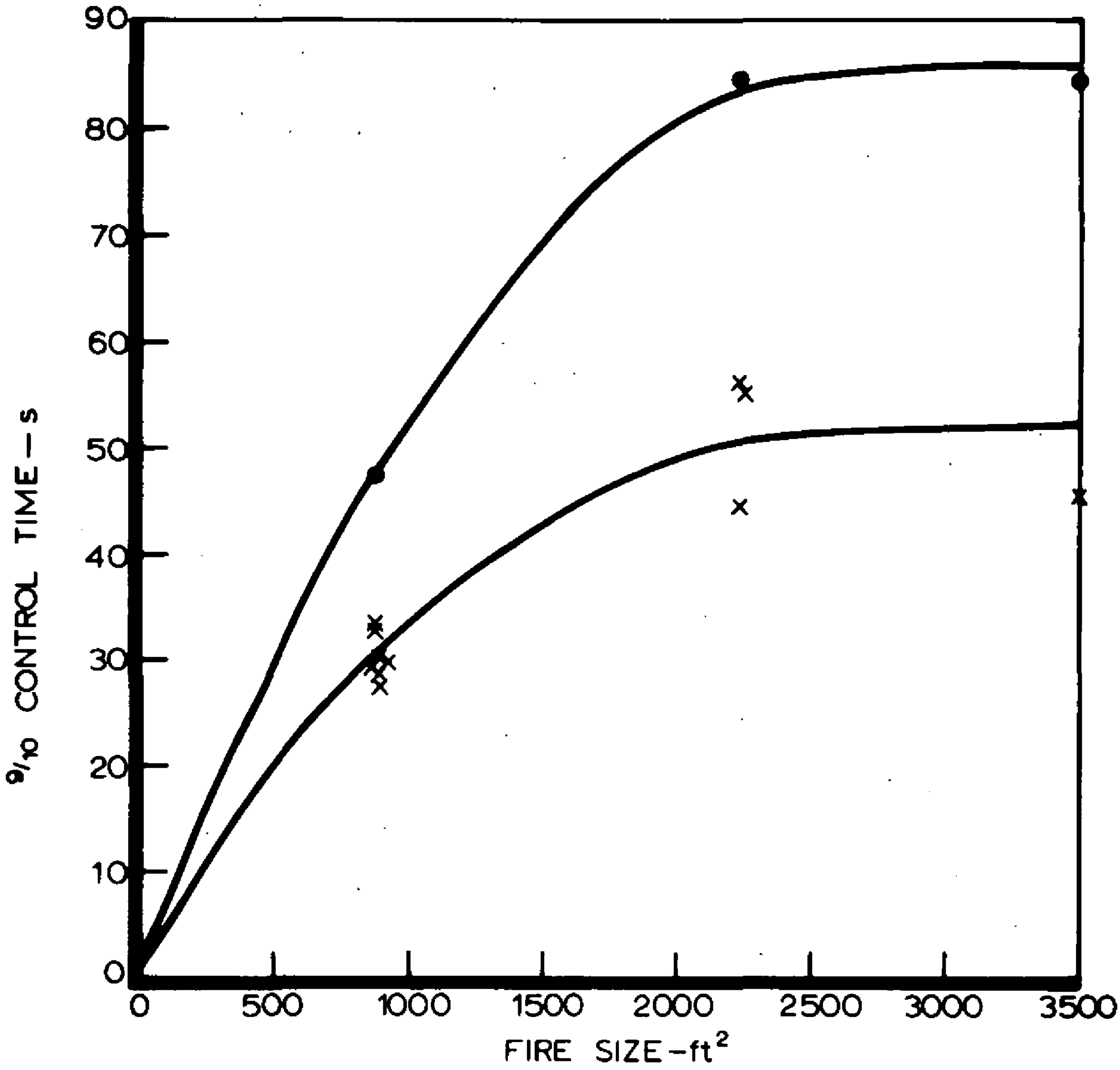
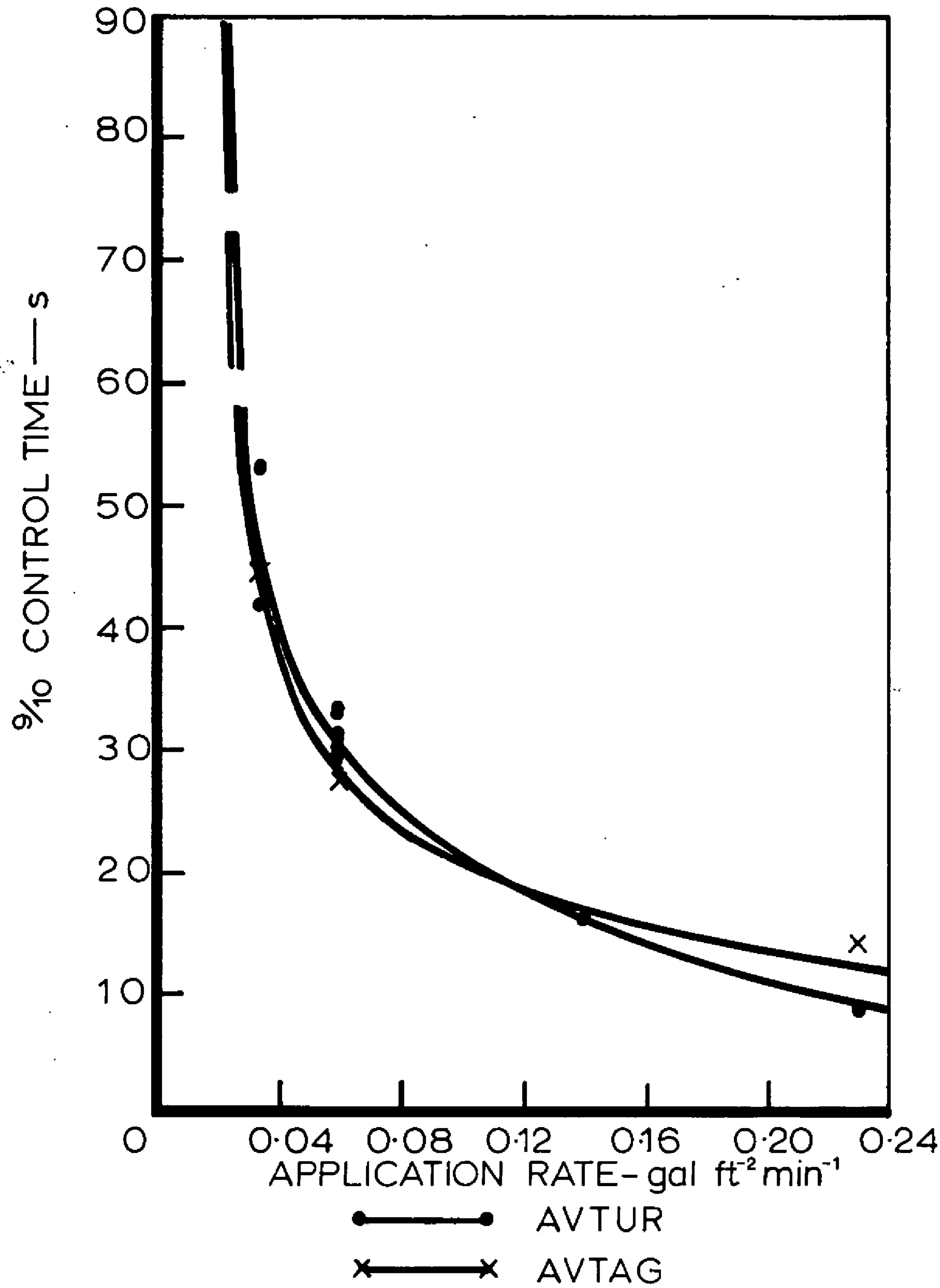


FIG.3. EFFECT OF SCALE ON 9/10 CONTROL TIME

572 F.R. 762.



Foam properties [Expansion 7·7 to 20
25 per cent drainage time 1·7 to 5·7 minutes

FIG. 4. CONTROL OF 875 FT^2 FIRE WITH 'LIGHT WATER' FOAM

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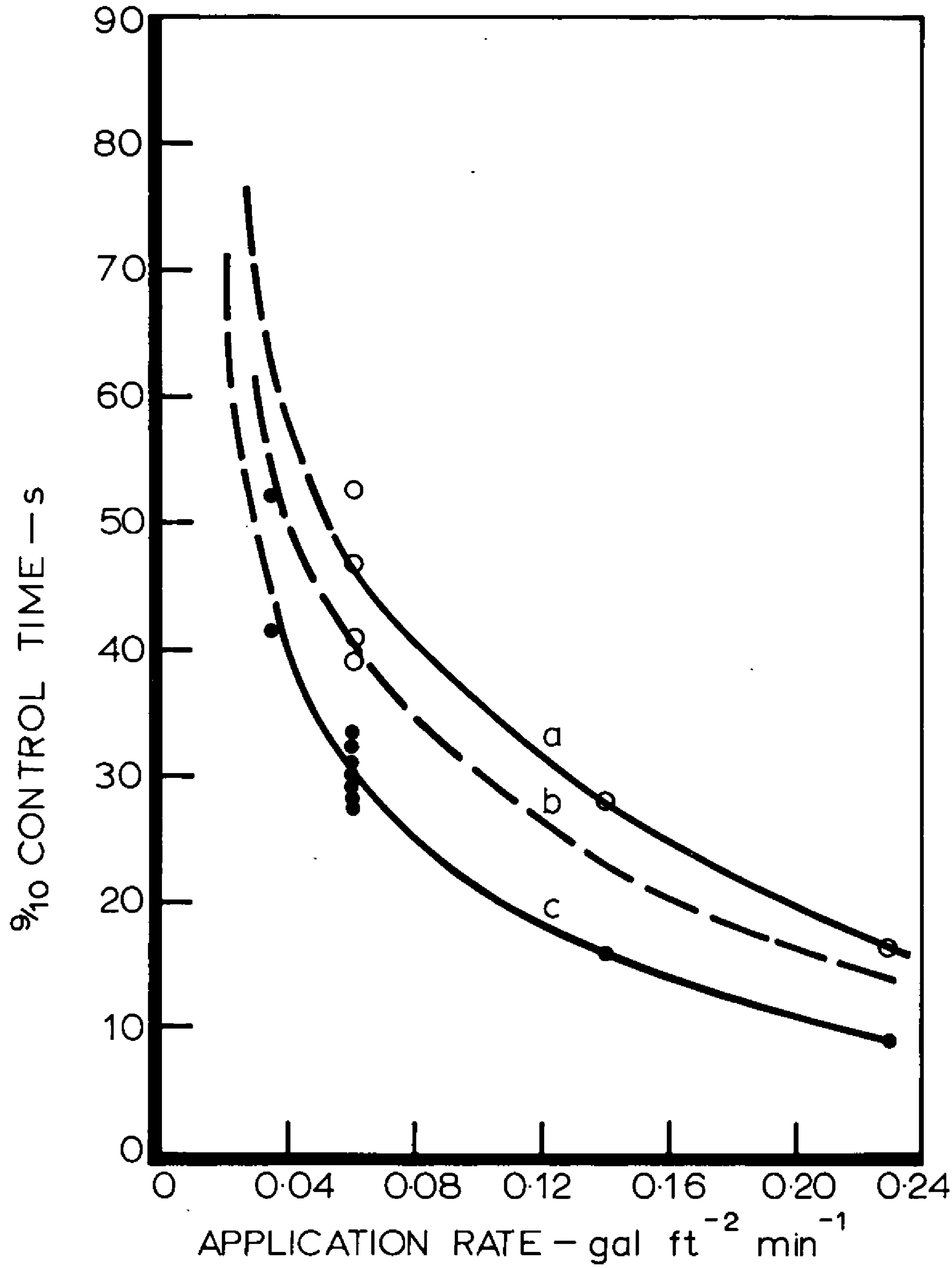


o a = Protein

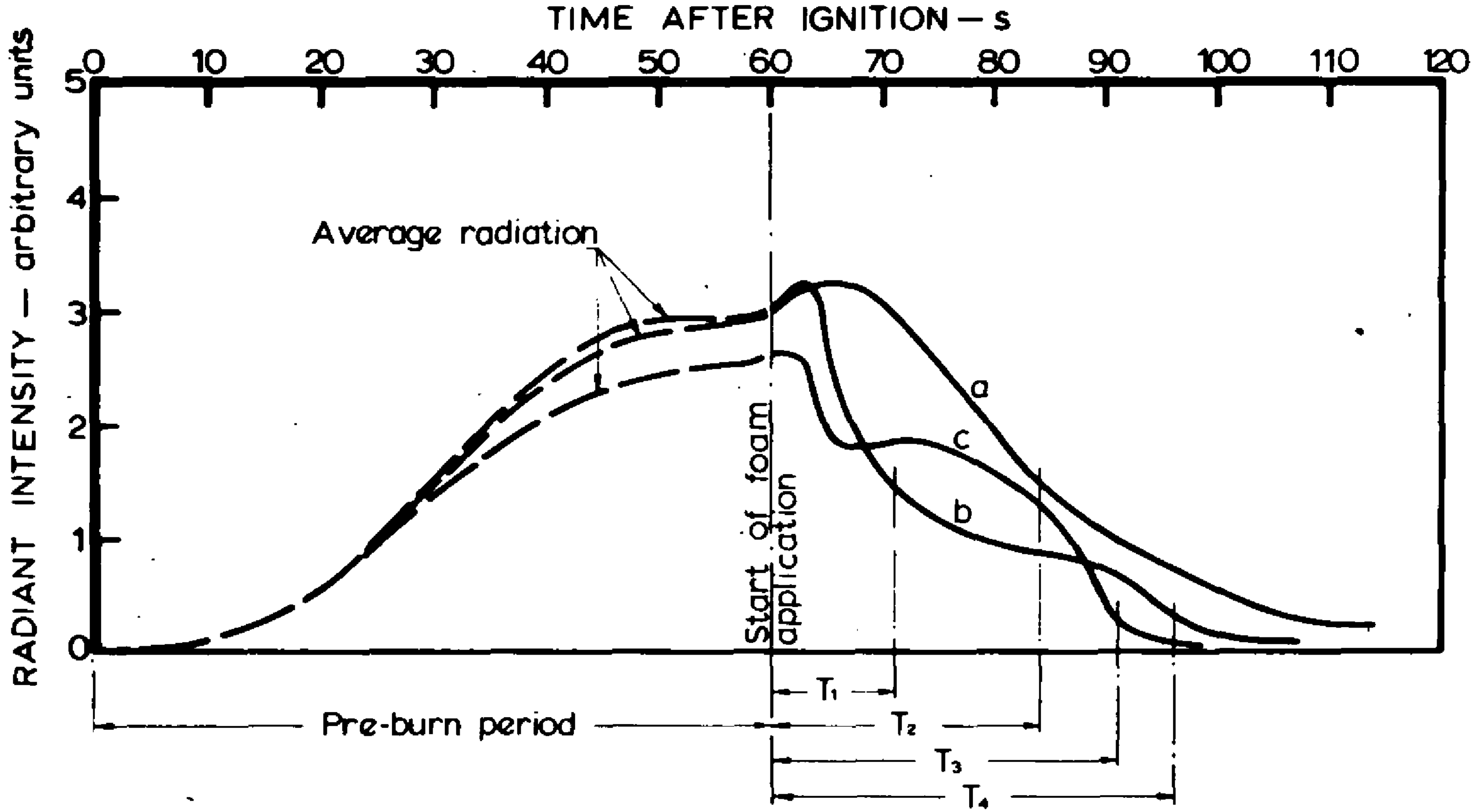
b = Fortified protein (estimated)

• c = Light water

Fire area 875 ft^2

Fuel – AVTUR

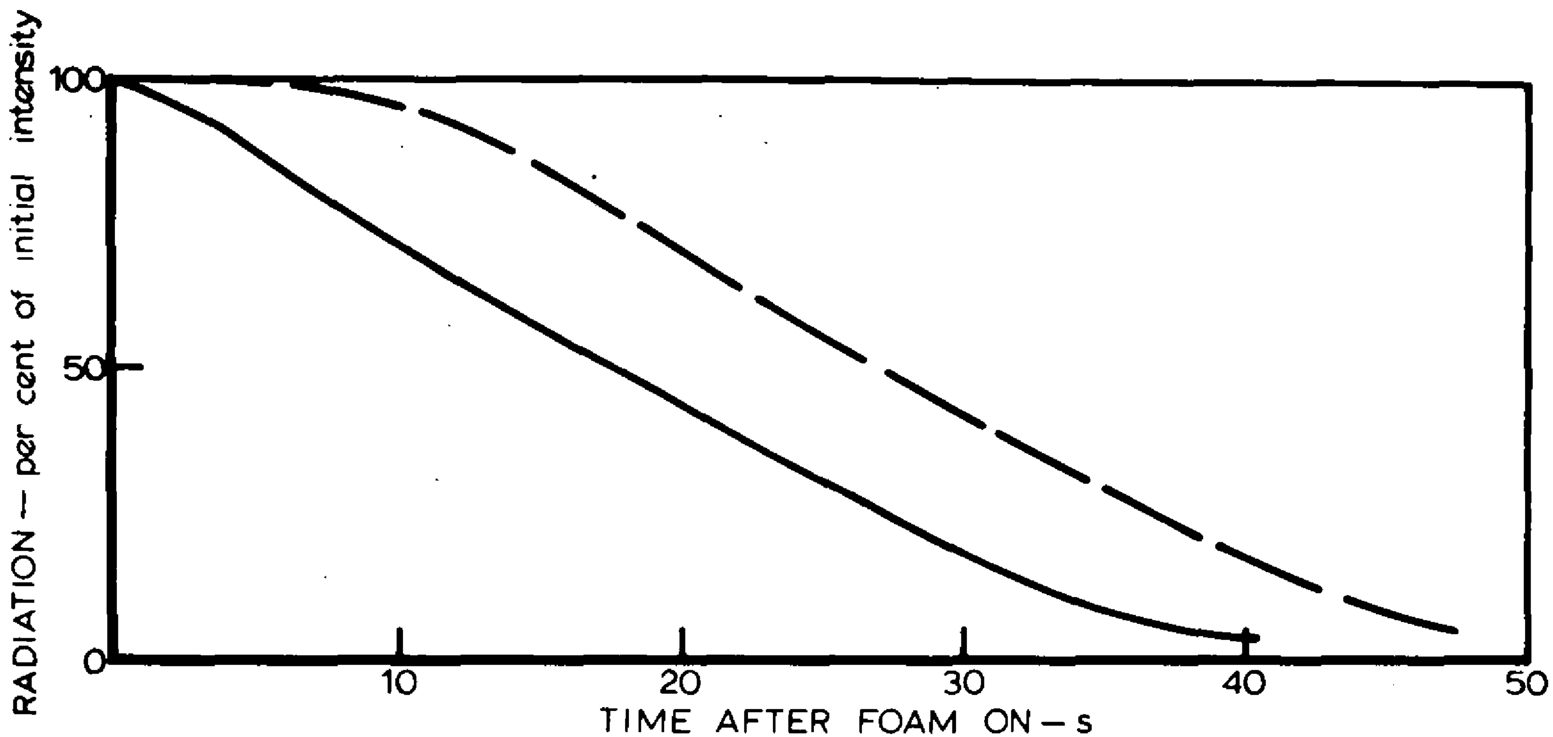
FIG. 5. COMPARISON OF 9/10 CONTROL WITH THE THREE AGENTS



a = Test 1 (Protein)
b = Test 20 Light water)
c = Test 21(Light water)

	Control time	Test	
T_1	5/10	20	11s
T_2	5/10	21	24s
T_3	9/10	21	31s
T_4	9/10	20	36s

FIG. 6. TYPICAL RADIATION RECORDS SHOWING 9/10 AND 5/10 CONTROL TIMES



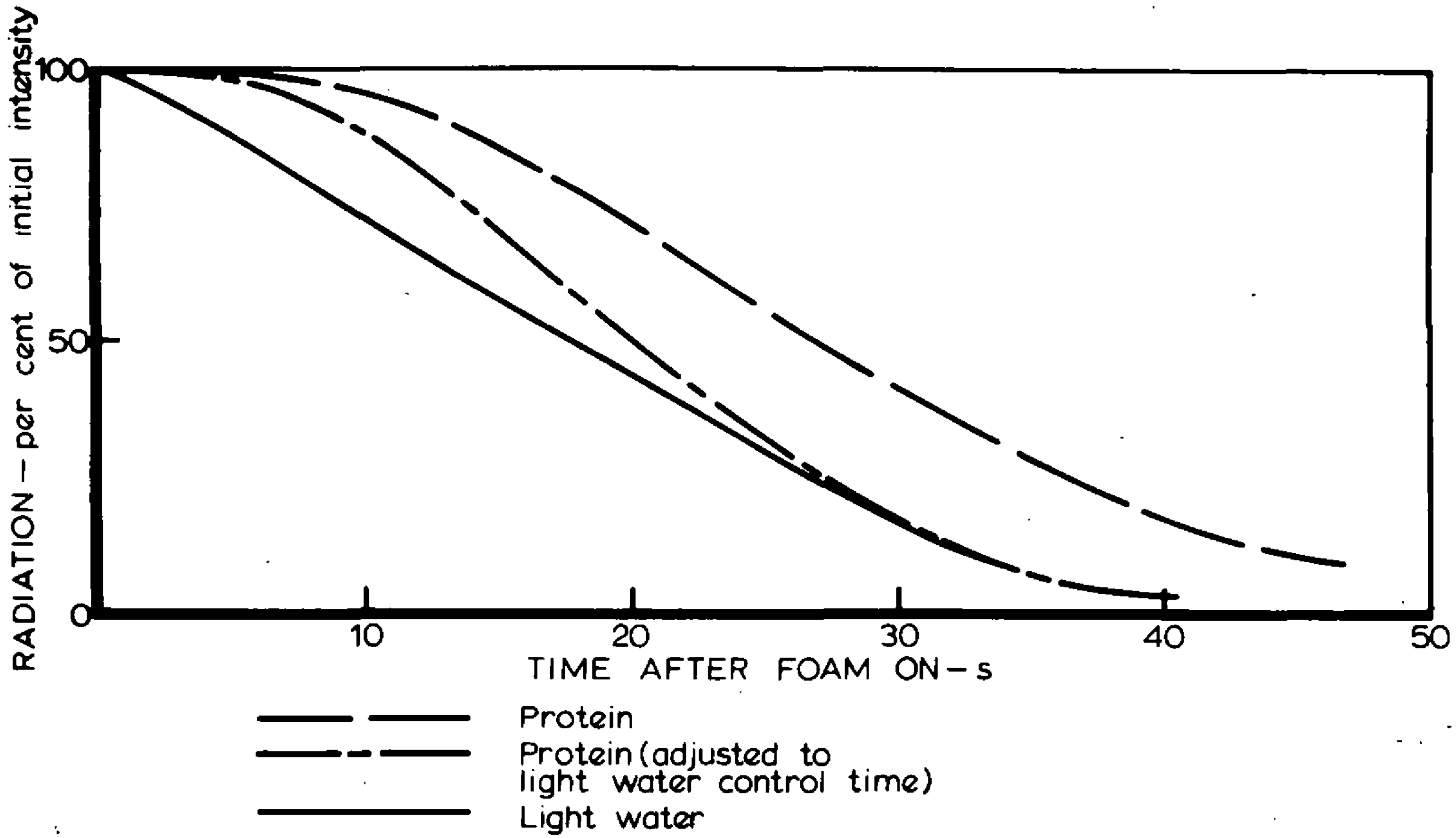
Light water] Mean of 4–5 tests
Protein]

Fire size – 875 ft^2
Fuel – AVTUR
Rate of application – 0·06 gal ft^{-2} min^{-1}

Light water [Expansion – 13 to 20
[25 per cent drainage time – 1·7 to 5·7 min

Protein foam [Expansion – 14
[25 per cent drainage time – 30 min

FIG. 7 COMPARISON OF FIRE CONTROL USING LIGHT WATER AND PROTEIN FOAMS

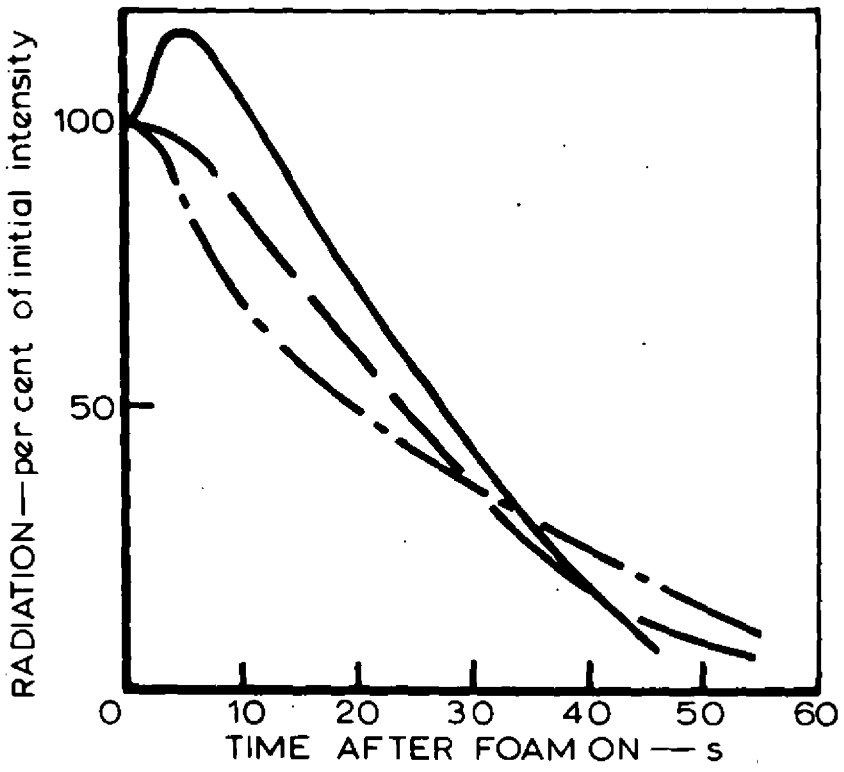


Fire size – 875 ft^2
Fuel – AVTUR
Rate of application – 0·06 gal ft^{-2} min^{-1}

Light water: Expansion – 13 to 20; 25 per cent drainage time – 1·7 to 5·7 min

Protein foam: Expansion – 14; 25 per cent drainage time – 30 min

FIG. 8. RADIATION – TIME CURVES ADJUSTED TO SAME 9/10 CONTROL



Light water application rate = 0·035 gal $ft^{-2} min^{-1}$ (test 37)
Light water application rate = 0·035 gal $ft^{-2} min^{-1}$ (test 36)
Protein application rate = 0·06 gal $ft^{-2} min^{-1}$ (test 1)

Fire area 875 ft^2
Fuel AVTUR

FIG. 9. COMPARISON OF FIRE CONTROL AT DIFFERENT RATES OF APPLICATION

1/9878 F.R. 762.