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ADDITIVES FOR HOSEREEL SYSTEMS: TRIALS OF FOAM ON 40 M² PETROL FIRES

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Central Fire Brigades
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Fire Research

Additives for Hosereel Systems: Trials of Foam on 40 M^2 Petrol Fires

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ABSTRACT

A series of foam trials was carried out at the Fire Service College in October and November 1986 on a 40 m^2 circular tray using 1000 litres of four star petrol as fuel for each test.

The objective was to assess suitable additives for hosereel systems for control and extinction of Class B fires. The additives tested were fluoroprotein(FP), aqueous film-forming foam (AFFF), alcohol resistant AFFF (AFFF-AR), film-forming fluoroprotein foam (FFFP), alcohol resistant FFFP (FFFP-AR) and a self-foaming additive "Halofoam". With the exception of "Halofoam" (non-aspirated only) and FP (aspirated only), the additives were used aspirated and non-aspirated.

In the tests the additive was applied through a hosereel gun at a solution flowrate of 100 lpm after a one minute preburn.

After extinction a burnback test was performed on the foam blanket to assess the resistance of the foam blanket to flame.

AFFF, AFFF-AR and FFFP gave convincing extinction when used aspirated. FFFP and FP gave the longest burnback times.

All the additives tested gave poor performance both for extinction and burnback resistance, when used non-aspirated.

The design of the branchpipe was found to be critical for FP.

MANAGEMENT SUMMARY

As part of the Home Office Fire Research Programme, the Fire Experimental Unit (FEU) of the Scientific Research and Development Branch were requested to undertake a project to recommend a suitable additive for use in hosereel systems.

The objectives of the project relate specifically to appliance hosereel systems and are as follows:-

1. To find which additives improve control and extinction of Class A fires.

2. To find the most suitable additives for control and extinction of Class B fires and to evaluate burnback resistance.

3. To evaluate additive performance against non-standard fuels, for example: tyres and polyurethane foam furniture.

4. To investigate the tactical variations possible when applying additives through hosereel systems, for example: aspirated/non-aspirated, high/low pressure, spray/jet, number of branches.

5. To study the corrosive effects on the hydraulic systems of fire appliances.

Background studies confirmed that knowledge was not available to answer these questions and therefore a project was necessary.

This report describes work on large scale Class B fires. The objective of this work was to select the most suitable additives for control and extinction of these fires and to evaluate burnback resistance.

Many water additives for fire-fighting are available, so small scale tests were carried out to select additives for the large scale fires. These used heptane and petrol as fuels. The additives tested were fluoroprotein (FP), aqueous film-forming foam (AFFF), alcohol resistant AFFF (AFFF-AR), film-forming fluoroprotein foam (FFFP), alcohol resistant FFFP (FFFP-AR), a self-foaming additive "Halofoam", and "Fireout". All the additives except "Fireout", which failed to extinguish a small heptane fire, were then tested on large scale fires. With the exception of "Halofoam" (non-aspirated only) and FP(aspirated only), the additives were used aspirated and non-aspirated.

An Angus Superfog Hosereel gun, with an aspirator attachment, developed by Cambridgeshire Fire and Rescue Service was used for most of the tests (Figure MS1). This was chosen as representative of the type of branches in general use.

The additive, under test, was made up into a premix at the manufacturer's recommended concentration, and supplied to the branch at 100 lpm using a Godiva UMPX pump through the high pressure hosereel system. This gave an application rate of 2.5 litres per minute per square metre. The flowrate was monitored throughout the tests.

Petrol was chosen as fuel, because it is a volatile hydrocarbon commonly encountered, and is a severe test of an extinguishing agent.

The petrol was dispensed onto a water base in a 40m^2 circular tray. This gave a fuel depth of 25mm. and estimated free burning time of 6 minutes. The fuel

was ignited and had a one minute preburn before the fire was attacked by an experienced fire officer. After extinction a burnback test was performed on the foam blanket to assess the resistance of the foam blanket to flame. The data recorded included times to 90% and 100% extinction and the time to 100% burnback. The tests were recorded on colour video equipment and copies are available at FEU for brigades to view. Details of the tests are given in the report. A summary of the results is given in Figure MS2 and below.

Aspirated Application

When applied with the aspirator attachment, AFFF, FFFP and AFFF-AR all produced closely similar results. Extinction was progressive with 100% extinction times of about 2 minutes.

FFFP-AR was less effective than the other film-forming additives.

FFFP-AR was used in one test against a backplate and gave improved performance. When used without a backplate and with two Fire Research Station laboratory foam branchipes (giving the same total flow of 100 lpm), improved performance was also acheived.

FP produced poor results when used through the Angus Superfog with aspirator. Much improved performance was obtained with two Fire Research Station laboratory foam branchpipes (giving same flow of 100 lpm). The result in Figure MS2 is for FP at 4% and shows extinction times of 3 minutes 15 seconds.

The Burnback tests showed that all the additives gave protection when used aspirated. FP foam gave the longest burnback time, followed by FFFP.

Non-aspirated Applications

All the additives, when applied non-aspirated, gave long extinction times.

AFFF, AFFF-AR and FFFP all gave extinction times of at least double those for aspirated applications. FFFP-AR also gave a longer time but the difference was less pronounced.

"Halofoam" gave the longest extinction time. "Halofoam" is an additive which has halons emulsified into the foaming agent. The theory is that the solution remains a liquid until it contacts flames or a hot surface and then self-foaming takes place. Although "Halofoam" had been sucessful in the SRDB small scale tests on heptane, poor results were obtained in the conditions of these tests.

Two techniques of application were used with non-aspirated AFFF: the branch was held stationary and also "swept" over the tray surface.

With stationary applications, long extinction times were obtained but the extinction was progressive. When the spray was "swept" across the surface, extinction was observed in areas of up to 70% in the first 15 seconds of application. The fire then grew back to 100% in some tests, before extinction was finally obtained after at least 4 minutes. This non-progressive and potentially dangerous characteristic, is further discussed in the report.

The burnback for non-aspirated applications progressed quickly compared with aspirated applications.

CONCLUSIONS

The conclusions from the work so far are given below. These relate to the conditions of the test, in particular to the fuel, the application rate and the use of one hosereel branch.

1. AFFF, AFFF-AR, and FFFP gave convincing extinction when used aspirated using a simple aspirating attachment. FFFP gave the longest burnback time.

2. FFFP-AR, when used with the aspirator, gave slower extinction times than AFFF, AFFF-AR and FFFP. When used with the FRS branchpipe or with a backplate, comparable performance with the other additives was obtained.

3. All the additives tested gave poor performance when used non-aspirated. Some tests showed that the extinction is not progressive and can redevelop. This may be potentially dangerous in fire-fighting operations. Non-aspirated application cannot be recommended in circumstances similar to those used in these tests.

4. FP when used through the aspirator, gave poor performance and convincing extinction was not obtained. However when used with the FRS branchpipes an improved, acceptable performance resulted.

   Development of a hosereel branchpipe would be necessary if FP were to be used at flowrates of 100 lpm. No suitable branchpipe for operational use is known.

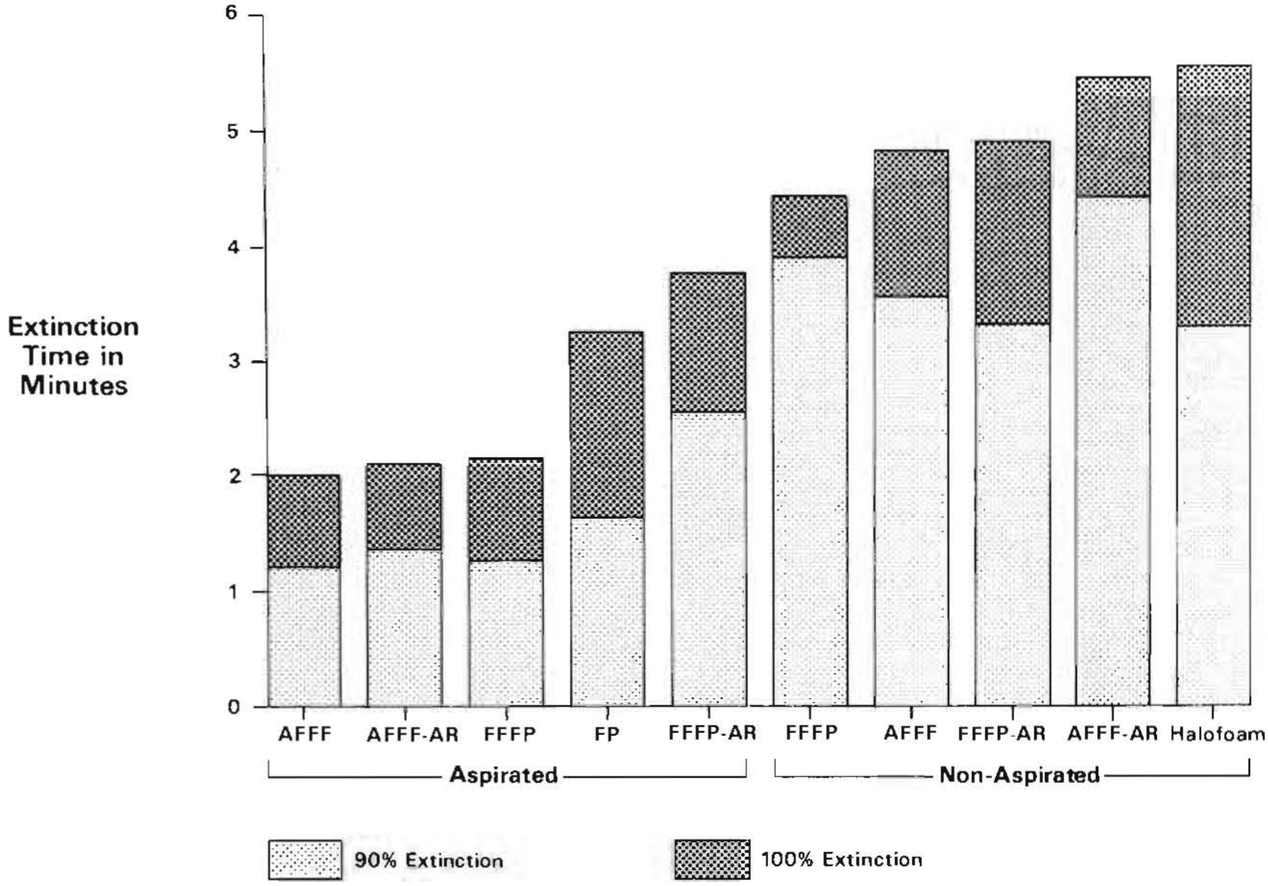
5. Non-aspirated performance gave poor burnback results. The best results for burnback were obtained with aspirated FP and FFFP.

Figure MS2 gives information on extinction times, burnback times and cost to extinction for hosereel systems in the test conditions. These factors together with the equipment to be used must be considered in selecting additives for use in brigades.

Further results on the use of additives for other than Class B fires will be given later in the project.

C/459/86

Figure MS1 : Modified Superfog hosereel branch fitted with aspirator.



Cost to Extinction in £	15	18	16	11	26	33	33	34	45	424

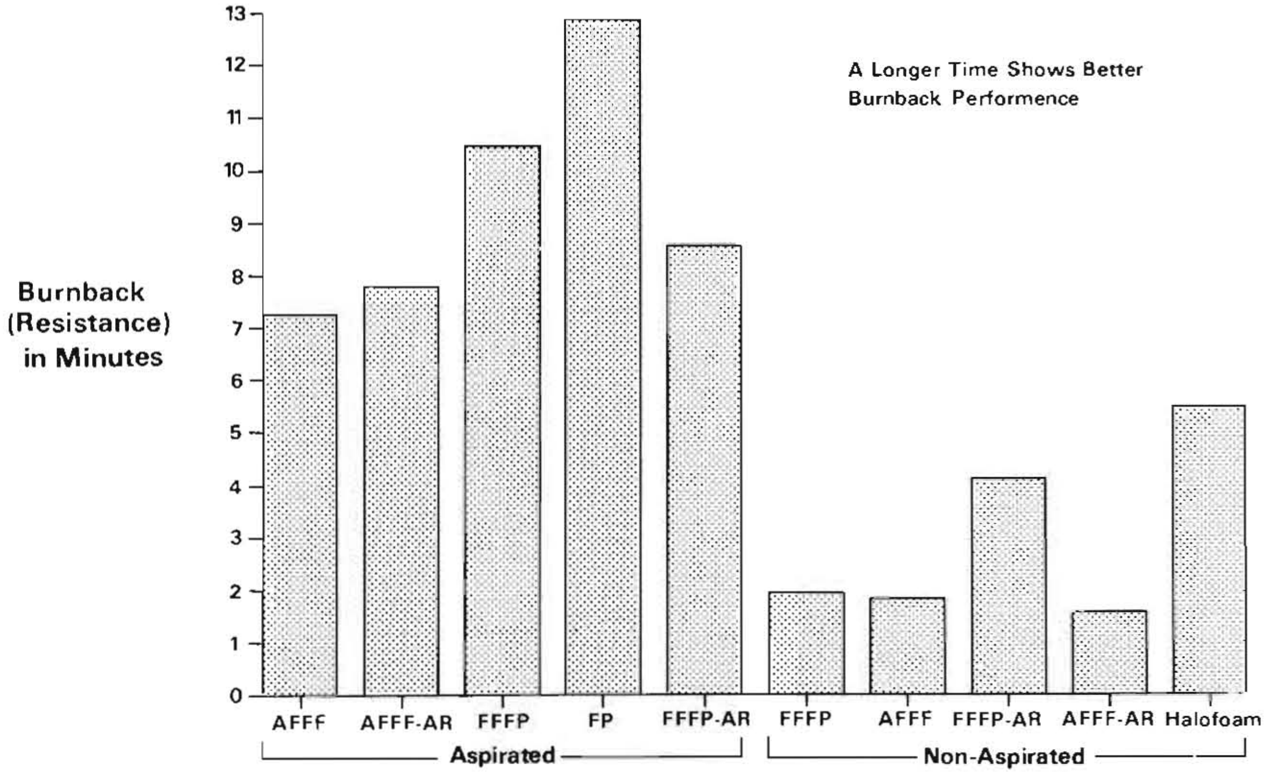


Fig MS2: Summary of Petrol Fires

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1. INTRODUCTION

The Fire Experimental Unit (FEU) of the Scientific Research and Development Branch (SRDB) of the Home Office was requested to undertake a project to recommend a suitable additive or selection of additives for use in hosereel systems. This is Fire Research Project F4.7 (85) and the problem description is given at Appendix A. The project proposal (Appendix B) gives work packages to define the proposed areas of work.

The objectives of the project relate specifically to appliance hosereel systems and are as follows:

1. To find which additives improve control and extinction of Class A fires.

2. To find the most suitable additives for control and extinction of Class B fires and to evaluate burnback resistance.

3. To evaluate additive performance against non-standard fuels, for example: tyres and polyurethane foam furniture.

4. To investigate the tactical variations possible when applying additives through hosereel systems, for example : aspirated/non-aspirated, high/low pressure, spray/jet, number of branches.

5. To study the corrosive effects on the hydraulic systems of fire appliances.

Background studies confirmed that knowledge was not available to answer these questions and therefore further work was necessary.

This report describes work on large scale Class B fires (Work package 6 - see Appendix C). The objective of this work was to select the most suitable additives for control and extinction of these fires and to evaluate burn-back resistance.

Many water additives for fire-fighting are available. A number fall within the definition "fire-fighting" foam, but there are also wetting agents and novel additives. The additives considered were those in use or under evaluation by brigades, and any other novel types. The additives selected were fluoroprotein (FP), aqueous film-forming foam (AFFF), alcohol resistant AFFF (AFFF-AR) , film-forming fluoroprotein foam (FFFP), alcohol resistant FFFP (FFFP-AR), a self-foaming additive "Halofoam", and "Fireout".[1] (Superscipts refer to notes on page 33).

It was necessary to carry out small scale tests to select additives for the large-scale fires.

In small and large scale tests, additives in solution to the manufacturers recommended concentration were applied through a hosereel at a rate of 2.5 litres per minute per square metre (Section 4.3). With the exception of "Halofoam" (non-aspirated only) and FP (aspirated only) the additives were used aspirated and non-aspirated.

The tray for the large scale test was of area 40 m^2 and the fuel for the fires was 1000 litres of 4 star petrol (motor spirit). Each fire had a one minute pre-burn before the additive solution was applied. After extinction, a burnback test was performed on the foam blanket (Section 4 discusses trials design criteria).

The data recorded included times to 90% and 100% extinction and time to 100% burnback.

A Glossary of terms used in this report is given in Appendix D.

2. PREVIOUS WORK.

2.1. SRDB Trials of Foams on 84 m^2 Petrol Fires

Two series of foam tests were carried out by the Home Office Scientific Research and Development Branch at the Fire Service College in 1974 and 1980 on pool fires of area 84 square metres using two star petrol (motor spirit) as fuel for the tests. Commercial branchpipes and foam generators were used and the total liquid flow of extinguishing agent was controlled at 227 litres per minute. This gave an application rate of 2.73 litres/m^2/min. The solution strength used was that recommended by the manufacturer of each foam concentrate.

After a one minute preburn the times for 90 per cent and 100 per cent extinction were observed, and burn-back tests were conducted. The test fires were recorded on cine film (1974) or video tape (1980).

In November 1974 (Reference 1) the foams used were protein and fluoroprotein at low expansion, fluorochemical (aqueous film-forming foam AFFF) as both low expansion foam and non-aspirated (spray), and synthetic foam used with an expansion ratio of 20-30 and at high-expansion.

Under the trials conditions, protein foam failed to extinguish the fire before the fuel was exhausted. Fluoroprotein, fluorochemical and synthetic foam all gave convincing control and extinction. Of these materials, fluoroprotein foam had much superior burn-back performance. Synthetic foam used at high-expansion (700) gave very good control and extinction times.

In 1980 (Reference 2) the foams used were fluoroprotein at low expansion (12), and synthetic foam at expansions of 65, 140, 400 and 500. In these tests, all foams gave convincing control and extinction. High-expansion (400 and 500) synthetic foam gave the quickest control and extinction, but also the quickest burnback.

Under the conditions of the tests, the higher expansion foams used (140, 400 and 500) gave progressive extinction and depended less on the skill of the branchmen in application than did lower expansion foams.

Table 1 gives a summary of the results from both series of tests. The results show similar extinction times for AFFF (fluorochemical) when used aspirated (foam) or non-aspirated (spray). The burnback developed more slowly with the foam.

2.2. Work Carried out at the Fire Research Station

The Fire Research Station (FRS) of the Department of the Enviroment has been active in research on foams and related equipment for many years and has published widely on the subject.

Work has been carried out on foam branchpipe design (Reference 3) and branchpipes have been developed at a range of flowrates. A 5 litre per minute standard foam branchpipe was developed for use in standard laboratory tests for the determination of foam properties (Reference 4). The design was extended to a 200 litre per minute branchpipe (the smallest size in general use by the fire service) and to assist the development of this a 50 litre per minute branchpipe was produced. 50 litres per minute was chosen as a useful size for experimental fires and it was also noted (Reference 5) that this size may have applications for use with a 19mm diameter hosereel to make foam from the appliance hosereel system.

FRS have developed performance specifications and quality control procedures for fire-fighting foams and branchpipes (Reference 6). Equipment for foam quality testing has also been designed e.g. Fire Research Station foam viscometer (Reference 7).

Problems with the use of fire-fighting foams have been identified and studied (Reference 8). Among the problems discussed in Reference 8 are foam spreading characteristics, mechanical difficulty of foam distribution, surface cooling and surface turbulence effects. The effect of the velocity of foam jets on the control and extinction of laboratory fires is considered in Reference 9.

Recent publications relevant to this report are References 10 and 11. Reference 10 discusses the effect of application turbulence of AFFF's on petrol fires and Reference 11 discusses the suggestion that certain AFFF's are capable of enhancing the ignition properties of liquid hydrocarbons when applied as a spray.

2.3. SRDB Study of Foams on Hydrocarbon Fires in the European Community

At the request of the CFBAC Joint Committee on Fire Research, the Home Office Fire Experimental Unit undertook a survey of foam trials held on large-scale hydrocarbon liquid fuel fires (Reference 12). The study was initiated by the European Community Working Group on Fire, and was intended to cover work undertaken in member countries.

The survey included large-scale tests of foam on hydrocarbon liquid fuel fires conducted by five member countries of the European Community Working Group on Fire. The aims and methods of the various trials are compared and discussed. General trends were apparent in the results, but variations in the test conditions adopted made numerical comparisons between trials impossible. In some of the trials reported, the information given on test conditions was incomplete.

Table 2 gives a brief resume of European foam trials.

The general trend was that AFFF was the most effective foam for a rapid extinction time. Fluoroprotein was also very effective and, in the Italian trials, performed better than AFFF. A general result overall was that the film formed by AFFF inhibited reignition but broke down rapidly once a fire was established, thus giving a poor result for burnback. The foam with the most effective sealing properties was fluoroprotein, which prevented re-ignition and inhibited fire-spread once the fuel had been ignited.

2.4. Brigade Trials of Additives

Many UK brigades have carried out reviews and comparison trials of additives. Results of these evaluations have usually been for internal use in the brigade and have not been formally published. Reference 13 gives details of comparison trials with AFFF carried out by Cambridgeshire Fire and Rescue Service.

3. SELECTION OF ADDITIVES

Additives are classified into various types e.g. FP, AFFF etc. and each type is available from several manufacturers. The objective of the work in this report is to compare types of additives and it is not intended to recommend one supplier against another.

To assist in the selection of additives for large-scale testing, small-scale extinction and burnback tests were carried out. Tests, using heptane as fuel, were performed by the Fire Insurers Research and Testing Organisation (FIRTO)[2] under a contract from SRDB. Small-scale tests were also carried out by FEU on the Fire Service College fireground using petrol and heptane as the fuels.

Alcohol resistant additives (AR) were included, because of current interest in some brigades to use a 'universal' concentrate. AR concentrates are recomended by the manufacturers to be used at 3% on hydrocarbon fires and 6% on water miscible fuels.

With the exception of AFFF (two suppliers), only one make of each type of additive was purchased.

Generally, throughout the report reference is made to the foam type only, however, when necessary the product is identified in the results tables. Table 3 gives details of the additives and indicates the tests in which they were used.

3.1 Small Scale Tests using Heptane carried out by FIRTO

Appendix E reproduces the FIRTO report. The Class A fire results will be discussed in later publications. The heptane tests were carried out inside the FRS Hangar at RAF Cardington, Bedfordshire.

3.1.1 Equipment

The premixed solution of additive was applied to the test fire by means of a gear pump feeding a 36.6m length of 19mm bore hose. The hydraulic arrangement is shown in Figure 1. The hose was fitted with either an aspirating or a non-aspirating nozzle. The nozzles selected, operated at the flowrates required for the small-scale tests (see below). The aspirating nozzle was taken from a Thorn-EMI Protech AFFF 9 litre foam extinguisher. The non-aspirating 'spray' nozzle was a garden hose nozzle (Figure 2). For the tests two settings were selected, one setting (designated Jetspray) gave a hollow-cone spray pattern with a small droplet size. The other designated Jet gave a coarser broken jet. An on/off control valve was fitted to the nozzle end of the hose.

The solution flowrate for the tests was standardised at 2.5 litres per minute per square metre (Section 4.3). This required flowrates of 2.8 litres per minute for a 34B tray (to BS 5423 Reference 14), 11.3 litres per minute for a

144B tray and 14.4 litres per minute for a 183B tray. The flowrate was adjusted using a gear pump[3], monitored by an electromagnetic flowmeter[4], and recorded throughout the tests using a UV recorder[5].

A propane gas/air blowtorch was used for the burnback test (Section 4.8).

3.1.2 Additives tested

The following additives were used:

Water
FFFP-AR (3%)
Fluoroprotein FP (3%)
"Fire-out" (0.2%)
AFFF (3%)
"Halofoam" (15%)

Figures in parenthesis indicate manufacturers recommended solution strength in water.

3.1.3 Extinction tests

3.1.3 (i) Screening tests

Screening tests were carried out on "Fire-out" and "Halofoam" on test fires conducted generally in accordance with Clause 27 of BS 5423:1980 (Reference 14). These tests were to assess the suitability of these additives for further testing on larger fires. Water was also used for comparison.

3.1.3 (ii) Test fires.

The test fires were conducted generally in accordance with clause 27 of BS 5423:1980 (Reference 14) with the exception that following complete extinguishment, a burnback test was conducted. In general, extinguishing agent was applied to the fire continuously until 90% extinction was acheived and then on at a reduced rate (spotting) for achieving final extinction. This latter phase was either continuous or intermittent at the discretion of the fire-fighter.

The burnback test involved applying a flame to the surface of the foam blanket, using the apparatus described in Section 4.8 and timing the period to until the whole surface was alight.

3.1.3 (iii) Instrumentation

In addition to the instrumentation required to carry out the tests in accordance with the British Standard test method, the radiation from the test fire was also monitored using two heat flux transducers and a chart recorder.

3.1.3 (iv) Results.

The detailed results are given in Appendix E. Table 2 of which gives the summary of the Class B fires. Class A tests are included in Appendix E and these are not discussed in this report.

The screening tests on the 34B fires eliminated "Fireout", which failed to extinguish the fire. Water also failed under the same conditions.

The first test with fluoroprotein (Test 4B) on 144B fires failed to extinguish the fire. Although 90% control was obtained the application technique was considered to be too forceful. The test was repeated with a revised technique and after 90% extinction, using reduced flow during the spotting phase. This permitted extinguishment although it took a long time.

AFFF and FFFP-AR gave good extinctions on 144B trays when aspirated. Both failed to extinguish in spray setting and only AFFF succeeded with the alternative jet nozzle setting.

The one test in which extinction was obtained with non-aspirated AFFF gave an extinction time over three times longer than was achieved with aspirated application. The burnback was quicker with non-aspirated application.

"Halofoam" gave good extinction times and the longest time to 100% burnback.

Only two tests were carried out on the 183B tray size. AFFF gave quicker extinction than "Halofoam", but the burnback took longer to reach 100% with "Halofoam" than with AFFF.

3.2 Small Scale Tests with Petrol and Heptane carried out by FEU

Further small-scale tests were carried out by FEU on the FSC fireground. The first series was performed in January 1986, before the FIRTO tests, and the primary objectives of these tests were to finalise the design of the $40m^2$ tray and to develop a new burnback test (Section 4.1) An opportunity was taken to test AFFF and FP on 183B petrol fires. The second series followed the FIRTO work and tested two further additives FFFP and AFFF-AR on 183B heptane fires.

3.2.1 Equipment and test procedure.

A 183B tray (to BS5423 Reference 14) was fabricated from mild steel, the base being from 6mm plate and the sides being of 8mm plate.

The tray was positioned on the concrete surround of the oil tank installation on the Fire Service College (FSC) fireground.

Before each test the tray was thoroughly cleaned out. An earthing spike was attached to the tray and the tray was scrubbed with yard brooms and clean water. The waste from this operation was removed by the FSC "sludge gulper'. When a water base was used, potable water was fed into the tray to provide a flat base for the fuel. The minimum depth of water was used, but it was important that this surface remained intact throughout the test and the water depth had to account for warping of the hot tray.

For tests using petrol (4 star), 183 litres of fuel was metered out of the FSC petrol pump into a 200 litre earthed steel drum for transport to the tray. The fuel was poured into the earthed tray through a petrol nozzle screwed into the drum. After the transfer of fuel, the drum was sealed, earthing cables disconnected and the drum removed from the test area.

In the tests using heptane[6] , the fuel was supplied in 200 litre drums, but the safety procedures described above were still observed while fuel was transferred to the tray.

For all the tests, during the transfer of fuel, a premix solution of the additive under test was made up, using potable water. The solution was thoroughly mixed and its temperature recorded. Initially 60 litres of solution was available, although in some tests more solution was required.

The hydraulic arrangement for the tests is shown in Figure 1 and details of the nozzles, flowmeter and gear pump are as described in Section 3.1.1 above.

Prior to each test the wind speed and direction were measured with a vane anemometer[7].

The tests were recorded on colour video equipment and two large synchronised digital clocks[8] were used to coordinate events.

The fuel was ignited with three small charges[9], positioned upwind at the edge of the tray and detonated simultaneously by an electrical firing box.

A one minute pre-burn was allowed before the fire-fighting commenced. During the final 30 seconds of the preburn the gear pump was run up and the fire-fighter ensured than the branch was operating correctly.

At one minute after ignition, foam was applied to the fire. The fire-fighter attempted to apply the foam gently to the fuel surface, running it off the back of the tray when he could see it. Initially foam was applied from one position upwind of the tray (Figure 3). As the fire began to be extinguished, the fire-fighter moved around the tray, directing the foam solution at the remaining pockets of flame. Application of solution was continued for a further 30s after 100% extinction of the fire.

During the test, two observers noted the progress of fire-fighting and the times to 90% and 100% extinction of the fire.

The burnback rig, described in Section 4.8, is shown in Figures 4 and 5. The flame was applied to the surface of the foam blanket one and a half minutes after extinction. The flame was left to play on the surface until the fire was "well developed" and then the torch was removed.

The observers noted the development of the burnback fire.

After the burnback the fire was allowed to burn out and the contaminated water base was removed by the 'sludge gulper'.

3.2.2 Results

The detailed results are given in Appendix F.

The results are summarised in Table 4. (Numbers in brackets after the Test numbers in Table 4 refer to the numbering system used during the tests).

The much longer extinction times obtained with fluoroprotein, compared with AFFF foams, may have been due primarily to the aspirating nozzle design and the resultant foam quality. The nozzle used for the tests was designed for use on a AFFF extinguisher and therefore may not give optimum properties for fluoroprotein. (This theory was later confirmed by the large scale tests see Section 8.3.3).

The expansion ratio and drainage time of the foam produced by the nozzle was measured before the trials. The values obtained were considered to be comparable with results from a commercial branchpipe. However other factors such as shear stress and impact velocity were not taken into account.

AFFF spray (Test 5) had a longer extinction time than AFFF foam (Test 4). The burnback with spray application was much faster than with foam application.

FFFP and AFFF-AR showed good performance as foam. FFFP, used as spray, extinguished the fire but took longer. AFFF-AR did not extinguish the fire when used as a spray.

3.3 Conclusion from Small-Scale Tests

The number of small-scale tests carried out were limited but they allowed techniques to be developed and gave indications of additive performance.

From the original list of additives given at the begining of this section, only "Fireout" was rejected for further testing on Class B fires. "Fireout" failed to extinguish a 34B heptane fire.

AFFF, AFFF-AR, FFFP, FFFP-AR, FP and "Halofoam" had all extinguished 183B or 144B heptane fires when used aspirated. When used non-aspirated, only AFFF applied as a jet extinguished a heptane fire, but this took a long time. FFFP, FFFP-AR and AFFF-AR were not successful on heptane.

"Halofoam" gave a quick extinction on 183B heptane.

Tests using petrol gave long extinction times with FP and this was thought to be due to the use of a nozzle designed for use with AFFF. They also indicated the superior peformance of AFFF when used aspirated when compared with its non-aspirated (spray) use.

3.4 Trials Plan for Large Scale Tests

Following the small scale tests the following trials plan was finalised.

Additive	No of tests (aspirated)	No of tests (non-aspirated)
FP	3	0
AFFF	3	3
AFFF-AR	3	1
FFFP	3	1
FFFP-AR	3	1
Halofoam	0	3

Three tests were considered the minimum number of tests to assess repeatability. More tests are desirable but the size and cost of the tests must impose limits. Although poor performance had been achieved in the small -scale tests with non-aspirated application, it was decided to include a series of three tests of AFFF, the most successful, and single tests of AFFF-AR, FFFP, and FFFP-AR to confirm small-scale tests.

4. FACTORS AFFECTING TRIALS DESIGN CRITERIA

4.1 Tray Design

Before finalising the design of the $40m^2$ fire test tray a number of small-scale tests were performed on two different trays to evaluate the effect of sloping as opposed to straight sides.

In fire tests, the tail end of the extinction process is notoriously variable. As well as total (100%) extinction time, therefore, it is usual to estimate a 'control' time, this usually being taken with liquid pool fires as the time to extinguish 90% of the pool area.

Experience on the $84m^2$ FSC tray (References 1 and 2), with sprays and low-expansion branches, was that the vertical sides made it difficult for the branchman to extinguish the last flames at the tray edge, performance depending greatly on the branchmans skill and chance in the tactical situations. A tray with sloping sides was considered in an attempt to minimize the edge effects and give more reproducible 100% extinction times.

4.1.1 Small-Scale Tests

A 'standard' 183B (to BS5423) vertical sided tray and a 150^o tray which was designed to give the same surface area ($5.75m^2$) with 183 litres of fuel with approximate depth 30mm, were obtained. The trays were fabricated from mild steel, the base being 6mm plate and the sides being of 8mm plate.

Tests were carried out in January 1986 on the FSC fireground, using procedures previously described (Section 3.2). These tests were primarily to establish tray shape, but opportunity was taken to test application rates and methods for the FIRTO trials.

4.1.2 Results

The results are given in Table 5. Details of the tests are given in Appendix F.

The results from this series of tests did not show one design giving more reproducible results than the other. Edge effects were a problem in the final stages of extinction with both tray designs.

4.1.3 Discussion

An objective determination of the 'best' tray design is difficult without a long series of repeated tests. There are, however, factors other than purely reproducibility which affect the choice of design. These factors include safety and comparison with other designs in current usage.

Ultimately the straight sided tray was preferred for a number of reasons, not least because all the trays used in standard tests have straight sides. Other factors included the problem of fuel being splashed out of the sloping sided tray by the force of the foam jet (Test 6) and the apparent gap between the edge of the foam blanket and the sloping sided tray (Tests 6 and 7).

4.1.4 Conclusion

The tests showed that no appreciable improvement in 100% extinction time reproducibility could be achieved by using a test tray with sloping sides.

There are certain disadvantages with the sloping tray such as displacement of burning fuel by the force of the foam jet and difficulties in edge sealing of the blanket.

These factors and the cost and problems of fabricating a large tray to a sloping sided design led to a straight sided tray being chosen for the large tests.

4.2. Fuel

A wide range of Class B fuels may be encountered by the Fire Service in operational use. For the $40m^2$ tests, a fuel was required to give an indication of performance under typical severe usage conditions.

4 star petrol was chosen, because it is a volatile hydrocarbon commonly encountered, and which is a severe test of an extinguishing agent. Petrol had also been used in earlier SRDB tests.

For comparative fire tests, consistency of the fuel is essential. Petrol may vary over a period and it was desirable to have all the fuel for the proposed 30 tests delivered from one batch to avoid any variations in the fuel. This was not possible because of the problems of storage on the FSC site, and therefore two deliveries were made by the petrol supplier. One delivery of fuel was made before the tests, and then a second delivery was made after Test 14.

The fuel from both deliveries was analysed and were found to be similar.

1000 litres of fuel was used for Tests 2-30. This gave a fuel depth of 25mm. Test 1 used only 500 litres.

At an estimated free burning rate of 4mm per minute (Reference 1), 1000 litres of petrol gave an estimated burning time of 6 minutes 15 seconds.

4.3. Application Rate

Successful use of foam is dependent on the rate of application. Application rates are generally defined in terms of the amount of foam solution in litres per minute reaching a $1m^2$ area of the fuel surface.

The characteristic curve of application rate versus extinction time is well known (Reference 15). There is a critical application rate below which the fire cannot be extinguished, and above this there is a recommended rate which will vary depending on the foam type, fuel and type of application. An application rate of 2.5 lpm per square metre was chosen for the following reasons:-

1. This was above the critical application rate for all the additives to be tested. Although below the ISO recommended rate of 4 lpm per square metre, it was hoped that this would differentiate between additives.

2. It compared with previous tests on the $84m^2$ tray (Section 2.1), which used a rate of 2.73 litres per minute per square metre.

3. The Manual of Firemanship (Ref. 9) indicates that 2.5 lpm per square metre is the most economical rate for a flourochemical foam.

4. A solution flowrate of 100 lpm was required to achieve 2.5 lpm per square metre on the $40m^2$ tray and this is generally compatible with hose-reel equipment in use in the fire service as identified by SRDB research project F4.6.(84) (High pressure/low pressure spray trials).

4.4. Branch

A wide range of hosereel branches are available. For the purpose of these trials the requirement was for a branch which operated with a flowrate of 100 lpm (Section 4.3) and to which an aspirator could be fitted.

Only two hosereel branches were identified to which an aspirator could be attached, these were an Angus Superfog[10] modified by Cambridgeshire Fire and Rescue Service and Rossenbauer Ni-Pi-Ro[11].

The Rossenbauer branch is designed to operate at 200 litres per minute and with this branch careful operation of the trigger control is necessary to maintain the spray setting required[19]. These factors together with the common usage of the Angus Superfog branch in UK brigades resulted in the selection of the Angus branch.

The branch with the aspirator is shown in Figures 6 and 7.

For reasons discussed later a Galena Hyperfog hosereel branch[12] and two FRS 50 litre per minute branches (Reference 5) were also used.

Prior to the tests, foam quality was checked with the branch/aspirator and the additives to be used.

4.5. Preburn

A preburn time of 1 minute was allowed from ignition to the start of foam application. This preburn time was considered sufficient to allow the fire column to obtain equilibrium and for the burning rate to steady, while allowing reasonable economy in fuel costs. (Reference 1).

Longer preburn times would cause more heating of surrounding metalwork, which might affect the different edge sealing qualities of foam blankets. However, with the fuel depth used in these tests, less volatiles may remain after longer preburn times and consequently a less severe fire may result.

4.6. Production of Foam Solution

Generally, all the additives were used at the manufacturers recommended concentration for hydrocarbon fires. "Halofoam" was used at 15% and all other additives used at 3%. FP recomended for use at 3% was also used at 4% and 6%.

In planning the trials it was decided that the branchman may desire to adjust the branch jet/spray setting or shut off the branch. Any changes in flowrate would require rapid adjustment of any induction system used to maintain the desired concentration.

A variety of hosereel induction systems were commercially available and many are in use with brigades. Evaluations of some of these systems have been carried out by FEU. No system was available which would maintain the solution concentration at varying flowrates with the branch selected, and therefore a premix solution was used to ensure precise proportioning for each test.

4.7. Tactics of foam and spray application

The branchman, an experienced Fire Officer, was asked to apply aspirated foam as gently as possible to the tray surface without using the tray sides. This was to avoid churning the surface and minimise contamination of foam by the fuel. In order to compare the various additives throughout the test series, it was essential to maintain the same application rate thoughout the extinction of the fire. Any adjustment of the branch setting would change the flow rate and thus the application rate. It was hoped however that the branchman would not wish to adjust the branch setting until 90% extinction had been achieved, but a reduced flow may have aided final extinction of flame remaining around the tray edge. The instructions to the branchman was that he should not adjust the branch or switch the branch on and off unless his experience or the progress of the extinction suggested otherwise.

In the majority of the tests a backplate was not available for the branchman to deflect the foam gently on to the tray surface. A backplate is not always available in operational use of foam, and application direct to the surface represents a more severe test of the additive.

In Tests 25 and 26 a backplate was mounted on the side of the trays. The branchman directed the foam stream at the backplate. This allowed the foam to run gently onto the fuel surface, build up a blanket which flowed over the burning surface and ensure the minimum of disturbance.

For non-aspirated applications there were more variations possible. The additive solution could be applied in jet or spray mode, and in each mode by applying with the branch stationary or by sweeping the spray across the fuel surface. Discussions with fire service personnel, before and during the test suggested that " sweeping" the spray over the surface of the fuel was the preferred technique for applying additives non-aspirated. These variations would be explored in the tests.

4.8. Burnback Test

The burnback test was required to assess the resistance of the foam blanket to flame. A convincing burnback is also important because this confirms that the fire has been extinguished by the application of foam and not because the fuel has all been burnt.

In earlier trials by the Fire Experimental Unit (Section 2.1), after extinction, foam application was continued for a further 30 seconds. This was intended to provide a standard condition for the burnback test which could be regarded as representing practical circumstances of use in fire fighting operations.

In those trials, a metal frame $1m^2$ with sides about 25cm in height was then placed in the large fire tray in the centre of the upwind side. Foam within this frame was scraped out with a plywood paddle, about 10 litres of petrol was added and ignited by a torch. When the fire in the frame was well developed, the frame was pulled out of the tray by attached wires. The time elapsing from this point until the entire fire tray was covered by flame was taken as the burnback time.

This method was found unsatisfactory because it was difficult to repeat consistently. In some instances it was difficult to remove the foam (particularly film-forming types) from the frame and re-ignite the fuel, in others the fire took some time to develop, both these problems resulting in a variable time between the end of the foam application and the start of the burnback timing. The removal of the frame also caused problems, in some tests actually extinguishing the fire.

A burnback test is used in the UK Defence Specification 42/22 (Reference 11). In this test a pot of burning fuel is lowered into the test tray and the time taken to re-involve the whole tray is noted as the burnback time. This is a laboratory test and with the $40m^2$ tests being outdoors, the effect of the wind may prove to render it unreproducible. In still air, the fire plume from the pot will be vertical, whereas in outdoor conditions the position of the plume will vary with the wind and lead to variable transfer of heat to the foam surface.

In the small scale tests (Section 3.2) previous described, an alternative burnback test which used a gas torch as an ignition source was assessed. A diagram of the apparatus is shown in Figure 4 and a photograph in Figure 5. The torch was lit immediately after the fire was extinguished. The propane pressure was approximatley 0.5 bar and the air pressure approximatley 3.5 bar. Pressures were adjusted to give a hot (blue) flame approximately 450mm long.

The flame was applied to the surface of the foam blanket one minute after the cessation of foam application (i.e. 1 minute 30 seconds after a 100% extinction). The flame was applied to the foam blanket approximately 0.5 metres from the edge of the tray. The flame was left to play on the surface until the fire was "well developed" (about 1 m^2 of fire), when the torch was removed.

It was concluded that this method produced a reproducible heat source that could be applied to the foam blanket at a given time after the end of foam application. It was also considered more representative of the conditions encountered at an incident. This method did allow foam to flow back over the developing fire, unlike the use of a pot or frame. In any burnback test, a long delay between 90% and 100% extinction can result in a thicker foam blanket (Section 8.3.4), but as this problem cannot be eliminated, this burnback method was adopted for the $40m^2$ tests and is further discussed later.

5. DESCRIPTION OF TRIALS SITE AND EQUIPMENT USED

5.1. Tray Site

The tray site was situated on the fireground of the Fire Service College, Moreton-in-Marsh. Figure 8 shows a general view of the site.

The base, side walls and immediate surround were constructed of concrete to general construction specifications, and the base of tray was a high temperature concrete. The $40m^2$ area of the fire was defined by a steel ring, which located in the drain gully around the tray centre. This method allowed the steel ring to expand during the fire, and avoided any distortion pushing the centre of the tray upwards.

The drain gully was designed with a valve outlet which would drain the residue from the fire test to a settlement and treatment system incorporated in the FSC fireground.

The outer area of the site was covered with gravel.

5.2. Water Supply

Potable water was required for premixing the additives, providing a water base for the tray and cleaning the tray and premix tank. There was no potable water supply on the tray site and so a 1200 litre portable dam was positioned near the tray site but away from any danger from the fire.

This dam was filled when necessary with water from a static tank at the FEU using a portable pump and 3 1/2" hose line.

An Emergency Pump adjacent to the dam was used to distribute potable water around the trials site (Figure 9).

Fireground hydrant water was used for cooling the concrete tray surround.

5.3. Instrumentation

The flowrate of solution to the firefighting branch was monitored using an electromagnetic flowmeter[13] connected to a digital display[14] which indicated the flowrate in litres per minute. An analogue output from the flowmeter was connected to an Orion Data logger [15] and a UV recorder[5] to record flowrate throughout the tests.

A pipe, with a thermocouple[16] fitted into a tapping, was also connected into the hoseline, to record the temperature of the solution. The thermocouple could be connected to a digital indicator[17] or to the Orion data logger. The flowmeter, pipe with thermocouple, and indicators were mounted on a trolley, so that the pump operator could set and adjust the pump throttle while monitoring the flowrate (Figure 10).

The Orion data logger and UV recorder were installed in an instrument contol van, located on the upwind side of the fire.

For each test, the wind speed was measured by a portable anemometer sited on open ground near the fire tray. The anemometer head was one metre above ground. The approximate wind direction was also noted using a compass. In later tests a wind station was mounted on top of the instrument van and the wind speed recorded on the Orion data logger.

Each test was recorded using colour video equipment. The camera was mounted on the roof platform of a van and the associated video recorder operated from inside. The direction of view of the camera was approximately broad-side to the wind direction. A portable video camera was also used during the trials to provide additional material.

Figure 11 shows a typical layout of appliances and equipment for a test.

Two large synchronised digital clocks[8], displaying minutes and seconds, were sited near the fire tray, one being conveniently in the field of view of the video camera and one at least being visible to personnel engaged in the conduct of the trial.

The clocks were preset to 99: 00 (min : sec) and started when all preparations were complete. Ignition took place 1 minute after the clocks were started at zero indicated time. Thus the video records were accurately timed, and a means of co-ordination provided for all involved with the trials.

Observations of the progress and timing of each fire were made by three observers. They used the times from the large digital clocks but also had analogue or digital stopwatches available with split time facilities.

A digital totaliser was also connected to the flowmeter. This incremented when each litre of solution passed through the flowmeter and recorded the number of litres of solution used to extinguish the fire. The flowmeter calibration was checked before and during the trials by timing the passage of a known volume of water.

5.4 Production of Foam Solution.

The premix solution was made up in a glass-fibre tank positioned adjacent to the appliance. The tank was thoroughly cleaned with potable water before each test.

The appliance used was a Bedford Carmichael water tender fitted with a Godiva UMPX 75 pump[18]. In all tests except those involving FRS branchpipes, the high-pressure stage was used (Section 6.2.1).

5.5. Safety

A safety procedure was followed for each test. This included use of a second appliance manned by firemen with a water spray branch and foam equipment who stood by in case of a mishap during fuel transfers and thoughout the fire tests.

The fuel was ignited by an electrically fired cartridge by an operator at a safe distance to avoid the risk of approaching the tray with a naked flame.

The safety instructions are given in the Appendix G.

6. EXPERIMENTAL PROCEDURE

6.1. Tray Preparation

Before each test the tray was thoroughly cleaned out using yard brushes or wet vacuum cleaners, and potable water.

Potable water was fed into the clean tray to provide a flat base for the fuel. The minimum depth of water to cover all the concrete base of the tray was used.

During the fire it was necessary to protect the concrete on the downwind side of the tray. This was done using ground monitors and diffuser nozzles, which were supplied from the fireground hydrant supply. These were adjusted before each test to ensure that no spray entered the fire tray and the spray adequately covered the downwind concrete area.

Following damage to the walls of the tray in the early tests, sheet metal protection pieces were fabricated and placed over the walls on most of the circumference.

6.2. Transfer of Fuel to Tray Site

1000 litres of 4 star petrol was metered out of the FSC fireground petrol pump into an earthed trailer tanker. A safety crew with an appliance stood by during the fuel transfer (Figure 12).

The tanker was then towed to the tray site.

6.3. Fire Tests- General Procedure

Before transfer of fuel to the tray, all equipment was operated to check correct functioning. The correct branch, with or without the aspirator was connected to the hoseline and tested. The Superfog branch was set to jet setting when used with the aspirator and a marked spray setting when used non-aspirated.

The trailer tankerr was moved alongside the tray and the towing vehicle moved to a safe distance.

The wind directions and speeds were monitored. The direction was checked to ensure all vehicles and equipment were suitably deployed for the wind directions. The general guidelines for weather conditions used for the tests were that tests would not be commenced if there was any precipitation or with wind speeds above 4 m/s.

The premix solution was made up in a glass fibre tank. The amounts of water and additive were calculated and a calibrated dipstick used to check potable water and solution depths. Additive was measured into the tank using the manufacturers drums, (which had been check weighed), and measuring cylinders where part drums were involved.

The premix was thoroughly mixed, and the solution temperature measured with a digital thermometer. For the first test of each additive 1500 litres of premix was available. Where possible for economy, this quantity was reduced, for subsequent tests. Fresh solution was used for each test.

The hydraulic arrangement used is shown in Figure 13.

During preparation of the premix, fuel was transferred from the tanker to the tray. The metal tray rim and tanker were connected to an earth spike. A length of petrol hose was connected from the tanker outlet to the tray. The water base and fuel temperature were recorded with a mercury in glass thermometer. The tanker valve was then opened, allowing fuel to be gravity fed into the tray (Figure 14). The valve was closed when the fuel in the tanker had reached a calibrated level which indicated 1000 litres of fuel had been transferred. The tanker was then removed from the tray site.

The aim was to carry out the tasks between fuel transfer to the tray and ignition, as quickly as possible to minimise fuel loss by vapourisation.

To ignite the fuel, an electrically fired cartridge[9] was attached to a wad of towel material and positioned, using a strap of aluminium, a few centimetres above the petrol surface, on the upwind side of the tray. Once positioned on the tray a small quantity (approx. 0.5 litre) of petrol was poured over the towelling from a petrol can.

Finally, when everyone was clear, the earth straps were disconnected.

The clocks (preset to 99 min : 00 sec) were started and the cartridge detonated, using a safety firing box, after one minute at zero indicated time. The cooling sprays were turned on prior to ignition. A one minute preburn was allowed before the fire fighting commenced. During the final 30 seconds of the preburn, the pump was run up to the operating conditions (flowrate 100 lpm) and the branchman ensured that the branch was operating correctly. Figure 15 shows a general view of the fire during the preburn.

The pump operator monitored the flowrate throughout the test and adjusted when necessary. He also recorded the volume of solution used, using the totaliser connected to the flowmeter. In Tests 1-16 the pump operator noted the maximum temperature on the display connected to the in-line temperature sensor, but in Tests 16 - 30 the sensor was connected to the datalogger for recording.

At one minute after ignition, foam or spray was applied to the fire from the upwind side of the tray. The fire fighter attempted to apply the foam gently to the fuel surface. In early tests with non-aspirated applications, the spray was applied without moving the branch, but after Test 8 the spray was applied by sweeping the spray across the tray surface.

Figures 16 and 17 show aspirated and non-aspirated application to the fire.

During the extinctions 3 observers noted the progress of the fire fighting and the times to 90% and 100% extinction.

Application was continued for a further 30 seconds after 100% extinction of the fire.

After foam application to the tray had ceased, the branchman directed foam to an NFPA foam collecting stand (Reference 16) on the edge of the tray site (Figure 18). The samples were taken to a instrument trailer for tests.

Measurements were made on the trials ground of foam quality in respect of expansion ratio, drainage time and in later tests shear stress[20]. These served as a general check on the quality of the foam concentrates and on the correct functioning of the foam branchpipes. Both aspirated and non-aspirated foams were tested. Details of the test procedures used are given in Reference 16.

Air and foam temperature were recorded using digital thermometers.

As soon as the fire was extinguished the burnback flame was lit. One minute 30 seconds after 100% extinction the burnback flame was applied to the surface of the foam blanket, at a position approximately 0.5 metre from the edge of the tray (Figure 19).

The flame was left to play onto the surface until a fire of approximately $1m^2$ was established, and at this time the burnback rig was withdrawn. The observers recorded the progress of the burnback.

6.4. Variations Used

6.4.1 Use of Branch other than Angus Superfog

Most tests were carried out with the Angus Superfog branch, with or without the aspirator. For reasons discussed later a Galena Hyperfog gun was used in Tests 17, and 23, and two FRS 50 lpm laboratory branchpipes used in Tests 28,29 and 30. The two FRS branchpipes were mounted on a plate for ease of handling by the branchman (Figure 20). The FRS branchpipes required the use of two flowmeters and two lengths of hose reel tubing as shown in the hydraulic arrangement of Figure 21.

6.4.2 Use of a Backplate

Tests 26 and 27 used a backplate on the tray. The backplates used are shown in Figure 22 and 23.

6.5 Measurement of branch operating pressure.

The branch operating pressure was measured by introducing a pressure pipe with gauge in between the branch and hosereel in the hydraulic diagrams of Figures 13 and 21. The branches were operated at the settings and flowrates used in the tests and the pump and branch pressures recorded. Pressures were not measured during the fire tests, but in separate tests on the trials site.

7. RESULTS

The results of the tests are tabulated as follows.

Table 6	Extinction and burnback times for each additive type. Wind speed, air and fuel temperatures also given.
Table 7	Summarises the results and gives average values where appropriate

Appendix H gives details of extinction and burnback tests and was compiled from observers notes and video records. Appendix H Table H1 gives all results in chronological order.

Graphs of the results are also given as follows.

- Figure 24 — Shows 90% and 100% extinction times for individual tests and average values.
- Figure 25 — Shows burnback times for individual tests and average values.
- Figure 26 — Shows the progression of the extinction with time. This is an indication of the process of extinction which has been produced from the results available. (Use of instrumentation eg radiometers would have produced improved results).

The extinction times are measured from the first application of foam to the tray until 90% or 100% extinction. The branch was only switched off for significant times in Tests 14 and 19. During the periods when the branch is off, the foam blanket can spread over the surface and the extinction continue, therefore in the results the time passed has been recorded.

There are only a limited number of tests for each condition, with only one for some conditions and these are not sufficient for statistical analysis. The average value should be assessed together with the spread of results. For FP the single result for 4% concentration using FRS branchpipes is used in the summary.

Results of Test 1 are not included because this test used only 500 litres of fuel and was used to develop trials procedures.

7.1 Extinction Tests

7.1.1 AFFF Aspirated Tests 3, 5 and 9.

Tests 3 and 5 gave closely similar results. 90% extinction times of 1min:08s(Test 3) and 1min: 06(Test 5) were recorded. 100% extinction times were 1min: 45s (Test 3) and 1 min 24s (Test 5). From the first appearance of a foam blanket, extinction continued progressively.

Test 9 gave similar results but with longer times i.e. 90% 1min : 24s and 100% 1min: 24s. The longer times resulted from some of the foam stream falling short of the tray for the first 40 seconds of foam application.

7.1.2 AFFF Non-aspirated (Spray). Tests 6,7,8,17,and 27.

In Tests 6 and 7 the spray was applied by the branchman holding the branch stationary for most of the test. This resulted in longer extinction times compared with aspirated AFFF. The 90% times were 2min: 42s (Test 6) and 4min :35s (Test 7) and 100% times were 4 min : 35 s and 5 min : 30 s repectively.

Test 8 used the technique of sweeping the spray over the tray surface and gave very different results from Tests 6 and 7. After only 12 seconds of foam 70% extinction was obtained (Figure 27). For one minute, an area free of flames was visible in the tray centre but then the fire was re-established (Figure

28). Fire fighting continued without success until, at 3 minutes, the branchman once again achieved a flame free area in the centre of the tray. However, at this stage the fire did not re-establish itself and extinction continued through 90% extinction at 3 min :25s to 100% extinction at 4 min: 22s. This type of extinction is referred to as non-progressive extinction in this report and is shown in Figure 26. The graphs for Tests 3,5,9,6 and 7 all show progressive extinction i.e. from the first appearance of the foam blanket, the area of foam blanket increases until extinction. In Test 8 this does not occur and the fire grew after significant extinction had been achieved.

The test plan included only three tests with AFFF non-aspirated, however following the poor performance non-aspirated, two extra tests were carried out.

Two characteristics of the spray, the droplet size and velocity, may have affected performance. These parameters have been measured for hosereel branches in SRDB project F4.6.(84). A second hosereel gun was selected which showed lower velocity droplets; this was the Galena Hyperfog. The velocity range from the Superfog was 18 to 24 metres per second and from the Hyperfog 5 to 8 metres per second.

Test 17 used a Galena Hyperfog branch, and the application technique was to sweep the spray over the tray area. This test showed similar results to Test 8, in that a significant extinction was achieved in the centre of the tray after about 10 seconds, but the fire grew again. The 90% and 100% times were faster than other non-aspirated times, these were 2min :08sec and 3min :39sec. It should be noted that the fuel temperature for this test was lower than for the other tests discussed.

Test 27 used the Angus Superfog branch but the AFFF used was Tridol-S. Reference 11 indicated that the performance of AFFF concentrates from different manufacturers may vary, and Tridol-S was tested as an alternative to Light water. The results were similar to previous tests, that is significant extinction occurred soon after the start of spray application, then this was not sustained and the extinction time was 4min: 53 seconds.

7.1.3 AFFF-AR. Aspirated Tests 15, 16 and 18

Extinction was progressive in all three tests. Tests 15 and 18 gave similar results with 100% times of 2 min: 31 s and 2 mins : 21 s. Test 16 gave a much shorter extinction time of 1 min : 21 s.

7.1.4 AFFF-AR. Non-aspirated. Test 19.

The branchman swept the spray across the tray area and a long non-progressive extinction resulted. The extinction times were 4 min:26s(90%) and 5 min: 27 s (100%).

7.1.5 FFFP aspirated. Tests 4 ,10 and 11.

All three tests showed very similar performance. Extinction was progressive and average 90% time was 1min: 16s and 100% time of 2 min:09s.

7.1.6 FFFP non-aspirated. Test 12.

The additive was applied by sweeping over the tray surface, and as with non-aspirated AFFF applied in this way, a quick knockdown was obtained but the fire then grew to 100%. The extinction times were 3 min:54s (90%) and 4 min : 26s (100%).

7.1.7. FFFP-AR aspirated. Tests 13,14 and 20.

FFFP-AR when applied aspirated, gave less progressive extinction than AFFF or FFFP. When the foam stream hit the flames there was a significant increase in the fire. 100% extinction times (average 3 min :46s) were approximately 50% longer than for AFFF or FFFP.

The FFFP-AR concentrate was very viscous and difficult to mix with water in the premix.

Two tests (Tests 25 and 26) were carried out where FFFP-AR was applied against a backplate. In Test 25 the backplate was positioned on the down wind side of the tray. The branchman could not see the backplate and therefore had difficulty in hitting it. Because of these difficulties the backplate structure collapsed and the results are discounted.

Test 26 used a sheet of steel approx. 1m x 0.8 m which was positioned at a broadside position to the tray. The branchman was able to see the backplate and a fast progressive extinction was obtained. Although only one test was carried out, this demonstrated the advantages of using backplates or other objects to assist gentle application of foam to the surface.

Test 30 used FFFP-AR applied through the FRS branchpipe. This was to assess the effect of branchpipe design. The result was a marked improvement on the earlier results.

7.1.8 FFFP-AR non-aspirated, Test 21

This was applied by sweeping over the tray surface and gave a quick knockdown but the fire then increased to nearly 100%. Extinction times were 3 min: 19s (90%) and 4min : 54s (100%).

7.1.9 "Halofoam". Tests 22 and 23.

"Halofoam" was applied non-aspirated using the Superfog branch (Test 22) and Hyperfog (Test 23). In both Tests extinction took over 5 minutes.

One suggestion from the manufacturers for the poor results was that the passage of the solution through the high pressure pump had resulted in the active halogens being released. Laboratory tests were carried out using a premix, and taking samples of solution from the premix, from the high-pressure output of the pump, and collected from the Superfog gun operating at 100 litres per minute. 100ml of solution was poured into a warmed 3 litre beaker and heated by a gas flame (Figure 29). The expansion of the solution was noted. All solutions showed expansions of at least 15: 1 which indicated the halogens were still active after passing through the pump.

No previous tests are known where "Halofoam" has been used through a high-pressure hosereel system.

Mixing of the "Halofoam" concentrate proved difficult, particularly in Test 22. Concentrate for this test had been stored overnight in an unheated vehicle. The concentrate was very viscous and difficult to pour from the container and mix in the premix tank.

For Test 23 the concentrate was stored in a heated room until required and was easier to pour and mix.

7.1.10 FP Tests 2,24,28,and 29.

Test 2 did not give convincing burnback and it was probable that the fire was starved of fuel rather than extinguished.

Although FP was recommended by the manufacturer for use at 3%, References 1 and 2 used FP at 4% and small scale tests suggested an improved performance at 4%. Foam quality tests were carried out using the aspirator attachment at concentrations greater than 3%. 6% concentration was chosen for Test 24 because acceptable foam quality was obtained and the fluidity was considered adequate for the tests. Test 24 extinguished the fire after 12min :58s and gave a convincing burnback.

Following Tests 2 and 24 it was concluded that the aspirator used was not suitable for FP foam. Alternative branchpipes were investigated.

The only foam branch available that operated at "low" flowrates was an FRS 50 litre per minute branch. This type of design was known to be effective in small scale fire tests. In order to maintain the application rate of the other tests, two of the FRS branchpipes were mounted on a plate so the branchman could hold them easily. Prior to the tests the foam quality was measured.

A much improved performance resulted in Test 28 where the concentration was 3%. In Test 29, the concentration was increased to 4% and gave further improvement.

The 90% extinction time was 1min: 39s and the 100% extinction time was 3min : 15s.

The interpretation of the results of the tests on FP was that, with the more conventional foam types such as FP, it is neccessary to " work" the foam more in the branchpipe than with a film forming foam type. The aspirator used in most of the tests is shown in Figure 30 and it can be seen that, unlike the design of low expansion branchpipes, there are no baffles or obstructions in the foam path except for the rod across the aspirator.

The only other foam type tested with the FRS branchpipe was FFFP-AR (Test 26). This showed a much improved extinction time relative to the other FFFP-AR tests (with the exception of the test using a back plate), and may indicate improved performance of some additives may be possible with better branchpipe design.

7.1.11 Summary of extinction tests

The ranking of extinction times are given below.

Concentrate	Application	90% Extinction time min : s	100% Extinction time min : s	No of tests averaged
AFFF	Aspirated	1 : 13	2 : 00	3
AFFF-AR	Aspirated	1 : 22	2 : 06	3
FFFP	Aspirated	1 : 16	2 : 09	3
FP	Aspirated	1 : 39	3 : 15	1
FFFP-AR	Aspirated	2 : 33	3 : 46	3
FFFP	Non-aspirated	3 : 54	4 : 26	1
AFFF	Non-aspirated	3 : 34	4 : 50	3
FFFP-AR	Non-aspirated	3 : 19	4 : 54	1
AFFF-AR	Non-aspirated	4 : 26	5 : 27	1
Halofoam	Non-aspirated	3 : 18	5 : 33	2

7.2 Burnback Tests

The burnback did not develop to 100% in all the tests and therefore the area of burnback is noted in the results in Table 6.

7.2.1 Aspirated application.

AFFF, AFFF-AR, FFFP, and FFFP-AR all gave similar burnback characteristics. Within one minute of application of the flame, ghost flames spread over the tray surface. These were small flames which moved over the foam surface and self-extinguished. The burnback developed slowly until about 10% of the tray was involved, when the fire spread quickly (about 2 minutes with AFFF and AFFF-AR and about 4 minutes with FFFP and FFFP-AR) to the whole tray.

The ranking of the times for burnback are given below. A longer time shows better burnback performance.

Concentrate	Burnback time min : s	No of tests averaged
FP	12 : 53	1
FFFP	10 : 28	3
FFFP-AR	8 : 33	3
AFFF-AR	7 : 46	3
AFFF	7 : 15	3

FP (Test 29 using FRS branchpipes and 4% concentration) gave the longest burnback time and it was 9 minutes before a 1 m^2 fire was established.

7.2.2 Non-aspirated application

When used non-aspirated, short burnback times resulted. The flame spread quickly across any breaks in the foam blanket and an established fire spread to the whole area of the tray.

The ranking of the times from non-aspirated application is given below.

Concentrate	Burnback time min : s	No of tests averaged
Halofoam	5 : 27	2
FFFP-AR	4 : 07	1
FFFP	1 : 56	1
AFFF	1 : 49	3
AFFF-AR	1 : 34	1

All these times are shorter than any of the burnback times for aspirated application.

Comparison of burnback times from tests where the extiinction times were long must be made with care, because of the change in burning characteristics of the fuel.

7.3 Foam properties.

The manufacturers literature states that the AFFF, AFFF-AR, FFFP ,FFFP-AR and FP concentrates used in the tests, pass the appropriate Defence Standards.
The results of measurements of foam properies are given in Table 10. The expansion ratios and drainage times recorded for aspirated foam were not untypical of results from larger branchpipes.(Reference 1). Results from non-aspirated gave expansion ratios of 2-3 and, as expected, very short drainage times.

The relevance of foam standards to fire performance may require further research (8.7).

7.4 Temperatures.

Appendix H Table H1 gives details of all the temperatures recorded.

7.4.1 Fuel temperatures.

Fuel was normally taken from the underground storage tanks and used within 2 hours. On occassions the fuel was left overnight in the tanker and in cold weather , this is reflected in the petrol temperatures (Tests 17, 20 and 13).

7.4.2 Solution temperatures

The solution temperature was measured in the premix tank and in the hosereel line. The solution temperature is affected by passing through the pump and use of the premix temperature can be misleading.

The in-line sensor was connected to a data logger after Test 16. Prior to this the pump operator recorded the maximum temperature reached during the extinction. The data logger results were averaged over the extinction phase and this gave a more useful result.

The foam temperature was influenced by both the solution and the air temperatures.

7.5 Flowrate and total flow

Close control of flowrate was acheived throughout the tests. Only in Tests 17 and 23 (both with the Hyperfog branch) was the flowrate different from 100 lpm.

The total flow, recorded from the flowmeter totaliser, generally agreed with that calculated from the flowrate, extinction time and time for which the branch was switched off during the extinction.

7.6 Wind speed

Wind speed was measured with a portable vane anemometer before each test and in later tests also with an anemometer mounted on the control van and connected to the data logger. The results from the datalogger were averages throughout the extinction and are generally higher than with the portable instrument.

Variations in the wind speed measurements are to be expected over the area of the exposed site used and from the different heights of the two sensors.

8. DISCUSSION

8.1 General

In order to compare the results from the tests by foam type and method of application, the following tables and graphs are included.

Table 7 This gives a summary of results by foam type. An average value is given where appropriate.

Figure 24 Shows 90% and 100% extinction times for individual tests together with the average values.

Figure 25 Shows burnback times for individual tests together with the average values.

Figure 31 Shows average values for extinction and burn back on one sheet.

There are only a limited number of tests for each condition, with only one for some conditions, and these are not sufficient for statistical analysis. The average value should be assessed together with the spread of results.

8.2 Choice of Additive

8.2.1 Extinction performance.

For aspirated application AFFF, AFFF-AR and FFFP gave closely similar extinction characteristics. The extinction was progressive, and the branchman was able to apply the foam from a safe distance from the tray, simply by directing the foam stream onto the fuel surface. No particular expertise or specialised training was required. When the foam stream was applied to a flaming area it did not cause a sudden increase in the fire.

FFFP-AR gave longer extinction times than the other film-forming additives used with the aspirator. It also gave non-progressive extinction characteristics. Foam applied directly to an area of flames caused an increase in the fire. However, FFFP-AR, applied with the aspirator against a backplate (Test 26) or using the FRS branchpipes gave an improved performance which was comparable with the results from AFFF, AFFF-AR and FFFP.

FP used through the aspirator gave poor performance, even when used at 6% concentration. However, when applied through the FRS branchpipe, FP gave extinction times faster than FFFP-AR (with the aspirator), but longer than AFFF, AFFF-AR, and FFFP.

For non-aspirated application, AFFF, AFFF-AR, and FFFP, all gave longer extinction times (by a factor of 2) compared with aspirated application. FFFP-AR (using the aspirator) was also longer but the difference was much less pronounced. "Halofoam" gave the longest extinction times.

8.2.2 Burnback Performance

The burnback results for aspirated application showed similar results from AFFF , AFFF-AR, and FFFP-AR but an improved (longer) burnback from FFFP and FP. The single test with FP, at 4% concentration, gave the longest burnback time.

All the burnback tests with non-aspirated application gave short burnback times, the burnback developing rapidly from the time the flame was applied. FFFP-AR and "Halofoam" produced the longer times, however the long extinction time with Halofoam may have contributed to this.

No tests have been carried out in this project to assess the performance of additives on alcohol fires and therefore in considering the choice of additive the performance relates only to petrol fires.

8.2.3 Costs

Table 7 includes a value for cost to extinction. This is based on the single test result or average (where available) for 100% extinction time, a flowrate of 100 lpm and the concentration used.

The costs were the cost as supplied to SRDB for the trials in Autumn 1986.

The costs to extinction for aspirated application are summarised below.

Concentrate	Cost in £ to extinction
FP	11.0
AFFF	14.7
FFFP	16.4
AFFF-AR	17.7
FFFP-AR	26.2

For non-aspirated application the costs are:

Concentrate	Cost in £ to extinction
AFFF	33.1
FFFP	33.4
FFFP-AR	34.3
AFFF-AR	45.0
Halofoam	424.0

("Halofoam" is recommended by the Manufacturer for use at 15% concentration with hydrocarbon fires and the unit cost is higher than other concentrates).

8.2.4 Induction Rate

The recommended concentration for the all the additives for use on petrol fires was 3% except for "Halofoam" which was 15%.

It must be noted that alternative concentrates are produced for some additives e.g. AFFF is produced as a 1%, 3%, and 6% concentrate. To achieve effective performance, the premix or induction system must take account of the concentrate used.

Induction systems are available which can be adapted to operate with concentrations of 1,3 and 6%, and also to perform with the range of physical properties of additives. Induction systems for 15%, as required by Halofoam, are not common.

AFFF-AR, FFFP-AR and Halofoam all proved difficult to mix into the premix solution. With the exception of the first test with Halofoam, satisfactory mixing was achieved.

8.3 Method of application

8.3.1 Aspirated v non-aspirated.

All tests using non-aspirated application resulted in long extinction times and short burnback times. For the conditions of the tests non-aspirated application cannot be recommended.

Extinction was obtained but the times were greater than 4 minutes. At this time the fuel had been burning for 5 minutes from ignition and the fire properties may have changed.

For non-aspirated application, two application techniques were explored. In the first the additive was applied with the branch stationary, this gave long extinction times but progressive extinction. In the second technique the branchman swept the spray accross the tray. A characteristic of this method of non-aspirated application, was that a quick "knockdown" to 80% in some cases, occured in the first 10-15 seconds, but the fire grew significantly again before final extinction was achieved. This occurred with all the film-forming additives used.

The change of branch to the Hyperfog appeared to improve performance, but the non-progressive characteristics still occurred.

From discussions with manufacturers and firefighting personnel, the technique of sweeping the spray appears to be the approach normally adopted in non-aspirated application. The upwind edge is normally extinguished first, then the fire "swept" away across the rest of the fuel surface. In the FEU tests, extinction of the upwind fire was not easily obtained, probably because the depth of the metal rim required the spray to be applied at a steep angle to the surface. This stirred up the fuel and made extinction difficult. The tray, however, is not untypical of situations that may be experienced in operational use.

In the tests using the aspirator, quick progressive extinction was obtained, and this required little skill or experience from the branchman. The best extinctions with non-aspirated application required the branchman to "fight" the fire from relatively close to the tray and in this position he was put at risk from possible flare back and made uncomfortable from the heat.

The reasons for poor performance non-aspirated are not fully understood. Possible areas for further investigation are droplet size, application rate, spray pattern (use as jet was not explored), spray velocity, concentration and burnback.

One important advantage of using aspirated foam is that the foam can be seen easily on the fuel surface or on the ground.

Non-aspirated application on petrol cannot be recommended.

8.3.2 Use of backplate.

A backplate was used in Tests 25 and 26. In Test 25 the backplate was positioned on the downwind tray edge. The branchman could not see this and had difficulty in hitting the plate with the foam stream. The plate became hot and collapsed and the test gave no meaningful results. In Test 26 the plate was positioned on the edge, broadside to the wind direction. A quick progressive extinction resulted, which demonstrated the advantages of using objects or backplates when these are available. The advantage being in allowing the foam to flow gently onto the surface without causing turbulence in the fuel.

8.4 Trial techniques

8.4.1 Tray design.

The concept of the tray design proved successful. The concrete walls were damaged in the early test and temporary repairs together with the use of sheet metal protection pieces around the downwind side of the tray enabled the trials programme to be completed. The walls will need to be replaced with a high-temperature resisting concrete.

Modifications to the drain gully and drain outlet are also desirable to allow faster draining of liquid from the tray and improve the times between tests.

An improvement on the method of cooling the tray surround by ground monitors would be to have a fixed controllable pipework arrangement around the tray.

8.4.2 Instrumentation

It was thought from previous experiences of foam trials that all extinctions would have been progressive and the 90% and 100% times would be adequate to quantify extinction. The tests when non-progressive extinction was obtained required further instrumentation to describe the progress of the extinction, and for this purpose radiometers would have been useful. Any quantitative results from the radiometers would have to be made with care, but the records would support the results from observers and video.

Radiometer results may also assist in quantifying progress of the burnback.

8.4.3 Branchpipe design

The results show that although a simple branchpipe design is adequate for film-forming type additives, it is not suitable for FP concentrate on petrol fires.

FP does not foam as readily as film forming additives and therefore requires to be "worked" more. This can be achieved by the use of foam forming sections of the branchpipe with orifices and baffles but development of a suitable branch would require further work.

The FRS branchpipe produced a longer drainage time than an aspirator. The foam stream from the FRS branchpipe, contained individual "lumps" of foam which were not produced by the aspirator. This is illustrated in Figures 32 and 33.

8.4.4 Burnback test

Useful results were obtained from the burnback test, however the depth of the foam blanket is very dependent on the extinction time and this depth also effects the burnback time. A prolonged extinction time can allow a thicker foam layer to build up on the surface of the tray.

A burnback test must be carried out after every extinction test to ensure that the fire has been extinguished by the application of foam and not because the fuel has all been burnt.

An alternative approach may be to carry out burnback tests on a foam blanket applied to fresh fuel which has not been ignited.

8.4.5 General

The tray size and trial techniques used were generally successful and although a severe fuel was used, the tests are considered an appropriate test of an additive and suitable for future work.

8.5 Comparisons with previous work

Previous SRDB tests (Section 2.1) showed similar extinction times for AFFF when used aspirated or non-aspirated. This result was not found in the recent work. Three areas may be different:

1. Petrol - 2 star was used previously. Changes may have been made to petrol over recent years. No details are available of petrol used in earlier tests.

2. Concentrate - AFFF formulation may have changed

3. Branch - The spray characteristics from the branch[21] used earlier may be significant.

It would be useful to identify the reasons for the difference because this may assist future research. Further information is being obtained.

8.6 Comparisons between large and small-scale tests

The results of the large- scale and small- scale tests both show poor performance of the additives when used non-aspirated and the poor performance of FP when used through a simple aspirator. "Halofoam" showed significantly different performance in the two cases.

A special aspirating branch would have to be developed for further small scale tests.

The small scale tests proved worthwhile as a screening technique, but are no substitute for large scale tests.

8.7 Implications for future research

The tests have identified several areas where further work is required. The poor performance of non-aspirated foam was shown on petrol, other less volatile fuels may show different performance.

Possible further tests include:
- Use of other fuels e.g. diesel to determine performance.
- Use of different spray branches, application rates and techniques
- Use of two hosereels.
- Different preburn times from the one minute used.
- Spill fires.
- Trays with obstructions and difficult access.

Other areas of possible work include:
- Branchpipe design.
- Foam concentrate and system specifications.
- Guidance to brigades on evaluation tests on additives.

9. CONCLUSION

Using test fires of 1000 litres of petrol in a tray of 40 m^2 and an application rate of 2.5 litres/m^2/minute, it was found that:

1. AFFF, AFFF-AR, and FFFP gave convincing extinction when used aspirated using a simple aspirating attachment. FFFP gave the longest burnback time.

2. FFFP-AR, when used with the aspirator, gave slower extinction times than AFFF, AFFF-AR and FFFP. However, when used with the FRS branchpipe

or with a backplate, performance was comparable with that of the other concentrates.

3. All the additives tested gave poor performance when used non-aspirated. The extinction is not progressive and can redevelop. This may be potentially dangerous in fire-fighting operations. Non-aspirated application on petrol cannot be recomended for use in circumstances similar to these tests.

4. FP when used through the aspirator, gave poor performance and convincing extinction was not obtained. However when used with the FRS branchpipe an improved, acceptable performance resulted as the foam was of a higher quality.

   Development of a suitable branchpipe would be necessary if FP were to be used at these flowrates.

5. Non-aspirated performance gave poor burnback results. The best results for burnback were obtained with aspirated FP and FFFP.

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Fire Research Station for the loan of their branchpipes and advice.

NOTES

1. See Appendix D Glossary for details.

2. FIRTO now known as The Loss Prevention Council.

3. Alpha Pumps, Ashford Road, Maidstone.
Model GP 1/2 /125/E.

4. Kent Instruments Measurements, Stonehouse, Glos.
15mm electromagnetic flowmeter, VAB 11/0/3/2/1/85/1/0

5. Bryans Southern Instruments Ltd. Willow Lane, Mitcham, Surrey.
UV Recorder series 45,000, Galvanometer drive amplifier model 40501.

6. Esso Chemicals Ltd. Portland Terrace, Southampton, SO9 2GW
Sovent 50 - Heptane fuel.

7. Vector Instruments, Marsh Road, Rhyl, Clwyd.
Wind speed indicator. D 600/120.

8. Maine Engineering, Rickmansworth, Herts. Model SD1200L.

9. Nobels Explosive Company Limited, Pontyclun, Mid-Glamorgan.
Blasting machine 60 shot ZEB/CU10/CA30 EL fuse PDR 3m CP25 PL

10. Angus Fire Armour Ltd. Thame, Oxfordshire.
Armrite Superfog gun Model ES4991 light alloy.

11. George Cohen Machinery Limited, Thame, Oxfordshire.
Rosenbauer NE-PI-RO high pressure fog gun with foam extension b/pipe.

12. Galena Fire Engineering Ltd. London.
Hyperfog hosereel branch.

13. Kent Industrial Measurements Ltd. Stonehouse Glos.
Electromagnetic flowmeter 15mm VTB 1129813049 with VKB converter.

14. Electroplan Ltd. Royston, Herts.
Digital indicator DPM 2435.

15. Solatron Instruments, Farnborough, Hampshire.
Orion datalogger 3530 Delta.

16. TC Ltd. Uxbridge.
Mineral Insulated K type thermocouple.

17. RS Components, Birmingham.
Panel mounting digital temperature indicator.

18. Godiva Fire Pumps, Warwick.
UMPX 652/4 light alloy pump (750 GPM)

19. This is not necessarily a criticism of the branch for operational use.

20. A Shear stress viscometer was used in tests to investigate the effects of changing concentration and branchpipe with FP (Section 7.1.10). Viscometer was then used also on the trials site. Measurement of shear stress is recommended for future work.

21. Branch used was Elkhart Select-O-Stream (Reference 1).

REFERENCES

1. JCFR Research Report Number 8, Trials of Foam on Petrol Fires at the Fire Service Technical College, 1976.

2. JCFR Research Report Number 19, Trials of Medium and High Expansion Foams on Petrol Fires. 1982.

3. Fire Research Note No. 970, Foam Branchpipe Design, S P Benson, D J Griffiths, D M Tucker and J G Corrie. May 1973.

4. Fire Research Note No.971, A 5 litre per minute Standard Foam Branchpipe,S P Benson, D J Griffiths and J G Corrie. June 1973.

5. Fire Research Note No 1045, A 50 litre per minute Standard Foam Branchpipe, S P Benson and J G Corrie, January 1976

6. BRE Current Paper 15/78, Quality control procedures for fire-fighting foams, J G Corrie, December 1977.

7. Fire Research Note No 1059, The Fire Research Station Foam Viscometer-Its construction and Use, J G Corrie, April 1977.

8. BRE Current Paper CP 25/75, Problems with the use of fire-fighting foams, J G Corrie, March 1975.

9. Fire Research Note 918, The effect of the velocity of foam jets on the control and extinction of laboratory fires, D M Tucker,D J Griffiths and J G Corrie, 1972.

10. Fire, Journal of the Fire Protection Profession,Testing concludes petrol can reduce the effectiveness of some foams, A A Briggs and J S Webb, January 1986.

11. Fire, Journal of the Fire Protection Profession,Tests show unfoamed agents capable of increasing fire potential in fuels, C Cousin and A A Briggs, April 1986.

12. SRDB Publication 8/85,Trials of foams on Hydrocarbon Fires in the European Community, F E Smith, January 1985.

13. Cambridgeshire Fire and Rescue / 3M Co. AFFF Comparison Trials.

14. BS 5423:1980 Specification for portable fire extinguishers, BSI, London.

15. Home Office (Fire Department), 'Manual of Firemanship', Book 3, London: Her Majesty's Stationery Office (1976).

16. SRDB Publication 9/87, Pilot Study on Low expansion foam-making branchpipes, B Johnson and P Parsons. Sept.1986.

FOAM TYPE	EXPANSION RANGE	90% EXTINCTION TIME min : s	100% EXTINCTION TIME min : s	BURN-BACK TIME min : s	NUMBER OF FIRE TESTS AVERAGED
Protein	Low	No effective extinction			1
Fluoroprotein (FP)	Low (12)	1 : 01	1 : 58	5 : 28	3[1]
Fluorochemical (AFFF)	Low	0 : 44	1 : 39	2 : 34	4
Fluorochemical (AFFF)	Spray	0 : 35	1 : 38	1 : 36	2
Synthetic	Low (20-30)	1 : 19	2 : 12	3 : 58	4[2]
Synthetic	Medium (65)	1 : 24	2 : 39	3 : 06	3
Synthetic	Medium (140)	1 : 35	1 : 58	4 : 23	3
Synthetic	High (400)	0 : 48	1 : 18	1 : 29	4[3]

1. Test 3 of 1980 series, Tests 6 and 7 of 1974 (Ref 1)
2. 1974 Tests (Ref 1).
3. Tests 6, 7 and 8 of 1980 series, Test 12 of 1974 (Ref 1).

TABLE 1 : 84m^2 PETROL FIRE TESTS : SUMMARY

Country	Fuel	Stated Volume	Fire Type	Area	Pre-Burn	Protein	Synthetic	Fluoro-Protein	AFFF	Application Rate	Mode of Application	Extinction Time 90%	Extinction Time 100%	Burn-Back	Foam Properties Tested
	———	Litres	———	m^2	minutes	———	———	———	———	l/min/m^2	———	90%	100%	———	———
(1961-62) Denmark (1969)	Aviation Petrol	2000	Tray	400	0.75	L				~ 7[1]	Direct	No	Yes	No	None
	Aviation Petrol		Tray	900											
France (1977)	Crude Oil		Tray	1920	~ 10	L	M	L	L	~ 4	Direct	Yes	Yes	Yes[2]	None
	Kerosine		Tray	170	~ 4	L		L	L	~4 or 12	Direct	Yes	Yes	No	None
Italy (1976)	Petrol Diesel Oil Toluene	Varied depending on tray size	Tray	9, 37 150 600	1 or 5	L	L	L	L	2, 4, 8	Direct and Indirect	Yes[3]	Yes[4]	No	In Lab
	Toluene		Tank	102	5			L		6	Base Injection	Yes[3]	Yes[4]	No	In Lab
(1975) United Kingdom (1981)	Petrol	1370	Tray	84	1	L	M H	L	L[5]	2.7	Direct	Yes	Yes	Yes	In Situ
	Petrol	1370-1827	Tray	84	1		M H	L		2.7	Direct	Yes	Yes	Yes	In Situ
West Germany	Methanol Aviation Petrol	1000-1200	Tray	50	1 – 2			L M		~ 4	Direct	No	Yes	Yes[6]	None

Notes

1. Calculated from water application rate
2. Time taken to reignite whole tray for 2nd test
3. 'Time to control' flames < 60cm high
4. 'Virtual extinction', isolated flames at corners
5. Aspirated and non-aspirated AFFF tested
6. Reignition test.

L, M, H denote low, medium and high expansions

Table 2 European foam trials – Liquid fuel fires: Summary

TABLE 3 : DETAILS OF ADDITIVES USED IN THIS WORK

FOAM TYPE	CONC.[4] %	TRADE NAME	MANUFACTURER/SUPPLIER	COST PER LITRE[3]
AFFF	3	'Light Water'[1]	3M Chemicals Division, Manchester.	2.45
AFFF	3	Tridol 'S'[2]	Angus Fire Armour Limited Thame, Oxfordshire.	2.19
AFFF-AR	3	'Light Water'	3M Chemicals Division, Manchester.	2.85
FFFP	3	'Petroseal'	Angus Fire Armour Limited, Thame, Oxfordshire.	2.61
FFFP-AR	3	'Alcoseal'	Angus Fire Armour Limited, Thame, Oxfordshire.	2.52
FP	3	FP70	Angus Fire Armour Limited, Thames, Oxfordshire.	0.84
Halofoam	15	Halofoam	Harrier Marketing Ltd, Wakefield.	5.30
Fire-out	0.2	Fire-out	Macron Fire Protection Ltd, Aylesbury.	2.42

1 - Used in all AFFF tests except Test 27.
2 - Used in Test 27 only. (Autumn 1986).
3 - Cost per litre as supplied for trials. Not including VAT.
4 - Conc. recommended by manufacturer for use on hydrocarbon fires.

DATE	TEST No	FUEL	WATER BASE yes/no	FOAM	CONC	APPL	WIND SPEED ms^{-1}	WIND DIRN from N	TEMPERATURE AIR °C	TEMPERATURE SOLN °C	FLOW $l min^{-1}$	EXTINCTION 90% min:s	EXTINCTION 100% min:s	BURNBACK 100% min:s
Jan. 86	1(1)	Petrol	YES	FP	3%	FOAM	1.3	20°	1.2	7.0	14.0	0.58	8.45	15.17
"	2(2)	Petrol	YES	FP	3%	FOAM	3.0	160°	1.0	10.0	14.0	7.28	16.22	7.55
"	3(3)	Petrol	YES	FP	3%	FOAM	2.5	160°	1.5	12.0	7.9	FUEL EXHAUSTED		
"	4(4)	Petrol	YES	AFFF	3%	FOAM	4.0	170°	2.5	9.5	14.1	0.39	1.07	7.58
"	5(5)	Petrol	YES	AFFF	3%	SPRAY	2.6	170°	2.5	11.0	13.8	1.08	3.09	4.48
Apr. 86	9(1A)	Heptane	NO	FP	3%	FOAM	4.0	200°	12.5	17.5	13.8	1.14	2.44	5.15
"	10(1B)	Heptane[1]	NO	FP	3%	FRS	4.0	200°	12.5	17.5	14.0	—	5.39	—
"	11(2A)	Heptane	NO	FFFP	3%	FOAM	4.6	220°	15.0	18.5	13.7	0.36	0.59	3.49
"	12(3)	Heptane	NO	FFFP	3%	SPRAY	4.6	200°	15.5	21.0	14.0	5.06	15.46	2.30
"	13(4)	Heptane	NO	AFFF-AR	3%	FOAM	3.4	180°	12.0	13.0	13.9	0.36	1.09	6.33
"	14(5)	Heptane	NO	AFFF-AR	3%	SPRAY	2.5	170°	15.0	14.5	14.0	—	—	
"	15(6A)	Petrol	YES	FP	4%	FOAM	4.5	170°	18.0	18.5	13.8	4.20	6.09	5.45

1. Fresh fuel not used for this test.

Results of Tests 6,7,8 given in Table 5.

TABLE 4 - RESULTS OF SMALL SCALE TESTS ON FSC FIREGROUND

DATE	TEST No	FUEL	TRAY	FOAM	CONC	APPL	WIND SPEED ms^{-1}	WIND DIRN from N	TEMPERATURE AIR °C	TEMPERATURE SOLN °C	FLOW $lmin^{-1}$	EXTINCTION 90% min:s	EXTINCTION 100% min:s	BURNBACK 100% min:s
Jan. 86	1(1)	Petrol	90°	FP	3%	FOAM	1.3	20°	1.2	7.0	14.0	0:58	8:45	15:17
"	2(2)	Petrol	90°	FP	3%	FOAM	3.0	160°	1.0	10.0	14.0	7:28	16:22	7:55
"	3(3)	Petrol	90°	FP	3%	FOAM	2.5	160°	1.5	12.0	7.9	FUEL EXHAUSTED		
"	4(4)	Petrol	90°	AFFF	3%	FOAM	4.0	170°	2.5	9.5	14.1	0:39	1:07	7:58
"	5(5)	Petrol	90°	AFFF	3%	SPRAY	2.6	170°	2.5	11.0	13.8	1:08	3:09	4:48
"	6(6)	Petrol	30°	FP	3%	FOAM	6.0	140°	-	-	14.1	5:30	9:45	11:41
"	7(7A)	Petrol	30°	AFFF	3%	FOAM	4.0	200°	10.8	19.0	14.1	0:39	0:47	3:00
"	8(8)	Petrol	30°	AFFF	3%	SPRAY	6.0	200°	11.0	11.0	13.6	1:10	3:05	0:28

All tests used a water base.

TABLE 5 : RESULTS OF TESTS ON TRAY DESIGN

FOAM TYPE	APPLICATION METHOD	BRANCH	TEST NO.	CONC. %	WIND SPEED	TEMPERATURE FUEL °C	TEMPERATURE AIR °C	EXTINCTION TIMES 90% min : s	EXTINCTION TIMES 100% min : s	NON PROGRESIVE EXTINCTION	BURNBACK TIME min : s	BURNBACK TIME 100%
AFFF (Light-water)	Aspirated	Superfog with aspirator	3	3	1.5	17	13	1 : 08	1 : 45	NO	8 : 43	98
			5	3	2	13	9.3	1 : 06	1 : 50	NO	7 : 20	100
			9	3	2	14	11.9	1 : 24	2 : 26	NO	5 : 42	100
AFFF (Light-water)	Non-aspirated (Spray)	Superfog	6	3	2.1	14	10.8	2 : 42	4 : 39	NO	2 : 00	98
			7	3	2.5	14	13	4 : 35	5 : 30	NO	1 : 11	100
			8	3	2	13	11.1	3 : 25	4 : 22	YES	2 : 17	90
AFFF (Light-water)	Non-aspirated (Spray)	Hyperfog	17	3	1	5	3.3	2 : 08	3 : 29	YES	1 : 21	100
AFFF (Tridol-S)	Non-aspirated (Spray)	Superfog	27	3	3.2	10	4	3 : 30	4 : 53	YES	3 : 06	100
AFFF-AR	Aspirated	Superfog with aspirator	15	3	2.5	12	8.1	1 : 54	2 : 31	NO	8 : 32	100
			16	3	4.5	13	9.8	0 : 57	1 : 25	NO	6 : 48	100
			18	3	4	11	6	1 : 14	2 : 21	NO	7 : 58	100
AFFF-AR	Non-aspirated	Superfog	19	3	6	12	7.6	4 : 26	5 : 27	YES	1 : 34	95
FFFP	Aspirated	Superfog with aspirator	4	3	1	14	13.3	1 : 07	2 : 18	NO	13 : 40	100
			10	3	1.8	16	16.1	1 : 17	2 : 07	NO	10 : 57	100
			11	3	4.5	13	11.8	1 : 23	2 : 01	NO	6 : 46	100
FFFP	Non-aspirated (Spray)	Superfog	12	3	2.5	15	14	3 : 54	4 : 26	YES	1 : 56	95

TABLE 6 : RESULTS OF 40m² TESTS FOR EACH FOAM TYPE

FOAM TYPE	APPLICATION METHOD	BRANCH	TEST NO.	CONC. %	WIND SPEED MS[1]	TEMPERATURE FUEL °C	AIR °C	EXTINCTION 90% min : s	100% min : s	NON PROGRESSIVE EXTINCTION	BURNBACK TIME min : s	100%
FFFP-AR	Aspirated	Superfog	13	3	1.8	17	14	3 : 40	3 : 57	YES	5 : 18	100
		with	14	3	0.4	15	13.7	1 : 56	3 : 50	YES	10 : 22	95
		aspirator	20	3	4	6	4.3	2 : 02	3 : 32	YES	9 : 58	100
FFFP-AP	Aspirated using backplate	With aspirator	26	3	0.8	12	8.2	1 : 21	2 : 09	YES	9 : 05	100
FFFP-AR	Aspirated	2 x FRS 50 LPM	30	3	5	11	9.1	1 : 45	2 : 21	NO	7 : 38	100
FFFP-AR	Non-aspirated (Spray)	Superfog	21	3	3	10	5.2	3 : 19	4 : 54	YES	4 : 07	80
FP	Aspirated	Superfog	2	3	4	18	19.0	8 : 58	12 : 26	NO	No burnback	
		with	24	6	1 .3	12	6.8	7 : 24	12 : 58	NO	16 : 17	90
		FRS	28	3	3	11	6.6	2 : 49	4 : 00	NO	9 : 20	100
			29	4	6.1	12	9.4	1 : 39	3 : 15	NO	12 : 53	100
Halofoam	Non-aspirated (Spray)	Superfog	22	15	3.5	11	7.3	3 : 46	5 : 52	YES	4 : 40	98
			23	15	0	4	3.2	2 : 49	5 : 14	YES	6 : 13	100

TABLE 6 : RESULTS OF 40m² TESTS FOR EACH FOAM TYPE (continued)

Foam Type	Application	Test No.	90% Extinction Times min : s	100% Extinction Times min:s	Vol. of Solution used. Litres	Vol. of Additive used. Litres	Cost to extinction £	Burn-back time min:s
AFFF	Aspirated	3	1 : 08	1 : 45				8 : 43
		5	1 : 06	1 : 50				7 : 20
		9	1 : 24	2 : 26				5 : 42
		Av	**1 : 13**	**2 : 00**	**200**	**6.0**	**14.7**	**7 : 15**
AFFF	Non-aspirated (Spray)	6	2 : 42	4 : 39				2 : 00
		7	4 : 35	5 : 30				1 : 11
		8	3 : 25	4 : 22				2 : 17
		Av	**3 : 34**	**4 : 50**	**450**	**13.5**	**33.1**	**1 : 49**
AFFF-AR	Aspirated	15	1 : 54	2 : 31				8 : 32
		16	0 : 57	1 : 25				6 : 48
		18	1 : 14	2 : 21				7 : 58
		Av	**1 : 22**	**2 : 06**	**206**	**6.2**	17.7	**7 : 46**
AFFF-AR	**Non-aspirated (Spray)**	**19**	**4 : 26**	**5 : 27**	**527**	**15.8**	**45.0**	**1 : 34**
FFFP	Aspirated	4	1 : 07	2 : 18				13 : 40
		10	1 : 17	2 : 07				10 : 57
		11	1 : 23	2 : 01				6 : 46
		Av	**1 : 16**	**2 : 09**	**209**	**6.3**	**16.4**	**10 : 28**
FFFP	**Non-aspirated (Spray)**	**12**	**3 : 54**	**4 : 26**	**426**	**12.8**	**33.4**	**1 : 56**
FFFP-AR	Aspirated	13	3 : 40	3 : 57				5 : 18
		14	1 : 56	3 : 50				10 : 22
		20	2 : 02	3 : 32				9 : 58
		Av	**2 : 33**	**3 : 46**	**346**	**10.4**	**26.2**	**8 : 33**
FFFP-AR	**Non-aspirated (Spray)**	**21**	**3 : 19**	**4 : 54**	**454**	**13.6**	**34.3**	**4 : 07**
FP	**Aspirated** (FRS Branchpipes)	**29**[1]	**1 : 39**	**3 : 15**	**315**	**12.6**	**10.6**	**12 : 53**
Halofoam	Non-aspirated (Spray)	22	3 : 46	5 : 52				4 : 40
		23	2 : 49	5 : 14				6 : 13
		Av	**3 : 18**	**5 : 33**	**533**	**80.0**	**424.0**	**5 : 27**

1 - FRS Branchpipes used with 4% concentration FP

TABLE 7 : FIRE TEST : SUMMARY

TABLE 8 : RESULTS OF MEASUREMENTS OF BRANCH OPERATING CONDITIONS

BRANCH	SETTING	PRESSURE		FLOW
		PUMP bar	BRANCH bar	lmp
Superfog	Jet (used with aspirator)	31	22	100
Superfog	Spray	33	23.5	100
Hyperfog	Spray	26	16	100
FRS 50 lpm (with control valve)		8	5.9	50
FRS 50 lpm (no control valve)		9	6.0	50

FOAM TYPE	APPLICATION	CONC. %	TEST NO.	EXPANSION RATIO	DRAINAGE TIME min : s	SHEAR STRESS N/m^2	TEMPERATURE AIR °C	TEMPERATURE FOAM °C	TEMPERATURE SOLUTION °C
AFFF	Aspirated	3	3	11.8	4 : 24		13.0	15.3	21.0[1]
AFFF	Aspirated	3	5	11.8	4 : 39		9.3	12.3	20.0[1]
AFFF	Aspirated	3	9	13.1	4 : 17		11.9	17.0	24.0[1]
AFFF	Aspirated		Average	12.2	4 : 27				
AFFF	Spray	3	6	2.1	0 : 52		10.8	13.1	20.0[1]
AFFF	Spray	3	7	2.5	1 : 27		13	14.3	23.0[1]
AFFF	Spray	3	8	2.2	1 : 12		11.1	13.2	22.0[1]
AFFF	Spray		Average	2.3	1 : 10				
AFFF	Hyperfog Spray	3	17	2.3	1 : 12		3.3	6.1	10.8[2]
AFFF (Tridol-S)	Superfog Spray	3	27	1.9	1 : 12		4.0	7.6	14.8[2]
AFFF-AR	Aspirated	3	15	4.9	10 : 17		8.1	12.6	16.0[2]
AFFF-AR	Aspirated	3	16	5.1	10 : 02		9.8	13.3	13.4[2]
AFFF-AR	Aspirated	3	18	6.8	9 : 01		6.0	10.1	11.6[2]
AFFF-AR	Aspirated	3	Average	5.6	9 : 47				
AFFF-AR	Spray	3	19	1.8	1 : 35		7.6	10.0	13.6
FFFP	Aspirated	3	4	9.8	4 : 25		13.3	17.4	20.0[1]
FFFP	Aspirated	3	10	8.7	4 : 29		16.1	19.2	22.0[1]
FFFP	Aspirated	3	11	8.9	4 : 46		11.8	18.7	19.0[1]
FFFP	Aspirated	3	Average	9.1	4 : 33				
FFFP	Spray	3	12	2.1	1 : 05		14.0	12.5	21.0[1]
FFFP-AR	Aspirated	3	13	7.0	5 : 23		14.0	16.0	22.0[1]
FFFP-AR	Aspirated	3	14	6.9	5 : 13		13.7	17.7	23.0[1]
FFFP-AR	Aspirated	3	20	6.6	6 : 34		4.3	9.8	12.5[2]
FFP-AR	Aspirated	3	Average	6.9	5 : 43				
FFFP-AR	Aspirated	3	26	5.7	6 : 39		8.2	11.8	17.0[2]
FFFP-AR	Aspirated	3	30	5.6	6 : 07	4	9.1	11.6	13.5[2]
FFFP-AR	Spray	3	21	1.9	1 : 30		5.2	7.6	11.0[2]
FP	Aspirated[3]	3	29	7.2	8 : 33	16	9.4	11.9	13.0[2]
HALOFOAM		15	22	1.1			7.3	9.9	
HALOFOAM		15	23	1.1			3.2	7.2	13.5[2]

1 - Pump operator reading of maximum temperature reached.
2 - Data logger results.
3 - FRS branchpipes used with 4% concentration FP.

Table 9: Results of measurements of foam properties

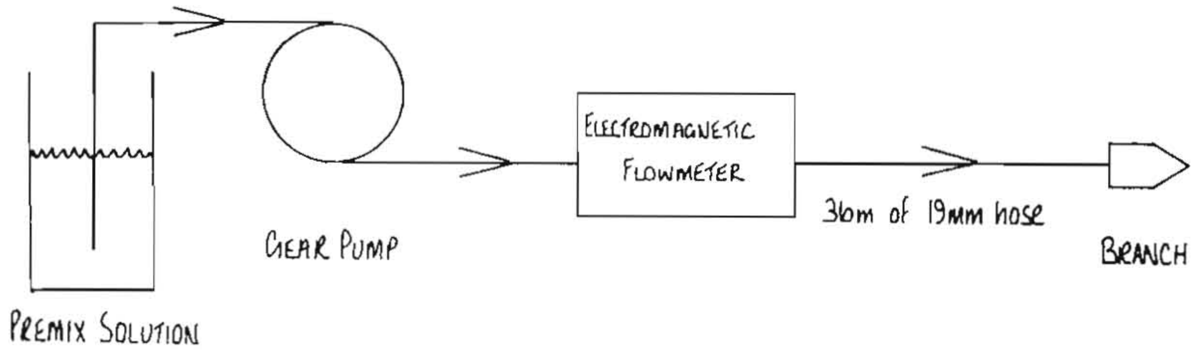
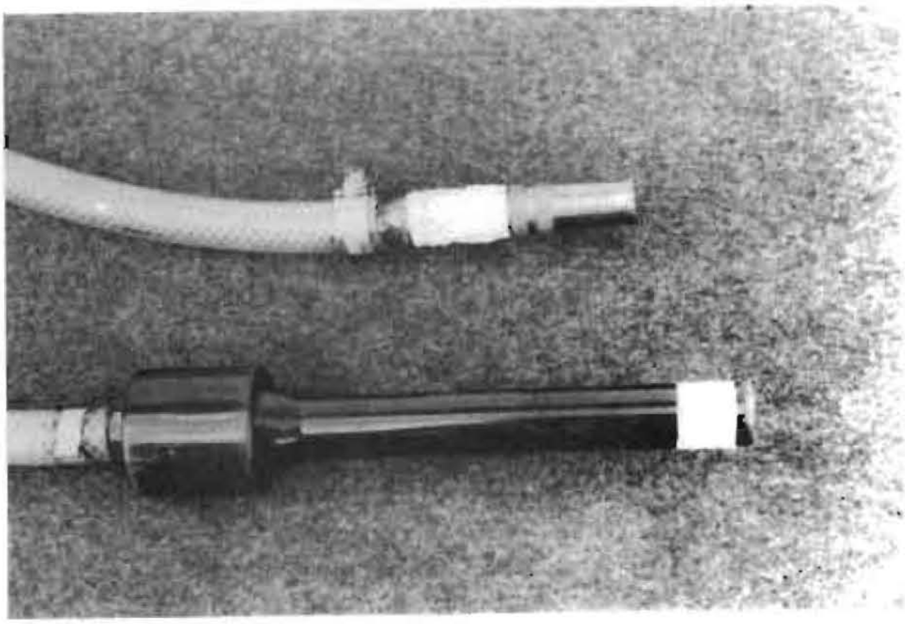


Figure 1 : Hydraulic arrangement for small scale tests.



C/139/87

Figure 2 : Two nozzles used for small-scale tests.

C/46/86

Figure 3 : Application of foam to the small scale fires.

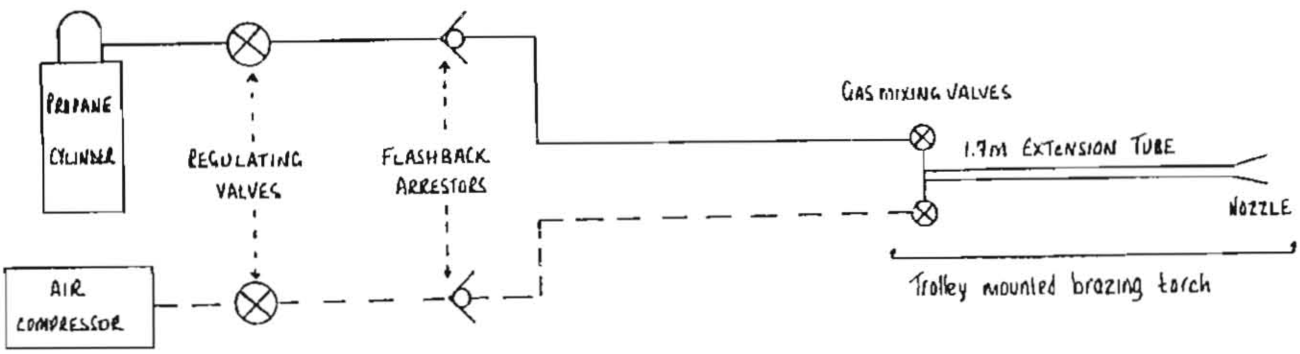
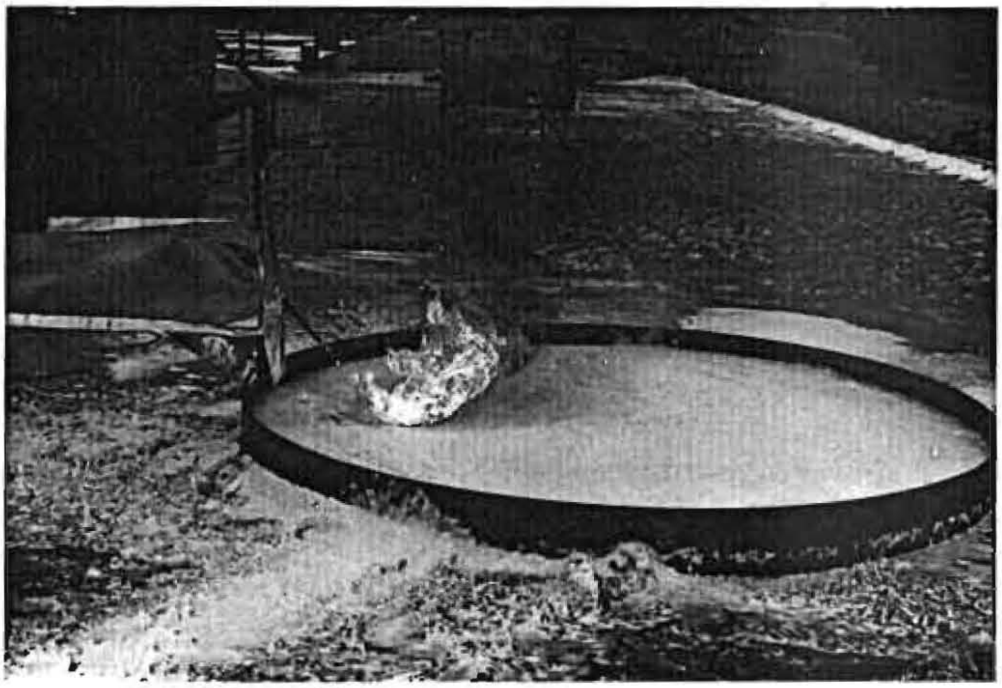


Figure 4 : Diagram of burnback rig.



S/151/86

Figure 5 : Burnback apparatus.

C/456/86

Figure 6 : Modified Superfog hosereel branch.

C/459/86

Figure 7 : Modified Superfog hosereel branch fitted with aspirator

C/520/86

Figure 8 : General view of test site

S/145/86

Figure 9 : Portable dam and Emergency Pump

S/207/86

Figure 10 : Flowmeter and indicators mounted on trolley adjacent to pump

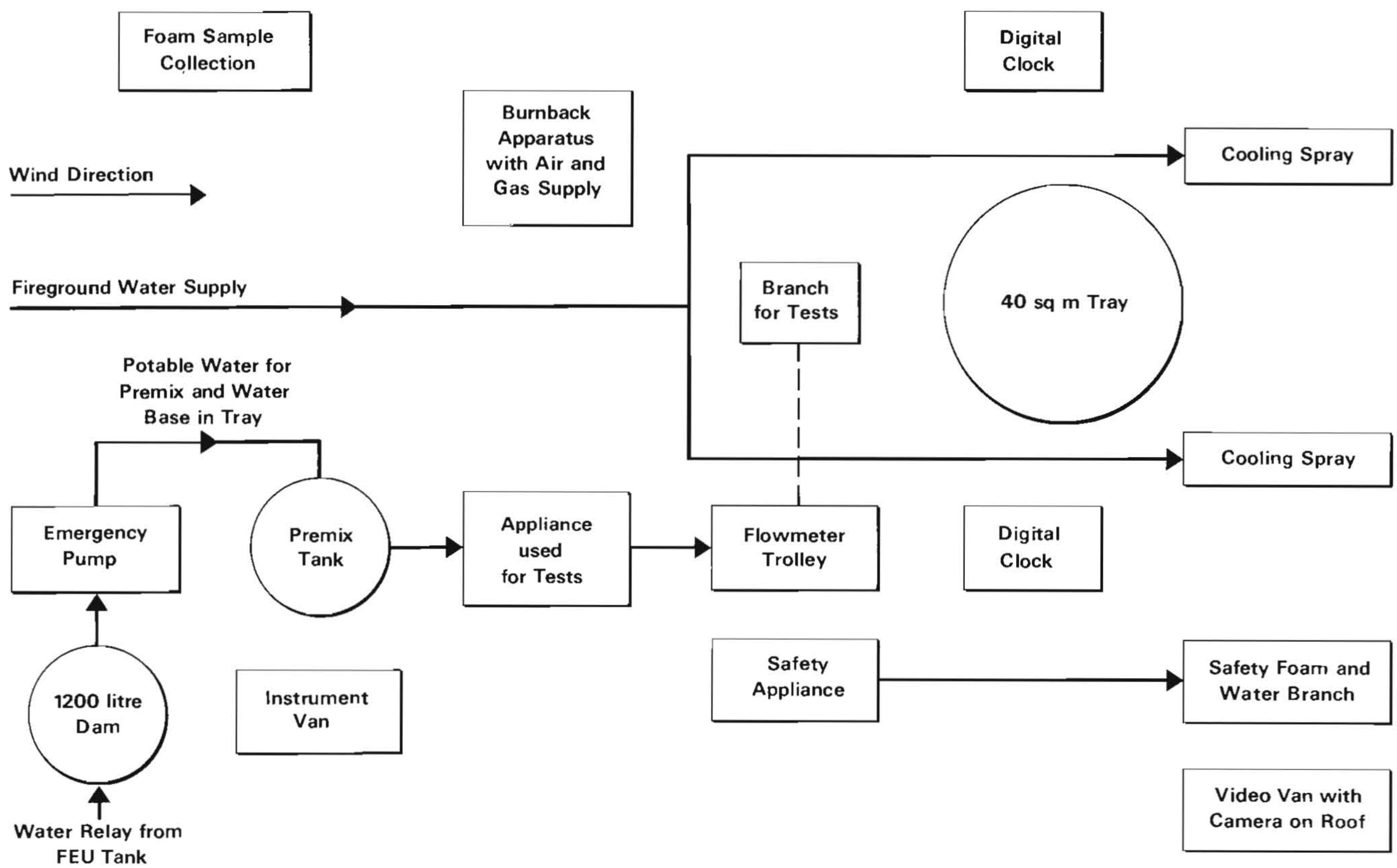


Fig 11 : Typical Layout of Appliances and Equipment

S/143/86

Figure 12 : Petrol trailer being filled at FSC pumps.

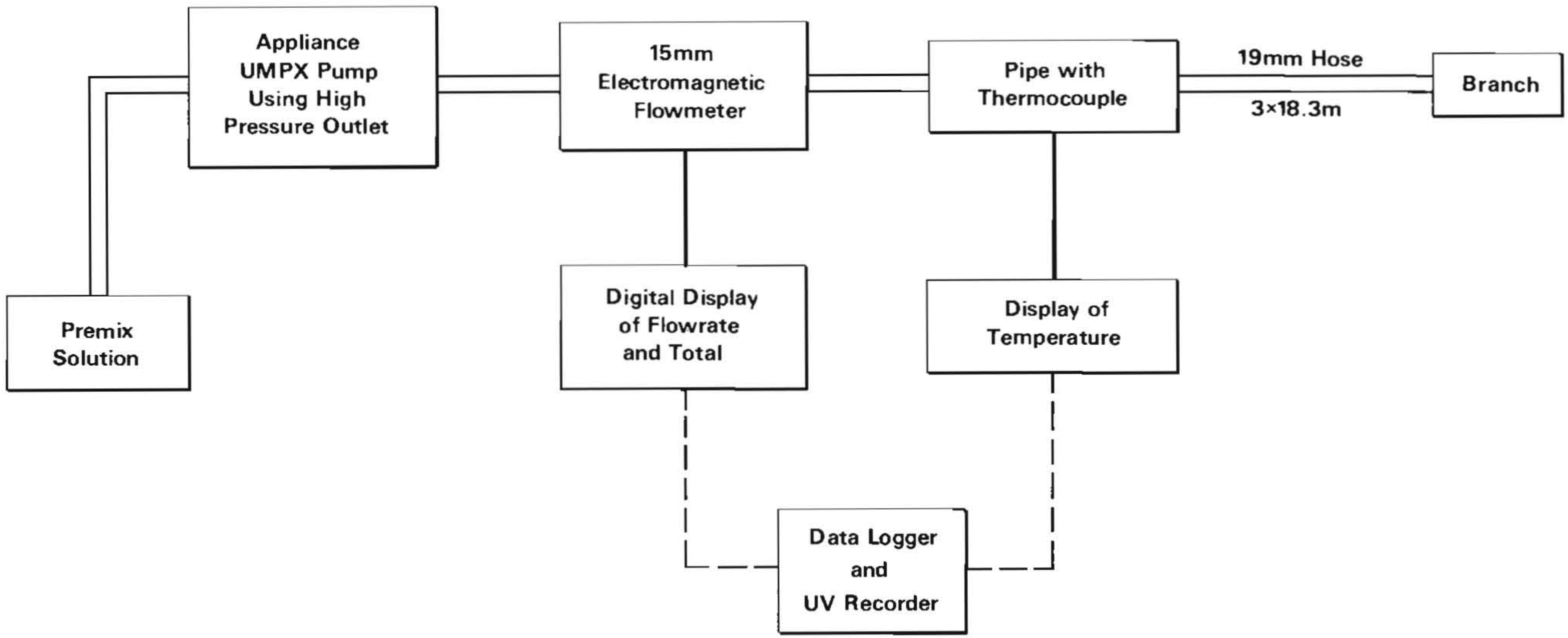
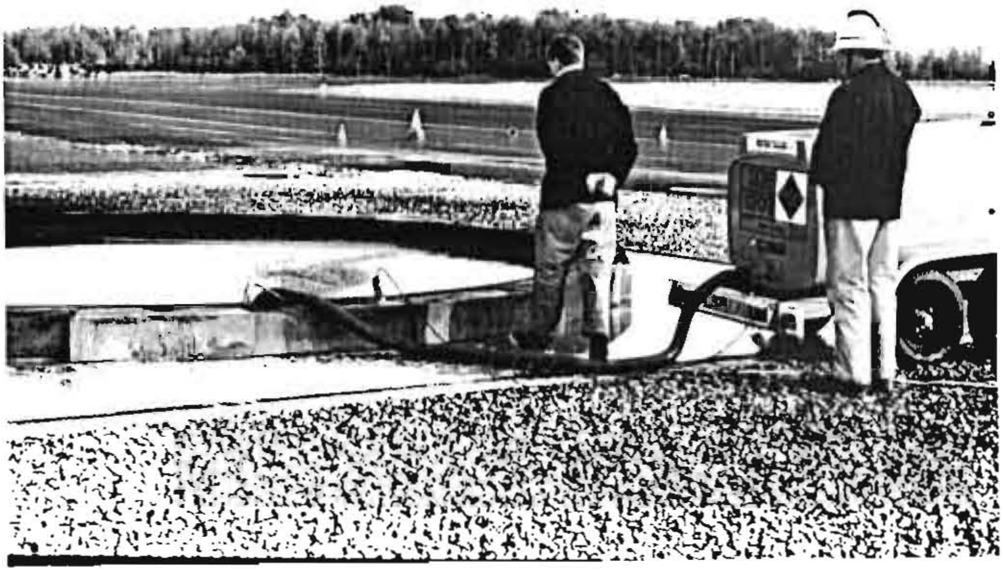


Fig 13: Hydraulic Arrangements for 40 sq m Petrol Fires

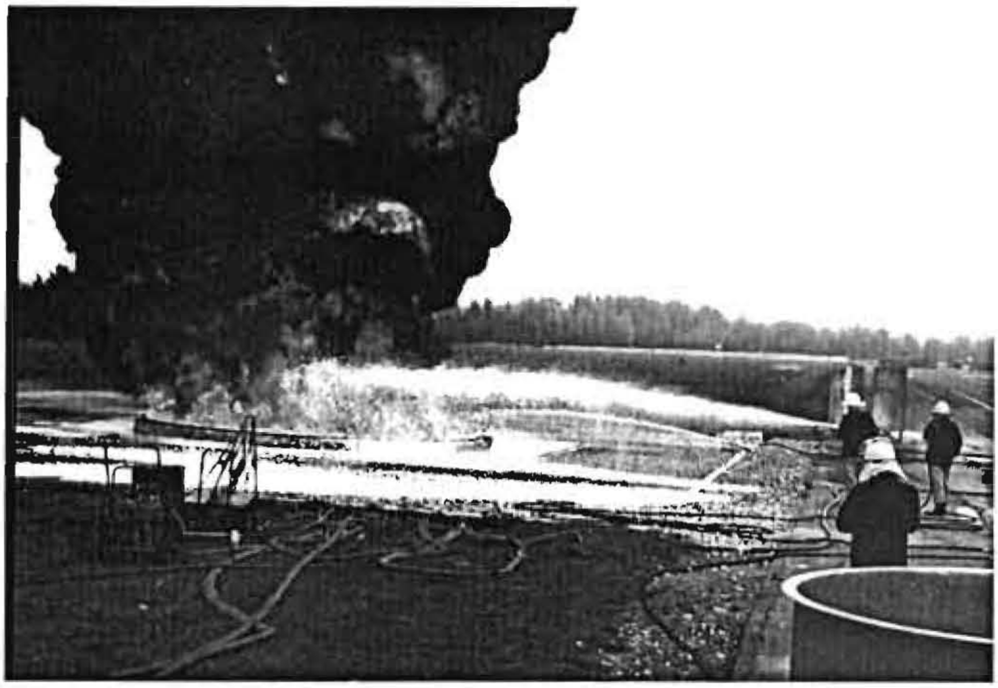


S/199/86

Figure 14 : Petrol being transferred to tray.

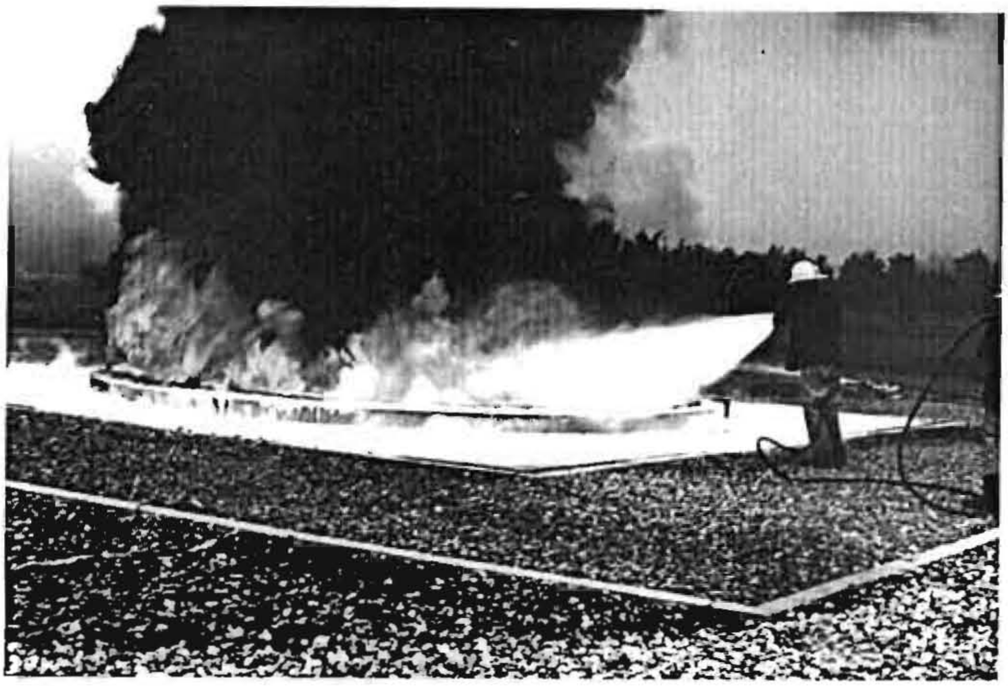
S/180/86

Figure 15 : General view of fire during preburn



S/81/86

Figure 16 : Aspirated application of foam to fire.

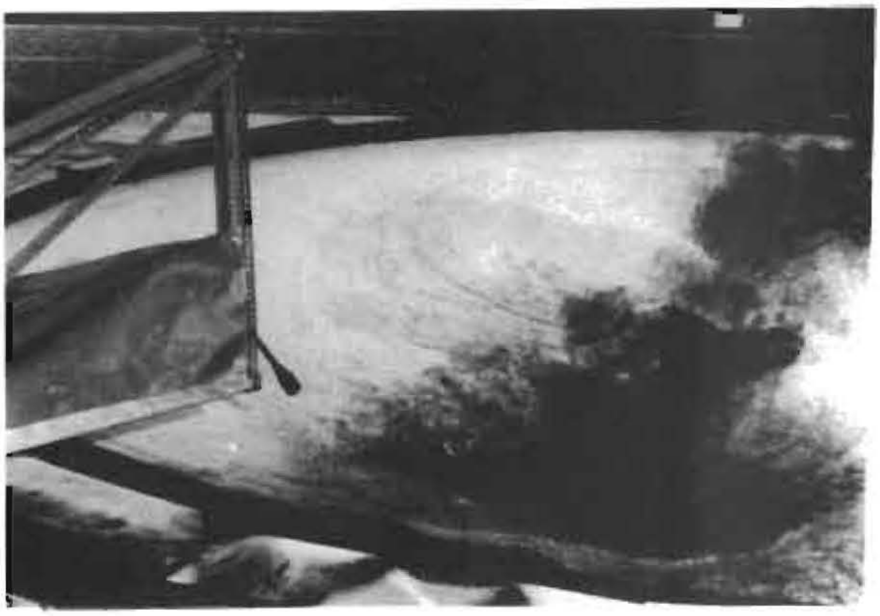


S/80/86

Figure 17 : Non-aspirated (Spray) application to fire.

S/87/86

Figure 18 : Foam sample collection on trial site.



S/151/86

Figure 19 : Burnback flame in position for burnback test.

C/451/86

Figure 20 : Two FRS branchpipes mounted on a plate.

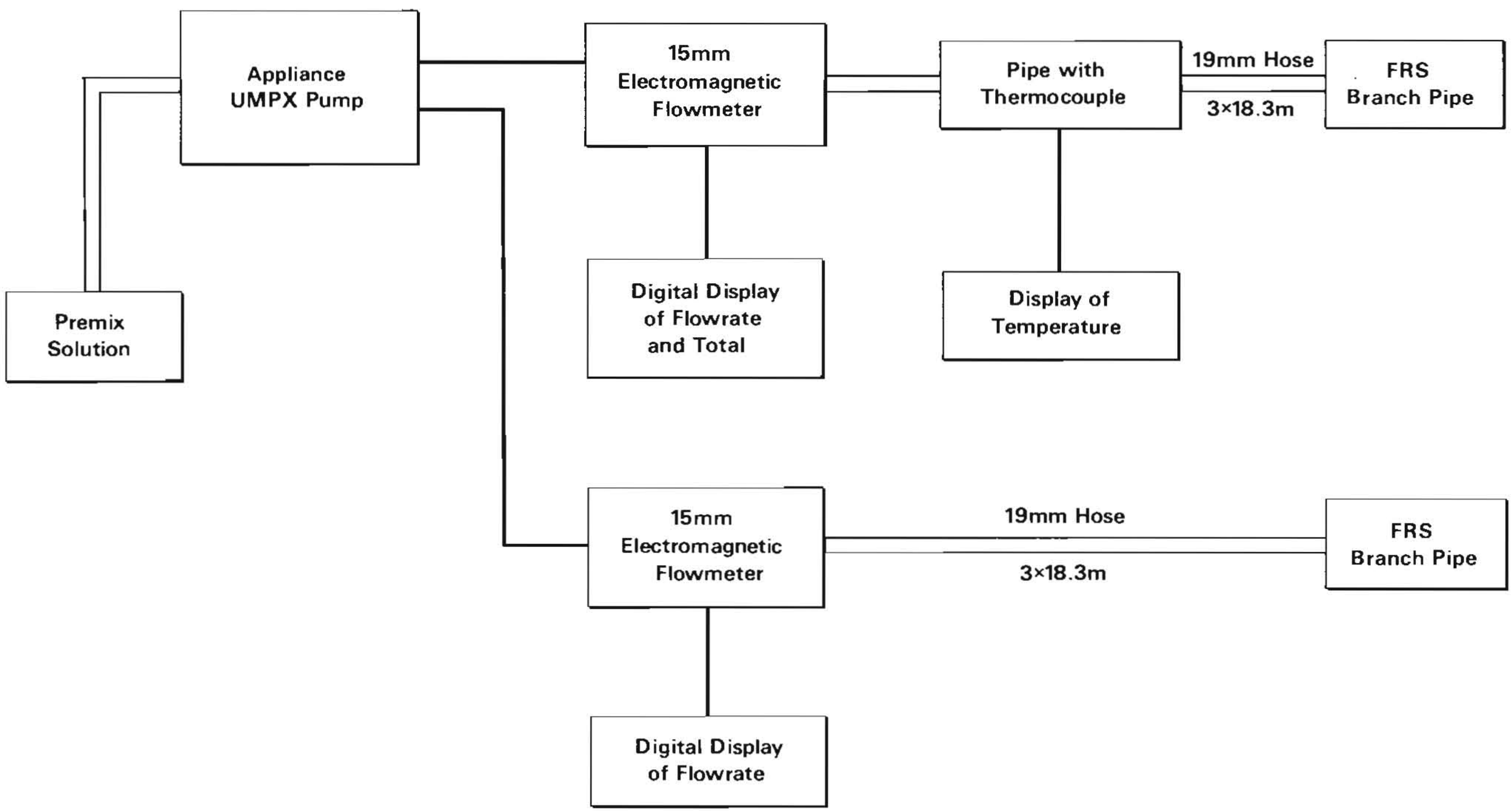
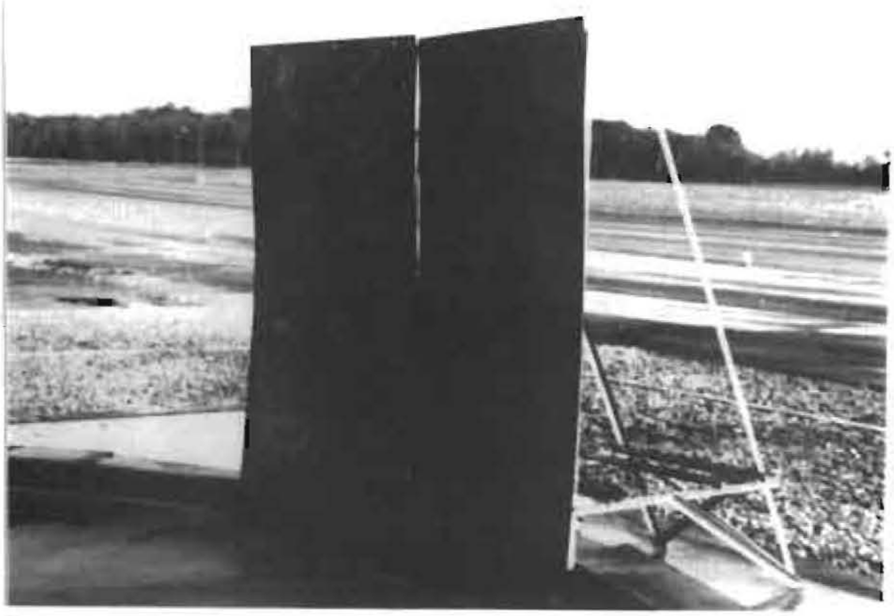
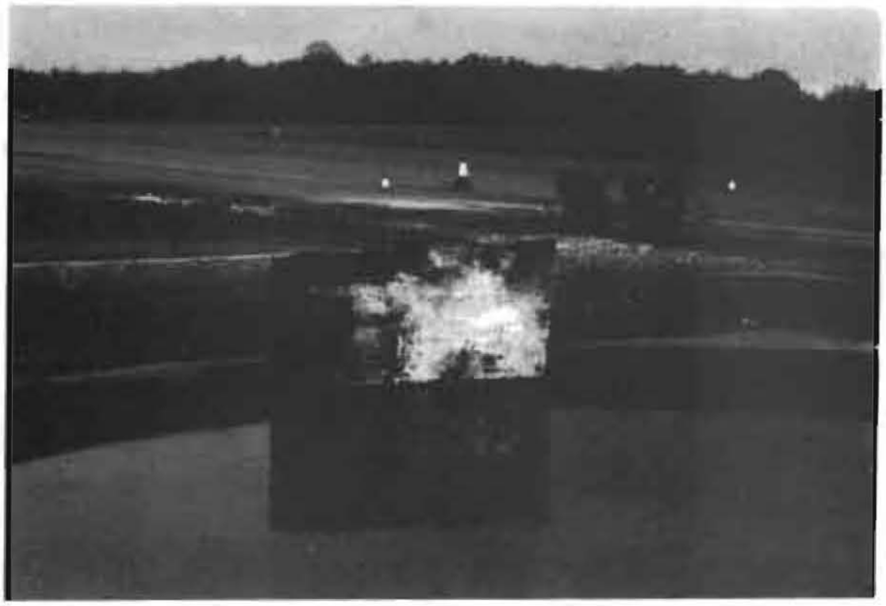


Fig 21: Hydraulic Arrangement for FRS 50 1pm Branchpipes



S/155/86

Figure 22 : Backplate used in Test 25.



S/115/86

Figure 23 : Backplate used in Test 26.

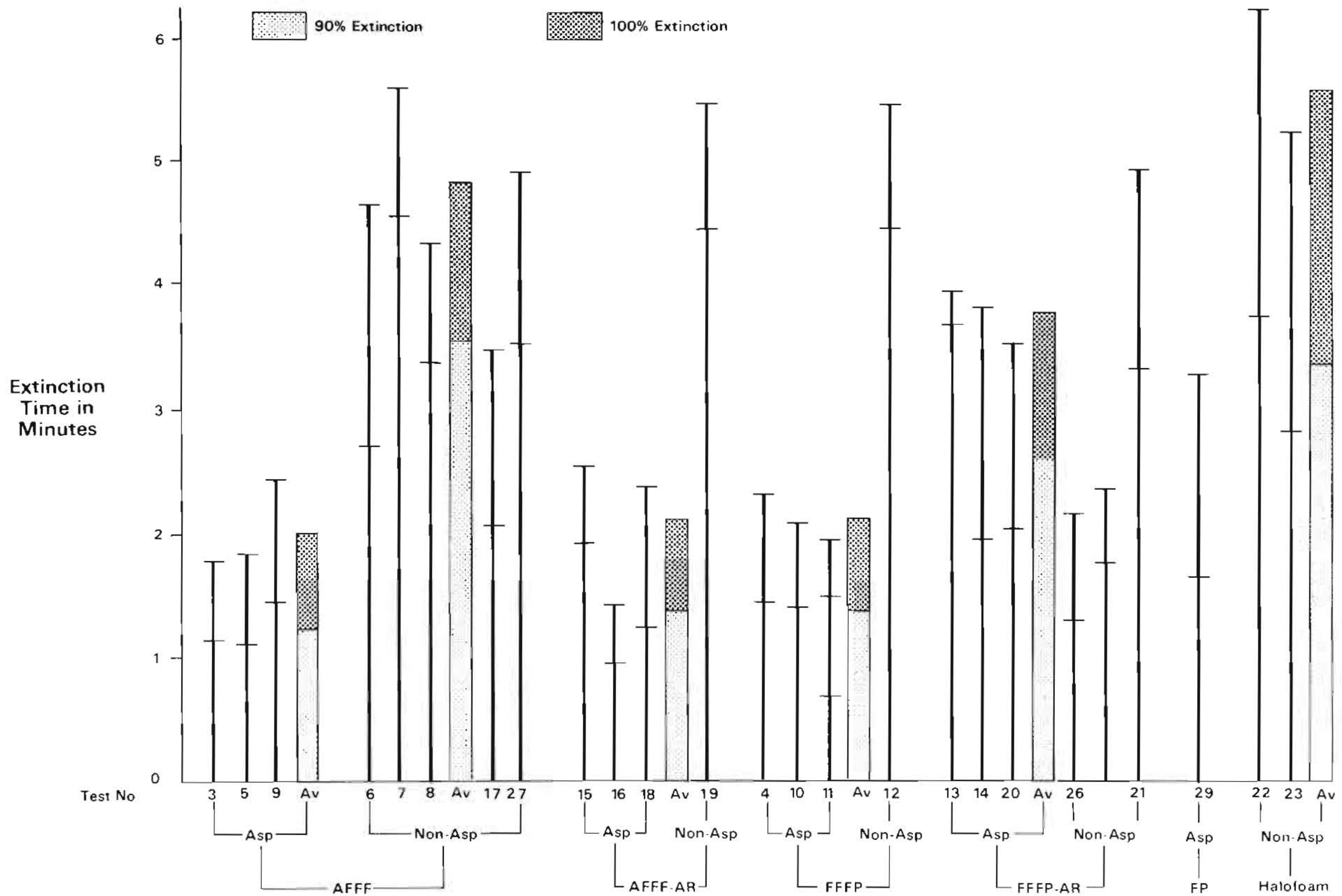


Fig 24: Graph of Extinction Results

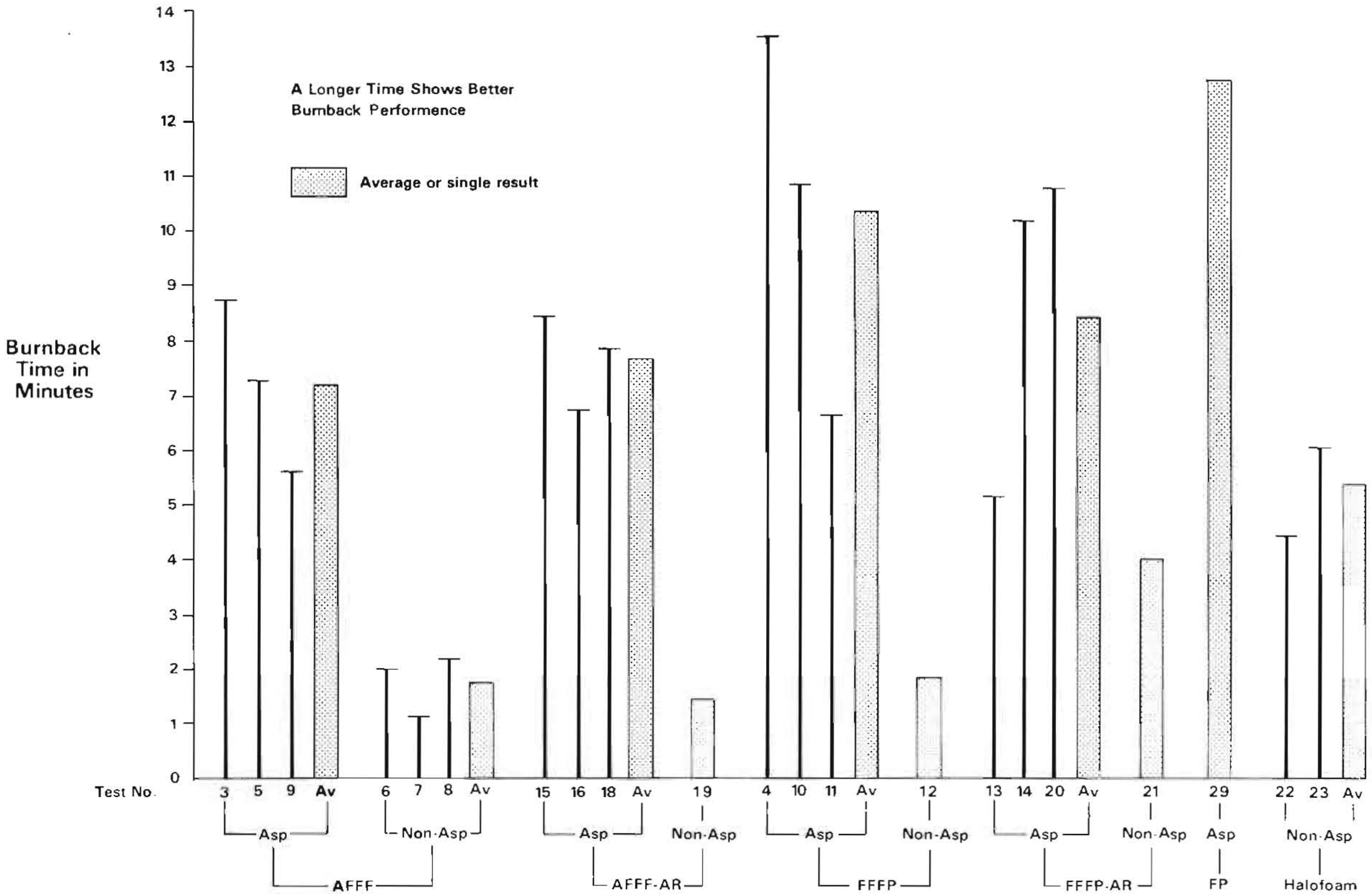
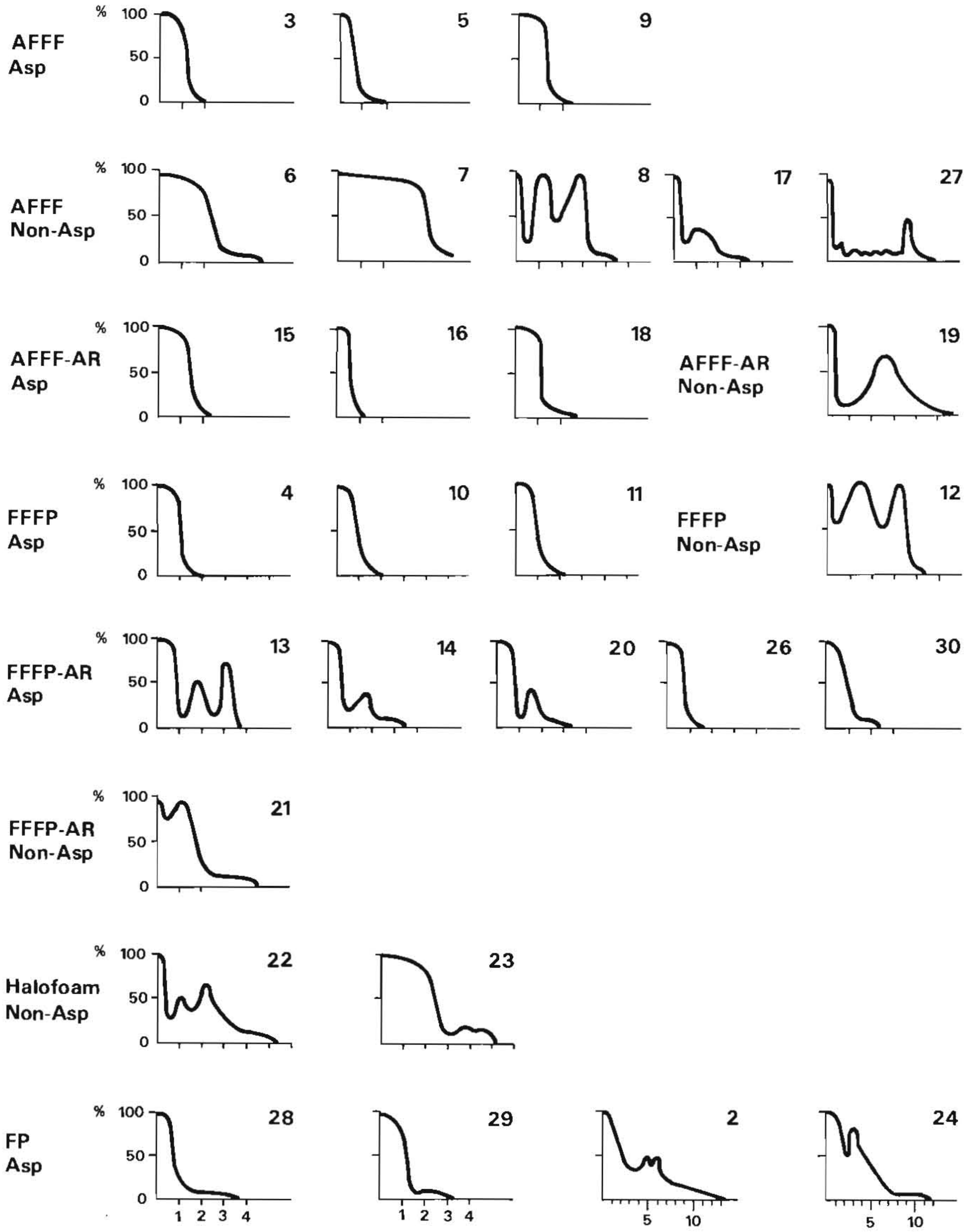


Fig 25: Graph of Burnback Results



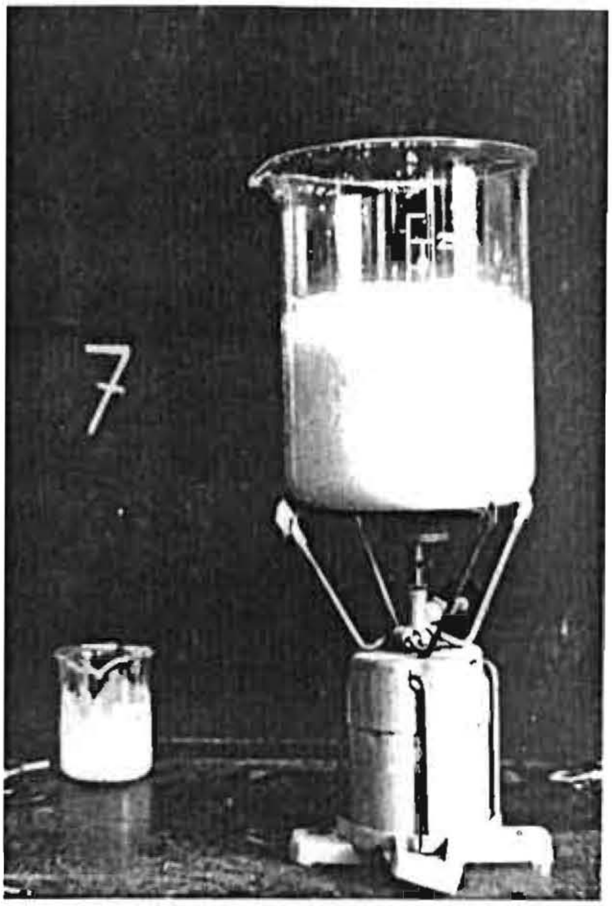
Horizontal Axis Shows Time in Minutes from Application of Foam

Vertical Axis Shows Fire Area as a % of Total Area

Fig 26: Area of Fire v Time for Tests

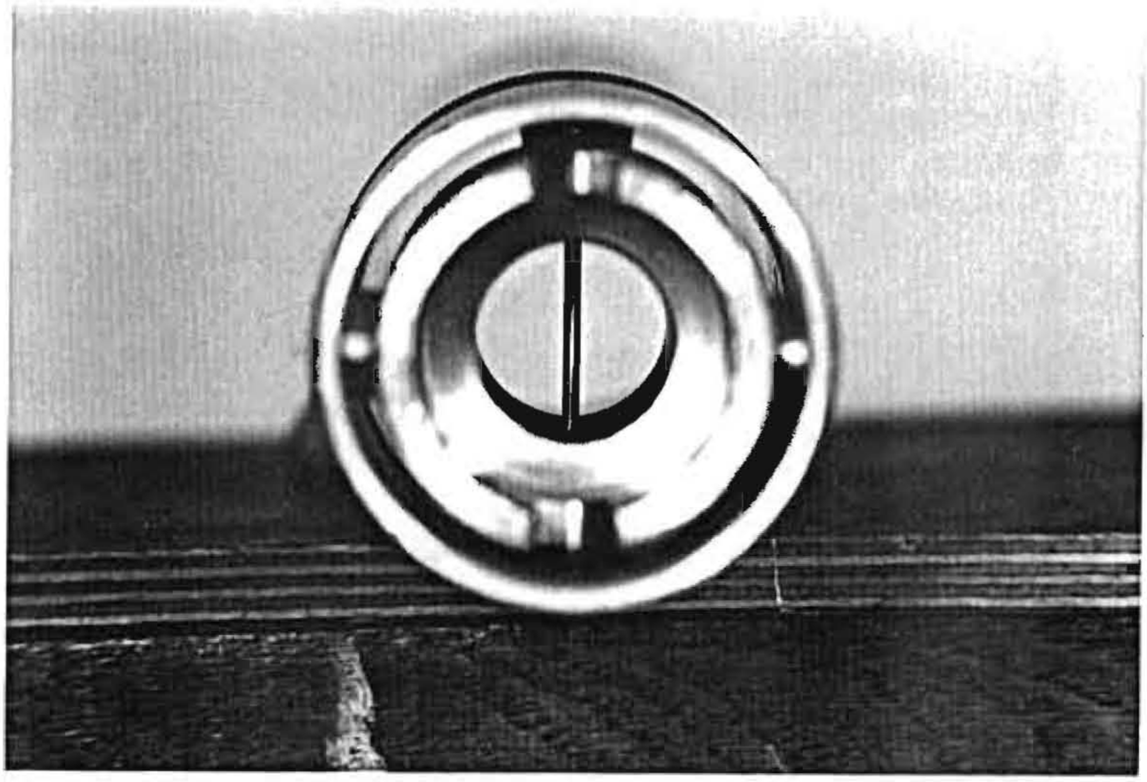
Figure 27 : Test 8, showing area of extinction after 13 seconds

Figure 28 : Test 8, showing fire increased at 1 minute 18 seconds



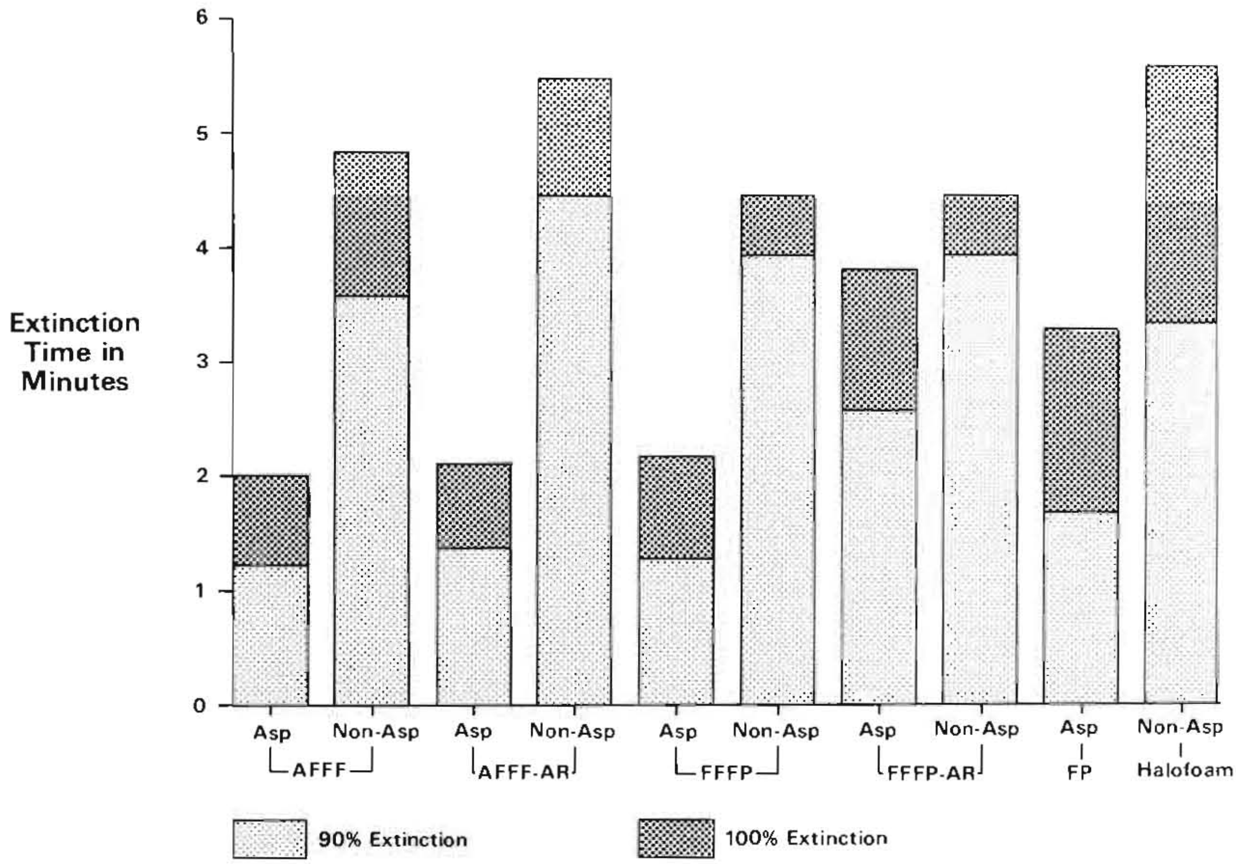
S/128/86

Figure 29 : Halofoam: expansion test.



C/463/86

Figure 30 : End view of Aspirator Attachment



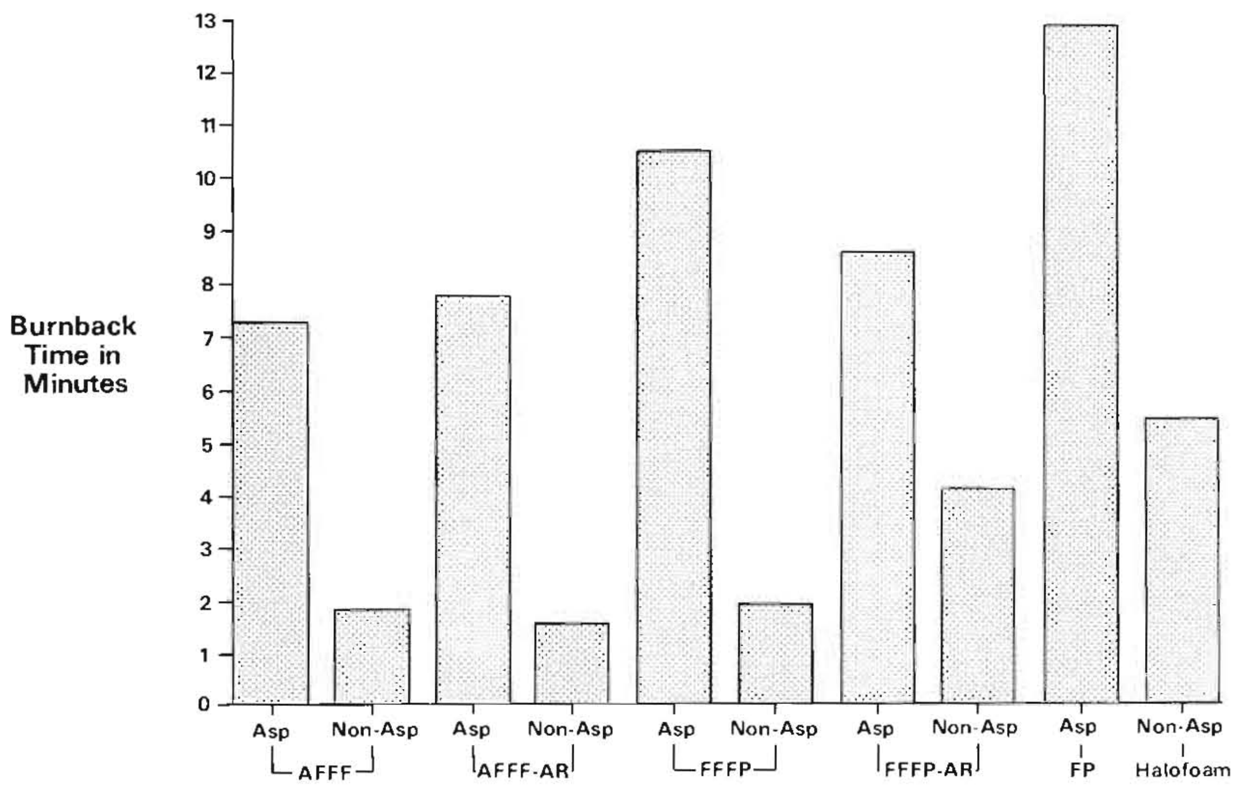
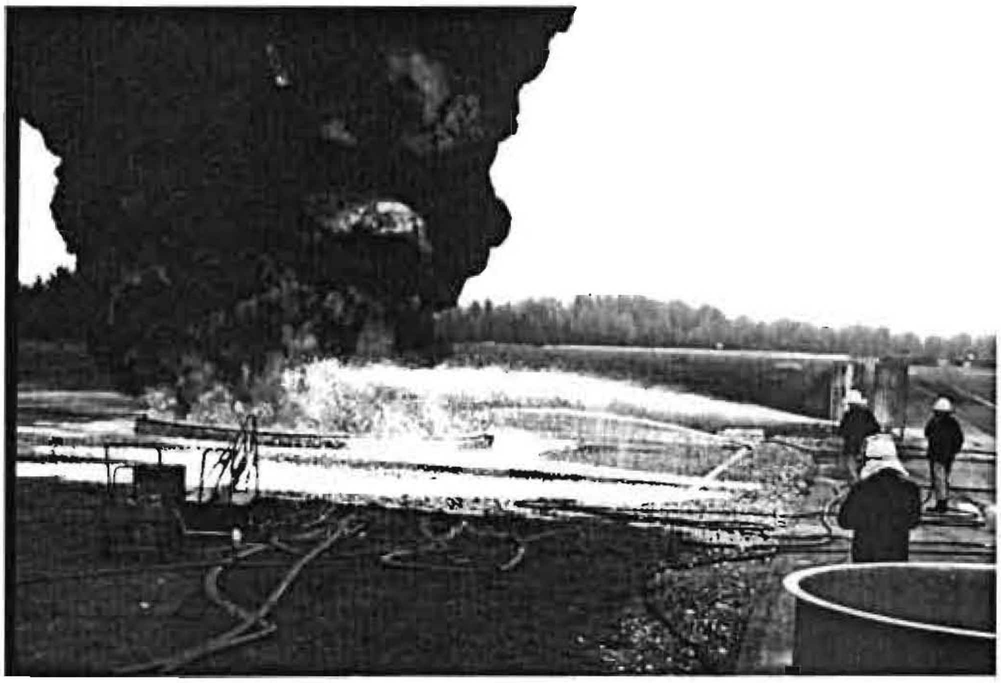


Fig 31: Summary of Petrol Fire Results

C/546/86

Figure 32 : Foam stream from FRS branchpipe



S/81/86

Figure 33 : Foam stream from branch with aspirator fitted

APPENDIX A PROBLEM DESCRIPTION

FIRE RESEARCH

PROBLEM DESCRIPTION

F4.7(85) The use of additives in Fire Service hosereel systems

Background

To improve fire-fighting efficiency the first strike capability of appliances must be optimised. In general this may be achieved by maximising the effectiveness of the initial supply of water in the appliance tank. Where water supplies are scarce, such as on motorways or in rural areas, it becomes critical that the tank supply is used efficiently.

The use of additives in appliance water supplies has already been adopted in some fire brigades to improve fire-fighting efficiency. It has been argued that they are particularly advantageous where water supplies are limited, for example at road traffic accidents on motorways or in rural areas. At incidents with adequate water supplies, control may be secured with less water if a greater wetting effect can be achieved with the water. The types of fires which fall into this category include thatch fires and industrial fires where the fire load includes large amounts of fluff or finished products such as carpets or matresses. An objective assessment of the merits of the various additives is required to help brigades use the most cost-effective extinguishing agent.

Additives may be foam concentrates, wetting agents or other products. Foam concentrate may be added to water for incidents involving volatile liquid fuels. A number of other chemicals are available to aid fire fighting by increasing the wetting ability of water or by enabling the water to vaporize more quickly thus removing a greater amount of heat from the fire. Additives of these types are commercially available but their relative effectiveness for fire service applications has not been fully quantified.

Problem description

To assess the performance of water additives for first attendance hosereel systems taking into account the different fuel loads which may be encountered operationally.

The suitability of some additives may be dependent on the tactics and equipment used to apply them and these aspects should not be overlooked in the final recommendations.

Timescale

The final report should be received in G2 by 31st January 1988.

Cost

Significant expenditure is contemplated for the duration of the project.

DURATION :	Initial study approximately 3 months. Testing approximately 6 months. A final report would be expected by Winter 1986.
COST :	£5000 minimum

Work Package 9

OBJECTIVES:	To produce final report.
METHOD:	A final report will be produced which will summarise and discuss all the work completed.
DURATION:	Final report will be made available to G2 by 31st January 1986.
COST:	Cost of production of report £500

3. Duration

A final report will be made available to G2 by 31st January 1988.

4. Cost

The overall cost is estimated at £95500

5. Manpower requirements

Fire Experimental Unit staff	2.20	man-years
Seconded Fire Officer	0.25	man-years
Local authority fire-fighters	0.80	man-years (1 crew (5 men) in attendance for each full scale fire)

Contractors - manpower costed in work packages.

Submitted by: , on behalf of SRDB.

Date:

Agreed with SRDB by:

On behalf of:

Date:

APPENDIX B PROJECT PROPOSAL

FIRE RESEARCH

PROJECT PROPOSAL

F4.7(85) The use of additives in Fire Service hosereel systems

1. General Considerations

Many water additives for fire-fighting are available. A number fall loosely into the definition 'fire-fighting foam' but the method of application, the requirement for aspiration and the fuels on which they are effective may differ. In addition to the 'foams' there are wetting agents (specifically for Class A fires), novel additives and special chemicals for forest fire-fighting. The scope of this project is to examine all these types of additives with the exception of those specifically for forestry fires.

To date, a laboratory size test which would accurately predict the fire-fighting performance of additives has not been developed. With foam agents there are problems in reproducing aspirated foam at small scale which has similar properties to that produced with fire service equipment. However, small scale tests may be useful for 'screening' products before embarking on full scale testing.

Full scale tests using fire service equipment on fires of realistic size are necessarily expensive. Unlike a laboratory test, a full scale test may have uncontrolled variables such as weather and the experience of the firefighter. However, they are important in order to gain an understanding of additive performance under operational conditions.

2. Project Proposal

The objectives of the project relate specifically to appliance hosereel systems and are as follows:

1) To find which additives improve control and extinction of Class A fires.

2) To find the most suitable additives for control and extinction of Class B fires and to evaluate burn-back resistance.

3) To evaluate additive performance against non-standard fuels, for example: tyres and polyurethane foam furniture.

4) To investigate the tactical variations possible when applying additives through hosereel systems, for example: aspirated/non-aspirated, high/low pressure, spray/jet, number of branches.

It is proposed to fulfil the objectives by a series of interlinked test programmes. Small scale standard tests will be undertaken to select additives for full scale testing. It is hoped that the small scale results may correlate with results from the full scale tests. Should this be the case, future products may be assessed relatively quickly against the bank of data acquired from the proposed project.
A standardised full scale test procedure will be developed for Class A fires using knowedge gained from Project F4.6(84) High pressure fog/Low pressure spray trials.

The additives selected for full scale testing will then be used to extinguish a standard room fireload using fire service hosereel equipment.

Similarly a standardised full scale test facility will be developed for Class B fires. Pool fires of a suitably severe fuel will be extinguised utilising selected additives through fire service equipment.

Both the full scale Class A and B fires will enable tactical variations to be tested in addition to testing the additives themselves.

It is proposed that in addition to the tests on wood cribs and hydrocarbon fuels further full scale tests are performed on such materials as tyres, polyurethane foam and alcohols.

Since the additives recommended at the conclusion of the project may be induced into the hydraulic system of a fire appliance it is proposed that a study be made of the corrosive effects of the additives. Such a study would offer guidance on the types of material to be avoided in additive systems.

The work will be divided into 9 work packages.

Work Package 1

OBJECTIVE: To establish the extent and value of current knowledge on additives.

METHOD: A continuing survey of literature throughout the duration of the project will be carried out to ascertain the current body of knowledge. Contact with Fire Service personnel involved in using or testing additives will be maintained. Liaison with other research agencies will be maintained.

DURATION: A survey of previous work will be included in the final project report.

COST: No significant cost.

Work Package 2

OBJECTIVES: To obtain small scale Class A fire test data to assist in the selection of additives for full scale testing.

To develop a small scale test method for future selection of additives.

To provide small scale test results for correlation with full scale tests.

METHOD: Tests based on BS 5423:1980 but modified by FEU will be carried out by an external contractor.

DURATION: A report from the contractor is expected in March 1986.

COST: Approximately £4400

Work Package 3

OBJECTIVES: To obtain small scale Class B fire test data to assist in the selection of additives for full scale testing.

To develop a small scale test method for future selection of additives.

To provide small scale test results for correlation with full scale tests.

METHOD: Tests based on BS 5423:1980 but modified by FEU will be carried out by an external contractor.

DURATION: A report from the contractor is expected in March 1986.

COST: Approximately £6000

Work Package 4

OBJECTIVES: To obtain Class A fire test data from realistically sized fires tackled with fire service equipment.

To select the most suitable additives for control and extinction of Class A fires.

METHOD: To use the fire test room and standard test procedure developed for Project F4.6(84) to compare the relative effectiveness of various additives.

DURATION: The fire test room will not be built until October 1986. F4.6(84) will then have priority in its use. It is thought that the start of the present work will be delayed until May 1987. Completion should be approximately 4 months from the commencement of testing.

COST: Approximately £5000 (10 tests)

Work Package 5

OBJECTIVES: To procure a test facility with a pool fire tray and develop test procedures.

METHOD: A test facility with a $40m^2$ pool fire tray will be built on site. An alternative burn-back test will be developed.

DURATION: The estimated completion date is June 1986.

COST: Approximately £26600

Work Package 6

OBJECTIVES: To obtain Class B fire test data from realistically sized fires tackled with fire service equipment.

To select the most suitable additives for control and extinction of Class B fires and to evaluate burn-back resistance.

METHOD:	The $40m^2$ pool fire tray will be used for this work. A standard test procedure will be developed based on past experience and current knowledge. The relative effectiveness of additives will be tested on petrol fires.
DURATION	Trials are scheduled to take place in October 1986 and the draft report should be available by the estimated completion date of January 1987.
COST:	Cost of trials £30000 (10 tests - 5 days)

Work Package 7

OBJECTIVES: To obtain full scale fire test data from non-standard fuels such as tyres, polyurethane foam furniture and alcohols.

To select the most suitable additives for control and extinction of such fires.

METHOD: Realistically sized test fires and a standard test procedure will be developed. Extinguishing tests will be performed with fire service hosereel equipment.

DURATION: Tyre fires and alcohol fires will be performed on the outdoor test facility which will be ready for use in 6 months. Preparation and testing will take 1 month for each fuel type. Work package 4 will take priority over this package and so it is unlikely that a report could be produced before Spring 1987.

Furniture tests will be performed in the fire test room. Work package 3 will take priority over these tests. Completion of the work should be approximately 4 months from the commencement of testing.

COST:

Cost of fuel : (approximate)	tyres	£2500	(10 fires - 10 tyres/fire)
	alcohol	£2500	(5 fires)
	furniture	£3000	(10 fires)
Cost of tests : (approximate)	tyres	£3000	(3 days)
	alcohol	£2000	(2 days)
	furniture	£5000	(5 days)

TOTAL : £18000

Work Package 8

OBJECTIVES: To study the corrosive effects of additives on the hydraulic systems of fire appliances.

To advise on materials to be avoided in appliances fitted with additive induction systems.

METHOD : An initial study will be undertaken by an external contractor into the most suitable test methods for gaining the information required. When test methods have been established, testing will be put out to further contract.

Priority

To be decided by Fire and Emergency Planning Department.

Other factors

The Fire Service has a statutory obligation to mitigate damage during fire-fighting operations. Benefits should therefore also be assessed in terms of reduced fire loss and quicker extinction if suitable additives can be found.

Factors which should be taken into account in the trials include the cost effectiveness of the products tested, the need to minimize the storage space required on appliances, the effect of additives on Fire Service equipment (including the appliances) and the possible hazard to personnel from a health and safety viewpoint.

Brigades have a clearly identified requirement to carry foam making equipment on first-line appliances. It may be that some would be reluctant to carry additional additives for specialist tasks; therefore the identification, if possible, of a multi-purpose additive would be advantageous.

Submitted by :

On behalf of :

Date :

Agreed with client, on behalf of SRDB :

Date :

APPENDIX C Work Package Definition

FIRE RESEARCH

WORK PACKAGE DEFINITION
F4.7(85) The use of additives in Fire Service hosereel systems

WORK PACKAGE 6 : Large scale Class B fire tests

Objectives

To obtain Class B fire test data from realistically sized fires tackled with fire service equipment.

To select the most suitable additives for control and extinction of Class B fires and to evaluate burn-back resistance.

Description of work

The $40m^2$ pool fire tray will be used for this work.

The fuel for the fires will be petrol. Each fire will have a one minute pre-burn before additive solution is applied. It is estimated that 1,125 litres of fuel will be required for each test to avoid fuel exhaustion terminating the test before extinction or burn-back has been achieved.

The following additives will be tested: 'FP70'- fluoroprotein, 'Light Water'- AFFF, 'Petroseal'- FFFP, 'Halofoam', ATC - alcohol resistant AFFF and 'Alcoseal'- alcohol resistant FFFP.

Additives in solution to the manufacturers recommended concentration will be applied through a high pressure hosereel branch at a rate of 2.5 litres per minute per square metre. 'FP70' will be tested aspirated, 'Halofoam' will be tested non-aspirated and the other additives will be tested both with and without aspiration, where appropriate as determined in Work Package 4. Each aspirated foam (with the exception of Halofoam which is self-aspirating and will therefore be applied non-aspirated) will be tested on three fires. Three tests will be performed on non-aspirated AFFF and one test will be performed on each of FFFP, Alcoseal and ATC non-aspirated as a demonstration. A total of 24 fires will be extinguished. Contingency for a further six fires will be made.

A burn-back test will be performed on the foam blanket after each extinction test.

The data recorded from each test will include times to 90% control and 100% extinction, radiation levels from the fire, volume of additive applied, time to 100% burn-back. A video record will be made of the trials.

Target dates

The estimated start date is August 1985.

Trials are scheduled to take place in October 1986.

The estimated completion date is January 1987.

Cost

Costs are calculated on the assumption that duty will be paid on fuel for experimental testing. The total cost on this basis is £30,000 of which £10,620 is fuel duty.

Manpower

The SRDB project leader will be J Foster until appointment of replacement for Fiona Smith.

Intramural manpower requirements .... 1.2 man-year
Seconded Fire Officer................... 0.1 man-year
Extramural manpower requirements........ 0.5 man-year

Extramural manpower requirements include a local authority Fire Brigade appliance and crew in attendance for fire tests.

Submitted by: Martin Thomas , on behalf of SRDB.

Date: 24.6.86

Agreed with SRDB by: J. Wake

On behalf of: G.2.

Date: 26.6.86.

APPENDIX D : GLOSSARY OF TERMS USED IN THE REPORT.

Alcohol resistant(AR) foam concentrates

These are formulated for use on water miscible liquids; the foams produced are more resistant than ordinary foams to breakdown by the liquid. They may be of any of the classes of foam concentrates e.g. AFFF-AR, FFFP-AR. Film-forming foams do not form films on water miscible liquids.

Generally used at 6% concentration on water miscible fuels and 3% on hydrocarbon fuels.

Application rate

The discharge rate/area measured in litres per minute per metre^2.

Aqueous film-forming foam(AFFF) concentrates

These are generally based upon mixtures of hydrocarbon and flourinated hydrocarbon surface active agents. Foam solutions made from flourochemical concentrates are film forming on some liquid hydrocarbon fuel surfaces. Generally used at 1%, 3%,or 6%.concentration.

To achieve effective performance, the premix or induction system must take account of the concentrate used. For each 100 litres of solution the concentrates must be mixed as follows:

Concentration	Volume of additive litres	Volume of water litres	Volume of solution litres
1%	1	99	100
3%	3	97	100
6%	6	94	100

Aspirator

An attachmnent to a hosereel branchpipe in which foam solution is aerated.

Concentration

The ratio of foam concentrate in the foam solution usually expressed as a percentage, vol/vol.

Drainage Time

The time for a defined percentage, 25 % in this report, of the liquid content of a foam to drain out under specified conditions.

Expansion ratio

The ratio of the volume of aerated foam to the volume of foam solution from which it was made.

Extinction times

The times from application of foam to extinction of 90% of tray area (90%

extinction) or the whole area (100% extinction).

Film forming

The characteristics of a foam or foam solution forming an aqueous film on some hydrocarbon liquids. The term may be applied to foam and foam concentrates and solutions.

Film-forming fluoroprotein FFFP foam concentrates.

Fluoroprotein foam concentrates which give foam solutions which are film forming on some hydrocarbon liquids.

Fireout

This is an additive of which few details are given in the manufacturers literature, but more information is given in United States Patent 4,398,605, dated August 16th 1983.

The abstract from this patent states "The fire fighting composition is formed from a concentrate comprising one or more nonionic surfactants having a combined cloud point of 68^{o} F-212^{o} F and sufficient water to form a concentrate solution of not greater than 30% by weight of the surfactant".

'Fireout' is claimed by the manufacturers to have a water cooling efficiency up to 40 times that of water.

Fluoroprotein (FP) foam concentrates.

These are protein foam concentrates with added flourinated surface active agents. the foam is generally more fluid than protein foam, gives faster control and extinction of the fire, and has a greater ability to resseal if the foam blanket is disturbed. The foam is more resistant to contamination by hydrocarbon liquids. Generally used at 3% or 6% concentration.

Foam

The result of mixing foam concentrate, water and air to produce bubbles.

Foam concentrate

Foam concentrates are liquids, usually aqueous solutions, which are mixed with water to produce the foam solution used to make foam.

Foam solution

A solution of foam concentrate in water at the appropriate concentration.

Halofoam

"Halofoam" is a relatively new additive that combines AFFF with halon compounds. In "Halofoam", emulsified halons are released by the heat of the fire and as they expand, they foam the AFFF solution. Halofoam is applied non-aspirated and claimed to produce an aspirated finished foam. The manufacturers state that " There is virtually no air trapped within the foam cells which could feed reignition or even explosion".

Non-progressive extinction

See Progressive extinction.

Progressive extinction

Used in this report to describe the extinction phase of a fire where from the first appearance of a foam blanket, the foam blanket area increases until the fire is extinguished.

Non-progressive extinction is used to describe the extinction when an area of foam may be visible but the foam blanket area then can decrease significantly before final extinction is obtained.

Shear Stress

The measurement of the stiffness of a foam sample in a viscometer in newtons per square metre (N/M^2).

Spotting

Term used to describe the reduced flowrate used after 90% extinction in FIRTO tests to achieve final extinction.

APPENDIX E FIRTO Report

TE 2326

February 1986

Fire extinguishing tests

Home Office Fire Experimental Unit

FIRTO

Technical Evaluation

Report for Home Office, Scientific Research and Development Branch, Fire Experimental Unit, c/o Fire Service College, Moreton-in-Marsh, Gloucestershire, GL56 ORH.

Fire extinguishing tests using water with and without various water additives or foam concentrates.

FIRE INSURERS' RESEARCH AND TESTING ORGANISATION
Melrose Avenue, Borehamwood, Hertfordshire, WD6 2BJ
Telephone: 01-207 2345 Telex: 291835

1 INTRODUCTION

This report describes a series of fire extinguishing tests conducted jointly with the Home Office Fire Experimental Unit (H.O.F.E.U.).

The tests involved the use of water with and without various water additives or foam concentrates as extinguishing agents and were preliminary to a more comprehensive H.O.F.E.U. project investigating the properties and use of water additives and foam concentrates for Fire Brigade purposes.

Participation in this phase of the project was requested by the H.O.F.E.U., order numbers SRDB M454 and SRDP M455, dated 25 November 1985.

2 EQUIPMENT AND EXTINGUISHING AGENTS SUPPLIED

2.1 Equipment

Extinguishing agent was applied to the test fire by means of a geared pump feeding a 36.6m length of 19.05mm bore hose fitted with either an aspirated or non-aspirated nozzle.

The pump was arranged to give a selectable, variable flow at a constant pressure. The pressures measured at the delivery end of the hose were:

Aspirated nozzle at 9L/min	-	2.7bar
at 11L/min	-	4.0bar
Non-aspirated nozzle (spray) at 11L/min	-	4.0bar
Non-aspirated nozzle (jet) at 9L/min	-	2.6bar
at 11L/min	-	4.0bar

The aspirated nozzle used was from a proprietary portable fire extinguisher (reference Thorn-EMI Protech 9L AFFF).

The non-aspirated nozzle was a standard, adjustable, garden-hose nozzle. For the tests described in this report two settings were selected. One setting (designated Jetspray) gave a hollow-cone spray pattern with a small droplet size. The other (designated Jet) delivered a coarse broken jet.

The delivery end of the hose was equipped with a device to interrupt discharge.

All extinguishing agents were pumped from an open reservoir.

For the 'burn-back' phase of the Class B test fire series a propane gas/air blowtorch was used, arranged to apply the flame to the surface of the foam at a fixed distance in from the edge of the test tray.

2.2 Extinguishing agents

The following extinguishing agents were used:

- Water
- Angus 'Alcoseal' (3%)
- Angus FP70 (3%)
- Macron 'Fire-out' (0.2%)
- 3M AFFF (3%)
- RTG 'Halofoam' (15%)

Figures in parenthesis indicate solution strength in water.

3 TEST PROGRAMME

3.1 General

The series of tests were undertaken in three phases:

Class A test fires
Class B indicative test fires
Class B test fires

Throughout the series of tests all aspects of test fire preparation, fire-fighting and data recording were the responsibility of FIRTO. Staff from the Fire Experimental Unit prepared each extinguishing agent for test, operated the delivery pump, took video recordings of each test and acted as observers.

3.2 Class A test fires

The Class A test fires were generally conducted in accordance with Clause 26 of B.S. 5423 : 1980[1], with the exception that extinguishing efficiency was based upon flame knockdown, rather than upon total extinguishment and subsequent 3 minute dormant period. The objective therefore was not to achieve a test rating but to use the test fire configuration in order to determine comparative extinguishing efficiency between water and the various additives and foam solutions. The extinguishing technique involved a continuous application of agent to achieve knockdown and, if necessary, additional cooling to prevent instant re-ignition.

3.3 Class B indicative test fires

The Class B indicative test fires were generally conducted in accordance with Clause 27 of B.S. 5423 : 1980[1] using a size 34B test tray. The object being to determine whether certain additives, of which little was known, were suitable for testing on larger-size test fires. Again water was used for datum purposes. Application of the extinguishing agent was on a continuous basis.

3.4 Class B test fires

The Class B test fires were also conducted generally in accordance with Clause 27 of B.S. 5423 : 1980[1] with the exception that following complete extinguishment a burn-back test was conducted. In general, extinguishing agent was applied to the fire continuously until effective knockdown was achieved and then on at a reduced rate for spotting purposes. This latter phase was either continuous or intermittent at the discretion of the fire-fighter.

The burn-back test involved applying a flame to the surface of the foam blanket, using the apparatus described in Section 2 until the fuel re-ignited and the fire became sustained, and then timing the period to 100% re-involvement.

3.5 Instrumentation

Apart from the instrumentation required to carry out the tests in accordance with the appropriate British Standard test method, the flow of extinguishing agent and radiation from the test fire were also monitored.

For radiation monitoring, two heat flux transducers were used, positioned as shown in Figures 1 and 2. All subsequent chart recordings were used by the Fire Experimental Unit for graphical representation of fire development and do not form part of this report.

Transducer positions – 1m high

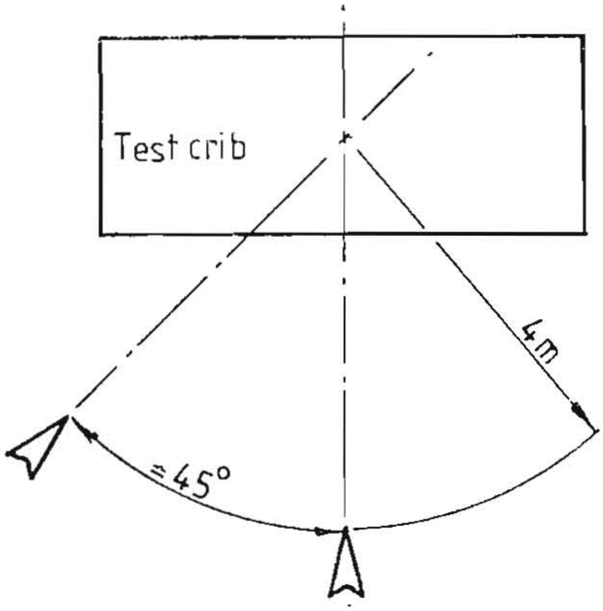


Figure 1 Position of heat flux transducers for Class A fire tests

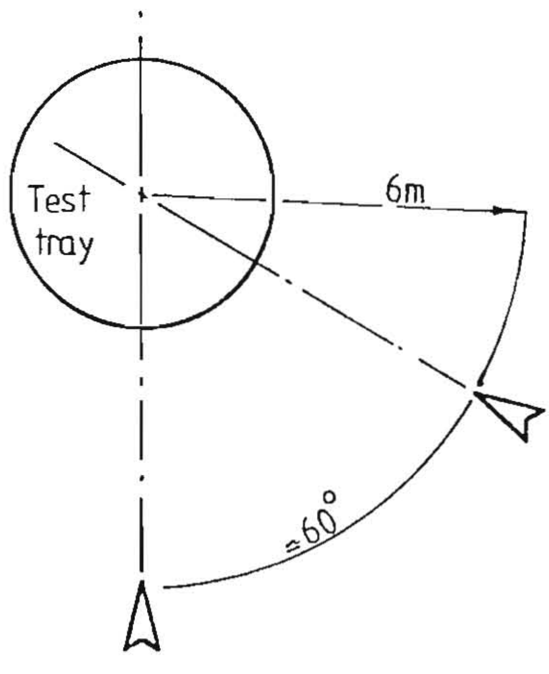


Figure 2 Position of heat flux transducers for Class B fire tests

4 RESULTS

4.1 Class A test fires

The results are summarized in Table 1.

Test Number :	1A
Extinguishing agent :	Water
Nozzle type :	Jet
Extinguishing agent temperature (°C) :	18.0
Ambient temperature (°C) :	2.7
Fire size :	13A
Rate of application (L/min) :	9.0
Application time (min:s) :	0:52
Quantity of agent used (L) :	7.8
Time to knockdown (min:s) :	0:52

Comments/observations

This test was to some degree exploratory since the datum point for knockdown had not been predetermined.

It was considered that tests 10A and 11A were more representative and that for this test a greater quantity of extinguishing agent may have been used unnecessarily in order to achieve the same end results. It was also noticeable that the heart of the test crib after extinguishing was cooler and exhibited less hot-spots than the corresponding test cribs of tests 10A and 11A.

X X X

Test Number :	2A
Extinguishing agent :	AFFF
Nozzle type :	Jet
Extinguishing agent temperature (°C) :	18.6
Ambient temperature (°C) :	5.9
Fire size :	13A
Rate of pplication (L/min) :	9.1
Application time (min:s) :	0:48
Quantity of agent used (L) :	7.3
Time to knockdown (min:s) :	0:48

Comments/observations

It was noticeable that the foam reduced the effective penetration of the jet and that the heart of the test crib was hotter than the corresponding crib of test 1A.

Test Number :	3A
Extinguishing agent :	AFFF
Nozzle type :	Aspirated
Extinguishing agent temperature (°C) :	22.0
Ambient temperature (°C) :	6.1
Fire size :	13A
Rate of application (L/min) :	9.0
Application time (min:s) :	0:33
Quantity of agent used (L) :	5.0
Time to knockdown (min:s) :	0:33

Comments/observations

Although the heart of the test crib after extinguishing was cooler than that of test 2A (non-aspirated AFFF), it still exhibited more hot-spots than test 1A (Water).

X X X

Test Number :	4A
Extinguishing agent :	FP70
Nozzle type :	Aspirated
Extinguishing agent temperature (°C) :	18.0
Ambient temperature (°C) :	6.0
Fire size :	13A
Rate of application (L/min) :	9.2
Application time (min:s) :	0:35
Quantity of agent used (L) :	5.4
Time to knockdown (min:s) :	0:35

Comments/observations

The incidence of hot-spots at the heart of the test crib after extinguishing was similar to test 3A (aspirated AFFF).

X X X

Test Number :	5A
Extinguishing agent :	FP70
Nozzle type :	Jet
Extinguishing agent temperature (°C) :	22.5
Ambient temperature (°C) :	6.7
Fire size :	13A
Rate of application (L/min) :	8.9
Application time (min:s) :	0:41
Quantity of agent used (L) :	6.1
Time to knockdown (min:s) :	0:41

Comments/observations

The incidence of hot-spots at the heart of the test crib after extinguishing was similar to test 2A (non-aspirated AFFF).

Test Number :	6A
Extinguishing agent :	Halofoam
Nozzle type :	Jet
Extinguishing agent temperature (°C) :	18.9
Ambient temperature (°C) :	6.5
Fire size :	13A
Rate of application (L/min) :	9.0
Application time (min:s) :	0:25
Quantity of agent used (L) :	3.8
Time to knockdown (min:s) :	0:25

Comments/observations

The point of knockdown was difficult to determine as the centre of the test crib was obscured by the foaming action of the extinguishing agent.

Because no allowance was made for the on-going reaction of Halofoam, extinguishing agent may have been applied to excess.

At the conclusion of the test the crib was totally extinguished with no hot-spots in evidence.

X X X

Test Number :	7A
Extinguishing agent :	Fire-out
Nozzle type :	Jet
Extinguishing agent temperature (°C) :	22.6
Ambient temperature (°C) :	5.4
Fire size :	13A
Rate of application (L/min) :	9.0
Application time (min:s) :	0:46
Quantity of agent used (L) :	6.9
Time to knockdown (min:s) :	0:46

Comments/observations

No significant differences when compared with the performance of water.

X X X

Test Number :	8A
Extinguishing agent :	Alcoseal
Nozzle type :	Aspirated
Extinguishing agent temperature (°C) :	21.0
Ambient temperature (°C) :	2.9
Fire size :	13A
Rate of application (L/min) :	9.0
Application time (min:s) :	0:40
Quantity of agent used (L) :	6.0
Time to knockdown (min:s) :	0:40

Comments/observations

Penetration of foam and subsequent crib hot-spots were similar to tests 3A (aspirated AFFF) and test 4A (aspirated FP70).

Test Number :	9A
Extinguishing agent :	Alcoseal
Nozzle type :	Jet
Extinguishing agent temperature (°C) :	22.2
Ambient temperature (°C) :	2.7
Fire size :	13A
Rate of application (L/min) :	9.0
Application time (min:s) :	0:42
Quantity of agent used (L) :	6.3
Time to knockdown (min:s) :	0:42

Comments/observations

No significant differences when compared with aspirated Alcoseal.

X X X

Test Number :	10A
Extinguishing agent :	Water
Nozzle type :	Jet
Extinguishing agent temperature (°C) :	23.4
Ambient temperature (°C) :	2.7
Fire size :	13A
Rate of application (L/min) :	9.0
Application time (min:s) :	0:36
Quantity of agent used (L) :	5.4
Time to knockdown (min:s) :	0:36

Comments/observations

Knockdown datum re-established, less extinguishing agent used.

X X X

Test Number :	11A
Extinguishing agent :	Water
Nozzle type :	Jet
Extinguishing agent temperature (°C) :	23.3
Ambient temperature (°C) :	2.7
Fire size :	13A
Rate of application (L/min) :	9.0
Application time (min:s) :	0:36
Quantity of agent used (L) :	5.4
Time to knockdown (min:s) :	0:36

Comments/observations

Confirmation of test 10A result.

Test Number :	12A
Extinguishing agent :	Water
Nozzle type :	Jet
Extinguishing agent temperature (°C) :	24.0
Ambient temperature (°C) :	4.0
Fire size :	27A
Rate of application (L/min) :	9.0
Application time (min:s) :	2:05
Quantity of agent used (L) :	18.8
Time to knockdown (min:s) :	2:05

Comments/observations

The doubling of the fire load did not yield a corresponding linear extinguishing efficiency owing to the increase in length of the crib which resulted in reduced penetration to the heart of the crib.

A secondary objective of this test and the following two tests was to compare the resistance to re-ignition and subsequent spread of flame.

Re-ignition occurred at one point, 50s after knockout followed by re-ignition at other points and gradual spread of flame.

X X X

Test Number :	13A
Extinguishing agent :	Halofoam
Nozzle type :	Jet
Extinguishing agent temperature (°C) :	17.6
Ambient temperature (°C) :	4.3
Fire size :	27A
Rate of application (L/min) :	9.0
Application time (min:s) :	0:56 + 0:20
Quantity of agent used (L) :	8.4 + 3.0
Time to knockdown (min:s) :	0:56 + 0:20

Comments/observations

As in test 6A vision of the crib heart was obscured by the foaming action of the agent, consequently knockdown was not completely successful at the first attempt and re-ignition occurred practically simultaneously with cessation of agent application.

Further extinguishing agent was therefore applied 15s later in order to achieve knockdown. Subsequent re-ignition occurred at a single point at the heart of the test crib 35s later with a gradual spread of flame at a rate slower than that of the previous test for water.

Test Number : 14A
Extinguishing agent : AFFF
Nozzle type : Aspirated
Extinguishing agent temperature (°C) : 22.2
Ambient temperature (°C) : 5.1
Fire size : 27A
Rate of application (L/min) : 9.0
Application time (min:s) : 1:09
Quantity of agent used (L) : 10.4
Time to knockdown (min:s) : 1:09

Comments/observations

Re-ignition of the test crib occurred at a number of different points, 15s after extinguishing agent had ceased to be applied.

The subsequent involvement of flame was more intense than for the previous two tests for a similar time period, indicating a lower resistance to burnback than that of water and Halofoam.

Table 1 Summary of results of Class A test fires

Fire size	Agent	Nozzle	Application time/ time to knockdown min:s	Agent used L	Test number
13A	Water	Jet	0:52 0:36 0:36	7.8 5.4 5.4	1A 10A 11A
	AFFF	Jet Aspirated	0:48 0:33	7.3 5.0	2A 3A
	FP70	Jet Aspirated	0:41 0:35	6.1 5.4	5A 4A
	Halofoam	Jet	0:25	3.8	6A
	Fire-out	Jet	0:46	6.9	7A
	Alcoseal	Jet Aspirated	0:42 0:40	6.3 6.0	9A 8A
27A	Water	Jet	2:05	18.8	12A
	Halofoam	Jet	0:56 + 0:20	8.4 + 3.0	13A
	AFFF	Aspirated	1:09	10.4	14A

4.2 Class B indicative test fires

The results are summarized in Table 2.

Test Number :	1B
Extinguishing agent :	Water
Nozzle type :	Jetspray
Extinguishing agent temperature (°C) :	25.0
Ambient temperature (°C) :	6.5
Fire size :	34B
Rate of application a) continuous (L/min) :	11.0
b) spotting (L/min) :	-
Application time - continuous (min:s) :	1:00
Quantity of agent used (L) :	11.0
Time to 90% extinction (min:s) :	-
Time to 100% extinction (min:s) :	-

Comments/observations

Test fire not extinguished, extinguishing agent had little effect, therefore the test was terminated.

X X X

Test Number :	2B
Extinguishing agent :	Fire-out
Nozzle type :	Jetspray
Extinguishing agent temperature (°C) :	25.0
Ambient temperature (°C) :	6.7
Fire size :	34B
Rate of application a) continuous (L/min) :	10.8
b) spotting (L/min) :	-
Application time - continuous (min:s) :	1:00
Quantity of agent used (L) :	10.8
Time to 90% extinction (min:s) :	-
Time to 100% extinction (min:s) :	-

Comments/observations

Test fire not extinguished, extinguishing agent had little effect, therefore the test was terminated.

No significant difference when compared with the performance of water.

Test Number :	3B
Extinguishing agent :	Halofoam
Nozzle type :	Jetspray
Extinguishing agent temperature (°C) :	25.0
Ambient temperature (°C) :	7.2
Fire size :	34B
Rate of application a) continuous (L/min) :	11.1
b) spotting (L/min) :	-
Application time - continuous (min:s) :	0:43
Quantity of agent used (L) :	8.0
Time to 90% extinction (min:s) :	0:38
Time to 100% extinction (min:s) :	0:43

Comments/observations

Owing to the spray pattern of the jet, a quantity of agent fell short of the test tray during initial application. As a result it was considered that extinguishing time and quantity of agent used could have been reduced.

It was also considered that the fine spray generated by the nozzle setting was detrimental to extinguishing efficiency and that a coarser jet would have been more efficient.

4.3 Class B test fires

The results are summarized in Table 2.

Test Number :	4B
Extinguishing agent :	FP70
Nozzle type :	Aspirated
Extinguishing agent temperature (°C) :	23.5
Ambient temperature (°C) :	7.8
Fire size :	144B
Rate of application a) continuous (L/min) :	10.7
b) spotting (L/min) :	7.8
Application time - continuous (min:s) :	1:40
Quantity of agent used (L) :	43.8
Time to 90% extinction (min:s) :	1:00
Time to 100% extinction (min:s) :	-

Comments/observations

Test fire not extinguished. Subsequent to initial knockdown the impact force of the jet destroyed the integrity of the foam blanket lying on the surface of the fuel. Little recovery was apparent and the fire gradually re-developed.

It was considered that improved performance could be obtained with a more efficient application technique.

Test Number :	5B
Extinguishing agent :	FP70
Nozzle type :	Aspirated
Extinguishing agent temperature (°C) :	24.2
Ambient temperature (°C) :	7.3
Fire size :	144B
Rate of application a) continuous (L/min) :	11.2
b) spotting (L/min) :	4.7
Application time - continuous (min:s) :	1:34
Quantity of agent used (L) :	23.0
Time to 90% extinction (min:s) :	1:05
Time to 100% extinction (min:s) :	9:10

Comments/observations

Generally similar to previous test (4B) but revised technique and reduced flow during the spotting phase permitted extinguishing albeit protracted.

Burn-back characteristics:

Time to application of flame (min:s) :	3:40
Application time of flame (min:s) :	2:40
Time to 25% burn-back (min:s) :	1:25
Time to 50% burn-back (min:s) :	1:40
Time to 100% burn-back (min:s) :	2:10

X X X

Test Number :	6B
Extinguishing agent :	Alcoseal
Nozzle type :	Aspirated
Extinguishing agent temperature (°C) :	25.5
Ambient temperature (°C) :	4.6
Fire size :	144B
Rate of application a) continuous (L/min) :	11.4
b) spotting (L/min) :	6.0 - continuous
Application time - continuous (min:s) :	1:25
Quantity of agent used (L) :	20.6
Time to 90% extinction (min:s) :	1:10
Time to 100% extinction (min:s) :	2:10

Comments/observations

Better flow characteristics resulted in more efficient extinguishing than that of FP70 (test 5B).

Burn-back characteristics:

Time to application of flame (min:s) :	4:43
Application time of flame (min:s) :	2:22
Time to 25% burn-back (min:s) :	0:50
Time to 50% burn-back (min:s) :	1:15
Time to 100% burn-back (min:s) :	1:25

Test Number :	7B
Extinguishing agent :	Alcoseal
Nozzle type :	Aspirated
Extinguishing agent temperature (°C) :	21.0
Ambient temperature (°C) :	5.5
Fire size :	144B
Rate of application a) continuous (L/min) :	11.3
b) spotting (L/min) :	-
Application time - continuous (min:s) :	1:14
Quantity of agent used (L) :	28.0
Time to 90% extinction (min:s) :	1:10
Time to 100% extinction (min:s) :	2:55

Comments/observations

Repeat of test 6B owing to malfunction of monitoring instrumentation.

Extinguishing characteristics similar to previous test but restriction in hose during the spotting phase caused protracted extinguishing time.

Burn-back characteristics:

Time to application of flame (min:s) :	2:00
Application time of flame (min:s) :	2:42
Time to 25% burn-back (min:s) :	0:40
Time to 50% burn-back (min:s) :	1:10
Time to 100% burn-back (min:s) :	1:30

X X X

Test Number :	8B
Extinguishing agent :	Alcoseal
Nozzle type :	Jetspray
Extinguishing agent temperature (°C) :	24.0
Ambient temperature (°C) :	5.8
Fire size :	144B
Rate of application a) continuous (L/min) :	11.1
b) spotting (L/min) :	-
Application time - continuous (min:s) :	3:35
Quantity of agent used (L) :	39.8
Time to 90% extinction (min:s) :	-
Time to 100% extinction (min:s) :	-

Comments/observations

Test fire not extinguished.

A thin foam film formed on the surface of the fuel during initial application. This film proved to be inadequate and was subsequently broken down allowing the fire to re-establish.

It was considered that the fine spray generated by the nozzle again contributed to inefficient extinguishing.

Test Number :	9B
Extinguishing agent :	AFFF
Nozzle type :	Aspirated
Extinguishing agent temperature (°C) :	24.0
Ambient temperature (°C) :	6.6
Fire size :	144B
Rate of application a) continuous (L/min) :	11.3
b) spotting (L/min) :	6.3 - continuous
Application time - continuous (min:s) :	0:55
Quantity of agent used (L) :	11.8
Time to 90% extinction (min:s) :	0:40
Time to 100% extinction (min:s) :	1:09

Comments/observations

Good knockdown and flow characteristics resulted in highly efficient extinguishing.

Burn-back characteristics:

Time to application of flame (min:s) :	2:00
Application time of flame (min:s) :	2:55
Time to 25% burn-back (min:s) :	1:35
Time to 50% burn-back (min:s) :	2:25
Time to 100% burn-back (min:s) :	2:44

X X X

Test Number :	10B
Extinguishing agent :	AFFF
Nozzle type :	Jetspray
Extinguishing agent temperature (°C) :	25.0
Ambient temperature (°C) :	7.0
Fire size :	144B
Rate of application a) continuous (L/min) :	11.3
b) spotting (L/min) :	-
Application time - continuous (min:s) :	2:55
Quantity of agent used (L) :	33.0
Time to 90% extinction (min:s) :	-
Time to 100% extinction (min:s) :	-

Comments/observations

Test fire not extinguished.

Apart from the formation of a fine film on the surface of the fuel the extinguishing agent had little effect.

Again the fine spray generated by the nozzle was considered to be a major contributory factor.

Test Number :	11B
Extinguishing agent :	Halofoam
Nozzle type :	Jet
Extinguishing agent temperature (°C) :	17.4
Ambient temperature (°C) :	7.2
Fire size :	144B
Rate of application a) continuous (L/min) :	11.3
b) spotting (L/min) :	-
Application time - continuous (min:s) :	1:14
Quantity of agent used (L) :	13.9
Time to 90% extinction (min:s) :	0:55
Time to 100% extinction (min:s) :	1:14

Comments/observations

The action of the foam was such that no spotting was required.

Burn-back characteristics:

Time to application of flame (min:s) :	2:00
Application time of flame (min:s) :	4:03
Time to 25% burn-back (min:s) :	2:30
Time to 50% burn-back (min:s) :	3:00
Time to 100% burn-back (min:s) :	3:10

During burn-back the foam continued to react, extinguishing isolated areas of flame and resisting its spread.

X X X

Test Number :	12B
Extinguishing agent :	AFFF
Nozzle type :	Jet
Extinguishing agent temperature (°C) :	20.4
Ambient temperature (°C) :	5.6
Fire size :	144B
Rate of application a) continuous (L/min) :	11.3
b) spotting (L/min) :	5.8 - continuous
Application time - continuous (min:s) :	2:35
Quantity of agent used (L) :	37.1
Time to 90% extinction (min:s) :	2:30
Time to 100% extinction (min:s) :	3:57

Comments/observations

Repeat of test 10B but with the alternative nozzle setting giving a broken jet instead of a fine spray.

Burn-back characteristics:

Time to application of flame (min:s) :	2:00
Application time of flame (min:s) :	1:30
Time to 25% burn-back (min:s) :	0:35
Time to 50% burn-back (min:s) :	0:50
Time to 100% burn-back (min:s) :	1:20

Test Number :	13B
Extinguishing agent :	Alcoseal
Nozzle type :	Jet
Extinguishing agent temperature (°C) :	21.8
Ambient temperature (°C) :	6.3
Fire size :	144B
Rate of application a) continuous (L/min) :	11.3
b) spotting (L/min) :	-
Application time - continuous (min:s) :	3:15
Quantity of agent used (L) :	36.7
Time to 90% extinction (min:s) :	-
Time to 100% extinction (min:s) :	-

Comments/observations

Test fire not extinguished.

Repeat of test 8B but with the alternative nozzle setting giving a broken jet instead of a fine spray.

No significant difference in result between this and the previous corresponding test.

X X X

Test Number :	14B
Extinguishing agent :	Halofoam
Nozzle type :	Jet
Extinguishing agent temperature (°C) :	24.4
Ambient temperature (°C) :	6.1
Fire size :	183B
Rate of application a) continuous (L/min) :	11.8
b) spotting (L/min) :	-
Application time - continuous (min:s) :	1:25
Quantity of agent used (L) :	24.0
Time to 90% extinction (min:s) :	1:20
Time to 100% extinction (min:s) :	2:00

Comments/observations

The increased surface area of test fire did not affect extinguishing efficiency.

Burn-back characteristics:

Time to application of flame (min:s) :	2:00
Application time of flame (min:s) :	2:00
Time to 25% burn-back (min:s) :	4:30
Time to 50% burn-back (min:s) :	5:05
Time to 100% burn-back (min:s) :	5:20

A secondary objective of this test and the following test was to compare burn-back resistance and subsequent fire re-involvement under the same conditions.

Test Number :	15B
Extinguishing agent :	AFFF
Nozzle type :	Aspirated
Extinguishing agent temperature (°C) :	21.0
Ambient temperature (°C) :	6.6
Fire size :	183B
Rate of application a) continuous (L/min) :	11.8
b) spotting (L/min) :	-
Application time - continuous (min:s) :	1:04
Quantity of agent used (L) :	18.7
Time to 90% extinction (min:s) :	0:55
Time to 100% extinction (min:s) :	1:35

Comments/observations

The increased surface area of test fire did not affect extinguishing efficiency.

Burn-back characteristics:

Time to application of flame (min:s) :	2:00
Application time of flame (min:s) :	2:00
Time to 25% burn-back (min:s) :	3:30
Time to 50% burn-back (min:s) :	3:50
Time to 100% burn-back (min:s) :	4:00

Table 2 Summary of results of Class B test fires

Fire size	Agent	Nozzle	Application time continuous min:s	Time to extinction 90% min:s	Time to extinction 100% min:s	Agent used L	Burn-back flame application time min:s	Burn-back time 25%	Burn-back time 50%	Burn-back time 100%	Test number
34B	Water	Jetspray	1:00	-	-	11.0	-	-	-	-	1B
	Fireout	Jetspray	1:00	-	-	10.8	-	-	-	-	2B
	Halofoam	Jetspray	0:43	0:38	0:43	8.0	-	-	-	-	3B
144B	FP70	Aspirated	1:40	1:00	-	43.8	-	-	-	-	4B
		Aspirated	1:34	1:05	9:10	23.0	2:40	1:25	1:40	2:10	5B
	Alcoseal	Aspirated	1:25	1:10	2:10	20.6	2:22	0:50	1:15	1:25	6B
		Aspirated	1:14	1:10	2:55	28.0	2:42	0:40	1:10	1:30	7B
		Jetspray	3:35	-	-	39.8	-	-	-	-	8B
		Jet	3:15	-	-	36.7	-	-	-	-	13B
	AFFF	Aspirated	0:55	0:40	1:09	11.8	2:55	1:35	2:25	2:44	9B
		Jetspray	2:55	-	-	33.0	-	-	-	-	10B
		Jet	2:35	2:30	3:57	37.1	1:30	0:35	0:50	1:20	12B
	Halofoam	Jet	1:14	0:55	1:14	13.9	4:03	2:30	3:00	3:10	11B
183B	Halofoam	Jet	1:25	1:20	2:00	24.0	2:00	4:30	5:05	5:20	14B
	AFFF	Aspirated	1:04	0:55	1:35	18.7	2:00	3:30	3:50	4:00	15B

5 CONCLUSION

No definitive conclusions can be drawn from the tests described in this report since the test programme was compiled as a fact-finding exercise. The data derived being a preliminary contribution to an on-going more comprehensive Fire Experimental Unit project.

It should be noted that the aspirated nozzle used was designed for optimum performance with AFFF in a portable fire extinguisher. When used as described in this report, with both AFFF and other foam solutions, it was possible that optimum performance may not have been attained.

Because of the manner in which Halofoam performed, it may be advantageous to conduct further tests with weaker solutions as it is considered that comparable performance could be achieved more economically.

It is also conceivable that enhanced performances may also be obtained using the various foam concentrates at different solution strengths.

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ART/ASF
18 February 1986

APPENDIX F DETAILS OF SMALL-SCALE TESTS

TEST 1 (FP70 foam)

Extinction: 90% control was achieved fairly rapidly. The period from 90% control to 100% extinction was dominated by the equilibrium between the established foam blanket holding the fire back and the newly arriving foam breaking up the blanket as it hit the fuel surface. After 7min:24 s the branchman retreated from the fire and angled the branch to apply foam more gently. From this point there was an immediate increase in control. The last flames to be extinguished were forming a 'fringe' around the rim for approximately 20s before the foam blanket finally sealed against the edge.

Burn-back: The foam blanket prevented reignition of the fuel for approximately 2min : 30s. At this time small petrol flames could be seen where the torch flame impinged on the blanket. 50% burn-back was not reached until 15 minutes into the test. 50% to 100% burn-back was very rapid (less than 30s).

TEST 2 (FP70 foam)

Extinction: In this test the branchman stood further from the fire and attempted to apply foam more gently than in Test 1. Nevertheless, time to 90% control was much longer and after control was achieved there was a period of 2 - 3 minutes when the fire appeared to be increasing again. Even gentle foam application seemed to cause the foam blanket to break up. The final 2 minutes of the test were devoted to the extinction of small flames around the rim edge.

Burn-back: The foam blanket resisted the torch flame for 30s before small petrol flames were seen. Development of the fire to 50% of the surface took approximately 7 minutes. As in Test 1, 50% to 100% involvement occured rapidly.

TEST 3 (90°, FP70 foam)

Extinction: In this test the solution flow was halved to 7 litres per minute ($lmin^{-1}$) in an attempt to simulate the impact velocity and foam delivered by an extinguisher. After 4 min: 30 s there had been no significant reduction in the fire and so flow was increased to 9 $lmin^{-1}$. 90% control was achieved after 7 min : 30s (ie 3 minutes after the flow was increased) and 100% extinction followed very rapidly after this. Attempts to reignite proved that the fuel had been exhausted and therefore the test was declared void.

TEST 4 (AFFF foam)

Extinction: 90% control was achieved rapidly. 100% extinction was delayed by residual flames at the rim of the tray.

Burn-back: Ignition of the petrol took approximately 30s. The integrity of the foam blanket remained for a further 7 minutes until 50% and then (rapidly) 100% burn-back was achieved. During the period when the fire was slowly gaining hold, flames were seen to flash across the surface of the foam blanket and ignite fuel at the edge of the tray. These small fires seemed to be self extinguishing as the foam flowed against the rim.

TEST 5 (AFFF spray)

Extinction: Rapid control was achieved but 100% extinction was delayed due to the fire-fighter having to 'chase' flames around the rim of the tray. The fuel surface was covered with thin foamy 'scum' after extinction.

Burn-back: The fuel ignited instantly when the flame was applied. However, the foam 'scum' prevented rapid overall spread of the fire although small flames were seen burning for short periods on top of the foam. 100% burn-back was achieved faster than in Test 4.

TEST 9(1A) (FP70 3% foam)

Extinction: Quick initial knock-down was achieved, 75% control within approximately 50s. 90% control took 1min: 12s after which the fire was confined to flames around the tray rim. These residual flames proved difficult to extinguish thus extending the time to 100% extinction.

Burn-back: Charring of the foam blanket was evident after 1 minute but the fuel under the blanket did not ignite until 1.6 minutes had elapsed. The torch was removed 4 minutes after placement and 50% of the fuel was involved at 4mins : 18s minutes. 100% involvement took a further 1 minute.

TEST 10(1B) (FP70 3% foam, FRS branch)

Extinction: The throw characteristic of the branch meant that some foam did not fall within the tray. Another problem was that the tray developed a pronounced central 'hump' 1 minute after foam was applied which effectively forced all the fuel into a well around the edge of the tray. It was therefore very difficult to estimate control times although the 100% extinction time was noted as 5mins : 42s.

TEST 11(2A) (Petroseal 3% foam)

Extinction: 90% control was achieved rapidly in 36s. A few flames were then evident around the tray edge but these were quickly extinguished as the foam flowed to seal against the sides.

Burn-back: The wind blew the foam blanket aside allowing the fuel to ignite instantly the torch was applied. However, the foam flowed into the burning area to limit the growth of the fire such that 50% burn-back took 2.5 minutes and 100% took a further 2 minutes.

TEST 12(3) (Petroseal 3% spray)

Extinction: The fire was reduced to 50% in about 2 mins : 30 s. At this point there was a 20s break in foam application but the fire did not significantly increase in this period. 90% control was achieved in 4mins: 30 s and the fire continued to decrease after this until a gust of wind at 7 minutes spread the flames and involved 30% of the fuel surface again. After 8minutes: 30 s the fire was very nearly out and only a small flame at the rim remained. However, the impact of the spray and the wind blowing the foam and fanning the flames resulted in final extinction being delayed for a further 7 minutes.

Burn-back: The foam blanket at the end of the test was thin and broken, exposing fuel to the torch. Ignition of the fuel was therefore almost immediate and 100% burn-back took 2mins : 30s.

TEST 13(4A) (ATC 3% foam)

Extinction: Control to 90% took 36s and 100% extinction followed at 1min: 12 s. Very few flames remained at the rim after control and the foam quickly flowed to make an edge seal.

Burn-back: The fuel resisted ignition for 3 minutes after which a fire was established at the torch flame with small flames travelling out across the foam blanket to the rim. 100% burn-back took 6 mins : 30 s.

TEST 14(5) (ATC 3% spray)

Extinction: The spray was having no significant effect in controlling the fire and the test was abandoned.

TEST 15(6A) (FP70 4% foam, Petrol fire with water base)

Extinction: Control was slow and gradual. 90% control was achieved after 4 min : 18 s. and 100% extinction took a further 1 mins : 54 s. The final stages of the fire were not confined to the rim, areas of flame were moving across the centre of the tray were the blanket was disturbed by newly arriving foam.

Burn-back: Initial development of the fire was fairly slow and 50% reinvolmement took 5 min : 18 s. However, the fire then took 30 s to involve the last 50% of the fuel surface.

The following tests used the 30^{0} tray.

TEST 6 (30°, FP70 foam)

Extinction: Initially the force of the foam jet and the sloping sides of the tray caused a small amount of burning fuel to be spilled on the surround. This was not thought to be a significant amount of fuel. 90% control appeared to be achieved several times only to have flames from the rim burn-back to give an equilibrium at about 80%. Problems with edge sealing of the foam accounted for the length of time between 90% and 100% extinction.

Burn-back: When the fuel had ignited and a small fire was established (diameter approximately 15cm and flames of height 30cm) the torch was removed. The foam flowed back over this fire and it was extinguished within 10s. The torch was re-applied until a 'well developed' fire was established. From the re-application of the flame to 100% involvement of the tray took approximately 11 minutes.

TEST 7A (30°, AFFF foam)

Extinction: Rapid control and extinction were achieved. A good seal was made between the foam and the rim.

Burn-back: Due to the wind the foam was blown to the side of the tray. This resulted in the exposed fuel surface igniting immediately the torch was applied. Initial fire development was quite rapid and the burn-back time was much faster than in the previous AFFF foam test (Test 4A).

TEST 7B (30°, AFFF foam)

Extinction: Rapid control was achieved but final extinction was delayed due to difficulties in extinguishing rim fires.

Burn-back: The torch was removed after a small fire had developed. As the fire was beginning to grow a strong gust of wind appeared to blow the flames out leaving a large area of the fuel surface without foam covering. Consequently, when the torch was re-applied the burn-back developed very rapidly.

TEST 8 (30°, AFFF spray)

Extinction: A gusty wind contributed to the difficulty in getting the spray on the fire and flames at the tray edge caused problems for 100% extinction. As a result the fuel surface did not appear to have very much foam covering at the end.

Burn-back: 80% of the fuel surface was involved immediately the torch was applied. 100% burn-back was therefore extremely rapid.

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APPENDIX G INSTRUCTIONS FOR FIRE TESTS.

APPENDIX G **INSTRUCTIONS FOR TRAY FIRE TESTS: OCTOBER 1986**

1. The trial will be directed by J.A. Foster. The Fire Officer, D.O R. Lock will be responsible for matters concerned with fire safety, the senior FEU officer present will be in charge overall.

2. The SRDB test site on the FSC Fireground will be used for the tests. This has a 40m^2 concrete based tray. The fuel for the fires will be petrol. Each fire will have a one minnute pre-burn before the additive solution is applied. The following additives will be tested.

Additive	No of tests aspirated	No of tests non-aspirated
FP70-Fluoroprotein	3	0
AFFF-Light Water	3	3
FFFP-Petroseal	3	1
Alcoseal	3	1
ATC-alcohol resistant AFFF	3	1
Halofoam	0	3

Contingency for a further six fires has been made.

A burn-back test will be performed on the foam blanket after each extinction test.

3. **No smoking** will be allowed in the vicinity of the test site and petrol storage area.

The area of the runway used for the tests will be coned off.

4. A Fire Appliance (VLU 208G), equipped with a diffuser branch and an in-line inductor and foam branchpipe, and a supply of foam concentrate, will be standing-by throughout the tests. The pump will be running and manned at all times during the transfer of fuel to the tray and the fire tests. The branches will be tested before any of these operations commence.

The appliance will have 2 dry powder extinguishers, a leather fire blanket and a first aid kit stowed in a locker.

The Fire Service College nurse and ambulance will be informed that the tests are taking place.

5. Unless a task demands otherwise, personnel should remain upwind of the tray behind safety barriers. Personnel involved in the tests will wear Nomex Fire tunics, Nomex leggings, and Safety fire-boots. Safety helmets or fire helmets will also be worn. Fire Officers will wear standard fire kit

6. Personnel involved in the tests should contact J Foster before leaving the trials site.

7. The following will be deployed on the test site.

Video Van (Operated by Viewpoint)

Appliance VLU207G and flowmeter- pump for tests (Operated by J Price)
Digital Clocks (Operated by J Foster)
Appliance VLU208G - to act as second pump for emergency fire fighting.
Appliance PGW4- to suuply potable water from portable dam.
Burnback rig.(Operated by J Rimen)
Wind measuring equipment (Operated by P Parsons)
Detonators and firing box (Operated by P Parsons)
Communications equipment. Line links between video van, VLU207G, Firing box area. Radio link to be available.
Petrol tanker with hose, nozzle, earthing lead.
Lynton trailer- to house foam testing equipment, including digital balance. R Han. This trailer will also be used to house tea or coffee urn.
Temporary water storage tank.
Instrument van RYX496- UV recorder/Orion. R Han

A. TRAY PREPARATION

8. The tray, the metal side of which will be earthed, will be cleaned out by scrubbing with brooms and clean water. Contaminated water will be drained via valved outlet.

9. After ensuring that the drain valve is closed, a water base of clean potable water will be fed into the tray.

10. When all equipment is deployed and checked, fuelling will commence. Each test requires 1000 litres of petrol. The petrol will be transferred from the fireground petrol pump to the tray in the petrol trailer.

11. Whilst the fuel is being transferred to the tray a Fire Officer will be standing by with appropriate equipment to deal with any incidents.

12. At the tray site the trailer and metal ring will be earthed. The fuel will be poured into the tray. Personnel not directly involved in this operation should be standing behind barriers an appropriate distance upwind of the tray.

13. After the fuel has been transfered the petrol trailer will be removed from the test area.

B. IGNITION AND PRE-BURN

14. Whilst the fuel is being transfered the pump operator should make up a premix solution of the foam under test. Approximately 1200 litres of solution should be available for each test. The solution should be at the recommended concentration and well mixed using fresh, potable water. A second person must observe and check this operation.

15. The pump should be primed and after ensuring that the branch (with or without the aspirator) is fitted then solution should be run through the hosereel to the branch. The pump should then be switched off.

16. The detonators should be placed in the tray on the instructions of the trials director by a person wearing protective clothing, including helmet with visor. This person should be in possession of the "key" for the

firing box.

17. The firing box will be sited behind the barrier upwind of the tray.

18. When the detonators are in place the trials director will ensure that all personnel are behind the barriers or at their designated places before the last connection is made to the firing box.

19. The large digital clocks will be preset to 99-00.

The following sequence will follow.

Clock time	Action
	Pump VLU207G started
	Video recorders started
	UV recorder started
99-00	Clock started
99-30	Cooling water turned on.
00-00	Fire ignited
00-30	Solution fed to branch
01-00	Foam applied to fire

After 100% extinction foaming continued for 30secs.

On direction of trials director burnback torch to be lit.

The aim is to apply the burnback torch to the foam 1min 30 secs after 100% extinction.
Burnback will be allowed to develop and should burn off all petrol

20. A torch will be passed over the surface of the tray to ensure all fuel has been burnt, before the tray is drained.

21. The appliance pump, hosereel and glass-fibre tank used with VLU207G will be flushed out with clean water after each test.

22. These procedures will be repeated for subsequent tests.

23. Observations to be made:
Wind speed and direction: P Parsons
Solution temperature,air temperature,flowrate, total solution vol.: R Han
Fuel temp. J Foster
90% and 100% Extinction times. Observers: J Foster, P Parsons and M Thomas.
Burnback time and time to ignition of foam surface. Observers: P Parsons, J Foster and M Thomas.
Measurement of foam expansion ratio and drainage times, foam temp. R Han
Record of flowrate v time and solution temperature v time R Han

Still photographs will be taken where possible: R Han, J Price, J Foster.

J Foster 6th Oct 1986

APPENDIX H - Detailed notes of fire tests

Test Number 2 **Additive** FP70 Aspirated Conc. **3%**
Branch Angus Superfog with aspirator

Ignition 0 : 0 Foam to fire 1 min: 01sec Burnback to tray 14m : 04s

Weather dry and sunnny.

Time from application of foam **min : sec**	**Observations**
0 : 0	Foam stream stationary.
3 : 40	30% extinction.
4 : 00	50% extinction. Flames 3 metres high.
4 : 04	Branchman directed foam stream to downwind edge of tray
4 : 40	40% extinction.
4 : 21	Foam stream directed across tray from broadside position.
5 : 07	50% extinction.
5 : 18	70% extinction.
7 : 00	Branchman moves around tray.
8 : 58	**90% extinction.**
10 : 22	Flames over 10% of rim on upwind edge of tray. Branchman switches off for 5 seconds and moves around tray. Tried to apply foam gently to remaining flames.
12 : 26	**100% Extinction** Foam blanket over all the tray.

Time from start of burnback **min : sec**	
2 : 11	0.1 m^2 petrol fire.
3 : 46	0.3 m^2 petrol fire.
6 : 21	0.5 m^2 petrol fire 1.5m high flames.
7 : 06	0.8 m^2 petrol fire 2.0m high flames.
8 : 16	1 m^2 petrol fire.
9 : 26	1.5 m^2 petrol fire.
9 : 58	Burnback rig removed.
23 : 05	Burnback rig re-applied on upwind side of tray.
23 : 14	40% fire only.

Test Number 3 **Additive** AFFF Aspirated **Conc.** 3%
Branch Angus Superfog with aspirator

Ignition 0 : 0 Foam to fire 1 min: 02sec Burnback to tray 4 min : 07 sec.

Weather Overcast Light rain.

Time from application of foam **min : sec**	**Observations**
0 : 0	Foam stream stationary.
0 : 25	Flame height reducing.
1 : 02	50% extinction.
1 : 08	**90% extinction.**
1 : 18	98% extinction. Remaining fire near edge for 30% of tray rim.
1 : 19	Branchman directed foam stream to opposite side of tray to flames.
1 : 28	Flames near edge for 10% of tray rim.
1 : 33	Branchman moves around tray and directed foam stream towards remaining flames.
1 : 41	Flash of flames for 1 second as fuel stirred up by branchman.
1 : 45	**100% extinction.**
	Foam blanket over all tray area.

Time from start of burnback **min : sec**	
0 : 28	Ghosts around tray edge.
1 : 06	1 m^2 petrol fire . Ghosts over 30% of tray.
1 : 34	Ghosts spread downwind over 1 m^2. Fringe fire at tray edge upwind.
1 : 51	Ghosts over 30% tray.
5 : 01	Burnback rig removed.
5 : 53	50% fire.
6 : 30	90% fire.
8 : 43	98% fire.
8 : 52	Fire dying.

Test Number 4 **Additive** FFFP Aspirated **Conc.** 3%
Branch Angus Superfog with aspirator

Ignition 0 : 0 Foam to fire 1 min: 02sec Burnback to tray 4m : 51s

Weather Sunny

Time from application of foam **min : sec**	**Observations**
0 : 0	Foam steam held stationary.
0 : 39	Flame height reduced to 5 metres.
1 : 01	50% extinction.
1 : 07	**90% extinction.**
1 : 17	Branchman moves and directed foam stream to side of tray with no flames.
1 : 24	Two areas of flames near rim each 5% of tray rim. Branchman applied foam to downwind flames.
1 : 52	Flames around upwind tray edge grow to 5%.
1 : 37	Flames downwind extinguished. Branchman applied foam to remaining flames on upwind tray edge.
2 : 18	**100% extinction.**

Time from start of burnback **min: s**	
1 : 18	0.1 ^{2} petrol fire.
2 : 30	Ghosts over 30% of tray and around rim.
3 : 25	0.2 m^2 petrol fire. Ghosts over most of tray.
4 : 09	0.3 m^2 petrol fire.
4 : 59	0.5 m^2 petrol fire. 1 metre long flames. Ghosts over most of tray.
6 : 46	1 m^2 fire . Burnback rig removed.
7 : 50	5 metre long flames.
8 : 04	Flames spread to downwind side of tray.
8 : 50	2 m^2 fire. Downwind fire self-extinguished.
12 : 09	10% fire.
13 : 00	Flames spread around rim.
13 : 02	98% fire.
13 : 40	100% fire.

Test Number 5 **Additive** AFFF Aspirated **Conc.** 3%
Branch Angus Superfog with aspirator

Ignition 0 : 0 Foam to fire 1 min: 01sec Burnback to tray 4m : 38s

Weather Sunny

Time from application of foam min : sec	Observations
0 : 0	Foam steam held stationary.
0 : 40	25% extinction on downwind side of tray.
0 : 49	50% extincttion. Ghosts over foam blanket.
0 : 53	60% extinction.
1 : 06	**90% extinction. Ghosts over foam blanket.**
1 : 10	Branchman moved to direct foam stream to upwind side of tray.
1 : 15	Flames near to upwind edge for 15% of rim.
1 : 23	Foam applied gently to 3 areas of flame around the rim.
1 : 34	100%extinction over tray, however igniter was left on side of tray and was still burning which caused reignition near tray edge.
1 : 42	Small flames around 25% of rim.
1 : 43	Foam stream directed at burning area which stirred up fuel. Foam stream then directed to opposite side of tray to flames.
1 : 50	**100% extinction.**
	Foam blanket covered all tray area.

Time from start of burnback min : sec	
1 : 20	0.1 m^2 petrol fire. Ghosts over tray.
1 : 50	0.2 m^2 petrol fire. Ghosts over tray.
2 : 31	Ghosts run to upwind edge causing reignition of igniter.
3 : 00	0.8 m^2 petrol fire. Flames 1 mlong.
3 : 10	Flames spread to 50% of tray rim.
4 : 01	1 m^2 fire below burner. Flames around tray rim.
4 : 33	2 m^2 fire. Flames 2 metres long.
	Burnback rig removed. Rim flames on downwind side.
6 : 10	3 m^2 fire at position of burner. 2 other fires,each of 1m^2.
6 : 27	30% fire.
6 : 39	70% fire.
6 : 45	90% fire.
7 : 20	100% fire.
9 : 22	Fire decreasing.

Test Number 6 **Additive** AFFF Non-aspirated **Conc.** 3%
Branch Angus Superfog

Ignition 0 : 0 Foam to fire 1 min: 02sec Burnback to tray 7m : 11s

Weather Sunny

Time from application of foam **min : sec**	**Observations**
0 : 0	Foam steam directed to left of centre of tray and held steady. Fire flared up initially.
1 : 11	5% foam blanket visible on downwind side for about 2 seconds.
1 : 17	Again 5 % blanket visible for 2 seconds.
1 : 40	10% foam blanket visible for 10seconds.
2 : 22	50% extinction on downwind side of tray.
2 : 37	70% extinction on downwind side of tray.
2 : 42	**90% extinction.** Most flames upwind. Flames around 50% of rim of extinguished area.
2 : 58	Branchman moved around tray sweeping spray over tray area.
3 : 00	95% extinction.
3 : 27	Flared up on upwind side.
4 : 28	Only small flames near rim for about 2 metres of circumference.
4 : 39	**100% extinction.**
5 : 09	Foam off tray.
	Foam blanket broken over 5% of area.

Time from start of burnback **min : s**	
0 : 0	Immediate fire $0.5m^2$ with 2 m long flames.
0 : 30	10% fire.
1 : 00	30% fire.
1 : 44	95% fire.
2 : 00	98% fire.
3 : 15	Fire decreasing.

Test Number 7 **Additive** AFFF Non-aspirated **Conc.** 3%
Branch Angus Superfog

Ignition 0 : 0 Foam to fire 1 min: 03s Burnback to tray 8m : 04s

Weather Sunny

Time from application of foam min : s	Observations
0 : 0	Spray held stationary. Flared up as foam applied. Some spray fell short of tray.
2 : 0	No reduction in fire observed.
3 : 53	Branchman moved to upwind siide of tray.
4 : 00	10% extinction on downwind side of tray.
4 : 05	50% extinction.
4 : 17	Branchman moved to downwind side and sweeps spray over tray area.
4 : 35	**90% extinction.**
5 : 00	95% extinction.
5 : 30	**100% extinction.**
	Foam blanket broken over 5% of area.

Time from start of burnback min : s	
0 : 0	Immediate fire of 1 m^2.
0 : 15	5 m^2 fire.
0 : 23	Burnback rig removed from tray.
0 : 41	20% fire. 6 m long flames.
0 : 47	50% fire.
1 : 11	100% fire.
1 : 37	Fire dying.

Test Number 8 **Additive** AFFF Non-aspirated **Conc.** 3%

Branch Angus Superfog

Ignition 0 : 0 Foam to fire 1 min: 01sec Burnback to tray 6m : 53s

Weather Sunny

Time from application of foam **min : sec**	**Observations**
0 : 0	Branchman moved close to tray and swept spray over tray area.
0 : 12	70% extinction
0 : 22	80% extinction.
1 : 00	100% fire.
1 : 11	Branchman moved around tray.
1 : 23	Fire still 100%.
1 : 27	Foam spray applied to upwind side of tray. Then sweeps spray across tray.
1 : 15	Branchman returns to upwind side and stops sweeping. Still 100% fire.
1 : 40	60% extinction.
3 : 01	100% fire. Branchman swept spray over tray and moved around tray.
3 : 21	80% extinction.
3 : 25	**90% extinction.** Remaining flames around the edge. Branchman sweeps from directly in front of him.
4 : 22	**100% extinction.** Foam blanket broken over 5% of tray area.

Time from start of burnback **min : s**	
0 : 16	10% fire.
0 : 31	Burnback rig removed.
0 : 57	30% fire.
1 : 27	50% fire.
2 : 17	90% fire.
2 : 57	Fire dying.

Test Number 9 **Additive** AFFF Aspirated **Conc.** 3%
Branch Angus Superfog with aspirator.

Ignition 0 : 0 Foam to fire 1 min: 02sec Burnback to tray 4m : 58s

Weather Sunny

Time from application of foam **min : sec**	**Observations**
0 : 0	Foam stream held stationary.
0 : 40	Much foam fall short of tray. Branchman moved closer.
1 : 24	**90% extinction.**
2 : 26	**100% extinction.**
2 : 57	Foam off fire.
	Foam blanket covered all tray area.

Time from start of burnback **min : s**	
1 : 01	0.1m^2 petrol fire. 1 m high flames. Ghosts over surface.
1 : 54	Ghosts extending across 20% of tray. Rim fringe fire for 50% of rim.
2 : 30	0.2m^2 petrol fire.
2 : 59	0.3m^2 petrol fire. Fire around complete rim.
3 : 44	Burnback rig removed.
4 : 34	10% fire. 6 m flames.
5 : 02	25% fire. 10m flames.
5 : 34	95% fire.
5 : 42	100% fire.
7 : 26	Fire reducing.

Test Number 10 **Additive** FFFP Aspirated **Conc.** 3%
Branch Angus Superfog with aspirator.

Ignition 0 : 0 Foam to fire 1 min: 01sec Burnback to tray 4m : 40s

Weather Sunny

Time from application of foam **min : sec**	**Observations**
0 : 0	Foam stream held stationary.
1 : 17	**90% extinction.**
1 : 38	Flickers of flame remain round rim and in tray centre.
2 : 07	**100% extinction.**
2 : 39	Foam off fire.
	Foam blanket covered all tray area.

Time from start of burnback **min : s**	
0 : 21	0.1 m^2 petrol fire.
0 : 50	0.1 m^2 petrol fire. 1 m flames.Ghosts run to tray edge.
1 : 20	25% of rim had ghosts.
1 : 55	0.2 m^2 petrol fire iM flames. Ghosts run to tray edge. tray.
2 : 03	Ghosts over all tray.
2 : 50	Ghosts over 50% of tray.
3 : 39	Fewer ghosts. None around rim.
4 : 47	0.3m^2 petrol fire.
5 : 01	Burnback rig removed from tray. 1 m^2 fire. A few ghosts.
5 : 24	0.5 m^2 fire.
6 : 19	2 m^2 fire. 6 m flames.
6 : 51	10% fire 10m flames.
7 : 39	30% fire. Wind direction changed 180^o.
8 : 50	40% fire.
9 : 29	70% fire.
10 : 57	100% fire.
11 : 50	Fire decreasing.

Test Number 11 **Additive** FFFP Aspirated **Conc.** 3%
Branch Angus Superfog with aspirator.

Ignition 0 : 0 Foam to fire 1 min: 01sec Burnback to tray 4m : 34s

Weather Sunny

Time from application of foam **min : sec**	**Observations**
0 : 0	Foam applied to left of centre of tray.
1 : 23	**90% extinction.** Small rim fire downwind and small fire in tray centre.
2 : 01	**100% extinction.**
	Foam blanket covered area of tray.

Time from start of burnback **min : s**	
0 : 32	0.1^2 petrol fire.
1 : 32	Ghosts run from burner to rim where ghosts established.
2 : 46	$0.1m^2$ petrol fire. Flames 1 m long.
4 : 15	Burnback flame removed from tray.
3 : 46	1 m^2 fire. Flames 2m long.
4 : 26	10% fire.
5 : 32	20% fire.
5 : 54	50% fire.
6 : 24	75% fire.
6 : 39	95% fire.
6 : 46	100% fire.

Test Number: 12 Additive: FFFP Non-aspirated Conc. 3%

Branch: Angus Superfog

Ignition: 0 : 0 Foam to fire: 1 min: 01s Burnback to tray: 6 min 58s

Weather: Sunny

Time from application of foam **min : sec**	Observations
0 : 0	Branchman swept across upwind side of tray. Flared up immediately.
0 : 10	50% extinction in centre of tray. But fire grew.
0 : 30	40% extinction.
1 : 37	100% fire.
2 : 43	50% extinction.
3 : 15	100% fire.
3 : 54	**90% extinction.**
4 : 26	**100% extinction.**
4 : 56	Foam off tray. Scummy foam blanket broken over 15% of tray area.
Time from start of burnback	
0 : 0	Flames spread once to $2m^2$ smoky fire
0 : 10	10% fire.
1 : 06	25% fire.
1 : 56	95%

Test Number: 13 **Additive:** FFFP.AR Aspirated **Conc.** 3%

Branch: Angus Superfog with aspirator.

Ignition: 0 : 0 Foam to fire: 1 min: 0s Burnback to tray: 6 min: 28s

Weather: Sunny

Time from application of foam **min : s**	**Observations**
0 : 0	Foam stream stationary.
0 : 48	50% extinction.
1 : 12	90% extinction.
1 : 35	Branchman moved around tray.
1 : 48	Fire grown to 50%
1 : 58	Branchman began to sweep.
2 : 18	70% extinction.
2 : 30	90% extinction.
2 : 40	Only small flame on rim downwind.
2 : 58	Flame appeared on upwind side.
3 : 05	Fire grew quickly to 70% fire.
3 : 40	**90% extinction.**
	Some foam missed tray for about 5 seconds.
3 : 47	0.2m^2 fire near rim.
3 : 57	**100% extinction.**
4 : 27	Foam off tray.
	Foam blanket covered tray.

Time from start of burnback **min : s**	
0 : 23	0.1m^2 petrol fire. No ghosts.
0 : 57	No ghosts.
1 : 14	0.2m^2 petrol fire 1m flames. Fire grew steadily.
2 : 43	0.3m^2 petrol fire. 3m long flames.
3 : 00	1m^2 petrol fire.
3 : 12	Burnback flame removed.
3 : 42	1m^2 fire 5m long flames. All fire in one area. No ghosts.
4 : 29	20% fire. Some ghosts downwind.
4 : 42	25% fire.
5 : 10	50% fire.
5 : 18	100% fire.

Test Number: 14 **Additive:** FFFP.AR **Conc.** 3%

Branch: Angus Superfog with aspirator.

Ignition: 0 : 0 Foam to fire: 1 min : 01s Burnback to tray: 6mm : 21s

Weather: Sunny.

Time from application of foam min : s	**Observations**
0 : 0	Some foam fell short of tray.
	Foam stream stationary.
0 : 58	70% extinction.
1 : 05	Foam off for 3 secs.
1 : 08	Flared up when foam hit fuel surface.
1 : 41	70% extinction.
1 : 50	Fire came back to 40% as foam stream applied to flames.
1 : 56	**90% extinction.**
2 : 14	Foam off for 14 secs.
2 : 19	Small flames only on 50% of tray rim.
2 : 28	Foam on.
2 : 35	5% fire on upwind side.
2 : 36	Foam off.
2 : 40	10% fire upwind.
2 : 53	Foam on.
3 : 07	Rim fire over 25% of tray rim.
3 : 29	Flared up.5%fire.
3 : 50	**100% extinction.**
4 : 20	Foam off tray.
	Foam blanket over all tray.

Time from start of burnback min : s	
0 : 37	0.1m^2 petrol fire. 1m flames.
0 : 42	Some ghosts.
1 : 49	Ghosts over most of foam surface.
2 : 09	0.2m^2 petrol fire. 1m flames. Small rim fire.
2 : 51	0.2m^2 petrol fire. 1m flames. Rim fire extinguished.
3 : 40	Fire growing. Ghosts around rim and over tray.
4 : 09	1m^2 fire. Ghosts around rim extinguished.
4 : 39	1.5m^2 fire.
5 : 11	Burnback flame removed.
6 : 04	0.3m^2 fire. Small rim fire. Some ghosts.
7 : 01	1m^2 fire. 2m long flames.
7 : 27	10% fire. 5m flames.
8 : 09	25% fire.
9 : 26	50% fire.
9 : 44	75% fire.
10: 14	90% fire.
10: 22	95% fire.
11. 44	Fire reducing.

Test Number: 15 **Additive:** AFFF.AR Aspirated **Conc.** 3%

Branch: Angus Superfog with aspirator.

Ignition: 0 : 0 Foam to fire: 1 min: 01s Burnback to tray: 5 min : 02s

Weather: Fine drizzle.

Time from application of foam	**Observations**
min : s	
0 : 0	Foam stream stationary.
1 : 01	50% extinction.
1 : 33	Foam off for 4 seconds. Branchman moved.
1 : 36	Foam applied from broadside position.
1 : 54	**90% extinction.**
	Rim fire upwind.
	Branchman moved downwind.
2 : 31	**100% extinction.**
4 : 01	Foam off.
	Foam blanket covered tray area.

Time from start of burnback	
min : s	
0 : 21	0.2m^2 petrol fire.
0 : 33	Some ghosting.
1 : 13	Ghosts over 5% upwind.
1 : 59	2m flames. Ghosts around rim.
2 : 33	0.2m^2 fire. 2m flames.
3 : 08	0.5m^2 fire.
3 : 57	Ghosts over 25% of tray.
4 : 16	0.3m^2 fire. 3m flames.
5 : 05	0.5m^2 fire. Some ghosts.
5 : 36	2m^2 fire. 5m flames. Small rim fire.
5 : 16	Burnback flame removed.
6 : 18	Ghosts over all tray.
6 : 42	10% fire.
7 : 15	15% fire.
7 : 21	40%.
7 : 34	50% fire.
8 : 08	90% fire.
8 : 32	100% fire.

Test Number: 16 **Additive:** AFFF.AR Aspirated **Conc.** 3%

Branch Angus Superfog with aspirator.

Ignition: 0 : 0 Foam to fire: 1 min: 02s Burnback to tray: 3 min : 54s

Weather: Sunny.

Time from application of foam **min : s**	**Observation**
0 : 0	Foam stream stationary.
0 : 43	50% extinction.
0 : 57	**90% extinction.** Branchman moved downwind. Rim fire upwind.
1 : 25	**100% extinction.**
1 : 55	Foam off tray.

Time from start of burnback **min : s**	
0 : 37	$0.2m^2$ fire.
1 : 13	Ghosts over tray.
2 : 19	$0.5m^2$ fire. Ghosts downwind.
3 : 02	Fire reduced slightly.
3 : 38	$0.5m^2$ fire. Some ghosts.
4 : 14	Ghosts over 30% of tray.
4 : 42	$1m^2$ fire. 3 metre frames. Ghosts downwind.
5 : 22	Burnback flame removed. $1m^2$ fire near rig. $1m^2$ fire downwind.
6 : 02	10% fire. 2 areas of flames.
6 : 13	20% fire.
6 : 20	50% fire.
6 : 48	100% fire.
8 : 30	Fire decreasing.

Test Number: 17 **Additive:** AFFF Non-aspirated **Conc.** 3%

Branch: Galena Hyperfog

Ignition: 0 :0 Foam to fire:1 min : 00s Burnback to tray: 5min : 59s

Weather:

Time from application of foam **min : s**	**Observations**
0 : 0	Branchman swept spray over tray.
0 : 10	80% extinction, but fire increased.
0 : 30	Branchman changed to jet for 2 seconds.
1 : 05	60% extinction, but fire increased.
1 : 26	Branchman changed to jet for 2 seconds,
2 : 08	**90% extinction.**
2 : 20	Fire flared up.
2 : 37	Ghosts and rim fire. Most spray missing tray.
2 : 57	0.2m^2 fire at rim.
3 : 29	**100% extinction.**
3 : 59	Foam off tray.
	90% of tray covered with scummy foam blanket.

Time from start of burnback	
0 : 10	2m^2 fire immediately.
0 : 24	10% fire. Burnback flame removed.
0 : 51	50% fire.
1 : 21	100% fire.

Test Number: 18 **Additive:** AFFF.AR Aspirated **Conc.** 3%

Branch: Angus Superfog with aspirator.

Ignition: 0 : 0 Foam to fire: 1 min : 01s Burnback to tray: 4min : 52s
Weather:

Time from application of foam **min : s**	**Observations**
0 : 0	Foam stream stationary.
1 : 14	**90% extinction.**
1 : 18	Rim fire upwind.
1 : 29	Foam off.
1 : 35	Foam on.
1 : 59	Foam off.
2 : 06	Foam on. Fire increased.
2 : 21	**100% extinction.**
2 : 51	Foam off tray.
	Foam blanket covered tray.

Time from start of burnback	
2 : 11	0.2m^2 fire. 1m long flames. Ghosts downwind.
4 : 19	1m^2 fire. 2m long flames.
5 : 19	Flames spread to rim but subsequently extinguished.
5 : 36	Burnback flame removed.
5 : 49	3m^2 fire. 6m flames also fire downwind.
6 : 04	3m^2 fire with 1m^2 fire downwind.
6 : 24	20% fire.
6 : 39	50% fire.
6 : 54	90% fire.
7 : 58	100% fire.

Test Number: 19 **Additive:** AFFF-AR Non-Aspirated **Conc.** 3%

Branch: Angus Superfog

Ignition 0 : 0 Foam to fire: 1 min : 01s Burnback to tray: 7min : 58s

Weather: Overcast.

Time from application of foam	**Observations**
min : s	
0 : 0	Flared up as spray hit fire. Branchman swept spray over tray.
0 : 12	80% extinction.
0 : 33	90% extinction.
1 : 32	80% extinction.
1 : 53	70% extinction. Fire increased.
2 : 21	Foam off.
2 : 27	30% extinction.
2 : 31	Foam on.
3 : 01	50% extinction.
3 : 26	30% extinction.
4 : 05	70% extinction.
4 : 11	80% extinction.
4 : 26	**90% extinction.**
5 : 27	**100% extinction.** 90% of tray covered by scummy foam.

Time from start of burnback	
0 : 03	1.4m^2 fire.
0 : 38	25% fire.
1 : 34	95% fire.

Test Number: 20 **Additive:** FFFP-AR Aspirated **Conc.** 3%

Branch: Angus Superfog with aspirator.

Ignition: 0 : 0 Foam to fire: 1 min : 01s Burnback to tray: 6 min : 03s

Weather: Overcast.

Time from application of foam **min : s**	**Observations**
0 : 0	Foam stream applied steadily.
1 : 04	50% extinction.
1 : 14	90% extinction. Flared up and fire grew.
1 : 24	Foam off.
1 : 29	Foam on.
1 : 36	40% extinction.
2 : 02	**90% extinction.**
2 : 17	Flared up on downwind rim.
2 : 24	Foam off.
2 : 26	Foam on.
2 : 49	Rim fire $0.2m^2$ upwind.
3 : 18	Fought downwind fire. Flared up.
3 : 32	**100% extinction.**
5 : 02	Foam off tray.
	Foam blanket over all tray area.
Time from start of burnback	
1 : 09	Good resistance, hardly a petrol fire.
2 : 53	$0.1m^2$ petrol fire.
3 : 17	Ghosts over surface.
4 : 42	$0.5m^2$ fire.
4 : 55	$1m^2$ fire. 2.5m flames.
4 : 55	Ghosts around rim but extinguished.
6 : 15	$1m^2$ fire.
6 : 15	$2m^2$ fire. 4m flames.
6 : 40	All ghosts extinguished.
7 : 17	$3m^2$ fire. 4m flames.
7 : 36	Burnback flame removed.
7 : 56	20% fire.
8 : 14	25% fire.
9 : 20	50% fire.
9 : 26	70% fire.
9 : 36	90% fire.
9 : 58	100% fire.

Test Number: 21 **Additive** FFFP-AR Non-aspirated **Conc.**3%

Branch: angus Superfog

Ignition: 0 : 0 Foam to fire: 1 min : 01s Burnback to tray: 7 min : 27s

Weather: Light drizzle.

Time from application of foam **min : s**	**Observations**
0 : 0	Branchman swept spray over tray, this caused fire to flare up.
0 : 23	30% extinction.
1 : 11	Fire nearly 100% again.
2 : 18	80% extinction. Branchman swept spray over tray.
3 : 03	90% extinction.
3 : 19	90% extinction.
3 : 48	90% extinction. Branchman had to step back quickly following flare up.
3 : 55	90% extinction.
3 : 19	**90% extinction.**
4 : 36	Foam off.
4 : 45	Foam on.
4 : 54	**100% extinction.**
5 : 24	Foam off tray. Weak scummy blanket.

Time from start of burnback	
0 : 38	Fire spread away from burnback flame.
0 : 58	0.2m^2 petrol fire.
2 : 00	1m^2 fire. 2m long flames.
2 : 09	Burnback flame removed.
2 : 39	25% fire.
3 : 22	50% fire.
3 : 50	70% fire.
4 : 07	80% fire. Convincing burnback.

Test Number: 22 **Additive:** Halofoam. Non-aspirated **Conc.** 15%

Branch: Angus Superfog

Ignition: 0 : 0 Foam to fire: 1 min : 01s Burnback to tray: 8 min : 25s

Weather: Overcast. Light drizzle during burnback.

Time from application of foam **min : s**	**Observations**
0 : 0	Spray swept over tray. Flared up as spray first applied.
0 : 32	75% extinction.
0 : 46	50% extinction.
1 : 15	Fire increased.
1 : 36	70% extinction.
2 : 15	30% extinction.
2 : 30	50% extinction.
3 : 02	30% extinction.
3 : 34	80% extinction.
3 : 46	**90% extinction.**
4 : 09	Flared up.
5 : 14	Flared up. Forceful application.
5 : 21	Foam off.
5 : 29	Foam on. Some spray missed tray.
5 : 52	**100% extinction.**
6 : 22	Foam off tray.
	Tray covered by scummy foam.

Time from start of burnback	
0 : 52	0.2m^2 fire. 1.5m flames.
1 : 00	1m^2 fire.
1 : 31	0.5m^2 fire. 2.5m flames.
2 : 00	2m^2 fire.
	Burnback flame removed.
2 : 24	3m^2 fire. 6m flames.
3 : 11	10% fire. 6m flames.
3 : 47	50% fire.
3 : 54	90% fire.
4 : 40	98% fire.
5 : 33	50% fire. Fire decreasing.

Test Number: 23 **Additive:** Halofoam Non-aspirated **Conc.** 3%

Branch: Galena Hyperfog

Ignition: 0 : 0 Foam to fire: 1 min : 01s Burnback to tray: 7 min : 48s

Weather: Sunny.

Time from application of foam **min : s**	**Observations**
0 : 0	Branchman swept over tray.Branch set on jet. White vapour observed low-lying downwind.
0 : 57	Changed to spray.
1 : 25	Branchman moved in. Flared up. Changed to jet mode.
1 : 45	Changed to spray.
2 : 25	50% extinction, then fire increased.
2 : 49	**90% extinction** - white vapour observed.
3 : 52	Minor flare-ups.
4 : 50	Branch off. Fire grew
5 : 00	Branch on.
5 : 14	**100% extinction.**
5 :44	Foam off tray. Weak scummy foam.

Time from start of burnback **min : s**	
0 : 30	0.2m^2 fire. 1m flames.
1 : 24	1m^2 fire. 3m flames.
2 : 09	Burnback flame removed. 2m^2 fire. 5m long flames.
2 : 36	10% fire. 10m flames, white fumes.
4 : 33	50% fire. Fire did not spread because of no wind.
5 : 32	70% fire.
5 : 38	80% fire.
5 : 41	90% fire.
6 : 13	100% fire.

Test Number: 24 **Additive:** F.P. Aspirated. **Conc.** 6%

Branch: Angus Superfog with aspirator.

Ignition: 0 : 0 Foam to fire: 1 min :01s Burnback to tray: 15min : 30s

Weather: Sunny.

Time from application of foam **min : s**	**Observations**
0 : 0	Foam stream stationay.
2 : 11	80% extinction.
2 : 17	50% extinction.
2 : 20	80% extinction.
3 : 16	Branch off.
3 : 25	Branch on.
4 : 30	Branch off. 50% extinction.
4 : 38	Branch on.
5 : 14	60% extinction.
7 : 24	**90% extinction.**
11: 18	95% extinction.
12: 58	**100% extinction.**
13 : 30	Foam off tray.

Time from start of burnback	
3 : 43	0.2m^2 fire. 1m flames.
9 : 26	1m^2 fire. 3m flames.
9 : 35	Burnback flame removed.
11 : 53	10% fire. 6m flames. Fire upwind only. Slow spread due to low wind speed.
12 : 49	Ghosts round tray edge.
14 : 56	Flames spread to rim.
15 : 40	40% fire.
16 : 17	90% fire.

Test Number: 25 **Additive:** FFFP-AR Aspirated **Conc.** 3%

Branch: Angus Superfog with aspirator.

Ignition: 0 : 0 Foam to fire: 1 min 0s Burnback to tray: 7 min : 59s

Weather: Sunny.

Time from application of foam	**Observations**
min : s	
0 : 0	Foam stream applied to $4m^2$ back plate on down wind side of tray
4 : 13	**90% extinction.** Backplate had collapsed at some time before this.
5 : 26	**100% extinction.**
5 : 56	Foam off tray. Foam blanket covered tray.

Time from start of burnback	
min : s	
5 : 40	Only $0.2m^2$ fire. 1m flames. Problem discovered with compressor for burnback flame.
12 : 00	Still only $0.2m^2$ fire. Concluded no petrol left.

Test Number: 26 **Additive:** FFFP-AR Aspirated **Conc.** 3%

Branch: Angus Superfog with aspirator.

Ignition: 0 : 0 Foam to fire: 1 min : 01s Burnback to tray: 4 min : 40s

Weather: Overcast.

Time from application of foam **min : s**	**Observations**
0 : 0	Foam stream applied towards backplate but missed for first 9 secs.
1 : 21	**90% extinction.**
	Backplate used, very effective.
2 : 09	**100% extinction.**
2 : 39	Foam off tray.
	Good foam blanket over most of tray. $0.5m^2$

Time from start of burnback **min : s**	
3 : 10	$0.5m^2$ fire.
3 : 56	$0.2m^2$ fire. 1m flame .
5 : 25	$1m^2$ fire. 2m flames.
6 : 00	Burnback flame removed.
6 : 33	$2m^2$ fire. 3m flames.
7 : 45	15% fire.
8 : 48	50% fire.
9 :05	100% fire.

Test Number: 27 **Additive:** AFFF Non-aspirated. **Conc.** 3% Tridol's

Branch: Angus Superfog

Ignition 0 : 0 Foam to fire: 1 min : 01s Burnback to tray: 7 min : 25s

Weather: Sunny.

Time from application of foam	**Observations**
min : s	
0 : 0	Branchman swept spray over tray. Flared up.
0 : 12	80% extinction.
0 : 21	90% extinction.
0 : 36	70% extinction.
0 : 55	95% extinction.
1 : 29	Fire grown to 15% fire.
1 : 58	Fire grew and waned.
2 : 09	90% extinction.
2 : 14	95% extinction.
2 : 23	99% extinction.
2 : 44	90% extinction. Fire growing.
3 : 14	90% extinction.
3 : 18	98% extinction.
3: 30	**90% extinction.**
3 : 32	Flash to 50% extinction.
3 : 50	98% extinction.
4 : 07	Branch off for 2 seconds.
4: 53	**100% extinction.**
6 : 23	Foam off tray.
	Foam blanket over all tray.

Time from start of burnback	
min : s	
0 : 05	Flash to 50%of rim.
0 : 18	$1m^2$ fire.
0 : 43	Ragged spread. $2m^2$ fire. 3m flames.
1 : 00	25% fire.
1 : 33	50% fire.
1 : 41	70% fire.
1 : 55	100% fire.
2 : 15	95% fire.
3 : 06	100% fire.

Test Number: 28 **Additive:** F.P. Aspirated. **Conc.** 3%

Branch: 2 off FRS 50lpm branchpipes.

Ignition: 0 : 0 Foam to fire: 1 min : 00s Burnback to tray: 6 min : 30s

Weather: Overcast. Sunny intervals.

Time from application of foam **min : s**	**Observations**
0 : 0	Foam applied gently to left of centre of tray.
0 : 48	50% extinction. Slow but progressive extinction.
2 : 12	Rim fire and dispersed ghosts.
2 : 19	90% extinction.
2 : 36	Steady 5% fire.
2: 49	**90% extinction.**
4: 00	**100% extinction.**
4 : 30	Foam off tray.
	Foam blanket over all tray.

Time from start of burnback **min : s**	
3 : 10	0.2m^2 fire. 1m flames.
3 : 58	A few ghosts only.
4 : 14	0.3m^2 fire. 1m flames.
5 : 22	Small flames spread over surface and extinguished.
5 : 50	1m^2. 3m flames.
7 : 14	20% fire. Burnback flame removed.
8 : 04	50% fire.
8 : 37	90% fire.
9 : 20	100% fire.

Test Number: 29 **Additive:** F.P. Aspirated **Conc.** 4%

Branch: 2 off FRS 50 lpm branchpipe.

Ignition: 0 : 0 Foam to fire: 1 min : 01s Burnback to tray: 5 min : 47s

Weather: Overcast. Sunny intervals.

Time from application of foam	**Observations**
min : s	
0 : 0	Foam applied gently.
0 : 58	80% extinction.
1 : 14	85% extinction.
1 : 39	**90% extinction.**
2 : 39	Fire grew.
3 : 15	**100% extinction.**
3 : 45	Foam off tray.
	Good foam blanket over all tray.

Time from start of burnback	
min : s	
2 : 06	Ghosts spread over surface.
2 : 52	$0.2m^2$ fire. Strong wind.
6 : 13	Small flames around rim.
9 : 05	$1m^2$ fire.
9 : 37	25% fire. Wind breaks up foam layer.
10 : 04	50% fire.
10 : 34	75% fire.
11 : 09	95% fire.
12 : 09	90% fire.
12 : 53	100% fire.
13 : 10	Fire decreasing.

Test Number: 30 **Additive:** FFFP-AR Aspirated **Conc.** 3%

Branch: 2 off FRS 50 lpm branchpipes.

Ignition: 0 : 0 Foam to fire: 1 min : 01s Burnback to tray: 4 min : 53s

Weather: Overcast.

Time from application of foam	**Observations**
min : s	
0 : 0	Foam applied gently.
1 : 03	50% extinction.
1 : 25	90% extinction.
1 : 40	85% extinction.
1 : 45	**90% extinction.**
2 : 21	**100% extinction.**
2 : 51	Foam off tray.
	Good foam blanket. Not as solid as with FP.

Time from start of burnback	
min : s	
1 : 17	Ghosts around rim.
1 : 38	0.2m^2 fire. Small rim fire.
2 : 45	0.2m^2 fire.
3 : 03	Ghosts spread to centre.
3 : 59	0.5m^2 1.5m flames. Ghosts around edge.
4 : 59	1m^2 fire. 3m flames.
5 : 25	Burnback flame removed.
5 : 46	2m^2 fire. 4m flames.
5 : 47	10% fire.
7 : 14	30% fire.
7 : 18	50% fire.
7 : 27	80% fire.
7 : 38	100% fire.

Test No	Date	Time (hh:mm)	Foam Type	Batch No. of conc.	Conc. (%)	Application Method	Branch	Premix Tank (dgC)	In-Line Avg (dgC)	In-Line S.D.[2]	Air (dgC)	Foam (dgC)	Water Base (dgC)	Petrol (dgC)	Expansion Ratio	Drainage Time Min:s	Shear Stress N/m²
1	9/10/86	12:00	FP	83	3	Aspirated	Superfog	20.0	20[3]	-	18.5	19.5	16	17	8.1	5:56	-
2	9/10/86	15:20	FP	1030/57/F	3	Aspirated	Superfog	18.0	25[3]	-	19.0	20.0	18	18	6.5	5:04	-
3	10/10/86	12:07	AFFF	2344A	3	Aspirated	Superfog	15.2	21[3]	-	13.0	15.3	15	17	11.8	4:24	-
4	10/10/86	14:47	FFFP	1050/19/F	3	Asoirated	Superfog	15.8	20[3]	-	13.3	17.4	16	14	9.8	4:25[1]	-
5	13/10/86	10:50	AFFF	2344A	3	Aspirated	Superfog	10.8	20[3]	-	9.3	12.3	13	13	11.8	4:39	-
6	13/10/86	12:38	AFFF	2344A	3	Non-aspirated	Superfog	12.3	20[3]	-	10.8	13.1	14	14	2.1	0:52[1]	-
7	13/10/86	15:00	AFFF	2344A	3	Non-aspirated	Superfog	14.0	23[3]	-	13.0	14.3	15	14	2.5	1:27[1]	-
8	14/10/86	10:00	AFFF	2344A	3	Non-aspirated	Superfog	12.4	22[3]	-	11.1	13.2	14	13	2.2	1:12[1]	-
9	14/10/86	11:54	AFFF	2344A	3	Aspirated	Superfog	13.7	24[3]	-	11.9	17.0	15	14	13.1	4:17	-
10	14/10/86	14:15	FFFP	1050/19/F	3	Aspirated	Superfog	15.0	22[3]	-	16.1	19.2	19	16	8.7	4:29	-
11	15/10/86	10:16	FFFP	1050/19/F	3	Aspirated	Superfog	12.3	19[3]	-	11.8	18.7	14	13	8.9	4:46	-
12	15/10/86	12:00	FFFP	1050/19/F	3	Non-aspirated	Superfog	14.0	21[3]	-	14.0	12.5	15	15	2.1	1:05[1]	-
13	15/10/86	14:24	FFFP-AR	1055/47/F	3	Aspirated	Superfog	13.6	22[3]	-	14.0	16.0	16	17	7.0	5:23	-
14	15/10/86	16:06	FFFP-AR	1055/47/F	3	Aspirated	Superfog	15.3	23[3]	-	13.7	17.7	16	15	6.9	5:13	-
15	22/10/86	10:25	AFFF-AR	2455	3	Aspirated	Superfog	8.7	16[4]	-	8.1	12.6	10	12	4.9	10:17	-
16	22/10/86	12:03	AFFF-AR	2455	3	Aspirated	Superfog	9.9	13.4[4]	.2	9.8	13.3	13	13	5.1	10:02	-
17	24/10/86	9:17	AFFF	234A/2351	3	Non-aspirated	Hyperfog	3.9	10.8[4]	.3	3.3	6.1	7	5	2.3	1:12[1]	-
18	24/10/86	10:39	AFFF-AR	2455	3	Aspirated	Superfog	11.1	11.6[4]	.5	6	10.1	9	11	6.8	9:01	-
19	24/10/86	11:59	AFFF-AR	2455	3	Non-aspirated	Superfog	8.1	13.6[4]	.7	7.6	10	10	12	1.8	1:35[1]	-
20	3/11/86	9:30	FFFP-AR	1055/47/F	3	Aspirated	Superfog	4.6	12.5[4]		4.3	9.8	7	6	6.6	6:34	-
21	3/11/86	11:30	FFFP-AR	1055/47/F	3	Non-aspirated	Superfog	5.5	11.0[4]	.3	5.2	7.6	9	10	1.9	1:30	-
22	3/11/86	14:00	HALOFOAM	-	15	Non-aspirated	Superfog	10.6			7.3	9.9	9	11	1.1	-	-
23	4/11/86	9:30	HALOFOAM	-	15	Non-aspirated	Hyperfog	3.4	13.5[4]	.8	3.2	7.2	7	4	1.1	-	-
24	4/11/86	11:15	FP	1030/57/F	6	Aspirated	Superfog	7.4	17.5[4]	.4	6.8	12.5	9	12	5.0	6:07	5
25	4/11/86	14:05	FFFP-AR	1055/47/F	3	Asoirated	Superfog	8.8	16.7[4]	.3	10.4	13.2	13	14	5.3	5:41	3
26	4/11/86	15:44	FFFP-AR	1055/47/F	3	Aspiratd	Superfog	8.8	17.0[4]	.1	8.2	11.8	11	12	5.7	6:39	-
27	12/11/86	9:47	AFFF (TRIDOL-S)	047987	3	Non-aspirated	Superfog	6.2	14.8[4]	.2	4.0	7.6	8	10	1.9	1:12	-
28	12/11/86	11:15	FP	1030/57/F	3	Aspirated	2 X FRS	7.3	12.0[4]	.1	6.6	9.7	10	11	6.5	7:28	13
29	12/11/86	12:35	FP	74,57	4	Aspirated	"	9.8	13.0[4]	.1	9.4	11.9	12	12	7.2	8:33	16
30	12/11/86	15:00	FFFP-AR	39	3	Aspirated	"	9.4	13.5[4]	.2	9.1	11.6	12	11	5.6	6:07	4

Test No	Extinction Time 90% min:s	Extinction Time 100% min:s	Burnback Time min:s	% Area of Burnback	Volume of Sol. used (lit)	Flowrate (lpm)	Off-Time secs.	Wind Speed (m/s) Portable	Wind Speed (m/s) Control Van Avg	Wind Speed (m/s) Control Van S.D.[2]	Wind Direction from north (magnetic)
1	-	-	-	-	233	100	[illegible]	6	-	-	180
2	8:58	12:26	No effective burnback		1169	100	5	4	-	-	200
3	1:08	1:45	8:43	98	179	100	0	1.5	-	-	270
4	1:07	2:18	13:40	100	235	100	0	1	-	-	270
5	1:06	1:50	7:20	100	210	100	0	2	-	-	-
6	2:42	4:39	2:00	98	505	100	0	2.1	-	-	190
7	4:35	5:30	1:11	100	525	100	0	2.5	-	-	150
8	3:25	4:22	2:17	90	447	100	0	2	-	-	160
9	1:24	2:26	5:42	100	253	100	0	2	-	-	190
10	1:17	2:07	10:57	100	219	100	0	1.8	-	-	180
11	1:23	2:01	6:46	100	203	100	0	4.5	-	-	20
12	3:54	4:26	1:56	95	471	100	0	2.5	-	-	30
13	3:40	3:57	5:18	100	403	100	0	2	-	-	0
14	1:56	3:50	10:22	95	328	100	39	0.4	-	-	10
15	1:54	2:31	8:32	100	237	100	11	2.5	-	-	270
16	0:57	1:25	6:48	100	147	100	0	4.5	4.3	1.1	260
17	2:08	3:29	1:21	100	356	102	0	1	4.5	0.9	180
18	1:14	2:21	7:58	100	216	100	16	4	5	0.8	180
19	4:26	5:27	1:34	95	499	100	35	6	7.4	1.4	180
20	2:02	3:32	9:58	100	344	100	7	4	4.8	0.6	180
21	3:19	4:54	4:07	80	482	100	10	3	4.3	0.7	180
22	3:46	5:52	4:40	98	583	100	9	3.5	5.8	0.3	190
23	2:49	5:14	6:13	100	576	105	13	0	1.8	0.5	270
24	7:24	12:59	16:17	90	1268	100	22	1.3	2.7	0.6	270
25	4:13	5:26	No petrol left		552	100	0	-	1.4	1	-
26	1:21	2:09	9:05	100	212	100	0	0.8	1.6	0.5	200
27	3:30	4:53	3:06	100	482	100	4	3.2	4	0.5	200
28	2:49	4:00	9:20	100	408	100	0	3	4.2	1.2	180
29	1:39	3:15	12:53	100	332	100	0		6	1.5	-
30	1:45	2:21	7:38	100	234	100	0	5	5.5	1	160

1. Extapolated from drained volume v time measurements.
2. Average and standard deviation calculated from datalogger results.
3. Pump operators reading of maximum temperature reached.
4. Data logger results.

FADD.HT1

Table H1: Results of $40\ m^2$ Petrol Fires.