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FIRE RESEARCH & DEVELOPMENT GROUP

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FEPD

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THE USE OF FOAM AGAINST LARGE-SCALE PETROLEUM FIRES INVOLVING LEAD-FREE PETROL

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ABSTRACT

In September 1991, a series of foam trials was carried out on a $56m^2$ circular tray using 3000 litres of petrol as fuel for each test, to establish whether the introduction of lead-free petrol conforming with current standards would present any new problems to the fire service when using their standard low expansion foam equipment and techniques. The conclusions were that, providing brigades followed the application rate guidance given in the Manual of Firemanship as amended by the DCO Letter 10/91, no problems would be expected when using good quality AFFF or FFFP against petrol formulations permitted by current and likely future standards.

FP achieved extinction with the unleaded fuel with no oxygenates when used at the minimum recommended application rate of 5 lpm/m^2 and with an Angus 225H branchpipe. Extinction was not achieved with the fuels with added oxygenates without using indirect application. The burnback performance of FP was better than that of AFFF and FFFP.

In selecting foam additives, brigades should consider the relative importance of extinguishing and burnback performance. FP has the better burnback performance. AFFF and FFFP have significantly better extinguishing performance.

MANAGEMENT SUMMARY

Introduction

As a result of public concern, the Fire Experimental Unit was asked to evaluate the performance of portable foam extinguishers on fires of various traditional and unleaded petrol formulations. The tests, carried out in 1989, revealed that the foams tested suffered no significant loss of fire extinguishing capability when used on small scale unleaded petrol fires. The report concluded that there appeared to be no need to change fire extinguisher requirements for garage forecourts or comparable situations.

The objective of the tests described in this report was to establish whether lead-free petrol, conforming with current standards, would present any problems to the fire service using their standard low expansion foam equipment and techniques.

Discussions were held between the Home Office and the petroleum industry during the planning of the trials. The industry co-operated fully and assisted with the specification, mixing and delivery of fuel. The fuel for the main tests was donated by the Industry with the Home Office paying the duty and VAT charges.

Fuel

Lead as lead tetra-ethyl (or lead tetra-methyl) has been used for about 60 years to improve the performance (octane rating) of the hydrocarbon mixtures which constitute petrol, but health and environmental concerns have resulted in the progressive reduction in amounts of lead in petrol from 1974 onwards. The reduction of the lead content has led to the use of oxygenates, for example ethers and alcohols, as alternative octane improvers. Oxygenates are only used in either leaded or unleaded fuels when the octane rating cannot be achieved cost effectively by refinery processes.

The choice of fuel was made after advice from the Petroleum Industry on the most suitable combinations to represent blends towards the upper limits of oxygenate concentrations which could potentially be present in the UK. The three fuel types agreed for testing were:

Fuel 1 - Unleaded petrol with no oxygenates. This was 95 octane premium unleaded petrol.

Fuel 2 - Unleaded petrol with a 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 UK maximum of 2.5%.

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

Each fuel was analysed by the supplier before delivery and samples were taken from the tanker at the test site by the FEU for independent analysis.

Additives

The additives tested were FP, AFFF and FFFP foams, chosen because these were the foam types most commonly used in the fire service.

One test with alcohol resistant AFFF (AFFF-AR), at 3% concentration, was included because of current interest from some brigades in using a 'universal' concentrate.

FIRE TEST PROCEDURES

The tests were performed in a purpose built $56m^2$ circular tray on the Fire Service College fireground. The tray had a concrete base and metal circular rim. For each test, 3000 litres of fuel were dispensed from a tanker into the tray. The fuel was ignited and allowed a one minute preburn before the foam stream was applied to the upwind side of the tray.

The branchman, an experienced fire officer, applied primary aspirated foam to the tray surface, attempting to cause minimum disturbance to the fuel.

Five minutes after the fire was extinguished, a burnback test was performed to assess the resistance of the foam blanket to flame.

Throughout the tests, observers noted the progress of the fire fighting, the times to 90% control and extinction and the times to 25% and 100% burnback. Radiometers were used to measure heat radiation and all tests were recorded on colour video equipment.

The foam solution was produced using an in-line inductor as a convenient way for introducing concentrate into the hoseline. The concentrate and solution flowrates were accurately monitored by the use of flowmeters and both could be controlled with the use of pumps.

RESULTS

Unleaded petrol with no oxygenates - Fuel 1

The results of the extinction tests are given in Figure MS1 which records the 90% and 100% extinction times in minutes and seconds.

AFFF and FFFP gave convincing extinction at 4 lpm/m^2 using the Chubb FB5X MkII. FP gave satisfactory extinction when used at 5 lpm/m^2 with the Angus 225H. The single test with AFFF-AR gave results similar to those of AFFF and FFFP.

The burnback tests using AFFF, FFFP and AFFF-AR produced similar results, with small flames developing over the foam surface and tray rim shortly after the burnback flame was applied. The foam blanket did resist a major burnback for several minutes before the flames quickly spread to the whole tray area. The performance of FP was much better with 25% burnback times in excess of 12 minutes.

Unleaded fuel with alcohols - Fuel 2 and Unleaded petrol with MTBE - Fuel 3

The extinction results are given in Figure MS2.

With Fuels 2 and 3, both AFFF and FFFP at 4 lpm/m² gave convincing control and extinction with a Chubb FB5X MKII Branch. FP at 5 lpm/m² with the Angus 225H Branch did not achieve 90% control until 11 minutes with Fuel 2 and 15 minutes with Fuel 3. The fire was only eventually extinguished when the firefighter directed the foam stream to hit the ground outside the tray and flow over the bund wall and gently onto the fuel surface. This tactic is referred to as indirect application. The burnback test results were similar to Fuel 1 with minimal resistance from AFFF and FFFP; FP showed superior performance.

Only three tests are reported with Fuel 2 because of a branch malfunction on one test.

A single test was carried out with Fuel 3 using FFFP and the Angus 225H branch at 4 lpm/m². This did not show a significant change in the extinction performance but it did give improved burnback times. The significant change in the measured foam properties was that FFFP had a longer drainage time when used with the Angus Branch.

DISCUSSION

Foam Types

The results indicate that there was no difficulty in extinguishing all three fuels tested using AFFF and FFFP with the Chubb FB5X MKII branch at the minimum recommended application rate of 4 lpm/m². The single test with AFFF-AR on Fuel 1, showed similar performance to AFFF and FFFP.

FP had to be used at 5 lpm/m², the recommended minimum rate, and with the Angus branchpipe to extinguish the unleaded fuel (Fuel 1). With the other two fuel types, the 90% times were much longer than with the other foam concentrates and indirect application was required for extinction. The branchmen were never confident with the use of FP because of the flaring that occurred wherever the foam stream hit the foam surface.

FP was more successful when the foam stream was applied indirectly. This gave gentler application as would be achieved with a backplate, frontplate or other objects which could be used to serve the same purpose. Gentle application is advocated by the fire service wherever possible.

The burnback times of FP were the longest showing that FP had better burnback resistance. However, care must be taken in comparing tests where the extinction times were very different, because the burning characteristics of the fuel change as it burns down, and because long application times allow a deep foam blanket to build up.

In selecting foam additives, brigades should consider the relative importance of extinguishing and burnback performance. FP has the better burnback performance. AFFF and FFFP have significantly better extinguishing performance.

From the results achieved with good quality AFFF and FFFP, there would appear to be no justification for using alcohol resistant type concentrates for petrol fires.

Branchpipes

The tests have supported the pilot study results and shown that with FP and FFFP the performance of the Chubb FB5X Mk II branchpipe is inferior to that of the Angus 225H.

Satisfactory performance with all the fuel types was achieved with the Chubb Branch when using AFFF and FFFP, but use of the Chubb branch with FP cannot be recommended.

CONCLUSIONS

The trials have shown that, using AFFF and FFFP through a Chubb FB5X MKII branchpipe at 4 lpm/m^2, there was no difficulty in extinguishing all the fuels tested. No difficulty is expected with petrol formulations in the current standards using the Chubb FB5X MKII or Angus 225H branchpipes under these conditions.

FP only achieved extinction with the unleaded fuel with no oxygenates when used at the minimum recommended application rate of 5 lpm/m^2 and with an Angus 225H branchpipe. Extinction was not achieved with the other two fuels without using indirect application. The burnback performance of FP was better than that of AFFF and FFFP.

The tests have shown that foams applied with the Angus 225H have superior performance than when applied with the Chubb FB5X MKII.

In selecting foam additives, brigades should consider the relative importance of extinguishing and burnback performance. FP has the better burnback performance. AFFF and FFFP have significantly better extinguishing performance.

Providing that brigades follow the guidance in the Manual of Firemanship, as amended by the DCO Letter 10/91, no problems would be expected when using good quality AFFF or FFFP against petrol formulations permitted by current and likely future standards.

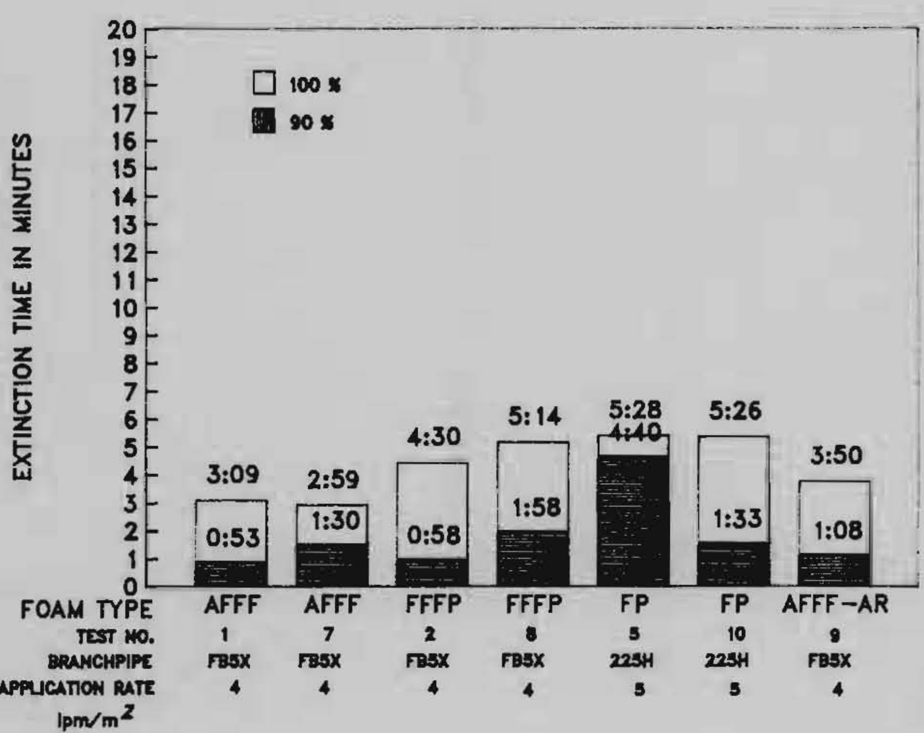

Figure MS1: Results of extinction tests for Fuel 1

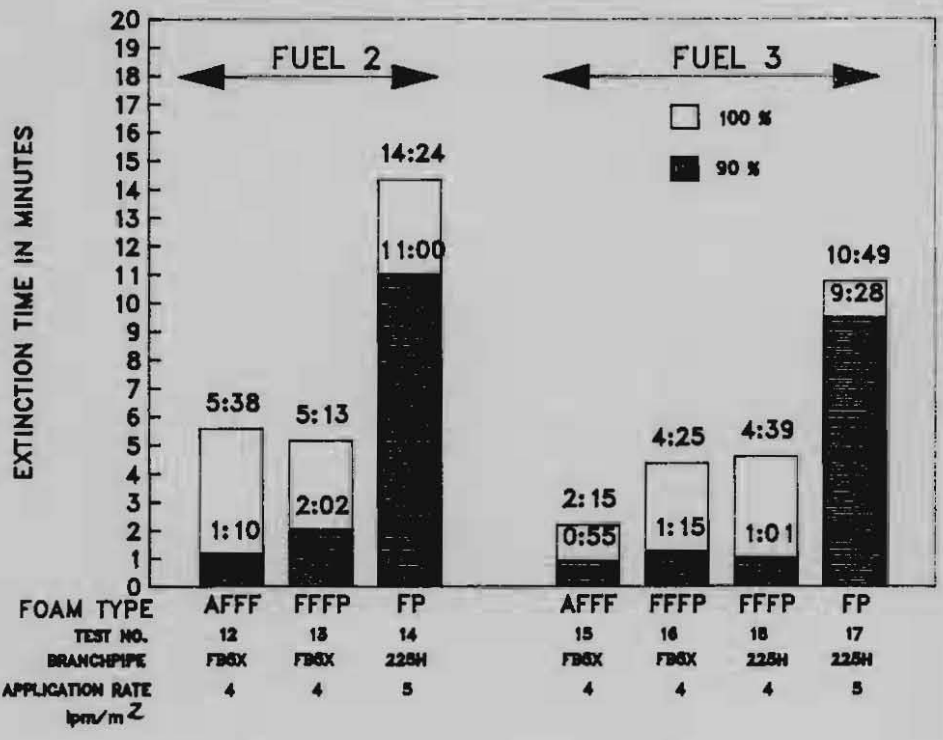

Figure MS2: Results of extinction tests for Fuels 2 and 3

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1. INTRODUCTION

As a result of public concern, the Fire Experimental Unit was asked to evaluate the performance of portable foam extinguishers on fires of various traditional and unleaded petrol formulations. The tests, carried out in 1989, revealed that the foams used suffered no significant loss of fire extinguishing capability when used on small scale unleaded petrol fires. The report (Reference 1) concluded that there appeared to be no need to change fire extinguisher requirements for retail petrol forecourts or comparable situations.

The report also suggested, however, that the stability of the foam blanket could be reduced at large scale incidents involving formulations containing high levels of oxygenates, and that further research might be required in this area. When the report was presented to the Joint Committee on Fire Brigade Operations, the members concluded that this should be the subject of further work.

The objective of the tests described in this report, was to establish whether lead free petrol conforming with current standards could present any problems to the fire service using their standard low expansion foam equipment and techniques. The tests were designed to represent an incident that would be tackled using one main delivery foam branchpipe.

Discussions were held between the Home Office and the petroleum industry during the planning of the trials. The industry co-operated fully, in particular the assistance of the industry was requested with the specification, mixing and delivery of fuel. The fuel for the preliminary tests was purchased by the Home Office but the fuel for the main tests was donated by the Industry with the Home Office only paying the duty and VAT element.

2. FACTORS AFFECTING TRIALS DESIGN

2.1 Application Rate

Successful use of foam is dependent on the rate of application. Application rates are generally defined in terms of the amount of foam solution in litres per minute expended on 1 square metre area of the fuel surface.

There is a critical application rate below which the fire cannot be extinguished and above this there is a recommended rate which will vary depending on the method of application and the size of fire. The most recent Home Office guidance was issued to brigades in a Dear Chief Officer letter Number 10/91 (Reference 2) in November 1991 which supplemented information given in the Manual of Firemanship (Reference 3).

The additives tested in these petrol trials were Fluoroprotein Foam (FP), Aqueous Film Forming Foam (AFFF) and Film Forming Fluoroprotein Foam (FFFP). The fuel depth for the trial was shallow (approximately 50 mm) representing a spill fire. The relevant application rate was 4 lpm/m^2 for AFFF and FFFP foam types and 5 lpm/m^2 for FP foam type.

Previous SRDB tests (References 4 and 5) have used 2.5 lpm/m^2, which was chosen because it was above the critical application, rate and it was hoped that this would differentiate between additives.

The objective of these tests was to establish whether lead free petrol conforming with current standards could present any problems to the fire service when using their standard equipment and techniques. It was therefore appropriate to use the rate currently recommended to the fire service (4.0 lpm/m^2) for all foam types for the preliminary tests. This is the rate recommended in Reference 2 for AFFF and FFFP but is less than the recommended rate for FP.

2.2 Choice of Branchpipe

A Pilot Study on Low Expansion Foam-making Branchpipes was carried out by FEU in 1986 and reported in Reference 6. For the purposes of the study, four branchpipes were chosen, all with flows of about 225 litres per minute. These were the Angus F225, the Angus F225H, the Chubb FB5X MK1 and Chubb FB5X MK2. These branchpipes were the ones in most common use on first line appliances in the United Kingdom.

The hydraulic characteristics of the branches, the foam pattern and throw and the quality of the finished foam were measured in the pilot study.

The Angus F225 had the shortest throw and a very tight "rope-like" stream.

The foam properties (using FP70), of the other branches are summarised below:

Branch	Expansion Rate	25% Drainage-Time Minutes
Angus F225H	9	5
Chubb FB5X Mk1	8.5	3
Chubb FB5X MK2	9	2

The Chubb branchpipes gave a much shorter drainage-time and more fluid foam. The report (Reference 6) noted that the significance of this difference in foam properties required assessment in full scale fire tests, but this comparison was not carried out before these current tests. In the absence of such results, the longer draining foam would be considered the better, particularly for burn-back resistance.

The main physical difference between the two branchpipes is the overall length. The Angus 225H is 795 mm compared with 460 mm for the Chubb FB5X. The extra length does allow more time to "work" the foam.

For the lead-free petrol tests the Angus F225 was rejected because of the short throw and the Chubb FB5X MK1 because a later version was available. The latest Chubb branchpipe, the FB5X MKII, was chosen on the basis that if this was successful, then better performance could be expected from the Angus 225H.

It was necessary to confirm that extinction could be achieved with this branchpipe at the proposed application rate of 4 lpm/m^2, the recommended rate for AFFF and FFFP foam types, and this was done during the preliminary tests.

In the earlier FEU work (Reference 6), the flowrate of the FB5X MkII was 234 lpm at the recommended operating conditions of 5.5 bar inlet pressure. A flowrate of 225 lpm was used in these tests. This is not significantly different from the recommended condition but is a more common value.

The application rate and flowrate of the branch together dictated the surface area of the tray to be used for these tests.

2.3 Preburn

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

The sealing qualities of the foams may not be fully tested with a one minute preburn because the metal tray rim will not be heated to significantly high temperatures.

2.4 Tactics of Foam Application

There are three ways in which a foam stream can be applied to a tray fire:

1. Gentle application

   The foam stream is allowed to fall as gently as possible onto the fuel surface, without allowing it to impact on the tray sides.

   Gentle application can be achieved without moving the branch or by moving the branch to produce a sweeping motion over the tray.

2. Forceful surface application

   The foam stream is directed forcefully into the fuel.

3. Use of a backplate or front plate.

   The foam stream is directed onto a plate above the fuel surface. This allows the foam to run gently onto the fuel surface, building up a blanket which can flow gently over the surface, so ensuring the minimum of disturbance.

   The tray sides can be treated as a backplate if there is enough metal above the fuel surface.

The branchman, an experienced Fire Officer, was asked to apply aspirated foam as gently as possible to the tray surface without using the tray sides. There was no backplate used because a backplate may not always be available to the branchman at operational incidents.

The technique agreed was gentle application until 90% control. For the initial attack the branch was directed so that the bulk foam stream hit the centre area of the tray.

The branchmen tried to keep the foam stream stationary for this phase.

When 90% extinction had been achieved with the branch stationary, the branchman was allowed to move the foam stream over the tray.

If a stage was reached when the extinction was no longer progressive, the branchmen changed their position and moved the foam stream over the surface. If the clock time was greater than 8 minutes the branch men were allowed to use forceful application and if this failed to extinguish the fire, the foam was directed onto the ground in front of the tray wall so that foam was pushed over the front. This later technique is referred to as indirect application in this report, and is equivalent to the use of a front plate.

2.5 Number of Test Fires

Three tests, in the same conditions, are preferable to assess repeatability. More tests are desirable but the size and cost of the these must impose limits.

It was decided at a preliminary meeting between the Home Office and the petroleum industry, to carry out 4 tests only for each fuel type.

This allowed for one test per fuel type and foam additive and a repeat of one combination only.

2.6 Production of Foam Solution

Brigades use in-line inductors or round-the-pump systems for the induction of additives on first-line appliance for main delivery foam branchpipes. Self inducting branchpipes are also used.

In these trials an in-line inductor system in conjunction with a gear pump and flowmeters (see Section 3.3.) was used because this could be used as a convenient way for introducing concentrate into the hoseline in a closely controlled way.

The use of this arrangement also avoided foam solution passing through the appliance pump and the consequential need for thorough flushing of the pump after each test. It was also more economical on the use of foam concentrate over the alternative approach of using a premix solution. The premix requires large volumes of solution to be available for the longest expected extinction times. When the concentrate is inducted, foam production can be terminated at the end of the test.

When the Chubb FB 5X branchpipe was used, it was set to the Premix setting.

2.7 Fuel

Lead as lead tetra-ethyl (or lead tetra-methyl) has been used for about 60 years to improve the performance (octane rating) of the hydrocarbon mixtures which constitute petrol, but health and environmental concerns have resulted in the progressive reduction in amounts of lead in petrol from 1974 onwards. The reduction of the lead content has lead to the use of oxygenates, for example ethers and alcohols, as alternative octane improvers. Oxygenates are only used in either leaded or unleaded fuels when the octane rating cannot be achieved cost effectively by refinery processes.

At the time of the setting up of the tests, Methyl Tertiary Butyl

Ether (MTBE) had been widely used in European Continental petrol and was increasingly appearing in UK blends. Alcohols, notably tertiary butyl alcohol (TBA) and methanol were also used intermittently as components in gasolines in Europe and, provided the fuels conform to the British Standards, could in theory be imported for sale in the UK. At present, however, the likelihood of this happening is low since alcohol-containing gasolines are unsuitable for the distribution system in the UK.

European Directive 85/210/EEC defines the permitted contents of both leaded and unleaded petrol, while 85/536/EEC, the 'Oxygenates Directive', specifies the national flexibility and composition limits for oxygen-containing components which may be added to both leaded and unleaded petrol. UK petrol specifications are set by the British Standards Institution: BS 4040 (1988) for leaded petrol and BS 7070 (1988) for unleaded petrol. These permit a virtually infinite number of oxygenate combinations up to the limits prescribed and reflect the requirements of 85/536/EEC.

As noted earlier, both leaded and unleaded grades may contain oxygenate additives. In practice, the higher octane unleaded grades are more likely to contain oxygenates: this is because it is harder to achieve these octane levels by means of refining alone.

The choice of fuel for these tests was made after advice from the Petroleum Industry on the most suitable combinations to represent blends towards the upper limits of oxygenate concentrations which could potentially be present in the UK. Although, for the reason given above, the use of alcohol-containing blends in the UK is unlikely, these fuels would tend to be more demanding of the foam performance during firefighting. An alcohol blend was therefore included in the series of fuel mixtures to be tested. The three fuel types agreed for testing were:

Fuel 1 - Unleaded petrol with no oxygenates. This was 95 octane premium unleaded petrol.

Fuel 2 - Unleaded petrol with a 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 UK maximum of 2.5%.

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

At the planning stage of the tests, the standard for volatility was being renegotiated and it was expected that the volatility value would be reduced by the end of 1992. Although this reduced volatility would result in a less severe fire, it was decided to use the lower figure. The reduced volatility specification was expected to be current at the time that the results of the tests would be widely promulgated. It was decided that all the fuels should have the same volatility (as measured by the Reid Vapour Pressure) and that this would be maximum allowed in the new standard. If possible, it would be arranged that all the fuel mixtures would contain broadly similar proportions of aromatic and aliphatic hydrocarbons.

Each fuel was analysed by the supplier before delivery and samples were taken from the tanker at the test site by the FEU for independent analysis.

2.8 Choice of Additives

It was decided to use good quality FP, AFFF and FFFP foams only. These were all used at 3% concentration. These were the foam types most commonly used in the Fire Service.

Generally, throughout the report, reference is made to the additive type only. Table 1 gives full details of the additives used during this work.

One test with alcohol resistant AFFF (AFFF-AR) was included, because of current interest in some brigades in using a 'universal' concentrate.

2.9 Tray Design

The area of the tray (56.25 m^2) was dictated by the application rate (4 lpm/m^2) and flowrate of the branch selected (225 lpm).

Reference 5 discussed the design of the 40 m^2 tray used in the earlier trials. This had a concrete base surrounded by a circular metal ring in a channel. Water was run into the tray to cover the base and then the fuel poured on top. The design was successful although there was damage to the concrete tray edges.

For the current tests, a water base could not be used because some of the petrol additives were water soluble. This complicated the design of the new tray because, with the 40 m^2 tray design, there would be fuel on both sides of the metal rim and burning fuel on the outside of the ring would affect the extinction.

It was therefore necessary to prevent the fuel from flowing to the outside of the rim by encasing the metal ring in concrete and using a flexible sealant around the inner tray rim.

A metal tray was not proposed because of the problems of manufacture and of distortion of the base during the fire. The distortion could affect the depth of fuel.

2.10 Fuel Depth

The deeper the fuel the more realistic and severe the test.

Previous tests have used a water base and this allowed any variations in tray level to be overcome by the water layer. This was not practicable because of the solubility of some of the fuel additives, so no water base was used in the tests. About 1300 litres of the 3000 litres of fuel were required to ensure that the whole area of the tray was covered with fuel. The concrete base of the tray was uneven, and this meant that in some areas of the tray the fuel depth was about 20mm before the whole tray base was completely covered with fuel.

At an estimated free burning rate of 4 mm per minute, 3000 litres of petrol gave an estimated free burning time of 13 minutes. With the uneven tray base, the fuel would burn for nearly eight minutes before the tray base became exposed.

2.11 Weather Conditions

The general guidelines for weather conditions used for the tests were that tests would not be commenced if there was any precipitation, or with wind speeds above 6 m/s.

Although desirable, it was not possible to control the fuel temperature.

The tests were suspended on one hot windless afternoon because the conditions were considered too dangerous with clouds of petrol vapour drifting over the whole trial site.

2.12 Burnback Test

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

The burnback apparatus used was a development of that described in Reference 5. This was a propane torch which was applied to the foam blanket approximately 0.5 metres from the edge of the tray.

Foam application was continued for a further 30 seconds after extinction. This was intended to provide a standard blanket condition for the burnback test which could be regarded as representing practical circumstances of use in fire fighting operations.

In earlier FEU trials, the flame from the propane torch had been applied to the foam surface after a further minute (i.e. 1 minute 30 seconds after 100% extinction). The flame was left to play on the surface until the fire was well developed (about 1 m^2 of exposed petrol surface on fire), when the torch was removed.

For these tests, where the foam blanket may be destroyed by the oxygenates in the fuel, the burnback flame was applied to the foam surface 5 minutes after 100% extinction. It was hoped that the longer delay might allow assessment of any difference in foam destruction by the foam and fuel types under test.

2.13 Safety

A safety procedure, including procedures for fuel transfers, was developed before the commencement of the trials and this was followed for each test. The procedure is given in Appendix A.

The fuel was ignited with an electrically fired cartridge[1] by an operator at a safe distance to avoid the risk of approaching the tray with a naked flame (Superscripts refer to notes on Page 27).

3. DESCRIPTION OF TRIALS SITE AND EQUIPMENT USED.

3.1 Tray Site

The tray site was situated on the fireground of the Fire Service College (FSC), Moreton-in-Marsh. Figure 1 shows a general view of the site.

The base, side walls and immediate surround were constructed of high temperature concrete. The 56.25 m^2 area of the fire was defined by a steel ring which was encased in concrete and sealed at the edges by a high temperature mastic material.

There was a drain outlet from the base of the tray and an outlet from the channel between the tray wall and the metal rim. Both these outlets had valves which allowed the residue from the fire tests to be drained to a settlement and treatment system incorporated in the FSC fireground.

The outer area of the site was covered with gravel.

3.2 Water Supply

Potable water was required for mixing with the additive for firefighting and for cleaning the tray. There was not an adequate potable water supply on the tray site and so two portable water dams were positioned near the tray site but away from any danger from the fire.

The dams were filled from a small bore potable water supply available on the site. The larger dam (24000 litres) had a control valve on the inlet water supply so that it could be allowed to fill overnight. There were occasions when the incoming supply was not adequate for the demand and potable water was transferred from a static tank at the FEU to the test site using the tanks of the FEU fire appliances.

A fire appliance adjacent to the dams was used to distribute potable water around the trials site (Figure 2).

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

3.3 Instrumentation

A typical layout of appliances and equipment is shown in Figure 3. This shows the relative positions of instrumentation and other equipment when deployed for the trials.

The hydraulic system is shown in Figure 4. Potable water from the pump passes through a standard in-line inductor and an electromagnetic flowmeter[2], then through three 21.3 metre lengths of 70mm hose to the foam branchpipe. The additive used was poured into an open drum. From this it was lifted by a small electrically driven gear-pump[3], through an orifice and then through a second electromagnetic flowmeter[4] before reaching the in-line inductor. The orifice was introduced to reduce variations in the concentrate flow. The gear pump was provided with an electrical variable speed drive control and both flowmeters were connected to digital displays. By adjusting the main pump throttle and the gear-pump control, the operator monitored and controlled the total liquid flow to the branchpipe and the correct percentage of foam concentrate. This arrangement ensured that the solution strength was accurately known and controlled.

The piezometer[5] tube housed a pressure transducer[6] and a temperature sensor[7]. Both these sensors were connected to digital displays[8,9] easily visible by the pump operator (Figure 5).

The temperature of the fuel in the tray was measured using a hand held intrinsically safe digital indicator and thermocouple probe[10].

The wind speed and direction was monitored using a wind station[11] mounted on a pole connected to the Instrument van. A humidity probe and an air temperature sensor[12] were also mounted on the pole (Figure 6). These instruments were connected to readouts in the control van and also recorded on a chart recorder[13] and datalogger[14].

A wind sock[15] was mounted on a mast upwind of the tray to give a visual indication of the wind direction and a guide to the wind speed (Figure 7).

Each test was recorded using colour video equipment. A Skystalk[16] mast (Figure 8) with a colour camera on top (Figure 9) was the main camera. The camera was mounted at a height of 20 metres for optimum viewing of the fire tray and could be remotely controlled from the instrument van. A second camera[17] was mounted on top of the instrument van. Both cameras were connected to video recorders[18,19] in the instrumentation van. The direction of view of the Skystalk camera was approximately broadside to the wind direction. A portable video camera[20] was also used during the trials to provide additional material.

Two large synchronised digital clocks[21], displaying minutes and seconds, were sited near to the fire tray. These were sited to be in the field of view of the cameras and at least one was visible to personnel engaged in the conduct of the trial.

The clocks were preset to 99 :00 (min : sec) and started when all preparations were complete and the fuel had been transferred to the tray. Ignition took place 1 minute after the clocks were started, at zero indicated time. Thus the video records were accurately timed, and a means of co-ordination provided for all involved with the trials. The time on the clock is referred to as clock time in this document.

Records of the progress and timing of each fire was made by observers. They used the times from the large digital clocks but also had digital stopwatches available with split time facilities. One observer used a portable camera as a notebook to record the progress of the extinction.

Two pairs of radiometers[22], were used to measure the radiation from the tests. The radiometers were deployed mounted at a height of 3 metres on a mast (Figure 10), with one radiometer from each pair diametrically opposite the other. The pairs had different sensitivities. Each radiometer was cooled by circulating water from a tank using a pump.

The radiometers were positioned 15 metres from the tray for most of the tests. Changes to the distance from the tray were necessary in some tests to avoid interference with the tanker and its approach and exit routes from the position used for transfer of fuel. The active faces of the radiometers were depressed about 10 degrees from the vertical. The signals from the radiometers were recorded on a datalogger[14] and on a chart recorder[13] .

All the instruments, the data logger, chart recorders and video recording equipment were housed in an instrumentation van (Figure 11).

4. EXPERIMENTAL PROCEDURE

4.1 Tray Preparation

Before each test the tray was thoroughly cleaned out using yard brushes, wet vacuum cleaners, and potable water (Figure 12). No surface water was left on the tray base before the test.

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

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

4.2 Fire Tests - General Procedure

Before transfer of fuel to the tray, all equipment was operated to check correct functioning. The foam branchpipe was connected to the hoseline and tested. The wind direction and speed were monitored. The direction was checked to ensure all vehicles and equipment were suitably deployed for the wind direction. The petrol tanker was then driven alongside the tray.

Whilst this was happening, the foam concentrate was poured into the container.

The metal tray rim and tanker were connected to an earth spike and a length of petrol hose was connected from the tanker outlet to the tray. Local Authority firefighters were deployed as safety crews.

When all preparations were complete fuel was transferred from the tanker to the tray: the tanker valve was opened, allowing fuel to be gravity fed in to the tray. The petrol tanker driver measured the quantity of fuel using a calibrated dipstick inserted into the top of the tank (Figure 13). When 3000 litres had been transferred the valve was closed, the earth connections removed and the hose underrun. The tanker was then driven away from the site. For some tests it was necessary to take petrol from more than one compartment of the tanker.

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

To ignite the fuel, an electrically fired cartridge[1] (two cartridges were used in later tests) was positioned, using a metal strap, a few centimetres above the petrol surface, on the upwind side of the tray. The fuel temperature was measured using a hand held intrinsically safe thermometer.

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

The datalogger, chart recorders and video recorders were all set to record data. Foam production from the firefighting branchpipe was commenced. The cooling sprays were turned on prior to ignition. The clocks (preset to 99min:00sec) were started and the cartridge detonated, using a safety firing box, after one minute at zero indicated time. A one minute preburn was allowed before the fire fighting commenced. When the clocks were started the pump operator adjusted the flowrates to give the required conditions for the branchpipe. This ensured that the conditions were correct at the branch when firefighting commenced.

Figure 14 shows a general view of the fire during the preburn.

The pump operator monitored the flowrate throughout the test and adjusted when necessary. He also recorded the temperature from the display connected to the in-line temperature sensor.

At one minute after ignition, the foam stream was applied to the fire from the upwind side of the tray. The fire fighter attempted to apply the foam gently to the fuel surface (Figure 15).

During the firefighting 4 observers noted progress and the times to 90% and 100% extinction. 90% extinction was taken as the time at which 90% of the tray area was free from flames.

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

After foam application to the tray had ceased, the branchman directed foam on to a NFPA foam collecting stand positioned on the edge of the tray side (Figure 16). The samples were taken to an instrument trailer, where measurements were made of foam quality in respect of expansion ratio and 25% drainage time using a 1600ml brass collecting vessel. These served as a general check on the quality of the foam concentrates and on the correct functioning of the foam branchpipes.

Air and foam temperatures during the foam tests were recorded using digital thermometers.

After extinction a pipe was positioned over the edge of the tray so that water could be introduced into the tray when the burnback had developed to 75%. This was to protect the base of the tray against damage during the burnback.

4 minutes after the fire was extinguished the burnback flame was lit. Five minutes after 100% extinction the burnback flame was applied to the surface of the foam blanket, at a position approximately 0.5 metre from the edge of the tray (Figure 17).

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

4.3 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 draft ISO standard (Reference 10) to calculate the times for 90% control and 25% and 100% burnback and other times.

Figure 18 shows an example of a radiometer record with the 90% extinction time and the 25% and 100% burnback times marked.

4.4 Analysis of Fuel.

Samples of the fuel were taken from the tanker while it was on the trials site. The fuel was sent for analysis which included the measurement of the Reid vapour pressure, evaporated percentage volumes and percentage oxygenates.

4.5 Medium Scale Tests.

FEU has carried out tests in recent years in support of British Standards, ISO and CEN Standards work. The tests have been carried out in a tray of diameter 2.4m and using 144 litres of fuel. The standard test fuel is Heptane but FEU has used petrol for comparative tests. Extra fuel was obtained for the 56.25 m^2 tests so that medium scale tests could be carried out to give a comparison between the two sizes of fire.

The test procedure is given in Reference 10. It was not possible to use a water base because some of the water additives were water soluble and therefore 215 litres of fuel instead of the standard 144 litres was used to allow for variations in the base of the tray base and to give the same free metal on the tray sides.

5. RESULTS

The results of the tests are tabulated as follows:

Table 2: Extinction and burnback times for each test. Air and Fuel temperatures are also given.

Table 3: Air, fuel and solution temperatures humidity,speed and wind direction for each test.

Table 4: Foam properties measured during the tests.

Appendix B gives details of extinction and burnback tests and was compiled from analysis of the radiometer records, observers notes and analysis of the video records. Graphical results of radiometer results are also included.

The extinction times are measured from the first application of foam until the 90% or 100% extinction. No account has been taken of any times when foam was missing the tray for any reason, although when this occurred, a comment will be given in Appendix B.

5.1 Preliminary Tests (Figures 19 and 20)

Preliminary tests (Test 1 to 6) were carried out on unleaded fuel with no oxygenates, to establish test procedures and to determine the branchpipe and application rates that should be used for the main tests.

These preliminary tests showed that the service's minimum recommended application rate of 4 lpm/m^2 produced acceptable results with AFFF and FFFP using the Chubb FB5X MKII branch. The 90% control times were less than one minute and 100% extinction was achieved by 4 minutes 30 seconds.

However, when FP was deployed under the same conditions it took over 12 minutes for 90% control and the test was terminated at 16 minutes without extinction. FP proved unable to extinguish the fire with the Chubb FB5X MKII even when the application rate was increased to the minimum recommended rate for FP of 5 lpm/m^2. It only proved possible to achieve successful extinction with FP when it was applied with an Angus 225H branch at an application rate of 5 lpm/m^2.

When FP was used at 4 lpm/m^2 with the Angus 225H, an improved 90% extinction time was achieved over the use of the Chubb FB5X branch at the same application rate, but further progress was not made until the tactics were changed to allow the foam stream to hit the front wall of the tray and thus push foam gently over the tray rim onto the fuel surface. The amount of foam reaching the surface was greatly reduced but the foam was more effective because it fell more gently onto the fuel surface. The whiter uncontaminated foam could be seen easily as it spread across the tray surface.

The tests confirmed the guidance in the DCO Letter 10/91 that FP must be used at a higher application rate than AFFF or FFFP.

5.2 Unleaded Petrol with no Oxygenates - Fuel 1 (Figures 21 and 22)

Tests 1 - 10 all used the same fuel but, as discussed above, Tests 1-6 were planned as preliminary tests to establish techniques and tactics. Tests 1,2 and 5 followed the same trials procedure as Tests 7 - 10 and so are included in these results in Figures 21 and 22.

Tests 3, 4 and 6 used FP and were used to explore the choice of application rate and branch for the main tests so these results are not included.

The results of the extinction tests are given in Figure 21 which records the 90% and 100% extinction times in minutes and seconds. The results of the burnback tests are given in Figure 22; the 25% and 100% burnback times are recorded.

AFFF and FFFP gave convincing extinction at 4 lpm/m² using the Chubb FB5X MkII. FP also gave satisfactory extinction used at 5 lpm/m² with the Angus 225H. The single test with AFFF-AR gave results similar to those of AFFF and FFFP.

The burnback tests using AFFF, FFFP and AFFF-AR produced similar results, with small flames developing over the foam surface and tray rim shortly after the burnback flame was applied. The foam blanket did resist a major burnback for several minutes before the flames quickly spread to the whole tray area. The performance of FP was much better with 25% burnback times in excess of 12 minutes.

5.3 Unleaded Fuel with Alcohols - Fuel 2 and Unleaded petrol with MTBE - Fuel 3 (Figures 23 and 24)

With Fuels 2 and 3, both AFFF and FFFP at 4 lpm/m² gave convincing control and extinction with a Chubb FB5X MKII Branch. FP at 5 lpm/m² with the Angus 225H Branch did not achieve 90% control until 11 minutes with Fuel 2 and 15 minutes with Fuel 3. The fire was only eventually extinguished after allowing the foam stream to hit the ground outside the tray and flow over the bund wall and gently onto the fuel surface. This tactic is referred to as indirect application and is equivalent to the use of front or back plate. The burnback test results were similar to Fuel 1 with minimal resistance from AFFF and FFFP; FP showed superior performance.

Only three tests are reported with Fuel 2 because of a branch malfunction on Test 11. In this test, about 30 seconds after foam was first applied to the tray, the branchmen noticed a change in the foam quality from the branch. The flowmeter readouts were observed and found to be reading the required flow. The foam properties measured after the test, showed that the expansion ratio was only 5 , which was lower than in the other results for these conditions. The change in the rate of extinction can be seen in the graph for Test 11 in Appendix B. Extinction times for this test were much longer than previous tests with AFFF.

After the test the flowmeters and all other equipment were checked and no problems or malfunctions were identified. The only explanation was that a partial blockage had occurred in the aspirating section of the branchpipe. Extensive testing was carried out with the branchpipe before the next test and this poor performance was never repeated.

A single test was carried out with Fuel 3 using FFFP and the Angus 225H branch at 4 lpm/m^2. This did not show significant change in the extinction performance but it did give improved burnback times. The significant change in the measured foam properties was that FFFP had a longer drainage time when used with the Angus Branch.

5.4 Medium Scale Tests - Figure 25

The 90% control times from the medium scale tests supported the results from 56 m^2 tests, AFFF and FFFP showing similar performance for extinction and burnback. However 100% extinction was not achieved because of small flames remaining around the tray rim that could not be extinguished with the fixed foam branchpipe. This is a known limitation of the proposed European Standard test.

It was only possible to test FP on the unleaded fuel with no oxygenates and although this gave a much longer 90% extinction time than AFFF or FFFP, it did achieve extinction.

The branchpipe used in the medium scale tests gave longer foam drainage times than with the Chubb branchpipe

5.5 Foam Properties.

The foam properties given in Table 4.

The use of the Angus Branchpipe showed an improved (longer) drainage time when used with FP and FFFP. The use of the Angus branchpipe with AFFF was not explored.

5.6 Temperatures.

5.6.1 Fuel Temperature.

The fuel was discharged from the tanker which had been parked outdoors. The fuel temperature ranged from a maximum of 19°C in

Test 13 to a minimum of 4.5°C in Test 15. Although it is desirable to control the fuel temperature , this is very difficult to achieve with 3000 litres of fuel per test.

5.6.2 Air Temperatures

The air temperatures ranged from 23.7°C to 14.8°C. These were relatively high for the UK, because of the good weather during the trials period.

5.6.3 Solution Temperatures.

The solution temperatures ranged from 19.4°C to 24.9°C. The temperature being influenced by the temperature of the water in the appliance tank or water dams and the temperature of the pump through which the water passed.

5.7 Flowrates.

The flowrates of the foam concentrate and solution to the branch were controlled and monitored by the pump operator. From Tests 11 onwards the flowrates were recorded on a datalogger every second and this showed accurate proporticning had been achieved.

5.8 Radiometers.

The radiometer records from one pair of radiometers are given in Appendix B. The second pair of radiometers gave similar results.

The extinction and burnback times quoted are generally those calculated from processing the radiometer results.

5.9 Fuel Analysis

The results of the fuel analysis are given in Table 5. The results from the analysis laboratory and those from the suppliers of the fuel are given. The results show the fuels had comparable volatility and broadly similar proportions of aromatic and aliphatic hydrocarbons.

6. DISCUSSION

6.1 Foam Types

The results indicate that there was no difficulty in extinguishing all three fuels tested using AFFF and FFFP with the Chubb FB5X MKII branch at the minimum recommended application rate of 4 lpm/m². The single test with AFFF-AR on Fuel 1, showed similar performance to AFFF and FFFP.

FP had to be used at 5 lpm/m², the minimum recommended rate for FP, and with the Angus branchpipe to extinguish the unleaded fuel (Fuel 1). With the other two fuel types, the 90% times were much longer than with the other foam concentrates and indirect application was required for extinction. The branchmen were never confident with the use of FP because of the flaring that occurred wherever the foam stream hit the foam surface.

FP was more successful when the foam stream was applied indirectly. This gave gentler application as would be achieved with a backplate, frontplate or objects which could be used to serve the same purpose. Gentle application is advocated by the fire service wherever possible.

The burnback times of FP were the longest showing that FP had better burnback resistance. However, care must be taken in comparing tests where the extinction times were very different, because the burning characteristics of the fuel change as it burns down, and because long application times and indirect applications allow a deep foam blanket to build up.

In selecting foam additives, brigades should consider the relative importance of extinguishing and burnback performance. FP has the better burnback performance. AFFF and FFFP have significantly better extinguishing performance.

From the results achieved with good quality AFFF and FFFP, there would appear to be no justification for using alcohol resistant type concentrates for petrol fires.

These tests do not assess the use of foam for large-scale tank fires. The tests are representative of an incident requiring the use of a small number of foam branchpipes.

Only primary aspirating branches were used. Test 11 had a malfunction of the branch and produced a low expansion ratio foam with poorer performance than when operating correctly.

6.2 Branchpipes

The tests have supported the pilot study results (Reference 6) and shown that with FP and FFFP the performance of the Chubb branchpipe is inferior to that of the Angus 225H. The use of the Angus Branchpipe with AFFF was not explored but it is reasonable to expect that this would also result in a better foam. The one test with the Angus 225H with FFFP did not show a significant change in extinction times but a superior burnback resulted. The foam properties showed the 225H gave an increase in expansion ratio but, more significantly, the drainage time was doubled.

Satisfactory performance with all the fuel types was achieved with the Chubb Branch when using AFFF and FFFP, but use of the Chubb branch with FP was poor.

6.3 Tactics of Foam Application

It was decided to apply foam to the fuel surface as gently as possible without the use of a backplate or frontplate. Direct application is the most testing condition likely to be experienced operationally because, in practice, there may be surfaces on to which the foam stream can be directed so that the foam flows more gently on to the fuel surface. The tests showed that AFFF and FFFP were more tolerant of direct application than FP.

After 95% extinction had been achieved, the final extinction was very much dependent on the tactics of the firefighter. When the remaining flames were attacked with the direct foam stream, this caused flaring. The recommended application rate is essential to bring the fire under control but, when small flames remain around the tray area, a gentler application, at a lower flow rate may prove more effective. The use of medium expansion foam may be useful at this stage because this does flow gently onto the foam surface and at this stage of the firefighting the limited throw of medium expansion would not be necessarily a restriction. It was not possible to explore these variations in tactics during these trials.

6.4 Use of a Water Base

These tests were the first large scale tests by FEU which did not use a water base. It was not possible within this project to explore experimentally the effect of this on extinction times.

6.5 Repeatability of Tests

Where tests have been repeated with the same branchpipe, concentrate and fuel there were variations in the results. A minimum of three tests employing the same conditions is ideally required to assess repeatability, although more are desirable. However, the size and cost of the tests impose practical limits. It was decided at the preliminary meetings between the Home Office and the petroleum industry to carry out 1 test only for each fuel type/foam type combination. One additional test was reserved to test for repeatability, if problems did not require that a test be discounted. More than 4 tests are reported with Fuel 1 because this fuel was used in the preliminary trials.

Wherever possible, test conditions and procedures were standardised. However, in large scale outdoor tests the temperatures and wind conditions cannot be controlled and these contribute to the variability of the tests.

6.6 Discussion on Equipment and Trials Ttechnique

6.6.1 Tray Design

The tray design proved satisfactory, however there was damage to the metal tray and the mastic used between the metal rim and the tray base.

The metal tray required re-welding on two occasions during the trials. The mastic was removed and another proprietary compound used for the last week of the tests. This again became damaged by the end of the tests but could be due to the compound not being cured for the recommended time due to the need to complete the trial series.

The height of the tray wall was not adequate and the tray was filled with foam during several tests. It is recommended that the wall is increased by 150mm before further tests.

A consequence of having a low tray rim is that there is little free area above the fuel to allow the branchmen to use the tray rim as a backplate.

6.6.2 Instrumentation.

The instrumentation proved satisfactory. This was the first time that FEU had used radiometers on outdoor trials of this size. The radiometers results provided quantitative results which supported the observers comments.

A problem with the radiometers was the background level would change with ambient light. A sapphire window can be used with this type radiometer and may eliminate the variation of background level.

The radiometers were cooled throughout the tests and although this did complicate the setting up it ensured that the radiometers operated within their calibrated range.

The data reduction technique used (Reference 10) did not require the absolute calibration of the radiometers, because the results are normalised to the radiation in the last seconds before application of foam.

The averaging of the two radiometers did seem to average out the effect of changes in the position of the plume with wind.

6.6.3 Video Equipment

The use of the Skystalk camera proved the most useful camera angle for data analysis. A second camera is highly desirable to supplement the Skystalk and with a field of view to cover the opposite side of the tray.

6.6.4 Burnback Test

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

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

There is scope for further consideration of a burnback test in which foam is applied to a fuel surface which has not been ignited. By controlling the foam solution flowrate and the time of foam application, a layer of foam could be built up which would be dependent on the foam characteristics and not influenced by the extinction performance. This would provide a more standard condition for the burnback test but could be criticised because there would be no hot metal surfaces to test the foam.

7. CONCLUSIONS

The trials have shown that, using AFFF and FFFP through a Chubb FB5X MKII branchpipe at 4 lpm/m², there was no difficulty in extinguishing all the fuels tested. No difficulty is expected with petrol formulations in the current standards using the Chubb FB5X MKII or Angus 225H branchpipes under these conditions.

FP only achieved extinction with the unleaded fuel with no oxygenates when used at the minimum recommended application rate of 5 lpm/m² and with an Angus 225H branchpipe. Extinction was not achieved with the other two fuels without using indirect application. The burnback performance of FP was better than that of AFFF and FFFP.

The tests have shown that foams applied with the Angus 225H have superior performance than when applied with the Chubb FB5X MKII.

In selecting foam additives, brigades should consider the relative importance of extinguishing and burnback performance. FP has the better burnback performance. AFFF and FFFP have significantly better extinguishing performance.

Providing that brigades follow the guidance in the Manual of Firemanship, as amended by the DCO Letter 10/91, no problems would be expected when using good quality AFFF or FFFP against petrol formulations permitted by current and likely future standards.

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10. ISO Tests Draft

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3. Autometric Pumps Ltd, Turkey Court, Ashford Road, Maidstone, Kent, ME14 5PP. Pump GP1/2/E.

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5. Piezometer tube

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Foam Type	Trade Name	Manufacturer
AFFF	Light Water	3M Chemicals Division, Manchester
AFFF-AR	Light Water ATC Plus	3M Chemicals Division Manchester
FFFP	Petroseal	Angus Fire Armour Limited, Thame, Oxfordshire
FP	FP70	Angus Fire Armour Limited Thame Oxfordshire

TABLE 1 : Details of additives used.

Test No.	Foam Type	Fuel Code	Application Rate	Branch	Temperature		Extinction Times			Burnback Times			
			lpm/m²		Air °C	Fuel °C	90% m : s	95% m : s	100% m : s	25% m : s	50% m : s	75% m : s	100%[1] m : s
1	AFFF	1	4	FB5X	17.9	11.5	0:53	0:56	3:09	3:16	3:21	3:31	4:32
2	FFFP	1	4	FB5X	24.9	17.5	0:58	1:04	4:30	3:05	3:13	3:30	3:54
3	FP	1	4	FB5X	16.5	11.5	12:16	No extinction		No Burnback test			
4	FP	1	4	225H	20.5	16.0	7:44	7:46	11:23	7:50	8:07	8:38	9:22
5	FP	1	5	225H	23.7	14.5	4:40	4:43	5:28	12:39	12:55	13:04	13:49
6	FP	1	5	FB5X	16.4	9.5	7:39	8:41	12:05	6:26	6:47	7:03	7:57
7	AFFF	1	4	FB5X	21.1	13.5	1:30	1:35	2:59	1:47	1:53	2:01	2:16
8	FFFP	1	4	FB5X	21.7	13.5	1:58	2:09	5.14	2:03	2:19	2:40	2:53
9	AFFF-AR	1	4	FB5X	14 8	12.5	1:08	1:17	3.50	3:19	3:31	4:42	4:46
10	FP	1	5	225H	23.0	19.0	1:33		5:26	14:58	15:10	15:29	16:02
11	AFFF	2	4	FB5X	18.0	17.5	3:51	4:06	13:26	2:42	2:51	3:09	3:23
12	AFFF	2	4	FB5X	22 4	19.0	1:10	1:16	5:38	2:19	2:29	2:45	2:52
13	FFFP	2	4	FB5X	14.3	7.0	2:02	2:15	5:13	1:11	1:54	2:16	2:30
14	FP	2	5	225H	14.0	7.5	11:00	11:13	14:24	9:10	9:49	10:06	10:25
15	AFFF	3	4	FB5X	15.4	4.5	0:55	0:58	2:15	1:50	1:57	2:02	2:31
16	FFFP	3	4	FB5X	20.6	9	1:15	1:18	4:24	1:33	1:46	1:54	2:13
17	FP	3	5	225H	15.6	5	9:28	9:53	10:49	15:31	15:54	16:20	16:52
18	FFFP	3	4	225H	18.5	11	1:01	1:13	4:39	7:28	7:42	7:50	7:58

1. 100% or maximum burnback

TABLE 2 : Results of tests : extinction and burnback times

Test No	Date	Time	Fuel Code	Temperatures in °C			Humidity	Wind	
				Fuel	Solution	Air	%	Speed in m/s	Direction °
1	2/9/91	12:13	1	11.5	23.8	17.9	83	3.4	350
2	2/9/91	15:03	1	17.5	25.2	24.9	59	3.2	325
3	3/9/91	10:13	1	11.5	23.1	16.5	82	4.0	100
4	3/9/91	12:10	1	16.0	22.7	20.5	67	3.8	45
5	3/9/91	15:23	1	14.5	25.6	23.7	53	4.2	25
6	4/9/91	10:54	1	9.5	22.1	16.4	82	4.0	20
7	4/9/91	13:53	1	13.5	22.9	21.1	68	3.8	45
8	4/9/91	15:17	1	13.5	22.9	21.7	67	3.6	30
9	5/9/91	10:38	1	12.5	21.2	14.8	94	1.6	330
10	5/9/91	16:05	1	19.0	22.4	23.0	64	2.3	338
11	10/9/91	10:16	2	17.5	22.8	18.0	72	0.7	198
12	10/9/91	14:00	2	19.0	24.8	22.4	51	2.4	256
13	11/9/91	10:22	2	7 0	21.1	14.3	89	3.4	46
14	11/9/91	12:14	2	7.5	21.0	14.0	87	4.2	59
15	17/9/91	9:23	3	4.5	19.4	15.4	75	6.7	251
16	17/9/91	15:02	3	9.0	22.8	20.6	56	5.5	280
17	18/9/91	9:54	3	5.0	20.8	15.6	94	4.5	212
18	18/9/91	2:20	3	11.0	22.2	18.5	59	4.7	302

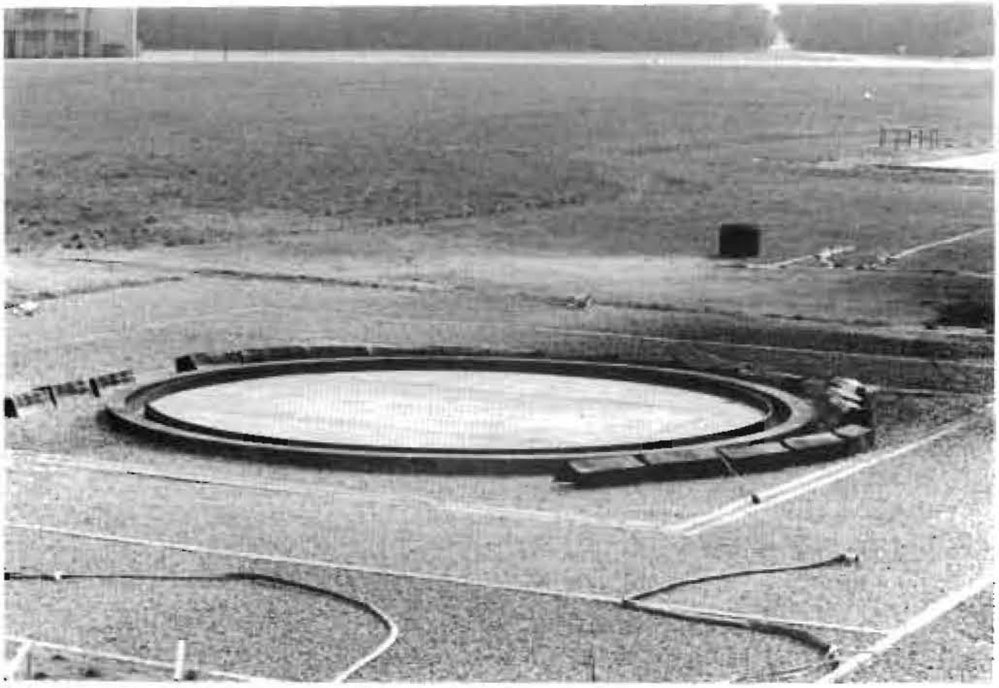
TABLE 3: RESULTS : Temperatures, wind data and humidity

Test No	Foam Type	Batch No	Application rate lpm/m2	Branch	Temperatures			Expansion Ratio	Drainage Time
					Air °C	Solution °C	Foam °C		m : s
1	AFFF	2376	4	FB5X	17.9	23.8		18.7	1:40
2	FFFP	1050/14/K	4	FB5X	24.9	25.2		12.9	0:34
3	FP	1030/22/k	4	FB5X	16.5	23.1	-	9.8	1:00
4	FP	1030/22/k	4	225H	20.5	22.7	23	11.6	3:15
5	FP	1030/22/k	5	225H	23.7	25.6	24	10.6	4.20
6	FP	1030/22/k	5	FB5X	16.4	22.1	19	9.4	2:45
7	AFFF	2376	4	FB5X	21.1	22.9	25	18.3	1:22
8	FFFP	1050/14/K	4	FB5X	21.7	22.9	23	12.9	1:00
9	AFFF-AR	2413	4	FB5X	14.8	21.2	18	14.2	3.15
10	FP	1030/22/k	5	225H	23.0	22.4	23	10.4	4:15
11	AFFF	2376	4	FB5X	18.0	22.8	20	5	
12	AFFF	2376	4	FB5X	22.4	24.8	24	14.3	1:50
13	FFFP	1050/14/K	4	FB5X	14.3	21.1	16	10.8	0:59
14	FP	1030/40/K	5	225H	14.0	21	18	10.8	4:45
15	AFFF	2376	4	FB5X	15.4	19.4	18	16.9	2:00
16	FFFP	1050/14/K	4	FB5X	20.6	22.8	21	10.8	1:04
17	FP	1030/10/K	5	225H	15.6	20.8	18	10.1	5;10
18	FFFP	1050/14/K	4	225H	18.5	22.2	21	13.7	2:15

TABLE 4 : Foam properties

TEST	METHOD	RESULTS					
Sample No :		Fuel 1		Fuel 2		Fuel 3	
		Lab	Fuel Supplier	Lab	Fuel Supplier	Lab	Fuel Supplier
Distillation, °C	IP123						
IBP °C		22.0	32	35.0	29	32.0	
10% Rec @ °C		48.5		45.5		44.0	
20% Rec @ °C		55.5		56.0		51.0	
30% Rec @ °C		70.0		76.0		58.5	
40% Rec @ °C		90.0		92.0		67.5	
50% Rec @ °C		107.0		106.5		77.5	
60% Rec @ °C		120.0		118.5		91.5	
70% Rec @ °C		131.5		130.0		104.0	
80% Rec @ °C		141.0		144.5		134.5	
90% Rec @ °C		168.0		163.0		159.0	
FBP °C		204.0	203	197.5	197	194.0	201
Evaporated @ 70°C, % vol		30.0	37	38.0	31	43.5	44
Evaporated @ 100°C, % vol		46.0	52	46.0	49	65.0	66
Evaporated @ 180°C, % vol		93.5		95.5	96	95.0	97
Recovery, % vol		97.0		98.0		97.0	
Residue, % vol		1.0		1.0		1.0	
Loss, % vol		2.0		1.0		2.0	
Oxygenates, % vol (as MTBE)	G.C.*	<1.0		-		17.5	15
Methanol, % vol		-		2.7		-	
Tert. Butanol, % vol		-		2.5		-	
Benzene, % vol	G.C.*	1.3		1.8		3.0	
Reid Vapour Pressure, kPa	IP69	88.5	95	89.5	94	91.8	92
FLA	IP156						
Aromatics, % vol		38.2		34.4	37	45.7	37
Olefins, % vol		12.4		17.2	16	33.8	10
Saturates, % vol		49.4		48.4	47	20.5	
Water Reaction	IP289						
Volume Change, ml		Nil		3.0		1.0	
Interface		1		1		1	
Appearance		1		1		1	

TABLE 5 - RESULTS OF THE FUEL ANALYSIS



C/1318/91

Figure 1: General View of Test Site

C/1390/91

Figure 2: Portable Dams

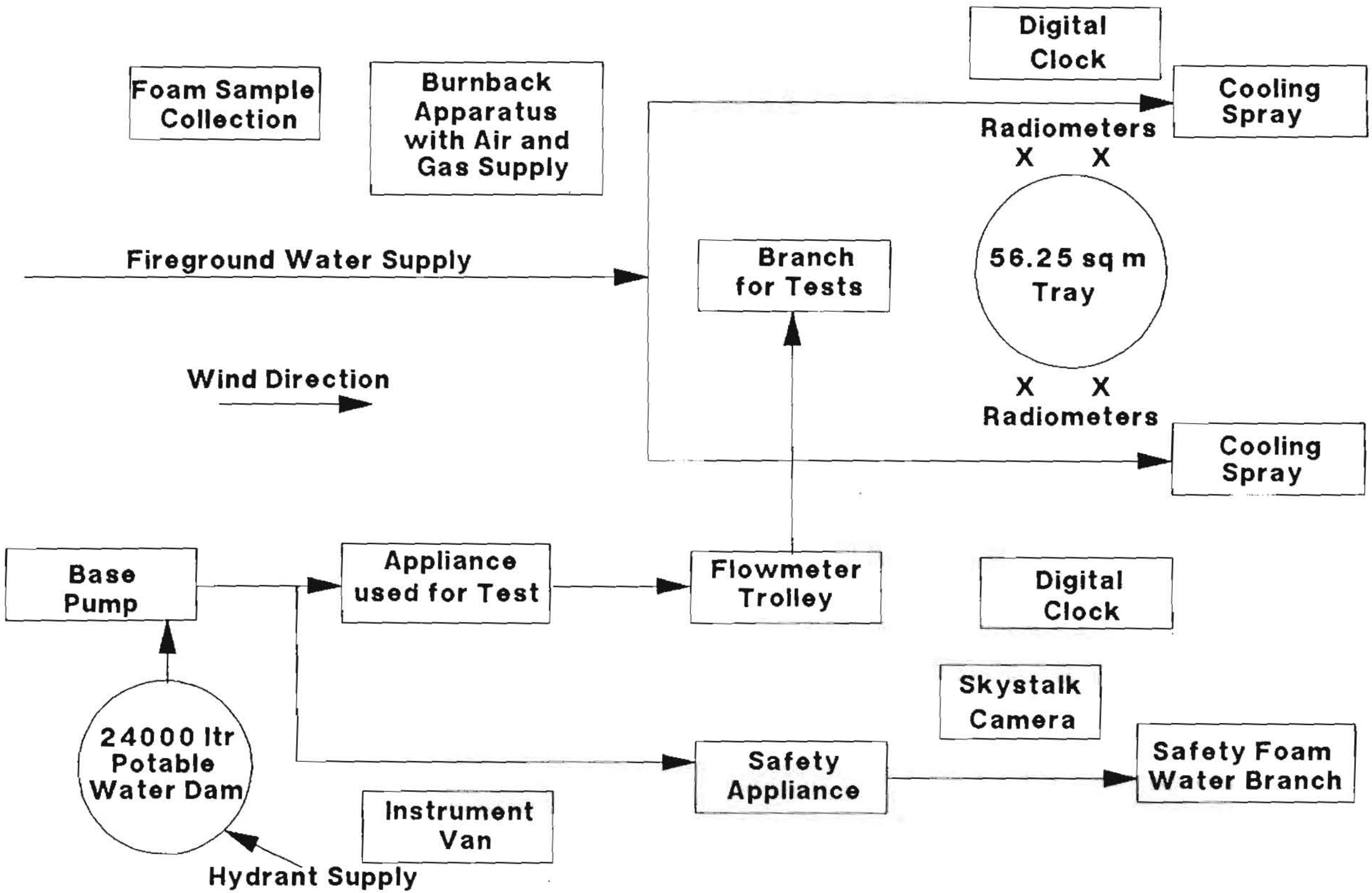


Figure 3: Layout of Appliances and Equipment

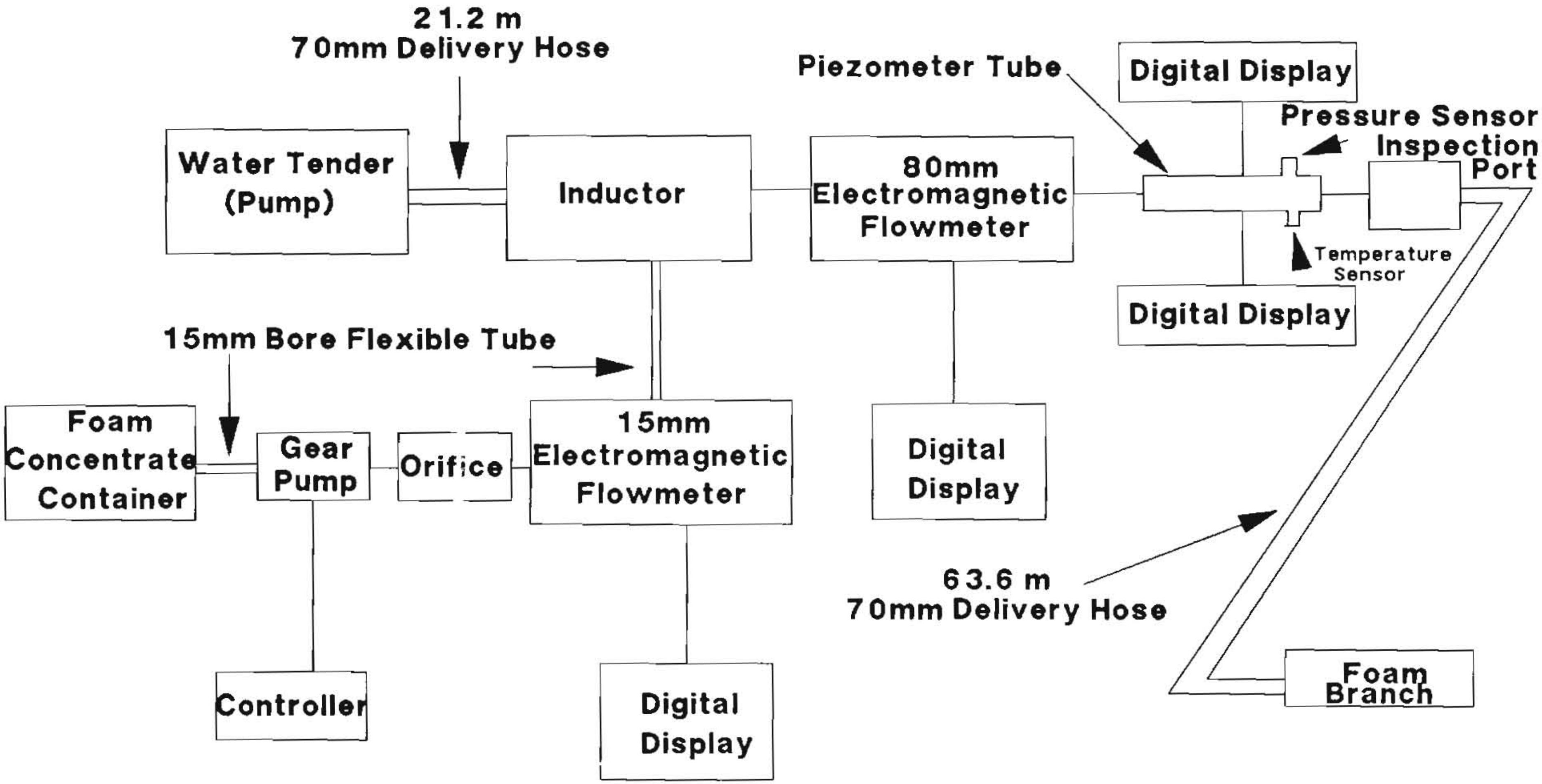
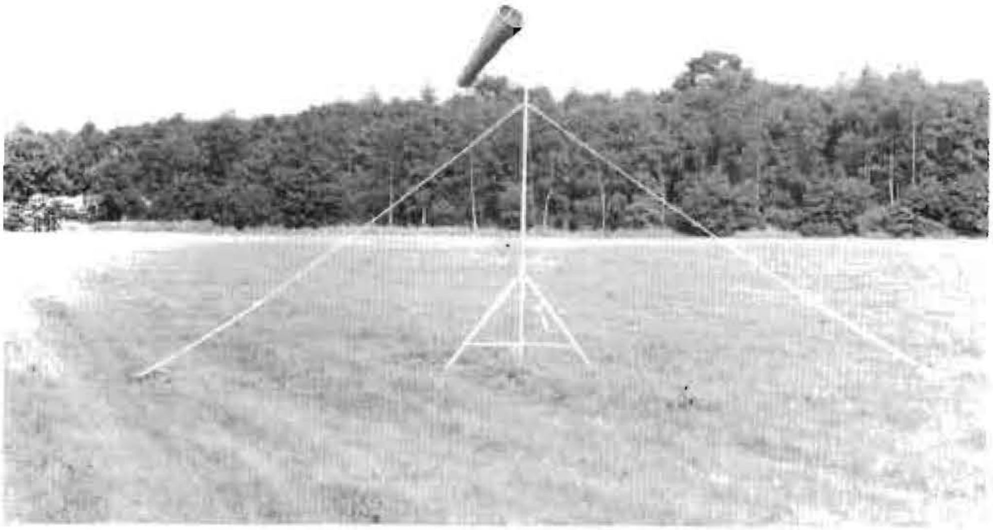


Figure 4: Hydraulic arrangement for 56.25 sq m Petrol fires

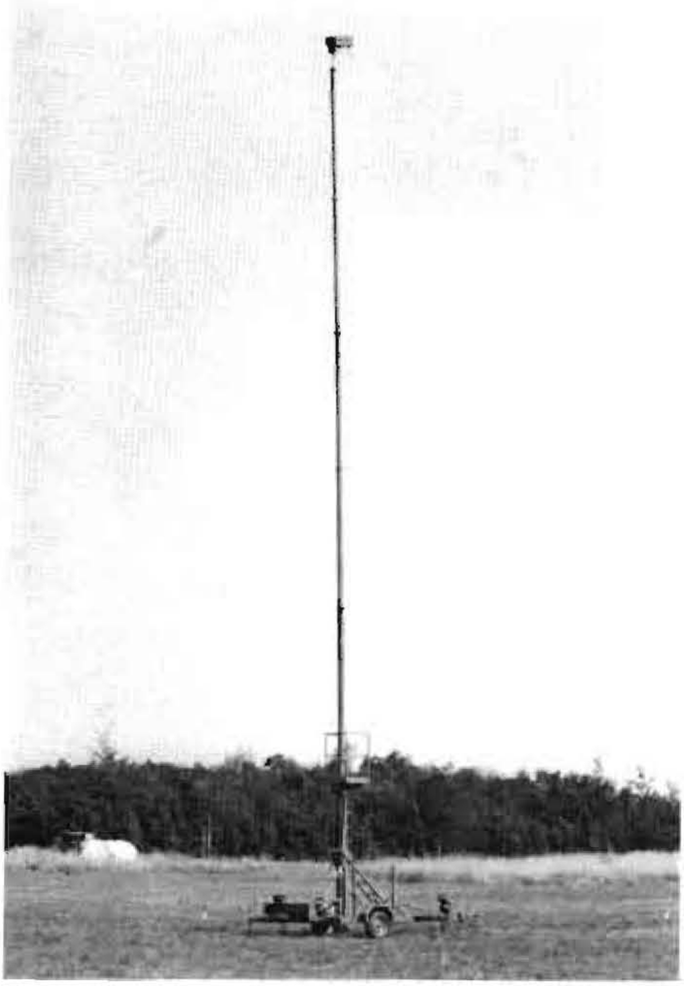
C/1435/91
Figure 5: Flowmeter and indicators mounted on trolley

C/1314/91
Figure 6: Wind speed, wind direction, air temperature and humidity sensors



C/1297/91

Figure 7: Windsock



C/1310/91

Figure 8: Skystalk Mast

B 142/92

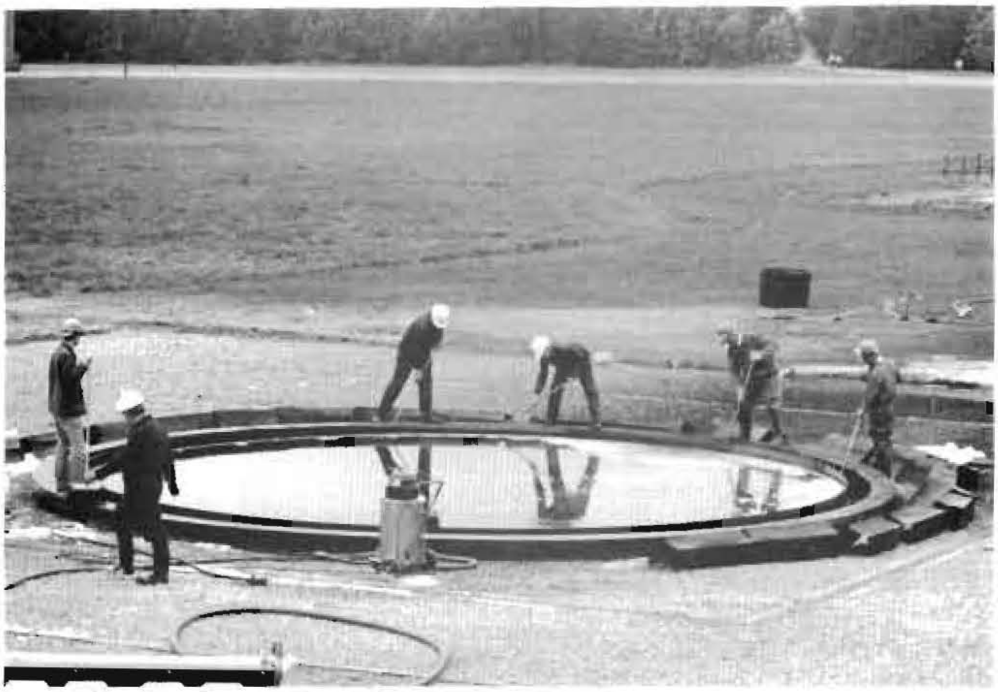
Figure 9: Camera mounted on Skystalk Mast

1486/91

Figure 10: Two radiometers mounted on masts

C 1473/91

Figure 11: Instrument Van



C 1347/91

Figure 12: Tray cleaning in progress

C 1492/91

Figure 13: Petrol being transferred to the tray

C 1400/91

Figure 14: General view of fire during preburn

C 1497/91

Figure 15: Foam stream being applied to fire

C 1395/91

Figure 16: Foam sample collection

1259/91

Figure 17: Burnback rig in position for burnback test

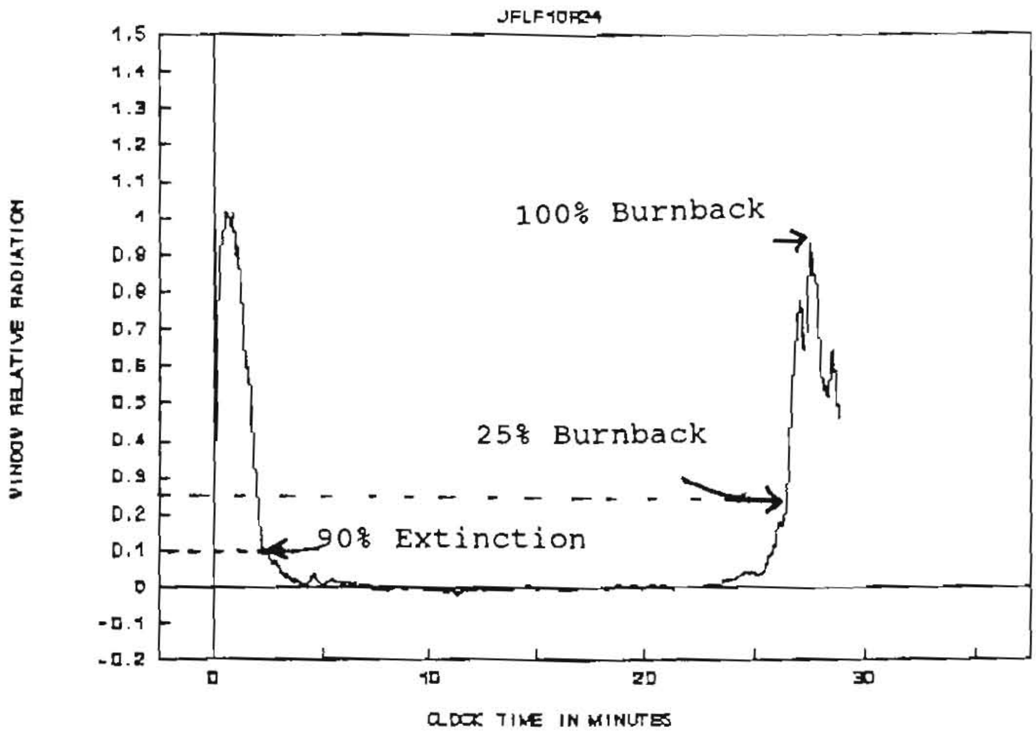


Figure 18 : Example of a Radiometer Record

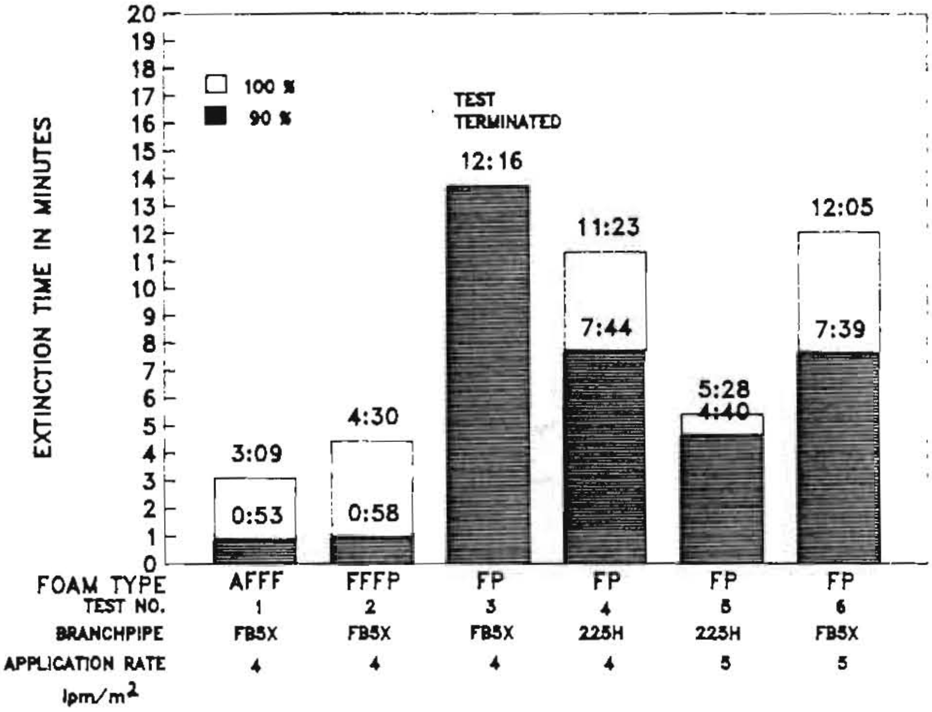


Figure 19 : Results of preliminary tests - 90% and 100% extinction times

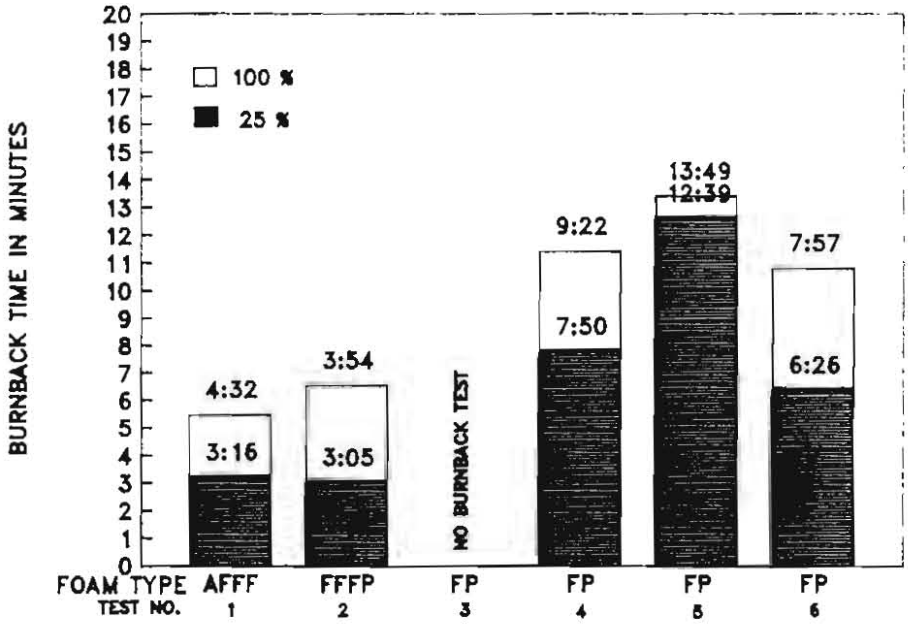


Figure 20 : Results of preliminary tests - 25% and 100% burnback times

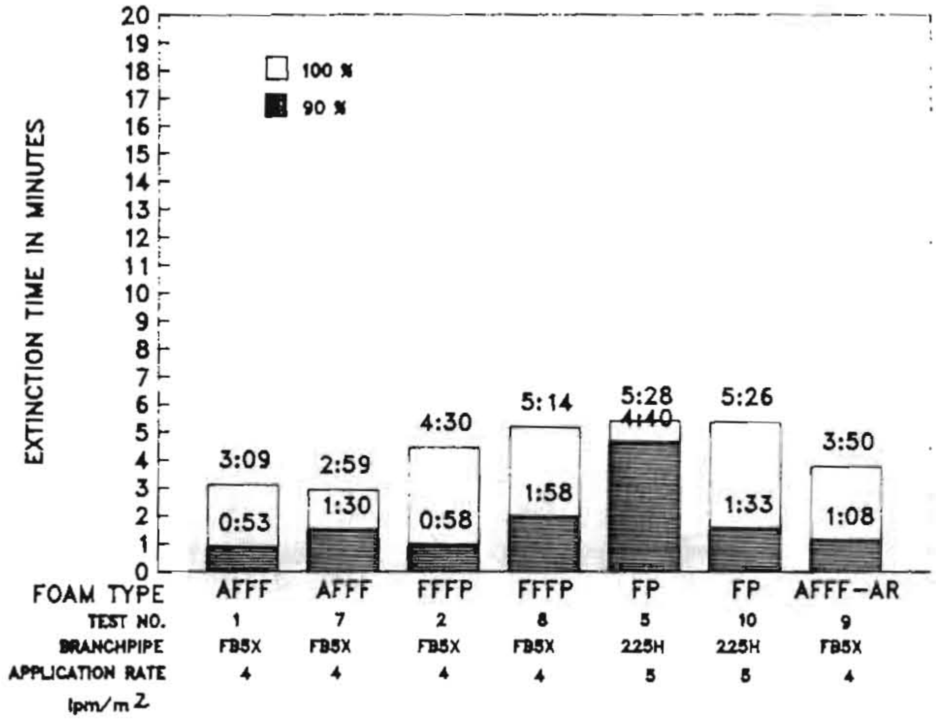


Figure 21 : Results of tests with Fuel 1 - 90% and 100% extinction times

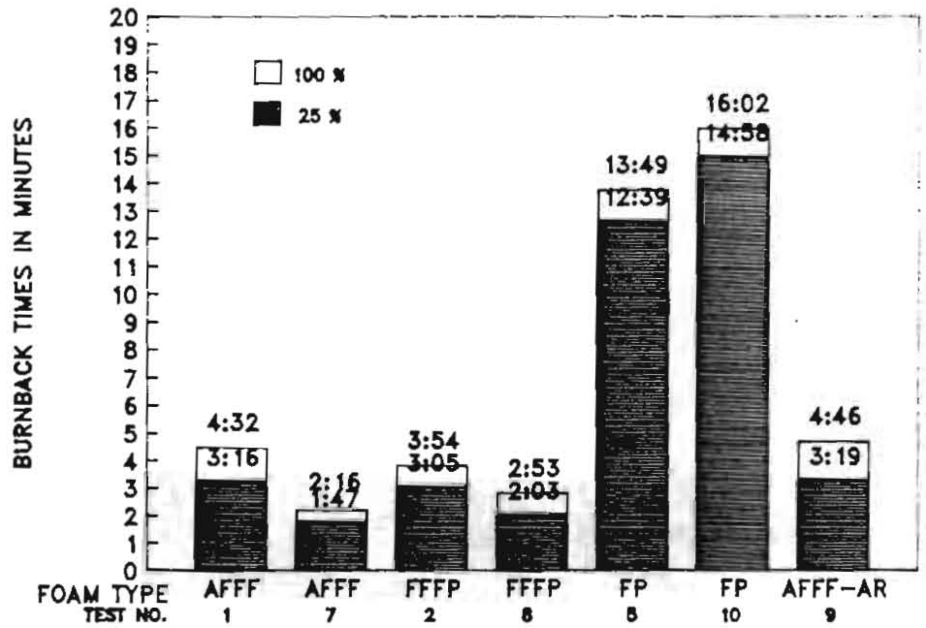


Figure 22 : Results of tests with Fuel 1 - 25% and 100% Burnback times

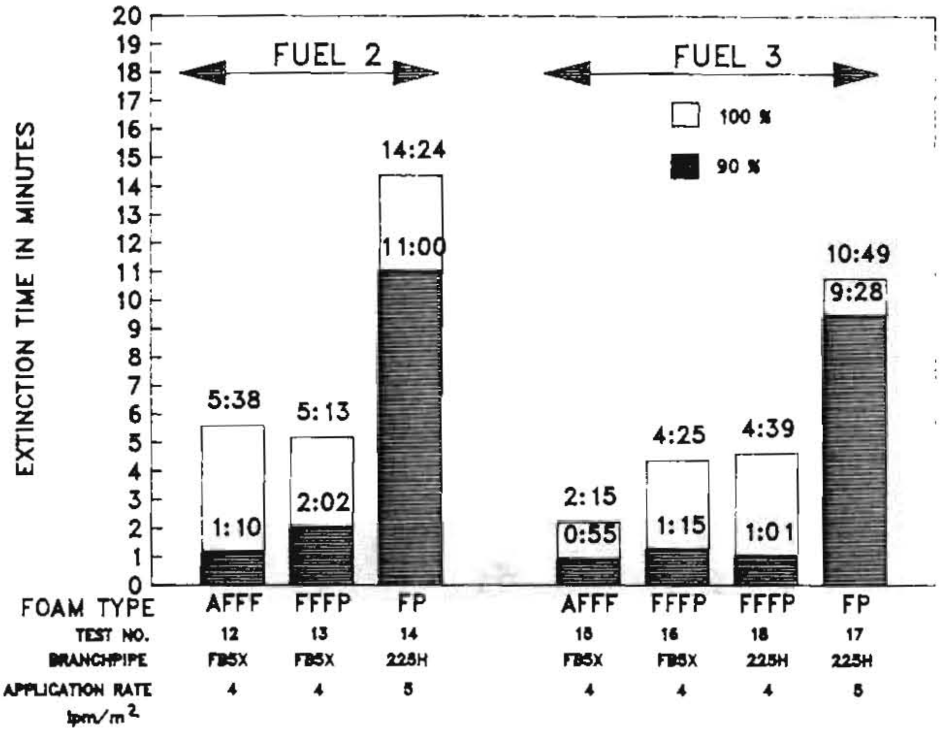


Figure 23 : Results of tests with Fuels 2 and 3 - 90% and 100% extinction times

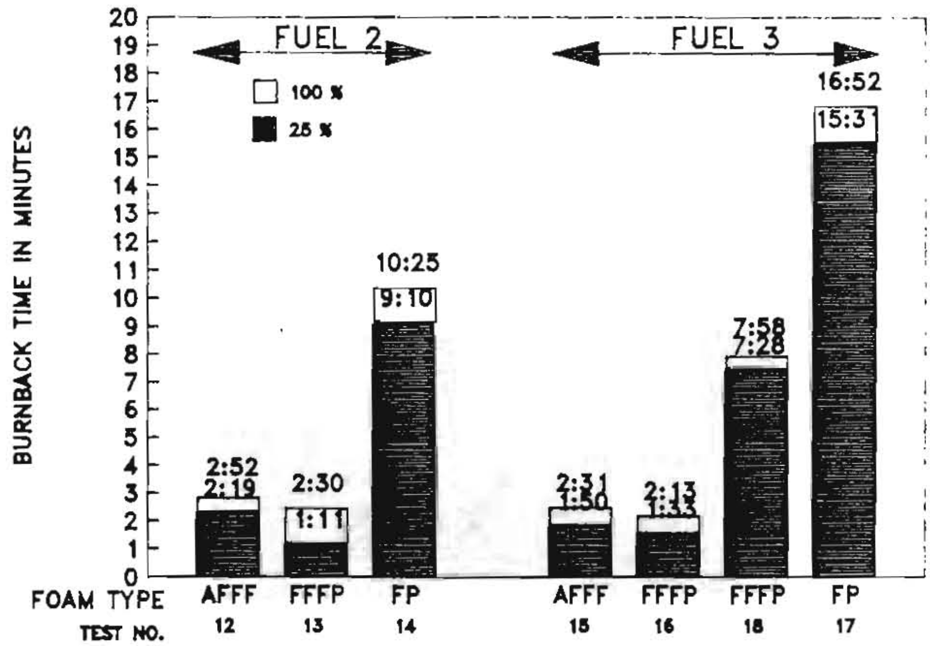


Figure 24 : Results of tests with Fuels 2 and 3 - 25% and 100% burnback times

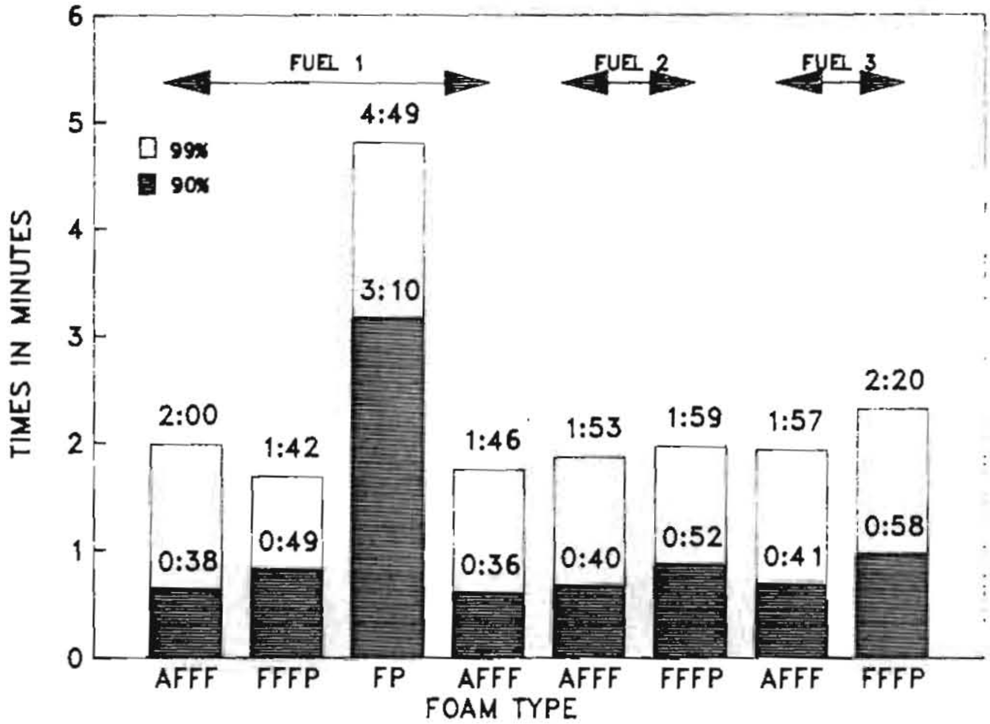


Figure 25 : Results of Medium Scale Trials - 90% and 99% extinction times

APPENDIX A

SAFETY INSTRUCTIONS FOR TRAY FIRE TESTS: September 1991

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SAFETY INSTRUCTIONS FOR TRAY FIRE TESTS: September 1991

Introduction

There is a requirement to establish, by means of large-scale tests, whether the stability of foam blankets is undermined by the presence of high levels of oxygenates in unleaded petrol formulations.

Trials are to commence on the 2nd September 1991.

The tests will be carried out on the fireground of the Fire Service College, in the FEU 56.25 m^2 circular tray using 3000 litres of petrol as fuel for each test.

Before each test, the tray will be thoroughly cleaned out. All equipment will be operated to check correct functioning. When preparations are complete, then the petrol tanker will be driven to a point on the runway alongside the tray and the fuel transferred to the open tray. The fuel will be ignited by an electrical detonator, then after a one-minute preburn the fire will be extinguished with the foam under test. A burn back test will then be carried out.

The proposed test plan is as follows:

Preliminary tests

6 tests using 3000 litres of fuel per test will be carried out to commission the test facility and prepare for the main tests.

Main Tests

12 tests will be carried out each using 3000 litres of petrol as fuel. 3 fuel types will be tested, i,e the 12 tests are made up of 4 tests with each fuel type.

The fuel types will be

a. unleaded petrol with no oxygenates
b. unleaded petrol with 3% Methanol and 2% TBA
c. unleaded petrol with 15% MTBE

The following instructions concern the safety aspects of these tests. These instructions must be complied with throughout the test series.

THE "HEALTH AND SAFETY AT WORK POLICY STATEMENT AND SAFETY INSTRUCTIONS FOR THE FIRE EXPERIMENTAL UNIT" ISSUE 5 SEPTEMBER 1989 MUST BE READ IN CONJUNCTION WITH THESE INSTRUCTIONS.
SAFETY PROCEDURE

1. General

1.1 Personnel Directly Involved in the Fire Tests

The trial will be directed by J A Foster. The Fire Officer, DO M Freeman will be responsible for matters concerned with fire safety, the senior FEU officer present will be in charge overall.
The following personnel will be involved
J Foster - Project Officer, observer
Dr M Thomas - Head of FEU, observer.
B Johnson - Observer, handling of detonators.
J Price - Pump operator and foam concentrate handler.
K Bosley - Instrumentation van
J Rimen- Burnback Rig

DO Freeman - Senior FEU Fire Officer
SO Fay - FEU Fire Officer

Local Authority Firefighters will provide the Safety cover.

Other contract personnel may supplement the FEU team.

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

1.2 Visitors and Casual Observers.

These are personnel who are not directly involved in the fire tests. These people may or may not be members of the Home Office. In all cases these must remain in the allocated areas during fuel handling and the fire tests.

They will wear Safety Helmets at all times on the fireground.

1.3. Fuel for the tests

The fuel types will be:
a. unleaded petrol with no oxygenates
b. unleaded petrol with 3% Methanol and 2% TBA
c. unleaded petrol with 15% MTBE

The Health and Safety Data Sheet for Petrol, MTBE , Methanol and TBA,will be found in the Health and Safety Data Sheet Library in the FEU Information Desk.

1.4. Foam Concentrates

The following types of foam concentrates will be used during the fire tests.

AFFF--Light Water
FFFP-Petroseal

FFFP-AR (Alcoseal) and AFFF-AR (ATC Plus) may be included in the preliminary tests.

The Health and Safety Data Sheets for these foam concentrates can be found in the Health and Safety Data Sheet Library (in the FEU Information Desk). All personnel involved in the trial should carefully read these safety data sheets.

1.5 Safety Fire Appliance.

A Fire Appliance (Registration No VLU 208G), equipped with a diffuser branch, an inline inductor, foam branchpipe and a supply of foam concentrate, will be standing-by throughout the tests. The pump will be running and manned at all times during the transfer of fuel to the tray and the fire tests. The branches will be tested before any of these operations commence.

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

1.6 Test area

The area of the runway used for the tests will be marked with cones.

Personnel involved in the tests should contact J Foster before leaving the test area.

1.7 No Smoking

No **smoking** will be allowed in the vicinity of the test site throughout the tests.

1.8 Emergency Procedures

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

A portable phone will be available to summon assistance if necessary.

1.10 Filtered air supply

A filtered air supply unit will be available to the pump operators. This will be used if it is necessary for them to operate in smoke for a short period.

2. Transfer of fuel to the tray

2.1 The tray will be cleaned out by scrubbing with brooms and potable water. Contaminated water will be drained via the valved outlet. After a final wash with clean water, the surface will be dried as far as possible using squeegees or a wet vacuum cleaner.

2.2 The drain valves will be closed.

2.3 Water will be poured into the area between the metal tray rim and the outer concrete bund.

2.4 When all equipment is deployed and checked, fuelling will commence. Each test requires 3,000 litres of petrol.

2.5 Whilst the fuel is being transferred, the pump operator (for the appliance to be used for the test) will ensure foam concentrate is available and pump is primed and the foam branch is connected to the hose.

2.6 Radio's will not be used during fuel handling.

2.7 The petrol tanker will be driven to a position upwind of the tray on the runway by the tanker driver. The roadway in front of the tanker must be kept clear at all times.

2.8 Personnel not directly involved in this operation should be standing behind barriers an appropriate distance upwind of the tray.

2.9 A Fire Officer will take charge of the safety fire appliance and will stand by with appropriate equipment to deal with any incidents during the fuel transfer to the tray and the whole of the fire tests.

2.10 Three or four lengths of 3" petrol hose will be connected from the tanker and into the tray.

2.11 The tanker, petrol hose and metal ring will be earthed to an earth spike in the ground. The tanker driver will do this operation with the assistance of a Fire Officer or member of FEU.

2.12 The valve on the tanker will be opened and petrol transferred by gravity into the tray. If possible an appropriate flowmeter will be used to measure the fuel volume, otherwise a dip stick in the tanker will be used.

2.13 When the required quantity of fuel has been discharged, the valve on the tanker will be closed. The petrol delivery hose will be underrun towards the tray. The end of the hose will be withdrawn from the tray and capped. The hose will be disconnected from the tanker and capped.

2.14 The tanker and hose earth will be removed, and the tanker driven away from the test site.

2.15 The petrol hose will be removed from the test site to a marked area on the opposite of the runway. (This is preferred to restowing on the tanker to save time at this critical point in the trials).

2.16 When the tanker is off the site, an electrical detonator will be placed over the tray edge by a person wearing protective clothing including helmet with visor. This person should be in possession of the key for the firing box.

2.17 The earth connection to the tray rim will be removed.

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

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

2.20 The large digital clocks will be preset to 99-00. The following sequence will follow.

Clock time	Action
	Start Instrumentation
99-00	Clock started
00-00	Fire ignited
00-00	Solution fed to branch
01-00	Foam applied to fire

After 100% extinction foaming will be continued for 30 secs.

On direction of the trials director, the burnback torch will be lit.

The aim is to apply the burnback torch to the foam 5 mins. after 100% extinction.

When the burnback is well developed, water will be poured into the tray and all the fuel allowed to burn off.

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

2.22 The firefighting hoses will be flushed out with clean water after each test.

2.23 These procedures will be repeated for subsequent tests.

8 Tanker Storage Area.

This refers to the area to be used for overnight storage of the tanker and fuel.

8.1 The tanker storage site will be not less than 20ft from any building or boundary.

8.2 The site will be either bunded by a retaining wall or in a depression in the ground.

8.3 The storage site will be not more than 150ft from a source of water, either a hydrant or an EWS.

8.4 Two 9kg dry powder extinguishers will be provided either on the tanker or adjacent to the tanker unit at all times.

8.5 Notices 'PETROLEUM SPIRIT - HIGHLY INFLAMMABLE - NO SMOKING' will be displayed.

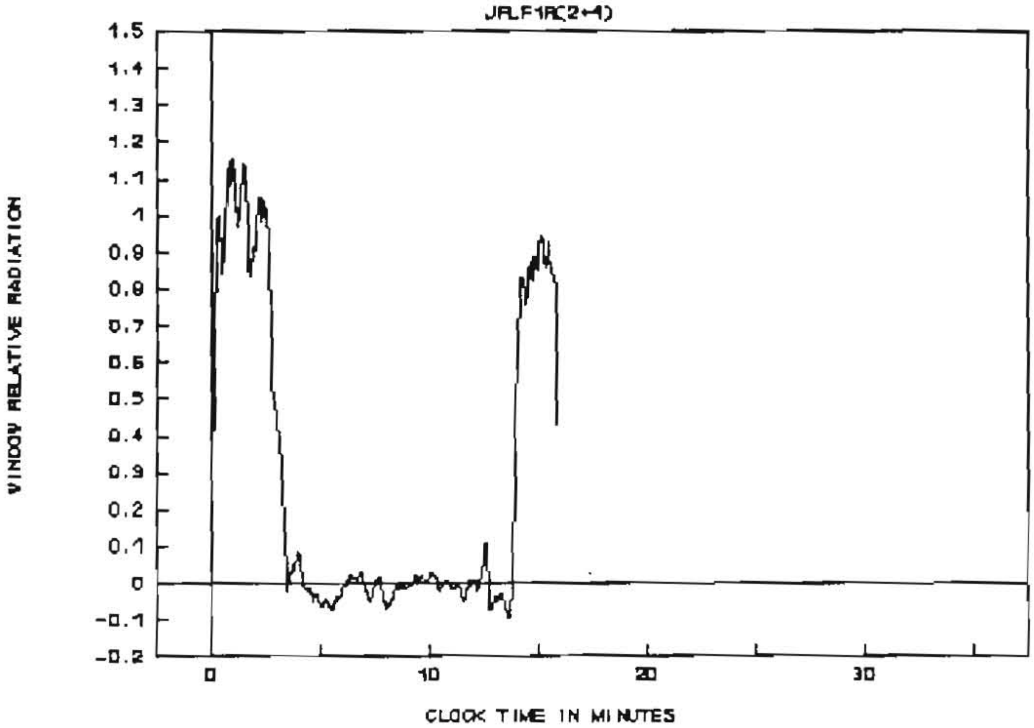
8.6 A fence not less than 7ft 6 inches of the unclimable type will be provided around the tanker site.

APPENDIX B - Detailed notes of fire tests

Test Number 1 **Additive** AFFF

Branch Chubb FB5X MKII **Fuel Code** 1
Weather Hazy Sunshine. Wind 2-3 m/s

Clock Time min :sec	Time from application of foam min : sec	Observations
0 : 0		Ignition
2 : 30	0 : 0	Foam stream applied to centre of tray
2 : 42	0 : 12	Foam blanket visible over 10% of tray area
3 : 03	**0 : 53**	**90% Extinction**
3 : 06	0 : 56	95% Extinction
3 : 03	1 : 03	Foam stream directed at flames around the rim. Flared up at impact point.
3 : 50	1 : 20	Flames around 50% of rim only. Flaring where-ever flames hit by foam stream.
3 : 57	1 : 27	Flames around 75% of tray rim
4 : 30	2 : 00	Gentler foam application attempted by elevating the branchpipe.
4 : 36	3 : 06	Branchmen moved in.
5 : 39	**3 : 09**	**100% Extinction**
6 : 09	3 : 39	Foam off tray
	Time from start of burnback min : sec	
10 : 39	0	Burnback flame on to tray
10 : 40		Flames around rim
11 : 30	0 : 51	Some flames around 75% of tray rim.
12 : 16	1 : 37	Burnback flame removed. Small flames over 10% of tray area.
13 : 14	2 : 35	Flames reduced to 25% rim fire.
13 : 30	2 : 51	10% of tray area on upwind side, .ree of a foam blanket but with no flames
13 :46	3 :07	Area free of foam ignited
13 : 55	3 : 16	25% Burnback
14 : 00	3 : 21	50% Burnback
14 :10	3 : 31	75% Burnback
15 : 11	4 : 32	100% Burnback



Graph of Window Relative Radiation v Time

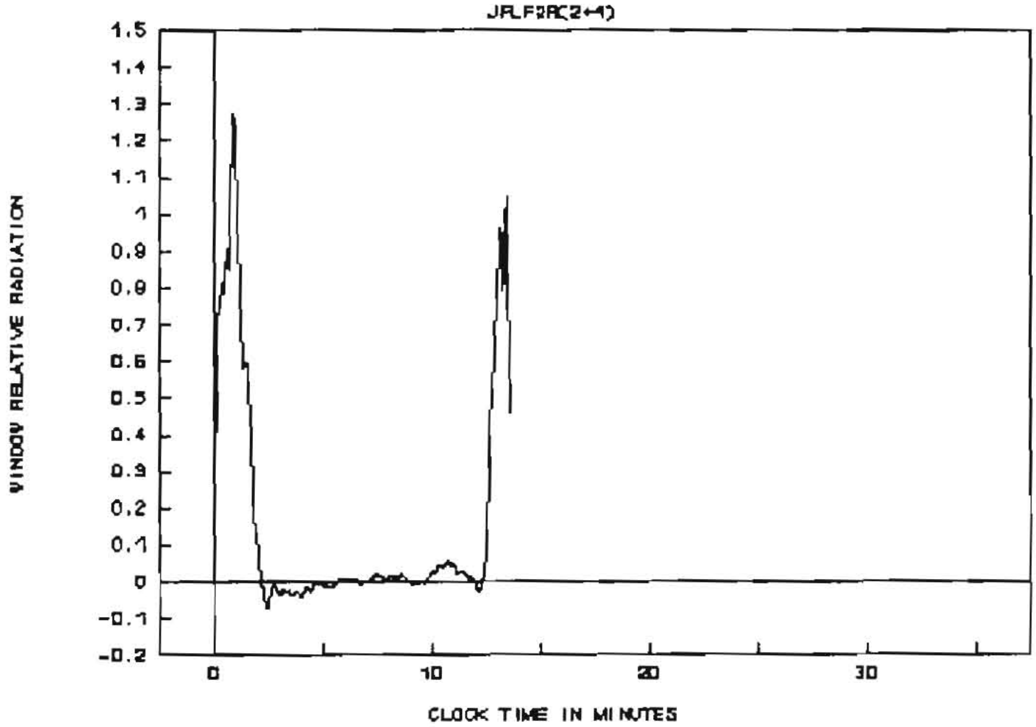
Test Number 2 **Additive FFFP**

Branch Chubb FB5X MKII **FEU Fuel Code 1**

Weather Sunny and hot

Clock Time min :sec	Time from application of foam min : sec	Observations
0 :00		Ignition. Plume angle 25 degrees.
1 : 01	0 : 0	Foam stream applied to tray
1 : 20	0 : 19	Some foam missing tray
1 : 26	0 : 25	Branchman adjusted foam branch to direct bulk foam to the tray
1 : 30	1 : 29	Foam blanket visible over 30% of tray area.
1 : 59	**0 : 58**	**90% extinction**
2 : 04	1 : 04	**95% Extinction**
2 : 16	2 : 15	Flames around 30% rim only Where foam stream hits surface, flaring occurred
2 : 20	2 : 19	Gentler foam application attempted by elevating branchpipe and directing stream around across the tray
2 : 32	2 : 31	Tray fire nearly extinguished
2 : 40	2 : 39	Flames re-established on upwind rim
2 : 50	2 : 49	Most of foam missing tray in attempt to apply gently
3 : 17	3 : 16	Only small flames on upwind and downwind rim
3 : 58	3 : 57	Downwind flames extinguished but difficulty in extinguishing flames on upwind rim
4 : 31	4 : 30	**100% Extinction**
5 : 01	5 : 00	Foam off tray
	Time from start of burnback	Test 2
9 : 31	0 : 0	Burnback flame to the tray. Rim fire immediately
9 : 53	0:18	Flames around 75% of rim
9 : 59	0:24	Fire above drain outside tray
10 : 27	0:56	Burnback flame removed
10: 36	1:05	Sustained fire over 5% of area
11 : 12	1:41	Flames reduced to only 1 m^2 fire and rim fire.
11 : 20	1:49	Only small flames in tray, flame sin outer rim.
12 : 05	2:34	25% area free of foam blanket

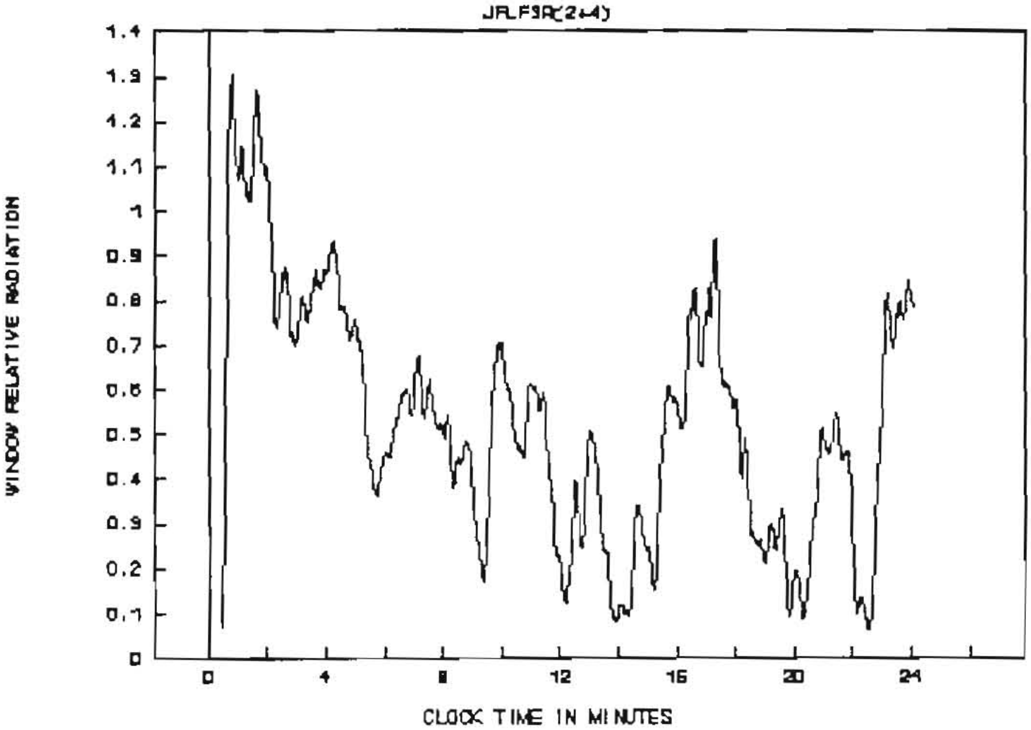
12:36	3:05	**25% Burnback**
12:44	3:13	**50% Burnback**
13:01	3:30	**75% Burnback**
13:25	3:54	**100% Burnback**



Test Number 3 **Additive** FP70

Branch Chubb FB5X MKII **FEU Fuel Code** 1 **Weather** Overcast

Clock Time min : sec	**Time from application of foam.** min : sec	**Observations**
0:30		Ignition
1:31	0:00	Foam on
1:32	0:01	Foam stream stationary
2:00	0:29	Foam blanket visible on 20% of surface
3:15	1:44	Some foam falling short
3:30	1:59	Branchmen move in
4:20	2:49	Foam blanket visible on 60% of surface
5:20	3:49	40% extinction
6:37	5:06	Fire increased to 40% extinction
7:18	5:47	Foam stream moved across tray surface
8:10	6:39	Foam branch elevated to attempt a more gentle application. Wherever foam stream strikes the fuel surface, flaming occurred
9:50	8:24	30% extinction then fire increases
10:45	9:14	Branchmen move in
12:07	10:36	85% extinction
13:47	12:16	**90% extinction**
13:54	12:23	99% extinction, flames around 60% of rim
14:03	12:32	Flames from centre of tray
16:07	15:36	Foam off tray. Allowed to burnback
16:16	15:44	Water sprayed into tray


JRLF3R(2+4)
WINDOW RELATIVE RADIATION
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
4
8
12
16
20
24
CLOCK TIME IN MINUTES

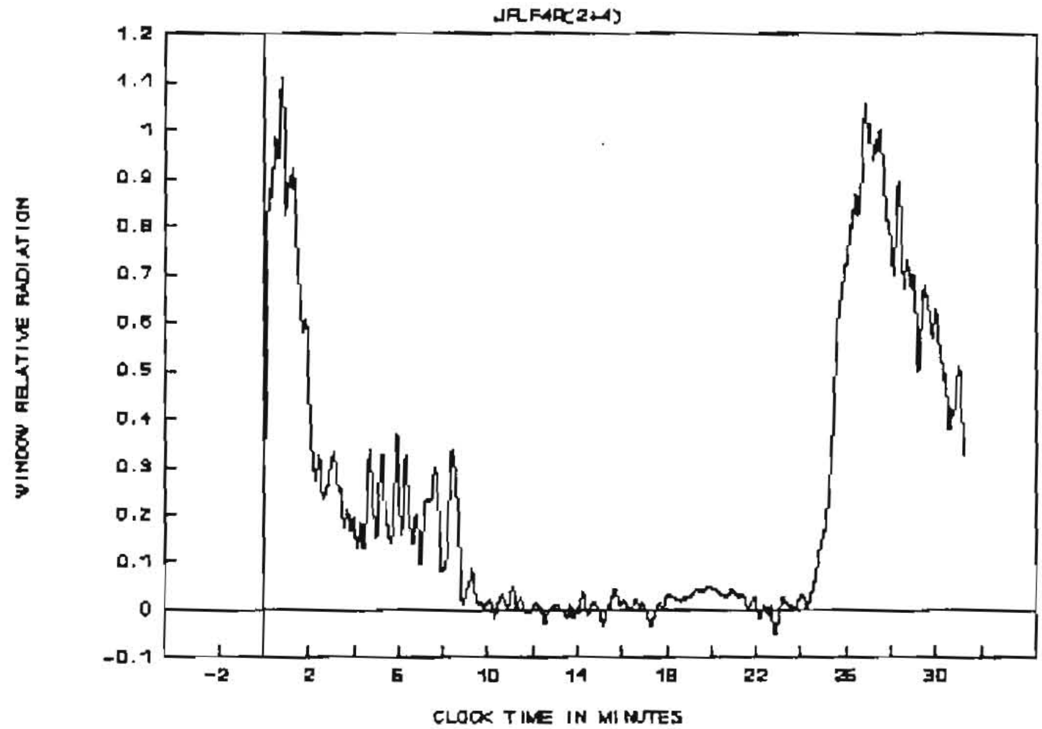
Test Number 4 **Additive FP70**

Branch Angus 225H **Fuel** Code 1

Weather Sunny

Clock Time min : sec	Time from application of foam min : sec	Observations
0:00		Ignition.
1:01	0:00	Foam stream applied to tray
1:53	0:52	Foam blanket visible over 30% of tray area.
2:46	1:45	75% Extinction, flames wherever the foam stream hits surface.
3:16	2:15	80% extinction with flames along centre opf tray where foam stream is landing Where foam stream hits surface, flaring occurred
4:00	2:59	No progress, flames wherever foam impacts. Branchmen direct foam stream around across the tray
5:00	3:59	Fire increased to 70% extinction
5:30	4:29	80 %extinction ,flames remrin on RHS of tray.
6:48	5:47	Foam branchpipe elevated to try to apply more gently to surface
6:59	5:58	**90% extinction**
7:46	6:45	No progress so branchpipe elevated further to try to apply more gently.
8:00	6:59	Much of foam missing tray. Foam reaching tray very gently but still causing flames at point of impact. Foam surface dark and appears contaminated.
8:40	7:39	Tactics changed to allowing foam stream to hit front wall and push foam over the tray rim onto surface.
8:45	7:44	**90% extinction**
		Test 4
8:47	7:46	**95% extinction**
9:12	8:11	More progressive extinction. Whiter foam blanket produced
10:48	9:47	Branchmen moved around to the right. Foam still applied over the wall.
11:36	10:35	Foam applied to tray edge
12:00	10:59	Foam stream applied gently over the flaming surface
12:24	11:23	**100% Extinction**
12:56	11:55	Foam off tray
	Time from start of burnback	
17:24	0:00	Burnback flame to the tray.
19:15	1:51	Some Candling

24:06	6:42	1 m² fire Burnback flame removed
25:14	7:50	**25% Burnback**
25:31	8:07	**50% Burnback**
26:02	8:38	**75% Burnback** and rim fire.
26:46	9:22	**100% Burnback**

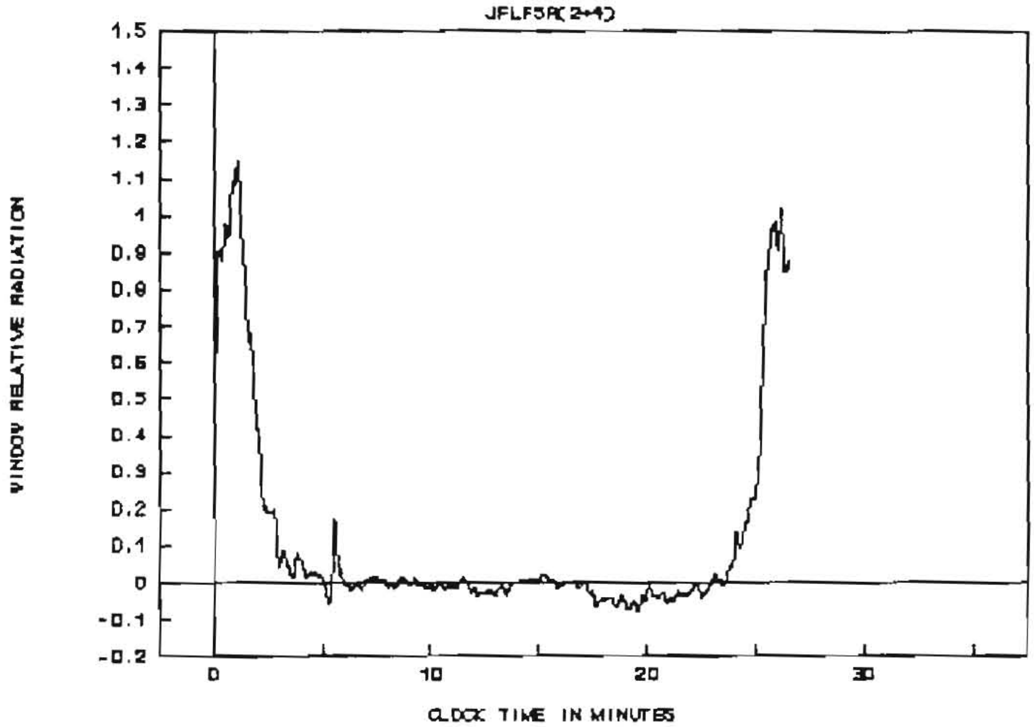


Test Number 5 Additive FP70

Branch Angus 225H **FEU Fuel Code** 1

Weather Sunny

Clock Time **min :sec**	**Time from application of foam** **min : sec**	**Observations**
0:00		Ignition
1:01	0:00	Foam on
1:40	0:39	Foam blanket visible over 20% of tray surface
2:56	1:55	**90% extinction**
3:22	2:21	**95% extinction**
3:50	2:49	Flaring where foam hits tray surface
4:43	3:42	Only fire around 20% of rim'
5:25	4:24	Virtual extinction,small flame on downwind rim
5:28	4:27	Flames spread to $2m^2$ hole in foam blanket and reignites fuel
5:41	4:40	**90% extinction**
5:44	4:43	**95% extinction**
6:29	5:28	**100% extinction**
6:59	5:58	Foam off
	Time from start of burnback	
12:22	0:00	Burnback flame on
18:00	5:38	$1m^2$ area of fire at burnback position
19:25	7:03	Burnback flame removed
19:42	7:20	Burnback flame returned to tray
23:35	11:13	Burnback flame removed.$2m^2$ fire at burnback position.20% of foam blanket contaminated
25:01	12:39	**25% burnback**
25:17	12:55	**50% burnback**
25:26	13:04	**75% burnback**
26:11	13:49	**100% burnback**



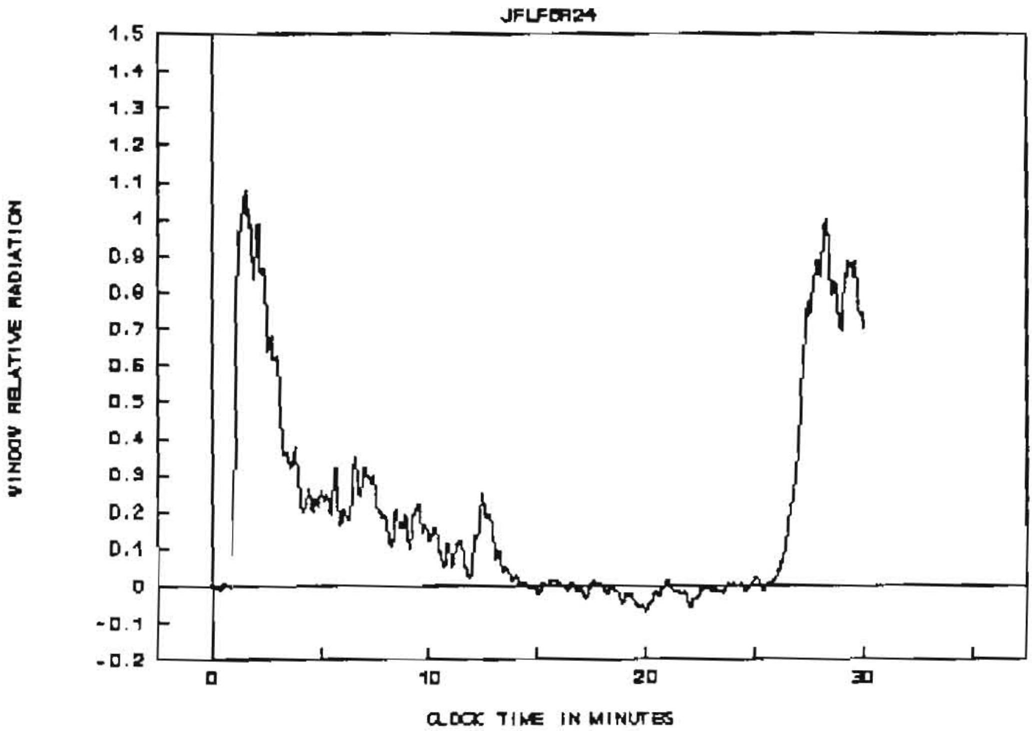
JFLFSR(2+4)
WINDOW RELATIVE RADIATION
CLOCK TIME IN MINUTES
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
10
20
30

Test Number 6 **Additive** FP70

Branch FB5X MK II **FEU Fuel Code** 1

Weather Overcast

Clock Time min :sec	Time from application of foam min : sec	Observations
1:00		Ignition
2:01	0:00	Foam on
3:07	1:06	Foam blanket visible over 20% of tray surface
4:18	2:17	Flaring where foam stream hits surface
9:40	7:39	**90% extinction**
10:42	8:41	**95% extinction**
10:50	8:49	Flames increase around rim.80% extinction
11:20	9:19	**90% extinction**
12:59	10:58	Foam applied over bund wall
13:45	11:44	**90% extinction** observed
14:06	12:05	**100% extinction** of tray, fire in outer rim
15:04	13:03	Total extinction
15:34	13:33	Foam off
	Time from start of burnback	
20:23	0:00	Burnback flame on
24:30	4:07	$2m^2$ fire at burnback position.Fire over 25% of tray rim
24:50	4:27	Burnback flame off
26:49	6:26	**25% burnback**
27:10	6:47	**50% burnback**
27:26	7:03	**75% burnback**
28:20	7:57	**100% burnback**



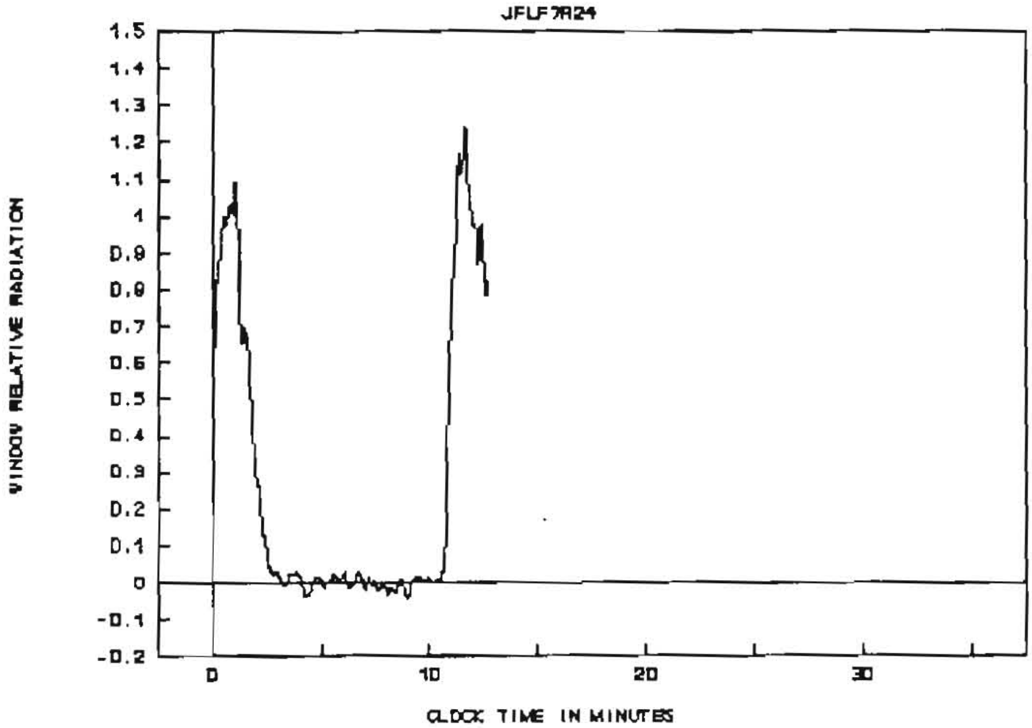
JFLF6R24
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
WINDOW RELATIVE RADIATION
0
10
20
30
CLOCK TIME IN MINUTES

Test Number 7 **Additive** AFFF

Branch FB5X MKII **Fuel Code** 1

Weather Sunny

Clock Time min :sec	Time from application of foam min : sec	Observations
0:00		Ignition
1:00	0:00	Foam on
1:03	0:03	Foam stream stationary
1:16	0:16	Foam blanket visable on 25% of tray surface
2:30	1:30	**90% extinction**
2:35	1:35	**95% extinction**
2:52	1:52	Small flames near tray rim
3:30	2:30	Only small flames on upwind rim
3:38	2:38	Branchmen direct foam at remaining flames
3:59	2:59	**100% extinction**
4:30	3:30	Foam off
	Time from start of burnback	
9:00	0:00	Burnback flame to tray
9:16	0:16	Flames around tray rim
9:37	0:37	Flames around 90% of rim,0.75m^2 area of flame at burnback position
10:04	1:04	Hole appears in foam blanket
10:20	1:20	Burnback flame off.Small flames over 50% of tray surface
10:47	1:47	**25% burnback**
10:53	1:53	**50% burnback**
11:01	2:01	**75% burnback**
11:16	2:16	**100% burnback**



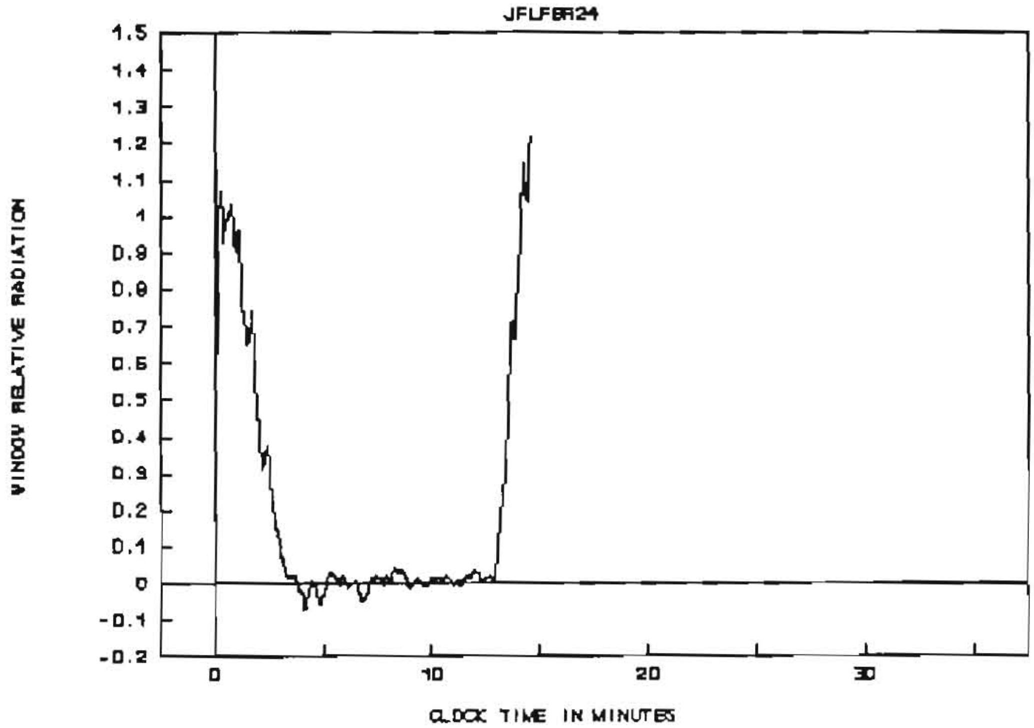
JFLF7R24
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
WINDOW RELATIVE RADIATION
0
10
20
30
CLOCK TIME IN MINUTES

Test Number 8 **Additive** FFFP

Branch FB5X MKII **FEU Fuel Code** 1

Weather Hazy sunshine

Clock Time min :sec	**Time from application of foam** min : sec	**Observations**
		Small area of contaminated foam on fuel surface
0:00	0:00	Ignition.
1:02	0:00	Foam on
1:14	0:12	Foam stream falls short
1:16	0:14	Foam visible over 10% of tray surface
1:23	0:21	Foam stream adjusted
1:38	0:36	Foam visible over 40% of tray surface
1:50	0:48	Foam stream falling short
2:03	1:01	Foam stream adjusted
3:00	1:58	**90% extinction**
3:11	2:09	**95% extinction**
3:30	2:28	Fire around 90% of rim.3% of tray surface on fire on upwind side
4:00	2:58	Fire around 60% of rim.1% of tray surface on fire on upwind side
5:00	3:58	Small flames on upwind rim only
6:16	5:14	**100% extinction**
6:48	5:46	Foam off
	Time from start of burnback	
11:16	0:00	Burnback flame on.Immediate candling and rim fire
11:26	0:10	Foam layer progressively degraded over tray area
11:35	0:19	Flames between rim and outer wall.
11:46	0:30	75% rim fire
12:00	0:44	Hole in foam blanket over 20%.No significant flame
12:06	0:50	Small flames spread over tray surface
13:00	1:44	$2m^2$ fire at burnback position
13:01	1:45	Burnback flame off
13:19	2:03	**25% burnback**
13:35	2:19	**50% burnback**
12:56	2:40	**75% burnback**
14:09	2:53	**100% burnback**

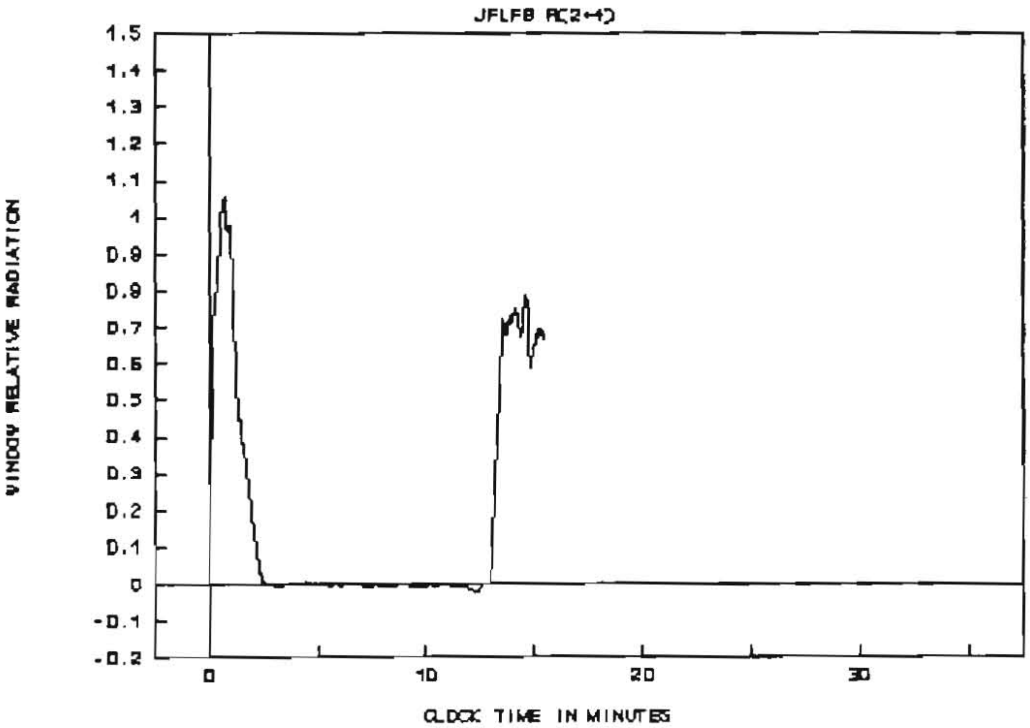

JFLFBR24
WINDOW RELATIVE RADIATION
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
10
20
30
CLOCK TIME IN MINUTES

Test Number 9 **Additive** AFFF-AR

Branch FB5X MKII **FEU Fuel Code** 1

Weather Overcast

Clock Time min :sec	**Time from application of foam** min : sec	**Observations**
0:00	0:00	Ignition
1:02	0:00	Foam on
1:08	0:06	Foam blanket visible over 5% of tray area
1:46	0:44	Foam blanket visible over 50% of downwind area
2:10	1:08	**90% Extinction**
2:19	1:17	**95% Extinction**
3:12	2:10	Only fire around 70% of rim
3:17	2:15	Branchmen gently direct foam stream at fire
3:20	2:18	1m2 of contaminated foam area ignites
4:00	2:58	Only small flames around 20% of rim
4:52	3:50	**100% extinction**
5:23	4:21	Foam off
	Time from start of burnback	
9:52	0:00	Burnback flame on.Immediate rim fire progresses around the tray
10:23	0:31	Some candling. Contaminated foam ignites. Fire on 75% of rim.
12:31	2:39	Sustained flame on contaminated foam
13:01	3:09	Burnback flame removed.Fire over 10% of tray area
13:11	**3:19**	**25% Burnback**
13:24	**3:31**	**50% Burnback**
14:34	**4:42**	**75% Burnback**
14:38	**4:46**	**Maximum Burnback 78%**

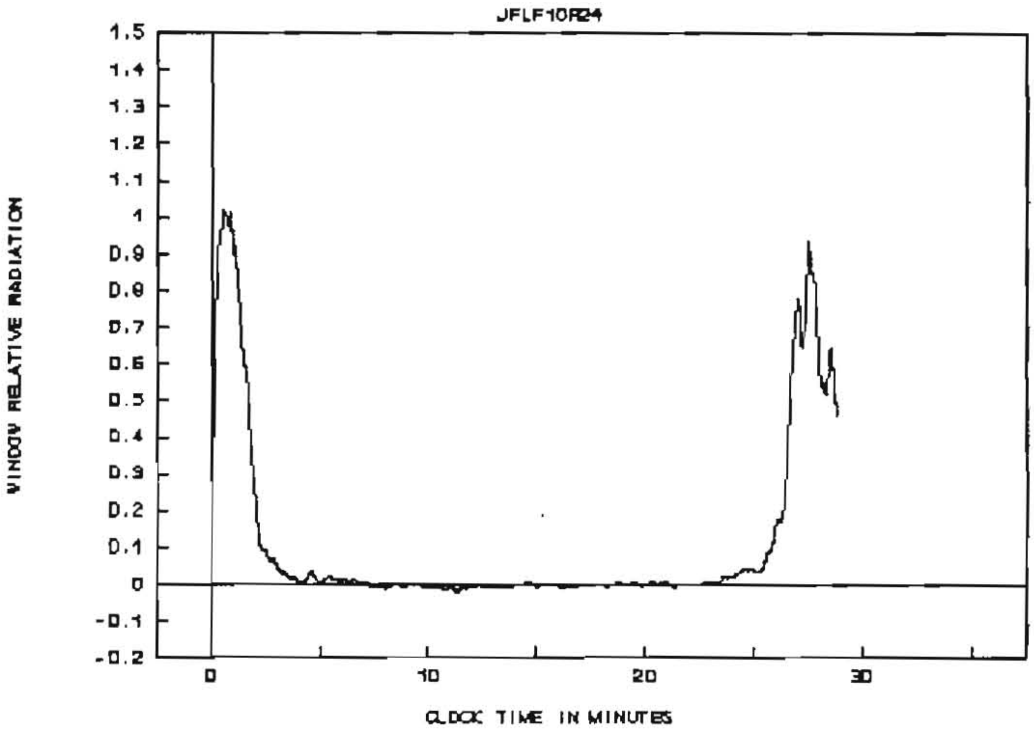

JFLFB R(2-4)
WINDOW RELATIVE RADIATION
CLOCK TIME IN MINUTES
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
10
20
30

Test Number 10 **Additive** FP70

Branch Angus 225H **FEU Fuel Code** 1

Weather Sunny

Clock Time min :sec	**Time from application of foam** min : sec	**Observations**
0:00	0:00	Ignition
1:02	0:00	Foam on
1:32	0:30	Foam blanket over 10% of tray surface on downwind side
2:03	1:01	Foam blanket over 40% of tray surface on downwind side
2:35	1:33	**90% Extinction.** (Observed)
3:19	2:17	Wind direction changes
3:25	2:23	Foam falls short
4:02	3:00	Foam directed to tray edge. Falmes self extinguish over most of tray area. Flaming where foam hits surface.
4:35	3:33	Large area of flame on upwind edge
4:26	3:24	Foam stream moved over surface for gentle application
5:35	4:33	Foam applied over bund wall
5:53	4:51	Foam applied over tray surface
6:28	5:26	**100% Extinction**
6:59	5:57	Foam off
	Time from start of burnback	
11:30	0:00	Burnback flame on
12:00	0:30	8cm hole in foam surface at burnback position
16:48	5:18	0.25m² hole in foam surface
21:30	10:00	0.5m² hole in foam aurface
23:25	11:55	Burnback flame removed. 1m² of flame at burnback position
25:50	14:20	Flame spreads to downwind side
26:28	**14:58**	**25% Burnback**
26:40	**15:10**	**50% Burnback**
27:14	**15:44**	Reduces to 64%
26:59	**15:29**	**75% Burnback**
27:32	**16:02**	**Maximum Burnback 93%**

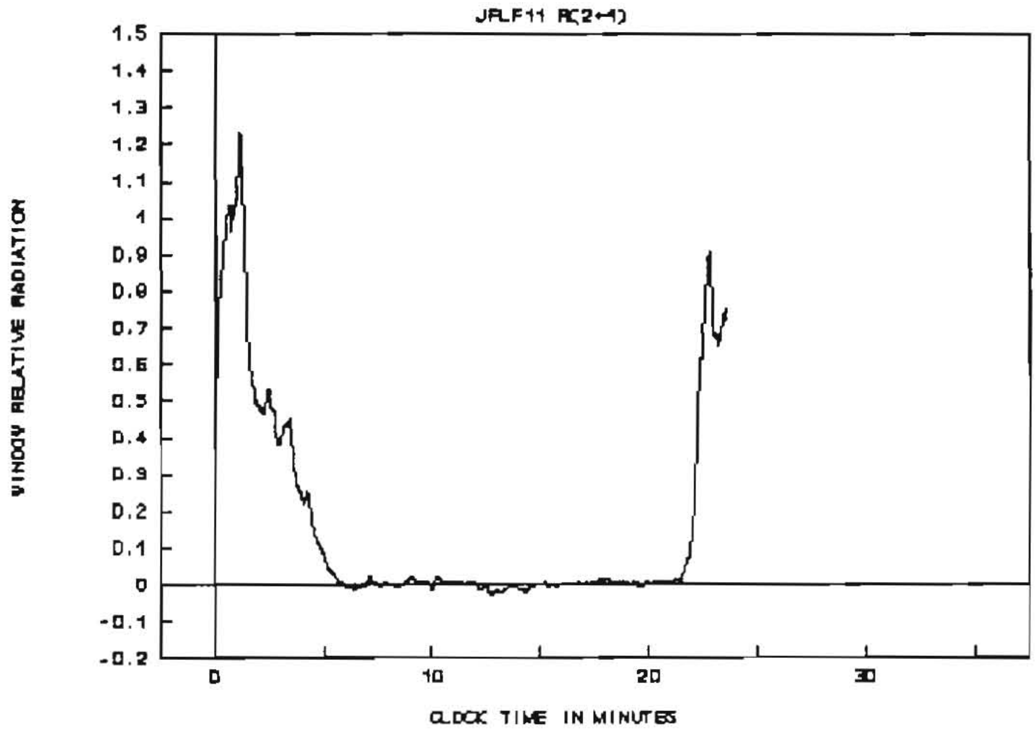

JFLF10R24
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
WINDOW RELATIVE RADIATION
0
10
20
30
CLOCK TIME IN MINUTES

Test Number 11 **Additive** AFFF

Branch FB5X MKII **FEU Fuel Code** 2

Weather Sunny

Clock Time min :sec	**Time from application of foam** min : sec	**Observations**
0:00		Ignition.Vertical plume. Very still conditions
1:02	0:00	Foam on
1:10	0:08	Foam blanket visible
1:23	0:21	Visible change in foam aspiration
1:54	0:52	Foam stream lifted vertically by plume
1:57	0:55	Foam lifted on tray surface by effect of vortex
3:39	2:37	Angle of foam stream decreased
4:53	**3:51**	**90% Extinction**
5:08	**4:06**	**95% Extinction**
5:38	4:36	Foam stream moved over surface for gentle application
12:32	11:30	Foam applied over bund wall
14:28	**13:26**	**100% Extinction**.Poor quality foam blanket
14:58	13:56	Foam off
	Time from start of burnback	
19:27	0:00	Burnback flame on
19:55	0:28	Flame towards centre of tray
20:26	0:59	Flames around 70% of rim
21:26	1:59	Burnback flame off
22:09	**2:42**	**25% Burnback**
22:18	**2:51**	**50% Burnback**
22:36	**3:09**	**75% Burnback**
22:50	**3:23**	**Maximum Burnback 90%**

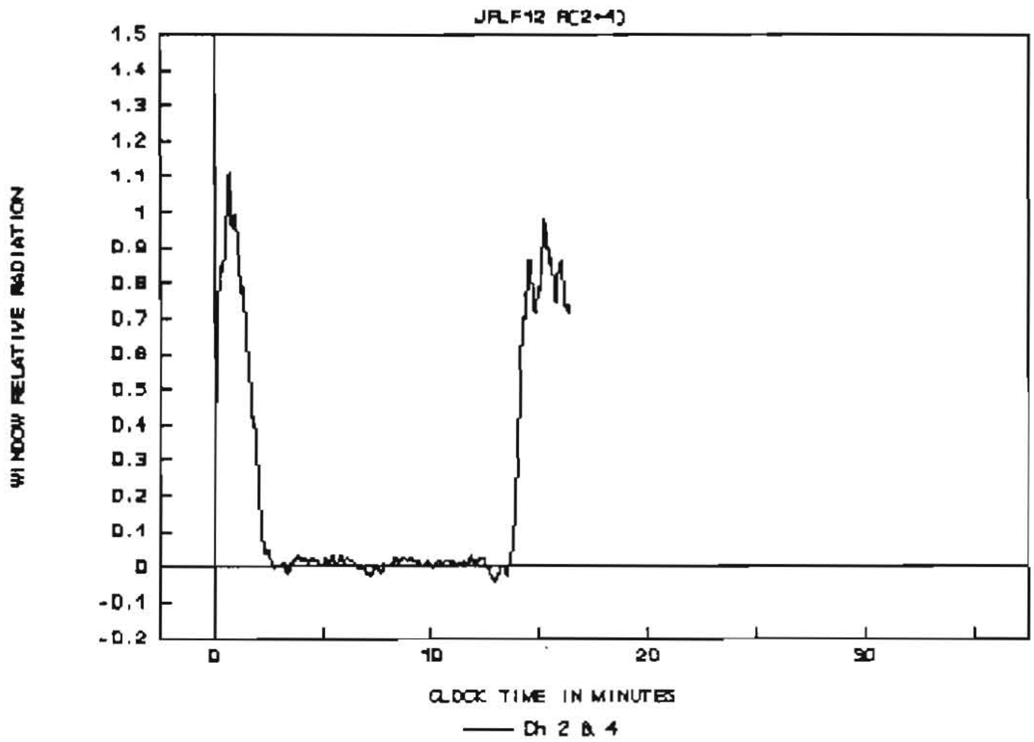

JRLF11 R(2+4)
WINDOW RELATIVE RADIATION
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
10
20
30
CLOCK TIME IN MINUTES

Test Number 12 **Additive** AFFF

Branch FB5X MkII FEU **Fuel Code** 2

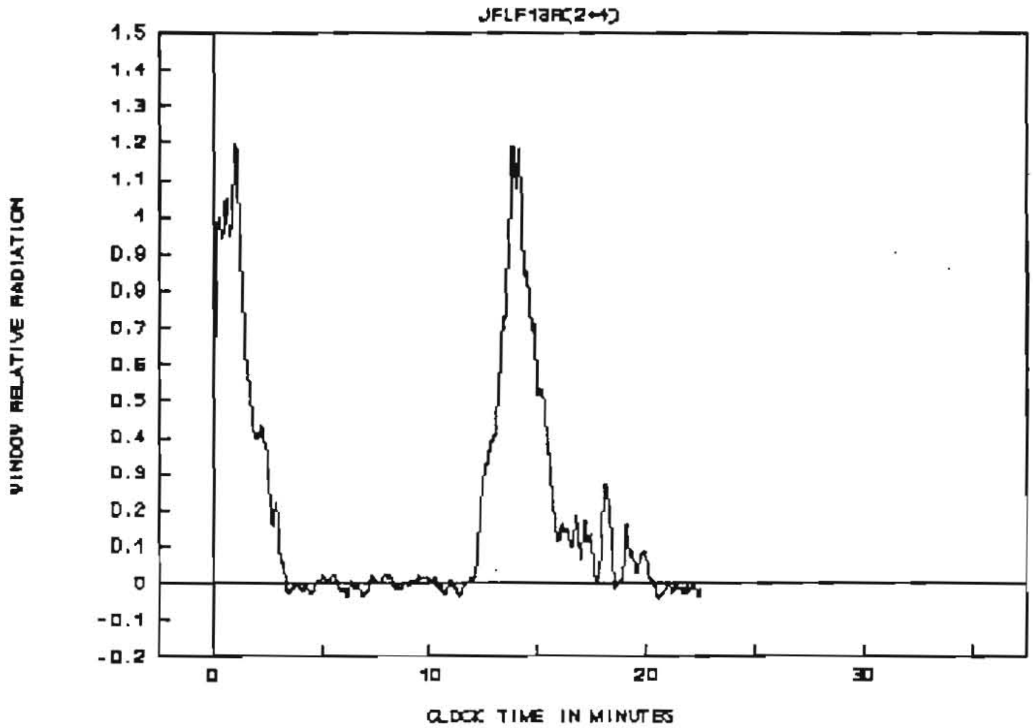
Weather Sunny,Hot,Still

Clock Time min :sec	**Time from application of foam** min : sec	**Observations**
0:00		Ignition
1:02	0:00	Foam on
1:07	0:05	Foam blanket visible over 5% of tray surface
1:50	0:48	Foam blanket visible over 50% of tray surface
2:12	**1:10**	**90% Extinction**
2:18	**1:16**	**95% Extinction**
5:00	3:58	virtual extinction.Small flame on upwind rim
5:06	4:04	Flames increase where surface disturbed by foam stream
5:20	4:18	Gentle foam application
6:20	5:18	Virtual extinction
6:40	**5:38**	**100% Extinction**
7:11	6:09	Foam off
	Time from start of burnback	
11:39	0:00	Burnback flame on
13:20	1:41	0.5m^2 flame at burnback position.1m^2 on downwind side
13:37	1:58	Burnback flame off
13:58	**2:19**	**25% Burnback**
14:08	**2:29**	**50% Burnback**
14:24	**2:45**	**75% Burnback**
14:31	**2:52**	**Maximum Burnback 86%**


JRLF12 R(2+4)
WINDOW RELATIVE RADIATION
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
10
20
30
CLOCK TIME IN MINUTES
Ch 2 & 4

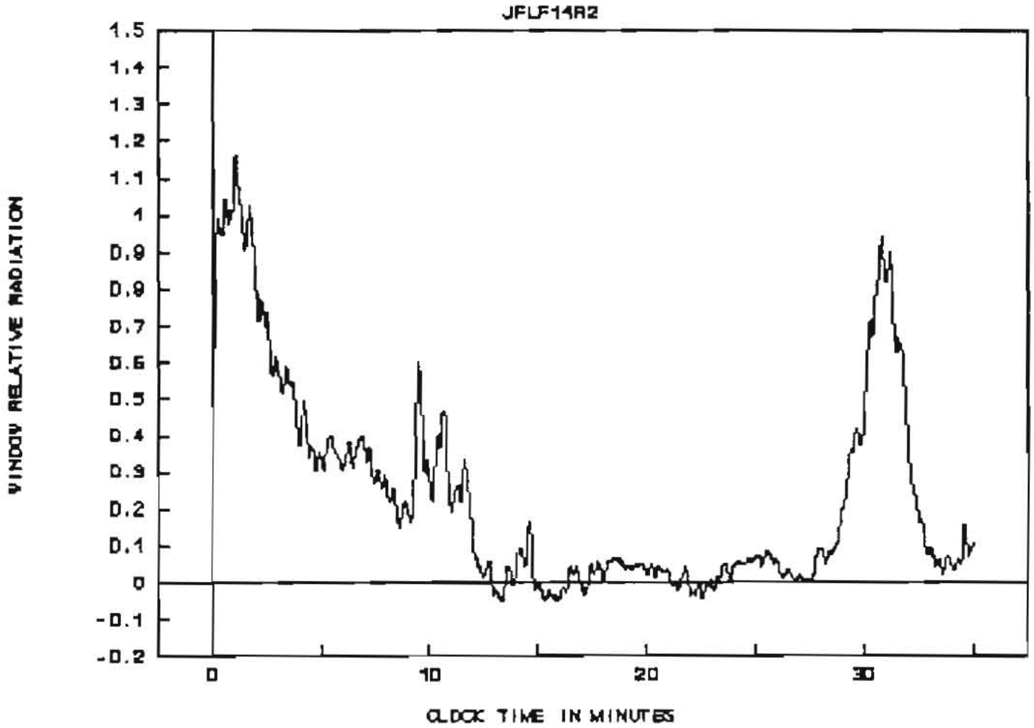
Test Number 13 **Additive** FFFP
Branch FB5X MKII **FEU Fuel Code** 2
Weather Overcast

Clock Time min :sec	Time from application of foam min : sec	Observations
0:00		Ignition.
1:01	0:00	Foam on.
1:34	0:33	Foam blanket visible over 10% of surface.
2:44	1:43	Foam blanket visible over 50% of surface.
3:03	2:02	**90% extinction.**
3:16	2:15	**95% extinction.**
3:52	2:51	Fire over 75% of rim.
4:16	3:15	Branchmen move foam stream over tray area.
4:31	3:30	Increase in flame where foam stream hits surface.
5:52	4:51	Foam stream taken off surface.
5:59	4:58	Foaming area self-extinguishes. Foam stream gently reapplied.
6:01	5:00	Fire virtually extinguished. Small flames on downwind rim.
6:14	5:13	**100% extinction.**
6:45	5:44	Foam off.
	Time from start of burnback	
11:14	0:00	Burnback flame on.
11:20	0:06	Flame around rim and candling over tray surface caausing breakdown of foam layer.
12:00	0:46	No foam blanket over 20% of tray surface. Flames over 10% of tray surface.
12:17	1:03	Burnback flame off. Flame over 3m^2 area.
12:25	1:11	**25% burnback.**
13:09	1:54	**50% burnback.**
13:30	2:16	**75% burnback.**
13:44	2:30	**100% burnback.**Foam applied after full burnback


JFLF13R(2+4)
WINDOW RELATIVE RADIATION
CLOCK TIME IN MINUTES
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
10
20
30

Test Number 14 **Additive** FP70
Branch Angus 225H FEU Fuel Code 2
Weather Overcast

Clock Time min :sec	Time from application of foam min : sec	Observations
0:00		Ignition
1:01	0:00	Foam on
3:46	2:45	50% extinction
4:00	2:59	Fire between rim and bund wall
8:23	7:22	75% extinction
8:46	7:45	Foam stream moved over tray area
9:13	8:12	Flaring where foam hits surface
9:45	8:44	Area of flame increases
12:01	11:00	**90% extinction**
12:06	11:05	Foam stream directed off surface
12:14	11:13	**95% extinction**
12:30	11:29	Fire over 50% of rim. Contaminated foam blanket
12:40	11:39	Foam applied gently over surface
14:55	13:54	Foam applied over bund wall
15:25	14:24	**100% extinction** of tray. Small flame in outer rim
15:36	14:35	Outer rim out
15:55	14:54	Foam off
	Time from start of burnback	
		20% of foam blanket destroyed before burnback flame on
20:25	0:00	Burnback flame to uncontaminated foam. 25% foam surface contaminated
28:08	7:43	Burnback flame off.2m² flame area
29:12	8:47	**25% burnback** (radiometers)
29:35	9:10	25% burnback (observed)
30:04	9:49	**50% burnback**
30:31	10:06	**75%burnback**
30:50	10:25	**Maximum burnback** (94%)



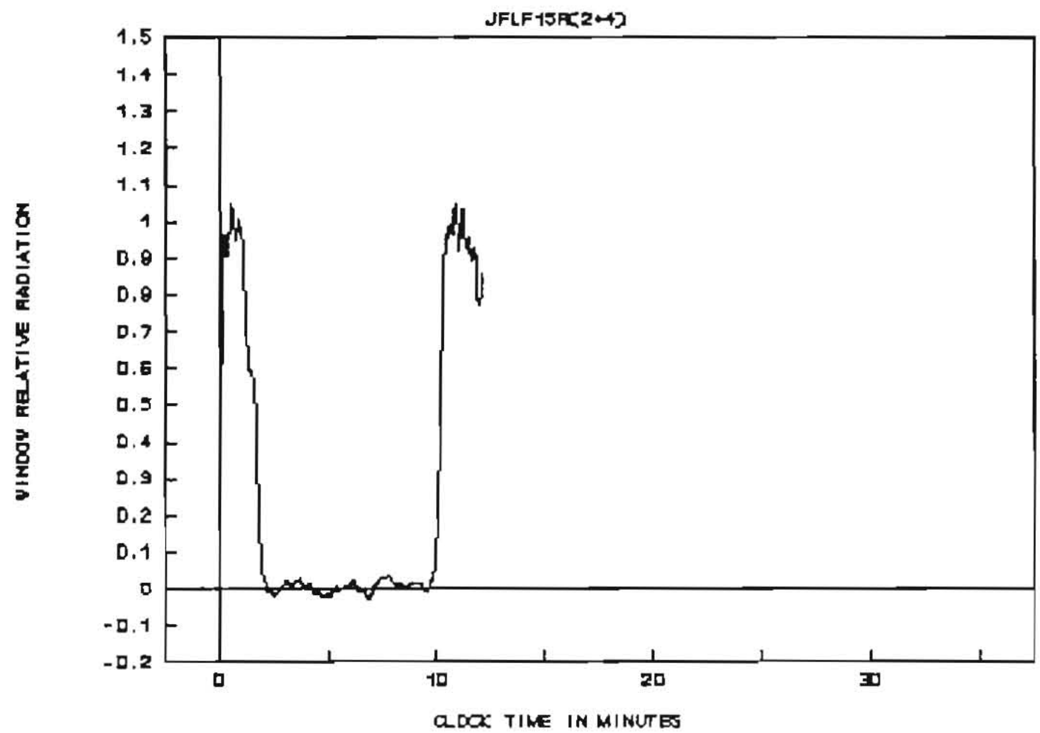
JFLF14R2
1.5
1.4
1.3
1.2
1.1
1
0.9
0.9
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
10
20
30
WINDOW RELATIVE RADIATION
CLOCK TIME IN MINUTES

Test Number 15 **Additive** AFFF

Branch Chubb FB5X MKII **FEU Fuel Code** 3

Weather Sunny

Clock Time **min :sec**	**Time from application of foam** **min : sec**	**Observations**
0:00		
1:01	0:00	Foam on
1:09	0:08	Foam blanket over 8% of tray surface
1:56	0:55	**90% extinction**
1:59	0:58	**95% extinction**
2:34	1:33	Fire over 5% of upwind tray rim
2:51	1:50	Virtual extinction. Small flames around rim
3:16	2:15	100% extinction
3:46	2:45	Foam off
	Time from start of burnback	
8:16	0:00	Burnback flame on
9:00	0:44	Ghosting over tray surface
9:11	0:55	Fire over 25% of rim
·9:30	1:14	Break in foam blanket of 5% of tray area
10:00	1:44	Burnback flame off. 1m² flame at burnback point. 10% of area flaming on downwind side
10:06	1:50	**25% burnback**
10:13	1:57	**50% burnback**
10:18	2:02	**75% burnback**
10:47	2:31	**100% burnback**

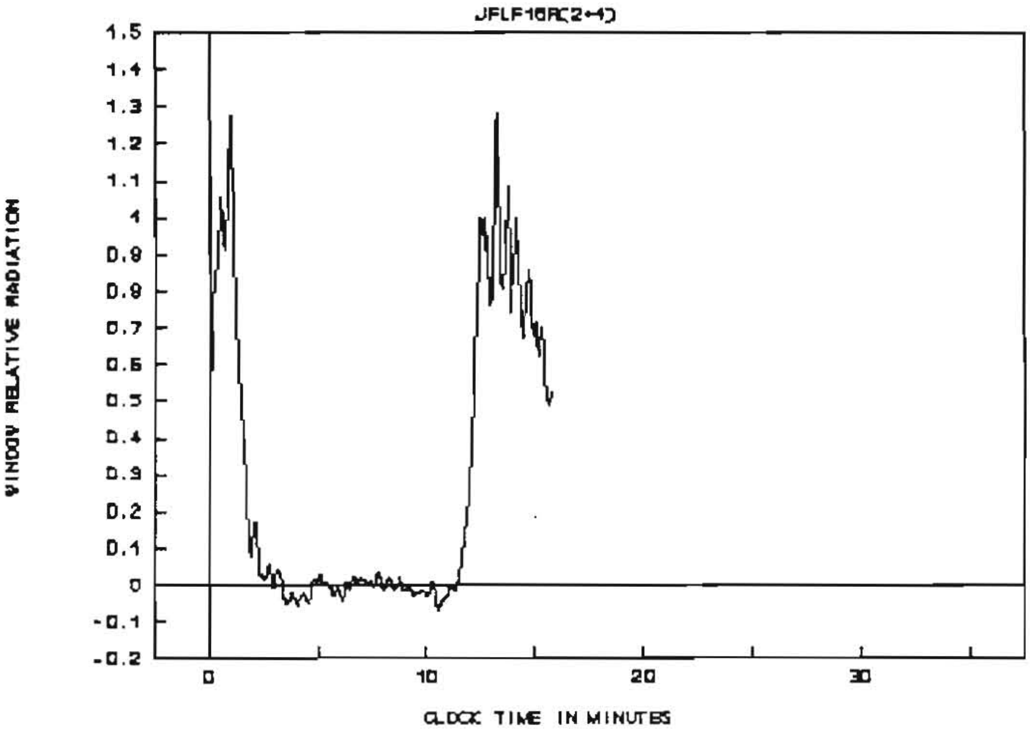

JFLF15R(2-4)
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
WINDOW RELATIVE RADIATION
0
10
20
30
CLOCK TIME IN MINUTES

Test Number 16 **Additive** FFFP

Branch Chubb FB5X MKII **FEU Fuel Code** 3

Weather Sunny

Clock Time min :sec	Time from application of foam min : sec	Observations
0:00		Ignition
1:01	0:00	Foam on
1:21	0:20	Foam blanket visible over 10% of tray area
2:16	1:15	**90% extinction**
2:19	1:18	**95% extinction**
2:46	1:45	Foam stream moved over tray area
3:30	2:29	Flames only around 30% of rim
4:00	2:59	Virtual extinction small flames on upwind rim
4:43	3:42	Area of flames increased to 3% of tray area
5:25	4:24	**100% extinction**
5:56	4:55	Foam off
	Time from start of burnback	
10:25	0:00	Burnback flame on. Ghosts immediately
10:44	0:19	Top layer of foam blanket destroyed over 60% of tray area.Ghosting over surface. 100% rim fire.
11:00	0:35	Fire over 5% of tray area on downwind side
11:06	0:41	Area of flame reduced on downwind side
11:20	0:55	Burnback flame off. Area of flame 5% on downwind side. 0.5m^2 fire at burnback point
11:58	1:33	**25% burnback**
12:11	1:46	**50% burnback**
12:20	1:54	**75% burnback**
12:38	2:13	**100% burnback**
13:17	2:52	**120% burnback** (radiometers)



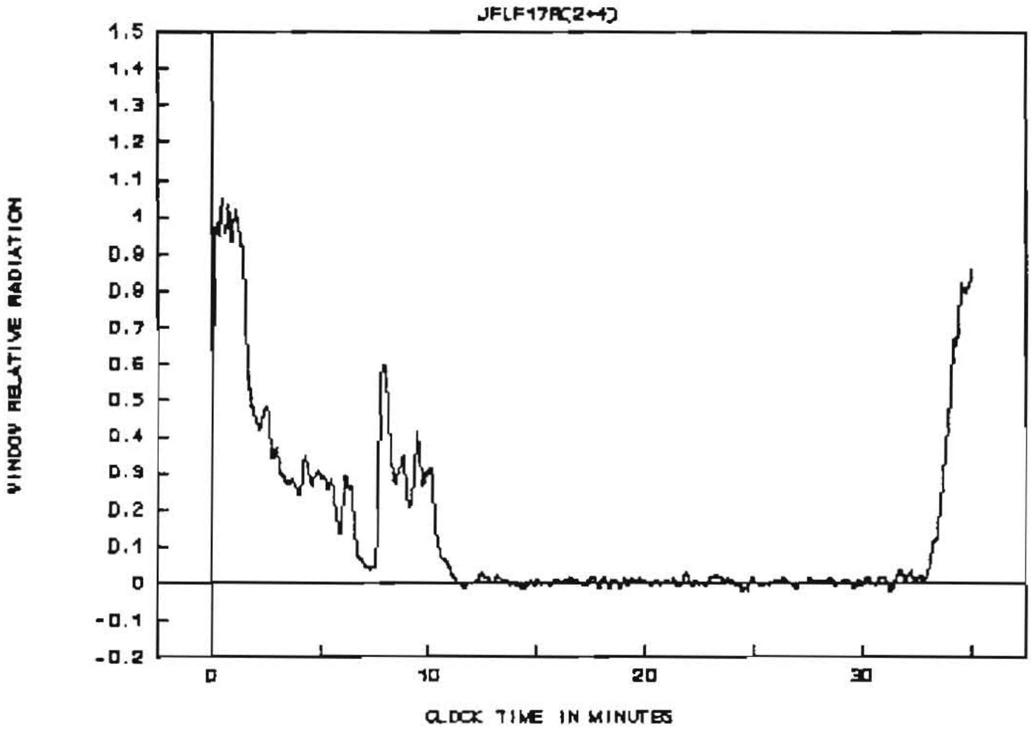
JFLF16R(2+4)
WINDOW RELATIVE RADIATION
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
10
20
30
CLOCK TIME IN MINUTES

Test Number 17 **Additive** FP70

Branch FB5X MKII **FEU Fuel Code** 3

Weather Overcast

Clock Time min :sec	Time from application of foam min : sec	Observations
0:00		Ignition
1:01	0:00	Foam on
1:50	0:49	50% extinction(radiometers)
3:12	2:11	70% extinction
4:30	3:29	Foam blanket visible over 6% of surface
5:38	4:37	Foam stream moved to right hand side of tray
6:32	5:31	Foam off. 80% extinction
6:40	5:39	Flames reduced to 90% extinction
7:25	6:24	**95% extinction**
7:30	6:29	Mainly fire around 70% of rim. Only 0.5m² fire in main tray area
7:39	6:38	Foam applied to tray surface. Rim fire increased to 90% extinction
7:47	6:46	Immediate flaming wherever foam lists tray surface
7:59	6:58	Fire increases to 40% extinction
8:30	7:29	Flames reduce in area where foam is not applied
10:14	9:13	Foam applied over bund wall
10:29	9:28	**90% extinction**
10:54	9:53	**95% extinction**
11:50	10:49	**100% extinction** of tray fire around 30% of rim and bund wall
13:09	12:08	Rim fire out
13:39	12:38	Foam off
	Time from start of burnback	
18:09	0:00	Burnback flame on
29:30	11:21	0.5m² flame at burnback position, no other flame
30:46	12:37	Flame spread to contaminated area of foam
30:58	12:49	Burnback flame off. 1m² fire at burnback position
33:40	15:31	**25% burnback**
34:03	15:54	**50% burnback**
34:29	16:20	**75% burnback**
35:01	16:52	**Maximum burnback 86%**

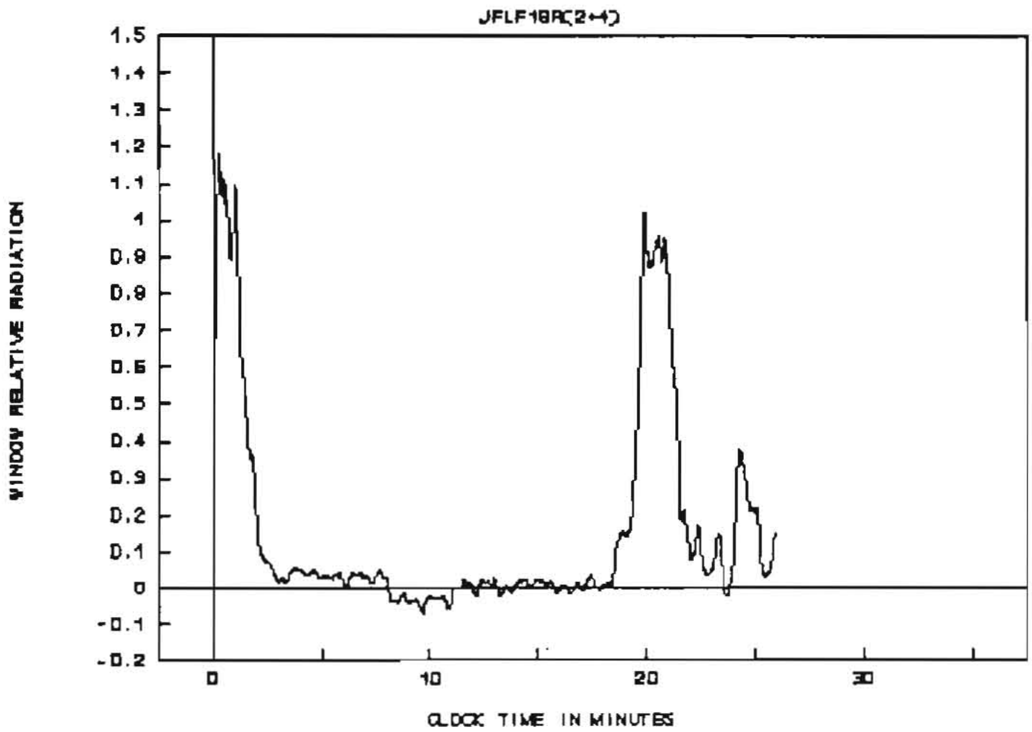

JFLF17R(2+4)
WINDOW RELATIVE RADIATION
CLOCK TIME IN MINUTES
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
10
20
30

Test Number 18 Additive **FFFP**

Branch Angus 225H FEU Fuel Code **3**

Weather **Sunny**

Clock Time min :sec	Time from application of foam min : sec	Observations
0:00		Ignition
1:01	0:00	Foam on
1:28	0:27	Foam blanket visible over 15% of tray area
2:02	1:01	**90% extinction observed**
2:13	1:12	**90% extinction** (radiometers)
2:14	1:13	**95% extinction** observed
2:46	1:45	**95% extinction** (radiometers)
2:42	1:41	Foam stream moved over tray area
3:45	2:44	Arm of flame from tray centre to rim moves with swirl of foam
5:40	4:39	**100% extinction** of tray.Fire in outer rim
6:56	5:55	Total extinction
	Time from start of burnback	
11:56	0:00	Burnback flame on
17:15	5:19	0.25m² flame at burnback position
18:27	6:31	Flame spreads to rim.1m² fire at burnback position
18:37	6:41	Burnback flame off
19:24	7:28	**25% burnback**
19:38	7:42	**50% burnback**
19:46	7:50	**75% burnback**
19:54	7:58	**100% burnback**



JFLF18R(2+4)
WINDOW RELATIVE RADIATION
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
10
20
30
CLOCK TIME IN MINUTES