FRDG Publication Number 4/94

HOME OFFICE

A Comparison of Various Low Expansion Foams when used against the Proposed ISO and CEN Standard Medium Scale ($4.5M^2$) Hydrocarbon Fuel Test Fire

B P Johnson

FIRE RESEARCH & DEVELOPMENT GROUP

Pub No 4/94 A Comparison of Various Low Expansion Foams when used against the Proposed ISO and CEN Standard Medium Scale ($4.5M^2$) Hydrocarbon Fuel Test Fire

Home Office
Fire Research and Development Group

A COMPARISON OF VARIOUS LOW EXPANSION FOAMS WHEN USED AGAINST THE PROPOSED ISO AND CEN STANDARD MEDIUM SCALE (4.5M^2) HYDROCARBON FUEL TEST FIRE

BY

B P JOHNSON

FRDG Publication Number 4/94
ISBN 1-85893-183-5

Home Office
Fire Research and Development Group
Horseferry House
Dean Ryle Street
LONDON
SW1P 2AW

ABSTRACT

Several series of fire tests have been carried out in order to evaluate the medium scale fire test method that is proposed for use within the ISO and CEN standards for low expansion foam concentrates. The test method involves extinguishing fires of heptane within a circular 4.5m^2 tray using forceful and gentle foam application methods.

The fire test methods used are described and the performance of the foam concentrates tested are presented. The results from the standard fire tests are compared with the results from tests which employed different fuels, methods and equipment. From these comparisons, it is apparent that there are some very serious weaknesses in the proposed ISO and CEN medium scale fire test. In particular, the test method is unable to distinguish between different qualities of the same foam product; the test method is unfairly biased towards AFFF and AFFF-AR foam types; and heptane is an unrealistic test fuel.

MANAGEMENT SUMMARY

For the past few years, members of the Fire Experimental Unit (FEU) of the Home Office Fire Research and Development Group (FRDG) have been involved in the formulation of European (CEN) and International (ISO) standards for firefighting foam concentrates. Standards for low, medium and high expansion foams are due to be issued shortly.

FEU has focused on the formulation of standards for low expansion foam concentrates for use on water immiscible fuels because it is these foam concentrates that are most commonly used by the UK fire service. The pool fire tests contained within the standards have been under particular scrutiny because they are intended to be the main means of classifying foam concentrate performance. These pool fire tests are referred to in this report as medium scale fires.

Several series of fire tests have been carried out in order to evaluate the draft ISO and CEN medium scale fire test methods. These fire tests are described within this report along with results and conclusions regarding both the performance of the foam concentrates used and of the test methods.

ISO and CEN Fire Test Method

The medium scale fire test method is essentially the same in both the ISO and CEN draft standards. The test consists of applying foam at 11.4 litres per minute through a standard branchpipe into a circular 4.5 m^2 fire tray. The tray contains 144 litres of burning heptane floating on a water base. For each test, foam application commences one minute after ignition of the fuel. The water base, heptane, ambient air and foam solution temperatures must all be within closely defined limits.

Two foam application methods are used, the first involves plunging the foam stream directly into the burning heptane for three minutes; the second involves applying the foam gently on to the surface of the burning fuel for five minutes via a backplate. Once the fire has been extinguished, a burnback test is performed by placing a steel pot containing heptane in the fire tray. This heptane is ignited 5 minutes after the cessation of foam application.

Foam Concentrates

The fire tests employed at least two manufacturers' versions of each of the following foam types: aqueous film forming foam (AFFF), alcohol resistant AFFF (AFFF-AR), film forming fluoroprotein foam (FFFP), alcohol resistant FFFP (FFFP-AR), fluoroprotein (FP), protein (P) and synthetic (S).

All of the foam concentrates were used at the manufacturers' recommended concentration for hydrocarbon fuel fires which was normally 3%. In addition, the film forming foam concentrates were tested at concentrations below those recommended by the

manufacturers, at 2% and 1.5%, to investigate the level of discrimination provided by the fire test.

Other Medium Scale Fire Tests

Some further fire tests, mostly employing the standard medium scale fire test equipment and methods, were also carried out using various petrol formulations. These tests were performed in order to provide results for fuels likely to be encountered operationally by brigades. A further set of tests were also carried out using a bigger 5.8m^2 fire tray in order to assess the effects that reducing the foam application rate has on the performance of foam concentrates.

Results

The ISO and CEN standards are currently only in draft form and so are liable to further change. Consequently, the results of the tests have not been interpreted using the criteria for firefighting performance contained within these draft standards. However, in order to enable a quick and easy comparison to be made of the test results in the report, a simple grading system was used.

The grading system was applied to foam concentrate performance in the areas of knockdown, extinction, burnback resistance and flare resistance.

The grading results from the standard fire tests were compared with the results from tests which employed different fuels, methods and equipment. From these comparisons, it became apparent that there were some very serious weaknesses in the proposed ISO and CEN medium scale fire test.

Conclusions

The fire tests described in the report were relatively small in size, they were performed indoors, under controlled conditions and used a laboratory type foam branchpipe. Consequently, care must be taken in applying these conclusions to other circumstances.

The majority of the medium scale fire tests carried out during this work employed the equipment and methods contained within the draft CEN and ISO standards for low expansion foam concentrates. Although these standards are liable to further change, it is unlikely that there will be any changes to these fire test methods or the equipment used.

Analysis of the results from these fire tests have highlighted the following serious weaknesses in the proposed ISO and CEN standard fire tests:-

1. The fire tests do not adequately distinguish between the performance of foam concentrates when used at either full

or half of their recommended concentration. Even increasing the area of the fire tray by over 25%, and hence reducing the foam application rate, did not significantly improve the discrimination provided by these fire tests.

2. The gentle application fire test is unfairly biased against FFFP and FFFP-AR foam concentrates. AFFF and AFFF-AR foam concentrates achieved quick extinctions while the FFFP and FFFP-AR extinction times were significantly slower due to flame flicker. FFFP and FFFP-AR foam concentrates performed as well as AFFF and AFFF-AR during the forceful application fire tests and during fires involving petrol.

3. The fuel used during the fire tests, heptane, is considerably easier than petrol to extinguish. Fire tests involving petrol were only occasionally extinguished by foams during this work. Heptane was easily extinguished by most foams, even when some of them were used at half of their recommended concentration. Consequently, the performance of foam concentrates during the proposed ISO and CEN standard fire tests cannot be relied upon to predict performance against fuels likely to be encountered by the fire service.

A further report will be issued once the ISO and CEN standards have been issued. It is intended that this further report will compare the firefighting performance of foams during these medium scale fire tests with their performance during large scale fire tests. It is hoped that advice can then be given on how the UK Fire Service should interpret the ISO and CEN standards in order to ensure that they continue to purchase good quality foam concentrates.

CONTENTS

TABLES

FIGURES

APPENDIX

1. INTRODUCTION

For the past few years, members of the Fire Experimental Unit (FEU) of the Home Office Fire Research and Development Group (FRDG) have been involved in the formulation of European (CEN) and International (ISO) standards for firefighting foam concentrates. Standards for low, medium and high expansion foams are due to be issued shortly.

Throughout this work, one of the main aims of the Fire Experimental Unit (FEU) has been to ensure that the quality of the foam concentrates currently being used by the UK fire service is not adversely affected by the introduction of these foam standards.

FEU has focused on the formulation of standards for low expansion foam concentrates for use on water immiscible fuels (References 1 and 2) because it is these foam concentrates that are most commonly used by the UK fire service. The pool fire tests contained within the standards have been under particular scrutiny because they are intended to be the main means of classifying foam concentrate performance. These pool fire tests are referred to by FEU within this FRDG report as medium scale fires.

The medium scale fire test method is essentially the same in both the ISO and CEN draft standards. The test consists of applying foam at 11.4 litres per minute through a standard branchpipe into a circular 4.5 m^2 fire tray. The tray contains 144 litres of burning heptane floating on a water base. For each test, foam application commences one minute after ignition of the fuel. The water base, heptane, ambient air and foam solution temperatures must all be within closely defined limits.

Two application methods are used, the first involves plunging the foam stream directly into the burning heptane for three minutes; the second involves applying the foam gently on to the surface of the burning fuel for five minutes via a backplate. Once the fire has been extinguished, a burnback test is performed by placing a steel pot containing heptane in the fire tray. This heptane is ignited 5 minutes after the cessation of foam application.

FEU has carried out 90 of these standard medium scale fire tests under a purpose built fire test hood at the FEU Still Air Facility. The tests involved at least two manufacturers' versions of each of the following foam types: aqueous film forming foam (AFFF), alcohol resistant AFFF (AFFF-AR), film forming fluoroprotein foam (FFFP), alcohol resistant FFFP (FFFP-AR), fluoroprotein (FP), protein (P) and synthetic (S). All of these foam concentrates were used at the manufacturers' recommended concentration for hydrocarbon fuel fires which was normally 3%. In addition, the film forming foam concentrates were tested at concentrations below those recommended by the manufacturers, at 2% and 1.5%, to investigate the level of discrimination provided by the fire test.

Some further fire tests, mostly employing the standard medium scale fire test equipment and methods, were also carried out using various petrol formulations in order to provide results for fuels likely to be encountered operationally by brigades. A further set of tests were also carried out using a bigger 5.8m^2 fire tray in order to assess the effects that reducing the foam application rate has on the performance of foam concentrates.

This report details all of the medium scale fire tests that have been carried out by FEU and provides results and conclusions on the performance of the various foam concentrates tested.

The ISO and CEN standards are currently only in draft form and so are liable to further change. Consequently, the results of the tests reported here have not been interpreted using the criteria for firefighting performance contained within these draft standards.

A further report will be issued once the firefighting performance criteria has been confirmed and the ISO and CEN standards have been issued. It is intended that this further report will compare the firefighting performance of foams during the medium scale fire tests with their performance during large scale fire tests (Reference 3). It is hoped that advice can then be given on how the UK Fire Service should interpret the ISO and CEN performance criteria in order to ensure that they continue to purchase good quality foam concentrates.

2. TEST APPARATUS AND METHODS

2.1 General

The fire test methods of the ISO and CEN foam standards (see References 1 and 2) are identical and have been followed during the vast majority of tests reported here.

As with many standards, some of the requirements contained within these test methods are open to interpretation. The following sections detail the fire test apparatus and methods used by FEU and consequently provide one interpretation of the requirements of these standards.

Where variations were made to the test methods or equipment in order to carry out non-standard fire tests with petrol or a bigger fire tray, these are also described below.

2.2 Test Site Location

All tests were performed under a fire test hood within the wind-free conditions of the Fire Experimental Unit's Still Air Facility, Hangar 97, RAF Little Rissington (Figure 1). This fire test hood requires only natural ventilation in order to extract the products of combustion. Consequently the wind speed in the vicinity of the tray during a fire test is virtually zero. The ISO and CEN draft standards require that the maximum wind speed should not exceed $3ms^{-1}$ in the proximity of the fire test tray.

2.3 Temperatures

Except where indicated in the results, all of the fire tests were conducted under the following temperature conditions :-

Air Temperature	15 ± 5°C
Fuel Temperature	17.5 ± 2.5°C
Water Temperature	17.5 ± 2.5°C
Foam Solution Temperature	17.5 ± 2.5°C

These are as specified in the ISO and CEN draft standards.

2.4 Fire Trays

The fire tray used for the $4.5m^2$ medium scale fire tests was circular and made from mild steel. Its dimensions were as follows:-

Diameter at rim:	2400mm
Depth :	200mm
Thickness of steel wall :	2.5mm

This tray is as specified in the draft ISO and CEN draft standards (References 1 and 2) and is also designated as a size 144B fire tray in Reference 4.

The tray had several supports welded to its base in order to prevent distortion.

For fire tests, the fire tray was placed within a larger tray (Figure 2). Prior to each test, enough water was poured into the large outer tray such that it just touched the whole of the base of the test tray. This gave a water depth in the outer tray of approximately 25mm. This was done to simulate placing the tray directly on the ground as required in the ISO and CEN draft standards. This arrangement also ensured that the tray was level before putting in the water base and fuel. Both trays were situated centrally under the fire test hood.

A 5.8m^2 surface area fire test tray was used during twenty four fire tests. This tray had the following dimensions:-

Diameter at rim:	2710mm
Depth :	200mm
Thickness of steel wall :	2.5mm

This tray is designated as a size 183B fire tray in Reference 4.

The 5.8m^2 tray had several supports welded to its base to prevent distortion. However, problems were experienced with the rigidity of this tray due to it being constructed with a steel wall thickness of 2.5mm.

This tray was placed directly on the floor and centrally under the fire test hood. The gap between the base of the tray and the floor was filled with bricks in order to simulate the tray base being positioned directly on the ground.

2.5 Foam Application

The CEN and ISO draft standards specify two ways of applying foam during the fire tests, these are:-

Gentle application

Foam is applied indirectly to the surface of the liquid fuel via a backplate (Figure 3). Foam is applied to the test fire for 5 minutes.

Forceful application

Foam is applied directly on to the surface of the fuel (Figure 4). Foam is applied to the test fire for 3 minutes.

For the gentle application fire tests, a metre square backplate was used. The backplate incorporated legs to enable it to be quickly positioned in the 4.5m^2 test tray (Figure 5). The backplate was supported horizontally within the tray with its bottom edge 5mm from the base of the fire tray. This ensured that any foam flowing down the backplate flowed directly on to the fuel surface. Earlier versions of the backplate employed 2.5mm thick steel, however this became severely distorted after just three tests and so a 5mm thick backplate was used during the majority of the tests.

Gentle application fire tests could not be performed with the 5.8m^2 fire tray because the throw of the branch was not sufficient for the foam to strike the backplate at the rear of the tray.

For gentle application with the 4.5m^2 tray, the foam branch was set up horizontally 1 ± 0.05 metres above the fuel level in the tray. The branch was positioned so that the central part of the foam discharge struck the central axis of the backplate 0.5 ± 0.1 metre above the fuel level (Figure 6).

For forceful application with both the 4.5m^2 and 5.8m^2 fire trays, the foam branch was set up horizontally 1 ± 0.05 metres above the fuel level in the tray. The branch was positioned so that the central part of the discharge fell directly on to the fuel surface at a point 1 ± 0.1 metre from the edge of the tray furthest from the nozzle (Figure 7).

During several petrol fire tests, gentle application of the foam to the fuel was made via a front plate. This frontplate was attached directly to the branch trolley and was inclined at 30° from the horizontal. The frontplate was constructed of 3mm thick mild steel with angle iron edging and was 1000mm long and 300mm wide. The bottom edge of the frontplate cleared the top of the fire tray side by approximately 10mm. When in position, the bottom edge of the front plate was allowed to protrude approximately 50mm into the tray.

2.6 Fuels

2.6.1 General

Several fuels were used during these fire tests. These were:-

- Heptane
- Four star petrol
- Lead-free petrol involving the following formulations:-

  FEU 1. With no oxygenates
  FEU 2. Containing 3% Methanol and 2% Tertiary Butyl Alcohol (TBA)
  FEU 3. Containing 15% Methyl Tertiary Butyl Ether (MTBE)

- Lead-free petrol with no oxygenates (burnback-only tests)

The ISO and CEN draft standards require heptane to be used as the fuel. The tests involving the 5.8m^2 fire tray also used heptane.

In order that fuel could be heated to, and maintained at, the required temperature (see Section 2.3), FEU installed a heated flammable liquid store external to its Still Air Facility at Little Rissington (Figure 8). This store was capable of holding up to 16 barrels of fuel (each containing 200 litres). The ambient air temperature within the store was maintained with the use of programmable thermostats. It took approximately 24 hours (depending on external ambient air temperature and initial liquid temperatures) for all of the fuel within the store to reach the required 15-20°C temperature range.

2.6.2 Heptane

All of the fire tests employing the complete ISO and CEN draft standards methods used 144 litres of heptane[1] (superscripts refer to the notes on page 47) floating on a 90 litre water base. The base of a fire tray can quickly become distorted with use, consequently the water base is necessary to ensure a level surface for the fuel.

The heptane used by FEU was to the following specification as given in the ISO and CEN draft standards (References 1 and 2):-

"Use of an aliphatic hydrocarbon mixture having physical properties according to the following specification:-

Distillation range :	84-105°C
Maximum difference between initial and final boiling points :	10°C
Maximum aromatic content :	1%
Density at 15°C :	700 ± 2.5 kg/m^3

"Typical fuels meeting this specification are n-heptane and certain solvent fractions sometimes referred to as commercial heptane."

2.6.3 Four Star Petrol

Some fire tests were performed using four star leaded petrol. This petrol was transferred from a single storage tank at the Fire Service College, Moreton-in-Marsh to 200 litre metal drums in a single dispensing session. These drums were sealed and stored at the FEU Still Air Facility flammable liquid store until the petrol was required for testing.

Most of the tests performed with this fuel used 144 litres of petrol floating on a 90 litre water base. However, several tests were used to experiment with different fuel and water depth combinations.

2.6.4 Lead-Free Petrol

The same fuels as used during the large scale petroleum fires involving lead-free petrol (Reference 5) were used during some tests.

These fuels were collected in 200 litre metal drums during the large scale trials, sealed and stored at the FEU Still Air Facility flammable liquid store until needed. The formulations of these lead-free petrols were as follows:-

FEU 1 : Lead-free petrol with no oxygenates. This was 95 octane premium unleaded petrol.

FEU 2 : Lead-free petrol with moderate oxygenate level, using an alcohol component of 3% Methanol and 2% Tertiary Butyl Alcohol (TBA). This gives a total oxygen content of 1.93% which approaches the British Standard (Reference 6) maximum of 2.5%.

FEU 3 : Lead-free petrol with 15% Methyl Tertiary Butyl Ether (MTBE). This is the maximum allowed under the EEC Directive (Reference 7) and is greater than that allowed in the British Standard for use in the UK.

It was not possible to use a water base during these tests because the additives within the petrol were water soluble. Due to distortion of the base of the fire tray and the requirement for a fuel depth of at least 30mm over the whole of the tray, 215 litres of fuel were used per test.

2.6.5 Lead-Free Petrol With No Oxygenates (Burnback-Only Tests)

The same lead-free petrol as used during the large scale petroleum fires carried out during May 1992 to compare the performances of various foam concentrates (Reference 3) was used during some tests. This petrol was collected in 200 litre metal drums during the large scale trials, sealed and stored at the FEU Still Air Facility flammable liquid store until needed.

Burnback-only tests were carried out with this fuel (see Section 2.8.2). For each test 113 litres of petrol floating on a 113 litre water base was used. This gave fuel and water base depths of 25mm each, the same depths as used during the large scale burnback-only tests.

2.7 Preburn

During all of the tests, except for the burnback-only tests, a preburn time of 1 minute was allowed from ignition to the start of foam application. This was sufficient to allow the fire column to obtain equilibrium and for the burning rate to steady.

2.8 Burnback

2.8.1 Medium Scale Fire Tests

A circular burnback pot with a wire handle was used during all of the medium scale burnback tests. This pot was manufactured from mild steel and had the following dimensions :-

Diameter at rim :	300mm
Depth :	250mm
Nominal thickness of steel wall :	2.5mm

This burnback pot meets the requirements of the ISO and CEN draft standards.

Burnback tests were carried out after both gentle and forceful application tests. A requirement of the ISO and CEN draft standards is that the burnback test should commence 5 minutes after the end of foam application.

During the FEU tests, the burnback pot, containing 2 litres of the fuel involved in the test, was placed centrally within the fire tray approximately 2 minutes before the commencement of the burnback test. The burnback test commenced with the ignition of the fuel in the burnback pot 5 minutes after the end of foam application using a flaming lance (Figures 9 and 10). Generally, the burnback pot was not placed within the fire tray if the test fire was still burning (not all of the foams tested extinguished the fire during the foam application period) and consequently some burnback tests commenced later than scheduled.

2.8.2 Burnback-Only Tests

The large scale fire tests previously carried out by FEU (see References 3, 5 and 8) involved a burnback test that required the use of a propane torch that was applied to the surface of the foam blanket at a set time after 100% extinction. During these large scale fire tests, foam was applied until 30 seconds after 100% extinction had been achieved. Unfortunately, due to the varying extinction performances of the foam concentrate types available, 100% extinction times and consequently foam blanket depth can vary considerably from one foam type to another, and from one test to another, during this type of large outdoor trial. This foam blanket depth can greatly influence the results from this type of burnback test.

It was therefore suggested that a different burnback test could be tried during large scale fire tests which would involve foam being applied to a fuel surface which had not been previously ignited. By controlling the foam solution flowrate and the time of foam application, a layer of foam could be built up which would be dependant on the foam characteristics and not influenced by the extinction performance.

To briefly assess this new burnback test, four 'burnback-only' tests were carried out during a large scale fire test trial (Reference 3). For each of these tests, foam was gently applied to unignited petrol within the fire tray for either one or two minutes. After a five minute waiting period, the burnback flame was applied to the foam blanket and the fire was left to develop.

In order to assess this burnback-only test on a smaller scale, 12 burnback-only tests were carried out using the ISO and CEN draft standards equipment and methods with a few modifications. The same fuel as used during the large scale tests was used (lead-free petrol, see Section 2.6.4). The test method was the same as used during the large scale tests and involved forceful foam application for 1 or 2 minutes and then a five minute waiting period. However, for these medium scale tests, the burnback pot was used (see Section 2.8.1) instead of a propane torch, with the fuel within the pot being ignited 5 minutes after the end of foam application. The fire was then allowed to develop normally.

2.9 Foam Making Branchpipe

A UNI86[2] foam making branchpipe was used for all tests (Figure 11). During the medium scale fire tests, the branchpipe was operated at a flow rate of 11.4 litres per minute to give a foam application rate of 2.5 litres per minute per square metre.

During each test, the branch was operated for 2 minutes before application of foam to the fire commenced. This ensured that steady branch operating conditions had been reached before foam was applied to the fire.

The ISO and CEN standards state that the output of the branch should be 11.4 litres per minute within an operating range of 6.3 ± 0.3 bar. Unfortunately, these fire test methods provide no information concerning where the pressure measurement should be made. FEU measured branch pressure just upstream from the branch, via a piezometer tube[3] and a pressure transducer[4,5]. The piezometer tube was connected directly to the branch with standard 'C' type couplings[6] (see Section 2.14.2 for more details of the hydraulic arrangement). When used in this configuration, the branch operated at 11.4 litres per minute with a pressure generally between 6.4 and 6.9 bar[7].

The FEU UNI86 branch was mounted horizontally on to a trolley (Figure 12) at the required height of 1±0.05m above the fuel surface.

In order to ensure that the foam stream struck the correct area of the tray (forceful application) or of the backplate (gentle application) (see Section 2.5), the following setup procedure was carried out prior to each fire test.

Thirty litres of a premix of the foam concentrate under tests was made up and the branch was operated at 11.4 litres per minute. The trolley was then moved so that the foam stream struck the correct area of the tray or backplate. An object was placed within the tray to represent the liquid surface, this saved the time and effort involved in filling and emptying the tray. The distance of the branch from the tray was then measured and recorded. The fire tray and surrounding area were then cleaned and the branch was thoroughly flushed through with potable water.

On most occasions, branch alignment was carried out away from the fire tray to reduce the time and effort required to clean the tray. Objects were placed on the test area floor to simulate the edges of the tray and the fuel level. Foam was directed at these and the relative position of the branch from 'the tray' was recorded. Once this position had been determined, the trolley was moved and the branch was thoroughly flushed through with potable water.

During forceful application fire tests, the branch and trolley needed to be positioned at least 2 metres away from the fire tray to enable the foam stream to strike the required area of the fuel. This allowed the trolley to be left in position during the preburn without damage due to radiated heat or flame. However, for the gentle application tests, the branch and trolley had to be as close as 0.2 metres from the tray edge to enable the foam stream to strike the correct area of the backplate. Consequently, the trolley was moved into position during the preburn to prevent heat or flame damage.

In order to allow the branch to be operated before and during the preburn, but without foam being applied to the fire, a deflector shield was built onto the branch trolley. This deflector shield directed the output from the branch nozzle to the floor and was lifted by a remote lever at the commencement of foam application to the test fire.

When foam was gently applied via the frontplate (see Section 2.5), the deflector shield was used to direct foam onto the front plate. Consequently, the deflector shield was left down for the duration of foam production during these tests.

The hydraulic arrangement was thoroughly washed through with potable water after each use with foam solution to prevent any contamination. Where a fire test involved a change of foam concentrate, the pump and hydraulic system were flushed through with a solution of the new foam concentrate prior to the fire test. The hydraulic system was then again flushed through with potable water.

For the tests that involved the 5.8m^2 tray, the branch was again operated at 11.4 litres per minute, this gave an application rate of just under 2 litres per square metre for this size of tray.

2.10 Foam Concentrates

The ISO and CEN draft low expansion foam standards are intended to be used for all existing types of low expansion foam concentrate. FEU decided to test only those foam concentrate types that were currently in use with UK fire brigades.

The following foam types were chosen:-

AFFF	Aqueous Film Forming Foam
AFFF-AR	Alcohol Resistant AFFF
P	Protein
FP	Fluoroprotein
FFFP	Film Forming FP
FFFP-AR	Alcohol Resistant FFFP
S	Synthetic

All of these foam types, except for synthetic, are sold in large quantities to UK fire brigades for use at low expansion on Class B hydrocarbon fuels. Synthetic is used in the UK for the production of medium and high expansion foam and it is also used extensively abroad to produce low, medium and high expansion foam.

Protein foam concentrates, although stored in bulk by several brigades, are not generally recommended for use because of their inferior firefighting properties.

At least two manufacturers' versions of each of the above foam types were used during these tests to enable comparisons to be made of possible variations within foam types. Further details of the foam concentrates used are given in Table 1.

All of these concentrates were used at the manufacturers' recommended solution strength for use against hydrocarbon liquid fuel fires - generally 3%. Also, in order to investigate how discriminating the ISO and CEN fire test methods were, the film-forming foam concentrates were used at reduced concentrations of 2% and 1.5% as well.

2.11 Premix

Foam concentrates were premixed with potable water before use to ensure precise proportioning. Two premix containers were used. One container was constructed out of GRP and could contain up to 100 litres of premix, the other container was made of high density plastic and could contain up to 200 litres of premix.

In order to ensure adequate foam solution supplies for the duration of each fire test (including run-up, fire test foam application and foam property measurements) the following volumes were used:-

5 minute foam applications : 150 Litres
3 minute foam applications : 100 Litres

A large wall-mounted water heater provided hot water which enabled the required foam solution temperature of 17.5 ± 2.5°C to be achieved.

The premix solutions were mixed immediately prior to each fire test. Usually, mixing took place as the water base and fuel were being added to the fire tray.

At the end of each test, the premix container used was thoroughly washed out with potable water.

2.12 Foam Property Measurements

Foam was collected from the UNI86 branch by using a sheet aluminium foam collector (Figure 13) to direct foam into a 1600ml brass collecting vessel. Details of these are given in the ISO and CEN draft standards. For each foam collection, the front of the nozzle was positioned 3 metres away from the top edge of the foam collector. Foam was collected and measurements were then made of the expansion ratio, 25% drainage time and temperature of the foam (Figure 14).

The ISO and CEN draft standards state that foam measurements should be made immediately before each fire test to ensure that the expected values for drainage time and expansion ratio are achieved. It also says that "preferably" the measurements should be made with the same premix batch as used for the fire test.

For convenience, FEU carried out these foam measurements immediately after foam application to the fire tray had ceased.

2.13 Potable Water

Potable water was used for premixing the foam concentrates, providing a water base in the fire test tray and for thoroughly cleaning the hydraulic system, the fire tray, the premix tank and the fire test area after each test.

Water for the water base was preheated in a large wall mounted water heater. Immediately prior to each test, the preheated water was poured into a 200 litre capacity steel drum where it was mixed with cold water to obtain the required quantity for the water base at a temperature of 17.5 ± 2.5 °C

2.14 Instrumentation

2.14.1 Radiometers

The signals from four radiometers[8] were recorded during each test. The positions of these during the tests involving the 4.5m^2 fire tray are given in Figure 15. For both the 4.5m^2 and 5.8m^2 fire trays, the radiometers were employed at a height of 1.5 metres above the top edge of the fire tray and with their

sensing faces depressed by 10 degrees from the vertical. The distance between the sensing face of each radiometer and the tray edge was twice the diameter of the fire tray. Each of the radiometers was cooled by recirculating water, at a temperature between 20°C and 40°C, from a tank using an electric pump.

Radiometers 1 and 3 were perpendicular to the direction of throw of the foam branch; these are the positions recommended in the informative parts of the ISO and CEN draft standards. Radiometers 2 and 4 were offset from these and were used by FEU as a check on the first set of radiometers. They also allowed for experimentation with different radiometer sensitivities.

The radiometer signals were recorded once every second on an Orion data logger. As a backup to this data logger, a chart recorder was also used to continuously record the signals.

2.14.2 Flowmeter and Associated Equipment

The hydraulic arrangement used during these tests is shown in Figure 16.

An electrically powered gear pump[9] was used to pump the foam solution from the open premix container to the branch. The gear pump was provided with an electrical variable speed drive control. The foam solution was passed through an electromagnetic flowmeter[10] and then through one 18.3 metre length of 19mm bore hose[11] to the piezometer tube and on to the UNI86 foam branchpipe.

The piezometer tube housed a pressure tapping which was connected to a pressure transducer via a 20 metre length of pressure tubing. The pressure transducer and the flowmeter were connected to digital indicators that could be easily seen by the gear pump operator. Both the pressure and flow were monitored throughout each test and the pump was adjusted if necessary to maintain the required flow of 11.4 litres per minute.

All temperatures were measured by using either mercury in glass thermometers, thermocouple with digital readout[12] or a platinum resistance thermometer with digital readout[13].

2.14.3 Timing

A large digital clock[14], displaying minutes and seconds, was sited near the fire test area, and was visible to all personnel engaged in the conduct of the trial.

The clock was preset to 97:00 (min:sec) and was started when all of the fuel had been poured into the fire tray. The time on this clock is referred to as test time throughout this document.

Generally, during the fire tests, events happened at the following test times:-

97:00	All fuel poured into fire test tray
99:00	Gear pump started, foam produced
00:00	Fuel ignited
01:00	Foam application commenced
04:00	Foam application stopped - forceful application
06:00	Foam application stopped - gentle application
09:00	Burnback pot ignited - forceful application
11:00	Burnback pot ignited - gentle application

The foam application periods during the petrol tests varied. See Section 4.4 for more details.

On some occasions, for both Heptane and Petrol tests, the commencement of the burnback test was delayed due to the late extinction of the fire.

2.14.4 Video

Each test was recorded by two video cameras[15]. The cameras were positioned to view opposite sides of the fire tray and were at 90° to the foam branch. The signals from these cameras were routed via video number generators/timers to two video recorders. The video number generators/timers were set up to indicate test time on the recorded video.

2.15 Safety

A safety procedure was followed for each test. This included firefighting cover during all fuel transfer operations and throughout the fire tests. Appendix A contains a copy of the safety instructions produced for these fire tests.

3. EXPERIMENTAL PROCEDURE

3.1 Branch and Fire Tray Preparation

Prior to each test, a small quantity of the foam solution under test was mixed, foam was produced through the branch at a flowrate of 11.4 litres per minute and the position of the branch for the fire test was determined (see Section 2.9). The fire tray (if used for the alignment) and surrounding area were then cleaned and the branch was flushed through using potable water.

The fire tray was placed centrally in the outer tray and water was poured into the outer tray until it reached the base of the fire tray. Water was sprayed onto the concrete floor around the trays to prevent damage to the floor.

The branch trolley was pushed into position and the direction of throw of the nozzle was checked and adjusted as required. If a forceful application test was to take place then the branch trolley was left in position, if a gentle application test was to take place, the trolley was rolled 3 metres backwards (see Section 2.9).

3.2 Fire Tests

3.2.1 General Procedure

This is the general procedure used throughout the FEU medium scale fire tests.

Before the transfer of fuel to the tray, all equipment was operated to check correct functioning.

Whilst this was happening, 90 litres of water (for the water base) at the required temperature were prepared in a 200 litre drum. 144 litres of heptane, at the required temperature, were pumped into a different 200 litre drum. Both of the drums were mounted on to trolleys and these were positioned near to the fire test tray.

Water was measured into the premix container and the required quantity of the foam concentrate under test was poured into measuring cylinders. Care was taken to ensure that the temperature of the premix water was within the required temperature range.

The drum containing the water base was lifted into position and its contents were poured into the fire test tray (Figure 17). The temperature of this water base was measured and recorded.

The drum containing the fuel was then carefully lifted into position and the fuel was poured into the fire test tray (Figure 18). During this process, the pump operator mixed the foam concentrate into the water contained within the premix container. The temperature of the premix was measured and recorded.

The datalogger, chart recorders and video recorders were all set to record.

Once all of the fuel had been poured into the fire tray, the test clock was started (from indicated time 97 min : 00 sec) and the fuel and ambient air temperatures were measured and recorded.

At indicated test time of 99 min : 00 sec, foam solution was pumped to the branch. At this stage, the foam issuing from the branch was deflected downwards to the floor to prevent it entering the fire tray. The pump operator monitored the flow rate throughout the test and adjusted when necessary.

At indicated test time of 99 min 30 secs the lance was transferred to the test area and ignited. Thirty seconds later, at zero indicated time, the fuel in the test tray was ignited.

At indicated test time 00 min 40 secs, the branch was moved into position (gentle application only, for forceful application the branch was already in its correct position). At 01 min 00 secs the foam deflector shield was lifted and foam was applied to the fire.

During foam application, two observers noted times to 90%, 99% and 100% extinction. Observer timing commenced from the start of foam application.

Foam was applied until test time 04 min 00 secs for a forceful application test and until test time 06 min 00 sec for a gentle application test. At the end of foam application, the deflector shield was replaced and the branch trolley moved to an area away from the fire tray. The deflector shield was then again lifted and the foam stream was aimed at the foam catcher. Foam was collected and measurements were made of foam temperature, expansion ratio and 25% drainage time.

A burnback test was performed at test time 09 min 00 secs for a forceful foam application test or test time 11 min 00 secs for a gentle foam application test. In both cases, three minutes after foam application had ceased, the burnback pot, containing 2 litres of heptane, was placed in the centre of the fire tray.

Five minutes after foam application had ceased, the fuel in the burnback pot was ignited using a flaming lance.

During the burnback tests, observers noted times to 25%, 50% and 100% burnback. Timing commenced from the ignition of the fuel in the burnback pot.

For those tests where the fire continued for a long period after foam application had ceased, the burnback tests were performed at various times depending on the final extinction time.

Once 100% burnback had been achieved, all of the instrumentation was switched off and the fire was allowed to burn out. The fire tray, branchpipe, hydraulic system and all other associated

equipment and foam contaminated areas were thoroughly cleaned with potable water.

3.2.2 Variations Used

Twenty four tests were carried out using 183 litres of heptane and a 113 litre water base in a fire tray of size 5.8m^2. However, the procedure as outlined above was followed.

For the fire tests involving petrol, the above procedures were generally followed except that fuel and water base quantities were varied as were the foam application times.

For the burnback-only tests, no firefighting took place although foam was applied to the fuel surface at zero indicated time for either one or two minutes. Three minutes after foam application had ceased, the burnback pot, containing 2 litres of unleaded petrol, was placed in the centre of the fire tray. After a further two minutes, the fuel in the burnback pot was ignited using a flaming lance and the burnback was allowed to develop normally.

3.3 Data Reduction of Radiometer Results

After the tests, the data recorded on the datalogger was transferred into a spreadsheet software package. The data was processed following the procedure given in the informative section of the ISO and CEN draft standards to calculate the times for 90% extinction, 25% burnback and 100% burnback as well as other intermediate times.

Figure 19 shows an example of a radiometer record with the 90% extinction time and the 25% and 100% burnback times marked.

4. RESULTS

4.1 Presentation of Results

4.1.1 General

The results of the fire tests are tabulated as follows, each table includes extinction and burnback times:-

Table 2 : Results, in chronological order, of fire tests involving a 4.5m^2 fire tray and using heptane as the fuel - includes temperature and foam quality measurements.

Table 3 : Results, by foam concentrate type, of forceful application tests using a 4.5m^2 fire tray and heptane as the fuel - includes flare-up results (see Section 4.1.2).

Table 4 : Results, by foam concentrate type, of gentle application tests using a 4.5m^2 fire tray and heptane as the fuel - includes flicker results (see Section 4.1.3).

Table 5 : Results, in chronological order, of forceful application tests involving a 5.8m^2 fire tray and using heptane as the fuel - includes temperature and foam quality measurements.

Table 6 : Results, by foam concentrate type, of forceful application tests using a 5.8m^2 fire tray and heptane as the fuel - includes flare-up results (see Section 4.1.2).

Table 7 : Results, in chronological order, of fire tests involving a 4.5m^2 fire tray and using four star petrol as the fuel - includes temperature and foam quality measurements.

Table 8 : Results, in chronological order, of fire tests involving a 4.5m^2 fire tray and using lead-free petrol as the fuel - includes temperature and foam quality measurements.

Table 9 : Results, in chronological order, of burnback-only fire tests involving a 4.5m^2 fire tray and using four star petrol as the fuel - includes temperature and foam quality measurements.

The sources of the 90%, 99% and 100% extinction and 25% burnback times quoted in the above tables are as follows:-

90% extinction times : Radiometer measurements and visual observations

99% extinction times : Visual observations

100% extinction times: Visual observations

25% burnback times : Radiometer measurements and visual observations

The visual observation results were compiled from the analysis of observers notes and video records of the tests.

Times were measured from the first application of foam to the tray until 90%, 99% and 100% extinction. Burnback times[16] were measured from the ignition of the fuel in the burnback pot.

4.1.2 Flare-ups

For the gentle application fire tests, the burnback flames tended to develop progressively from around the burnback pot and only involved visible areas of fuel where the foam had disintegrated.

However, during many of the burnback tests that were performed after the forceful application fire tests, 'flare-ups' occurred.

These flare-ups only involved the foam surface and generally did not involve or directly result in areas of fuel being revealed. Flare-ups generally escalated quickly to very intense fires and then died down leaving the foam blanket intact. They were probably due to the ignition of contaminated foam within the foam blankets.

The flare-up results in the results tables record the times at which flare-ups involved 25% of the area of the tray and the time of occurrence, and the area involved, at maximum flare-up. The results from radiometer readings and visual observations are recorded in each instance.

4.1.3 Flickers

During the gentle application fire tests, some foams were unable to completely extinguish the test fire due to flames persisting along the edge of the fire tray furthest away from the backplate. In this report, these small flames are referred to as 'flickers'.

The flicker results in the results tables record the area of fuel covered by the foam blanket and the size of any remaining flames at the end of foam application. Any increases in flame intensity prior to the burnback tests are also recorded.

4.1.4 Performance Grades - Fire Tests Using Heptane With 4.5m² and 5.8m² Fire Trays Only

(i) General

Due to the large number of fire tests carried out involving heptane in the 4.5m² and 5.8m² fire trays, a performance grading system has been introduced to enable a quick and easy comparison to be made of the results of these tests.

The system has been used to grade the performance of foam concentrates in the following areas:-

1. Knockdown
2. Extinction
3. Burnback resistance
4. Flare resistance (forceful application fire tests only - see Section 4.1.2)

In general, a difference in performance of one grade is not regarded as significant due to the tight cut off points between grades. However, where there is a difference in performance of two or more grades, the difference can be regarded as significant (see Section 5.1.3).

The grading system is explained in detail in the following sections.

(ii) Knockdown

The grades for knockdown are based on the 90% extinction times and are as follows:-

GRADE	90% EXTINCTION TIME	
	Forceful and Gentle Application Tests	
	More than (Min:Sec)	Less than or equal to (Min:Sec)
□□□□□		1 min
□□□□	1 min	1 min 30 sec
□□□	1 min 30 sec	2 min
□□	2 min	3 min
□	3 min	

(iii) Extinction

The grades for extinction are based on 100% extinction times and are as follows:-

GRADE	100% EXTINCTION TIME			
	Forceful Application		Gentle Application	
	More than (Min:Sec)	Less than or equal to (Min:Sec)	More than (Min:Sec)	Less than or equal to (Min:Sec)
■■■■■		1 min 30 sec		2 min
■■■■	1 min 30 sec	3 min	2 min	3 min 30 sec
■■■	3 min	4 min	3 min 30 sec	5 min
■■	4 min	12 min	5 min	10 min
■	Not Extinguished		10 min (or Not Extinguished)	

(iv) Burnback

The assessment of the burnback resistance of the foam blankets is based on the 25% burnback time.

The performance grades for the 25% burnback times achieved by each of the foam concentrates used during these tests are as follows (the higher the 25% burnback time the better the performance):-

GRADE	25% BURNBACK TIME			
	Forceful Application		Gentle Application	
	More than or equal to (Min:Sec)	Less than (Min:Sec)	More than or equal to (Min:Sec)	Less than (Min:Sec)
♦♦♦♦♦	15 min		25 min	
♦♦♦♦	12 min 30 sec	15 min	20 min	25 min
♦♦♦	10 min	12 min 30 sec	15 min	20 min
♦♦	7 min 30 sec	10 min	10 min	15 min
♦		7 min 30 sec		10 min

Burnback performance grades have not been given to those foams that did not extinguish the fire or control the fire well enough to enable burnback tests to be performed.

Flare-ups have not been taken into consideration for any of these burnback results. See Section (v) below.

(v) Flare Resistance - Forceful Application Only

The flare resistance grades are based on the largest area of the foam blanket involved in a flare-up during the burnback tests carried out after forceful application fire tests. A flare-up involves the foam blanket surface in flames which quickly escalate and then die down leaving the foam blanket intact. Flare-ups are probably due to the ignition of contaminated foam within the foam blankets.

Performance grades for flare resistance are as follows (the smaller the area of the tray involved in flame the better the performance):-

GRADE	AREA OF TRAY INVOLVED IN LARGE FLARE FLAME	
	Forceful Application Only	
	More than or equal to (%)	Less than (%)
ooooo		1%
oooo	1%	5%
ooo	5%	15%
oo	15%	25%
o	25%	

(vi) Tests Used For Performance Grading

All of the fire tests which involved the 4.5m^2 fire tray and heptane are graded except for those that were performed in conditions outside of the temperature limits specified in Section 2.3 or where there were equipment problems during the tests.

Consequently, tests 55, 56, 57, 58 and 59 have not been graded due to air, fuel and water base temperatures being lower than required. Also, tests 50 and 53 have not been graded due to equipment failure during these tests.

All of the twenty four 5.8m^2 tray fire tests carried out have been graded. Unfortunately, the required air temperature range of 15 ± 5 °C could not be achieved during test numbers 91, 92 and 93 (AFFF(1), FFFP(1) and FFFP-AR(3) all at 3%) due to inclement weather conditions. However, when compared with the results from similar tests, this does not appear to have significantly affected the grading results for these.

(vii) Grade Results For Fire Test Involving Heptane and 4.5m^2 Fire Tray

The performance grades applied to the results of the fire tests involving heptane and a 4.5m^2 fire tray are presented in the following tables:-

Table 10: Performance grade results for all concentrations of foam concentrates when used during the forceful application fire tests.

Table 11: Performance grade results for foam concentrates when used at the concentrations recommended by the manufacturers during the forceful application fire tests.

Table 12: Performance grade results for all concentrations of foam concentrates when used during the gentle application fire tests.

Table 13: Performance grade results for foam concentrates when used at the concentrations recommended by the manufacturers during the gentle application fire tests.

(viii) Grade Results For Fire Tests Involving Heptane and 5.8m^2 Fire Tray

The performance gradings applied to the results of the fire tests involving heptane in a 5.8m^2 fire tray are presented in the following tables:-

Table 14: Performance grade results for all concentrations of foam concentrates when used during the forceful application fire tests.

Table 15: Performance grade results for foam concentrates when used at the concentrations recommended by the manufacturers during the forceful application fire tests.

4.2 Results of Fire Tests Using Heptane and 4.5m^2 Fire Tray

4.2.1 Forceful Application Fire Tests

(i) Knockdown Performance

At full strength, S(1), S(2) and all of the film forming foam concentrates (AFFF, FFFP, AFFF-AR and FFFP-AR) gave quick knockdown performances during these tests. FP(2) and P(2) gave slow knockdowns with FP(1) and P(1) even slower still. FP(3) gave the slowest knockdown performance.

The knockdown performances of all of the film forming foam concentrates did not significantly degrade when reducing the foam concentration from 3% to 2%. However, in almost all cases, knockdown times were longer.

When the usage concentration was reduced from 3% to 1.5%, the knockdown performances of AFFF(1), AFFF(2), AFFF-AR(1), FFFP(1), FFFP(2), FFFP-AR(1) and FFFP-AR(3) did not significantly degrade. However, the knockdown performances of AFFF-AR(2) and FFFP-AR(2) began to degrade significantly. In all but one test, the knockdown times were longer when the foam concentrates were used at 1.5% than when they were used at 3%.

(ii) Extinction Performance

At full strength, all of the film forming foam concentrates, with the exception of FFFP-AR(1), gave quick extinction performances during these tests. The extinction performance of FFFP-AR(1) was significantly slower than all of the other film formers and was similar to the performance achieved by FP(2), neither of these managed to extinguish the test fire during the three minute foam application period. The extinction performances of FP(1) and P(1) were much slower than FP(2) and all of the film forming foam concentrates. FP(3), P(2), S(1) and S(2) all failed to extinguish the forceful application test fire.

Reducing the usage concentration from 3% to 2% did not affect the extinction grades achieved by AFFF(2), AFFF-AR(1), FFFP(2) and FFFP-AR(1). However, the extinction performances of all of the other film forming foam concentrates began to show signs of degradation. When used at 2% concentration, FFFP(1), FFFP-AR(1) and FFFP-AR(2) were unable to extinguish the test fire within the three minute foam application period. In all cases, the extinction times of the foam concentrates at 3% were faster than those achieved at 2%.

When the concentration of the film forming foam concentrates was reduced from 3% to 1.5%, the extinction grades of AFFF(2) and FFFP-AR(1) were not affected. However, all of the other film formers showed signs of degradation. At 1.5% concentration, AFFF-AR(2) was unable to extinguish the forceful application test fire.

When the film formers were used at 1.5% concentration, the performances of AFFF(1) and AFFF(2) were significantly better than all of the others. At this concentration, these two foam concentrates were the only ones that extinguished the forceful application fire test during the three minute foam application period. In almost all cases, the extinction times of the foam concentrates at 3% were faster than those achieved at 1.5%.

(iii) Burnback Performance

When used at full strength, AFFF-AR(2) gave the best burnback performance closely followed by AFFF-AR(1), FFFP(2) and FFFP-AR(3). FFFP(1), FFFP-AR(2), FP(1), FP(2) and P(1) gave slightly shorter times than these. AFFF(1), AFFF(2) and FFFP-AR(1) all gave poor burnback performances. For FP(3), P(2), S(1) and S(2), the test fires were not extinguished or controlled well enough to enable burnback tests to be performed.

When the concentration of the film forming foam concentrates was reduced from 3% to 2%, there were no significant differences in the burnback performances of AFFF(1), AFFF-AR(1), AFFF-AR(2) and FFFP-AR(1). However, the performance of AFFF(2) improved slightly and the performances of FFFP(1) and FFFP-AR(2) degraded slightly. The burnback performance of FFFP(2) was significantly shorter when used at 2% compared with its performance at 3%.

When the concentration of the film forming foam concentrates was reduced from 3% to 1.5% concentration, there was no significant difference in the burnback performance of FFFP-AR(1). However, the performances of AFFF(1), AFFF(2) improved slightly while those of AFFF-AR(1) and FFFP(1) degraded slightly. The burnback performances of FFFP(2), FFFP-AR(2) and FFFP-AR(3) were significantly worse when used at 1.5% compared to their performance at 3%. AFFF-AR(2) was unable to extinguish the test fire when used at 1.5% and so no burnback test could be performed.

The 25% burnback times of AFFF(2) at 3%, and those of FFFP(2) and FFFP-AR(2) at 1.5%, were particularly poor.

(iv) Flare Resistance

The majority of the forceful application burnback tests commenced with flare-ups. These began with small flames ghosting over the foam surface and around the edge of the tray. This spread of flames generally began within 1 minute of the ignition of the fuel within the burnback pot although sometimes flame spread started within 10 seconds. The speed of escalation of these small flames to peak flare-up was unpredictable. In some tests, peak flare-ups occurred within 45 seconds of the spread of small flames, in others it took more than 9 minutes. Generally, flare-ups quickly subsided, sometimes within seconds, often within 1 or 2 minutes. Peak flare-ups can vary from nothing to 100% of the tray area depending on the foam concentrate tested.

At peak flare-up, the flame intensity indicated by the radiometer results was noticeably lower than expected for the area of the foam blanket involved in flame. This was mainly due to the varying density of flames and height of flames on the foam blanket surface.

When used at full strength (3%), FP(1) and P(1) were only marginally affected by flare-ups during the burnback tests.

However, AFFF(1), AFFF(2), FFFP(1) and FFFP-AR(1) were all badly affected by flares with over 25% of the surface of their foam blankets being involved in large flames within two minutes of the start of the burnback tests.

When the concentration of the film forming foam concentrates was reduced from 3% to 2%, FFFP-AR(1) and FFFP-AR(2) became significantly more resistance to flare ups and AFFF-AR(2) slightly more resistant. FFFP(2) became slightly less resistance to flare-ups. The flare resistances of AFFF(1), AFFF(2), AFFF-AR(1) and FFFP(1) were unaffected by this dilution in foam concentration. AFFF(1), AFFF(2) and FFFP(1) were all badly affected by flares at this concentration while FFFP-AR(1) and FFFP-AR(2) were only marginally affected.

When the concentration of the film forming foam concentrates was reduced from 3% to 1.5% concentration, AFFF-AR(1), FFFP-AR(1), and FFFP-AR(2) became significantly more resistant to flares. The resistance to flare-ups of AFFF(1), AFFF(2), FFFP(1), FFFP(2) and FFFP-AR(3) either remained the same or became slightly more resistant to flares with this concentration. AFFF(1) and AFFF(2) were both badly affected by flares while AFFF-AR(1), FFFP-AR(1) and FFFP-AR(2) were only marginally affected by flares when used at 1.5%.

4.2.2 Gentle Application Fire Tests

(i) Knockdown Performance

At full strength, all of the foam concentrates tested gave quick knockdown performances during the gentle foam application fire tests.

The knockdown performance of FFFP-AR(2) was significantly slower when its concentration was reduced from 3% to 2%. The performances of the other film forming foam concentrates were only marginally affected by this reduction in concentration. For the majority of film forming foam concentrates tested, knockdown times at 2% were slower than those achieved at 3%.

When the usage concentration was reduced from 3% to 1.5%, the knockdown performances of AFFF(1), AFFF(2), AFFF-AR(1), FFFP(1), FFFP(2), FFFP-AR(1) and FFFP-AR(3) did not significantly degrade. However, the knockdown performances of AFFF-AR(2) and FFFP-AR(2) did degrade significantly. In all but one test, the film forming foam concentrates gave longer knockdown times at 1.5% than they achieved at 3%.

(ii) Extinction Performance

At full strength, AFFF(1), AFFF(2), AFFF-AR(1), FP(1), FP(3), P(1) and S(2) gave quick extinction performances during the gentle application fire tests. AFFF-AR(2), FFFP-AR(3) and P(2)

all extinguished the test fires slowly but within the five minute foam application period.

FFFP(1), FFFP(2), FFFP-AR(1), FFFP-AR(2), FP(2) and S(1) all gave poor extinction performances with extinction only taking place after foam application had ceased. All of these foams were unsuccessful in extinguishing the test fires during foam application due to flickers (see Sections 4.1.3 and 5.1.1).

Reducing the usage concentration of the film forming foam concentrates from 3% to 2% did not affect the extinction grades achieved by AFFF(1), AFFF(2) and AFFF-AR(2). In addition, there were also slightly improved performances for FFFP(1), FFFP(2) and FFFP-AR(1); in particular, FFFP-AR(1) extinguished the test fire within the five minute foam application period. However, the extinction performances of AFFF-AR(1) and FFFP-AR(2) showed signs of degradation.

When the concentration of the film forming foam concentrates was reduced from 3% to 1.5%, the extinction performances of AFFF(2) and AFFF-AR(2) degraded significantly while the performances of AFFF(1), AFFF-AR(1) and FFFP-AR(3) degraded slightly. FFFP(1), FFFP(2), FFFP-AR(1) and FFFP-AR(2) all gave similar extinction performances at 3% and 1.5% concentrations.

AFFF(1) and AFFF-AR(1) were the only foam concentrates used at 1.5% concentration that extinguished the gentle application test fire within the five minutes foam application period. AFFF-AR(2), when used at 1.5%, failed to extinguish the gentle application fire test.

(iii) Burnback Performance

When used at full strength, FP(1), FP(2), FP(3) and P(1) gave the best burnback performances closely followed by FFFP-AR(3) and P(2). AFFF-AR(2) and FFFP-AR(2) gave slightly shorter times than these. AFFF(1), AFFF(2), AFFF-AR(1), FFFP(1), FFFP(2), FFFP-AR(1) and S(1) all gave poor burnback performances. The burnback performance of S(1) was exceptionally poor.

When the concentration of the film forming foam concentrates was reduced from 3% to 2%, there were no significant differences in the burnback performances of AFFF(1) and AFFF(2). However, the performances of AFFF-AR(1), AFFF-AR(2), FFFP(1), FFFP(2) and FFFP-AR(1) all improved slightly. The burnback performance of FFFP-AR(2) was significantly shorter when used at 2% compared with its performance at 3%.

AFFF(1) and AFFF(2) gave poor burnback performances and FFFP-AR(2) gave an exceptionally poor burnback performance when all were used at 2%

When the concentration of the film forming foam concentrates was reduced from 3% to 1.5% concentration, there was no significant difference in the burnback performances of AFFF(1), AFFF(2), and

AFFF-AR(1). However, the performances of FFFP(1), FFFP(2) and FFFP-AR(1) improved slightly while that of FFFP-AR(2) degraded slightly. AFFF-AR(2) was unable to extinguish the test fire when used at 1.5% and so no burnback test could be performed.

When used at 1.5% concentration, poor burnback performances were achieved by AFFF(1), AFFF(2), AFFF-AR(1), FFFP-AR(2).

4.3 Results of Fire Tests Using Heptane and 5.8m^2 Fire Tray

4.3.1 General

Twenty four 5.8m^2 tray fire tests were carried out using heptane as the fuel and forceful foam application. Unfortunately, due to inclement weather conditions, the required air temperature range of 15 ± 5 °C (see Section 2.3) could not be achieved during test numbers 91, 92 and 93 (AFFF(1), FFFP(1) and FFFP-AR(3) all at 3%) although this does not appear to have significantly affected these results.

4.3.2 Forceful Application Fire Test Results

(i) Knockdown Performance

At full strength, all of the film forming foam concentrates (AFFF, FFFP, AFFF-AR and FFFP-AR) gave quick knockdown performances during these tests. FP(2) gave a slow knockdown with FP(1) even slower still.

The knockdown performances of all of the film forming foam concentrates did not significantly degrade when reducing the foam concentration from 3% to 2%. However, in almost all cases, knockdown times were longer.

When the usage concentration was reduced from 3% to 1.5%, the knockdown performances of AFFF(1), AFFF(2), AFFF-AR(1), FFFP(1), and FFFP-AR(3) did not significantly degrade. However, the knockdown performances of AFFF-AR(2) and FFFP-AR(1) degraded badly with their performances at 1.5% concentration being particularly poor. In all tests, the knockdown times were longer when the foam concentrates were used at 1.5% than when they were used at 3%.

(ii) Extinction Performance

At full strength, all of the film forming foam concentrates, with the exception of FFFP-AR(2), gave quick extinction performances during these tests. The extinction performance of FFFP-AR(2) was significantly slower than all of the other film formers. FFFP-AR(2) failed to extinguish the test fire during the three minute foam application period. FP(1) and FP(2) both failed to extinguish the forceful application test fire.

Reducing the usage concentration of the film forming foam concentrates from 3% to 2% did not affect the extinction grades achieved by AFFF(2), AFFF-AR(1) or AFFF-AR(2). However, the extinction performances of AFFF(1), FFFP(1) and FFFP-AR(1) began to show signs of degradation. When used at 2% concentration, FFFP(1) and FFFP-AR(1) were unable to extinguish the test fire within the three minute foam application period. In all cases, the extinction times of the foam concentrates at 3% were faster than those achieved at 2%.
When the concentration of the film forming foam concentrates was reduced from 3% to 1.5%, the extinction grade of AFFF(2) was not affected. However, the extinction grades of AFFF(1), AFFF-AR(1) and FFFP(1) began to show signs of degradation. The extinction performances of AFFF-AR(2), FFFP-AR(1) and FFFP-AR(3) degraded badly. At 1.5% concentration, AFFF-AR(1) and FFFP(1) were unable to extinguish the test fire within the three minute foam application period. AFFF-AR(2), FFFP-AR(1) and FFFP-AR(3), when used at 1.5% concentration, were unable to extinguish the forceful application test fire.

When all were used at 1.5% concentration, the performances of AFFF(1) and AFFF(2) were significantly better than the other film forming concentrates. At this concentration, these two foam concentrates were the only ones that extinguished the forceful application fire test during the three minute foam application period.

In all cases, the extinction times of the foam concentrates at 3% were faster than those achieved at 1.5%.

(iii) Burnback Performance

When used at full strength, AFFF-AR(2) gave the best burnback performance closely followed by AFFF-AR(1). FFFP(1), FFFP-AR(1) and FFFP-AR(3) gave slightly shorter times than these. AFFF(1), AFFF(2), FFFP(2) and FFFP-AR(2) all gave poor burnback performances with the burnback performance of AFFF(2) being particularly poor. For FP(1) and FP(2), the test fires were not extinguished, or controlled well enough, to enable burnback tests to be performed.

When the concentration of the film forming foam concentrates was reduced from 3% to 2%, there were no significant differences in the burnback performances of AFFF(1) and AFFF-AR(2). However, the performance of AFFF(2) improved slightly and the performance of AFFF-AR(1) degraded slightly. The burnback performances of FFFP(1) and FFFP-AR(1) degraded significantly. The burnback performances of FFFP(1) and FFFP-AR(1) were significantly shorter when used at 2% compared with their performances at 3%.

When the concentration of the film forming foam concentrates was reduced from 3% to 1.5% concentration, the burnback performances of AFFF(1) and AFFF(2) improved slightly while those of AFFF-AR(1), and FFFP(1) degraded significantly. AFFF-AR(2), FFFP-AR(1) and FFFP-AR(3) were unable to extinguish the test fires

when used at 1.5% and so no burnback tests could be performed.

The 25% burnback times of AFFF(2) at 3%, FFFP(1) and FFFP-AR(1) at 2% and of FFFP(1) at 1.5%, were particularly poor.

(iv) Flare Resistance

When used at 3% concentration, AFFF(1), AFFF(2), AFFF-AR(1), AFFF-AR(2), FFFP(1), FFFP(2) and FFFP-AR(3) were all badly affected by flare-ups with over 25% of the surface of their foam blankets being involved in large flames. FFFP-AR(1) and FFFP-AR(2) gave flare resistances which were only slightly better than these. The flare-up area for all of these foams generally reached 25% within 2 minutes of the commencement of the burnback tests. However, the 25% area flare-up time for AFFF-AR(1) was 2 minutes 28 seconds, the time for AFFF-AR(2) was 8 minutes 46 seconds and the time for FFFP-AR(3) was 3 minutes 51 seconds.

When the concentration of the film forming foam concentrates was reduced from 3% to 2%, AFFF-AR(1) and AFFF-AR(2) became significantly more resistance to flare ups and FFFP(1) and FFFP-AR(1) slightly more resistant. The flare resistances of AFFF(1) and AFFF(2) were unaffected by this reduction in foam concentration. AFFF(1) and AFFF(2) were all badly affected by flares at this concentration while FFFP-AR(1) was only marginally affected.

When the concentration of the film forming foam concentrates was reduced from 3% to 1.5%, AFFF-AR(1) and FFFP(1) became significantly more resistant to flares. The resistance to flare-ups of AFFF(1) and AFFF(2) remained the same with this reduction in concentration. AFFF(1) and AFFF(2) were both badly affected by flares while FFFP(1) was only marginally affected by flares when used at 1.5%.

4.4 Results of Four Star Petrol Fire Tests

4.4.1 Extinction Results

A total of 20 fire tests were carried out using four star petrol as the fuel and a 4.5m^2 fire tray.

In tests P1 and P2, AFFF(1) and FP(1) respectively were applied forcefully to the test fire for 3 minutes. Neither foam achieved 100% extinction of the test fire in addition, FP(1) was also unable to achieve 99% extinction.

During test P3, FP(1) was applied gently, via a backplate at the rear of the fire tray, for 5 minutes. Again, 100% extinction was not achieved.

In an attempt to achieve 100% extinction during these tests, the foam application periods were increased from 5 minutes to 7 minutes for gentle application tests P4 to P6, and from 3 minutes

to 5 minutes for forceful application tests P7 to P9. At the end of these foam application periods, the tray was completely full of foam. Consequently, longer foam application periods could not be used.

Tests P4, P5 and P6 involved the gentle application of AFFF(1), FP(1) and FFFP(1) foams respectively. In each case, 100% extinction only occurred between two and seven minutes after foam application had ceased.

Tests P7, P8 and P9 involved the forceful application of AFFF(1), FP(2) and FFFP(1) respectively. 100% extinction was only achieved by FFFP(1). The 100% extinction time of 2 minutes 19 seconds suggests that the extinction performance of FFFP(1) was not assisted by the extending the foam application period from 3 to 5 minutes.

In a further attempt to achieve 100% extinction using a gentle application method, foam was applied via a plate at the front of the tray (see Section 2.5) during tests P10 to P14 (test P10 has not been used in the analysis of results due to equipment failure during the test). The foam application period was restricted to 5 minutes during these tests because the tray was full of foam by this time. AFFF(1), FFFP(1), FP(1) and P(1) were all applied during these tests, however, none of them achieved 100% extinction during the foam application period.

Test P15 was carried out in an attempt to achieve 100% extinction using forceful application with AFFF(1). During this test, foam was applied directly to the fuel surface but with the foam stream directed to the left of the tray, just avoiding the tray edge to the left of the branch. Again, 100% extinction was not achieved.

During these petrol fire tests, non-extinction or delayed extinction of the test fire was generally due to small, persistent, flames burning between the edge of the foam blanket and the tray side. These persistent flames were normally present at the edge of the tray nearest to the branch. The only exceptions to this were during the gentle applications via the front plate where the persistent flames continued to burn at the edge of the tray furthest from the branch.

Despite the various application methods and foam concentrates used, these petrol fires proved almost impossible to extinguish during the foam application period. The results of these tests do however provide 90% and 99% extinction times for foams when used against fires of four star petrol.

During the forceful application tests, AFFF(1) gave quicker times to 90% and 99% extinction than FFFP(1). Both AFFF(1) and FFFP(1) were much quicker than FP(1) and FP(2) to 90% and 99% extinction.

In the gentle application tests, AFFF(1) gave quicker times than both FFFP(1) and FP(1) to 90% and 99% extinction. FFFP(1) was considerably quicker than FP(1) to 90% extinction however, times

to 99% extinction were similar. FP(1) and P(1) gave similar 90% and 99% extinction times.

A summary table of these results is given below:-

Test No.	Foam Type	App. Method	App. Period	90% Ext.	99% Ext.	100% Ext.
P1	AFFF(1)	Forceful (Centre)	3m	38s	1m 22s	No
P7	AFFF(1)	Forceful (Centre)	5m	33s	1m 17s	No
P9	FFFP(1)	Forceful (Centre)	5m	50s	1m 27s	2m 19s
P2	FP(1)	Forceful (Centre)	3m	3m 22s	No	No
P8	FP(2)	Forceful (Centre)	5m	3m 16s	5m	No
P15	AFFF(1)	Forceful (Side)	3m	42s	1m 11s	No
P4	AFFF(1)	Gentle (Rear)	7m	50s	3m	13m 25s
P6	FFFP(1)	Gentle (Rear)	7m	56s	5m	8m 58s
P3	FP(1)	Gentle (Rear)	5m	2m 13s	4m 30s	No
P5	FP(1)	Gentle (Rear)	7m	1m 57s	4m 55s	13m 3s
P11	AFFF(1)	Gentle (Front)	5m	39s	1m 39s	5m 38s
P12	FFFP(1)	Gentle (Front)	5m	52s	2m 34s	12m 34s
P13	FP(1)	Gentle (Front)	5m	1m 22s	2m 23s	5m 35s
P14	P(1)	Gentle (Front)	5m	1m 24s	2m 24s	17m 55s

Test P16 to P20 were carried out to indicate the effects of different fuel depths and the presence of a water base on the firefighting performance of foam concentrates to assist in the selection of fuel depth for the large scale fire tests (Reference 3). The results of these tests were as follows:-

Foam Type	Fuel Depth (mm)	Water Base Depth (mm)	90% Ext. (min : sec)	99% Ext. (min : sec)	100% Ext.
AFFF(1)	25	25	0 : 35	1 : 08	No
AFFF(1)	25	25	0 : 37	1 : 12	No
AFFF(1)	50	0	0 : 38	1 : 23	No
AFFF(1)	48	0	0 : 38	1 : 50	No
FFFP(1)	48	0	0 : 51	2 : 02	No

For AFFF(1) the 90% extinction times do not appear to be affected by changes in the depth of fuel/presence of a water base. However, the times to 99% extinction are longer for the deeper fuel layer.

4.4.2 Burnback Results

In only three of the twenty fire tests involving four star petrol were burnback tests performed at the correct time. Unfortunately, these tests involved different application methods and so the burnback results of these cannot sensibly be compared.

During six of these petrol tests, burnback tests were delayed due to long 100% extinction times and no burnback tests were carried out after the remaining fifteen tests because 100% extinction was not achieved. Consequently, comparisons of burnback performance of various foams after extinction of fires involving four star petrol are not available from the results of these tests.

4.5 Results of Lead-Free Petrol Fire Tests

4.5.1 Extinction Results

Eight fire tests were carried out which involved lead-free petrol. All involved the forceful application of foam for 5 minutes into 215 litres (48mm depth) of fuel with no water base.

The extinction results were as follows:-

Foam Type	Fuel	90% Ext. (min : sec)	99% Ext. (min : sec)	100% Ext. (min : sec)
AFFF(1)	FEU 1	0 : 37	1 : 53	No
AFFF(1)	FEU 2	0 : 40	1 : 53	No
AFFF(1)	FEU 3	0 : 41	1 : 57	No
FFFP(1)	FEU 1	0 : 49	1 : 42	No
FFFP(1)	FEU 2	0 : 52	1 : 59	No
FFFP(1)	FEU 3	0 : 58	2 : 20	No
FP(1)	FEU 1	3 : 10	4 : 49	5 : 19

AFFF(1) gave similar 90% and 99% extinction times for all three types of fuel. The firefighting performance of FFFP(1) showed signs of degradation with each successive fuel type. FP(1) was the only foam tested here to extinguish a lead-free petrol test fire although this occurred after the end of the foam application period. FP(1) was considerably slower then the other two foam types to 90% and 99% extinction.

4.5.2 Burnback Results

Only one of the eight lead-free petrol fire tests was extinguished and so only one burnback test was performed. FP(1) extinguished the test fire and achieved a 25% burnback time of 10 minutes 9 seconds. A flare-up did not occur although within 1 minute of the commencement of the burnback test, some small flames, less than 100mm in height, were observed sparsely spread over 75% of the surface of the foam blanket. These small flames continued to burn throughout most of the burnback test.

4.6 Results of Burnback-Only Tests

Twelve burnback-only test were carried out using unleaded petrol with no oxygenates. The results for the forceful and the gentle application tests were as follows (a longer 25% burnback time indicates better burnback performance):-

Foam Type	Application Period (Minutes)	25% Burnback Time	
		Forceful App. (min : sec)	Gentle App. (min : sec)
AFFF(1)	1	3 : 28	7 : 53
AFFF(1)	2	4 : 34	9 : 02
FFFP(1)	2	6 : 38	10 : 19
FP(1)	2	11 : 04	15 : 58
AFFF-AR(1)	2	7 : 06	10 : 18
FFFP-AR(1)	2	7 : 05	11 : 34

Flare-ups only occurred during burnback tests that were performed after forceful foam application. The flare-ups recorded during these tests were as follows (a smaller flare area indicates better performance):-

Foam Type	Application Period (Minutes)	Maximum Flare Area (as %age of tray area)	Time Flare Observed (min : sec)
AFFF(1)	1	75%	0 : 43
AFFF(1)	2	75%	1 : 45
FFFP(1)	2	25%	1 : 33
FP(1)	2	80%	0 : 40
AFFF-AR(1)	2	30%	2 : 00
FFFP-AR(1)	2	10%	2 : 01

4.7 Foam Properties

The foam expansion and 25% drainage time results are given in Tables 2, 5, 7, 8 and 9. A UNI-86 foam branchpipe, operating at a flow rate of 11.4 litres per minute, was used during all of these tests. A summary of the average foam properties recorded during these tests is given below:-

Foam Type	Foam Conc.	Expansion Ratio		25% Drainage Time	
		Average	Range	Average	Range
AFFF	3% 2% 1.5%	11.4 10.7 8.6	10.8 - 11.8 10.1 - 11.0 7.3 - 9.5	3m 28s 3m 04s 2m 29s	3m - 4m 15s 2m 38s - 3m 24s 2m - 2m 53s
AFFF-AR	3% 2% 1.5%	7.8 5.3 4.3	5.9 - 9.8 4.1 - 7.2 3.6 - 5.3	7m 56s 4m 14s 3m 1s	4m 52s - 9m 37s 3m 10s - 4m 54s 2m 37s - 3m 24s
FFFP	3% 2% 1.5%	9.8 7.9 5.9	8.8 - 10.3 7.3 - 8.9 5.1 - 7.1	3m 39s 2m 42s 2m 18s	2m 47s - 4m 12s 2m 28s - 2m 58s 2m 2s - 2m 28s
FFFP-AR	3% 2% 1.5%	8.0 5.6 4.4	6.2 - 8.7 5.2 - 5.8 4.1 - 4.7	4m 59s 3m 50s 2m 42s	2m 46s - 6m 15s 3m 3s - 4m 13s 2m 9s - 2m 53s
FP	3%[1]	8.2	7.2 - 8.8	5m 31s	4m 59s - 5m 55s
P	3%	8.1	7.7 - 8.5	5m 13s	4m 49s - 5m 30s
S	3%	11.4	11.3 - 11.5	7m 36s	6m 34s - 8m 30s

Note:- 1. Includes results for FP(3) which was used at the recommended concentration of 6%.

5. DISCUSSION

5.1 Fires Involving Heptane and 4.5m^2 Fire tray

5.1.1 Comparison of Forceful Application and Gentle Application Test Results - Full Strength Foam Concentrates

i) Extinction

The forceful application test fires were quickly extinguished by most of the film forming foam concentrates. However, the non-film forming foam concentrates gave poor extinction performances.

The gentle application fire test was extinguished within the 5 minute foam application time by most of the foam concentrates tested. However, particular problems were experienced by the FFFP, two of the FFFP-ARs and several of the non-film forming foam concentrates. Here, flame flickers led to very long extinction times.

Flame flickers were only experienced during the gentle application fire tests and consisted of small flames which persisted along the tray edge furthest away from the backplate. The foam lying around this portion of the tray edge was the first to be applied to the fire during each test. This foam had not only been projected by the branchpipe through the flames at their peak, but it had also impacted on a very hot back plate.

This initial foam appeared to bounce off the surface of the plate and impact heavily on to the burning fuel causing some foam contamination. This effect significantly altered as the plate cooled down, with foam gradually beginning to flow down the backplate to give a more gentle application.

Once the initial foam had hit the burning fuel, it was then pushed across the fuel surface by the continuing foam application. The time taken for the initial foam to travel across the burning surface of the fuel to the furthest edge of the tray was at least 30 seconds. Consequently, this foam was not only the "oldest" in the tray, but it had also experienced some very severe conditions.

A wall of the initial foam was eventually formed at the tray edge furthest away from the backplate. Small flickering flames often burnt between the foam and the tray edge or appeared to burn within the foam wall itself. These flickers may indicate that the initial foam had degraded to such an extent during application that it was no longer able to seal around the tray edge or that a great deal of fuel pick-up had occurred.

The temperature of the plate used to gently apply foam to the surface of a liquid fuel fire has previously been shown by FEU (Reference 9) to affect the extinction performance of foam concentrates.

ii) Burnback

AFFF-AR and FFFP foam concentrates gave better burnback performances after the forceful application tests than they did after the gentle application tests. The reverse is true for the non-film forming foam concentrates where burnback tests were carried out (some of these foam concentrates did not extinguish the forceful application fire test and so burnback test could not be performed). The remainder of the foam concentrates gave similar burnback performances during both sets of tests.

Many of the burnback tests performed after the forceful application tests resulted in flare-ups (see Section 4.1.2). These were generally much more severe for the film forming foam concentrates than they were for the non-film formers.

5.1.2 Comparison of Forceful Application and Gentle Application Test Results - Reduced Strength Foam Concentrates

i) General

Only the Film forming foam concentrates were tested at reduced strength.

ii) Extinction

The grading results show that generally there were only minor reductions in extinction performance for the majority of the reduced strength film forming foam concentrates during the forceful application tests. However, AFFF-AR(2) gave a particularly poor extinction performance when used at 1.5% concentration.

During the gentle application tests, reductions in foam concentration did not significantly affect extinction performances of AFFF(1) and AFFF-AR(1). However, the extinction performances of AFFF(2) and AFFF-AR(2) when used at 1.5% concentration were particularly poor. In general, the FFFP and FFFP-AR foam concentrates gave improved extinction performances with increased dilution. However, most of these were unable to extinguish the test fire during the foam application period due to flame flickers (see Section 5.1.1).

The magnitude of these flame flickers decreased with reduced concentration. This apparent improvement in performance with concentrates used at below their recommended concentration may have been due to several factors such as:-

1. Increased fluidity enabling the foam to cover the burning fuel quicker thus reducing the damage to the initial foam wall.

2. Quicker foam drainage allowing the amount of any contaminated foam to be reduced.

3. Quicker foam drainage providing an increased rate of tray edge cooling and consequently better edge sealing.

iii) Burnback

Reductions in the concentration of most of the film forming foam concentrates did not significantly affect their burnback performances during either the gentle or forceful application tests. The only exception to this was with FFFP(2) where its burnback resistance significantly degraded with dilution during the forceful application tests but improved slightly during the gentle application tests.

5.1.3 Repeatability

A minimum of three tests employing the same conditions is ideally required to assess repeatability, although more are desirable. Due to the range of foam concentrates and concentrations tested by FEU during these tests, often only one test was carried out for most conditions.

However, some tests were repeated, for instance the forceful application of AFFF(1) at 3% was carried out five times. The average time to extinction of these tests was 66 seconds with the fastest time 58 seconds and the slowest time 72 seconds. These results indicates a reasonable level of repeatability for extinction time.

However, when considering the burnback results for the forceful application of AFFF(1) at 3%, the average 25% burnback time was 8 minutes 44 seconds with times varying between 5 minutes 28 seconds and 10 minutes 55 seconds. This does not appear to represent an acceptable level of repeatability. Maximum flare areas for this foam were also not of an acceptable level of repeatability with results varying between 40% and 90% of the tray area and the time of maximum flare varying between 44 seconds and 2 minutes 11 seconds.

FFFP(1) was used at 3% for forceful application during 3 tests. the results for this foam show less repeatability for extinction time but better repeatability for burnback and maximum flare area.

Every attempt was made to make the tests as repeatable as possible. For instance a standard fuel, commercial heptane was used, and fuel, water base, air and foam solution temperatures were controlled. Tests were also held in the wind-free conditions of the FEU Still Air Facility.

5.2 Comparison of the 4.5m^2 and 5.8m^2 Fire Test Results

The UNI86 branch used during these tests was operated at a flow rate of 11.4 litres per minute. This gives foam application rates of 2.5 and 2 litres per minute per square metre for the 4.5m^2 and 5.8m^2 trays respectively. This lowering of foam application rate should ensure that the 5.8m^2 size fire is more difficult to extinguish than the 4.5m^2 fire.

Tables 16 and 17 compare the 100% extinction results and the 25% burnback results achieved during the 4.5m^2 and 5.8m^2 fire tests. These indicate that in almost all cases, the 5.8m^2 times to 100% extinction were longer than those achieved during the 4.5m^2 tests.

Only two tests produced quicker 5.8m^2 extinction times, these were FFFP(2) and FFFP-AR(1) when both were used at their recommended 3% concentration. 100% extinction did not occur in six of the 5.8m^2 fire tests and only one of the 4.5m^2 fire tests.

These results indicate that generally the 5.8m^2 fire was a more severe test than the 4.5m^2 fire test. However, the differences in the 100% extinction times of foam concentrates when used at different concentrations were not as great as expected. In particular, the difference in extinction time for AFFF(1) when used at 3% and 1.5% concentration during the 4.5m^2 fire tests was 51 seconds while during the 5.8m^2 fire test it was 59 seconds. It was hoped that by using this larger fire size, the performances of reduced strength foam concentrates compared with their performances at full strength would be accentuated. For most of the foam concentrates tested here, this was not the case.

In terms of the extinction grades, the 5.8m^2 and 4.5m^2 results are very similar. The main differences only occur where the 5.8m^2 fires were not extinguished.

The burnback results achieved during both sizes of fire test were also very similar. In general, the burnback times achieved by foams during the 5.8m^2 fires were generally only slightly shorter than those achieved during the 4.5m^2 fires. Consequently, the burnback grades achieved by each foam type for both fire sizes were similar.

The 5.8m^2 fire tests generally produced greater maximum flare-ups areas for the AFFF and AFFF-AR foam concentrates than the 4.5m^2 fire tests. However, for the FFFP and FFFP-AR tests, the greater flare-ups were generally produced during the 4.5m^2 fire tests.

5.3 Fires Involving Four Star Petrol and 4.5m^2 Fire Tray

5.3.1 General

The four star petrol fires proved to be very difficult to extinguish even though various foam application methods, foam

application times and foam concentrates were used. Where extinction did occur, it was normally after the end of foam application. Consequently, only times to 90% and 99% extinction could be used for comparison purposes.

Only one fire test was performed for each condition during these tests. Consequently, it is not possible to comment on the level of repeatability obtainable from these tests.

5.3.2 Comparison With 4.5m^2 Heptane Fires

The fire tests involving gentle application via a backplate showed that times to 90% and 99% extinction were considerably longer with petrol than with heptane for all foam types tested.

Comparing the 90% and 99% extinction times of foam concentrates used during forceful application tests against petrol with those against heptane showed the following:-

- 90% and 99% extinction times for AFFF(1) and FP(1) were significantly longer with fires involving petrol than with those involving heptane.

- 90% and 99% extinction times for FFFP(1) were similar with both petrol and heptane.

The above results indicate that heptane is considerably easier than petrol to extinguish during gentle application fire tests for all foam types. When the forceful application tests are considered, heptane appears to be considerably easier for AFFF(1) and FP(1) to extinguish while it provides a sterner test for FFFP(1).

In terms of Fire Service requirements where petrol is likely to be the most commonly encountered fuel, the use of heptane in the these medium scale fire tests appears to discriminate against FFFP type foam concentrates.

The use of a front plate instead of a backplate for gentle foam application on to petrol fires resulted in much shorter 90% and 99% extinction times. However, the front plate was relatively cool immediately prior to foam application to the fire due to it being positioned away from the fire tray during the preburn. In contrast, the backplate was in flame throughout the preburn and would have been extremely hot prior to foam application (see Section 5.1.1). Foam hitting this, appeared to bounce off and impact heavily on to the burning fuel.

When applying foam via the cool frontplate, the foam immediately adhered to the surface of the plate and flowed gently, with low velocity, on to the surface of the fuel.

In addition to these points, the foam stream was applied to the backplate after travelling through flame, and this may have affected the performance of the foam. Foam did not travel through flame when applied via the front plate.

Due to the late extinction or non-extinction of the majority of the petrol fire tests, burnback tests were generally either performed late or not at all and so there are not enough results to allow adequate comparisons of burnback performance to be made.

5.4 Fires Involving Lead Free Petrol - Comparisons With Large Scale Fire Tests

The medium scale fire tests carried out during this work, involved the same fuels as used during the large scale lead-free petroleum fires (Reference 5).

The 90% extinction times achieved during the medium scale tests showed similar trends to those achieved during the large scale tests. In both sets of tests, AFFF and FFFP foam concentrates achieved quick 90% extinction times when used against each of the three lead-free petrol formulations tested (see Section 2.6.1).

100% extinctions could not be achieved during the medium scale fire tests when using either AFFF or FFFP foam concentrates. This was due to small flames remaining around the tray edge. These flames could not be extinguished with the fixed foam branchpipe used during these tests. However, comparisons of the 100% extinction times achieved during the large scale tests with the 99% extinction times achieved during the medium scale tests again show similar trends for AFFF and FFFP foam concentrates with good performances on all three lead-free petrol formulations tested.

During the medium scale fire tests, it was only possible to test FP against the lead-free fuel containing no oxygenates (FEU 1). During this test, FP gave much longer times to 90% and 99% extinction when compared with those achieved by AFFF or FFFP. However, it did achieve extinction. This trend for longer control times when using FP was also noted during the large scale fire tests.

Only one burnback test could be performed during the medium scale fire tests, consequently, it is not possible to compare the burnback performances of the medium and large scale fire tests.

5.5 Burnback-Only Tests

5.5.1 General

The same lead-free petrol (with no oxygenates) as used during the large scale petroleum fires carried out during May 1992 (Reference 3) was used during these tests. During the large scale trials, four burnback-only tests were carried out to assess a burnback test which involved foam being applied to a fuel surface which had not been previously ignited (see Section 2.8.2). The foams used during the large scale tests were AFFF(1), FFFP(1) and FP(1).

In order to assess this burnback-only test on a smaller scale, 12 burnback-only tests have been carried out during these medium scale trials.

5.5.2 Medium Scale Fire Tests

During these medium scale tests, foam was applied using both the forceful and the gentle foam application methods to the surface of lead-free petrol.

The results of the tests indicate that a considerable amount of contamination of the foam blankets occurred after forceful application for each of the foams tested. No observable contamination occurred during gentle application of the foams.

During each of the forceful application burnback-only tests, AFFF(1) applied for 1 and 2 minutes, and FP(2) applied for 2 minutes, produced severe flares of at least 75% of the foam blanket surface.

For FFFP(1), AFFF-AR(1) and FFFP-AR(1), where foam was applied for 2 minutes, the areas of foam blanket involved in flare-ups were between 10% and 30% of the tray area. However, these were still very severe fires.

Doubling the forceful foam application time for AFFF(1) greatly increased the time before which the maximum flare occurred and increased the burnback time by over 30%.

FP(1) gave the best burnback performance with a time that was more than twice that achieved by AFFF(1). The other foams all gave burnback times that were significantly shorter than that achieved by FP(1) but significantly longer than that achieved by AFFF(1).

The gentle application tests gave 25% burnback times for all foams that were significantly longer than the times achieved during the forceful application tests. Again, FP(1) gave the best burnback performance.

5.5.3 Comparison With Large Scale Fire Tests

During the large scale burnback-only tests, foam was applied as gently as possible but impacted directly on to the surface of the petrol. During the medium scale tests, the foams were applied using the forceful and gentle methods.

The burnback results of the large and medium scale tests show broadly similar trends. In all cases, the ranking orders are the same. AFFF(1) (applied for one minute) gives the worst 25% burnback performance with increasingly better performances being achieved by AFFF(1), FFFP(1) and FP(1) (all applied for two minutes). FP(1) gave burnback times that were significantly better than the other foams tested.

The burnback times achieved during the medium scale fire tests were significantly longer than those achieved during the medium scale tests.

In general, it took longer to reach the maximum flare-ups during the medium scale tests than it did during the large scale tests. However, the maximum flare areas achieved during the medium scale tests were either similar or much greater than the flare-ups recorded during the large scale fire tests.

It must be remembered however that for all of the burnback-only tests, only one test was performed for each condition. Consequently, the repeatability of this type of test has not been assessed.

6. CONCLUSIONS

The fire tests described in this report were relatively small in size, they were performed indoors, under controlled conditions and used a laboratory type foam branchpipe. Consequently, care must be taken in applying these conclusions to other circumstances.

The majority of the medium scale fire tests carried out during this work employed the equipment and methods contained within the draft CEN and ISO standards for low expansion foam concentrates. Although these standards are liable to further change, it is unlikely that there will be any changes to these fire test methods or the equipment used.

Analysis of the results from these fire tests have highlighted the following serious weaknesses in the proposed ISO and CEN standard fire tests:-

1. The fire tests do not adequately distinguish between the performance of foam concentrates when used at either full or half of their recommended concentration. Even increasing the area of the fire tray by over 25%, and hence reducing the foam application rate, did not significantly improve the discrimination provided by these fire tests.

2. The gentle application fire test is unfairly biased against FFFP and FFFP-AR foam concentrates. AFFF and AFFF-AR foam concentrates achieved quick extinctions while the FFFP and FFFP-AR extinction times were significantly slower due to flame flicker. FFFP and FFFP-AR foam concentrates performed as well as AFFF and AFFF-AR during the forceful application fire tests and during fires involving petrol.

3. The fuel used during the fire tests, heptane, is considerably easier than petrol to extinguish. Fire tests involving petrol were only occasionally extinguished by foams during this work. Heptane was easily extinguished by most foams, even when some of them were used at half of their recommended concentration. Consequently, the performance of foam concentrates during the proposed ISO and CEN standard fire tests cannot be relied upon to predict performance against fuels likely to be encountered by the fire service.

A further report will be issued once the ISO and CEN standards have been issued. It is intended that this further report will compare the firefighting performance of foams during these medium scale fire tests with their performance during large scale fire tests. It is hoped that advice can then be given on how the UK Fire Service should interpret the ISO and CEN standards in order to ensure that they continue to purchase good quality foam concentrates.

REFERENCES

1. Draft International Standard ISO/DIS 7203-1, Fire Extinguishing Media - Foam Concentrates - Part 1: Specification For Low expansion Foam Concentrates for Top Application to Water-immiscible Liquids. International Organisation for Standardization, 1992.

2. Draft CEN Standard CEN/TC191/WG3, Fire Extinguishing Media - Foam Concentrates - Part 1: Low Expansion Foams For Liquid Hydrocarbons. European Committee For Standardization.

3. FRDG Publication 2/93, A Comparison of Various Foams When Used Against Large Scale Petroleum Fires, B P Johnson, 1993, ISBN 0-86252-949-2.

4. BS 5423:1987, Specification for Portable Fire Extinguishers, British Standards Institution, 1987.

5. FRDG Publication 5/92, The Use of Foam Against Large Scale Petroleum Fires Involving Lead-Free Petrol, J A Foster, 1992, ISBN 0-86252-701-5.

6. BS 7070:1988, Specification for Unleaded Petrol (Gasoline) for Motor Vehicles, British Standards Institution, 1988.

7. EC Directive 85/536/EEC.

8. SRDB Publication 40/87, Additives for Hose Reel Systems: Trials of Foam on 40m^2 Petrol Fires, J A Foster, 1987.

9. SRDB Publication 22/88, Additives For Hosereel Systems, Preliminary Trials of Foam on Small Scale Isopropanol Fires, B P Johnson, 1988.

ACKNOWLEDGEMENTS

Acknowledgements are due to all members of the Fire Experimental Unit for assistance with this work especially during the fire tests and the analysis of data.

NOTES

1. Esso Solvent 50 (also known as Exxsol Heptane)

2. Drawings for the UNI86 foam making branchpipe are given in Appendix A and Appendix B. Alternatively, they can be supplied by SABO, Via Caravaggi 9, I-24040 Levate BG, Italy. One of these was purchased by FEU during 1991 at a cost of £200.

3. Stainless steel piezometer tube. Made to FEU drawing FEU-4-028, High Pressure Delivery Pipe (Adflow Coupling).

4. RS Components Limited, Corby, Northants.
Pressure sensor, RKC model PRT/AF4.

5. RS Components Limited, Corby, Northants.
Digital pressure indicator type 646-763.

6. Adflow International Limited, Bath Road, Woolhampton, Reading Berks.
3/4" Adflow-'C' type hermaphrodite couplings.

7. When the UNI86 branch purchased form SABO was operated at 11.4 litres per minute using this configuration, it too operated in the pressure range of 6.4 to 6.9 bar.

8. Medtherm type 64-1-20 radiometers were found to meet the requirements specified within the draft standards. In particular they gave the required 60% utilisation of the nominal range of measurement during preburn. Medtherm type 64-10-20 radiometers were normally used for the secondary pair of radiometers, however these did not satisfy the utilisation of nominal range criteria.

9. Autometric Pumps Limited, Turkey Court, Ashford Road, Maidstone, Kent, ME14 5PP. Model GP 1/2/125/E.

10. Endress and Hauser Limited, Ledson Road, Manchester.
15mm flowmeter type Picomag.

11. Dunlop Limited, Hose Division (Midland Region), Building 33, Penareth Trading Estate, Kingswindford, West Midlands, DY6 7PD. Dunlop "Gacord-26", 19mm bore hose.

12. Comark, Rustington, Sussex.
Intrinsically safe Ni-Cr/Ni-Al thermometer, Type 3006.

13. PRT thermometer

14. Maine Engineering, Howe Park, Kings Langley, Herts.
Model SD1200L. This company no longer makes these clocks.

15. Sony (UK) Limited, Sony House, South Street, Staines, Middlesex. Video-8 CCD-V8AF-E and Video-8 Pro CCD V100E.

16. The time taken for 25% of the area of the foam blanket to be completely eroded by flames to reveal burning fuel below was recorded by observers as the 25% burnback time. Times to 50% and 100% burnback (by area) were also recorded.

    Radiometers were also used for recording burnback progress. For these, the time taken for the radiated heat to reach 25% of its preburn level was recorded as the 25% burnback time. Times to 50% and 100% burnback (by radiated heat) were also recorded. In all cases, timing commenced

from the ignition of the fuel in the burnback pot.

During these tests, the burnback times recorded by observers and obtained from the radiometers were very similar. The radiometer results are generally quoted in this report.

FEU CODE NAME	TRADE NAME	MANUFACTURER
AFFF(1)	Lightwater FC 203	3M Chemicals Division, Manchester
AFFF(2)	Tridol-S	Angus Fire Armour Limited, Thame, Oxfordshire
AFFF-AR(1)	Lightwater ATC FC 600	3M Chemicals Division, Manchester
AFFF-AR(2)	Universal	Chubb Fire Engineering, High Wycombe
FFFP(1)	Petroseal	Angus Fire Armour Limited, Thame, Oxfordshire
FFFP(2)	Centrifoam 903	Croda Kerr Limited, Kirkby, Liverpool
FFFP-AR(1)	Alcoseal	Angus Fire Armour Limited, Thame, Oxfordshire
FFFP-AR(2)	Centrifoam A936	Croda Kerr Limited, Kirkby, Liverpool
FFFP-AR(3)	Alcoseal 3x3	Angus Fire Armour Limited,Thame, Oxfordshire
FP(1)	FP70	Angus Fire Armour Limited, Thame, Oxfordshire
FP(2)	Plus-F	Chubb Fire Engineering, High Wycombe
FP(3)	Sabo Fluoroprotein	Sabo, Italy
P(1)	Nicerol-HC	Angus Fire Armour Limited, Thame, Oxfordshire
P(2)	Profoam 803	Croda Kerr Limited, Kirkby, Liverpool
S(1)	Expandol	Angus Fire Armour Limited, Thame, Oxfordshire
S(2)	Hex S	Chubb Fire Engineering, High Wycombe

TABLE 1 : Details of Foam Concentrates Used

Test No.	1	2	3	4	5	6
Date	19/6/90	22/6/90	28/6/90	28/6/90	12/7/90	12/7/90
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	AFFF(1) 3%	AFFF(1) 3%	AFFF(1) 3%	FP(1) 3%	FP(1) 3%	FP(1) 3%
Concentration Used	3%	3%	3%	3%	3%	3%
Fuel	Heptane	Heptane	Heptane	Heptane	Heptane	Heptane
Foam Application Method	Forceful	Forceful	Forceful	Forceful	Forceful	Forceful
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.7	6.8	6.8	6.8	6.8	6.9
Foam Solution Temp (°C)	17	18	20	19	20	19
Water Base Temp (°C)	17	15	19	19	19	20
Fuel Temp (°C)	15	16	19	19	19	20
Air Temp (°C)	10	10	13	13	16	19
Foam Temp (°C)	17	--[1]	18	17	19	19
Expansion Ratio	11.2	11.4	11.2	7.8	7.8	8.1
25% Drainage Time	3m 44s	3m 46s	3m 35s	4m 59s	5m 15s	5m 2s
90% Extinction	40s	40s	40s	2m 14s	2m 29s	2m 11s
99% Extinction	44s	48s	45s	3m 10s	3m 9s	3m 5s
100% Extinction	1m 11s	1m 4s	1m 12s	11m 18s	9m 19s	8m 32s
Burnback Start Time[2]	9m	9m	9m	$12m^3$	$11m^3$	$10m^3$
25% Burnback[4]	7m 39s (36s)	5m 28s (40s)	10m 55s (1m 55s)	9m 8s (--)	10m 2s (--)	11m 3s (--)
Foam Application Period	3m	3m	3m	3m	3m	3m

TABLE 2 : Results of Fire Tests - $4.5m^2$ Fire Tray and Heptane - in Chronological Order

Test No.	7	8	9	10	11	12
Date	17/7/90	17/7/90	17/7/90	18/7/90	18/7/90	23/7/90
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	FFFP(1) 3%	FFFP(1) 3%	FFFP(1) 3%	FFFP-AR(1) 3%	FFFP-AR(1) 3%	FFFP-AR(1) 3%
Concentration Used	3%	3%	3%	3%	3%	3%
Fuel	Heptane	Heptane	Heptane	Heptane	Heptane	Heptane
Foam Application Method	Forceful	Forceful	Forceful	Forceful	Forceful	Forceful
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.9	6.8	6.8	6.7	6.6	6.7
Foam Solution Temp (°C)	17	19	17	17	17	17
Water Base Temp (°C)	19	20	20	19	19	20
Fuel Temp (°C)	19	20	20	19	20	20
Air Temp (°C)	17	20	20	18	20	18
Foam Temp (°C)	18	19	19	18	19	18
Expansion Ratio	9.3	9.6	9.5	8.3	8.2	8.2
25% Drainage Time	3m 37s	3m 37s	3m 45s	5m 11s	4m 49s	4m 48s
90% Extinction	46s	51s	43s	58s	59s	49s
99% Extinction	1m 10s	1m 30s	1m 40s	3m 1s	3m 1s	2m 58s
100% Extinction	1m 29s	1m 45s	1m 55s	3m 18s	3m 18s	3m 19s
Burnback Start Time[2]	9m	9m	9m	9m	9m	9m
25% Burnback[4]	13m 1s (1m 22s)	12m 18s (1m)	12m 10s (54s)	8m 53s (1m 8s)	8m 39s (1m 8s)	8m 13s (1m 9s)
Foam Application Period	3m	3m	3m	3m	3m	3m

TABLE 2 : Results of Fire Tests - 4.5m^2 Fire Tray and Heptane - in Chronological Order (Continued)

Test No.	13	14	15	16	17	18
Date	23/7/90	23/7/90	24/7/90	24/7/90	24/7/90	26/7/90
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	FFFP-AR(1) 3%	FFFP-AR(1) 3%	FFFP-AR(1) 3%	FFFP(1) 3%	FFFP(1) 3%	AFFF-AR(1) 3%
Concentration Used	3%	3%	3%	3%	3%	3%
Fuel	Heptane	Heptane	Heptane	Heptane	Heptane	Heptane
Foam Application Method	Gentle	Gentle	Gentle	Gentle	Gentle	Forceful
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.7	6.7	6.6	6.8	6.7	6.7
Foam Solution Temp (°C)	17	17	17	17	18	18
Water Base Temp (°C)	20	20	18	19	19	18
Fuel Temp (°C)	19	20	19	19	19	19
Air Temp (°C)	19	20	17	19	20	18
Foam Temp (°C)	19	19	19	19	19	19
Expansion Ratio	8.5	8.3	8.4	9.4	9.7	5.9
25% Drainage Time	4m 40s	4m 41s	4m 37s	3m 18s	3m 33s	5m 7s
90% Extinction	1m 27s	1m 10s	1m 2s	39s	40s	43s
99% Extinction	2m 30s	1m 50s	1m 43s	1m 27s	1m 34s	1m 23s
100% Extinction	7m 58s	5m 59s	13m 24s	12m 1s	12m 22s	1m 39s
Burnback Start Time[2]	11m	11m	$16m^3$	$16m^3$	$16m^3$	9m
25% Burnback[4]	13m 30s (--)	14m 39s (--)	11m 52s (--)	13m 53s (--)	15m 53s (--)	14m 25s (--)
Foam Application Period	5m	5m	5m	5m	5m	3m

TABLE 2 : Results of Fire Tests - $4.5m^2$ Fire Tray and Heptane - in Chronological Order (Continued)

Test No.	19	20	21	22	23	24
Date	26/7/90	26/7/90	30/7/90	30/7/90	2/8/90	11/9/90
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	S(1) 3%	P(1) 3%	FFFP-AR(1) 3%	AFFF-AR(I) 3%	AFFF(1) 3%	FP(1) 3%
Concentration Used	3%	3%	3%	3%	3%	3%
Fuel	Heptane	Heptane	Heptane	Heptane	Heptane	Heptane
Foam Application Method	Forceful	Forceful	Gentle	Gentle	Forceful	Gentle
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.7	6.7	6.7	6.7	6.8	6.9
Foam Solution Temp (°C)	18	18	17	17	18	16
Water Base Temp (°C)	19	19	20	20	18	17
Fuel Temp (°C)	19	20	20	19	19	17
Air Temp (°C)	19	20	18	19	20	15
Foam Temp (°C)	20	20	20	20	20	16
Expansion Ratio	11.4	7.8	8.2	6.5	11.8	7.8
25% Drainage Time	6m 34s	4m 49s	4m 34s	4m 52s	3m 33s	5m 15s
90% Extinction	55s	2m 43s	1m 2s	59s	46s	1m 4s
99% Extinction	2m 41s	3m 11s	1m 55s	1m 9s	56s	1m 57s
100% Extinction	No[5]	7m 40s	13m 35s	3m 14s	1m 3s	3m 10s
Burnback Start Time[2]	None[6]	12m[3]	18m[3]	11m	9m	11m
25% Burnback[4]	None[6]	12m 9s (--)	9m 38s (--)	14m 45s (--)	8m 58s (1m 33s)	28m 58s (--)
Foam Application Period	3m	3m	5m	5m	3m	5m

TABLE 2 : Results of Fire Tests - 4.5m² Fire Tray and Heptane - in Chronological Order (Continued)

Test No.	25	26	27	28	29	30
Date	11/9/90	11/9/90	12/9/90	12/9/90	12/9/90	12/9/90
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	P(1) 3%	AFFF(1) 3%	S(1) 3%	FP(2) 3%	FP(2) 3%	AFFF(2) 3%
Concentration Used	3%	3%	3%	3%	3%	3%
Fuel	Heptane	Heptane	Heptane	Heptane	Heptane	Heptane
Foam Application Method	Gentle	Gentle	Gentle	Forceful	Gentle	Gentle
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.8	6.8	6.7	6.8	6.8	6.7
Foam Solution Temp (°C)	16	17	16	16	16	16
Water Base Temp (°C)	17	17	17	17	17	17
Fuel Temp (°C)	18	18	18	19	18	18
Air Temp (°C)	16	17	15	16	17	18
Foam Temp (°C)	17	17	17	18	18	18
Expansion Ratio	8.0	11.2	11.4	8.5	8.8	11.4
25% Drainage Time	5m 30s	3m 33s	6m 58s	5m 28s	5m 31s	<3m
90% Extinction	1m 2s	45s	1m 6s	1m 44s	1m 14s	44s
99% Extinction	1m 56s	59s	1m 42s	3m 10s	2m 32s	1m 32s
100% Extinction	2m 34s	1m 34s	6m 38s	3m 36s	5m 29s	2m 14s
Burnback Start Time[2]	11m	11m	11m	9m	11m	11m
25% Burnback[4]	26m 6s (--)	12m 14s (--)	9m 32s (--)	11m 14s (--)	26m 4s (--)	12m 42s (--)
Foam Application Period	5m	5m	5m	3m	5m	5m

TABLE 2 : Results of Fire Tests - 4.5m^2 Fire Tray and Heptane - in Chronological Order (Continued)

Test No.	31	32	33	34	35	36
Date	13/9/90	13/9/90	13/9/90	18/9/90	18/9/90	18/9/90
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	AFFF(2) 3%	FP(3) 6%	FP(3) 6%	FP(3) 6%	FFFP(2) 3%	FFFP(2) 3%
Concentration Used	3%	6%	6%	6%	3%	3%
Fuel	Heptane	Heptane	Heptane	Heptane	Heptane	Heptane
Foam Application Method	Forceful	Forceful	Gentle	Forceful	Forceful	Gentle
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.7	6.8	6.8	6.7	6.8	6.8
Foam Solution Temp (°C)	16	16	16	16	16	16
Water Base Temp (°C)	18	17	16	17	18	20
Fuel Temp (°C)	19	18	18	16	17	18
Air Temp (°C)	15	17	17	14	16	16
Foam Temp (°C)	18	18	18	17	17	17
Expansion Ratio	11.6	7.2	8.4	8.5	10.3	10.2
25% Drainage Time	3m 14s	5m 13s	5m 46s	5m 46s	3m 28s	3m 35s
90% Extinction	42s	3m 2s	1m 11s	3m 2s	48s	44s
99% Extinction	1m 14s	No[7]	2m 43s	3m 5s	55s	2m 14s
100% Extinction	1m 31s	No[5]	3m 5s	No[5]	1m 49s	No[5]
Burnback Start Time[2]	9m	None[6]	11m	None[6]	9m	None[6]
25% Burnback[4]	7m 12s (1m 13s)	None[6]	30m 22s (--)	None[6]	13m 17s (--)	None[6]
Foam Application Period	3m	3m	5m	3m	3m	5m

TABLE 2 : Results of Fire Tests - 4.5m^2 Fire Tray and Heptane - in Chronological Order (Continued)

Test No.	37	38	39	40	41	42
Date	11/10/91	11/10/91	11/10/91	14/10/91	14/10/91	14/10/91
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	AFFF(1) 3%	AFFF(1) 3%	AFFF(1) 3%	AFFF(2) 3%	AFFF(2) 3%	AFFF-AR(2) 3%
Concentration Used	3%	2%	1.5%	2%	1.5%	3%
Fuel	Heptane	Heptane	Heptane	Heptane	Heptane	Heptane
Foam Application Method	Forceful	Forceful	Forceful	Forceful	Forceful	Forceful
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.5	6.5	6.5	6.5	6.5	6.5
Foam Solution Temp (°C)	16	17	17	17	17	17
Water Base Temp (°C)	20	19	20	17	19	19
Fuel Temp (°C)	20	20	20	17	19	18
Air Temp (°C)	13	14	15	11	12	12
Foam Temp (°C)	16	17	18	16	16	17
Expansion Ratio	11.3	10.5	8.8	11.0	9.5	7.6
25% Drainage Time	3m 45s	3m 12s	2m 47s	2m 55s	2m 05s	8m 35s
90% Extinction	41s	47s	45s	41s	50s	46s
99% Extinction	47s	1m 0s	1m 21s	1m 16s	1m 51s	1m 09s
100% Extinction	58s	1m 34s	1m 57s	1m 41s	2m 15s	1m 29s
Burnback Start Time[2]	9m	9m	9m	9m	9m	9m
25% Burnback[4]	10m 42s (1m 52s)	9m 42s (1m)	11m 05s (36s)	8m 13s (1m 21s)	8m 10s (1m 5s)	16m 48s (--)
Foam Application Period	3m	3m	3m	3m	3m	3m

TABLE 2 : Results of Fire Tests - 4.5m² Fire Tray and Heptane - in Chronological Order (Continued)

Test No.	43	44	45	46	47	48
Date	14/10/91	14/10/91	16/10/91	16/10/91	16/10/91	16/10/91
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	AFFF-AR(2) 3%	AFFF-AR(2) 3%	AFFF-AR(1) 3%	AFFF-AR(1) 3%	FFFP(1) 3%	FFFP(1) 3%
Concentration Used	2%	1.5%	2%	1.5%	2%	1.5%
Fuel	Heptane	Heptane	Heptane	Heptane	Heptane	Heptane
Foam Application Method	Forceful	Forceful	Forceful	Forceful	Forceful	Forceful
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.5	6.5	6.5	6.5	6.5	6.5
Foam Solution Temp (°C)	16	17	17	16	16	17
Water Base Temp (°C)	20	20	18	20	20	20
Fuel Temp (°C)	20	20	19	20	20	20
Air Temp (°C)	13	13	11	12	13	13
Foam Temp (°C)	17	19	17	16	16	17
Expansion Ratio	4.3	3.6	6.5	4.3	7.5	6.0
25% Drainage Time	4m 30s	2m 47s	3m 45s	2m 37s	2m 47s	2m 02s
90% Extinction	51s	1m 55s	47s	57s	56s	1m 18s
99% Extinction	2m 04s	3m 0s	1m 33s	2m 22s	2m 16s	3m 2s
100% Extinction	2m 21s	No[5]	2m 10s	3m 01s	3m 03s	3m 14s
Burnback Start Time[2]	9m	None[6]	9m	9m	9m	9m
25% Burnback[4]	15m 40s (--)	None[6]	13m 06s (--)	10m 14s (--)	7m 54s (1m 30s)	7m 46s (--)
Foam Application Period	3m	3m	3m	3m	3m	3m

TABLE 2 : Results of Fire Tests - 4.5m² Fire Tray and Heptane - in Chronological Order (Continued)

Test No.	49	*50[8]*	51	52	*53[8]*	54
Date	16/10/91	*18/10/91*	18/10/91	18/10/91	*18/10/91*	21/10/91
Branch	UNI 86	*UNI 86*	UNI 86	UNI 86	*UNI 86*	UNI 86
Foam Concentrate	AFFF(1) 3%	*AFFF(1) 3%*	AFFF(1) 3%	AFFF(1) 3%	*FFFP(1) 3%*	FFFP(1) 3%
Concentration Used	2%	*1.5%*	1.5%	3%	*2%*	2%
Fuel	Heptane	*Heptane*	Heptane	Heptane	*Heptane*	Heptane
Foam Application Method	Gentle	*Gentle*	Gentle	Gentle	*Gentle*	Gentle
Flow (lpm)	11.4	*11.4*	11.4	11.4	*11.4*	11.4
Pressure (bar)	6.5	*6.5*	6.5	6.5	*6.5*	6.6
Foam Solution Temp (°C)	16	*16*	16	16	*16*	17
Water Base Temp (°C)	19	*17*	19	19	*17*	18
Fuel Temp (°C)	19	*16*	17	18	*18*	18
Air Temp (°C)	14	*10*	11	11	*11*	10
Foam Temp (°C)	17	*15*	15	15	*15*	16
Expansion Ratio	10.1	*7.4*	8.7	11.2	*7.6*	8.2
25% Drainage Time	3m 13s	*1m 38s[8]*	2m 47s	3m 58s	*1m 57s[8]*	2m 58s
90% Extinction	51s	*1m 15s[8]*	1m 27s	43s	*3m 09s[8]*	1m 14s
99% Extinction	1m 10s	*1m 52s[8]*	2m 25s	1m 10s	*No[8]*	2m 38s
100% Extinction	1m 29s	*2m 56s[8]*	2m 43s	1m 38s	*No[8]*	8m 21s
Burnback Start Time[2]	11m	*11m*	11m	11m	*None[8]*	11m
25% Burnback[4]	14m 18s (--)	*8m 20s[8] (--)*	12m 51s (--)	14m 03s (--)	*None[8] (--)*	15m 36s (--)
Foam Application Period	5m	*5m*	5m	5m	*5m*	5m

TABLE 2 : Results of Fire Tests - 4.5m² Fire Tray and Heptane - in Chronological Order (Continued)

Test No.	55°	56°	57°	58°	59°	60
Date	23/10/91	23/10/91	23/10/91	23/10/91	23/10/91	30/10/91
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	AFFF(1) 3%	AFFF(1) 3%	FFFP(1) 3%	FFFP(1) 3%	FFFP-AR(1) 3%	AFFF(2) 3%
Concentration Used	3%	3%	3%	3%	3%	2%
Fuel	Heptane	Heptane	Heptane	Heptane	Heptane	Heptane
Foam Application Method	Forceful	Gentle	Gentle	Forceful	Gentle	Gentle
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.5	6.5	6.5	6.5	6.5	6.5
Foam Solution Temp (°C)	17	17	16	17	16	16
Water Base Temp (°C)	10°	12°	12°	12°	12°	18
Fuel Temp (°C)	8°	9°	9°	10°	9°	18
Air Temp (°C)	9°	9°	9°	9°	9°	10
Foam Temp (°C)	14	14	15	15	15	14
Expansion Ratio	11.5	10.9	9.8	9.5	8.1	10.8
25% Drainage Time	4m 00s	3m 58s	4m 15s	4m 03s	5m 00s	2m 51s
90% Extinction	41s	40s	50s	45s	1m 29s	1m 17s
99% Extinction	42s	1m 17s	2m 59s	1m 12s	4m 25s	2m 31s
100% Extinction	1m 7s	1m 32s	4m 17s	1m 47s	6m 06s	2m 56s
Burnback Start Time[2]	9m	11m	11m	9m	11m	11m
25% Burnback[4]	10m 53s	15m 34s	18m 52s	12m 49s	13m 02s	12m 33s (--)
Foam Application Period	3m	5m	5m	3m	5m	5m

TABLE 2 : Results of Fire Tests - 4.5m² Fire Tray and Heptane - in Chronological Order (Continued)

Test No.	61	62	63	64	65	66
Date	30/10/91	30/10/91	30/10/91	30/10/91	1/11/91	1/11/91
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	AFFF-AR (1) 3%	FFFP-AR (2) 3%	FFFP-AR (2) 3%	AFFF-AR (2) 3%	FFFP(2) 3%	FFFP(2) 3%
Concentration Used	2%	3%	3%	3%	2%	3%
Fuel	Heptane	Heptane	Heptane	Heptane	Heptane	Heptane
Foam Application Method	Gentle	Forceful	Gentle	Gentle	Gentle	Gentle
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.4	6.5	6.5	6.4	6.6	6.6
Foam Solution Temp (°C)	16	15	17	16	16	17
Water Base Temp (°C)	19	18	19	17	17	19
Fuel Temp (°C)	19	16	18	17	17	19
Air Temp (°C)	11	12	12	11	11	12
Foam Temp (°C)	16	15	17	15	16	16
Expansion Ratio	4.9	8.7	6.2	7.4	7.3	10.0
25% Drainage Time	3m 10s	6m 00s	2m 46s	9m 15s	2m 28s	3m 30s
90% Extinction	1m 26s	50s	1m 30s	1m 08s	1m 24s	56s
99% Extinction	3m 24s	2m 03s	2m 48s	2m 11s	3m 31s	2m 11s
100% Extinction	4m 47s	2m 07s	5m 25s	3m 36s	5m 25s	12m 48s
Burnback Start Time[2]	11m	9m	11m	11m	11m	17m[3]
25% Burnback[4]	16m 52s (--)	11m 49s (--)	18m 55s (--)	19m 29s (--)	16m 31s (--)	14m 31s (--)
Foam Application Period	5m	3m	5m	5m	5m	5m

TABLE 2 : Results of Fire Tests - 4.5m² Fire Tray and Heptane - in Chronological Order (Continued)

Test No.	67	68	69	70	71	72
Date	1/11/91	1/11/91	29/9/92	29/9/92	29/9/92	29/9/92
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	FFFP(2) 3%	AFFF-AR(2) 3%	P(2) 3%	P(2) 3%	S(2) 3%	S(2) 3%
Concentration Used	2%	2%	3%	3%	3%	3%
Fuel	Heptane	Heptane	Heptane	Heptane	Heptane	Heptane
Foam Application Method	Forceful	Gentle	Forceful	Gentle	Forceful	Gentle
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.6	6.5	6.9	6.8	6.9	6.8
Foam Solution Temp (°C)	17	19	18	19	19	18
Water Base Temp (°C)	19	19	15	17	19	18
Fuel Temp (°C)	19	19	16	18	18	19
Air Temp (°C)	12	12	15	16	17	17
Foam Temp (°C)	16	18	19	20	19	18
Expansion Ratio	7.9	4.1	8.3	8.5	11.5	11.3
25% Drainage Time	2m 32s	4m 16s	5m 15s	5m 17s	8m 20s	8m 30s
90% Extinction	55s	1m 09s	1m 58s	1m 3s	43s	1m 5s
99% Extinction	1m 50s	3m 17s	3m 6s	2m 13s	No[7]	1m 37s
100% Extinction	2m 18s	4m 32s	No[10]	4m	No[5]	1m 46s
Burnback Start Time[2]	9m	11m	9m	11m	None[6]	11m
25% Burnback[4]	9m 28s (1m 18s)	20m 14s (--)	11m 7s (--)	24m 53s (--)	None[6]	10m 40s (--)
Foam Application Period	3m	5m	3m	5m	3m	5m

TABLE 2 : Results of Fire Tests - 4.5m^2 Fire Tray and Heptane - in Chronological Order (Continued)

Test No.	73	74	75	76	77	78
Date	30/9/92	30/9/92	30/9/92	30/9/92	1/10/92	1/10/92
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	FFFP-AR(1) 3%	FFFP-AR(1) 3%	FFFP-AR(1) 3%	FFFP-AR(1) 3%	FFFP-AR(2) 3%	FFFP-AR(2) 3%
Concentration Used	2%	2%	1.5%	1.5%	2%	2%
Fuel	Heptane	Heptane	Heptane	Heptane	Heptane	Heptane
Foam Application Method	Forceful	Gentle	Gentle	Forceful	Forceful	Gentle
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.8	6.8	6.8	6.8	6.9	6.9
Foam Solution Temp (°C)	18	18	18	19	17	19
Water Base Temp (°C)	17	17	19	19	17	18
Fuel Temp (°C)	18	17	19	19	17	17
Air Temp (°C)	15	15	16	17	14	15
Foam Temp (°C)	18	18	19	19	18	19
Expansion Ratio	5.2	5.7	4.3	4.3	5.6	5.3
25% Drainage Time	3m 3s	3m 33s	2m 14s	2m 15s	4m 13s	4m
90% Extinction	45s	1m	1m 40s	1m 7s	1m 12s	2m 27s
99% Extinction	3m 2s	3m 54s	6m	3m 4s	3m 2s	6m 15s
100% Extinction	3m 15s	4m 47s	8m 12s	3m 13s	3m 9s	No[10]
Burnback Start Time[2]	9m	11m	11m	9m	9m	11m
25% Burnback[4]	8m 15s (--)	16m 56s (--)	18m 16s (--)	8m 2s (--)	9m 42s (--)	6m 35s (--)
Foam Application Period	3m	5m	5m	3m	3m	5m

TABLE 2 : Results of Fire Tests - 4.5m² Fire Tray and Heptane - in Chronological Order (Continued)

Test No.	79	80	81	82	83	84
Date	1/10/92	1/10/92	1/10/92	2/10/92	2/10/92	2/10/92
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	FFFP-AR(2) 3%	FFFP-AR(2) 3%	FFFP(2) 3%	FFFP(2) 3%	FFFP(1) 3%	AFFF(2) 3%
Concentration Used	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
Fuel	Heptane	Heptane	Heptane	Heptane	Heptane	Heptane
Foam Application Method	Forceful	Gentle	Forceful	Gentle	Gentle	Gentle
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.8	6.8	6.8	6.9	6.8	6.8
Foam Solution Temp (°C)	18	18	18	17	18	18
Water Base Temp (°C)	19	18	19	16	18	19
Fuel Temp (°C)	18	18	18	16	18	18
Air Temp (°C)	16	16	17	14	14	15
Foam Temp (°C)	19	19	19	18	18	18
Expansion Ratio	4.3	4.2	5.4	5.1	6.4	7.3
25% Drainage Time	2m 53s	2m 45s	2m 20s	2m 23s	2m 13s	2m
90% Extinction	1m 40s	1m 55s	50s	2m 22s	1m 9s	1m 3s
99% Extinction	3m 5s	4m 13s	3m 2s	4m 31s	2m 44s	2m
100% Extinction	3m 15s	8m 52s	3m 14s	8m 40s	9m 9s	10m 58s
Burnback Start Time[2]	9m	11m	9m	11m	11m	11m
25% Burnback[4]	7m 3s (--)	14m 3s (--)	6m 52s (--)	15m 15s (--)	15m 23s (--)	11m 8s (--)
Foam Application Period	3m	5m	3m	5m	5m	5m

TABLE 2 : Results of Fire Tests - 4.5m² Fire Tray and Heptane - in Chronological Order (Continued)

Test No.	85	86	87	88	89	90
Date	2/10/92	7/10/92	14/10/92	14/10/92	14/10/92	14/10/92
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	AFFF-AR(1) 3%	AFFF-AR(2) 3%	FFFP-AR(3) 3%	FFFP-AR(3) 3%	FFFP-AR (3) 3%	FFFP-AR (3) 3%
Concentration Used	1.5%	1.5%	3%	3%	1.5%	1.5%
Fuel	Heptane	Heptane	Heptane	Heptane	Heptane	Heptane
Foam Application Method	Gentle	Gentle	Forceful	Gentle	Gentle	Forceful
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.7	6.8	6.8	6.8	6.8	6.8
Foam Solution Temp (°C)	18	16	17	17	17	18
Water Base Temp (°C)	19	15	17	17	17	18
Fuel Temp (°C)	18	15	17	15	18	18
Air Temp (°C)	15	11	11	11	12	12
Foam Temp (°C)	19	16	19	20	20	18
Expansion Ratio	5.3	4.2	8.2	8.1	4.4	4.1
25% Drainage Time	2m 54s	3m 24s	5m 15s	5m 10s	2m 9s	2m 12s
90% Extinction	1m 18s	3m 20s	44s	38s	1m 28s	51s
99% Extinction	2m 59s	No[7]	1m 33s	2m 54s	4m 39s	3m 3s
100% Extinction	4m 21s	No[5]	1m 35s	3m 39s	7m 52s	3m 12s
Burnback Start Time[2]	11m	None[6]	9m	11m	11m	9m
25% Burnback[4]	14m (--)	None[6]	13m 16s (--)	20m 8s (--)	18m 45s (--)	9m 6s (--)
Foam Application Period	5m	5m	3m	5m	3m	5m

TABLE 2 : Results of Fire Tests - 4.5m² Fire Tray and Heptane - in Chronological Order (Continued)

NOTES FOR TABLE 2 : (All tests not carried out within the required temperature limits (see note 9 below) have been shown in italics in the table)

1. Measurement not recorded.

2. Generally, during these fire tests, events happened at the following test times:-

   97 : 00 All fuel poured into tray
   99 : 00 Gear pump started, foam produced
   00 : 00 Fuel ignited
   01 : 00 Foam application commenced
   04 : 00 Foam application ceased - forceful application
   06 : 00 Foam application ceased - gentle application
   09 : 00 Burnback pot ignited - forceful application
   11 : 00 Burnback pot ignited - gentle application

3. Burnback delayed due to long 100% extinction time.

4. Figures given without brackets are 25% burnback times ignoring flare-ups, figures given within brackets are 25% burnback times which take into account 25% flare-ups by area. Flare-ups only occurred after forceful application tests; flare-ups never occurred after gentle application tests. (--) means that a 25% flare-up did not occur during that test.

   Flare-ups are where the foam blanket becomes involved in surface flames during a burnback test. A flare-up quickly escalates to involve large areas of the foam blanket and then dies down leaving the foam blanket intact.

5. 100% extinction not achieved.

6. Test fire not extinguished, no burnback test could be performed.

7. 99% extinction not achieved.

8. Equipment failure during test, test results not valid.

9. Test results not included in analysis due to temperatures being below those required by the ISO and CEN fire test methods. The required temperatures are:-

Fuel temperature	17.5 ± 2.5°C
Water base temperature	17.5 ± 2.5°C
Air temperature	15 ± 5°C
Foam solution temperature	17.5 ± 2.5°C

10. 100% extinction not achieved although flames controlled sufficiently to allow burnback test to be carried out.

FOAM TYPE AND NORMAL USE CONC.	CONC. USED	FORCEFUL APPLICATION								
		EXTINCTION				25% BURNBACK				
		Test No.	90% Ext.	99% Ext.	Ext.	Time of 25% Flare Radiometers	Max Flare and Time Radiometers	Time of 25% Area Flare Observed	Max Flare Area and Time Observed	25% BB (Ignores flare) Radiometers
AFFF(1) 3%	3%	1	40s	44s	1m 11s	----	20% 44s	36s	40% 44s	7m 39s
		2	40s	48s	1m 4s	----	20% 51s	40s	50% 51s	5m 28s
		3	40s	45s	1m 12s	1m 51s	36% 2m 9s	1m 55s	90% 2m	10m 55s
		23	46s	56s	1m 3s	1m 41s	43% 1m 52s	1m 33s	50% 1m 46s	8m 58s
		37	41s	47s	58s	-----	23% 2m 11s	1m 52s	50% 2m 8s	10m 42s
	2%	38	47s	1m 0s	1m 34s	----	22% 1m 12s	1m	80% 1m 16s	9m 42s
	1.5%	39	45s	1m 21s	1m 57s	-----	18% 43s	36s	90% 45s	11m 5s
AFFF(2) 3%	3%	31	42s	1m 14s	1m 31s	-----	24% 1m 56s	1m 13s	50% 1m 47s	7m 12s
	2%	40	41s	1m 16s	1m 41s	----	16% 1m 44s	1m 21s	70% 1m 26s	8m 13s
	1.5%	41	50s	1m 51s	2m 15s	1m 9s	30% 1m 13s	1m 5s	100% 1m 10s	8m 10s
AFFF-AR(1) 3%	3%	18	43s	1m 23s	1m 39s	----	----	----	15% 2m 13s	14m 25s
	2%	45	47s	1m 33s	2m 10s	-----	2% 2m 49s	----	20% 2m 51s	13m 6s
	1.5%	46	57s	2m 22s	3m 1s	-----	----	----	2% 2m 11s	10m 14s
AFFF-AR(2) 3%	3%	42	46s	1m 9s	1m 29s	----	3% 9m 16s	----	20% 9m 16s	16m 48s
	2%	43	51s	2m 4s	2m 21s	----	----	----	10% 8m 31s	15m 40s
	1.5%	44	1m 55s	3m 0s	NE[1]	----	----	----	----	NBBT[2]

TABLE 3 : Results, By Foam Concentrate Type, of Forceful Application Tests - 4.5m^2 Fire Tray and Heptane

FOAM TYPE AND NORMAL USE CONC.	CONC. USED	FORCEFUL APPLICATION								
		EXTINCTION				25% BURNBACK				
		Test No.	90% Ext.	99% Ext.	Ext.	Time of 25% Flare Radiometers	Max Flare and Time Radiometers	Time of 25% Area Flare Observed	Max Flare Area and Time Observed	25% BB (Ignores Flare) Radiometers
FFFP (1) 3%	3%	7	46s	1m 10s	1m 29s	-----	23% 1m 32s	1m 22s	100% 1m 36s	13m 1s
		8	51s	1m 30s	1m 45s	1m 5s	39% 1m 10s	1m	100% 1m 10s	12m 18s
		9	43s	1m 40s	1m 55s	55s	38% 1m 1s	54s	100% 1m	12m 10s
	2%	47	56s	2m 16s	3m 3s	1m 38s	26% 1m 40s	1m 30s	70% 1m 39s	7m 54s
	1.5%	48	1m 18s	3m 2s	3m 14s	-----	2% 3m 50s	------	15% 3m 50s	7m 46s
FFFP (2) 3%	3%	35	48s	55s	1m 49s	-----	10% 1m 40s	------	20% 1m 40s	13m 17s
	2%	67	55s	1m 50s	2m 18s	-----	6% 1m 16s	1m 18s	25% 1m 18s	9m 28s
	1.5%	81	50s	3m 2s	3m 14s	-----	4% 2m 30s	------	15% 2m 30s	6m 52s
FFFP-AR (1) 3%	3%	10	58s	3m 1s	3m 18s	1m 9s	34% 1m 15s	1m 8s	100% 1m 13s	8m 53s
		11	59s	3m 1s	3m 18s	1m 9s	31% 1m 14s	1m 8s	100% 1m 14s	8m 39s
		12	49s	2m 58s	3m 19s	-----	11% 1m 13s	1m 9s	40% 1m 13s	8m 13s
	2%	73	45s	3m 2s	3m 15s	-----	----	------	3% 1m 26s	8m 15s
	1.5%	76	1m 7s	3m 4s	3m 13s	-----	----	------	2% 11s	8m 2s
FFFP-AR (2) 3%	3%	62	50s	2m 3s	2m 7s	-----	7% 2m 18s	------	20% 2m 17s	11m 49s
	2%	77	1m 12s	3m 2s	3m 9s	-----	----	------	2% 41s	9m 42s
	1.5%	79	1m 40s	3m 5s	3m 15s	-----	----	------	2% 50s	7m 3s
FFFP-AR (3) 3%	3%	87	44s	1m 33s	1m 35s	----	3% 4m 39s	------	20% 4m 41s	13m 16s
	1.5%	90	51s	3m 3s	3m 12s	-----	2% 5m 12s	------	20% 5m 12s	9m 6s

TABLE 3 : Results, By Foam Concentrate Type, of Forceful Application Tests - 4.5m² Fire Tray and Heptane (Continued)

FOAM TYPE AND NORMAL USE CONC.	CONC. USED	FORCEFUL APPLICATION								
		EXTINCTION				25% BURNBACK				
		Test No.	90% Ext.	99% Ext.	Ext.	Time of 25% Flare Radiometers	Max Flare and Time Radiometers	Time of 25% Area Flare Observed	Max Flare Area and Time Observed	25% BB (Ignores flare) Radiometers
FP(1) 3%	3%	4	2m 14s	3m 10s	11m 18s	-----	-----	----	-----	9m 8s
		5	2m 29s	3m 9s	9m 19s	-----	-----	-----	----	10m 2s
		6	2m 11s	3m 5s	8m 32s	-----	-----	----	-----	11m 3s
FP(2) 3%	3%	28	1m 44s	3m 10s	3m 36s	-----	----	-----	10% 3m	11m 14s
FP(3) 6%	6%	32	3m 2s	NC[3]	NE[1]	----	----	----	----	NBBT[2]
		34	3m 2s	3m 5s	NE[1]	-----	-----	----	----	NBBT[2]
P(1) 3%	3%	20	2m 43s	3m 11s	7m 40s	-----	----	----	----	12m 9s
P(2) 3%	3%	69	1m 58s	3m 6s	NE[1]	----	----	-----	----	NBBT[2]
S(1) 3%	3%	19	55s	2m 41s	NE[1]	-----	----	-----	----	NBBT[2]
S(2) 3%	3%	71	43s	NC[3]	NE[1]	----	-----	-----	-----	NBBT[2]

TABLE 3 : Results, By Foam Concentrate Type, of Forceful Application Tests - 4.5m^2 Fire Tray and Heptane (Continued)

NOTES FOR TABLE 3 :

1. NE = Not extinguished
2. NBBT = No burnback test performed due to inadequate control of the test fire
3. NC = Not controlled

FOAM TYPE AND NORMAL USE CONC.	CONC. USED	GENTLE APPLICATION										
		EXTINCTION										BURNBACK
		Test No.	90% Ext.	99% Ext.	Ext.	Flickers at End of Foam Application Period						25% BB Time
						Fuel Cover (%)	All Flames Ext?	Any Remaining Flames Within 0.1m of Rim?	Flame Height Above Tray Rim	Total Flame Width	Any Increase in Intensity Prior to Burnback Test?	
AFFF(1) 3%	3%	26	45s	59s	1m 34s	100%	Yes	-----	-----	—	-----	12m 14s
		52	43s	1m 10s	1m 38s	100%	Yes	-----	-----	—	-----	14m 3s
	2%	49	51s	1m 10s	1m 29s	100%	Yes	-----	-----	—	-----	14m 18s
	1.5%	51	1m 27s	2m 25s	2m 43s	100%	Yes	-----	-----	—	-----	12m 51s
AFFF(2) 3%	3%	30	44s	1m 32s	2m 14s	100%	Yes	-----	-----	-----	-----	12m 42s
	2%	60	1m 17s	2m 31s	2m 56s	100%	Yes	-----	—	—	-----	12m 33s
	1.5%	84	1m 3s	2m 0s	10m 58s	100%	No	Yes	100mm	200mm	Yes	11m 8s
AFFF-AR(1) 3%	3%	22	59s	1m 9s	3m 14s	100%	Yes	-----	—	-----	-----	14m 45s
	2%	61	1m 26s	3m 24s	4m 47s	100%	Yes	—	—	-----	-----	16m 52s
	1.5%	85	1m 18s	2m 59s	4m 21s	100%	Yes	—	—	-----	-----	14m
AFFF-AR(2) 3%	3%	64	1m 8s	2m 11s	3m 36s	100%	Yes	—	-----	-----	-----	19m 29s
	2%	68	1m 9s	3m 17s	4m 32s	100%	Yes	—	—	—	—	20m 14s
	1.5%	86	3m 20s	NC[1]	NE[3]	100%	No	Yes	500mm	3000mm	Yes	NBBT[3]

TABLE 4 : Results, By Foam Concentrate Type, of Gentle Application Tests - 4.5m² Fire Tray and Heptane

FOAM TYPE AND NORMAL USE CONC.	CONC. USED	GENTLE APPLICATION										
		EXTINCTION										BURNBACK
		Test No.	90% Ext.	99% Ext.	Ext.	Flickers at End of Foam Application Period						25% BB Time
						Fuel Cover (%)	All Flames Ext?	Any Remaining Flames Within 0.1m of Rim?	Flame Height Above Tray Rim	Total Flame Width	Any Increase in Intensity Prior to Burnback Test?	
FFFP(1) 3%	3%	16	39s	1m 27s	12m 1s	100%	No	No 0.2m	250mm	600mm	Yes	13m 53s
		17	40s	1m 34s	12m 22s	100%	No	No 0.2m	300mm	1200mm	Yes	15m 53s
	2%	54	1m 14s	2m 38s	8m 21s	100%	No	Yes	150mm	350mm	No	15m 36s
	1.5%	83	1m 9s	2m 44s	9m 9s	100%	No	Yes	100mm	250mm	No	15m 23s
FFFP(2) 3%	3%	36	44s	2m 14s	NE[2]	100%	No	No 0.2m	200mm	600mm	Yes	NBBT[3]
		66	56s	2m 11s	12m 48s	100%	No	No 0.2m	100mm	150mm	Yes	14m 31s
	2%	65	1m 24s	3m 31s	5m 25s	100%	No	Yes	150mm	280mm	No	16m 31s
	1.5%	82	2m 22s	4m 31s	8m 40s	100%	No	Yes	300mm	250mm	Yes	15m 15s
FFFP-AR(1) 3%	3%	13	1m 27s	2m 30s	7m 58s	100%	No	Yes	300mm	1000mm	No	13m 30s
		14	1m 10s	1m 50s	5m 59s	100%	No	Yes	225mm	250mm	No	14m 39s
		15	1m 2s	1m 43s	13m 24s	100%	No	Yes	200mm	300mm	No	11m 52s
		21	1m 2s	1m 55s	13m 35s	100%	No	Yes	225mm	450mm	No	9m 38s
	2%	74	1m	3m 54s	4m 47s	100%	Yes	---	-----	——	--	16m 56s
	1.5%	75	1m 40s	6m	8m 12s	100%	No	Yes	200mm	1000mm	No	18m 16s
FFFP-AR(2) 3%	3%	63	1m 30s	2m 48s	5m 25s	100%	No	Yes	100mm	50mm	No	18m 55s
	2%	78	2m 27s	6m 15s	NE[2]	100%	No	Yes	400mm	2500mm	No	6m 35s
	1.5%	80	1m 55s	4m 13s	8m 52s	100%	No	Yes	200mm	500mm	Yes	14m 3s
FFFP-AR(3) 3%	3%	88	38s	2m 54s	3m 39s	100%	Yes	---	-----	-----	—	20m 8s
	1.5%	89	1m 28s	4m 39s	7m 52s	100%	No	Yes	200mm	800mm	No	18m 45s

TABLE 4 : Results, By Foam Concentrate Type, of Gentle Application Tests - 4.5m² Fire Tray and Heptane (Continued)

FOAM TYPE AND NORMAL USE CONC.	CONC. USED	GENTLE APPLICATION										
		EXTINCTION										BURNBACK
		Test No.	90% Ext.	99% Ext.	Ext.	Flickers at End of Foam Application Period						25% BB Time
						Fuel Cover (%)	All Flames Ext?	Any Remaining Flames Within 0.1m of Rim?	Flame Height Above Tray Rim	Total Flame Width	Increase in Intensity Prior to Burnback Test?	
FP(1) 3%	3%	24	1m 4s	1m 57s	3m 10s	100%	Yes	—	—	-----	-----	28m 58s
FP(2) 3%	3%	29	1m 14s	2m 32s	5m 29s	100%	No	Yes	100mm	100mm	No	26m 4s
FP(3) 6%	6%	33	1m 11s	2m 43s	3m 5s	100%	Yes	----	—	-----	----	30m 22s
P(1) 3%	3%	25	1m 2s	1m 56s	2m 34s	100%	Yes	—	—	-----	-----	26m 6s
P(2) 3%	3%	70	1m 3s	2m 13s	4m	100%	Yes	—	—	—	—	24m 53s
S(1) 3%	3%	27	1m 6s	1m 42s	6m 38s	100%	No	Yes	400mm	400mm	No	9m 32s
S(2) 3%	3%	72	1m 5s	1m 37s	1m 46s	100%	Yes	-----	—	-----	----	10m 40s

TABLE 4 : Results, By Foam Concentrate Type, of Gentle Application Tests - 4.5m^2 Fire Tray and Heptane (Continued)

NOTES FOR TABLE 4 :

1. NC = Not controlled
2. NE = Not extinguished
3. NBBT = No burnback test performed due to inadequate control of the test fire

Test No.	91	92	93	94	95	96
Date	23/10/92	23/10/92	23/10/92	23/10/92	25/6/93	25/6/93
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	AFFF(1) 3%	FFFP(1) 3%	FFFP-AR (3) 3%	AFFF-AR (1) 3%	AFFF(1) 3%	AFFF(1) 3%
Concentration Used	3%	3%	3%	3%	2%	1.5%
Fuel	Heptane	Heptane	Heptane	Heptane	Heptane	Heptane
Foam Application Method	Forceful	Forceful	Forceful	Forceful	Forceful	Forceful
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.8	6.9	6.8	6.8	7.0	7.0
Foam Solution Temp (°C)	16	16	17	16	17	17
Water Base Temp (°C)	17	17	18	18	20	17
Fuel Temp (°C)	19	17	18	18	19	18
Air Temp (°C)	8	8	9	10	15	16
Foam Temp (°C)	13	14	15	15	17	17
Expansion Ratio	11.0	9.4	8.5	9.3	10.9	8.6
25% Drainage Time	4m 15s	4m 6s	5m 15s	7m 35s	3m 24s	2m 57s
90% Extinction	46s	49s	54s	48s	48s	52s
99% Extinction	1m 21s	2m 19s	2m 20s	1m 32s	1m 36s	2m
100% Extinction	1m 24s	2m 27s	2m 23s	1m 51s	2m 5s	2m 22s
Burnback Start Time[1]	9m	9m	9m	9m	9m	9m
25% Burnback	8m 42s (1m 22s)	10m 11s (1m 36s)	10m 48s (3m 51s)	13m 29s (2m 28s)	9m 24s (36s)	11m 29s (44s)
Foam Application Period	3m	3m	3m	3m	3m	3m

TABLE 5 : Results of Fire Tests - 5.8m² Fire Tray and Heptane - in Chronological Order

Test No.	97	98	99	100	101	102
Date	25/6/93	2/7/93	2/7/93	2/7/93	2/7/93	7/7/93
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	AFFF-AR (1) 3%	AFFF-AR (1) 3%	FFFP(1) 3%	FFFP(1) 3%	FFFP-AR (1) 3%	FFFP-AR (1) 3%
Concentration Used	2%	1.5%	2%	1.5%	2%	1.5%
Fuel	Heptane	Heptane	Heptane	Heptane	Heptane	Heptane
Foam Application Method	Forceful	Forceful	Forceful	Forceful	Forceful	Forceful
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	7.0	6.9	7.0	7.0	7.0	7.0
Foam Solution Temp (°C)	17	17	18	17	17	18
Water Base Temp (°C)	17	18	20	20	20	19
Fuel Temp (°C)	18	19	19	20	20	19
Air Temp (°C)	17	17	18	19	20	16
Foam Temp (°C)	18	18	20	20	20	19
Expansion Ratio	7.2	5.3	8.9	7.1	5.8	4.7
25% Drainage Time	4m 54s	3m 15s	2m 57s	2m 28s	3m 28s	2m 32s
90% Extinction	46s	55s	55s	1m 8s	1m 28s	3m 07s
99% Extinction	2m	2m 46s	3m 3s	3m 3s	3m 12s	No
100% Extinction	2m 28s	3m 6s	3m 17s	3m 18s	No	No
Burnback Start Time[1]	9m	9m	9m	9m	9m	9m
25% Burnback	11m 57s	8m 10s	7m 14s	7m 4s	6m 17s	No
Foam Application Period	3m	3m	3m	3m	3m	3m

TABLE 5 : Results of Fire Tests - 5.8m^2 Fire Tray and Heptane - in Chronological Order (Continued)

Test No.	103	104	105	106	107	108
Date	7/7/93	7/7/93	7/7/93	7/7/93	7/7/93	8/7/93
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	AFFF(2) 3%	AFFF(2) 3%	AFFF(2) 3%	AFFF-AR (2) 3%	FP(1) 3%	AFFF-AR (2) 3%
Concentration Used	3%	2%	1.5%	1.5%	3%	3%
Fuel	Heptane	Heptane	Heptane	Heptane	Heptane	Heptane
Foam Application Method	Forceful	Forceful	Forceful	Forceful	Forceful	Forceful
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	7.0	7.0	7.0	7.0	7.0	7.0
Foam Solution Temp (°C)	18	18	17	17	17	16
Water Base Temp (°C)	19	18	18	19	18	18
Fuel Temp (°C)	19	18	18	19	19	19
Air Temp (°C)	18	19	19	19	20	17
Foam Temp (°C)	19	19	19	20	19	19
Expansion Ratio	11.6	10.9	9.0	3.8	8.0	7.3
25% Drainage Time	3m 8s	2m 38s	2m 20s	3m 07s	5m 34s	9m 37s
90% Extinction	46s	54s	57s	2m 32s	2m 02s	54s
99% Extinction	1m 19s	1m 58s	2m 38s	4m	3m 06s	1m 48s
100% Extinction	1m 46s	2m 07s	2m 45s	No	No	1m 59s
Burnback Start Time[1]	9m	9m	9m	9m	9m	9m
25% Burnback	6m 15s (1m 44s)	7m 56s (1m 1s)	7m 38s (56s)	8m 6s	8m 12s	15m 31s (8m 46s)
Foam Application Period	3m	3m	3m	3m	3m	3m

TABLE 5 : Results of Fire Tests - 5.8m² Fire Tray With Heptane - in Chronological Order (Continued)

Test No.	109	110	111	112	113	114
Date	8/7/93	8/7/93	8/7/93	14/7/93	14/7/93	14/7/93
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	AFFF-AR(2) 3%	FP(2) 3%	FFFP(2) 3%	FFFP-AR (2) 3%	FFFP-AR (1) 3%	FFFP-AR (3) 3%
Concentration Used	2%	3%	3%	3%	3%	1.5%
Fuel	Heptane	Heptane	Heptane	Heptane	Heptane	Heptane
Foam Application Method	Forceful	Forceful	Forceful	Forceful	Forceful	Forceful
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	7.0	7.0	7.0	7.0	7.0	7.0
Foam Solution Temp (°C)	18	17	17	16	17	16
Water Base Temp (°C)	18	18	18	17	17	18
Fuel Temp (°C)	19	19	19	18	18	19
Air Temp (°C)	18	19	19	15	17	18
Foam Temp (°C)	19	20	20	17	18	18
Expansion Ratio	4.7	8.8	9.5	7.3	8.2	4.7
25% Drainage Time	4m 51s	5m 42s	3m 34s	4m 58s	5m 50s	2m 22s
90% Extinction	1m 01s	1m 44s	54s	1m 2s	54s	1m 16s
99% Extinction	2m 50s	3m 07s	1m 34s	2m 59s	2m 08s	3m 01s
100% Extinction	2m 59s	No	1m 46s	3m 06s	2m 17s	No
Burnback Start Time[1]	9m	9m	9m	9m	9m	9m
25% Burnback	15m 08s	11m 10s	9m 20s (55s)	9m 52s	11m 40s	9m 30s
Foam Application Period	3m	3m	3m	3m	3m	3m

TABLE 5 : Results of Fire Tests - 5.8m^2 Fire Tray With Heptane - in Chronological Order (Continued)

NOTE FOR TABLE 5 :

1. During these fire tests, events happened at the following test times:-

97 : 00 All fuel poured into tray
99 : 00 Gear pump started, foam produced
00 : 00 Fuel ignited
01 : 00 Foam application commenced
04 : 00 Foam application ceased
09 : 00 Burnback pot ignited

FOAM TYPE AND NORMAL USE CONC.	CONC. USED	FORCEFUL APPLICATION								
		EXTINCTION				25% BURNBACK				
		Test No.	90% Ext.	99% Ext.	Ext.	Time of 25% Flare Radiometers	Max Flare and Time Radiometers	Time of 25% Area Flare Observed	Max Flare Area and Time Observed	25% BB (Ignores flare) Radiometers
AFFF(1) 3%	3%	91	46s	1m 21s	1m 24s	1m 28s	26% 1m 26s	1m 22s	75% 1m 27s	8m 42s
	2%	95	48s	1m 36s	2m 5s	40s	26% 40s	36s	100% 41s	9m 24s
	1.5%	96	52s	2m	2m 22s	-----	21% 47s	44s	100% 48s	11m 29s
AFFF(2) 3%	3%	103	46s	1m 19s	1m 46s	56s	37% 2m 7s	1m 44s	100% 1m 56s	6m 15s
	2%	104	54s	1m 58s	2m 7s	1m 8s	38% 1m 14s	1m 1s	100% 1m 12s	7m 56s
	1.5%	105	57s	2m 38s	2m 45s	-----	24% 1m 6s	56s	100% 1m 10s	7m 38s
AFFF-AR(1) 3%	3%	94	48s	1m 32s	1m 51s	-----	2% 2m 24s	2m 28s	25% 2m 28s	13m 29s
	2%	97	46s	2m	2m 28s	-----	----	-----	10% 1m 42s	11m 57s
	1.5%	98	55s	2m 46s	3m 6s	-----	—	—	10% 23s	8m 10s
AFFF-AR(2) 3%	3%	108	54s	1m 48s	1m 59s	-----	11% 9m 11s	8m 46s	100% 9m 25s	15m 31s
	2%	109	1m 1s	2m 50s	2m 59s	-----	----	-----	10% 3m 50s	15m 08s
	1.5%	106	2m 32s	4m	NE[1]	-----	-----	NE[1]	NE[1]	8m 6s[2]
FFFP(1)	3%	92	49s	2m 19s	2m 27s	-----	23% 1m 41s	1m 36s	100% 1m 43s	10m 11s
	2%	99	55s	3m 3s	3m 17s	-----	3% 1m 38s	-----	20% 1m 38s	7m 14s
	1.5%	100	1m 8s	3m 3s	3m 18s	-----	-----	-----	1% 1m 10s	7m 4s

TABLE 6 : Results, By Foam Concentrate Type, of Forceful Application Tests - 5.8m^2 Fire Tray and Heptane

FOAM TYPE AND NORMAL USE CONC.	CONC. USED	FORCEFUL APPLICATION								
		EXTINCTION				25% BURNBACK				
		Test No.	90% Ext.	99% Ext.	Ext.	Time of 25% Flare Radiometers	Max Flare and Time Radiometers	Time of 25% Area Flare Observed	Max Flare Area and Time Observed	25% BB (Ignores flare) Radiometers
FFFP(2) 3%	3%	111	54s	1m 34s	1m 46s	-----	12% 59s	55s	50% 1m 1s	9m 20s
FFFP-AR(1) 3%	3%	113	54s	2m 8s	2m 17s	-----	-----	-----	10% 3m 36s	11m 40s
	2%	101	1m 28s	3m 12s	3m 18s	-----	-----	-----	1% 1m 20s	6m 17s
	1.5%	102	3m 7s	NC[3]	NE[1]	-----	-----	NE[1]	NE[1]	NBBT[4]
FFFP-AR(2)	3%	112	1m 2s	2m 59s	3m 6s	—	3% 2m 57s	-----	15% 3m	9m 52s
FFFP-AR(3)	3%	93	54s	2m 20s	2m 23s	—	-----	3m 51s	25% 3m 51s	10m 48s
	1.5%	114	1m 16s	3m 1s	NE[1]	—	-----	NE[1]	NE[1]	9m 30s[2]
FP(1) 3%	3%	107	2m 2s	3m 6s	NE[1]	—	—	NE[1]	NE[1]	8m 12s[2]
FP(2) 3%	3%	110	1m 44s	3m 7s	NE[1]	—	—	NE[1]	NE[1]	11m 10s[2]

NOTES FOR TABLE 6 :

1. NE = Not extinguished
2. Fire not extinguished before burnback test commenced
3. NC = Not controlled
4. NBBT = No burnback test performed due to inadequate control of the test fire

TABLE 6 : Results, By Foam Concentrate Type, of Forceful Application Tests - 5.8m² Fire Tray and Heptane (Continued)

Test No.	P1	P2	P3	P4	P5	P6
Date	24/9/90	24/9/90	24/9/90	26/9/90	26/9/90	26/9/90
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	AFFF(1) 3%	FP(1) 3%	FP(1) 3%	AFFF(1) 3%	FP(1) 3%	FFFP(1) 3%
Concentration Used	3%	3%	3%	3%	3%	3%
Fuel[1]	Petrol	Petrol	Petrol	Petrol	Petrol	Petrol
Foam Application Method[2]	Forceful (Centre)	Forceful (Centre)	Gentle (Rear)	Gentle (Rear)	Gentle (Rear)	Gentle (Rear)
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.8	6.8	6.8	6.6	6.7	6.7
Foam Solution Temp (°C)	18	20	18	18	17	17
Water Base Temp (°C)	15	17	17	17	17	16
Fuel Temp (°C)	16	17	16	16	17	16
Air Temp (°C)	12	13	14	12	13	14
Foam Temp (°C)	16	18	18	14	14	14
Expansion Ratio	11.2	8.6	8.1	11.3	8.2	9.7
25% Drainage Time	3m 35s	5m 7s	5m 23s	3m 58s	5m 37s	3m 41s
90% Extinction	38s	3m 22s	2m 13s	50s	1m 57s	56s
99% Extinction	1m 22s	No[3]	4m 30s	3m	4m 55s	5m
100% Extinction	No[4]	No[4]	No[4]	13m 25s	13m 3s	8m 58s
Burnback Start Time[5]	None[6]	None[6]	None[6]	19m 25s[7]	19m 3s[7]	14m 58s[7]
25% Burnback	None	None	None	5m 20s	12m 48s	10m 43s
Foam Application Period[5]	3m	3m	5m	7m	7m	7m

TABLE 7 : Results of Fire Tests - 4.5m^2 Fire Tray and Four Star Petrol - in Chronological order

Test No.	P7	P8	P9	*P10*[8]	P11	P12
Date	27/9/90	27/9/90	27/9/90	*5/10/90*	5/10/90	10/10/90
Branch	UNI 86	UNI 86	UNI 86	*UNI 86*	UNI 86	UNI 86
Foam Concentrate	AFFF(1) 3%	FP(2) 3%	FFFP(1) 3%	*AFFF(1) 3%*	AFFF(1) 3%	FFFP(1) 3%
Concentration Used	3%	3%	3%	*3%*	3%	3%
Fuel[1]	Petrol	Petrol	Petrol	*Petrol*	Petrol	Petrol
Foam Application Method[2]	Forceful (Centre)	Forceful (Centre)	Forceful (Centre)	*Gentle (Front)*	Gentle (Front)	Gentle (Front)
Flow (lpm)	11.4	11.4	11.4	*11.4*	11.4	11.4
Pressure (bar)	6.7	6.7	6.8	*7.1*	6.8	6.9
Foam Solution Temp (°C)	19	18	18	*17*	17	18
Water Base Temp (°C)	17	17	17	*18*	20	16
Fuel Temp (°C)	15	15	16	*17*	19	17
Air Temp (°C)	11	12	14	*14*	14	13
Foam Temp (°C)	14	14	16	--	--	17
Expansion Ratio	11.5	8.6	9.8	*10.2*	10.9	8.8
25% Drainage Time	3m 53s	5m 31s	3m 48s	*3m 38s*[8]	3m 34s	2m 47s
90% Extinction	33s	3m 16s	50s	*38s*[8]	39s	52s
99% Extinction	1m 17s	5m	1m 27s	*1m 48s*[8]	1m 39s	2m 34s
100% Extinction	No[4]	No[4]	2m 19s	*11m 26s*[8]	5m 38s	12m 34s
Burnback Start Time[5]	None[6]	None[6]	11m	*17m 26s*[8]	11m	18m 34s[7]
25% Burnback	None	None	6m 33s	*4m 18s*	7m 47s	6m 5s
Foam Application Period[5]	5m	5m	5m	*5m*	5m	5m

TABLE 7 : Results of Fire Tests - 4.5m² Fire Tray and Four Star Petrol - in Chronological Order (Continued)

Test No.	P13	P14	P15	P16	P17	P18
Date	10/10/90	10/10/90	10/10/90	7/10/91	7/10/91	21/10/91
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	FP(1) 3%	P(1) 3%	AFFF(1) 3%	AFFF(1) 3%	FFFP(1) 3%	AFFF(1) 3%
Concentration Used	3%	3%	3%	3%	3%	3%
Fuel[1]	Petrol	Petrol	Petrol	Petrol	Petrol	Petrol
Foam Application Method[2]	Gentle (Front)	Gentle (Front)	Forceful (Side)	Forceful (Centre)	Forceful (Centre)	Forceful (Centre)
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.8	6.8	6.8	6.5	6.5	6.5
Foam Solution Temp (°C)	17	18	19	17	17	17
Water Base Temp (°C)	20	18	19	None[9] used	None[9] used	15[9] (113 L)
Fuel Temp (°C)	20	18	19	17[9] (215L)	17[9] (215L)	15[9] (113 L)
Air Temp (°C)	14	14	15	13	13	8
Foam Temp (°C)	17	17	17	16	16	14
Expansion Ratio	7.9	7.7	11.5	11.5	8.9	11.4
25% Drainage Time	5m 38s	5m 10s	3m 28s	3m 32s	3m 50s	3m 55s
90% Extinction	1m 22s	1m 24s	42s	38s	51s	37s
99% Extinction	2m 23s	2m 24s	1m 11s	1m 50s	2m 02s	1m 12s
100% Extinction	5m 35s	17m 55s	No[4]	No[4]	No[4]	No[4]
Burnback Start Time[5]	11m	23m 55s[7]	None[6]	None[6]	None[6]	None[6]
25% Burnback	15m 23s	7m 21s	None	None	None	None
Foam Application Period[5]	5m	5m	3m	5m	5m	5m

TABLE 7 : Results of Fire Tests - 4.5m^2 Fire Tray and Four Star Petrol - in Chronological Order (Continued)

Test No.	P19	P20
Date	21/10/91	21/10/91
Branch	UNI 86	UNI 86
Foam Concentrate	AFFF(1) 3%	AFFF(1) 3%
Concentration Used	3%	3%
Fuel[1]	Petrol	Petrol
Foam Application Method[2]	Forceful (Centre)	Forceful (Centre)
Flow (lpm)	11.4	11.4
Pressure (bar)	6.5	6.6
Foam Solution Temp (°C)	15	17
Water Base Temp (°C)	None Used[9]	20 (113L)[9]
Fuel Temp (°C)	16 (226L)[9]	18 (113L)[9]
Air Temp (°C)	9	10
Foam Temp (°C)	13	14
Expansion Ratio	10.8	11.3
25% Drainage Time	4m 00s	3m 58s
90% Extinction	38s	35s
99% Extinction	1m 23s	1m 08s
100% Extinction	No[4]	No[4]
Burnback Start Time[5]	None[6]	None[6]
25% Burnback	None	None
Foam Application Period[5]	5m	5m

TABLE 7 : Results of Fire Tests - 4.5m² Fire Tray and Four Star Petrol - in Chronological Order (Continued)

NOTES FOR TABLE 7 :

1. Four-star leaded petrol, obtained from a single storage tank at the Fire Service College Moreton-in-Marsh on 21/9/1990 and stored in sealed 200 litre steel drums, was used throughout these tests.

2. Due to problems experienced in extinguishing petrol fires during these tests, several different application methods were tried in order to aid firefighting:-

   Forceful (centre): Foam applied forcefully direct to the fuel surface along the centre line of the tray and 1 metre from the furthest tray edge (as specified in the ISO and CEN methods).

   Gentle (rear): Foam applied gently to the surface of the foam blanket via a metal plate at the rear of the tray (as specified in the ISO and CEN methods).

   Gentle (front): Foam applied gently to the surface of the fuel via a metal plate attached to the firefighting branch trolley. Foam applied at the front edge of the tray.

   Forceful (side): Foam applied forcefully direct to the fuel surface. Foam stream directed to the left of the tray, just avoiding the tray sides.

3. 99% extinction not achieved.

4. 100% extinction not achieved.

5. During these fire tests, events generally happened at the following test times:-

   97 : 00 All fuel poured into tray
   99 : 00 Gear pump started, foam produced
   00 : 00 Fuel ignited
   01 : 00 Foam application commenced
   06 : 00 Foam application ceased
   11 : 00 Burnback pot ignited

   However, various foam application periods were tried during these tests and some of the burnback tests were delayed due to long 100% extinction times. See table for exact times.

6. Test fire not extinguished, no burnback test could be performed.

7. Burnback delayed due to long 100% extinction time.

8. Equipment failure during test, test results not valid (test shown in italics in the table).

9. These tests involved the use of various fuel/water base combinations:-

   Test P16: 215 litres of petrol, no water base
   Test P17: 215 litres of petrol, no water base
   Test P18: 113 litres of petrol, 113 litres of water
   Test P19: 226 litres of petrol, no water base
   Test P20: 113 litres of petrol, 113 litres of water

Test No.	LF1	LF2	LF3	LF4	LF5	LF6
Date	2/10/91	2/10/91	3/10/91	3/10/91	3/10/91	3/10/91
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	AFFF(1) 3%	FFFP(1) 3%	FP(1) 3%	AFFF(1) 3%	AFFF(1) 3%	FFFP(1) 3%
Concentration Used	3%	3%	3%	3%	3%	3%
Fuel[1]	FEU 1	FEU 1	FEU 1	FEU 1	FEU 2	FEU 2
Foam Application Method	Forceful	Forceful	Forceful	Forceful	Forceful	Forceful
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.5	6.5	6.5	6.5	6.5	6.5
Foam Solution Temp (°C)	15	16	16	18	16	17
Water Base Temp (°C)	None used	None used	None used	None used	None used	None used
Fuel Temp (°C)	16	20	18	20	18	19
Air Temp(°C)	14	15	14	14	15	15
Foam Temp (°C)	15	16	16	17	17	16
Expansion Ratio	11.3	9.5	8.2	11.5	11.4	9.5
25% Drainage Time	3m 50s	4m 12s	5m 30s	3m 35s	3m 45s	3m 58s
90% Extinction	38s	49s	3m 10s	36s	40s	52s
99% Extinction	2m 0s	1m 42s	4m 49s	1m 46s	1m 53s	1m 59s
100% Extinction	No[2]	No[2]	5m 19s	No[2]	No[2]	No[2]
Burnback Start Time[3]	None[4]	None[4]	11m	None[4]	None[4]	None[4]
25% Burnback	None	None	10m 09s	None	None	None
Foam Application Period	5m	5m	5m	5m	5m	5m

TABLE 8 : Results of Fire Tests - 4.5m² Fire Tray and Lead-free Petrol - in Chronological Order

Test No.	LF7	LF8
Date	7/10/91	7/10/91
Branch	UNI 86	UNI 86
Foam Concentrate	AFFF(I) 3%	FFFP(1) 3%
Concentration Used	3%	3%
Fuel	FEU 3	FEU 3
Foam Application Method	Forceful	Forceful
Flow (lpm)	11.4	11.4
Pressure (bar)	6.5	6.5
Foam Solution Temp (°C)	16	16
Water Base Temp (°C)	None used	None used
Fuel Temp (°C)	15	16
Air Temp (°C)	12	12
Foam Temp (°C)	15	16
Expansion Ratio	11.3	9.3
25% Drainage Time	3m 45s	3m 57s
90% Extinction	41s	58s
99% Extinction	1m 57s	2m 20s
100% Extinction	No	No
Burnback Start Time[3]	None	None
25% Burnback	None	None
Foam Application Period	5m	5m

TABLE 8 : Results of Fire Tests - 4.5m^2 Fire Tray and Lead-free Petrol - in Chronological Order (Continued)

NOTES FOR TABLE 8 :

1. The same lead-free petrols, as used during the September 1991 large petrol fires, were used during these tests. This petrol had been collected in 200 litre sealed drums during the large scale trials and stored until needed. The petrol formulations were as follows:-

   FEU 1 : Unleaded petrol with no oxygenates. This was 95 octane premium unleaded petrol.

   FEU 2 : Unleaded petrol with moderate oxygenate level, using an alcohol component of 3% Methanol and 2% Tertiary Butyl Alcohol (TBA). This gives a total oxygen content of 1.93% which approaches the British Standard maximum of 2.5%.

   FEU 3 : Unleaded petrol with 15% Methyl Tertiary Butyl Ether (MTBE). This is the maximum allowed under the EEC Directive and is greater than that allowed in the British Standard for use in the UK.

   It was not possible to use a water base during these tests because the additives within the petrol were water soluble. 2 litres of fuel were used per test instead of the CEN/ISO 144 litres of fuel with a 90 litre water base.

2. 100% extinction not achieved.

3. During these tests, events happened at the following test times:-

   97 : 00 All fuel poured into tray
   99 : 00 Gear pump started, foam produced
   00 : 00 Fuel ignited
   01 : 00 Foam application commenced
   06 : 00 Foam application ceased
   11 : 00 Burnback pot ignited

4. Test fire not extinguished, no burnback test could be performed.

Test No.	BB1	BB2	BB3	BB4	BB5	BB6
Date	7/10/92	7/10/92	7/10/92	7/10/92	9/10/92	9/10/92
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	AFFF(1) 3%	AFFF(1) 3%	FFFP(1) 3%	FP(1) 3%	FP(1) 3%	FFFP(1) 3%
Concentration Used	3%	3%	3%	3%	3%	3%
Fuel[1]	Petrol	Petrol	Petrol	Petrol	Petrol	Petrol
Foam Application Method	Forceful	Forceful	Forceful	Forceful	Gentle	Gentle
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.8	6.8	6.8	6.9	6.8	6.8
Foam Solution Temp (°C)	17	18	19	18	17	17
Water Base Temp (°C)	16	16	18	17	17	18
Fuel Temp (°C)	15	15	17	15	15	17
Air Temp (°C)	12	12	11	11	11	11
Foam Temp (°C)	16	16	17	17	16	15
Expansion Ratio	11.1	10.8	9.9	8.0	8.0	9.8
25% Drainage Time	4m 10s	3m 52s	3m 52s	5m 55s	5m 55s	4m 5s
Burnback Start Time[2]	7m	8m	8m	8m	8m	8m
25% Burnback	3m 28s	4m 34s	6m 38s	11m 4s	15m 58s	10m 19s
Foam Application Period	1m	2m	2m	2m	2m	2m

TABLE 9 : Results of Burnback-only Fire Tests - 4.5m^2 Fire Tray and Petrol - in Chronological Order

Test No.	BB7	BB8	BB9	BB10	BB11	BB12
Date	9/10/92	9/10/92	13/10/92	13/10/92	13/10/92	13/10/92
Branch	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86	UNI 86
Foam Concentrate	AFFF(1) 3%	AFFF(1) 3%	AFFF-AR(1) 3%	AFFF-AR(1) 3%	FFFP-AR(1) 3%	FFFP-AR(1) 3%
Concentration Used	3%	3%	3%	3%	3%	3%
Fuel[1]	Petrol	Petrol	Petrol	Petrol	Petrol	Petrol
Foam Application Method	Gentle	Gentle	Forceful	Gentle	Gentle	Forceful
Flow (lpm)	11.4	11.4	11.4	11.4	11.4	11.4
Pressure (bar)	6.8	6.8	6.8	6.8	6.8	6.8
Foam Solution Temp (°C)	18	17	17	16	18	17
Water Base Temp (°C)	19	18	17	17	17	19
Fuel Temp (°C)	19	18	15	17	17	19
Air Temp (°C)	12	12	10	10	11	12
Foam Temp (°C)	15	16	14	14	15	15
Expansion Ratio	11.2	11.4	9.8	9.4	8.5	8.3
25% Drainage Time	4m	4m	8m 7s	7m 53s	6m 10s	6m 15s
Burnback Start Time[2]	8m	7m	8m	8m	8m	8m
25% Burnback	9m 2s	7m 53s	7m 6s	10m 18s	11m 34s	7m 5s
Foam Application Period	2m	1m	2m	2m	2m	2m

TABLE 9 : Results of Burnback-only Fire Tests - 4.5m² Fire Tray and Petrol - in Chronological Order (Continued)

NOTES FOR TABLE 9 :

1. The same lead-free petrol, as used during the May 1992 large petrol fires, was used during these tests. This petrol had been collected in 200 litre sealed drums during the large scale trials and stored until needed.

2. During these burnback-only tests, events happened at the following test times:-

   97 : 00 All fuel poured into tray
   99 : 00 Gear pump started, foam produced
   01 : 00 Foam application commenced
   02 : 00 Foam application ceased (1 minute foam application)
   03 : 00 Foam application ceased (2 minute foam application)
   07 : 00 Burnback pot ignited (1 minute foam application)
   08 : 00 Burnback pot ignited (2 minute foam application)

FOAM TYPE	CONC USED	KNOCKDOWN GRADE[1]	EXTINCTION GRADE[2]	BURNBACK GRADE[3]	FLARE RESISTANCE GRADE[4]
AFFF(1)	3% 2% 1.5%	□□□□□ □□□□□ □□□□□	■■■■■ ■■■■ ■■■■	♦♦ ♦♦ ♦♦♦	o o o
AFFF(2)	3% 2% 1.5%	□□□□□ □□□□□ □□□□□	■■■■ ■■■■ ■■■■	♦ ♦♦ ♦♦	o o o
AFFF-AR(1)	3% 2% 1.5%	□□□□□ □□□□□ □□□□□	■■■■ ■■■■ ■■■	♦♦♦♦ ♦♦♦♦ ♦♦♦	oo oo oooo
AFFF-AR(2)	3% 2% 1.5%	□□□□□ □□□□□ □□□	■■■■■ ■■■■ ■	♦♦♦♦♦ ♦♦♦♦♦ --	oo ooo --
FFFP(1)	3% 2% 1.5%	□□□□□ □□□□□ □□□□	■■■■ ■■■ ■■■	♦♦♦ ♦♦ ♦♦	o o oo
FFFP(2)	3% 2% 1.5%	□□□□□ □□□□□ □□□□□	■■■■ ■■■■ ■■■	♦♦♦♦ ♦♦ ♦	oo o oo
FFFP-AR(1)	3% 2% 1.5%	□□□□□ □□□□□ □□□□	■■■ ■■■ ■■■	♦♦ ♦♦ ♦♦	o oooo oooo
FFFP-AR(2)	3% 2% 1.5%	□□□□□ □□□□ □□□	■■■■ ■■■ ■■■	♦♦♦ ♦♦ ♦	oo oooo oooo
FFFP-AR(3)	3% 1.5%	□□□□□ □□□□□	■■■■ ■■■	♦♦♦♦ ♦♦	oo oo
FP(1)	3%	□□	■■	♦♦♦	ooooo
FP(2)	3%	□□□	■■■	♦♦♦	ooo
FP(3)	6%	□	■	--	--
P(1)	3%	□□	■■	♦♦♦	ooooo
P(2)	3%	□□□	■	--	--
S(1)	3%	□□□□□	■	--	--
S(2)	3%	□□□□□	■	--	--

A difference in performance of one grade is not significant due to the tight cut off points between grades and the level of repeatability of the tests. However, where there is a difference in performance of two or more grades, the difference is significant.

TABLE 10 : Performance Gradings - 4.5m^2 Fire Tray and Heptane - all Foam Concentrates at all Concentrations Tested - Forceful Application Tests

NOTES FOR TABLE 10 :

1. Knockdown Grade - The knockdown grades are based on the 90% extinction times achieved during the forceful application tests and are as follows:-

Grade	90% Extinction Time
□□□□□	Less than or equal to 1 minute
□□□□	More than 1 minute but less than or equal to 1 minute 30 seconds
□□□	More than 1 minute 30 seconds but less than or equal to 2 minutes
□□	More than 2 minutes but less than or equal to 3 minutes
□	More than 3 minutes

2. Extinction Grade - The extinction grades are based on the 100% extinction times achieved during the forceful application tests and are as follows:-

Grade	100% Extinction Time
■■■■■	Less than or equal to 1 minute 30 seconds
■■■■	More than 1 minute 30 seconds but less than or equal to 3 minutes
■■■	More than 3 minutes but less than or equal to 4 minutes
■■	More than 4 minutes but less than or equal to 12 minutes
■	Not extinguished

3. Burnback Grade - The assessments of the burnback resistance of the foam blankets formed after forceful application are based on the 25% burnback times and are as follows (the higher the 25% burnback time the better the performance):-

Grade	25% Burnback Time
◆◆◆◆◆	More than or equal to 15 minutes
◆◆◆◆	More than or equal to 12 minutes 30 seconds but less than 15 minutes
◆◆◆	More than or equal to 10 minutes but less than 12 minutes 30 seconds
◆◆	More than or equal to 7 minutes 30 seconds but less than 10 minutes
◆	Less than 7 minutes 30 seconds
--	Fire not extinguished or controlled well enough to enable a burnback test to be performed.

Flare-ups have not been taken into consideration for any of these burnback results. See below.

4. Flare Resistance Grade - The flare resistance grades are based on the largest area of the foam blanket involved in a flare up during burnback tests carried out after forceful foam application fire tests. A flare-up involves the foam blanket surface in flames which quickly escalate and then die down leaving the foam blanket intact. Flare-ups are probably due to the ignition of contaminated foam within the foam blankets.

Performance grades for flare resistance are as follows (the smaller the area of tray involved in flame the better the performance):-

Grade	Area of Foam Blanket Involved in Large Flare Flames
○○○○○	Less than 1%
○○○○	More than or equal to 1% but less than 5%
○○○	More than or equal to 5% but less than 15%
○○	More than or equal to 15% but less than 25%
○	More than or equal to 25%
--	Fire not extinguished or controlled well enough to enable a burnback test to be performed.

FOAM TYPE	CONC USED	KNOCKDOWN GRADE[1]	EXTINCTION GRADE[2]	BURNBACK GRADE[3]	FLARE RESISTANCE GRADE[4]
AFFF(1)	3%	□□□□□	■■■■■	♦♦	o
AFFF(2)	3%	□□□□□	■■■■	♦	o
AFFF-AR(1)	3%	□□□□□	■■■■	♦♦♦♦	oo
AFFF-AR(2)	3%	□□□□□	■■■■■	♦♦♦♦♦	oo
FFFP(1)	3%	□□□□□	■■■■	♦♦♦	o
FFFP(2)	3%	□□□□□	■■■■	♦♦♦♦	oo
FFFP-AR(1)	3%	□□□□□	■■■	♦♦	o
FFFP-AR(2)	3%	□□□□□	■■■■	♦♦♦	oo
FFFP-AR(3)	3%	□□□□□	■■■■	♦♦♦♦	oo
FP(1)	3%	□□	■■	♦♦♦	ooooo
FP(2)	3%	□□□	■■■	♦♦♦	ooo
FP(3)	6%	□	■	--	--
P(1)	3%	□□	■■	♦♦♦	ooooo
P(2)	3%	□□□	■	--	--
S(1)	3%	□□□□□	■	--	--
S(2)	3%	□□□□□	■	--	--

A difference in performance of one grade is not significant due to the tight cut off points between grades and the level of repeatability of the tests. However, where there is a difference in performance of two or more grades, the difference is significant.

TABLE 11 : Performance Gradings - 4.5m² Fire Tray - all Foam Concentrates When Used at the Concentrations Recommended by the Manufacturers - Forceful Application Tests

NOTES FOR TABLE 11 :

1. Knockdown Grade - The knockdown grades are based on the 90% extinction times achieved during the forceful application tests and are as follows:-

Grade	90% Extinction Time
□□□□□	Less than or equal to 1 minute
□□□□	More than 1 minute but less than or equal to 1 minute 30 seconds
□□□	More than 1 minute 30 seconds but less than or equal to 2 minutes
□□	More than 2 minutes but less than or equal to 3 minutes
□	More than 3 minutes

2. Extinction Grade - The extinction grades are based on the 100% extinction times achieved during the forceful application tests and are as follows:-

Grade	100% Extinction Time
■■■■■	Less than or equal to 1 minute 30 seconds
■■■■	More than 1 minute 30 seconds but less than or equal to 3 minutes
■■■	More than 3 minutes but less than or equal to 4 minutes
■■	More than 4 minutes but less than or equal to 12 minutes
■	Not extinguished

3. Burnback Grade - The assessments of the burnback resistance of the foam blankets formed after forceful application are based on the 25% burnback times and are as follows (the higher the 25% burnback time the better the performance):-

Grade	25% Burnback Time
◆◆◆◆◆	More than or equal to 15 minutes
◆◆◆◆	More than or equal to 12 minutes 30 seconds but less than 15 minutes
◆◆◆	More than or equal to 10 minutes but less than 12 minutes 30 seconds
◆◆	More than or equal to 7 minutes 30 seconds but less than 10 minutes
◆	Less than 7 minutes 30 seconds
--	Fire not extinguished or controlled well enough to enable a burnback test to be performed.

Flare-ups have not been taken into consideration for any of these burnback results. See below.

4. Flare Resistance Grade - The flare resistance grades are based on the largest area of the foam blanket involved in a flare up during burnback tests carried out after forceful foam application fire tests. A flare-up involves the foam blanket surface in flames which quickly escalate and then die down leaving the foam blanket intact. Flare-ups are probably due to the ignition of contaminated foam within the foam blankets.

Performance grades for flare resistance are as follows (the smaller the area of tray involved in flame the better the performance):-

Grade	Area of Foam Blanket Involved in Large Flare Flames
○○○○○	Less than 1%
○○○○	More than or equal to 1% but less than 5%
○○○	More than or equal to 5% but less than 15%
○○	More than or equal to 15% but less than 25%
○	More than or equal to 25%
--	Fire not extinguished or controlled well enough to enable a burnback test to be performed.

FOAM TYPE	CONC USED	KNOCKDOWN GRADE[1]	EXTINCTION GRADE[2]	BURNBACK GRADE[3]
AFFF(1)	3% 2% 1.5%	□□□□□ □□□□□ □□□□	■■■■■ ■■■■■ ■■■■	♦♦ ♦♦ ♦♦
AFFF(2)	3% 2% 1.5%	□□□□□ □□□□ □□□□	■■■■ ■■■■ ■	♦♦ ♦♦ ♦♦
AFFF-AR(1)	3% 2% 1.5%	□□□□□ □□□□ □□□□	■■■■ ■■■ ■■■	♦♦ ♦♦♦ ♦♦
AFFF-AR(2)	3% 2% 1.5%	□□□□ □□□□ □	■■■ ■■■ ■	♦♦♦ ♦♦♦♦ --
FFFP(1)	3% 2% 1.5%	□□□□□ □□□□ □□□□	■ ■■ ■■	♦♦ ♦♦♦ ♦♦♦
FFFP(2)	3% 2% 1.5%	□□□□□ □□□□ □□	■ ■■ ■■	♦♦ ♦♦♦ ♦♦♦
FFFP-AR(1)	3% 2% 1.5%	□□□□ □□□□□ □□□	■ ■■■ ■■	♦♦ ♦♦♦ ♦♦♦
FFFP-AR(2)	3% 2% 1.5%	□□□□ □□ □□□	■■ ■ ■■	♦♦♦ ♦ ♦♦
FFFP-AR(3)	3% 1.5%	□□□□□ □□□□	■■■ ■■	♦♦♦♦ ♦♦♦
FP(1)	3%	□□□□	■■■■	♦♦♦♦♦
FP(2)	3%	□□□□	■■	♦♦♦♦♦
FP(3)	6%	□□□□	■■■■	♦♦♦♦♦
P(1)	3%	□□□□	■■■■	♦♦♦♦♦
P(2)	3%	□□□□	■■■	♦♦♦♦
S(1)	3%	□□□□	■■	♦
S(2)	3%	□□□□	■■■■■	♦♦

A difference in performance of one grade is not significant due to the tight cut off points between grades and the level of repeatability of the tests. However, where there is a difference in performance of two or more grades, the difference is significant.

TABLE 12 : Performance Gradings - 4.5m^2 Fire Tray and Heptane - all Foam Concentrates at all Concentrations Tested - Gentle Application Tests

NOTES FOR TABLE 12 :

1. Knockdown Grade - The knockdown grades are based on the 90% extinction times achieved during the gentle application tests and are as follows:-

Grade	90% Extinction Time
□□□□□	Less than or equal to 1 minute
□□□□	More than 1 minute but less than or equal to 1 minute 30 seconds
□□□	More than 1 minute 30 seconds but less than or equal to 2 minutes
□□	More than 2 minutes but less than or equal to 3 minutes
□	More than 3 minutes

2. Extinction Grade - The extinction grades are based on the 100% extinction times achieved during the gentle application tests and are as follows:-

Grade	100% Extinction Time
■■■■■	Less than or equal to 2 minutes
■■■■	More than 2 minutes but less than or equal to 3 minutes 30 seconds
■■■	More than 3 minutes 30 seconds but less than or equal to 5 minutes
■■	More than 5 minutes but less than or equal to 10 minutes
■	More than 10 minutes or not extinguished

3. Burnback Grade - The assessments of the burnback resistance of the foam blankets formed after gentle application are based on the 25% burnback times and are as follows (the higher the 25% burnback time the better the performance):-

Grade	25% Burnback Time
◆◆◆◆◆	More than or equal to 25 minutes
◆◆◆◆	More than or equal to 20 minutes but less than 25 minutes
◆◆◆	More than or equal to 15 minutes but less than 20 minutes
◆◆	More than or equal to 10 minutes but less than 15 minutes
◆	Less than 10 minutes
--	Fire not extinguished or controlled well enough to enable a burnback test to be performed.

FOAM TYPE	CONC USED	KNOCKDOWN GRADE[1]	EXTINCTION GRADE[2]	BURNBACK GRADE[3]
AFFF(1)	3%	□□□□□	■■■■■	♦♦
AFFF(2)	3%	□□□□□	■■■■	♦♦
AFFF-AR(1)	3%	□□□□□	■■■■	♦♦
AFFF-AR(2)	3%	□□□□	■■■	♦♦♦
FFFP(1)	3%	□□□□□	■	♦♦
FFFP(2)	3%	□□□□□	■	♦♦
FFFP-AR(1)	3%	□□□□	■	♦♦
FFFP-AR(2)	3%	□□□□	■■	♦♦♦
FFFP-AR(3)	3%	□□□□□	■■■	♦♦♦♦
FP(1)	3%	□□□□	■■■■	♦♦♦♦♦
FP(2)	3%	□□□□	■■	♦♦♦♦♦
FP(3)	6%	□□□□	■■■■	♦♦♦♦♦
P(1)	3%	□□□□	■■■■	♦♦♦♦♦
P(2)	3%	□□□□	■■■	♦♦♦♦
S(1)	3%	□□□□	■■	♦
S(2)	3%	□□□□	■■■■■	♦♦

A difference in performance of one grade is not significant due to the tight cut off points between grades and the level of repeatability of the tests. However, where there is a difference in performance of two or more grades, the difference is significant.

TABLE 13 : Performance Gradings - 4.5m^2 Fire Tray and Heptane - Foam Concentrates Used at the Concentrations Recommended by the Manufacturers - Gentle Application Tests

NOTES FOR TABLE 13 :

1. Knockdown Grade - The knockdown grades are based on the 90% extinction times achieved during the gentle application tests and are as follows:-

Grade	90% Extinction Time
□□□□□	Less than or equal to 1 minute
□□□□	More than 1 minute but less than or equal to 1 minute 30 seconds
□□□	More than 1 minute 30 seconds but less than or equal to 2 minutes
□□	More than 2 minutes but less than or equal to 3 minutes
□	More than 3 minutes

2. Extinction Grade - The extinction grades are based on the 100% extinction times achieved during the gentle application tests and are as follows:-

Grade	100% Extinction Time
■■■■■	Less than or equal to 2 minutes
■■■■	More than 2 minutes but less than or equal to 3 minutes 30 seconds
■■■	More than 3 minutes 30 seconds but less than or equal to 5 minutes
■■	More than 5 minutes but less than or equal to 10 minutes
■	More than 10 minutes or not extinguished

3. Burnback Grade - The assessments of the burnback resistance of the foam blankets formed after gentle application are based on the 25% burnback times and are as follows (the higher the 25% burnback time the better the performance):-

Grade	25% Burnback Time
◆◆◆◆◆	More than or equal to 25 minutes
◆◆◆◆	More than or equal to 20 minutes but less than 25 minutes
◆◆◆	More than or equal to 15 minutes but less than 20 minutes
◆◆	More than or equal to 10 minutes but less than 15 minutes
◆	Less than 10 minutes
--	Fire not extinguished or controlled well enough to enable a burnback test to be performed.

Foam Type	Conc. Used	KNOCKDOWN GRADE[1]	EXTINCTION GRADE[2]	BURNBACK GRADE[3]	FLARE RESISTANCE GRADE[4]
AFFF(1)	3% 2% 1.5%	□□□□□ □□□□□ □□□□□	■■■■■ ■■■■ ■■■■	♦♦ ♦♦ ♦♦♦	o o o
AFFF(2)	3% 2% 1.5%	□□□□□ □□□□□ □□□□□	■■■■ ■■■■ ■■■■	♦ ♦♦ ♦♦	o o o
AFFF-AR(1)	3% 2% 1.5%	□□□□□ □□□□□ □□□□□	■■■■ ■■■■ ■■■	♦♦♦♦ ♦♦♦ ♦♦	o ooo ooo
AFFF-AR(2)	3% 2% 1.5%	□□□□□ □□□□ □□	■■■■ ■■■■ ■	♦♦♦♦♦ ♦♦♦♦♦ --	o ooo --
FFFP(1)	3% 2% 1.5%	□□□□□ □□□□□ □□□□	■■■■ ■■■ ■■■	♦♦♦ ♦ ♦	o oo oooo
FFFP(2)	3%	□□□□□	■■■■	♦♦	o
FFFP-AR(1)	3% 2% 1.5%	□□□□□ □□□□ □	■■■■ ■■■ ■	♦♦♦ ♦ --	ooo oooo --
FFFP-AR(2)	3%	□□□□	■■■	♦♦	oo
FFFP-AR(3)	3% 1.5%	□□□□□ □□□□	■■■■ ■	♦♦♦ --	o --
FP(1)	3%	□□	■	--	--
FP(2)	3%	□□□	■	--	--

Table 14 : Performance Gradings - 5.8m^2 Fire Tray and Heptane - all Foam Concentrates at all Concentrations Tested

NOTES FOR TABLE 14 :

1. Knockdown Grade - The knockdown grades are based on the 90% extinction times achieved during the forceful application tests and are as follows:-

Grade	90% Extinction Time
□□□□□	Less than or equal to 1 minute
□□□□	More than 1 minute but less than or equal to 1 minute 30 seconds
□□□	More than 1 minute 30 seconds but less than or equal to 2 minutes
□□	More than 2 minutes but less than or equal to 3 minutes
□	More than 3 minutes

2. Extinction Grade - The extinction grades are based on the 100% extinction times achieved during the forceful application tests and are as follows:-

Grade	100% Extinction Time
■■■■■	Less than or equal to 1 minute 30 seconds
■■■■	More than 1 minute 30 seconds but less than or equal to 3 minutes
■■■	More than 3 minutes but less than or equal to 4 minutes
■■	More than 4 minutes but less than or equal to 12 minutes
■	Not extinguished

3. Burnback Grade - The assessments of the burnback resistance of the foam blankets formed after forceful application are based on the 25% burnback times and are as follows (the higher the 25% burnback time the better the performance):-

Grade	25% Burnback Time
◆◆◆◆◆	More than or equal to 15 minutes
◆◆◆◆	More than or equal to 12 minutes 30 seconds but less than 15 minutes
◆◆◆	More than or equal to 10 minutes but less than 12 minutes 30 seconds
◆◆	More than or equal to 7 minutes 30 seconds but less than 10 minutes
◆	Less than 7 minutes 30 seconds
--	Fire not extinguished or controlled well enough to enable a burnback test to be performed.

Flare-ups have not been taken into consideration for any of these burnback results. See below.

4. Flare Resistance Grade - The flare resistance grades are based on the largest area of the foam blanket involved in a flare up during burnback tests carried out after forceful foam application fire tests. A flare-up involves the foam blanket surface in flames which quickly escalate and then die down leaving the foam blanket intact. Flare-ups are probably due to the ignition of contaminated foam within the foam blankets.

Performance grades for flare resistance are as follows (the smaller the area of tray involved in flame the better the performance):-

Grade	Area of Foam Blanket Involved in Large Flare Flames
○○○○○	Less than 1%
○○○○	More than or equal to 1% but less than 5%
○○○	More than or equal to 5% but less than 15%
○○	More than or equal to 15% but less than 25%
○	More than or equal to 25%
--	Fire not extinguished or controlled well enough to enable a burnback test to be performed.

Foam Type	Conc. Used	KNOCKDOWN GRADE[1]	EXTINCTION GRADE[2]	BURNBACK GRADE[3]	FLARE RESISTANCE GRADE[4]
AFFF(1)	3%	□□□□□	■■■■■	♦♦	o
AFFF(2)	3%	□□□□□	■■■■	♦	o
AFFF-AR(1)	3%	□□□□□	■■■■	♦♦♦♦	o
AFFF-AR(2)	3%	□□□□□	■■■■	♦♦♦♦♦	o
FFFP(1)	3%	□□□□□	■■■■	♦♦♦	o
FFFP(2)	3%	□□□□□	■■■■	♦♦	o
FFFP-AR(1)	3%	□□□□□	■■■■	♦♦♦	ooo
FFFP-AR(2)	3%	□□□□	■■■	♦♦	oo
FFFP-AR(3)	3%	□□□□□	■■■■	♦♦♦	o
FP(1)	3%	□□	■	--	--
FP(2)	3%	□□□	■	--	--

Table 15 : Performance Gradings - 5.8m^2 Fire Tray and Heptane - Foam Concentrates Used at the Concentrations Recommended by the Manufacturers

NOTES FOR TABLE 15 :

1. Knockdown Grade - The knockdown grades are based on the 90% extinction times achieved during the forceful application tests and are as follows:-

Grade	90% Extinction Time
□□□□□	Less than or equal to 1 minute
□□□□	More than 1 minute but less than or equal to 1 minute 30 seconds
□□□	More than 1 minute 30 seconds but less than or equal to 2 minutes
□□	More than 2 minutes but less than or equal to 3 minutes
□	More than 3 minutes

2. Extinction Grade - The extinction grades are based on the 100% extinction times achieved during the forceful application tests and are as follows:-

Grade	100% Extinction Time
■■■■■	Less than or equal to 1 minute 30 seconds
■■■■	More than 1 minute 30 seconds but less than or equal to 3 minutes
■■■	More than 3 minutes but less than or equal to 4 minutes
■■	More than 4 minutes but less than or equal to 12 minutes
■	Not extinguished

3. Burnback Grade - The assessments of the burnback resistance of the foam blankets formed after forceful application are based on the 25% burnback times and are as follows (the higher the 25% burnback time the better the performance):-

Grade	25% Burnback Time
◆◆◆◆◆	More than or equal to 15 minutes
◆◆◆◆	More than or equal to 12 minutes 30 seconds but less than 15 minutes
◆◆◆	More than or equal to 10 minutes but less than 12 minutes 30 seconds
◆◆	More than or equal to 7 minutes 30 seconds but less than 10 minutes
◆	Less than 7 minutes 30 seconds
--	Fire not extinguished or controlled well enough to enable a burnback test to be performed.

Flare-ups have not been taken into consideration for any of these burnback results. See below.

4. Flare Resistance Grade - The flare resistance grades are based on the largest area of the foam blanket involved in a flare up during burnback tests carried out after forceful foam application fire tests. A flare-up involves the foam blanket surface in flames which quickly escalate and then die down leaving the foam blanket intact. Flare-ups are probably due to the ignition of contaminated foam within the foam blankets.

Performance grades for flare resistance are as follows (the smaller the area of tray involved in flame the better the performance):-

Grade	Area of Foam Blanket Involved in Large Flare Flames
○○○○○	Less than 1%
○○○○	More than or equal to 1% but less than 5%
○○○	More than or equal to 5% but less than 15%
○○	More than or equal to 15% but less than 25%
○	More than or equal to 25%
--	Fire not extinguished or controlled well enough to enable a burnback test to be performed.

Foam Type	Conc. Used	100% Extinction Times			
		$4.5m^2$ Tray min : sec	$5.8m^2$ Tray min : sec	$4.5m^2$ Extinction Grade	$5.8m^2$ Extinction Grade
AFFF(1)	3% 2% 1.5%	1 : 06 1 : 34 1 : 57	1 : 24 2 : 05 2 : 22	▪▪▪▪▪ ▪▪▪▪ ▪▪▪▪	▪▪▪▪▪ ▪▪▪▪ ▪▪▪▪
AFFF(2)	3% 2% 1.5%	1 : 31 1 : 41 2 : 15	1 : 46 2 : 07 2 : 45	▪▪▪▪ ▪▪▪▪ ▪▪▪▪	▪▪▪▪ ▪▪▪▪ ▪▪▪▪
AFFF-AR(1)	3% 2% 1.5%	1 : 39 2 : 10 3 : 01	1 : 51 2 : 28 3 : 06	▪▪▪▪ ▪▪▪▪ ▪▪▪	▪▪▪▪ ▪▪▪▪ ▪▪▪
AFFF-AR(2)	3% 2% 1.5%	1 : 29 2 : 21 NE	1 : 59 2 : 59 NE	▪▪▪▪▪ ▪▪▪▪ ▪	▪▪▪▪ ▪▪▪▪ ▪
FFFP(1)	3% 2% 1.5%	1 : 43 3 : 03 3 : 14	2 : 27 3 : 17 3 : 18	▪▪▪▪ ▪▪▪ ▪▪▪	▪▪▪▪ ▪▪▪ ▪▪▪
FFFP(2)	3%	1 : 49	1 : 46	▪▪▪▪	▪▪▪▪
FFFP-AR(1)	3% 2% 1.5%	3 : 18 3 : 15 3 : 13	2 : 17 NE NE	▪▪▪ ▪▪▪ ▪▪▪	▪▪▪▪ ▪ ▪
FFFP-AR(2)	3%	2 : 07	3 : 06	▪▪▪▪	▪▪▪
FFFP-AR(3)	3% 1.5%	1 : 35 3 : 12	2 : 23 NE	▪▪▪▪ ▪▪▪	▪▪▪▪ ▪
FP(1)	3%	9 : 43	NE	▪▪	▪
FP(2)	3%	3 : 36	NE	▪▪▪	▪

NOTES FOR TABLE 16

Extinction Grade - The extinction grades are based on the 100% extinction times achieved during these forceful application tests and are as follows:-

Grade	100% Extinction Time
▪▪▪▪▪	Less than or equal to 2 minutes
▪▪▪▪	More than 2 minutes but less than or equal to 3 minutes 30 seconds
▪▪▪	More than 3 minutes 30 seconds but less than or equal to 5 minutes
▪▪	More than 5 minutes but less than or equal to 10 minutes
▪	More than 10 minutes or not extinguished

NE - Not Extinguished

Table 16 : Comparison of Extinction Times and Extinction Performance Gradings For $4.5m^2$ and $5.8m^2$ Fire Tests

Foam Type	Foam Conc.	25% Burnback Time (Ignores Flares)			
		4.5m² Tray min : sec	5.8m² Tray min : sec	4.5m² Burnback Grade	5.8m² Burnback Grade
AFFF(1)	3% 2% 1.5%	8 : 44 9 : 42 11 : 05	8 : 42 9 : 24 11 : 29	♦♦ ♦♦ ♦♦♦	♦♦ ♦♦ ♦♦♦
AFFF(2)	3% 2% 1.5%	7 : 12 8 : 13 8 : 10	6 : 15 7 : 56 7 : 38	♦ ♦♦ ♦♦	♦ ♦♦ ♦♦
AFFF-AR(1)	3% 2% 1.5%	14 : 25 13 : 06 10 : 14	13 : 29 11 : 57 8 : 10	♦♦♦♦ ♦♦♦♦ ♦♦♦	♦♦♦♦ ♦♦♦ ♦♦
AFFF-AR(2)	3% 2% 1.5%	16 : 48 15 : 40 NE	15 : 31 15 : 08 NE	♦♦♦♦♦ ♦♦♦♦♦ --	♦♦♦♦♦ ♦♦♦♦♦ --
FFFP(1)	3% 2% 1.5%	12 : 30 7 : 54 7 : 46	10 : 11 7 : 14 7 : 04	♦♦♦ ♦♦ ♦♦	♦♦♦ ♦ ♦
FFFP(2)	3%	13 : 17	9 : 20	♦♦♦♦	♦♦
FFFP-AR(1)	3% 2% 1.5%	8 : 35 8 : 15 8 : 02	11 : 40 NE NE	♦♦ ♦♦ ♦♦	♦♦♦ ♦ --
FFFP-AR(2)	3%	11 : 49	9 : 52	♦♦♦	♦♦
FFFP-AR(3)	3% 1.5%	13 : 16 9 : 06	10 : 48 NE	♦♦♦♦ ♦♦	♦♦♦ --
FP(1)	3%	10 : 04	NE	♦♦♦	--
FP(2)	3%	11 : 14	NE	♦♦♦	--

NOTES FOR TABLE 17

Burnback Grade - The assessments of the burnback resistance of the foam blanket formed after forceful application are based on the 25% burnback times and are a follows (the higher the 25% burnback time the better the performance):-

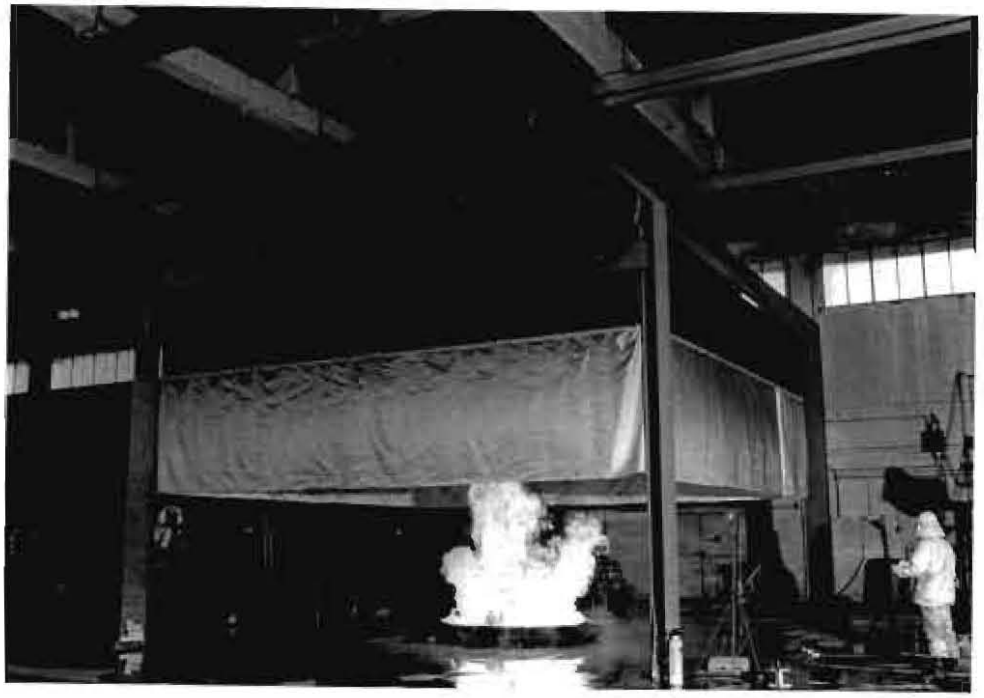
Grade **25% Burnback Time**

♦♦♦♦♦ More than or equal to 15 minutes
♦♦♦♦ More than or equal to 12 minutes 30 seconds but less than 15 minutes
♦♦♦ More than or equal to 10 minutes but less than 12 minutes 30 seconds
♦♦ More than or equal to 7 minutes 30 seconds but less than 10 minutes
♦ Less than 7 minutes 30 seconds
-- Fire not extinguished or controlled well enough to enable a burnback test to be performed.

Flare-ups have not been taken into consideration for any of these burnback results.

NE - Not Extinguished, any resulting burnback test void.

Table 17 : Comparison of 25% Burnback Times and Burnback Performance Gradings For 4.5m² and 5.8m² Fire Tests



S/320/90

Figure 1 : The Fire Test Hood at the FEU Still Air Facility (Fire Test in Progress)

S/813/91

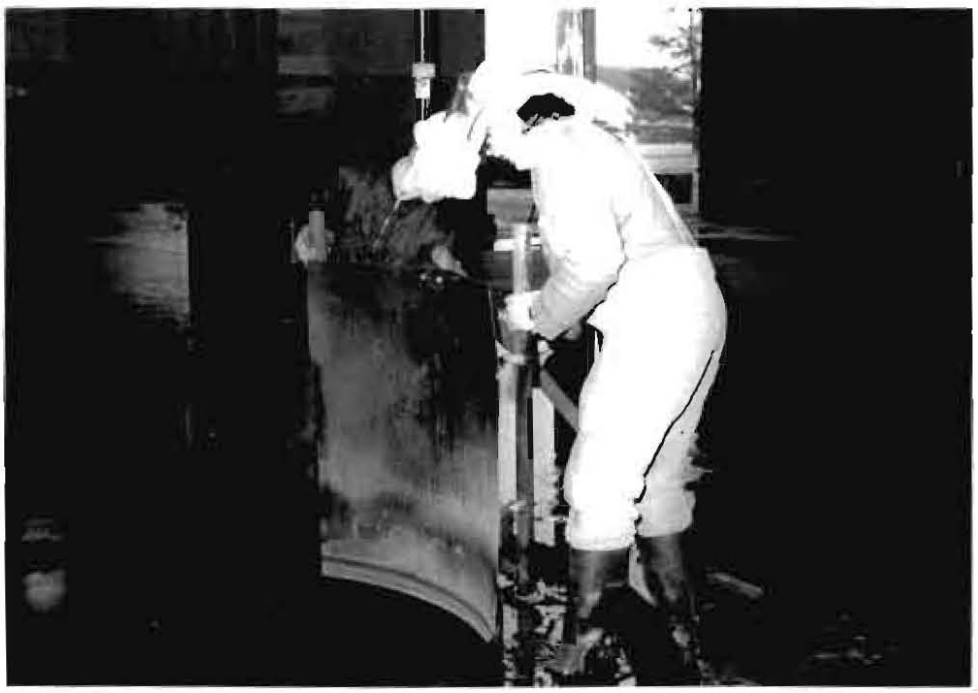
Figure 2 : The 4.5m^2 Fire Tray Positioned Within the Outer Tray Prior to a Test, Backplate also in Position

S/826/91

Figure 3 : A Gentle Application Fire Test in Progress

S/808/91

Figure 4 : A Forceful Application Fire Test in Progress



S/588/91

Figure 5 : Backplate Being Positioned Within the 4.5m^2 Fire Tray

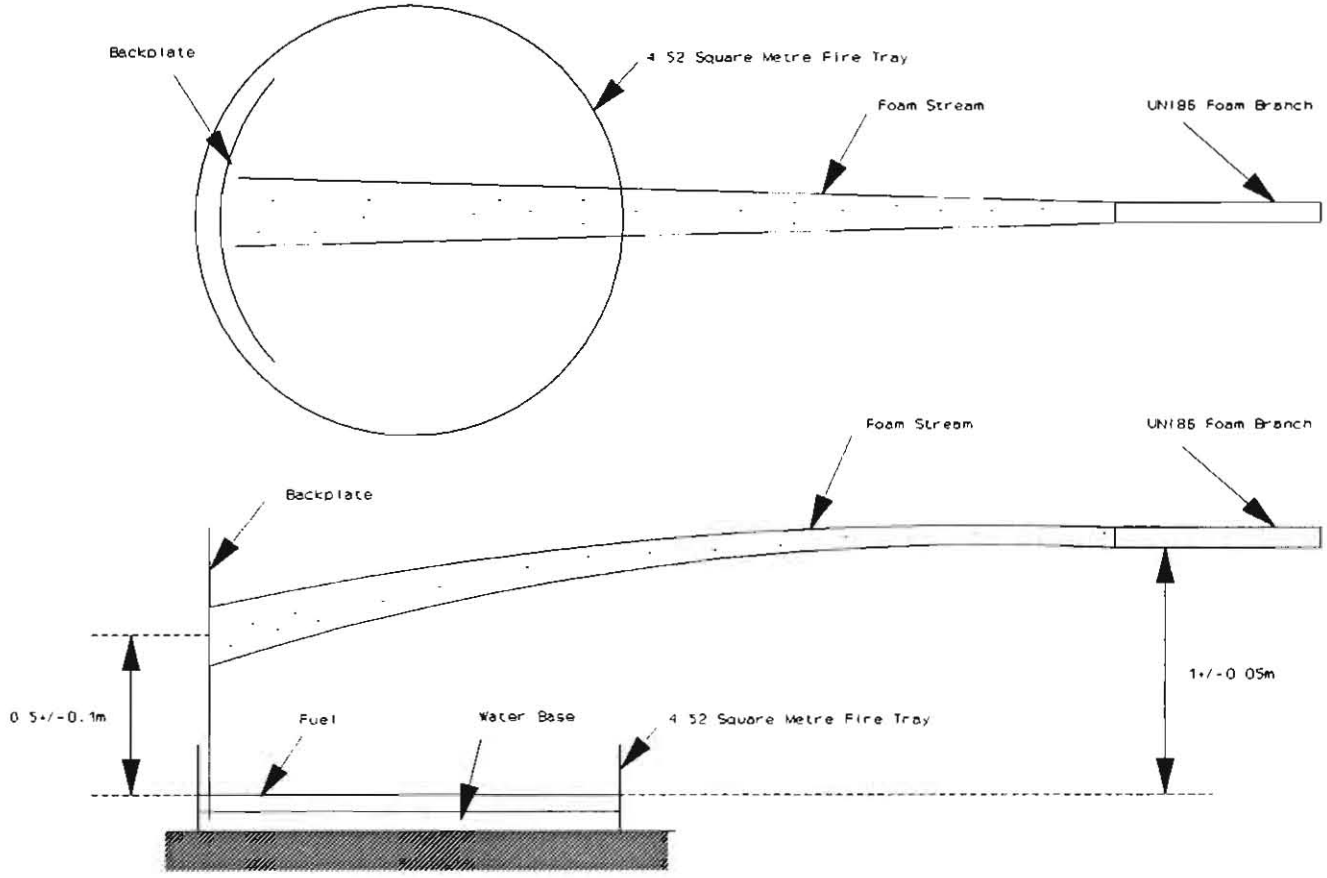


Figure 6 : Branch Positioning Diagram For Gentle Application Tests ($4.5m^2$ Tray)

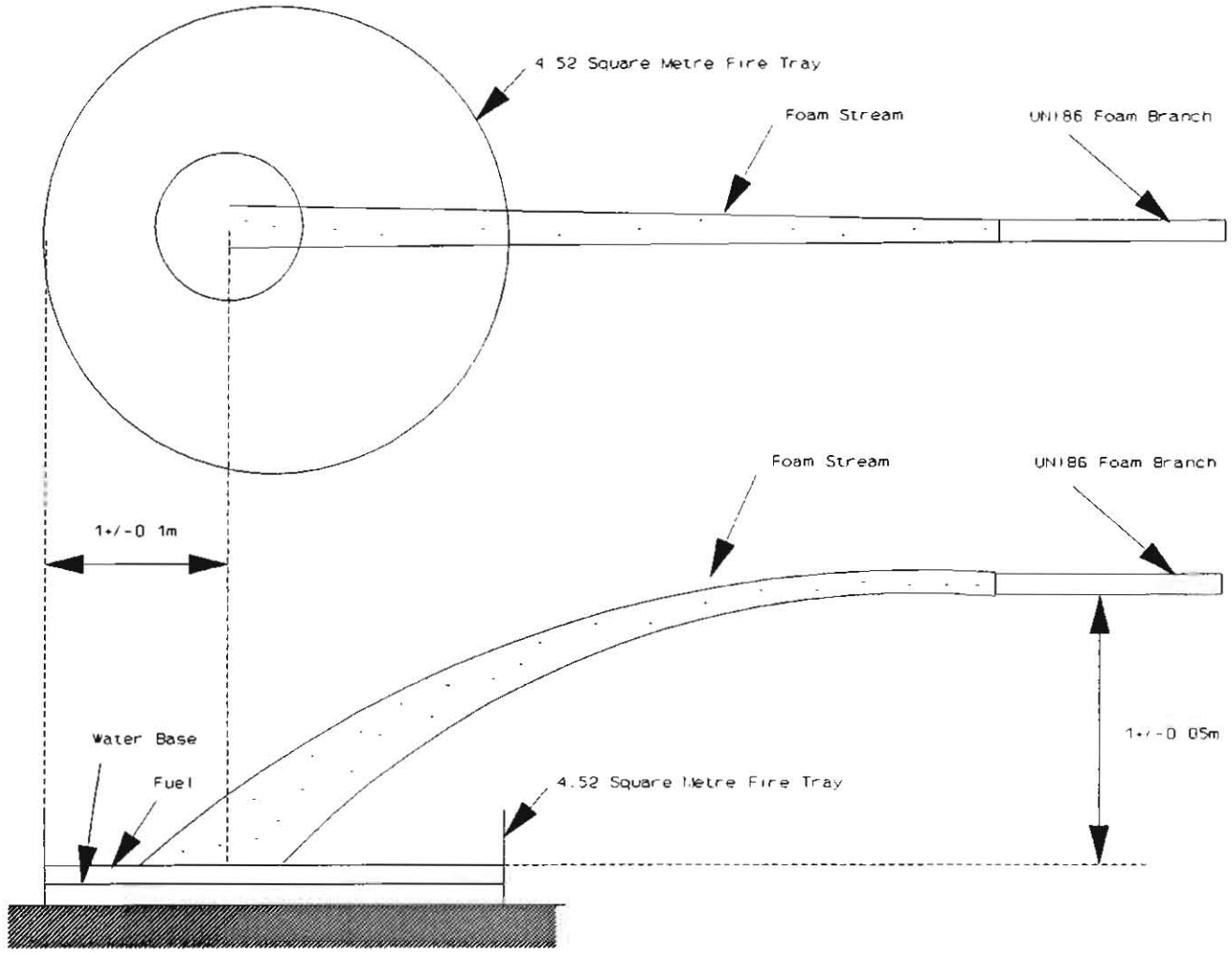


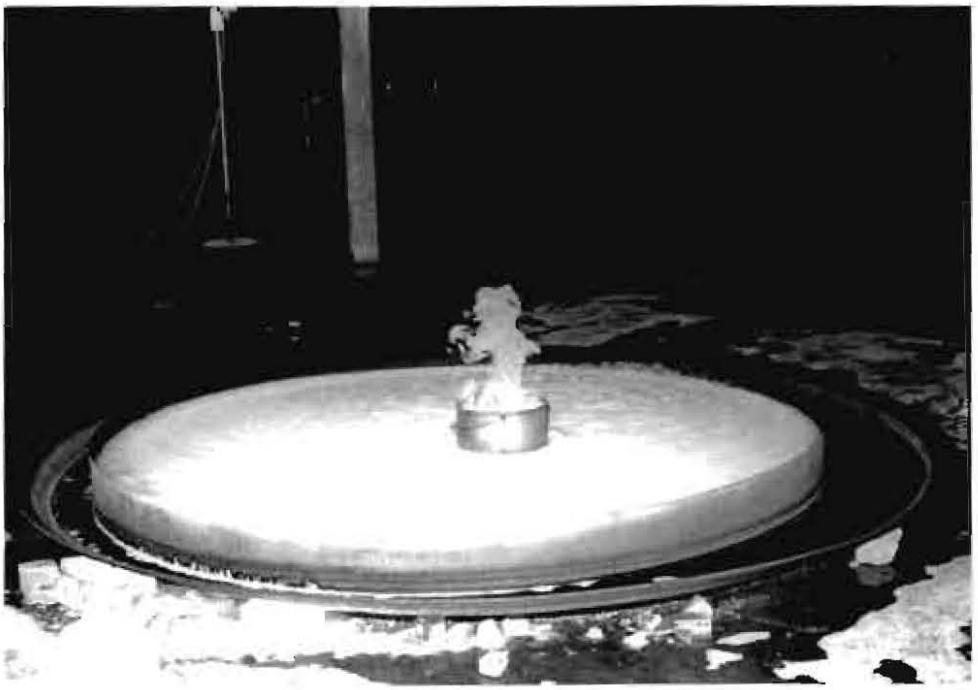
Figure 7 : Branch Positioning Diagram For Forceful Application (4.5m^2 Tray)

S/583/91

Figure 8 : Heated Flammable Liquid Store (The Smaller Store to the Left of The Picture)

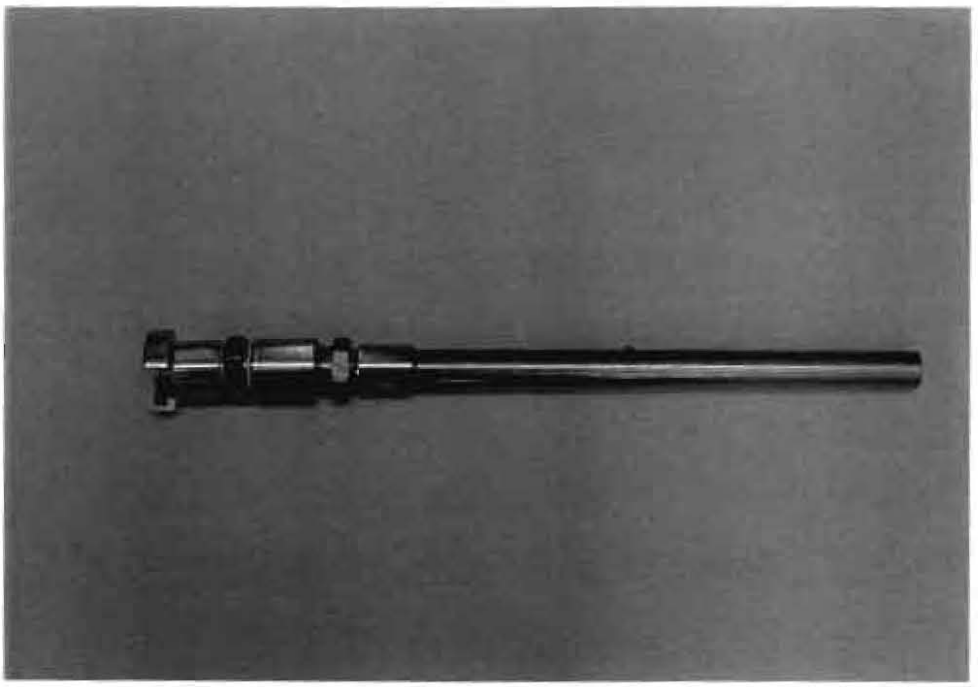
S/661/91

Figure 9 : Ignition of the Burnback Pot Using a Lance



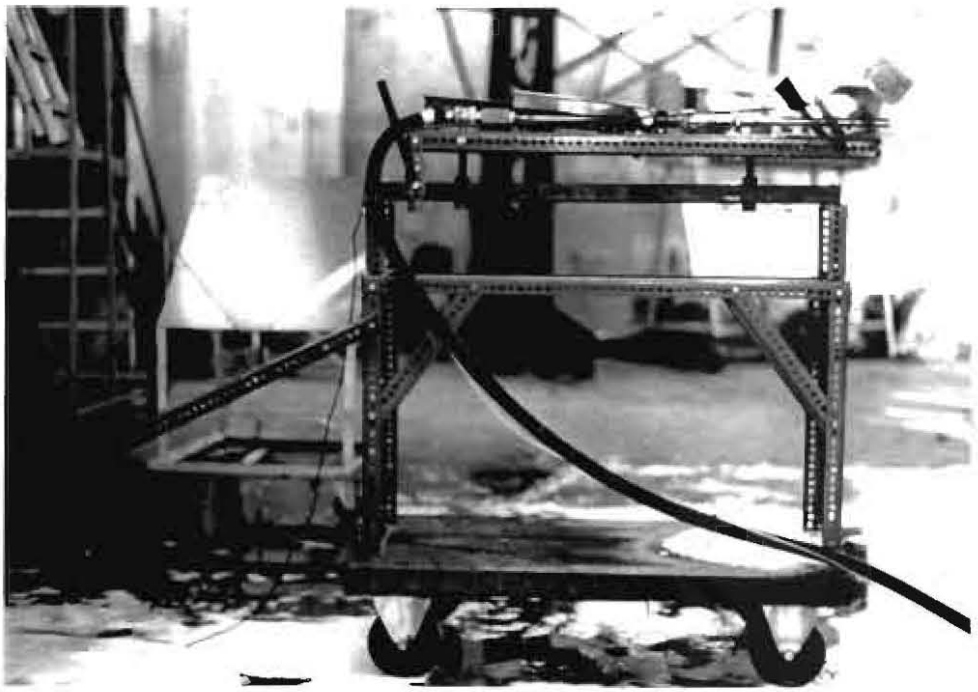
S/700/91

Figure 10 : General View of a Medium Scale Fire During the Early Stages of Burnback



B/161/94

Figure 11 : The UNI86 Branch



S/821/91

Figure 12 : Branch Trolley Showing Deflector in the Up Position

S/669/91

Figure 13 : Foam Sample Collection

S/673/91

Figure 14 : Measurements of Foam Quality

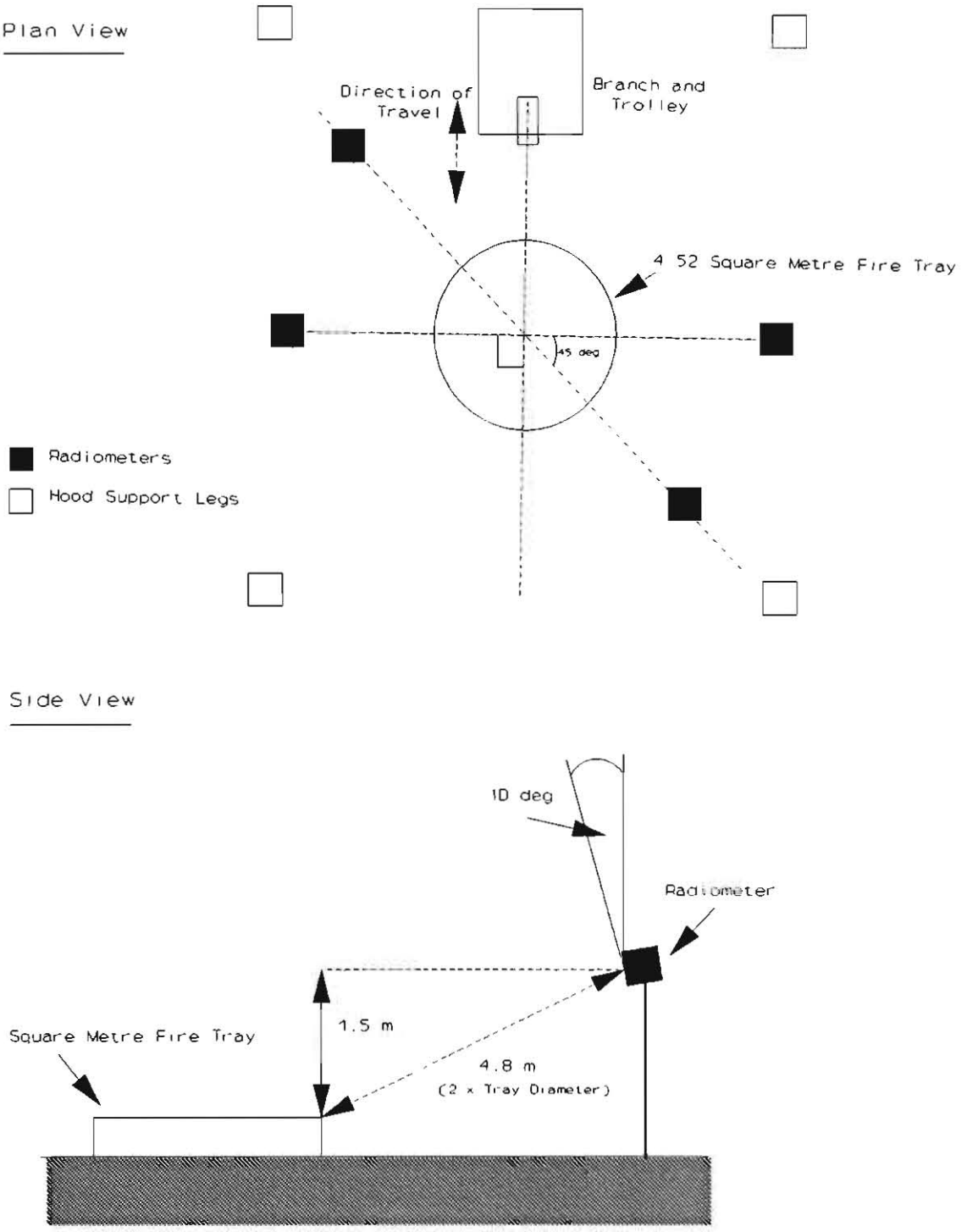


Figure 15 : Radiometer Positions During Medium Scale Fire Tests ($4.5m^2$ Tray)

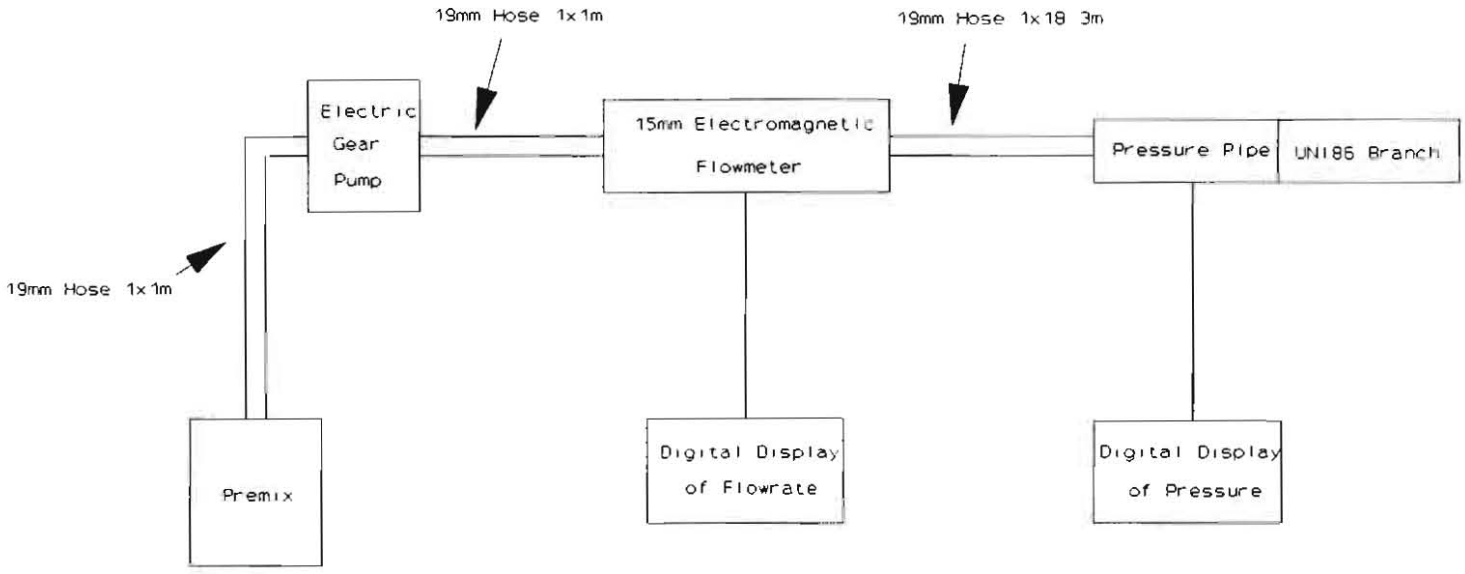
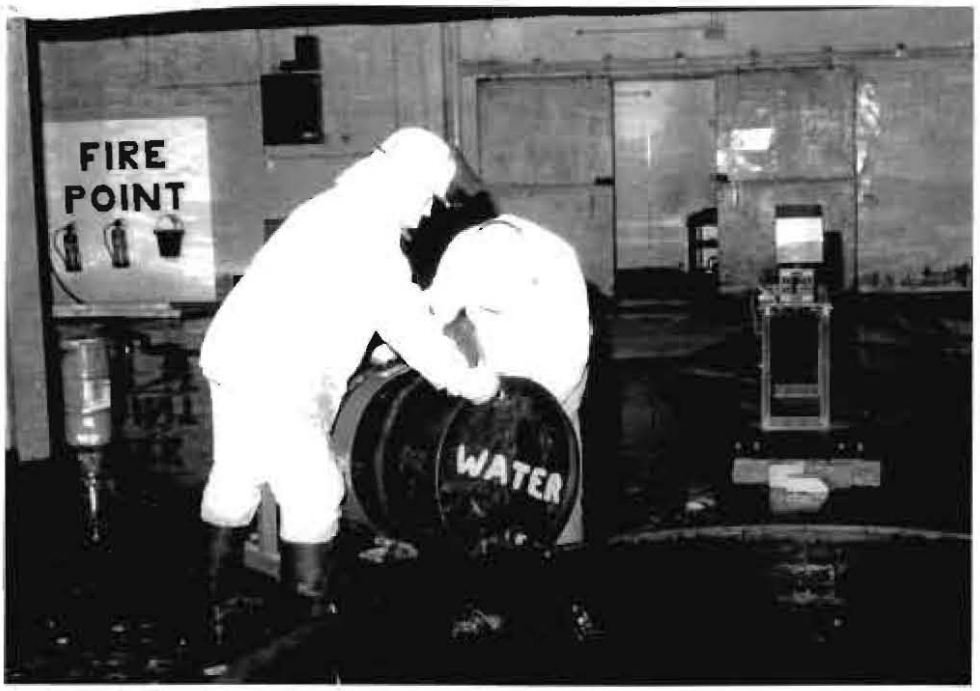


Figure 16 : Hydraulic Arrangement During Medium Scale Fire Tests



S/688/91

Figure 17 : The Water Base Being Added to the Fire tray

S/689/91

Figure 18 : Fuel Being Added to the Fire Tray

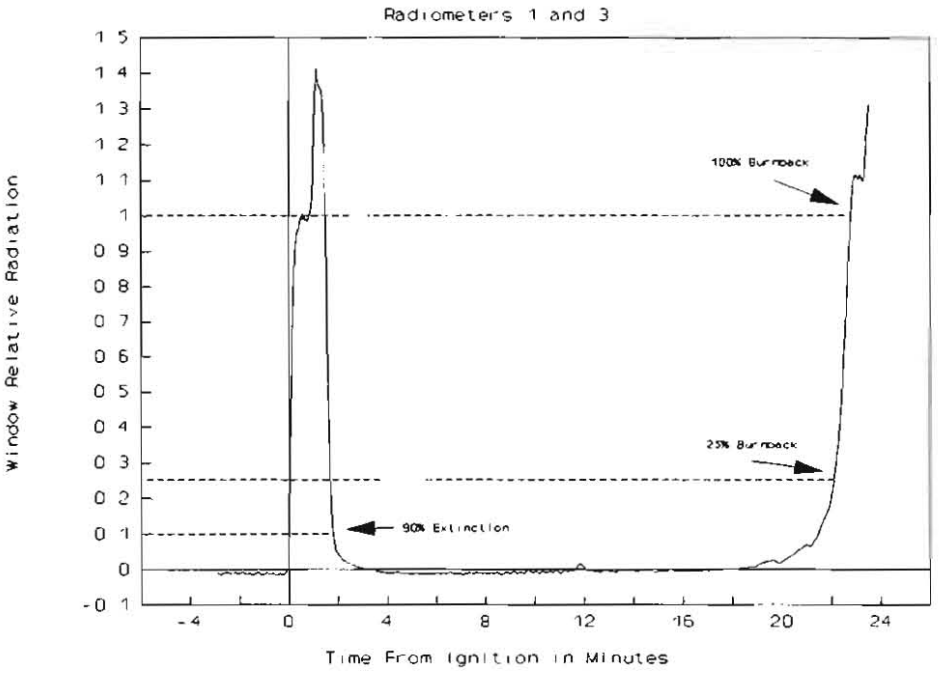


Figure 19 : Example of a Radiometer Record

APPENDIX A - Safety instructions for medium scale tray fire tests

SAFETY INSTRUCTIONS FOR MEDIUM SCALE FIRE TESTS

General

The following instructions concern the safety aspects of the medium scale fire tests. These instructions **must be** adhered to throughout.

YOUR ATTENTION IS DRAWN TO THE CONTENTS OF THE FEU INSTRUCTIONS FOR HEALTH AND SAFETY AT WORK WHICH SHOULD BE READ IN CONJUNCTION WITH THIS DOCUMENT

SAFETY PROCEDURE

Personnel Directly Involved in the Fire Tests

The following personnel will be involved:-

Bryan Johnson - Project Officer, Observer and Fire Safety Cover
John Price - Fuel handler and fire safety cover
Kirsty Bosley - Fuel handler, Fuel igniter, Observer
Guy Roberts - Concentrate mixing, foam generation, foam testing and Fire Safety Cover

Other contract personnel may supplement the FEU team.

A minimum of four people will be in attendance during each fire test.

Casual observers

These are personnel who are not directly involved in the fire tests. These people may or may not be members of the Fire Experimental Unit. In all cases, unsupervised casual observers **MUST** read these safety notes before being allowed to observe a fire test.

Project Officer

1. The project officer responsible for this work is Bryan Johnson. In the first instance, all matters of safety during these fire tests are his responsibility.

No Smoking

2. No smoking will be allowed in the Still Air Facility or the flammable liquid stores.

Fuels

3. The following fuel will be used during these trials :-

Heptane (Solvent 50), also now known (and sold as) Exxsol Heptane

144 Litres of fuel will be required for each fire test. A further 2 litres of fuel will be required for use during the burnback test.

The Health and Safety Data Sheets for Heptane can be found in the Health and Safety Data Sheet Library (in the Information Desk). **ALL PERSONNEL INVOLVED IN THIS TRIAL SHOULD CAREFULLY READ THESE SAFETY DATA SHEETS**

4. All fuel and fuel waste containers will be correctly labelled indicating their contents.

Foam Concentrates

5. The following types of foam concentrates will be used during these fire tests:-

Type of Concentrate

Protein (P)
Fluoroprotein (FP)
Film Forming FP (FFFP)
Alcohol Resistant FFFP (FFFP-AR)
Aqueous Film Forming Foam (AFFF)
Alcohol Resistant AFFF (AFFF-AR)
Synthetic

The Health and Safety Data Sheets for these foam concentrates can be found in the Health and Safety Data Sheet Library (in the Information Desk). **ALL PERSONNEL INVOLVED IN THIS TRIAL SHOULD CAREFULLY READ THESE SAFETY DATA SHEETS.** In particular, gloves and goggles should be worn when pouring out and handling these foam concentrates.

Fuel Handling

6. The person handling or measuring out fuels will be dressed in a Fleet Suit, safety fire boots and wearing a protective helmet with integral face visor and flame resistant protective gloves. All operations which involve the handling of fuels will be overseen by a second person standing at a safe distance and holding a fully charged dry powder fire extinguisher and with access to a foam extinguisher. This second person will be dressed in non-flammable clothing and have experience in the use of fire extinguishers. When fuel is being

poured into the fire tray, two people will handle the drum/pour the fuel while a third oversees them with firefighting equipment.

7. All fuel operations which involve the removal of caps from flammable liquid containers will be carried out with the protection specified in 6. above.

8. The measuring out of fuels will be performed within the large flammable store external to Hangar 97. All of the flammable store doors (including the safety door) must be open during this operation.

9. Where possible, the correct drum handling equipment should be used for moving fuel drums. Pushing drums along the ground/fuel store floor should be avoided.

10. When fuel is being measured out, the fuel drums involved must be earthed.

11. All fuel drums within the small, heated, flammable store must be earthed.

12. Measurement of fuel temperatures will only be carried out with an intrinsically safe thermocouple/indicator or with a mercury in glass thermometer.

13. Several AFFF and dry powder extinguishers will be positioned around the fire test area prior to each test. Extinguishers will be located within the fuel stores at all times.

14. The person igniting the fuel will do so with a flaming lance. This person will be dressed as specified in 6. above and will be provided with fire safety cover.

15. Burnback fuel will be stored within the yellow flammable store in Hangar 97. Only enough fuel for one days testing will be stored there at any one time. All other fuel must be stored within the large flammable store.

16. Only 1 litre of fuel will be placed in a measuring cylinder for use with the lance. This measuring cylinder will be placed within a metal tray close to the yellow flammable store. This fuel must be transferred to a safety container at the end of each working day.

17. Ignition of the lance will take place in a designated area which is a safe distance from the yellow flammable store and the fire tray.

18. The lance must be extinguished immediately after use.

Electrical Equipment

19. All electrical equipment, plugs, sockets, distribution boards etc. will be lifted off the floor and positioned to prevent the ingress of liquid.

20. Only 110v equipment should be used around the trials area. 240v transformers may be used along the Hangar walls. 240v equipment may be used within the instrumentation cabin via the cabins own 240v supply.

Casual Observers

21. Casual observers will not be allowed under the smoke hood during a fire test unless they are dressed as specified in 6. above. (A fire test commences at the point at which fuel is poured into the fire tray and ends when the fuel has completely burnt out at the end of burnback test).

Exits

22. All hangar doors are closed and will remain closed during a fire test to minimise the effect of wind on the test fire. However, the personnel doors at the north and south ends of the hangar will not be locked and may be used for exits in an emergency. The centre door nearest to the fire appliance will not be locked and may also be used as an emergency exit.

Additional Fire Cover

23. A fire appliance will be positioned at the centre door of the hangar, nearest to the crew room. This appliance will have connected to it a foam making branchpipe with inductor and foam concentrate, and a main line (70mm) water branch. The appliance will be connected directly to a hydrant. The appliance will be started and warmed up before each test to ensure it functions correctly.

24. A main line water branch will be connected directly to a hydrant with sufficient hose length to allow it to be used to cover all fuel operations within the fuel stores and within the hangar.