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A LABORATORY FIRE TEST FOR FOAM LIQUIDS

by

S P Benson, P R Bevan and J G Corrie

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**FIRE
RESEARCH
STATION**

50795

Fire Research Station
BOREHAMWOOD
Hertfordshire WD6 2BL
Tel: 01 953 6177

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SUMMARY

A fire test which can be conducted in the laboratory and which is suitable for the quality control of foam liquids is described.

The test fire was 56.5 cm dia and 9 litres of fuel were used for each test. The foam was applied as a jet from a model branchpipe at $3.0 \text{ l/m}^2/\text{min}$. Control and extinction times were measured and a burn-back resistance test was made.

Test results are given for 17 samples of foam liquid representing all groups. Duplicate fire tests were made with each foam liquid and three aviation fuels.

Values are proposed for the quality control of protein, fluoroprotein, and fluorochemical foam liquids.

KEY WORDS: Foam, Laboratory, Fire Test, Protein, Fluoroprotein, Fluorochemical, Burn-back.

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INTRODUCTION

In the United Kingdom the tests described in Defence Standard 42-3¹ are used for accessing the quality of foam liquids. The principal test is a laboratory fire test using a 0.28 m² area fire. Foam is first produced in a standard 225 l/min branchpipe and the expansion, shear stress, and quarter drainage time of the foam are determined. Foam, with identical physical properties is then produced in a laboratory generator at 0.68 l/min, and is applied gently to the surface of the test fire. Petrol with a boiling range of 62°-68°C is used as fuel. The Defence Standard specifies limits for foam expansion, the 90 per cent fire control time and the quantity of liquid draining in a given time, from the foam applied to the fire.

This test served well while only protein foam liquid was available, and maintained supplies at a high standard of quality and uniformity. With the introduction of new foam liquids for use in branchpipes the test proved less satisfactory. In the case of fluoroprotein foams it was necessary to resort temporarily to using large scale test fires (81 m² area) and the need for an improved laboratory test fire became an urgent requirement. This report describes a laboratory test fire which fulfills this requirement.

DESIRABLE ATTRIBUTES OF A NEW FIRE TEST

The following are desirable attributes, or factors which must be allowed for, in the design of a new fire test.

1. Small enough to be conducted in a test building and thus independent of wind effects and the necessity for fair weather.
2. Economic of fuel, time, labour; so that the number of tests do not have to be restricted.
3. Equipment to be simple and easily constructed to uniform standards by different laboratories.
4. Procedure to be simple and the results not to depend upon acquired skill of the operator, and to be readily reproducible in different laboratories.
5. Foam must be produced in a standard manner, preferably related to the methods used in practice.

6. Foam efficiency varies with the application rate and this should be allowed for.
7. Efficiency varies with the impact of the foam upon the fuel surface² and the test must take account of this.
8. Efficiency varies with the type of fuel. The fuel used in the test should match the hazard to be protected.
9. The drainage rate from the foam, after it is applied to the fire, is not a measure of the burnback resistance and a different measurement is required³.
10. The preburn time will affect the results obtained^{3,4}.
11. Foam properties, and therefore its extinction performance are temperature dependent⁵.
12. The test must provide comparisons between foam liquids which will be true for large fires, and if possible permit the prediction of extinction quantities for large fires.

DEVELOPMENT OF THE NEW FIRE TEST

The new test equipment and experimental procedure are described in detail later; here are discussed some of the considerations which affected the selection of test details.

FIRE SIZE

It is known that fire diameter affects the behaviour of a fire and 1 metre or more is required to obtain fully turbulent flame conditions⁶. A fire of this size is too large for many laboratories and a smaller fire was considered acceptable as the primary purpose of the test is to compare and control the quality of foam liquids, rather than the prediction of foam requirements for large fires. The choice of a 0.25 m² area fire was made when an appropriate simple method of producing foam at the required rate was established as described below.

FOAM PRODUCTION

The method used in the Defence Standard of producing foam in a 225 l/min branchpipe, and matching this in a laboratory generator has a number of disadvantages. It requires a standard branchpipe and the one now specified is no longer obtainable and is expensive to construct. The branchpipe foam properties are not accurately reproducible in different laboratories, the foam temperature is difficult to control, and frequently the branchpipe test has to be conducted outside and is therefore dependent upon weather conditions. Difficulty is experienced in matching the laboratory generator foam to the branchpipe foam and on occasions this requires several hours. Even when the foam is matched for expansion, drainage rate and yield

stress, the generator foam is not identical to the branchpipe foam which has a wider range of bubble sizes.

A 5 l/min standard foam branchpipe is now available⁷, which has been shown to have a good performance with most foam liquids. This application rate would require a 2 m² area fire - much too large for a laboratory test. Experiments resulted in the development of a modified outlet section for this branchpipe which enabled the discharge to be split into two streams of appropriate proportions so that the smaller stream matched a 0.25 m² area fire. It was necessary to adjust the proportioning device for each foam liquid, but this proved to be a simple and quick procedure. It was found to be important that the modified outlet section had a fixed relationship to the branchpipe baffles. The modified outlet section slightly changed the foam properties which were usually improved as compared with those of foam produced with the standard outlet. Table 1 shows some comparisons of foam properties obtained with the new outlet.

Table 1

Foam liquid	Foam property	Standard outlet	Modified outlet
Protein	Expansion	8.55	9.5
	Yield Stress N/m ²	26.5	32.2
	20 cm 25 per cent drainage min-s	8-20	9-45
Fluoroprotein A	Expansion	7.4	9.0
	Yield Stress N/m ²	12.8	19.2
	20 cm 25 per cent drainage min-s	8-24	9-03
Fluoroprotein B	Expansion	8.8	8.95
	Yield Stress N/m ²	12.9	13.3
	20 cm 25 per cent drainage min-s	7-30	8-28
Fluorochemical	Expansion	10.1	9.75
	Yield Stress N/m ²	4.6	5.0
	20 cm 25 per cent drainage min-s	4-30	4-17

COMPARISON OF FOAM PROPERTIES FROM 5L/min BRANCHPIPE -
BEFORE AND AFTER MODIFYING THE OUTLET

It would have been desirable to use a laboratory branchpipe which produced foam identical to that from branchpipes used in practice. This was not possible because there are no standards for branchpipes and those used produce foams with widely varying properties. Few branchpipes used in practice produce foam with such good physical properties as the laboratory branchpipe with the modified outlet. It is not a simple task to modify the laboratory branchpipe to reduce its efficiency and maintain an outlet velocity suitable for the test fire (see over)

It was decided to adopt the laboratory branchpipe with the modified outlet, the debatable disadvantage of its very good performance (better than that obtained with the standard outlet) being offset by the important advantages of simplicity and reproducibility.

FOAM IMPACT VELOCITY

Previous work² had shown that the effect of impact velocity upon control and extinction time just begins to become apparent, with the more sensitive combinations of fuel and foam liquid, around a jet velocity of 2-3 m/s. A velocity of 2.9 m/s (calculated at expansion 9.0) was selected, as it was judged that this would introduce the impact effect to a limited degree without it becoming a major controlling factor. (D.E.Breen⁸ calculated the terminal velocity of foam flakes of expansion 10, 25 mm diameter falling in still air as 6.1 m/s: the jet velocity from 225 l/min branchpipes is in the range 10-15 m/s). The selected velocity was also found to be suitable to permit the foam from the branchpipe to fall onto the fuel surface when the branchpipe was in a horizontal position, thus permitting the branchpipe to be used from a standard position except in exceptional cases.

APPLICATION RATE

The relative performances of different foam liquids depends upon the application rate at which they are compared. For a complete assessment, application rate x control and extinction time curves are required. To obtain these is far too involved for a routine test procedure. A single rate of 3 l/m²/min was selected. This is lower than would usually be used in practice but is representative of the rate which would apply in an incident which stretched the fire service to capacity. It also has the advantage that differences between foams are generally more pronounced at low application rates.

APPLICATION TIME

Because it provided a substantial economy of time and effort it was decided to follow each extinction test with a burn-back test. This necessitated using a fixed foam application time so that a substantial layer of foam was applied after extinction to provide a foam cover for the burn-back test. Most foams would extinguish the test fire in about one minute and it was decided to use a total foam application time of three minutes (at 3 l/m²/min) to provide approx 6 l/m² surplus foam for the burn-back test. D.J.Griffiths³ had shown that at this quantity the burn-back time is becoming less dependent upon foam quantity than it is at lower applications. The three minute application time also had the advantage that results could be obtained for poor foam liquids which had long extinction times without deviating from a standard procedure.

OBSERVATIONS

In the Defence Standard limits are only placed upon the control time and not upon the extinction time. This is inadequate because when some of the new foam liquids are applied forcefully, to some fuels, the fire can be controlled but cannot be extinguished². The extinction time was therefore regarded as an equally important measurement.

Radiometers were not used to monitor the fire as it was considered that the additional complexity they introduced was not merited by any advantages they possess. On most tests observers can agree closely upon the control time: only occasionally will fires hesitate around the 90 per cent control point and cause significant differences between observers. Such fires can also cause problems when their radiometer charts are being interpreted.

FUEL

The abandonment of the fire drainage measurement enabled the conical base of the fire tray to be reduced to just sufficient to assist washing out. The fuel quantity was reduced to the minimum depth judged to be necessary to maintain a fuel layer over the base of the tray at the point of foam impingement. The starting depth was 2.6 cm at the perimeter and 5.6 cm at the tray centre - giving 2 cm minimum at the perimeter when allowance is made for the preburn loss. This required 9 litres of fuel. In the Defence Standard test 35 litres of fuel are used, but because a narrow boiling range fuel is used it can be 'topped-up' between consecutive tests, providing the same foam liquid is used. Because wide boiling range fuels were now to be used it was considered essential to commence each test with a new supply. This had the advantage that the fire tray, besides being washed clean between tests was also thoroughly cooled.

IGNITION

When using AVTUR and similar fuels which will not readily ignite, ignition was assisted by using several wood sticks which could be removed as soon as the fuel 'caught'. This avoided the use of a quantity of a priming fuel which might affect the results, particularly because of the shallow depth of fuel. A gas jet would be an acceptable alternative.

PREBURN

D Hird et al⁴ showed that preburn time markedly affects control and extinction times, and D.J.Griffiths³ that it affects the burn-back time. The effects extend for a number of minutes, and in the case of burn-back time D.J.Griffiths found it most pronounced in the first minute. A preburn time of 1 minute was selected as compared with 30 s used in the Defence Standard test.

An even larger preburn period would have been chosen but consideration was given to the problems of smoke and radiant heat which can cause embarrassment in the laboratory.

BURN-BACK

The hydrogen jets used by D J Griffiths as a standard source of ignition were not adopted because it was found that results with good reproducibility could be obtained using the simpler procedure of a pot containing burning fuel. The pot dimensions had to be selected carefully and affected the result. A large diameter increases the radiant heat effect and with a pot of small diameter the radiant heat is insufficient to ignite AVTUR, and ignition occurs when the fuel level in the pot burns down to the fuel level in the tray. It is therefore necessary to carefully standardize the size of the pot and the quantity of fuel it contains. The problem of foam overflaming into the pot and suppressing its burning, which can readily occur with fluorochemical foams, was overcome by igniting the pot and lowering it slowly into the centre of the foam.

The end point of the burn-back test was easily determined when the flames permanently covered the entire tray surface. Draught appeared to have a slight effect upon the burn-back test and this was overcome by stopping the smoke exhaust fan during the burn-back test until the fire was repropagating across the tray and smoke production was becoming substantial. Thus the fan was only started during the last 1-2 minutes of the test and did not appreciably affect the results. This procedure was followed up to test No 72 when the long burn-back times with fluoroprotein foams caused smoke problems in the laboratory. The procedure was then changed to run the exhaust fan throughout the burn-back test, with the damper adjusted to extract a small flow via the hood over the fire and the major flow from the laboratory at ceiling level. This procedure had the minimum effect upon the fire behaviour which was consistent with maintaining acceptable conditions in the laboratory.

TEMPERATURE CONTROL

By adjusting the premix water temperature appropriately, foam could be produced to within $\pm 2^{\circ}\text{C}$ of 20°C and this was judged to be a practical range to obtain. Foam temperature has a significant effect upon foam properties⁵, and introducing temperature limits will be a step towards obtaining agreement between laboratories. This is particularly true when the new test is compared with the Defence Standard test in which the 225 l/min branchpipe test to fix the foam properties was often done at a different temperature from the laboratory fire test.

MATERIALS USED

Fuels

Aviation kerosine - AVTUR (JET A.1.) - D.ENG. RD.2494

Aviation wide-cut gasoline - AVTAG (Similar to J.P.4) - D.ENG. RD.2486

Aviation gasoline - AVGAS - D.ENG. RD.2485

Foam Liquids

Designation	Source	Age in Months	Premix concentration Per cent
Protein A1	Manufacturer A - U.K.	12	4
" A2	" "	7	4
Protein B1	Manufacturer B - U.K.	19	4
" B2	" " "	6	4
Protein C1	Manufacturer C - U.K.	1	4
Protein D	Germany	1	4
Fluoroprotein A1	Manufacturer A - U.K.	19	4
" A2	"	6	4
" A3	"	1	4
Fluoroprotein B1	Manufacturer B - U.K.	17	4
" B2	"	10	4
" B3	"	3	4
Synthetic C	Manufacturer C - U.K.	19	3
Synthetic D	Manufacturer D - U.K.	18	3
Fluorochemical A	Belgium	3	6
" B	U.S.A.	17	6
" C	France	19	4

DESCRIPTION OF APPARATUS AND EXPERIMENTAL PROCEDURE

THE BRANCHPIPE

Figure 1 shows the modified laboratory branchpipe which was used for foam production. The unmodified branchpipe is described in Fire Research Note No 971⁷. The foam liquid premix was prepared in a stainless steel container which could be pressurized with air to 700 kPa, to discharge the liquid to the branchpipe; to which it was connected by approx 3 m of 12 mm bore flexible hose.

FIRE TEST APPARATUS

The fire test was conducted in a circular tray depicted in Fig.2. The tray had the following dimensions

Internal diam.	-	56.5 cm
Area	-	0.25 m ²
Vertical side	-	15 cm height
Conical base	-	3 cm deep

The tray was constructed from brass 1.22 mm thick and had a rim 2.44 mm thick and 15 mm deep. In the centre was a 12.5 mm dia drain point fitted with a brass gate valve. The tray was supported on a steel frame with four legs, approx 1 metre above the floor. The fire tray was situated beneath an extraction hood 3 m dia and 3 m above the floor.

The branchpipe was supported from the steel frame so that it was horizontal, with the 7 mm dia nozzle 15 cm above the tray edge with the by-pass holes discharging vertically downwards. The support permitted the branchpipe to be swivelled so that foam from the nozzle could either be directed into the centre of the tray or outside the tray, and its distance from the tray could be varied.

For the burn-back test a brass pot was used, 12 cm internal diameter, 11 cm internal height, with four studs on the base to give an overall height of 12.6 cm. The side was 1.22 mm thick and had a rim 2.44 mm thick and 8 mm deep. The base of the pot was 3.25 mm thick. There was a chain handle across the top of the pot and a hooked rod 60 cm long was provided for lowering the pot into the centre of the fire tray. A mark on the rod which aligned with the tray edge assisted in positioning the pot centrally in the tray.

EXPANSION

Expansion of the foam was determined by weighing a 1250 ml plastic beaker of foam

YIELD STRESS

The yield stress of the foam was determined using a torsional vane viscometer. The vane was 31.8 mm width, 31.8 mm height, and 1.22 mm thick, and rotated at 0.14 hz.

The top edge of the vane was 15 mm below the surface of the foam. The yield stress was measured 1 min from collecting the sample.

25 PER CENT DRAINAGE TIME

This was determined using a brass drainage pan as described in Fire Research Note No 972⁹. The pan was 10 cm dia and 20 cm height of straight side, with a conical base having an 11° slope. The centre of the conical base was rounded into a 12.7 mm internal dia x 25 mm long Perspex tube with a 1.6 mm bore brass drain cock at its lower end, from which the draining liquid was run into a 100 ml graduated cylinder. The pan was supported on 4 legs. The 25 per cent drainage volume was calculated from the foam expansion and the drainage pan volume. The drainage time was measured from commencing to fill the pan with foam. After the drainage time had been measured the temperature of the foam was determined using a mercury-in-glass thermometer which was moved continuously until a constant temperature was obtained.

PROCEDURE FOR CONDUCTING A TEST

Eighteen litres of premix were prepared. The water was first adjusted in temperature to produce foam at $20^{\circ}\text{C} \pm 2^{\circ}\text{C}$ and then the concentrate was added and the volume made up. Potable water supply was used from the hot and cold supplies in the laboratory as required. In the laboratory conditions prevailing, a starting temperature of 24°C produced foam in the desired temperature range.

The premix was placed in the stainless steel container, which was connected to the branchpipe and pressurized with air at 700 kPa.

The collar on the branchpipe was adjusted so that the discharge from the 7 mm nozzle was close to 750 g/min. This was done by weighing the quantity of foam collected over a period of 6 seconds. The foam temperature was then checked, and the expansion, shear stress and 25 per cent drainage time were determined. The distance of the branchpipe from the tray was adjusted so that the foam stream fell near the centre of the tray.

The fire tray was washed out with cold water and filled with 9 litres of the fuel to be tested. The burn-back pot was filled with 1 litre of AVGAS and placed in readiness a safe distance from the fire tray.

The extraction fan was started and the fuel was ignited. When AVTUR fuel was used, to assist its ignition three wood sticks (3 cm section x 75 cm long) were placed in the fuel and ignited, these were then removed as soon as the fuel 'caught'. Two stop watches were started from the point of full involvement of the fuel surface.

After 50 seconds the branchpipe was directed away from the fire and foam production was commenced. At 60 seconds the branchpipe was directed onto the fire so that the foam stream fell into the centre.

The time when the fire was reduced to $1/10$ of its initial size and the extinction time, were noted. Foam application was continued for a total time of 3 minutes, and the branchpipe was then turned off.

The burn-back pot was carefully lowered into the centre of the tray and held suspended so that foam would not flow into it. It was ignited at 1 minute after completion of foam application and then gently lowered to stand in the centre of the tray. The time was noted when the flames permanently spanned the entire tray. Two tests were made with each combination of fuel and foam liquid.

Plates 1-9 show the equipment and tests in progress.

EXPERIMENTAL RESULTS

The results obtained are given in Table 2 which shows the averages for duplicate fire tests. The temperature shown for foam properties is that measured when the drainage rate was determined. The expansion and yield stress samples had slightly different temperatures but always close to the drainage test sample.

In the tests with fluorochemical B, using AVGAS, one fire did not extinguish and three tests were made. The burn-back time shown in Table 2 is the average for two fires and the repropagation time of the third fire: the extinguishing time is the average for two fires.

With protein D using AVGAS, and with synthetic D using AVTAG extinction was not achieved and the repropagation time is shown in Table 2 in place of the burn-back time.

With synthetic D and AVTUR, one fire extinguished only after the 3 minutes application period and the burn-back test was commenced one minute after extinction.

The protein of German origin did not foam satisfactorily and it was impossible to reduce the discharge rate to $3 \text{ l/m}^2\text{-min}$ and the tests were made at $3.78 \text{ l/m}^2\text{-min}$.

Figs 3,4,5 illustrate the data obtained on the range of foams used, and Figs 6,7 and 8 compare data obtained on samples of protein and fluoroprotein manufactured in U.K.

DISCUSSION

The new test was found to be very practical and substantially independent of operator skill. In a normal working day, two operators could complete a test on a single foam liquid, including foam properties, branchpipe adjustment, and duplicate fires with three fuels.

A useful improvement may be to provide a premix tank and pump to replace the pressurized container, and fit hot and cold water coils in the tank for temperature adjustment.

The degree of mixing of fuel and foam was an important factor. The first portion of foam applied, before a foam layer was formed, often showed evidence of fuel contamination. This contaminated foam was pushed as a crescent to the jet

side of the tray (side nearest branch-pipe outlet) or as a collar around the perimeter and with some foams delayed extinction and accelerated burn-back. With fluorochemical foams and AVGAS fuel, and to a lesser extent with AVTAG fuel, sections of contaminated foam would burn away in the early stages of the burn-back test and extinguish when the contaminated fuel was consumed.

The data illustrated in Figs 3,4 and 5 show many interesting comparisons between the foam liquids. Some of the more important ones are as follows.

Fluorochemical A (Belgium) was the best of the three fluorochemicals and was superior to all other foams in control and extinction time. Its burn-back resistance was inferior to that of fluoroprotein and protein but markedly better than the synthetic foams.

Fluorochemical B (USA) performed well on AVTUR and AVTAG fires but was not so good on the AVGAS fires, of which one fire was not extinguished.

The French fluorochemical gave good control and extinction of all three fuels but had low burn-back resistance.

The two synthetic foams gave poor results, some fires were not extinguished, and burn-back resistance was low.

The UK protein and fluoroprotein gave good control and extinction times, the fluoroprotein being superior to the protein. Both had good burn-back resistance.

The protein of German origin did not make a good quality foam and poor test results were obtained. This is a difficult solution to foam well, but large scale branchpipes in which it produces good foam may exist. The laboratory tests cannot reflect its worth if it was used in such a branchpipe.

Figures 6,7 and 8 compare three batches of fluoroprotein from each of UK manufacturers A & B, with two batches of protein foam each of the same sources, and one from UK manufacturer C.

The fluoroproteins were generally markedly superior to the proteins in control and extinction. The best results with protein were as good as some of the fluoroprotein results, but no protein was as good as fluoroprotein on all three fuels, neither for control nor for extinction. The fluoroproteins gave more consistent results than the proteins. The proteins from manufacturer B gave shorter control and extinction times than the proteins from manufacturer A, while their fluoro-proteins had similar control times. Extinction times tended to be superior for fluoroprotein B.

Burn-back times for proteins showed a substantial spread (eg. $21\frac{1}{2}$ - $33\frac{1}{2}$ mins for AVTUR fires) but the fluoroproteins were more consistent ($25\frac{1}{2}$ - $30\frac{1}{2}$ mins for AVTUR fires)

The UK proteins and fluoroproteins varied in age from recently manufactured to 19 months - there was no indication of deterioration in the older samples.

The protein from manufacturer C produced a foam with mediocre physical properties (expansion 5.6, shear 11.1, drainage time 5-01). Nevertheless it gave good control and extinction of the AVTUR and AVTAG fires, equalling some of the fluoroproteins, but it was not so good on AVGAS fires.

The results of the 60 fires with proteins and fluoroproteins from UK manufacturers A & B were used to make a statistical assessment of the reproducibility of the test, with the following results.

Estimated deviation of the mean
of duplicate tests-P=.05

90 per cent control time	± 6 seconds
extinction time	± 10 seconds
burn-back time	± 1 minute

This assessment is based upon duplicate tests in one laboratory, on the same day. When testing is extended to other laboratories this will introduce additional sources of variation - eg.

- Possible variations in equipment details
- Adjustment of the application rate
- Adjustment of the branchpipe position
- Discharge pressure control
- Estimation of control time by different operators
- Initial temperature of fuel
- Ambient temperature

It is considered that these additional sources of variation will not substantially reduce the effectiveness of the test when its use is extended to other laboratories.

If a test of this design is to be used to control the quality of foam liquids the specification requirements given in Table 3 would be appropriate. They would ensure that batches of foam liquid of significantly inferior quality would be eliminated, without rejection problems frequently arising because of test method imprecision.

Figure 9 shows the relationship between control time and shear stress, for the proteins and fluoroproteins from UK Manufacturers A & B, with AVTUR Fires. With both types of foam higher shear stresses favoured rapid control. This is interesting because with tests using gently surface application the reverse

relationship exists. P Nash (et al)¹⁰ in a series of tests using protein foam on 81 m² area fires and branchpipe application found that foam with shear stresses of 40-50 N/m² controlled more quickly than foams with higher or lower shear stresses.

Since it is currently common practice to use branchpipes, with 5 per cent solution of protein, which give foams with shear stress in the range 15-25 N/m², this aspect merits further study.

When designing the new test, regard was paid to the principles which apply to large fires. The test results obtained are in accord with the generally accepted merits of the various foams when they are used on large fires. A difficult and expensive test programme would be required to obtain a precise correlation between this laboratory fire and large fires.

In real fire situations the presence of plant and structures complicate the fire scene, and access is often restricted in an unpredictable manner: much further work is required before test results on a small laboratory fire can be used to predict with confidence the quantity of foam required to extinguish large fires.

CONCLUSIONS AND RECOMMENDATIONS

1. The 0.25 m² area fire test described provides a practical laboratory method for assessing the control, extinction, and burn-back properties of foams.
2. The test provides a more valid index of the value of a foam for application by branchpipe than do tests using gentle surface application.
3. Table 3 gives control, extinction, and burn-back times which would be appropriate values for specifications using this test for the quality control of protein, fluoroprotein, and fluorochemical foam liquids, using three aviation fuels.
4. Further studies of the relationships between foam properties and fire suppression when foam is applied by branchpipes, is desirable.
5. It would be worthwhile to conduct a series of large fires (say 100 m² area) using a range of foam liquids and fuels to establish a correlation between the new test method and large scale results.

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Table 2. Foam properties and fire test results

Test Nos	Foam liquid	Origin	Age months	Concentration %	Fuel	Rate l/m^2-min	Foam properties				Fire test average of two tests			
							Temp. °C	Expansion	Shear N/m^2	25% drainage min - s	Temp. °C	90% control min - s	Extinction min - s	Burn-back min
92/93	Protein A1	UK	12	4	Avtur	3.04	19.0	8.82	26.6	9 - 20	20.6 21.4	1 - 06	1 - 40	23.9
90/91	"	"	"	"	Avtag	"	"	"	"	"	19.6 18.0	1 - 35	2 - 07	21.2
88/89	"	"	"	"	Avgas	"	"	"	"	"	21.8 19.5	1 - 34.5	2 - 16	13.4
104/105	Protein A2	"	7	4	Avtur	2.98	"	7.75	24.4	9 - 53	19.0 23.0	1 - 16	1 - 50	21.5
102/103	"	"	"	"	Avtag	"	"	"	"	"	20.1 21.8	1 - 44	2 - 14	19.0
100/101	"	"	"	"	Avgas	"	"	"	"	"	21.6 21.2	1 - 53	2 - 43	15.0
13/20	Protein B1	"	19	"	Avtur	2.99	20.0	9.5	32.2	9 - 45	21.5 20.5	0 - 57	1 - 21	29.5
14/19	"	"	"	"	Avtag	"	"	"	"	"	20.5 21.5	1 - 01	1 - 26	27.9
15/18	"	"	"	"	Avgas	"	"	"	"	"	21.0 21.0	1 - 08	1 - 28	17.1

Table 2. Foam properties and fire test results

Test Nos	Foam liquid	Origin	Age months	Concentration %	Fuel	Rate l/m^2-min	Foam properties				Fire test average of two tests			
							Temp. °C	Expansion	Shear N/m^2	25% drainage min - s	Temp. °C	90% control min - s	Extinction min - s	Burn-back min
98/99	Protein B2	UK	6	4	Avtur	3.04	19.5	9.4	34.4	9 - 37	20.4 20.1	0 - 41	0 - 57.5	32.3
96/97	"	"	"	"	Avtag	"	"	"	"	"	19.9 22.5	1 - 00	1 - 19	28.25
94/95	"	"	"	"	Avgas	"	"	"	"	"	20.8 17.8	1 - 05.5	1 - 50	20.3
110/111	Protein C1	"	1	"	Avtur	3.08	20.2	5.6	11.1	5 - 01	19.6 20.5	0 - 39.5	0 - 58.5	32.7
108/109	"	"	"	"	Avtag	"	"	"	"	"	20.2 20.2	0 - 45	1 - 09.5	27.25
106/107	"	"	"	"	Avgas	"	"	"	"	"	22.0 20.4	1 - 33	2 - 10	18.0
58/59	Protein D	Germany	"	"	Avtur	3.78	22	4.2	7.21	4 - 05	21.0 22.0	0 - 55	1 - 09	38.9
62/63	"	"	"	"	Avtag	"	"	"	"	"	21.8 21.0	0 - 55.5	1 - 06	29.7
60/61	"	"	"	"	Avgas	"	"	"	"	"	21.2 20.4	2 - 31	Not achieved	12.5*

*Repropagation time from foam stop

Table 2. Foam properties and fire test results

Test Nos	Foam liquid	Origin	Age months	Concentration %	Fuel	Rate l/m ² -min	Foam-properties				Fire test Average of two tests			
							Temp. °C	Expansion	Shear N/m ²	25% drainage min - s	Temp. °C	90% control min - s	Extinction min - s	Burn- back min
16/17	Fluoroprotein A1	UK	19	4	Avtur	2.92	20.0	9.0	19.2	9 - 03	19.5 20.8	0 - 39	0 - 59	27.4
9/10	"	"	"	"	Avtag	3.0	"	"	"	"	19.0 21.5	0 - 41	1 - 07	23.25
11/12	"	"	"	"	Avgas	"	"	"	"	"	20.0 21.0	0 - 53	1 - 20	17.75
68/69	Fluoroprotein A2	"	6	4	Avtur	3.10	20.8	8.05	16.65	7 - 58	21.8 22.0	0 - 40	1 - 12	30.3
66/67	"	"	"	"	Avtag	"	"	"	"	"	20.5 19.8	0 - 47	1 - 11	21.3
64/65	"	"	"	"	Avgas	"	"	"	"	"	22.0 20.5	1 - 09	1 - 40	14.95
84/85	Fluoroprotein A3	"	1	"	Avtur	2.94	19.0	8.25	21.1	9 - 02	24.0 19.8	0 - 30.5	0 - 49	29.2
86/87	"	"	"	"	Avtag	"	"	"	"	"	18.8 19.7	0 - 35.5	1 - 01.5	27.0
82/83	"	"	"	"	Avgas	"	"	"	"	"	17.0 19.4	0 - 53.5	1 - 35	16.7

Table 2. Foam properties and fire test results

Test Nos.	Foam liquid	Origin	Age months	Concentration %	Fuel	Rate l/m^2-min	Foam properties				Fire test Average of two tests			
							Temp. °C	Expansion	Shear N/m^2	25% drainage min - s	Temp. °C	90% control min - s	Extinction min - s	Burn-back min
74/75	Fluoroprotein B1	UK	17	4	Avtur	3.12	18.8	8.65	12.2	7 - 53	20.6 17.6	0 - 42.5	0 - 55.5	25.6
72/73	"	"	"	"	Avtag	"	"	"	"	"	18 20.8	0 - 41.5	0 - 50.5	20.2
70/71	"	"	"	"	Avgas	"	"	"	"	"	21.8 22	0 - 54	1 - 02	14.9
21/22	Fluoroprotein B2	UK	10	4	Avtur	2.93	18.0	8.95	13.3	8 - 28	18.5 22.0	0 - 38	1 - 01	27.1
23/24	"	"	"	"	Avtag	"	"	"	"	"	21.8 25.0	0 - 40	0 - 53	20.7
25/26	"	"	"	"	Avgas	"	"	"	"	"	21.0 20.0	0 - 53	1 - 21	16.4
78/79	Fluoroprotein B3	UK	3	4	Avtur	3.0	18.2	8.85	12.8	8 - 23	20.8 20.5	0 - 40	0 - 56.5	25.4
80/81	"	"	"	"	Avtag	"	"	"	"	"	21.2 20.1	0 - 40	0 - 57	20.6
76/77	"	"	"	"	Avgas	"	"	"	"	"	19.0 20.1	0 - 58.5	1 - 17	15.45

Table 2. Foam properties and fire test results

Test Nos.	Foam liquid	Origin	Age months	Concentration %	Fuel	Rate l/m^2-min	Foam properties				Fire test Average of two tests			
							Temp °C	Expansion	Shear N/m^2	25% drainage min - s	Temp °C	90% control min - s	Extinction min - s	Burn-back min
43/44	Synthetic C	UK	19	3	Avtur	2.98	17	10.65	13.3	11 - 35	17.0 19.0	1 - 29	2 - 13	8.15
41/42	"	"	"	"	Avtag	"	"	"	"	"	18.0 19.0	2 - 00	2 - 52	6.6
39/40	"	"	"	"	Avgas	"	"	"	"	"	17.0 16.0	1 - 21	3 - 53	6.95
37/38	Synthetic D	UK	18	3	Avtur	2.8	21.6	8.4	10.0	10 - 27	17.5 18.8	1 - 00	3 - 12	6.7*
35/36	"	"	"	"	Avtag	"	"	"	"	"	17.2 19.8	2 - 16	Not achieved	4.1 ⁺
33/34	"	"	"	"	Avgas	"	"	"	"	"	19.5 18.6	0 - 54	1 - 02	7.5
27/28	Fluorochemical A	Belgium	3	6	Avtur	3.04	21.5	9.75	5.0	4 - 17	20.0 20.0	0 - 17	0 - 20	20.0
30/31	"	"	"	"	Avtag	"	"	"	"	"	17.5 23.0	0 - 25	0 - 33	16.2
29/32	"	"	"	"	Avgas	"	"	"	"	"	22.8 20.0	0 - 31	0 - 40	9.55

*One fire timed from 1 min after extinction at 5 - 08

+Repropagation time from foam stop

Table 2. Foam properties and fire test results

Test Nos	Foam liquid	Origin	Age months	Concentration %	Fuel	Rate l/m^2 -min	Foam properties				Fire test Average of two tests			
							Temp. °C	Expansion	Shear N/m^2	25% drainage min - s	Temp. °C	90% control min - s	Extinction min - s	Burn-back min
56/57	Fluorochemical B	USA	17	6	Avtur	3.1	18.8	10.55	10.0	5 - 54	20.0 22.5	0 - 19.5	0 - 26	20.5
53/54	"	"	"	"	Avtag	"	"	"	"	"	20.9 21.5	0 - 34	0 - 54	13.8
51/52 & 53	"	"	"	"	Avgas	"	"	"	"	"	21.5 21.8 20.3	0 - 52	1 - 08	14.6*
49/50	Fluorochemical C	France	19	4	Avtur	2.96	20.0	10.8	13.3	12 - 17	21.0 20.0	0 - 48	1 - 01	8.6
47/48	"	"	"	"	Avtag	"	"	"	"	"	18.5 18.9	0 - 45	1 - 04	6.85
45/46	"	"	"	"	Avgas	"	"	"	"	"	17.0 19.0	0 - 52	1 - 00	7.2

*One fire did not extinguish

TABLE 3

Proposed specification requirementsFigures in brackets show normal expectation

	AVTUR	AVTAG	AVGAS
<u>FLUOROPROTEIN</u>			
90 per cent control - S	✕ 50 (35-45)	55 (35-45)	75 (50-60)
Extinction - S	✕ 80 (50-60)	80 (55-65)	110 (75-100)
Burn-back - min	✕ 18 (25-30)	15 (20-25)	12 (15-18)
<u>PROTEIN</u>			
90 per cent control - S	✕ 100 (55-80)	120 (55-110)	140 (60-120)
Extinction - S	✕ 130 (75-115)	150 (75-135)	180 (80-165)
Burn-back - min	✕ 18 (20-30)	15 (18-28)	12 (15-20)
<u>FLUOROCHEMICAL</u>			
90 per cent control - S	✕ 25 (15-20)	35 (22-28)	45 (27-33)
Extinction - S	✕ 35 (20-25)	45 (30-35)	55 (38-42)
Burnback - min	✕ 15 (18-22)	10 (12-18)	5 (8-12)

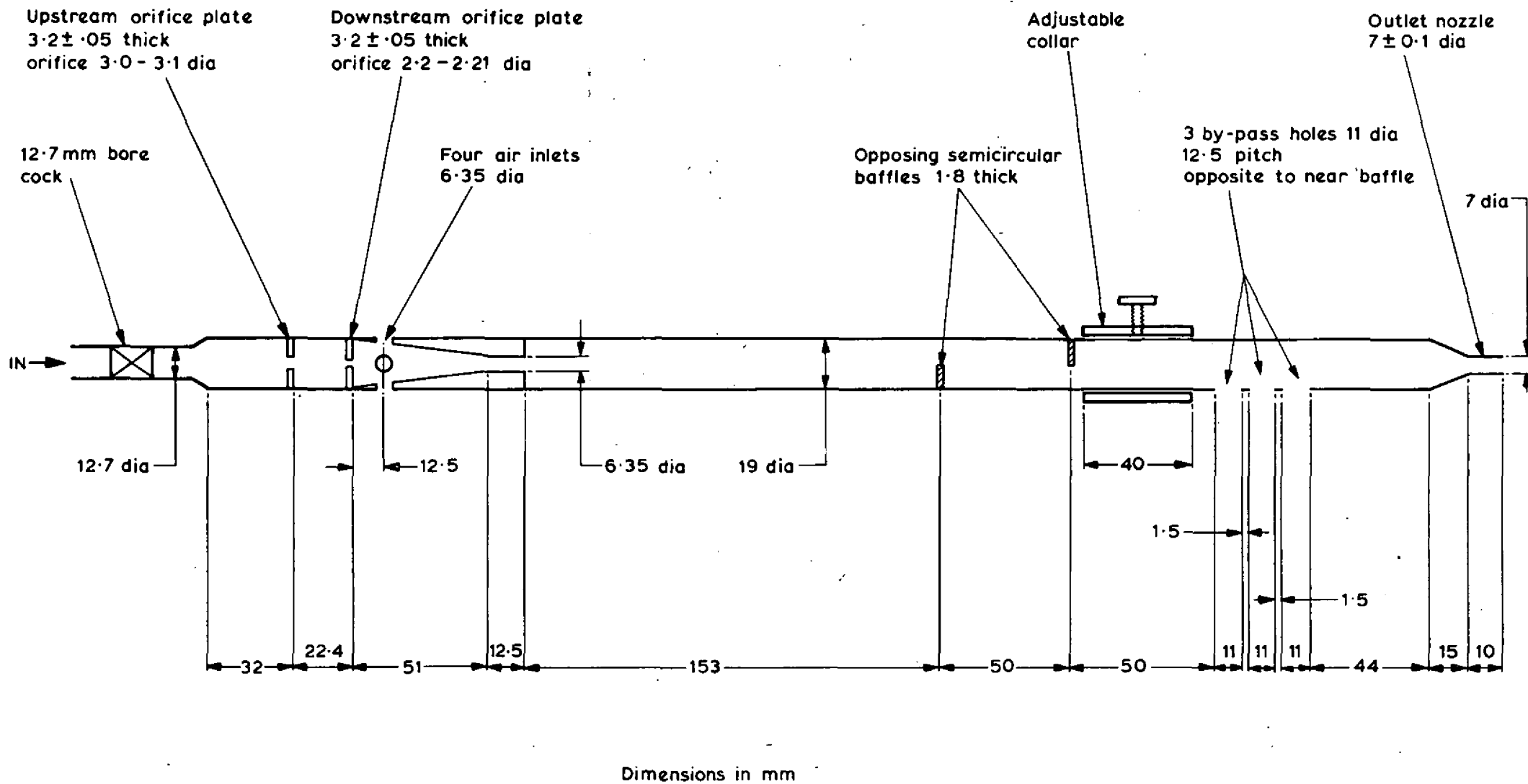


Figure 1 Foam branchpipe

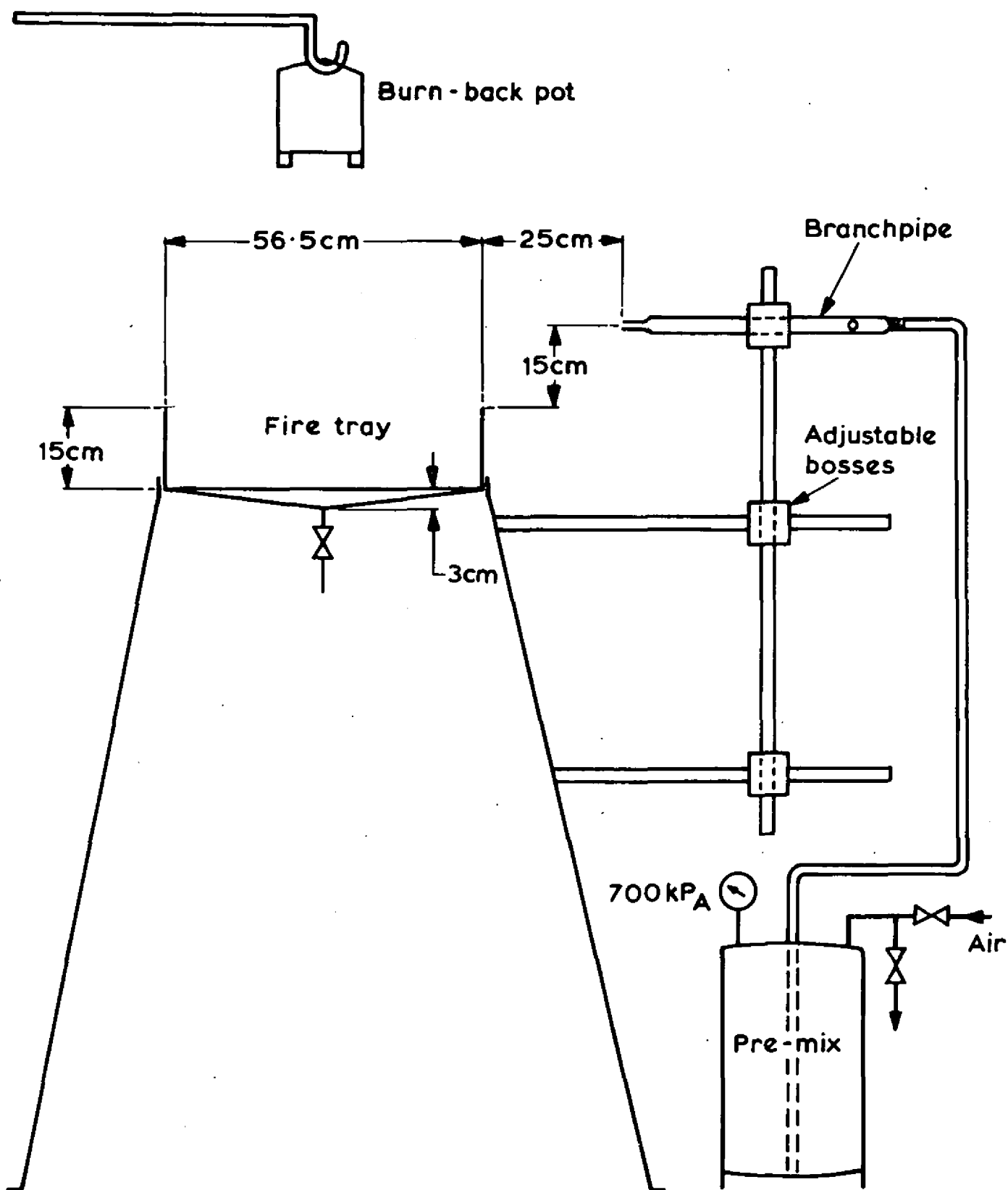


Figure 2 Fire tray, burn-back pot and branchpipe

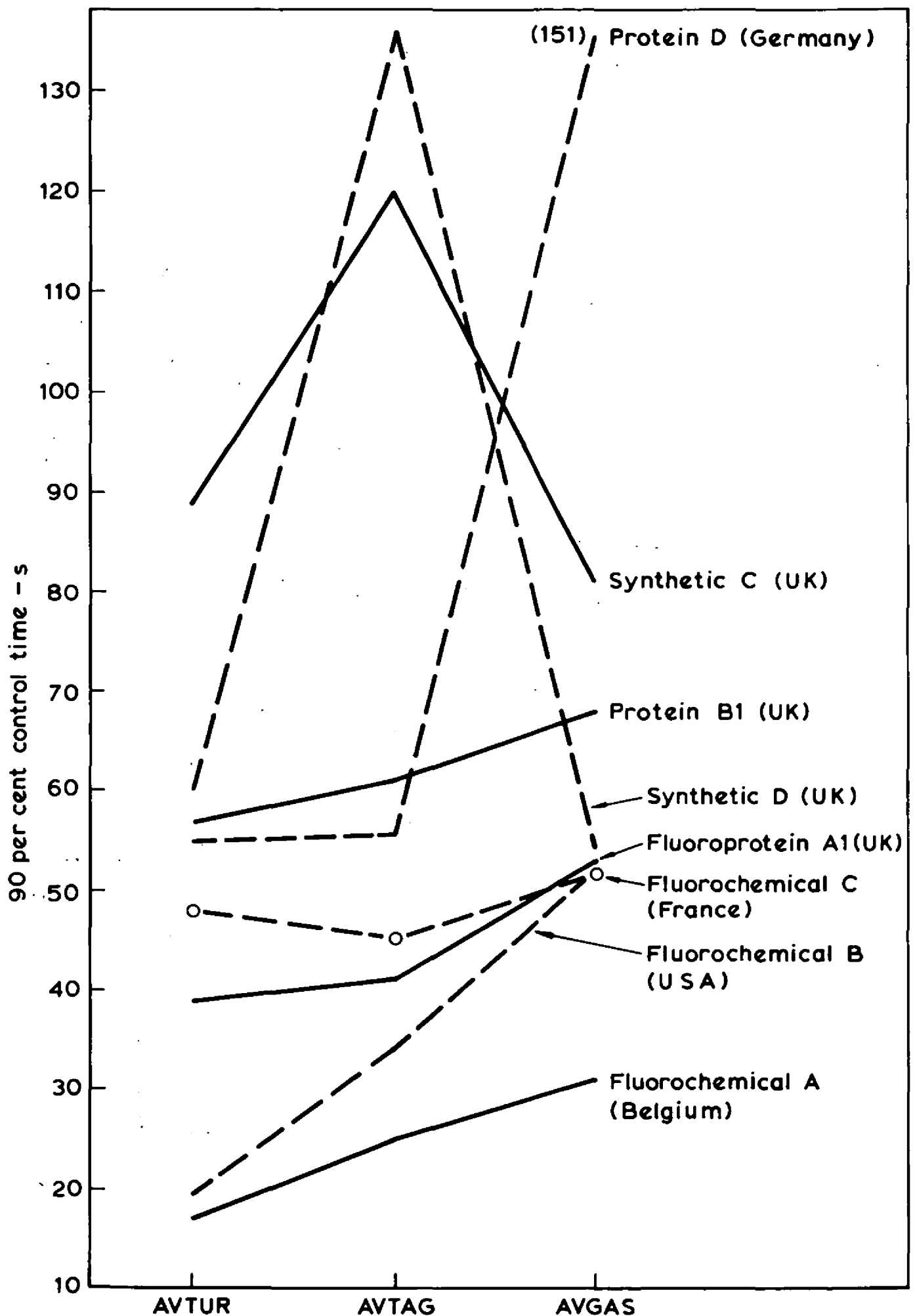


Figure 3: 90 per cent control times of various foam liquids with three aviation fuels

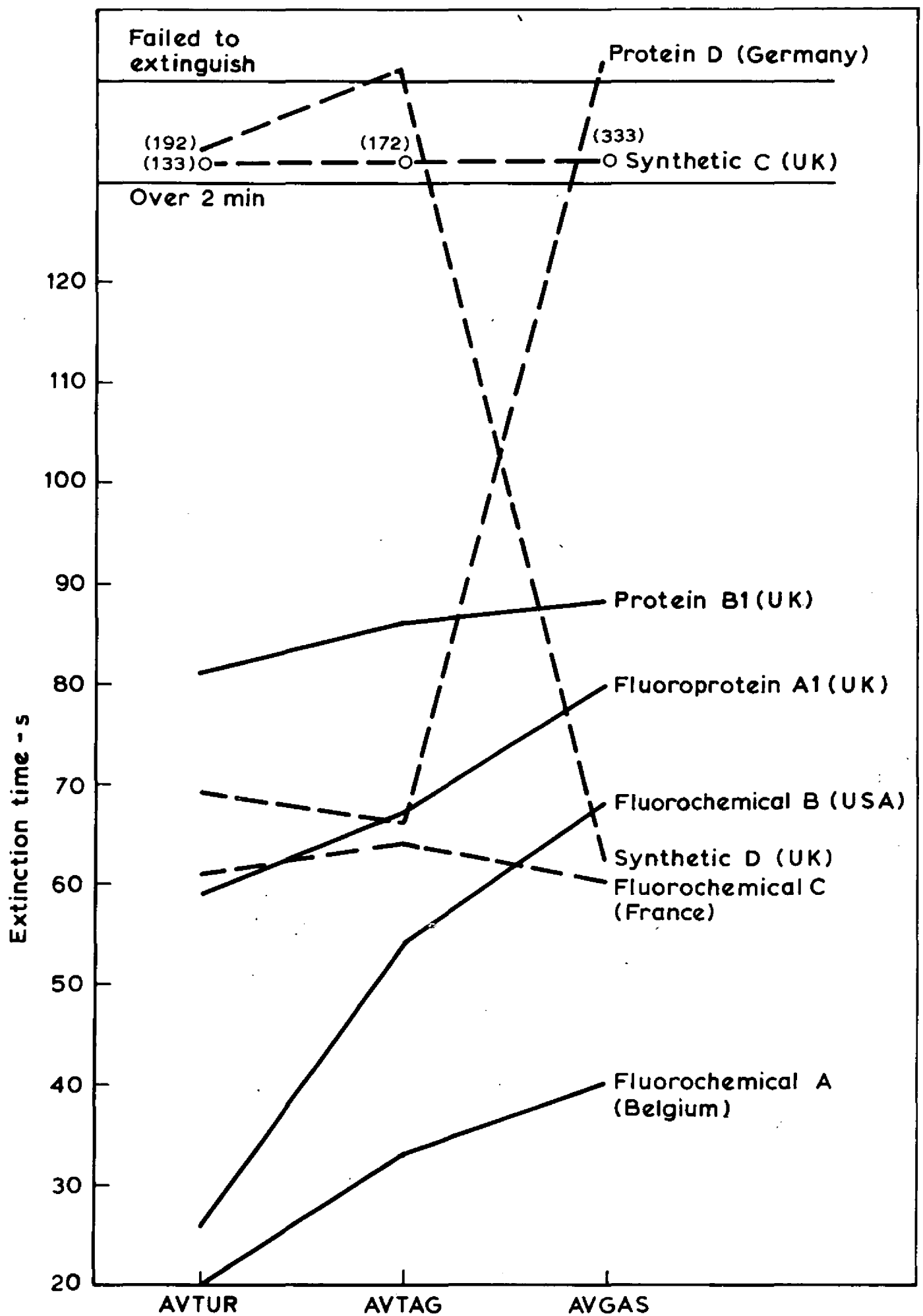


Figure 4 Extinction times of various foam liquids with three aviation fuels

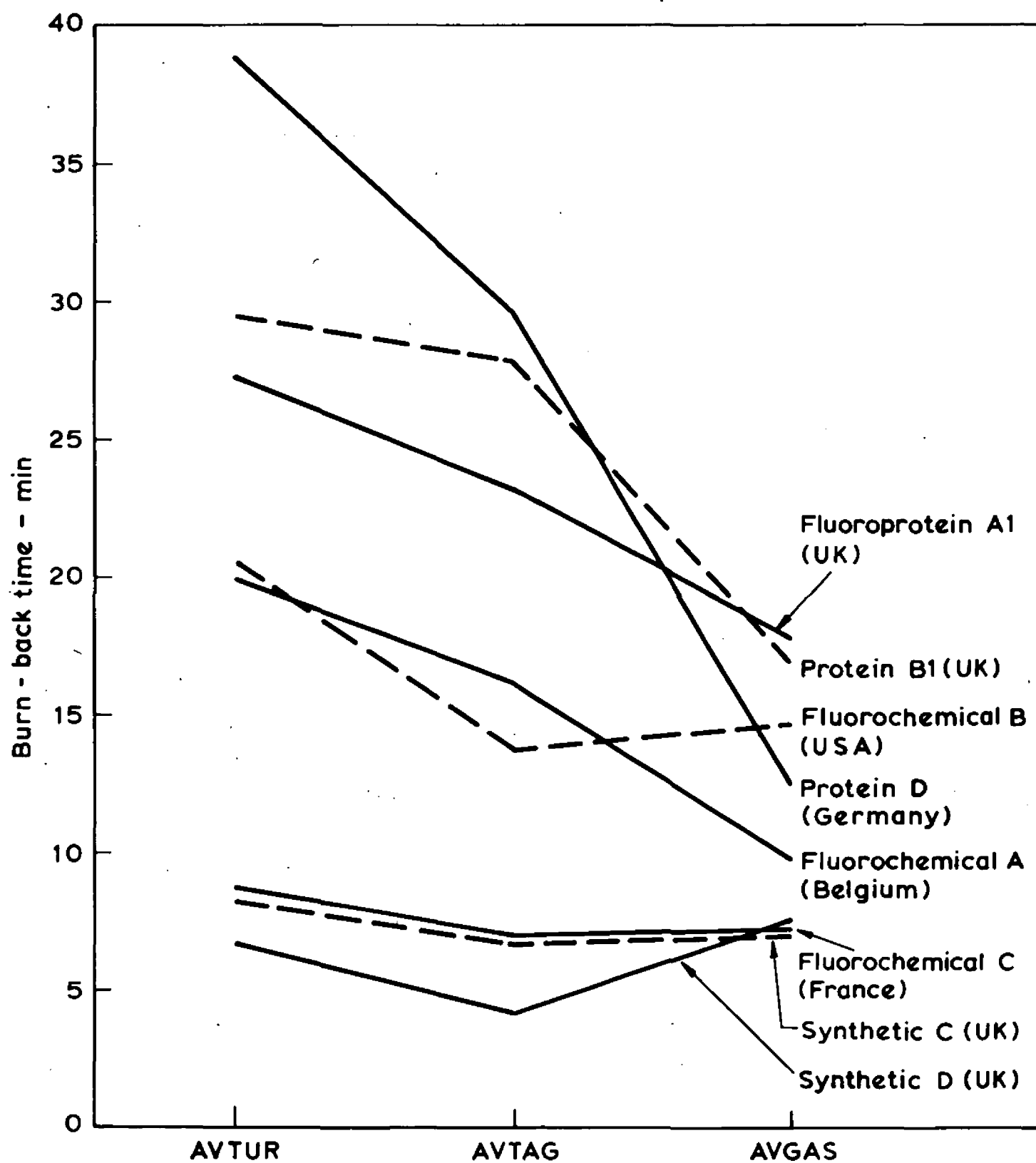


Figure 5 Burn-back times of various foam liquids with three aviation fuels

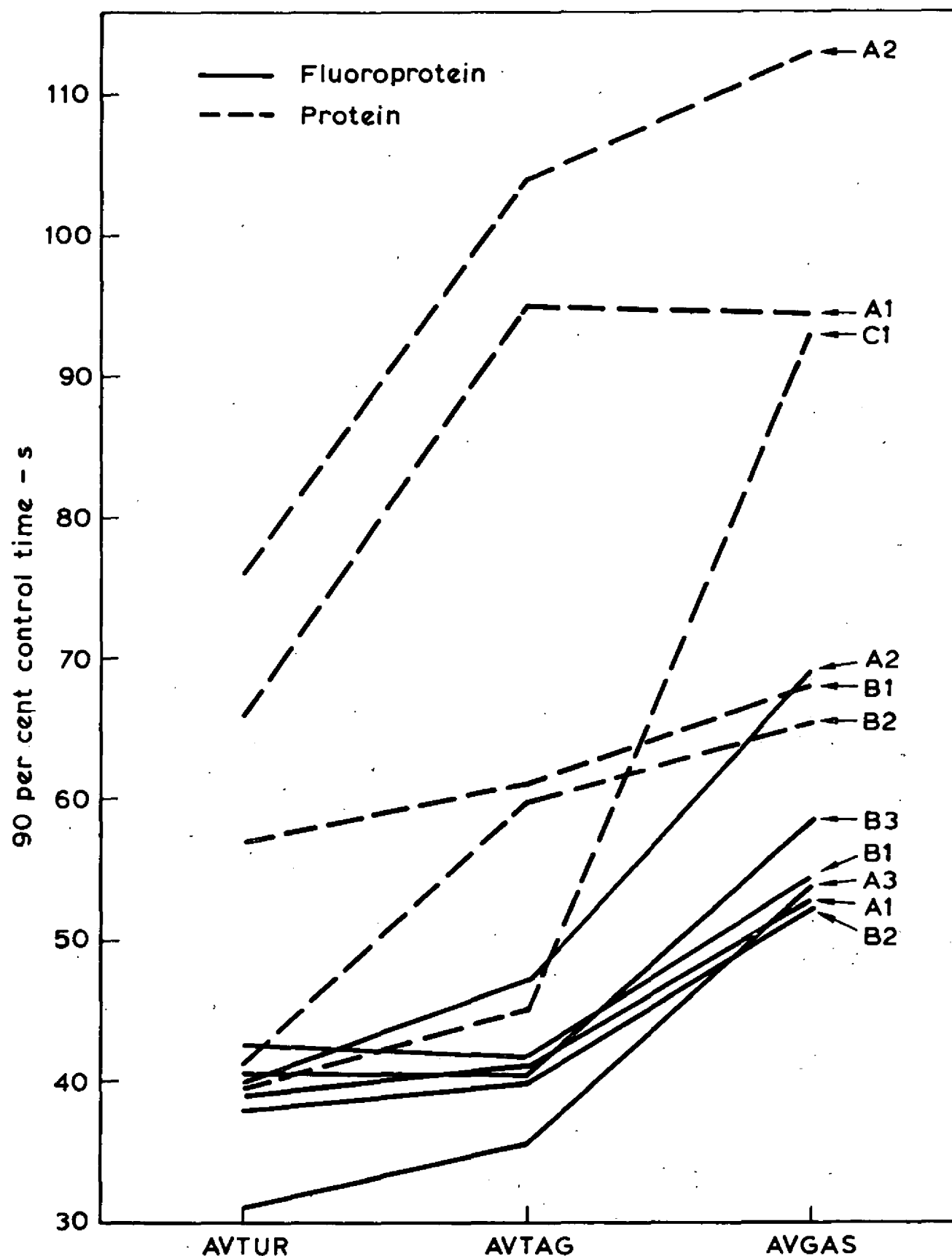


Figure 6 90 per cent control times of protein and fluoroprotein foams from three UK manufacturers - with three aviation fuels

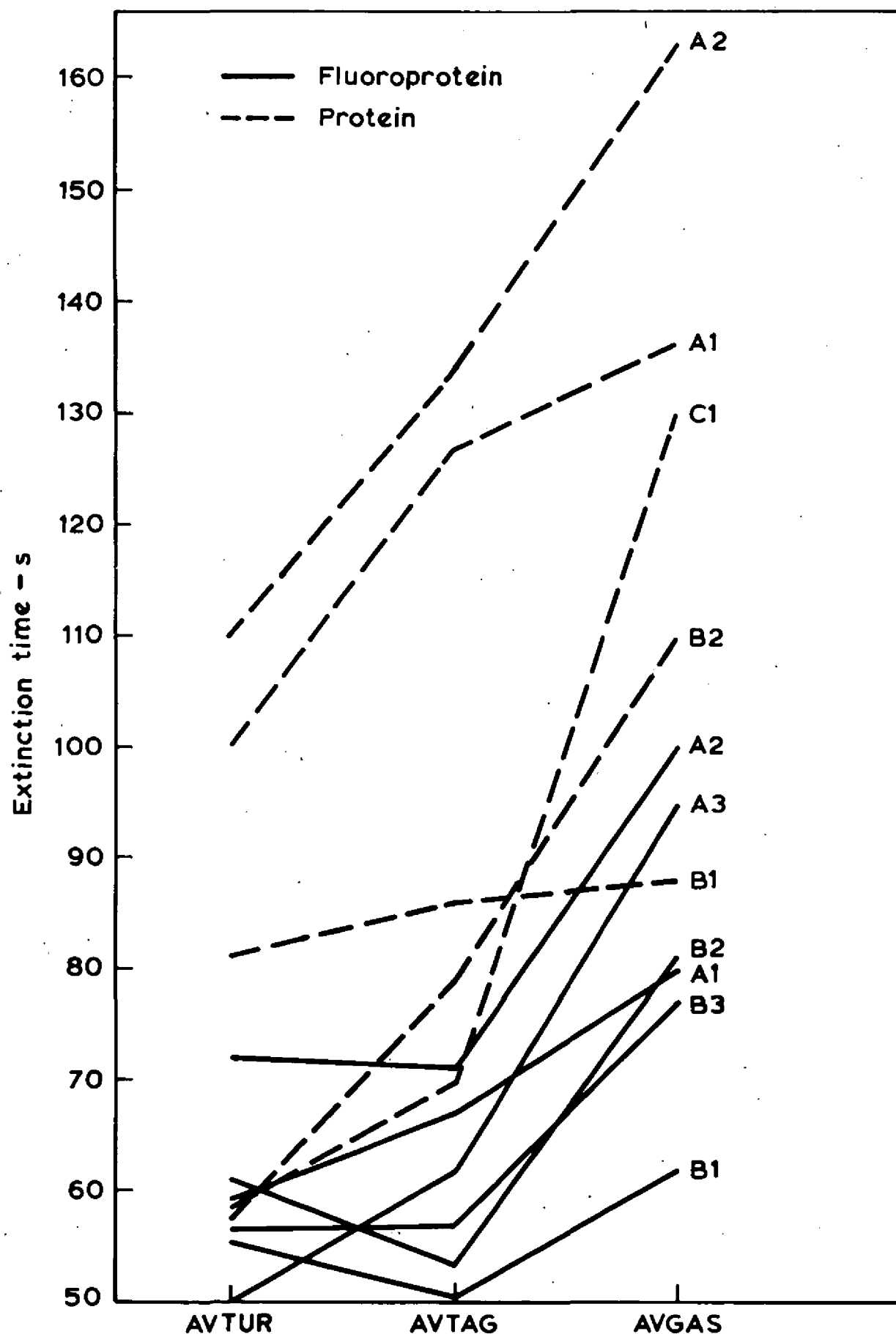


Figure 7 Extinction times of protein and fluoroprotein foams from three U K manufacturers – with three aviation fuels

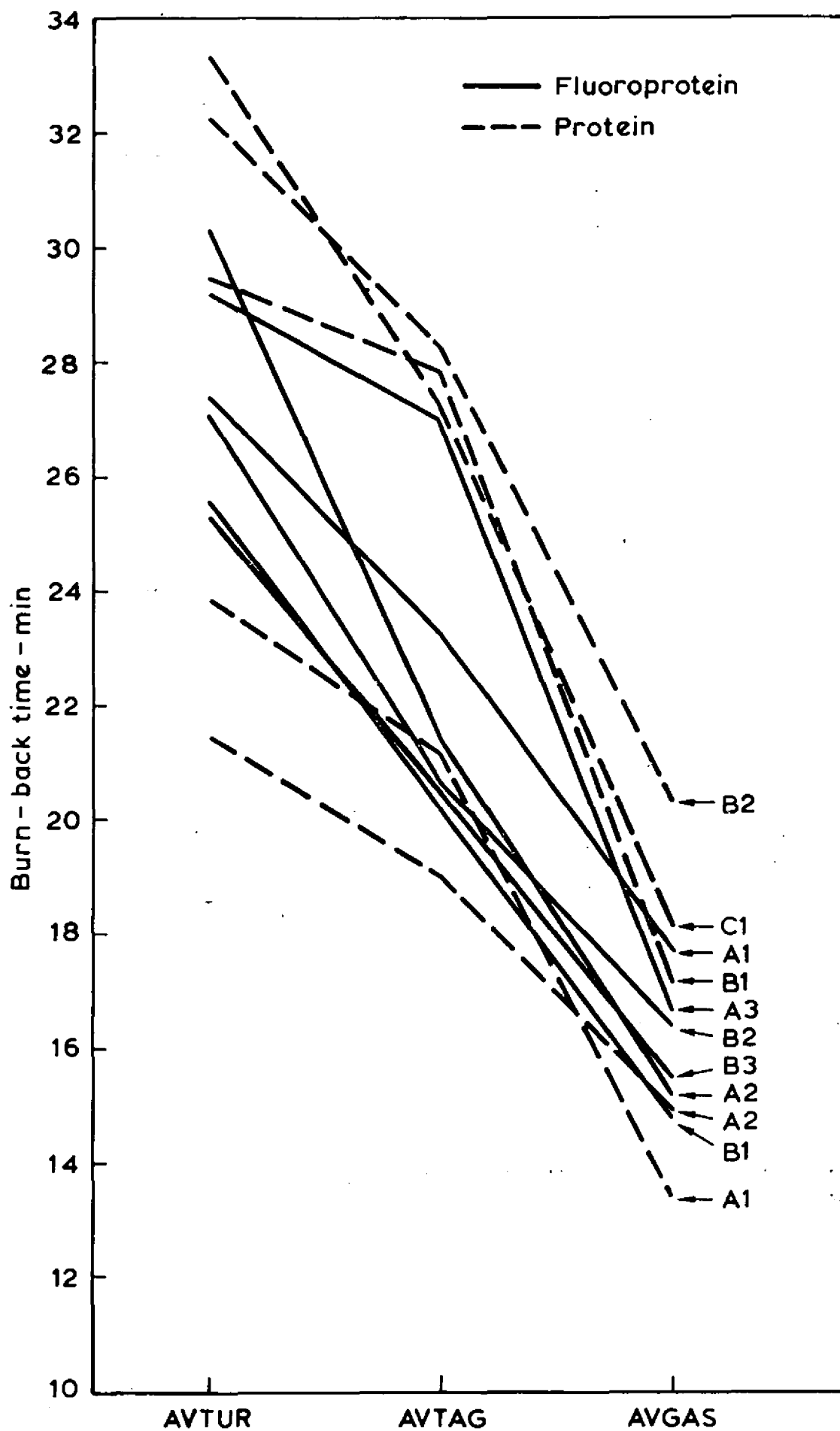


Figure 8 Burn-back times of protein and fluoroprotein foam liquids from three UK manufacturers - with three aviation fuels

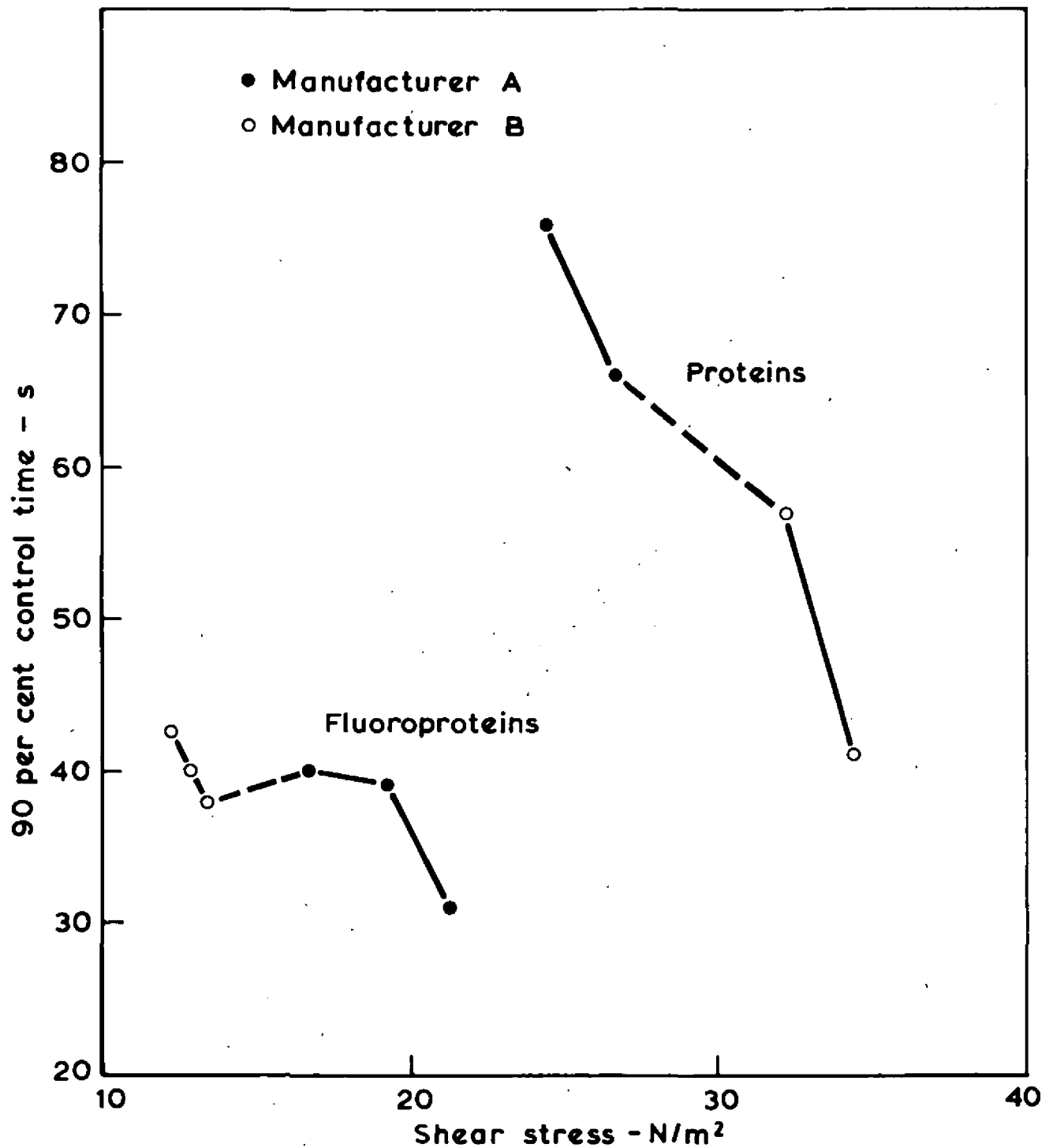


Figure 9 Relationship between control time and shear stress for protein and fluoroprotein foams on AVTUR fires

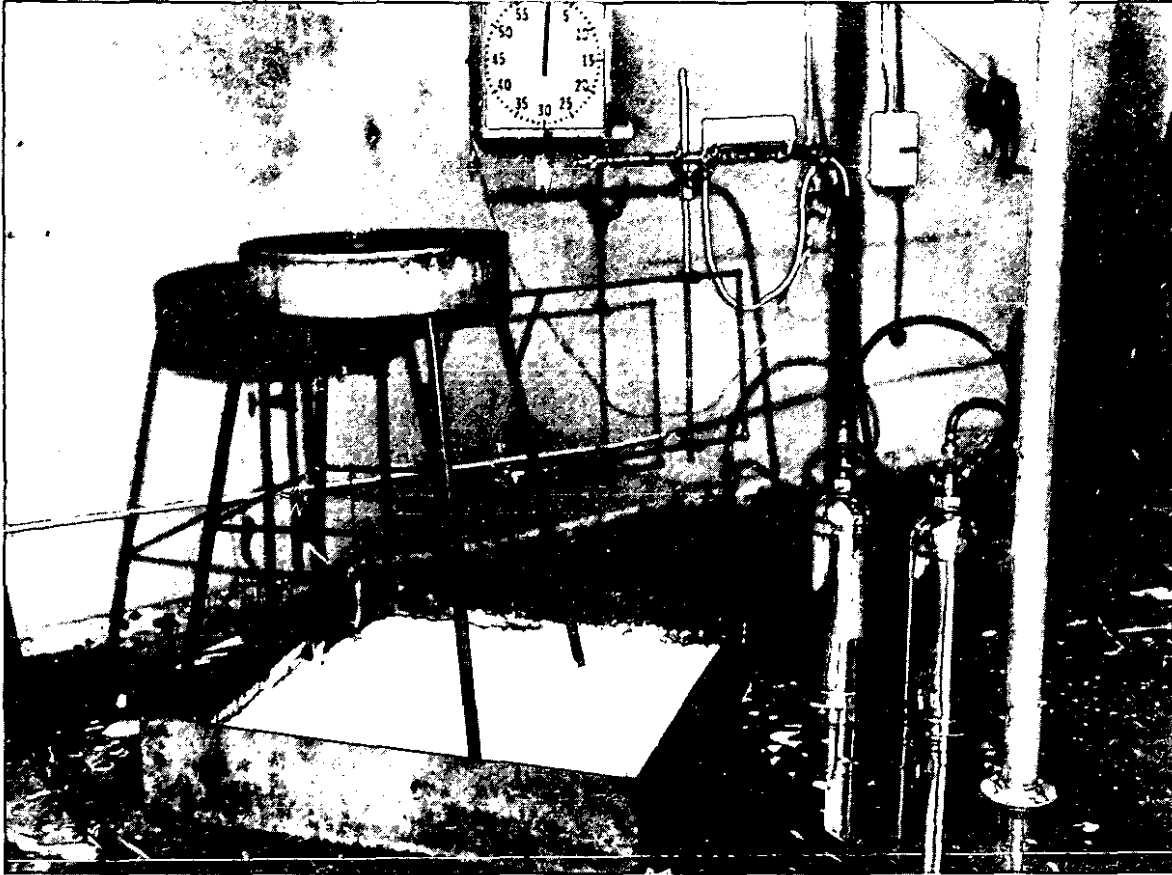


PLATE 1. GENERAL VIEW OF EQUIPMENT

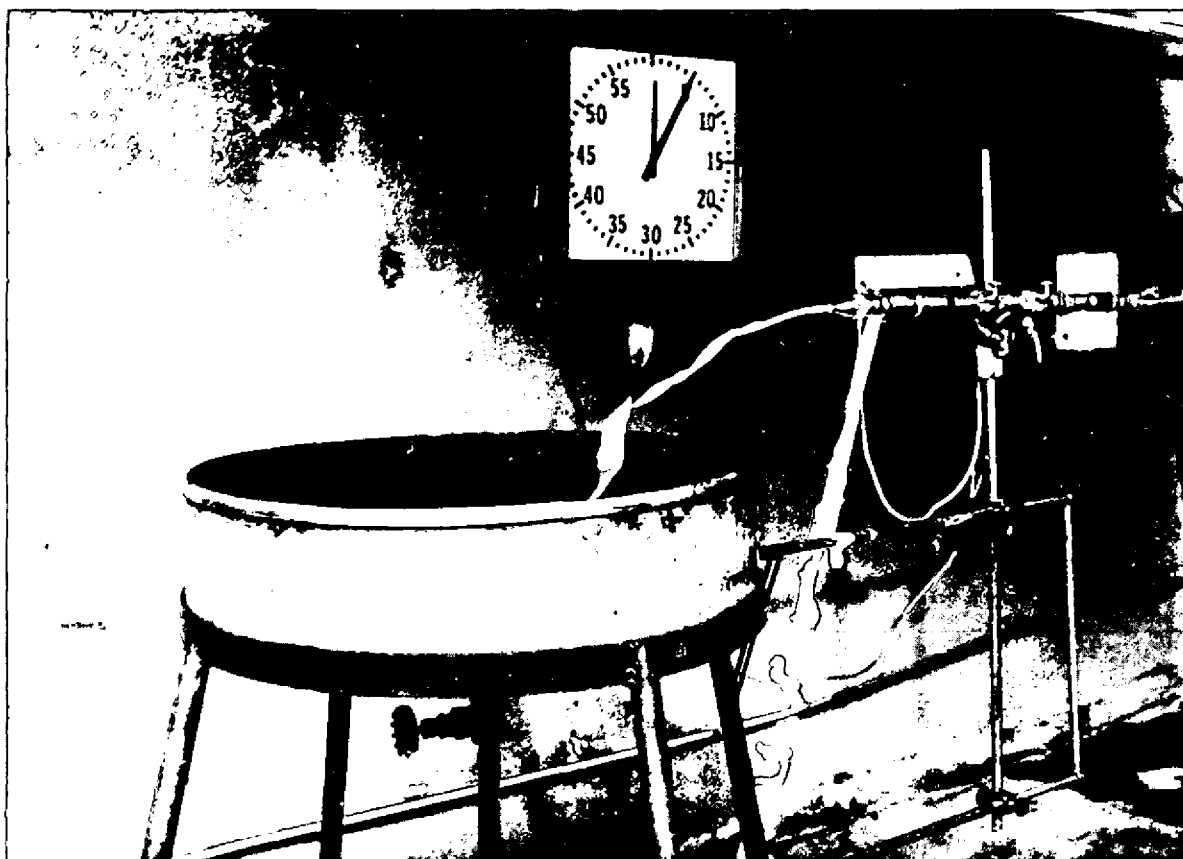


PLATE 2. FOAM STREAM ADJUSTED TO
CENTRE OF TRAY

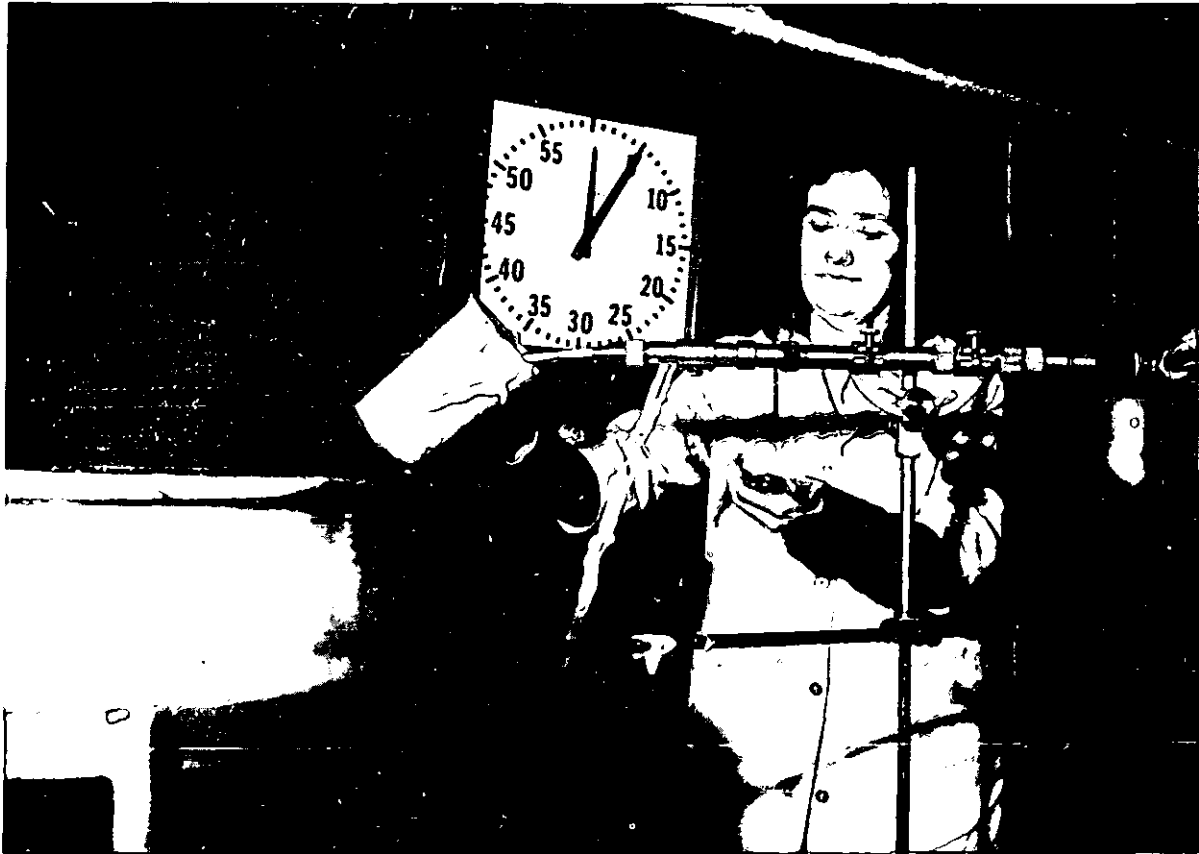


PLATE 3. SAMPLING FOR DISCHARGE RATE



PLATE 4. COMMENCEMENT OF EXTINCTION

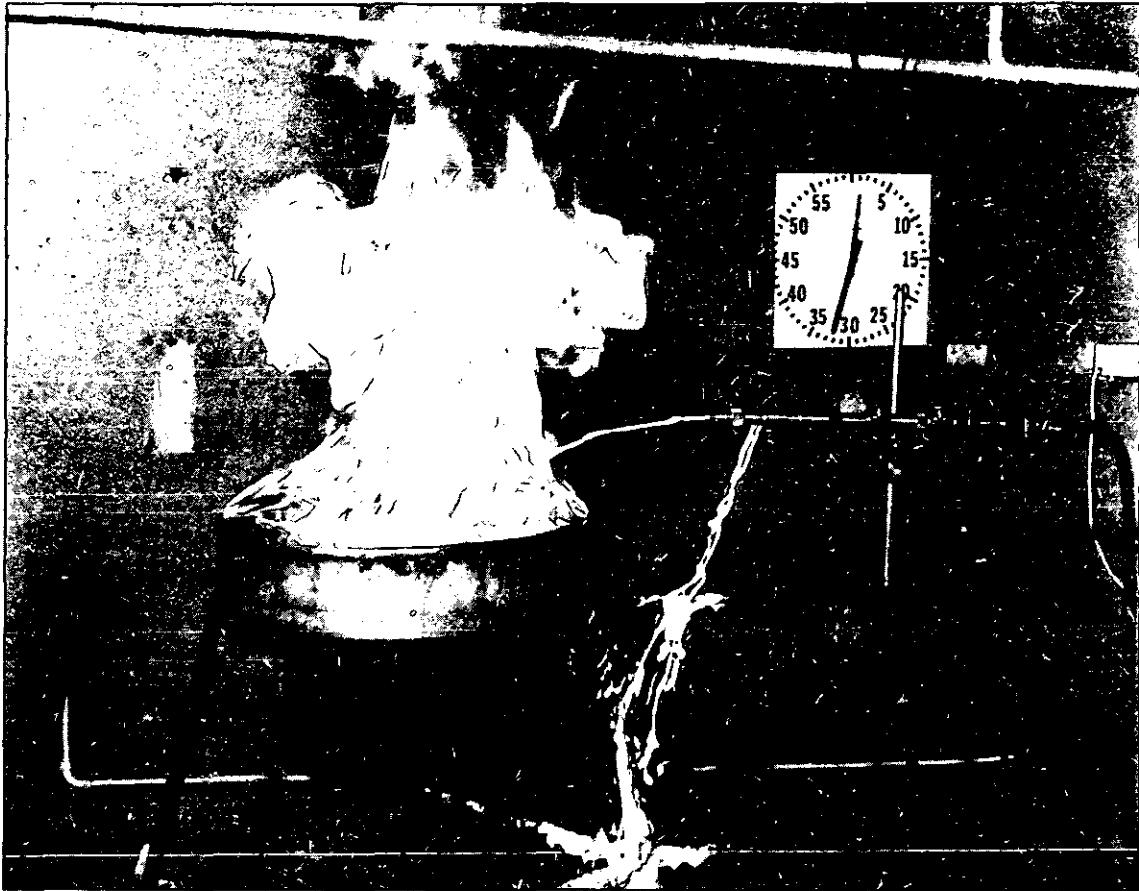


PLATE 5. EXTINCTION PROGRESSING

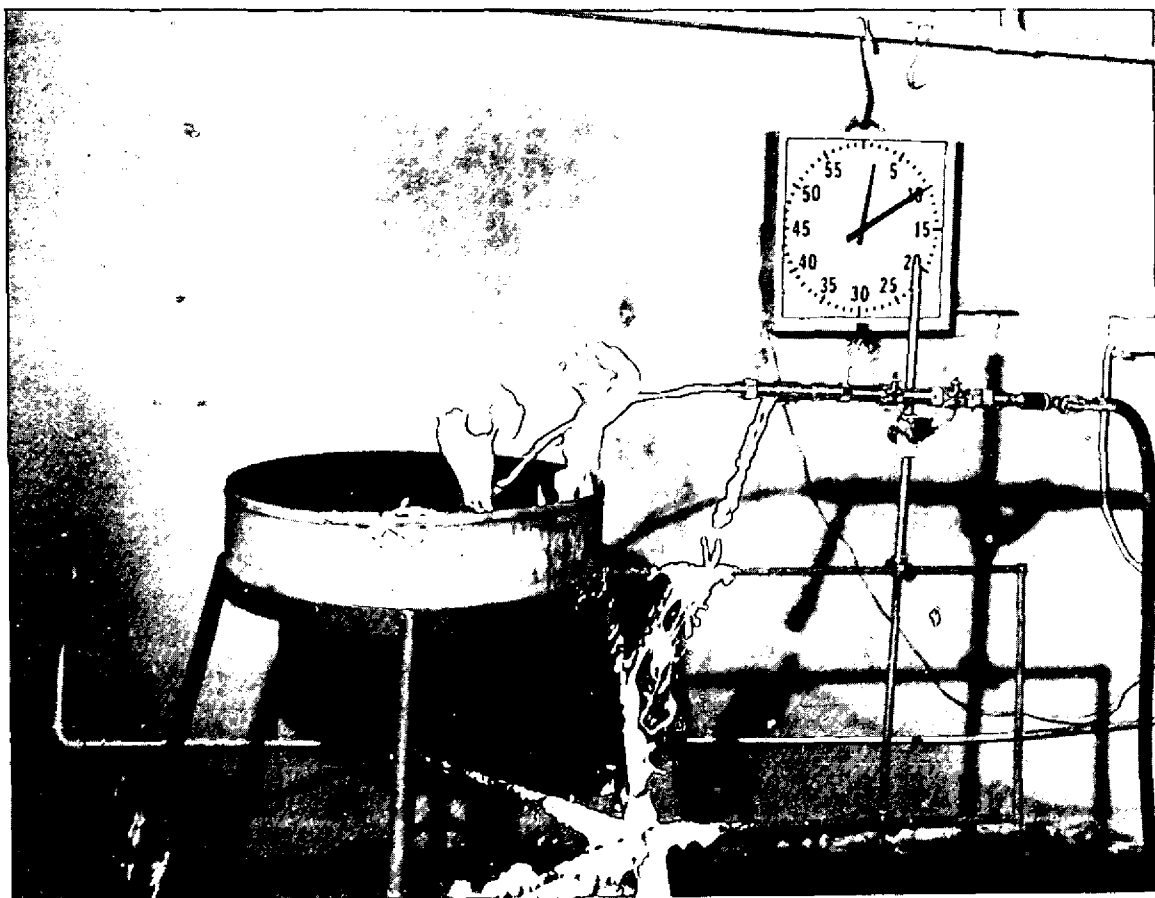


PLATE 6. APPROACHING EXTINCTION



PLATE 7. PLACING THE BURN-BACK POT



PLATE 8. COMMENCEMENT OF BURN-BACK



PLATE 9. COMPLETION OF BURN-BACK

