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HOME OFFICE

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FIRE RESEARCH & DEVELOPMENT GROUP

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FIRE AND EMERGENCY
PLANNING DIRECTORATE
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Water Additives for Fighting Class A Fires

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FRDG

ABSTRACT

In recent years, a range of additives intended for use on Class A fires has been marketed. These additives were developed in the US for use, at very low concentrations, on brush fires. They are now also being recommended for use on structural fires. The Fire Experimental Unit (FEU) was asked to investigate the effectiveness of Class A additives for normal UK fire service firefighting operations. This was done by carrying out test fires, each containing 56 new, wooden pallets of a consistent design.

The results of initial trials did not rule out possible benefits from some additives, but the trials were too limited to be conclusive. A second phase of trials was carried out. The results of these trials showed that there is little or no benefit to using additives, over using water alone.

MANAGEMENT SUMMARY

In recent years, a range of additives intended for use on Class A fires has been marketed. These additives were developed in the US for use, at very low concentrations, on brush fires. They are now also being recommended for use on structural fires. The Fire Experimental Unit (FEU) was asked to investigate the effectiveness of Class A additives in normal firefighting operations. A series of fire tests was carried out in 1995, and as a consequence of these tests a second series was carried out in 1996.

1995 Tests

The 1995 tests aimed to give a broad initial view of the performance of the Class A additives. The results of these tests would then be used to decide whether further, more closely controlled tests were justified.

Each test fire consisted of 56 wooden pallets, arranged in a square of 4 stacks of 14 pallets. The pallets were ignited with a tray of heptane beneath each stack. The heptane was measured to burn out after 2 minutes. The pallets were allowed to burn until a steady fire was achieved (the preburn). Firefighting then commenced.

A total of 13 Class A additives were used during this series of tests. Water, a synthetic detergent based foam (Expandol) and an AFFF were also used for comparative purposes. Each of the Class A additives was premixed to the manufacturers' recommended concentration and was applied to the test fire, through a high pressure hosereel, at 50 litres per minute. Firefighting was carried out by an experienced local authority firefighter who had free access all around the fire. The first minute of firefighting was carried out with a jet, after which he switched to spray and continued firefighting until he felt that he had achieved a consistent level of extinguishment. Usually however, some hot spots remained and reignition often occurred. The decision on when to cease firefighting rested with the firefighter. For consistency, the same firefighter was used throughout the series of tests.

The progress of the fire was monitored using radiometers to measure the radiant heat output. Video recordings were used to check the timings of the firefighter's activities (e.g. the time firefighting ceased).

1995 Results

In early tests, a 5½ minute preburn was used; this was later reduced to 5 minutes in an attempt to prevent stack collapses. Stack collapses occurred when the horizontal members of the pallets burned through. Once the pallets collapsed, the results were invalidated since the characteristics of the test fire had changed in an unpredictable manner.

Of the 13 Class A additives used, only 10 of these were successfully tested (stack collapses negated the other results).

The time at which firefighting stopped did not provide a reliable measure of the effectiveness of the firefighting solutions. A more reliable measure of performance was the radiant heat output measured by the radiometers. This data was processed to find the area under the radiant heat output curve.

Most fire reduction was achieved in the first two minutes of firefighting. For this reason, the area under the radiated heat output curve over these two minutes was used as the primary measurement of firefighting progress. This area represents the heat reduction of the test fire; the lower the value for the area under the curve, the more quickly the heat of the fire has been reduced and the more effective the additives have been at suppressing it.

Table MS 1 lists the additives that were successfully tested and gives a summary of the results. Some additives that were tested are not listed here because no valid results were obtained from them due to problems with the test fire (e.g. stack collapses).

Although there are differences between the results of the tests, they are not proportionally very great. Each additive type was only tested once and any variations were not sufficient to discount any of the additives from further testing. It was therefore decided that all of the additives tested should be subjected to further, more rigorous tests and the second series of fire tests was commissioned.

Additive Type	Concen-tration (%)	Preburn Time (mins)	Area under the Curve		
			First minute	Second minute	First two minutes
Control A	0.5	5½	36	3.5	39.5
Phirex +	1	5½	35	8.4	43.4
Ecofoam	1	5½	38	12.5	50.5
Cold Fire	3	5½	34	3.7	37.7
Chemguard	0.5	5½	38	4.2	42.2
Phos-Chek	1	5½	38	4.0	42.0
Water		5½	39	8.8	47.8
JJD	0.025	5	32	2.8	34.8
Forexpan	0.5	5	33	12.4	45.4
1st Defense	1	5	30	7.0	37.0
Silv-ex	0.5	5	31	2.2	33.2
AFFF	3	5	32	2.6	34.6
Water		5	31	4.8	35.8

Table MS 1 : 1995 tests - summary of the area under the curve results
(The lower the value, the better the additive performed)

1996 Tests

The test method for 1996 was a more strictly controlled version of the 1995 test method. All but one of the Class A additives used in 1995 were tested at least twice, as were water, AFFF and synthetic detergent (Expandol). The one additive that was not re-tested (Cold Fire) was not available at the time of this second series of tests.

The thickness of the horizontal members of the wooden pallets was increased to ensure that no stack collapses occurred. In addition, the moisture content of the wood was more closely controlled than in 1995 to help to ensure a more consistent fire and to prevent stack collapses.

All tests used a 5½ minute preburn. In order to extend the firefighting phase, and to improve the discrimination between the performances of the additives, all firefighting was carried out with the hosereel gun on a spray setting only. This limited the reach of the extinguishing media and resulted in longer firefighting times. As in 1995, the flowrate used was 50 lpm.

1996 Results

In 1996 the heat output data from the radiometers was processed in the same way as it had been in 1995. The area under the radiated heat output curve was used as the primary indicator of additive performance. In 1996, the area under the curve was calculated over 4 minutes of firefighting, as opposed to two minutes used for the 1995 fires. The longer firefighting times were due to the use of spray application only during the 1996 fires.

A summary of the area under the curve results of the 1996 tests is shown in Table MS 2. As with the 1995 results, the lower the value for the area under the curve, the more effective the additives have been at suppressing the fire.

Additive type	Concentration (%)	Area under the curve calculated over the first 4 minutes of firefighting			
		First test	Second test	Subsequent tests	
1st Defense	1	26.2	30.9		
AFFF	3	38.0	33.3		
Chemguard	0.5	36.3	43.4		
Chubb 1%	1	34.8	35.0		
Control A	0.5	33.9	32.9	32.3	
Ecofoam	1	29.5	40.3		
Expandol	3	27.0	42.0		
Fire Out I	0.3	36.2	26.7		
Forexpan	0.5	36.0	32.6		
Fuel Buster	1	49.2	31.3		
JJD	0.025	33.2	31.0		
Phirex +	1	30.5	34.4		
Phos-Chek	1	29.0	43.5		
Silv-ex	0.5	39.1	40.5		
Water		34.3	30.1	36.8	38.1

Table MS 2: 1996 tests - Summary of the results of the area under the curve over 4 minutes (The lower the value, the better the additive performed)

Statistical Analysis of the 1996 Results

Although the results show some differences in the firefighting performances of additives during the tests, it was difficult to assess whether these could be assigned to the various additives themselves, or whether they were no more than unavoidable experimental variation. Statistical analysis was used to evaluate these differences.

The first of these statistical checks gave confidence that the only differences between the results of the fire tests were caused by the firefighting performances of the different extinguishing media.

Statistical tests were then carried out on groups of results. The aim of the tests was to show whether the additives gave genuinely different results from water alone. To assess this, comparisons were made in two ways: First of all the results were assessed by comparing the water tests with *all* the other tests; secondly the water tests were compared with the tests on each individual additive type.

Considering first of all the comparison of the 4 water test results with all 29 results of additive tests, the statistical tests indicated a 99% likelihood that the additive results came from the same group of results as the water ones. That means that it is 99% probable that the firefighting performance of Class A additives generically is the same as that of water.

The individual additive results were then compared, in turn, with the water results. These comparisons tell us whether it is likely that the individual additives produced the same performance as water, or whether they performed differently (better *or* worse). None of the additives produced statistically significantly different performances to water alone.

Conclusions

In these trials there is no significant difference in firefighting performance due to the use of Class A additives, even under the closely controlled conditions of the trials. Under normal operational circumstances there are so many uncontrollable variables affecting the fire that any change in firefighting performance that may potentially result from the use of Class A additives would probably be rendered unnoticeable.

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1. INTRODUCTION

In recent years, a range of additives intended for use on Class A fires has been marketed. These additives were developed in the USA for use, at very low concentrations in water, on brush fires. They are now also being recommended for use on structural fires. Although they are generically known as Class A foams, they are more accurately Class A additives, since they do not all produce foam as an end product. The additives are claimed to improve the firefighting performance of water and therefore to use less water, to reduce the likelihood of reignition and to improve the environment for the firefighter. Details of these claimed improvements are included in Section 2.2.

As part of the Home Office Fire Research Programme, the Fire Experimental Unit (FEU) of the Fire Research and Development Group (FRDG) was asked to investigate the effectiveness of Class A additives in firefighting operations.

The work described in this report concentrates on the firefighting performance of the Class A additives. In order to assess any improvements offered by the additives it was decided that full scale, realistic fire tests should be carried out. The fires had to be big enough to discriminate between good and poor firefighting solutions.

2. BACKGROUND TO THE TESTS

2.1 Class A Fires

Class A fires are defined as "Fires involving solid materials, usually of an organic nature (compounds of carbon), in which combustion normally takes place with the formation of glowing embers" (Reference 1). The Manual of Firemanship (Reference 2) states that "Class A Fires are the most common, and the most effective extinguishing agent is generally water in the form of a jet or a spray."

Class A fires occur in ordinary combustible materials including wood, paper and rubber, as well as many other natural fibres. Extinguishing Class A fires requires the use of a heat-absorbing agent such as water, or an extinguishing agent that will interrupt the chemical chain reaction. A distinguishing feature of Class A fires is that they proceed from a flaming surface combustion to a deep-seated glowing combustion. The extinguishing agent must penetrate the burning material (Reference 3).

2.2 Class A Additives

Many Class A additives have recently been developed in the USA. Manufacturers of the additives list a range of properties of the additives, and maintain that these properties improve their firefighting performances five fold in comparison with water alone (Reference 4).

In a series of articles discussing firefighting foams (Reference 5) Leslie P. Omans gives this description of Class A foams:

> "Class A foams, as their name implies, are intended for use on ordinary combustible or Class A materials such as wood, plastic, rubber and vegetation. They were initially used in vegetation fires and were referred to as "wildland foams". They are also being used more and more on structural fires, with very positive results.
>
> Compressed-air Class A foam will stick to vertical surfaces, a quality that differentiates it from other foams. These adhering bubbles will hold the moisture on to the burning materials longer, allowing the surface to absorb more water. Class A foams insulate, protect and cool the materials they cover and prevent the spread of fire by radiation. These foams also lower the surface tension of water so it penetrates into the fuel deeper and faster. Firefighters get more extinguishment and exposure protection from their available water, and there is usually less water damage."

In several published articles, the authors quote the properties of Class A additives that make them good at extinguishing fires, brush fires in particular. Ken Farmer, in Fire Engineering (Reference 6) describes Class A additives:

> "Class A foam is a synthetic water-soluble organic preparation that is chemically different from soap. However it resembles soap in its ability to emulsify oils and hold dirt (or carbon) in suspension.
>
> "In a fire, one side of the foam molecule bonds with water, the other with the carbon that is created by the fire. This results in the fire being extinguished quickly and greatly reduces the chance of a rekindle."

The American standard NFPA 298 (Reference 7) applies to firefighting foam on Class A fuels in rural, suburban and vegetated areas. The standard includes acceptance criteria for corrosion, toxicity, biodegradability and physical characteristics such as viscosity, miscibility and flash point. It does not include any firefighting performance criteria.

The properties that are quoted for Class A additives can generally be divided into those of a foam and those of a wetting agent (References 4, 8 and 9).

Foam

- Has a 'fragile bubble structure' which means that the bubbles burst easily, releasing their moisture on to a fuel.

- Reflects radiant heat.

- Spreads the firefighting solution over a larger area than could be done without bubbles.

- The bubbles are able to hold more firefighting solution on to the hot surface than water alone.

- Reduces the air flow next to the hot surface, preventing both oxygen and heat transfer.

Wetting agent

- Reduces the surface tension of the firefighting solution with water. This helps the solution to spread on the surface of the fuel and to penetrate it.

- Has an affinity for carbons (oleophilic) which helps the water in the firefighting solution to cling to the fuel and then to drain out of the bubble blanket.

2.3 Previous Work

In 1988 the FEU undertook an evaluation of the use of additives in hosereel systems (Reference 10). The majority of additives which were tested were intended primarily for use against Class B fires, and their assessment against Class A fires was only one of the issues under consideration. At that time, it was concluded that the best of the additives tested would reduce the time taken to control a room fire but the overall saving in water and any reduction in fire damage would be small.

In 1993 a technical report on 'Knockdown, Exposure and Retention Tests' was published by the US National Fire Protection Research Foundation (Reference 11). In the fire tests, one type of additive was tested at different concentrations with water, and using three application methods against a single standard crib (a Class 20-A crib, Reference 12). These tests demonstrated a reduction in firefighting time when using the Class A additive, but the authors recommended further work against full scale fires with realistic fire loads.

In Germany tests were carried by the University of Wuppertal in 1994 (Reference 13) using a 10 litre fire extinguisher. Two tests were carried out against a 13A crib (Reference 14), one with only water in the extinguisher, one with a 0.5% solution of a Class A additive. Water alone did not extinguish the crib, but the solution of Class A additive extinguished the fire and prevented burnback. Further larger tests using 12 wooden pallets were also carried out. Again the Class A additive extinguished the pallets more quickly than water alone and was also better at preventing burnback.

Tests have been carried out in the USA by those involved in the manufacture or sales of Class A additives. In the Salem fire tests (Reference 15) similar rooms were loaded with straw and pallets. The most dramatic result of these tests was that the air temperature 4 feet from the floor was reduced more quickly with Class A additives than with water alone.

2.4 Discussion

Overall, most of the published material concludes that Class A additives provide an improved firefighting solution, when compared to water alone. The tests described in this report were intended to confirm and quantify that effect using realistically sized fires and UK fire service equipment and tactics.

3. 1995 TEST APPARATUS AND METHODS

3.1 General

In 1995 the first stage of testing Class A additives commenced. This stage was an exploratory survey involving a series of test fires to assess whether there were any immediately obvious differences in the firefighting performance of Class A additives over water alone. Further stages of testing would be dependent upon the outcome of this first stage and would aim to quantify any improvement.

The fire tests were carried out by the FEU under the smoke hood in the Still Air Facility at RAF Little Rissington (see Figure 1). Each one of 13 Class A additives was mixed in solution to the manufacturers recommended firefighting concentration and was tested once. Tests using water alone were also carried out for control purposes, as were tests using an AFFF and a SYNDET foam concentrate.

The fire load consisted of 56 standard, new wooden pallets. Firefighting was carried out using fire service equipment. The additives were applied using a hosereel branch and secondary aspiration. The test method was based upon BS EN 3 (Reference 14) and previous work carried out by the FEU (Reference 10).

The general test method (described more fully in Section 5) was to ignite the pallets with priming fuel and allow the fire to become established. After a given preburn an experienced firefighter tackled the fire using a hosereel branch in a consistent and realistic manner. After some preliminary tests, it was decided to use a jet setting for the first minute and then to switch to a spray setting to complete the extinction.

Various measurements were recorded (see Section 3.5) to quantify the differences between tests.

The following sections describe in more detail the methods and equipment used.

3.2 Description of the Fire Area

The 1988, FEU tests (see Reference 10) had been carried out in the Fire Test Room in the Still Air Facility, i.e. in an enclosed compartment. However, in the current series of tests, the size of the fires and the safety implications for the firefighter required an easily accessible fire in an open space. It was therefore decided to carry out these tests under the smoke hood in the Still Air Facility (see Figure 1). Figure 2 shows a plan of the area.

The smoke hood covers an area 8m square, with stanchions at each corner. The pallets were positioned along the diagonal between the stanchions. The central point under the hood was marked with a bolt in the floor and lines were painted on the floor between the stanchions to make positioning the fire load easier.

An instrumentation pod was positioned approximately 20m away from the edge of the hood and overlooking the fire area. Two pumping appliances were available for use and positioned beside the instrumentation pod. One was running prior to and during the tests, and was used to supply the firefighting solution under test. The other had a full water tank and was available in an emergency. Hoselines were run out from the appliances and from a mains water hydrant for use in an emergency.

3.3 Additives Tested

In the early stages of the project, 6 Class A additives were identified for testing. As planning progressed, more products became available and a total of 13 different Class A additives was tested. Several of these were not available in the UK at the time of testing and had to be imported. The additives that were tested are listed below. The names listed in Table 1 were used throughout testing for identification purposes. In addition to the Class A additives, 2 types of foam concentrate that are used by the UK fire service were tested. One was a SYNDET and one was an AFFF. Water alone was also tested.

A Class A additive from Pyrocap was also identified. However the company was unwilling to allow it to be subjected to testing unless they were allowed control over the results that were published. This was unacceptable in a fully independent series of tests and the Pyrocap Class A additive was not tested.

Full details of the additives, the suppliers and the instructions supplied on the containers are provided in Appendix A.

The manufacturer or supplier of each additive was given details of the proposed fire load in order for them to recommend the ideal concentration of the additive in water for fighting the fire. The concentration that is listed in the table below is the one that they recommended specifically for these tests.

Details of the mixing and use of the firefighting solution are included in Section 3.6.2.

Name used for test purposes	Manufacturer	Additive	Additive concentration in water (%)
AFFF	3M	Lightwater (AFFF)	3
Forexpan Expandol	Angus	Forexpan S Expandol (Synthetic)	0.5 3
Silv-ex	Ansul	Silv-ex	0.5
Chubb 1%	Chubb	Chubb Class A 1%	1
Chemguard	Chemguard	C-111 Class A Plus Foam	0.5
Control A	Drexel	Control A	0.5
Fire Out I	Thermal Science & Technology	Fire Out I	0.3
Cold Fire	Fire Safety Services	Cold Fire	3
Fuel Buster	Fuel Buster	Fuel Buster	1
Phos-Chek	Monsanto	Phos-Chek	1
1st Defense	National Foam	1st Defense	1
Phirex + Ecofoam	Phirex +	Phirex + Ecofoam	1 1
JJD	JJD/Spumifer American Co.	Class A Concentrate	0.025

Table 1 : The additives used during testing

3.4 Fire Load

3.4.1 Selecting the Fire Load

In order to keep costs down during this exploratory stage of testing, it was decided that standard wooden pallets should be used as the fire load. A simple pallet design was selected (see Figure 3).

In the 1988 FEU tests three cribs were used in each test (two of size 27A and one of size 34A). These were extinguished within 2 minutes with a handheld hosereel delivering the firefighting solution at a flowrate of 100 litres per minute (lpm). In the tests reported here, it was decided to try to increase the firefighting time and hence the discrimination between good and poor firefighting solution by increasing the fireload by at least a factor of 2 but still using a flowrate of 100 lpm.

The open surface area of wood was considered to be a critical factor of the fire load. Three cribs, as used in 1988, gave a total surface area of approximately $79m^2$. Using pallets 1.2 m square, as shown in Figure 3, 54 pallets gave approximately twice that surface area. However in order to have a symmetrical fire load, it was decided to use 56 pallets (4 stacks of 14 pallets, surface area $164m^2$). Each pallet weighed approximately 21 kg making a total fire load of almost 1.2 tonnes.

The pallets were stacked on a steel test rig (see Figure 4) which held the bottom pallet 0.25 m off the ground. The pallets alone were 1.7m tall; together the stack of pallets on the stand stood 1.95m tall. The 4 stacks of pallets were arranged in a square formation as shown in Figure 5. Each side of the fire had one open face (the fronts of the pallets) and one closed face (the sides of the pallets).

3.4.2 Conditioning the Pallets

The pallets were new and made from home-grown softwood. They were made by Hambrook Pallets of Bristol[1] (superscripts refer to notes on page 42 of this report). Pallets for the preliminary fire were delivered on 30th March 1995, the rest were purchased in 3 batches, each of 560 pallets, delivered on 28th April, 19th May and 10th August 1995.

When the pallets were delivered in April, their moisture content was high and it was hoped that the pallets would dry out while they were stored in the Still Air Facility. However, the temperature and humidity in the Facility in the spring were such that, after several weeks, the wood moisture content had not reduced.

Consequently, the pallets had to be conditioned by putting them into two containers each one with one fixed and one portable[2] dehumidifier. The pallets were checked daily using a Protimeter wood moisture content meter[3]. Each container contained enough wood for two tests and it took approximately two days to bring the moisture content of the wood to within acceptable limits.

By the summer, the later batches of pallets were dryer when they were delivered and they dried to acceptable moisture content levels in the Still Air Facility without the need for dehumidifiers.

3.4.3 Priming Fuel

A tray, 1.5 m x 0.8 m, containing 6.25 litres of heptane[4] on a water base was positioned beneath each stack of pallets. The trays were arranged underneath the test rigs as shown in Figure 6, with the back of the tray level with the back of the rig, and the front of the tray extending 30 cm in front of the rig.

A requirement of the fire test method described in BS EN 3 (Reference 14) is that the priming fuel trays should be removed from under the cribs after a 2 minute preburn. Previous tests carried out by the FEU have concluded that a preferable procedure is to achieve an approximate preburn time of two minutes by pouring a known quantity of heptane into each tray. Given the surface area of the tray and the burning rate of heptane, it was calculated that 6.25 litres of heptane would burn out after 2 minutes.

A water base was provided in each tray to give a level surface for the heptane and to provide some protection for the trays. The water was sufficient to cover all of the bottom surface of the trays, to at least 25 mm depth.

Four cans of heptane were measured out before each test, one for each tray. For each can, 6.25 litres of heptane was pumped from a 200 litre drum into a perspex measuring cylinder. It was then poured into the 10 litre steel fuel can[5]. This operation took place in a fuel store outside the Still Air Facility. The fuel cans were loaded on to a wheeled trolley and taken into the Still Air Facility when they were needed.

3.4.4 Detonators

To ignite the heptane, an electrically operated detonator[6] was placed in a clip within each tray. The clips fitted over the lip of the tray and held the detonator just above the surface of the priming fuel. The detonators were wired in parallel and connected to a firing box in the instrumentation pod by a system of two core cable and ceramic connectors. This enabled them to be simultaneously fired when required. Each detonator was also wired with a shorting link for safety. During all operations involving the detonators, the safety key was removed from the firing box and was in the possession of the person responsible for detonator handling. Prior to the commencement of each test, the safety key was handed to the project officer to be placed in to the firing box.

3.5 Instrumentation

3.5.1 Thermocouples

During a preliminary fire, 3 thermocouples[7] were positioned at heights of 0.5 m, 1.0 m and 1.5 m in the centre of the fire, between the stacks of pallets. The tips of the thermocouples were cemented into 2 m long stainless steel tubes which were clamped to a metal frame. The thermocouples were used to give information on the temperature in localised positions of the fire.

After the preliminary fire, it was decided not to use the thermocouples during the other tests, but to use radiometer information to give a more general indication of fire progress. This is discussed further in Section 4.2.2.

3.5.2 Radiometers

The heat output of the fire was measured using four radiometers[8], each with a 180° field of view. Each was positioned on a bracket clamped to a stanchion of the smoke hood (see Figure 7). The radiometers were positioned at a height of 2m and the front faces were 0.25m from the inner side of the stanchion and with their faces vertical. The front face of each radiometer was 4.25m horizontally from the closest face of the stack of pallets. The positioning of the pallets meant that each radiometer could see one open face and one closed face of the stacks (see Section 3.4.1 and Figure 5).

The radiometers were cooled by recirculating water from a tank using an electric pump[9]. Each pump serviced two radiometers. The pumps and water were housed in plastic tanks which were shielded from the heat by large metal plates. They were positioned outside the area under the hood, and centrally between the stanchions (see Figure 2).

The radiometer signals were recorded once a second on to a Scorpio datalogger[10] located in the instrumentation pod.

Prior to each test, the radiometers were checked using a 600 W lamp[11] at a fixed distance from the radiometer face. This ensured that the readings were consistent and that the radiometers were operating correctly.

3.5.3 Video Recordings

Each test was recorded by two video cameras[12]. The cameras were positioned between the stanchions, slightly off centre, opposite each other (see Figure 2). Each was able to see two sides of the fire. The video signals were recorded on U-matic video recorders[13] in the instrumentation pod. Large clocks[14] were positioned in the field of view of the cameras, giving a visible record of test time on the video recording.

3.5.4 Wood Moisture Content

The wood moisture content of the pallets was monitored regularly. Readings were taken from a variety of locations throughout the stacks of stored pallets using the Protimeter Timbermaster[3].

The wood moisture content of the specific pallets to be used in a test was measured immediately prior to each test. After the pallets had been positioned, 4 measurements were taken in each of the 4 stacks. Samples of 2 bearers and 2 deckboards (one of each in a high and a low pallet) were measured in each stack. The 16 measurements were used to calculate a mean wood moisture content for the total fire load.

3.5.5 Ambient Temperature and Humidity

The ambient temperature and humidity[15] in the Still Air Facility were noted immediately prior to ignition of each fire and recorded on the Scorpio datalogger throughout each test.

3.5.6 Datalogging

The radiometer data, ambient air temperature and humidity and the firefighting solution flow and pump pressure were recorded on the Scorpio datalogger. The datalogger was connected, via a GPIB interface[16] to a computer running Windows based software[17]. This enabled the datalogger to be controlled from the computer, and aided the transfer of data on to spreadsheet software after each test.

The large clocks and the datalogger program were both initiated by the same start signal.

3.5.7 Timing

Two large clocks were placed outside the test area and in view of the cameras. Prior to the tests they were set to 99:00 (minutes : seconds) to give a 1 minute countdown to 00:00 when the fire was ignited. The clocks were visible to all personnel.

3.5.8 Flowmeter and Associated Equipment

A diagram of the hydraulic arrangement for the tests is shown as Figure 8. The flowrate of firefighting solution to the branch was monitored using an electromagnetic flowmeter[18] connected to a digital display[19] which indicated the flowrate in litres per minute (lpm). An analogue output was connected to the Scorpio datalogger to record flowrate during the tests. A pipe, with a temperature transducer fitted into a tapping, was also connected to the hoseline. The transducer[20] was connected to a digital indicator[21] and measured the temperature of the firefighting solution being delivered to the branch.

A pressure tapping tube was connected to the outlet of the flowmeter to record the pressure near the pump. This was connected to a pressure transducer which fed the output to a digital readout and to the Scorpio datalogger.

The flowmeter, temperature transducer, pressure gauge and associated equipment were mounted on a trolley so that the pump operator could set and adjust the pump throttle while monitoring the flowrate and pressure.

3.5.9 Foam Measurement

Foam was collected and measured immediately after firefighting ceased. The branch was directed at an aluminium collector which directed foam into a 1600 ml brass collecting pot. Measurements of foam expansion ratio and, where possible, drainage time were made

Details of the procedure and equipment used are contained in BS ISO standard 7203-1 (Reference 16).

3.6 Firefighting Equipment

3.6.1 General

Firefighting was carried out by an experienced local authority firefighter. The same firefighter fought all of the fires in the 1995 series of tests to ensure consistency. Safety cover was provided by another firefighter who also moved the hose and, in the later stages of the test, helped to check for areas that needed further firefighting.

The primary firefighter wore breathing apparatus (BA) because of his proximity to the fire. The back up firefighter did not wear BA.

3.6.2 Firefighting Solution

A premix firefighting solution was made up in a clean fibre glass tank. The tank was located on a platform scale[22] to enable the required amount of water to be accurately weighed on it. Five minutes before each test, additive was measured into the water in the tank using calibrated containers and then thoroughly mixed to achieve the manufacturers' recommended concentration. For each test either 1000 litres or 1500 litres of firefighting solution was made up. A fresh firefighting solution was made for each test. In tests using water alone, the water was also used from the premix tank.

3.6.3 Hydraulic Arrangement

A schematic diagram of the hydraulic arrangement is shown as Figure 8.

A suction hose was connected to the pump and the open end was placed in the premix tank. A single 3m length of 19mm bore, high pressure 'hosereel' hose connected the high pressure outlet of the FEU appliance pump to the inlet of the flowmeter. A pressure tapping tube was connected onto the outlet of the flowmeter, with the readout on the flowmeter trolley. The pressure and flow readings were fed back to be recorded on to the datalogger in the instrumentation pod. Three lengths of 19mm bore hosereel were connected, via hermaphrodite couplings, at one end to the outlet of the flowmeter and at the other to the branch used for firefighting .

Measurements of the pressure at the branch were also taken at the beginning of the series of tests, for information only.

3.6.4 Firefighting Branch

The branch used throughout the tests was the Elkhart SFS 'Select-O-Stream' hosereel gun[23] (see Figure 9). The branch had been included in the FEU Appraisal of Jet/Spray branches (Reference 17). It was selected because it had an adjusting collar located into grooves which allowed fast, repeatable switching from a fixed jet to a fixed spray. During tests, when the branch was changed from a jet to a spray after 1 minute, the ability to find and maintain a specific jet or spray pattern was particularly important. The adjusting collar could be set to provide two spray patterns, the narrower spray produced a spray with an included angle of approximately 60° and was used for the spray phase of firefighting throughout the 1995 tests.

3.6.5 Flowrate

Initially it had been intended to use a flowrate of 100 lpm in keeping with the 1988 FEU tests (Reference 10). However, after a number of preliminary tests (see Section 4.3), it became clear that this would not provide sufficient discrimination between additives and so the flowrate was reduced to 50 lpm.

The flowrate was constantly monitored during the firefighting phase of the tests using the flowmeter digital readout (see Section 3.5.8). It was set prior to the commencement of firefighting and minor adjustments were made to maintain this flowrate, if necessary, using the appliance throttle.

3.7 Safety

A safety procedure was followed for each test. This included fire cover for all heptane transfer operations and throughout the fire tests. Appendix B contains a copy of the safety notes produced for these fire tests.

4. DEVELOPMENT OF THE FIRE TEST METHOD

4.1 Test Schedule

The first test carried out was a preliminary test, to help establish the test procedure, in particular the length of preburn required to achieve a stable fire. The results of the preliminary test are discussed in Section 4.2.2 and it was hoped that the subsequent test method could be based upon these results. However, in the next 6 tests a number of issues arose, all of which required modification to the test method. Table 6 lists the test methods used in Tests 1 - 6 and the results are discussed in Section 4.3. After Test 6 the fire tests followed a consistent method and contributed to useful test data, although the test method had to be amended again after Test 23 (see Section 5.1) following a series of stack collapses that invalidated several results.

Table 7 lists the tests that were carried out using the finalised test method.

4.2 Preliminary Test Fire

4.2.1 General

A preliminary fire was carried out in which the fire load was allowed to burn freely until the stacks had collapsed. Once that had occurred the fire was cooled and extinguished using 100 lpm of water through the test branch.

One of the points to be established by the preliminary fire was how long the pallets should be allowed to burn before firefighting commenced. Ideally the fire would be burning strongly but steadily, without the possibility of any of the stacks of pallets collapsing. Firefighting was required to be safe but sufficiently taxing to produce significant differences between good and poor firefighting solutions. The preliminary fire enabled the firefighter to plan his firefighting strategy.

Measurements of the radiated heat output of the fire and the temperature at three heights in the centre of the stacks were recorded. Figure 10 shows the radiometer results and Figure 11 the thermocouple results of the preliminary fire.

4.2.2 Discussion of the Preliminary Fire

4.2.2.1 Preburn Time

The fire reached an equilibrium at about 5 - 6 minutes from ignition and the pallets did not collapse until over 9 minutes from ignition. The pallets started to collapse as the horizontal bearers burned through. On the basis of the progress of this fire, it was decided that a preburn time of 6 minutes should be used.

4.2.2.2 Thermocouple Results

Thermocouples had been used in the 1988 FEU work (Reference 10) and in the German work on Class A foam (Reference 13), and values that could be used to compare these previous tests with the current tests would have been desirable. However, the 1988 FEU work involved three cribs in an enclosed room and a large number of thermocouples were used to calculate an average temperature within the room. The cribs were arranged around the edges of the room and so the thermocouple cables were taken from the centre of the cribs, out through the walls of the room.

The preliminary fire test showed that it was not feasible to use thermocouples during these fires; the rigs that were used to hold the thermocouples in position were damaged beyond repair after the preliminary fire and the cables presented a trip hazard to the firefighter. There were not enough thermocouples to give a good record of the whole fire. They were prone to the effects of individual flames and localised conditions. During firefighting the readings fluctuated considerably (see Figure 11).

4.2.2.3 Radiometers

The information provided by the radiometers in the preliminary fire gave a good indication of the fire as a whole. Figure 10 shows each radiometer reading as an individual trace before any data processing was carried out.

It was decided that the radiated heat output, as recorded using the radiometers, would be used as the primary indicator of the performance of the firefighting solution.

4.2.2.4 Stack Collapses

During the preliminary fire, the stacks of pallets stayed intact for over 9 minutes from ignition. This suggested that using a preburn time of around 5 or 6 minutes should ensure that no stacks would collapse during the test.

4.3 Tests 1 to 6

4.3.1 General

Tests 1 to 6 were used to develop the test method fully. The methods used are listed in Table 6.

4.3.2 Discussion of Tests 1 to 6

Although it had been hoped to establish a consistent test method using the results from the preliminary fire this did not prove possible. The firefighting time and flowrate, and the preburn were all varied to try to produce an ideal test fire.

Tests 1 - 4 used a flowrate of 100 lpm with the branch on a jet setting for 30 seconds and then on a spray setting for the remainder of each test. This flowrate was used for consistency with tests carried out in 1988 and because it is a typical operational flowrate. However, this flowrate proved too high as the fires were too easily extinguished. It was reduced to 75 lpm in Test 5 and 50 lpm in Test 6.

With the lower flowrate used for Test 6, the firefighting time using the jet setting was extended to 1 minute. This enabled the firefighter to adequately achieve initial knockdown with the reduced throw of the jet and then allowed him close enough access to the fire with the branch on the spray setting.

Tests 1,2,4,5 and 6 all used a preburn time of 6 minutes. In Tests 2 and 6 stacks collapsed invalidating the results of the test. The characteristics of the fire were changed to such an extent that the results were no longer comparable to other data. To try and prevent this, the preburn was reduced to 5 minutes in Test 3. This fire was poor, with a low maximum radiated heat output and so a preburn time of 5½ minutes was selected for Test 7 onwards. Further details of the finalised test method are included in Section 5.

5. THE 1995 FINAL TEST METHOD

5.1 General

Following the development of the test method during the preliminary fires, Tests 7 to 23 were carried out with the following parameters:

- Preburn time 5½ minutes
- Flowrate 50 lpm
- The firefighter fought the fire for 1 minute with a jet setting, and then switched to a spray.

Tests 24 to 30 used a preburn time of 5 minutes (see Section 7.1 for the full reasons behind this decision), but all other parameters remained the same.

Details of the test procedure are contained in Sections 5.2 to 5.3.

5.2 Experimental Procedure

The 4 test rigs were positioned centrally under the hood and the pallets stacked, 14 high, on top of them. The pallets were carefully positioned and knocked together with a mallet to ensure that all air spaces between stacks of pallets were kept to a minimum.

The 4 priming fuel trays were then pushed into position under the stands. Enough water was put into each of the trays to cover the bottom surface by at least 25mm. The moisture content of the pallets was recorded.

6.25 litres of heptane were transferred into each of 4 smaller, flammable liquid containers. These smaller containers were placed on a hand trolley which was positioned in a coned off flammable liquid area inside the Still Air Facility.

The detonators were set up and checked before the fuel was transferred to the trays, they were then removed during fuel transfer. During all operations involving the detonators, the safety key was removed from the firing box and was in the possession of the person responsible for detonator handling.

1,500 or 1,000 litres of water was measured into a large tank and the additive was mixed into it to produce the firefighting solution (see Section 3.6.2). Where water alone was used it was also used from the tank, but not measured.

Once the pallets and the firefighting solution were ready, the trolley containing the four cans of priming fuel was moved over to the hood and one can of fuel was poured into each tray. One fire officer transferred the fuel, the other provided fire cover with a dry powder extinguisher.

The fuel temperature in each of the trays was noted. The detonators, in their clips, were placed over the edge of the trays and the shorting links were cut. The safety key was then handed to the project officer who placed it in the firing box.

Three tones were sounded over a PA system and the clocks were started (preset to 99:00). The datalogger and video recorders were started. After 1 minute, with the clocks reading 00:00, the detonators were fired.

A preburn was allowed (of 5 or 5½ minutes). During the final 90 seconds of the preburn the pump was run up to the required operating conditions (flowrate 50 lpm). This also ensured that all water had been flushed out and firefighting solution was flowing correctly as firefighting commenced. Until this time the firefighting solution was kept out of the area under the hood.

The pump operator monitored and recorded the flowrate and pump pressure throughout the test and adjusted the pump, when necessary, to maintain the required flowrate. He also noted the temperature of the firefighting solution displayed by the in-line temperature display.

At the end of the preburn, firefighting commenced. The firefighting procedure is described in more detail in Section 5.3. Firefighting ceased when the firefighter deemed that the fire was sufficiently extinguished.

After firefighting had ceased, foam measurements of the firefighting solution were made.

The fire was left for 10 minutes to establish whether any burnback occurred. After this time the level of burnback was noted and the test was deemed to have ended. If the fire had burned back, the firefighter extinguished it and damped it down until it was safe and cool.

After a test was over, the main doors to the Still Air Facility were opened to allow any smoke to clear. The pallets were then removed to skips outside the Still Air Facility and the area was cleared. The area under the hood was then washed down before the next test. The fuel trays and stands were cleaned and all firefighting solution from the previous test was cleared away. The radiometers were checked (see Section 3.5.2).

A check list, used to ensure all procedures had been completed, is contained in Appendix C.

5.3 Firefighting Procedure

The firefighter's instructions were to extinguish the fire as quickly as possible, but in a consistent manner. He was to use his own judgement on how close to approach the fire, and on when to cease firefighting. However each fire was to be extinguished to the same conditions as far as was possible.

In order to maintain the application rate of the firefighting solution, the firefighter was not allowed to adjust the branch spray pattern *except* at 1 minute after firefighting commenced, when the branch was turned from jet to spray. He was not allowed to switch the branch off until firefighting was complete.

Figure 12 shows the fire approximately 2 minutes into the preburn, with the heptane just burning out and the closed and open sides of the stacks burning distinctly differently. Firefighting was therefore concentrated on the open sides of the stacks because it had far more effect than on the closed sides.

Smaller compartments were also created between the horizontal (deckboards) and vertical members (bearers) of the pallets. Figure 12 also shows this effect. To extinguish the fire fully, the spray had to enter each compartment and fight each small fire individually. During the final 90 seconds of the preburn the firefighter opened the branch to allow the pump operator to adjust the pump to provide the correct conditions. The project officer called the time 10 seconds before the end of the preburn, when the firefighter moved towards the area of the smoke hood. At 5 seconds before the end of the preburn the project officer started to count down and the firefighter moved into position with the branch pointing downwards. At the end of the preburn, firefighting commenced. For the purposes of this report, the stacks of pallets will be called A, B, C and D.

The fires were fought in the following predetermined manner:

Starting at stack A, the firefighter was to commence firefighting. In the first minute he was to travel anticlockwise around the fire, tackling B and C until he reached the far side of Stack D. There, at one minute after the start of firefighting, he would switch the branch from a jet to a spray, change direction and return the way he had come until he was back to the start. This was to be repeated until the fire was almost extinguished and the areas that needed further firefighting were more dispersed. Then the routine became less strict and hotspots were tackled individually.

During the first minute of firefighting, times were called out at regular intervals so that the firefighter was aware of the time spent on each stack. He could then move on at approximately 15 second intervals.

The first sweep around the stacks was a quick sweep to knock down the worst of the burning. The second and third sweeps became more methodically fought, attacking the open side of the stack and spraying into each compartment up one side of the central bearers and then into each compartment down the other side. Later sweeps were dependent upon the areas that needed more attention.

The time at which firefighting ceased was decided by the firefighter and was described as "the time at which the firefighter would be happy to leave the fire to be dragged apart and damped down". In some cases embers and hot spots had to be left because the spray would not reach them despite efforts by the firefighter.

Table 2 below shows the sequence of events during a test.

Time from Ignition (mins)	
-1:00	Test commences, instrumentation and video recording started
0:00	Detonators ignite the heptane
2:00 approx	Heptane burns out
4:00 (3:30 in later tests)	Branch opened, pump run up to correct pressure and flow rate
5:30 (5:00 in later tests)	Firefighting commences on jet setting
6:30 (6:00 in later tests)	Branch turned from jet to spray

Table 2 : A summary of events and times during a test

6. RESULTS OF THE 1995 TESTS

6.1 General

Tests 7 - 23 were carried out with a 5½ minute preburn. However, as the stacks of pallets collapsed during several of the tests, it was decided to reduce the preburn time for Tests 24 - 30 to 5 minutes.

The results of tests 7 - 30 are shown in Table 7 to Table 12. A summary of the contents of each table is given below:

Table	Contents	Associated Section or Figure
7	Additive used and solution concentration with water	Section 3.3
	Number of stack collapses	Sections 4.2.2 and
	Preburn time	7.1
	Wood moisture content	Section 3.5.4
8	Time spent firefighting	Section 6.2 and
	Time of the last major flame	Figure 13

9	Radiometer results - Time to 90% and 95% reduction in heat output Maximum radiated heat during the preburn	Appendix D and Section 6.3.2
10	Area under the normalised radiated heat curve over : the first minute, the second minute the first two minutes of firefighting	Section 6.3.3
	Percentage reduction in area under the normalised radiated heat curve	Section 6.3.4
11	Pump pressure and firefighting solution temperature	Section 6.4
12	Foam expansion ratio	Section 6.5

Table 7 contains a column showing tests where one or more of the stacks of pallets collapsed before or during firefighting. When a stack of pallets collapsed, it altered the burning characteristics of the fire so that the data from that test was not valid for comparison with that from other tests. Table 7 therefore indicates which of the tests can be regarded as 'successful' in that they provide valid results. The results for unsuccessful fires are included in Tables 7 to 12, but the rows containing the results of those tests are written in italics and shaded grey. This format will be used throughout this report.

Tests with a 5 minute preburn cannot be directly compared with those with a 5½ minute preburn. The results are separated in the tables using a double line. Tests using water as the firefighting solution were carried out with both preburn times to give comparative data in either case. Where possible, tests where a stack collapse had occurred were repeated to provide valid data for each additive, however this was not possible in all cases.

During Test 13 the pump lost suction during the firefighting phase and so the flow of firefighting solution failed. Nevertheless, it is included in the tables of results as an invalid test.

6.2 Firefighting Time, Last Major Flame and Video Observations

The length of time that the firefighter spent firefighting is recorded in Table 8 (the column headed 'Firefighting time'). The firefighter kept the firefighting solution flowing throughout the test until he was satisfied that the fire was extinguished. Times are stated from the start of firefighting until the firefighter stepped back from the fire and turned off the branch. The times were noted during the test and checked on videotape later.

Table 8 also contains the results of the time at which the last flame was visible *through* the top of the stacks of pallets. This was considered to be the 'last major flame'. Video observations showed that, as the firefighter tackled the last stack that was still alight, the major flames ceased suddenly. In some tests, some small flames were left burning within the stacks, but they were not burning through the stack and extinguishing them was more dependent on their accessibility than the performance of the firefighting solution.

The firefighting time and time of the last major flame are shown in Figure 13 as a bar graph.

6.3 Radiometer Results - Data Processing

6.3.1 General

The raw data from the radiometers was imported from the datalogger into a spreadsheet[24]. Figure 14 shows a typical radiometer output graph of a successful fire (no stack collapses) before any data processing has been carried out.

The radiometer data was processed to give a standardised measure of the effects of the firefighting solution on the fire. Several data processing methods were tried, not all of them successfully. The methods, and the reasons behind them, are briefly summarised in the following sections, and described fully in Appendix D.

6.3.2 Reduction in Radiated Heat Output

The data was reduced following a procedure given in the BS/ISO standard (Reference 16) for foam concentrates for use on Class B fires. This procedure calculates the mean value for the radiometer readings and then normalises the data, so that for each test firefighting commences with a maximum radiated heat output equal to 1. Then, the time taken for the maximum radiated heat output of the fire to reduce by 90% and 95% can be found.

Table 9 contains the results of the above processing. The figures for the maximum radiated heat output of the fire (measured at the end of the preburn) have also been included. These give an indication of the variability between fires.

An annotated graph of a typical smoothed, normalised radiant heat output is shown as Figure 15. Graphs of all tests are shown as Figure 16 (5½ minute preburn) and Figure 17 (5 minute preburn).

6.3.3 Area under the Radiated Heat Output Curve

For reasons that are discussed more fully in Section 7.5.1 of this report, the times to achieve the reductions in radiated heat were not the best measures of the performance of the firefighting solution. Instead it was decided to consider the area under the mean radiated heat curve. The area under this curve gives an indication of how quickly the fire was reduced and how much it burned back while firefighting continued on the other side of the fire. The area was calculated over the first minute of firefighting, the second minute and over the first and second minutes together.

The results of these calculations are listed in Table 10 and shown as a bar chart in Figure 18 and Figure 19 and discussed in Section 7.5.2.

6.3.4 Percentage Reduction in Radiated Heat Output

From the area under the curve, the percentage heat reduction was calculated (see Appendix D). These values are also recorded in Table 10 and discussed in Section 7.5.3.

6.4 Flow and Pressure Results

The flow and pressure at the pump were recorded on the datalogger. The pressure results are recorded in Table 11, the flow was controlled at 50 lpm and is therefore not listed in the table. Figure 20 is a graph of the flow during a typical test. The flow was stable throughout each test.

The pressure results show a degree of variation, in particular Tests 21 to 23 show a markedly lower pressure (5.9 bar) for a flow of 50 lpm. The variations are largely due to the branch that was selected. The Elkhart Select-O-Stream branch can be adjusted in two ways during firefighting. The adjustable spray pattern is the reason the branch was selected for these tests. A notched ring allows the spray pattern to be adjusted to a jet setting or any one of 5 spray settings. Figure 21 shows the notches for the spray settings. The jet setting and the first (narrowest) spray setting were used during testing.

Behind the notched ring is another collar, allowing the flowrate to be altered under normal operational circumstances. There are 4 discrete settings on this collar, marked in US gallons per minute (GPM) 10, 20, 30 and 'Flush'. The flush setting opens the branch fully to allow any dirt or grit to be flushed out. The branch should have been set to the 10 GPM setting on the flow collar for all tests. However, the design of the branch was such that the flow collar setting could be overlooked. It is believed that the flow collar setting was mistakenly altered to the 20 GPM setting during Tests 21 to 23. In this case, with the pump operator controlling the flow to a constant 50 lpm, the pressure dropped. This accounts for the lower pressures recorded during these tests. Tests 21 to 23 were carried out on the same day, in later tests the flow collar was returned to its correct position.

The tests apart from Tests 21 to 23 showed pressure varying between 8.3 and 13.1 bar. Later tests using the branch indicated that with a constant flow, the pressure did vary between tests, although it remained constant during the test.

The pressure summary for all 1995 tests was:

Minimum	Maximum	Mean	Standard deviation
5.8 bar	14.0 bar	11.1 bar	2.6

When Tests 21 to 23 were taken out of the calculation the results were:

Minimum	Maximum	Mean	Standard deviation
9.2 bar	14.0 bar	11.8 bar	1.8

6.5 Foam Test Results

After each test using an additive, the firefighting solution was directed on to a foam collector and its expansion ratio measured (see Section 3.5.9). It was not possible to measure the drainage time of the foam because it drained off so quickly. The results of the foam testing are shown in Table 12.

7. DISCUSSION OF THE 1995 RESULTS

7.1 Stack Collapses

The number of stack collapses was a major problem in the test procedure. A number of factors affected the likelihood of stack collapse:

- The moisture content of the wood - in general, the lower the moisture content, the faster the wood burned and the more likely it was to collapse.
- The quality of the pallets - the pallets used in the preliminary fire, delivered in a batch of 60 pallets, did not begin to collapse until after 9 minutes of burning. After the preliminary fire, pallets were delivered in batches of 560 at a time and later collapses tended to occur in groups, suggesting that some aspect of the particular batch of pallets was causing the collapses. Some defects were apparent, e.g. knots in the wood, sections that were not square or had visible damage, nails at an angle.

- The accuracy of the stacking - the stacks would resist collapse for longer if they were stacked squarely on top of each other. In this way the weight would be directly downwards, on to the strongest section of the pallets.

As tests progressed, each of these issues was addressed to try and reduce the number of stack collapses:

The first issue was addressed by conditioning the wood to a moisture content of 15% ± 2.5%. In planning the tests it had been hoped that, for the purposes of an initial broad picture of the effectiveness of Class A additives, it would be possible to use unconditioned wood. This proved unrealistic and so the wood moisture content was controlled to 15% ± 2.5%, the limits as specified for crib wood in BS EN 3 (Reference 14). Although this improved the consistency of the fire load, it did not eliminate stack collapses.

In response to the second point, the manufacturers of the pallets were alerted to the variable quality of their products. The last batch of pallets produced fewer stack collapses than the previous one.

All stacks of pallets were positioned on the rig and then the individual pallets were knocked accurately into position with a mallet. The alignment was closely checked prior to a test.

After a series of stack collapses during tests 20 - 23 the preburn time was reduced to 5 minutes. During Test 3 this preburn time was tried but found to be easy to extinguish with 100 lpm of firefighting solution. However tests after Test 23 all used a preburn of 5 minutes and produced reasonable results with a flow rate of 50 lpm. Except for Test 27, all of the tests with a 5 minute preburn were carried out without stack collapse.

7.2 The Effects of the Branch Setting

At the beginning of the series of tests, the firefighter was consulted for advice on firefighting techniques. The firefighter's preferred method of attack was to use the branch on a jet setting. His rationale was to increase the throw of the firefighting solution, which enabled him to stand further from the fire for the initial attack. The jet also gave greater penetration of the fire. It was the way he would have tackled the fire in an operational situation.

For experimental purposes, the preferred firefighting method would be one that was only just capable of extinguishing the fire. This would provide better discrimination between good and poor firefighting solutions.

The manufacturers of the additives were consulted during the planning stages of these tests to ascertain their preferred application method. Those who expressed a preference said that a narrow spray was the optimum use of the firefighting solution, although it could be applied using a jet or spray setting.

So, although there were some aspects to recommend using a spray, the safety of the firefighter was considered paramount and a jet was used for the initial attack. After 1 minute this was changed to a spray setting.

The effect of firefighting on the radiated heat output of the fire can be seen by looking at Figure 15. Comparisons of the test results are shown as the bar charts Figure 18 (the area under the curve over the first minute of firefighting) and Figure 19 (the area under the curve over the second minute of firefighting). In these graphs, the majority of the fire knockdown occurs in the first minute. The firefighting in the second minute causes a much smaller drop in the radiated heat output. The differences between tests are more marked where the spray setting was used than when the jet setting was used. While this could be ascribed to the difference in branch settings, it may be due to the different states of the fire at the start of the measurement time and no conclusions can be drawn about the efficacy of the branch setting.

7.3 Firefighting Time

As the firefighter travelled around the fireload for the first time, with the branch set to jet, the fire was greatly reduced. However, as he started his return sweep, with the branch now turned to spray, the first stack began to burn back strongly, as did the other stacks in turn. Equally when he had arrived back at the start point for the second time, the last stack had reignited again.

There was a careful balance to achieve between cooling and damping each stack so that it did not reignite so readily, and passing from stack to stack quickly so that the fire did not have a chance to build back up. As the fire progressively reduced, it reached a state where the stack furthest from the current firefighting position did not fully reignite in the time it took to make a complete sweep of the fire.

Pockets of flame did persist inside the pallets once this stage had been reached. These were difficult to access with the spray at a flowrate of 50 lpm and their final extinguishment was more reliant upon finding them and accessing them than in the firefighting solution's ability. For this reason, the firefighting time, which stopped when the firefighter stepped back from the fire (as described in Section 6.2), did not give an accurate picture of the firefighting performance of the solution. A bar chart of the firefighting time and the time of the last major flame is shown as Figure 13.

7.4 Time of the Last Major Flame

The time of the last major flame (see Section 6.2) was also used to measure the performance of the firefighting solution. The time of the last major flame was less reliant on finding and extinguishing the last, small pockets of flame than the firefighting time described in Section 7.3.

Although the time of the last major flame was a more accurate measurement than the firefighting time, the radiated heat output of the fire was considered to give a preferable measurement of the performance of the firefighting solution.

7.5 Radiometer Results

7.5.1 90% and 95% Reduction in Radiated Heat Output

In Section 7.3, the characteristics of the fire during firefighting were described: the initial quick knockdown was followed by several increases in the heat output. This aspect of the tests is relevant to the validity of using the 90% and 95% reductions in heat output (see Section 6.3.2) as a measure of the performance of the additives.

The 90% reduction times produced results that generally fell into one of two categories. On closer inspection, these were found to be dependent on a final peak on the graph. This peak represents a fire burning back in a stack of pallets that has already been virtually extinguished. Although the final 90% or 95% reduction in radiated heat output therefore takes in to account the suppression qualities of the additives, it is almost a matter of chance whether the peak affects the 90% or 95% reduction time. At 80% radiation reduction time the effect of the peak was even more pronounced, although at 95% the results were more acceptable.

This made it difficult to use the 90% and 95% reductions in heat output as reliable indicators of fire extinguishment. Ideally the radiated heat output curve would pass through the reduction limits once only. In fact it passed through several times as the fire grew and was knocked down, which resulted in several possible times to record. Initially a 99% reduction time was considered, but few of the tests reduced to this level of radiated heat during the datalogging period (including the 10 minute period to allow for burnback) because the residual heat in the test area, even after the fire was fully extinguished, was too great.

This method of data processing was rejected as a measure of the firefighting solution performance.

7.5.2 Area Under the Radiated Heat Output Curve

The area under the radiated heat output curve was calculated over the first minute of firefighting, the second minute of firefighting and over the first two minutes together (see Section 6.3.3). Figure 18 shows a bar chart of the results of the area under the radiated heat output curve over the first minute of firefighting and Figure 19 shows the results over the second minute of firefighting.

Where the fire was quickly controlled and extinguished, the radiated heat output fell quickly and stayed low, resulting in a small area under the curve. If the fire was quickly knocked down, but the firefighting solution did not continue to suppress the fire, the area under the curve took into account these peaks and gave a higher result. Where a fire was not controlled in the early firefighting sweeps, the radiated heat output stayed high and increased the area under the curve.

The area considered over the first minute's firefighting provided less discrimination between tests than that over the second. During the first minute the fire was fought with a jet and quickly knocked down. This stage of the tests was strictly timed and displayed the ability of the firefighting solution to cool and penetrate the burning surface.

In the second minute of firefighting the fire in each stack of pallets had recovered to some degree. Firefighting with a spray setting therefore had to knock down this fire and to suppress it so that it did not recover as the firefighter moved on around the stacks.

Some Class A additives performed better than water, while others were only as good as, or worse than water alone.

Table 3 below summarises the results of the area under the radiated heat output curve for the successful tests; the lower the value, the better the additive performed. Water results are shown in bold.

Ecofoam and Forexpan performed poorly in these tests when the results over the first two minutes of firefighting were taken in comparison with water.

Silv-ex, JJD, Control A, Cold Fire, Phos-Chek and Chemguard gave better performances than water when the first two minutes of firefighting were taken into account.

1st Defense performed better than water in the test with a 5½ minute preburn, but worse than water with a 5 minute preburn.

Fire Out I, Chubb 1% additive and Fuel Buster were not tested on successful fires.

Additive Type	Preburn Time (mins)	Area under the Graph		
		First minute	Second minute	First two minutes
Control A	5½	36	3.5	39.5
1st Defense	5½	22	2	24.0
Phirex +	5½	35	8.4	43.4
Ecofoam	5½	38	12.5	50.5
Cold Fire	5½	34	3.7	37.7
Chemguard	5½	38	4.2	40.2
Phos-Chek	5½	38	4.0	42.0
WATER	**5½**	**39**	**8.8**	47.7
JJD	5	32	2.8	34.8
Forexpan	5	32	12.7	44.7
1st Defense	5	30	7.0	37.0
Silv-ex	5	31	2.2	33.2
AFFF	5	32	2.6	34.6
WATER	**5**	**31**	**4.8**	**35.8**

Table 3 : A summary of the results of the area under the radiated heat output curves - 1995 tests

7.5.3 Percentage Heat Reduction

This measure used the area under the curve to calculate the amount by which the heat output had been reduced. In fact the values were all very close and did not add any further information to the values already established. It was not used as a decision making measure. The results are shown in Table 10.

7.6 Additive performance

Class A additives are claimed to have increased suppression qualities over water alone. These qualities should have resulted in a slower reignition of the stacks, which would have enabled a much faster extinguishment. This was not in evidence as is shown in Figure 13. Neither the time of the last major flame, the firefighting times (Section 7.3), nor the areas under the curve (Section 7.5), indicated any great improvement in performance of Class A additive over water alone.

8. CONCLUSIONS OF THE 1995 TESTS

The main measure of the effectiveness of the firefighting solution was the area under the radiated heat curve.

Some variations in firefighting performance were shown in the results of the tests. However, the differences were slight and it was difficult to separate inevitable experimental variation and genuine improvements in firefighting performance. Not all additives were successfully tested due to stack collapses which nullified the results of the tests.

The initial aim of this part of the project was to establish whether there were any broad benefits to be gained by the use of Class A additives. If there were, the next stage of the project would aim to evaluate those improvements. If there were obviously no benefits, the project would not be continued.

The results of the 1995 tests were analysed and presented to a steering group of Her Majesty's Fire Service Inspectorate. The options available to them were to:

- continue testing all additives

- continue testing only the more successful additives

- terminate testing altogether

The steering group decided that it would be unreasonable to discount any of the additives on the basis of the slight differences in performance indicated by these results. It was decided that, although the improvements in performance were not as great as the literature had indicated, the second part of the project would be instigated and the additives would all be retested.

9. 1996 TEST APPARATUS AND METHODS

9.1 General

Following the decision to continue testing, modifications were made to the test method to avoid the problems encountered in 1995. Briefly, the problems and solutions were:

Problem in 1995 Tests	Solution for 1996 Tests
• too many stack collapses	• strengthen the pallets
• insufficient discrimination between tests	• alter the firefighting method to exclude any firefighting using the jet
• each additive was only tested once	• each additive should be tested at least twice

The modifications that were made are described in more detail below.

The additives tested were the same as those used in 1995 (see Section 3.3) and from the same batches. The only change was that Cold Fire was no longer available. Attempts were made to obtain more supplies, but the original supplier could not be contacted.

Safety notes for the 1996 tests are not included because they are generally very similar to those included as Appendix B for the 1995 tests.

A preburn time of 5½ minutes was used throughout the 1996 tests. Firefighting was carried out using the spray setting only (see Section 9.3).

All other aspects of the tests, methods and instrumentation remained as they had been in 1995 (see Section 3).

9.2 Fire Load

9.2.1 Pallet Dimensions

The fire load used in 1996 was similar to that of 1995 (4 x 14 pallets arranged in a square and ignited by heptane, see Section 3.4.1), but the pallets were strengthened. The horizontal bearers of the pallets were increased to 30mm depth from 18 mm (see Figure 3). They were made by Cotswold and Vale Sawmills[25] to an otherwise similar specification to those of 1995.

9.2.2 Conditioning the Pallets

All of the pallets for the 1996 tests were purchased in a single batch. When they were delivered, the pallets were stacked alternately with one pallet the right way up and the next upside down so that they were closely packed for transporting. They were restacked in the Still Air Facility to be all the correct way up, with 14 pallets in each stack ready for use in the fire tests. This also improved the air flow around the wood.

The pallets were left to dry in the Still Air Facility, but after several weeks the wood moisture content had not reduced to 15% ± 2.5%. Therefore the problem of reducing the wood moisture content was approached by contracting a team of salvage specialists[26] to bring in large dehumidifiers to dry out all of the pallets at once.

All 2,020 pallets were arranged in a block and covered with polythene (see Figure 22). Two dehumidifiers and a fan dried and circulated the air around the pallets. The pallets were brought within acceptable wood moisture content limits in 8 days. After this time the dehumidifiers were removed.

To maintain the wood moisture content throughout the duration of the tests the pallets were kept covered with the polythene and the fan was occasionally used to keep air moving around them.

9.3 Firefighting

Because in 1995 such a large proportion of the fire reduction occurred in the first minute of firefighting, with the branch set to jet (see Section 7.2), it was decided that further tests should use the branch on a spray setting only. Although this meant that the firefighter had to start firefighting closer to the fire, because of the reduced throw of the wider spray, it was hoped that the firefighting time would be extended, increasing any variations in the performance of the firefighting solution. The firefighter was instructed to fight the fire as he felt comfortable, without taking unnecessary risks.

The branch and the spray setting were the same as were used in the spray phase of firefighting in 1995 (see Section 3.6.4). A 50 lpm flow was maintained throughout firefighting and the branch was not switched off until firefighting was complete.

The firefighter was not the same local authority firefighter as had fought the 1995 test fires, but a single fire officer fought all of the 1996 fires for consistency.

10. RESULTS OF THE 1996 TESTS

10.1 General

36 fire tests were carried out in 1996. Numbering continued from the previous tests and so the first fire in 1996 was Test 31. All tests had a preburn time of 5½ minutes. The results are contained in Tables 8 to 11 as shown below. The mean normalised radiated heat output graphs of all 1996 tests are included in Figure 23.

Table	Contents	Associated Section or Figure
13	The wood moisture content and ambient conditions	Section 12.2
14	Firefighting time and time of the last major flame	Section 10.2, Section 12.3 Figure 24 and Figure 25
15	The area under the normalised radiated heat output curve and the maximum radiated heat output during the preburn	Section 10.3, Section 11 Figure 26
16	Pressure, firefighting solution temperature and foam expansion ratio results	Section 10.4, Section 10.5

In this series of tests statistical analysis was used to discern whether the results obtained from testing showed genuine differences in extinguishing performance, or whether variations were due to unavoidable experimental variability. The results of the statistical analysis are listed in Table 17 and are discussed more fully in Section 11.

No stack collapses occurred. However in three cases (Tests 34, 43 and 66), the radiometer results were affected by electrical interference which made the results invalid. In each case the test was successfully repeated. During test 34, the firefighting was also affected when the firefighter's BA cylinder ran out of air and the back up firefighter took over the firefighting role. The results of these tests were invalidated, but are included for completeness. The results are shaded grey and written in italics in the results tables.

10.2 Firefighting Time, Last Major Flame and Video Observations

The firefighting time was recorded as the time from commencement of firefighting to the time when the firefighter turned off the branch and stood back from the fire. The branch was not switched off or directed away from the fire at any time during the firefighting phase. Firefighting times are recorded in Table 14.

The decision on when to cease firefighting was left to the firefighter (see Section 5.3). In the 1996 tests the fire was more fully extinguished than in 1995; there were few occasions on which the fire reignited during the 10 minute waiting period after firefighting ceased. After several of the tests, areas of glowing or localised flame remained, although usually this burned out before the end of the waiting period. In only 2 tests did the fire burn back more severely (Tests 35 and 55).

The time of the last major flame was recorded from the video in the same way as it had been in 1995 (see Section 6.2). The flames usually ceased suddenly, and the last major flame was the one that was burning *through* the top of the stack, i.e. small localised flames were discounted. The results of the time of the last major flame are listed in Table 14 and shown as a bar chart in Figure 24.

10.3 Radiometer Results

The radiometer results provided the best indication of the performance of the firefighting solution.

The raw data that was recorded on the datalogger was transferred to a spreadsheet and treated in the same way as it had been in 1995 (see Section 6.3 and Appendix D). The annotated graph in Figure 27 shows the normalised radiant heat output of a typical fire. The primary measure used in the 1996 tests was the area under the curve over the first 4 minutes of firefighting. Various other timescales were considered, but 4 minutes gave the best overall representation of the performance of the firefighting solution. The values for the area under the curve over the first 4 minutes of firefighting are included in Table 15 and are shown in Figure 26. The results are summarised below.

The percentage heat reduction was not calculated because it had not proved to be a useful measure for the 1995 results (see Section 7.5.3).

The area under the curve over 4 minutes gave a single figure representing the performance of the additive. The rate at which the fire was knocked down made the major impact on this figure, with the continued suppression of the fire making a lesser impact.

The results range from a value of 26.2 to 49.2, with a mean value for all additives and water of 34.8. The values give a measure of the overall radiated heat over a given time. The lower the value, the better the firefighting solution has worked. Several of the additives produced consistent results in two or more fires. Chubb 1% additive gave an average result in both tests, Control A and JJD additives were slightly better than average and Silv-ex was slightly worse than average. Expandol, Fuel Buster and Phos-Chek produced results where one result was good and the other poor.

Overall the results did not immediately prove that additives improved the firefighting performance of water, and statistical analysis was carried out to distinguish actual differences from experimental variability (see Section 11).

Additive type	Concen-tration (%)	Area under the graph calculated over the first 4 minutes of firefighting			
		First test	Second test	Subsequent tests	
1st Defense	1	26.2	30.9		
AFFF	3	38.0	33.3		
Chemguard	0.5	36.3	43.4		
Chubb 1%	1	34.8	35.0		
Control A	0.5	33.9	32.9	32.3	
Ecofoam	1	29.5	40.3		
Expandol	3	27.0	42.0		
Fire Out I	0.3	36.2	26.7		
Forexpan	0.5	36.0	32.6		
Fuel Buster	1	49.2	31.3		
JJD	0.025	33.2	31.0		
Phirex +	1	30.5	34.4		
Phos-Chek	1	29.0	43.5		
Silv-ex	0.5	39.1	40.5		
Water		34.3	30.1	36.8	38.1

Table 4 : Results of the area under the graph over 4 minutes - 1996 tests (the lower the value, the better the additive performed).

10.4 Flow and Pressure Results

The flow and pressure were not recorded on the datalogger for the 1996 tests because the information had not proved useful in 1995. The flow was kept constant during firefighting. Both flow and pressure at the pump were noted by the pump operator during the test and the results are included in Table 16.

During the 1996 tests the adjusting collars on the branch were clamped in a fixed position. No alteration in the spray pattern was possible. This also eliminated the risk of accidentally altering the flow collar, although it did prevent the firefighter being able to flush out the branch by turning the flow collar to its widest setting. The results were subject to a similar variability as that experienced during the 1995 tests, probably due to the variability of the branch itself, as much as to the differences between the different firefighting solutions.

The summary of the pressure results for 1996 was:

Minimum	Maximum	Mean	Standard deviation
9.2 bar	14.8 bar	14.0 bar	1.7 bar

These results are similar to the 1995 results.

10.5 Foam Test Results

The foam expansion ratio was tested as described in Section 3.5.9 and the results are included in Table 16. Because the firefighting solution is applied through a jet/spray branch, the expansion ratio is low. The minimum ratio is 1.2 and the maximum for a Class A additive is 2.6. AFFF produced foam with an expansion ratio of 3.3. All the foams produced were too free draining to enable the 25% drainage time measurements to be made; by the time the collecting pot full of foam had been weighed, more than 25% of the firefighting solution had already drained off as a liquid.

11. STATISTICAL ANALYSIS OF THE 1996 RESULTS

11.1 Reasons for Statistical Analysis

Although the results of the area under the curve over 4 minutes show some differences in the firefighting performances of additives during the tests, it was difficult to assess whether these could be assigned to the various additives themselves, or whether they were no more than unavoidable experimental variation. Statistical analysis was used to evaluate these differences. The statistical package SPSS[27] was used for the statistical analysis. The full details of all statistical analyses carried out are contained in Appendix E.

The radiometer readings of Tests 43 and 66 were affected by interference and these results were *not* used in the statistical analysis involving the area under the curve over 4 minutes. They were used in the statistical analysis involving the time at which the last major flame was extinguished. The measurement of the time of the last major flame was not affected by the interference.

The results of Test 34 were not used at all because problems with the firefighter's BA set affected the firefighting technique.

11.2 The Effects of Independent Variables

Initially it was important to ensure that the results of the tests were not significantly affected by any factors except the extinguishing medium. Statistical checks (T-tests) were carried out on the following five factors to find out whether these factors affected each other.

- maximum radiated preburn heat
- wood moisture content
- air temperature in the Still Air Facility
- the humidity in the Still Air Facility
- the area under the curve in the first four minutes of firefighting

These tests showed that there was a significant probability that the following relationships existed.

- wood moisture content and maximum radiated heat are related
- temperature and humidity in the Still Air Facility are related
- air temperature in the Still Air Facility and maximum radiated heat are related.

The first point showed that the wood moisture content affected the maximum radiated preburn heat output of the fire; that is, as the wood moisture content increased, the heat output of the fire decreased. This was minimised as far as possible by conditioning the wood prior to testing.

The second and third points were to be expected and could not be controlled.

The five factors were then checked against the result for the area under the curve over 4 minutes to find out whether they affected that. None of the factors influenced the area under the curve. These statistical checks give confidence that the only differences between the results of the fire tests were caused by the firefighting performances of the different firefighting solutions.

11.3 The Effects of Additives

Statistical tests were carried out on groups of results of the area under the curve over 4 minutes (details of the tests are contained in Appendix E). The aim of the tests was to show whether or not the results could be from the same distribution; that is, whether the additives gave genuinely different results from water alone. To assess this, comparisons were made in two ways:

The results of the area under the graph over 4 minutes were tested to discover:

- whether there was any statistical difference between the results of the water tests in comparison to those of all the additive tests, taken together.

- whether there was any statistical difference between the results of the water tests in comparison to the results for the individual additives.

Considering first of all the comparison of the 4 water test results with all 29 results of additive tests. The statistical tests give a value of 0.991. This indicates a 99% likelihood that the additive results came from the same group of results as the water ones. That means that there is no evidence to suggest any improvement in firefighting performance between Class A additives generically, and water.

The individual additive results were then compared, in turn, with the water results. Table 17 gives the results of these statistical tests. These values tell us the probability that the results for individual additives come from the same distribution as the results for water. For example, the results from 1st Defense additive have only a slightly higher than one in ten chance of coming from the same distribution as the water results (i.e. producing the same results as water).

A figure of 5% or less would indicate a statistically significant change in the results (only a 1 in 20 chance of having the same performance as water). None of the results produced a significantly different performance to water alone.

There is a slight chance that the 1st Defense additive is better than water, but the difference is too small to be proved with this limited number of tests. If more tests were undertaken, the statistical confidence in the results might increase.

12. DISCUSSION OF THE 1996 RESULTS

12.1 General

The results of the 1996 tests failed to show any significant improvement due to the use of Class A additives in place of water alone.

It should be noted that the tests described in this report were rigorously controlled, with all other factors that may have affected the fire kept to a minimum. Under normal operational circumstances there are so many uncontrollable variables affecting the fire, that any change in firefighting performance that may potentially result from the use of Class A additives would probably be rendered unnoticeable.

The manufacturers claim that Class A additives possess a number of characteristics that make them good at extinguishing Class A fires. Firstly, they are oleophilic and contain hydrocarbon surfactants. It is claimed that this makes them behave like super-detergents, forming a bond between carbon and water, causing the additive solution to stick better to solid fuels, making them wetter.

In their foam forms, Class A additives are said to adhere to vertical surfaces, allowing the water contained in the foam to make contact with the fuel. Additionally the foam is said to have a 'fragile bubble structure' which bursts easily, releasing the water on to the surface of the fuel.

These properties have not been investigated in depth during this project. At this stage of the research the only important property of the additive is its firefighting ability. If the addition of Class A additives does not improve firefighting performance over that of water, the other properties of the additives need not be considered further.

In fighting brush fires, Class A additives are claimed to improve the penetration of the solution into the fuel, increasing wetting and cooling and reducing the possibility of the fire reigniting. Thus Class A additives could be claimed to increase the effectiveness of the limited water available to fight brush fires, maximising a valuable resource. Although these properties have not been directly investigated during this project, an improvement would be expected in these tests if there were to be any improvement against brush fires.

Most of the additives are recommended for use at a concentration of 1% or less in water. A small amount of additive will therefore produce a large amount of solution. The cost of the additive per unit volume of solution is therefore low. From the results of the tests described in this paper, even a low additive cost would not be justified by the benefits.

12.2 Test Method

The modifications that had been made to the test method for the 1996 tests - changing the pallet dimensions and firefighting with a spray setting only - were both successful. The stacks of pallets did not collapse during testing. The wood moisture content and maximum radiated heat results were contained within a much narrower range than the 1995 tests, indicating a much more consistent fire. The firefighting time was more discriminating, with an increased range of results. The improvement in these parameters is summarised in Table 5 below.

	1995	1996
Wood moisture content (%)	13.1 to 19.5	13.2 to 16.0
Maximum radiated heat (kW/m^2)	12.0 to 22.0	8.5 to 11.0
Firefighting time (min:sec)	1:52 to 3:47	2:51 to 9:53

Table 5 : The parameter ranges - 1995 tests compared to 1996 tests

Different firefighters fought the 1995 and the 1996 tests. Both were Station Officers in local authority fire brigades and both were given the same instructions, however the interpretations of these instructions varied slightly. In the 1995 tests the fires were 'virtually extinguished' and sometimes reignited in the 10 minutes after firefighting ceased. In the 1996 tests, the fires were extinguished more completely and none reignited in the 10 minutes after firefighting ceased. However within each series of tests only one firefighter was used, thus the firefighting in all 1995 tests is comparable and in all the 1996 tests is comparable. Additionally, the firefighting time was not a primary source of information about the firefighting performance of the additives tested due to the problems of accessing any hot spots at the end of some tests (see Section 12.3).

Overall, the test method provided a good test of the firefighting solution because it tested both the initial flame knockdown and the continued fire suppression.

12.3 Firefighting Time and Video Observations

The firefighting time did not provide a representative indication of the performance of the firefighting solution. Although the firefighting was carried out in a repeatable, methodical manner, the variations in extinguishing the final hot spots made an inordinate impact on the firefighting time.

The time of the last major flame, a measure of the firefighting solution's ability to knock down flames, provided a more useful indication of performance (see Figure 24). However, 30 of the 33 valid last major flame results were within 2 minutes of each other, suggesting that most of the firefighting solutions initially knocked down the fire in a broadly similar time.

12.4 Radiometer Results

Two or more tests using the same firefighting solution, on the whole, gave similar results for the area under the curve over 4 minutes. There were exceptions to this, for example AFFF gave one very poor result and one slightly better than average result. Forexpan and Phirex + both gave one good result and one average result. The results were close enough to give confidence that the tests were repeatable enough to be reflecting the performance of the additive.

13. OVERALL CONCLUSIONS

In these trials there is no significant difference in firefighting performance due to the use of Class A additives, even under the closely controlled conditions of these trials. Under normal operational circumstances there are so many uncontrollable variables affecting the fire that any change in firefighting performance that may potentially result from the use of Class A additives would probably be rendered unnoticeable.

The theory of Class A additives suggests that they should suppress reignition better than water alone. The statistical analysis shows no evidence of any significant change in reignition suppression due to the use of additives.

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NOTES

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[2] Fosseway Hire, Station Road Industrial Estate, Bourton-on -the-Water, Glos. 10 gallon dehumidifier.

[3] Protimeter plc, Meter House, Marlow, Bucks, SL7 1LX. Protimeter Timbermaster wood moisture content meter

[4] Multisol Ltd., Welsh House, Welsh Row, Nantwich, Cheshire, CW5 5ET. Exxsol heptane.

[5] Key Industrial Equipment Limited, Ebblake Industrial Estate, Verwood, Dorset, BH31 6AT 10 litre jerrican - reference 101S185A

[6] Le Maitre Sales, Unit 4 Forval Close, Wandle Way, Mitcham, Surrey, CR4 4NE. Reduced Flame Roman Candles (electrically detonated) - 2 second gerbs.

[7] Minta Instrumentation Limited, Caddick Road, Knowsley Industrial Park (South), Knowsley, Prescot, Merseyside, L34 9HP. K Type thermocouples

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[23] Amendola Engineering Limited, 80 Hewell Road, Barnt Green, Birmingham B45 8NF. Elkhart Select-o-Flow, SFS - G hosereel gun.

[24] Excel Microsoft Excel, Microsoft Excel, The Microsoft Corporation,1 Microsoft Way, Redmond, WA 98052-6399, USA.

[25] Cotswold and Vale Sawmills, Toddington, Glos, GL54 5DF

[26] Munters Incentive Group, Moisture Control Services, Blackstone Road, Huntingdon, Cambs, PE18 6EF.

[27] SPSS, St Andrews House, West Street, Woking, GU21 1EB

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CONTINUATION OF TABLES

Test No.	Firefighting solution	No of stacks that collapsed	Preburn (minutes)	Method
1	Water		6	Flow 100 lpm, 30 seconds jet, then switch to spray
2	Water	2	6	Flow 100 lpm, 30 seconds jet, then switch to spray
3	Water		5	Flow 100 lpm, 30 seconds jet, then switch to spray
4	Water		6	Flow 100 lpm, 30 seconds jet, then switch to spray, 2 minutes firefighting only
5	Water		6	Flow 75 lpm, 30 second jet, then switch to spray
6	Water	1	6	Flow 50 lpm, 1 minute jet, then switch to spray

Table 6 : The preliminary tests used to develop the 1995 test method

Test No.	Additive	Number of stacks that collapsed	Additive concen-tration with water (%)	Preburn Time (min:sec)	Mean wood moisture content (%)
7	*Water*	*1*		*5:30*	*19.5*
8	*AFFF*	*3*	*3*	*5:30*	*15.6*
9	*Expandol*	*4*	*3*	*5:30*	*15.8*
10	*Silv-ex*	*2*	*0.5*	*5:30*	*15.4*
11	*Forexpan*	*4*	*0.5*	*5:30*	*16.4*
12	Control A	0	0.5	5:30	14.9
13	*1st Defense*	*lost suction*	*1*	*5:30*	*15.4*
14	1st Defense	0	1	5:30	17.0
15	Phirex +	0	1	5:30	17.3
16	Ecofoam	0	1	5:30	17.2
17	Cold Fire	0	3	5:30	17.2
18	Water	0		5:30	16.5
19	Chemguard	0	0.5	5:30	17.3
20	Phos-Chek	0	1	5:30	17.4
21	*Fire Out I*	*3*	*0.3*	*5:30*	*13.3*
22	*Chubb 1%*	*2*	*1*	*5:30*	*13.1*
23	*Fuel Buster*	*1*	*1*	*5:30*	*14.5*
24	JJD	0	0.025	5	15.9
25	Forexpan	0	0.5	5	16.0
26	AFFF	0	3	5	16.8
27	*Expandol*	*2*	*3*	*5*	*16.0*
28	1st Defense	0	1	5	15.7
29	Silv-ex	0	0.5	5	14.7
30	Water	0		5	14.9

Table 7 : The additives and solution rates, number of stack collapses and the wood moisture content - 1995 tests

Rows that are shaded grey and written in italics are invalid results - either because of stack collapses, or because the pump lost suction during the test.

Test No.	Additive	Preburn time (min:sec)	Firefighting time (min:sec)	Time when the last major flame was extinguished (min:sec)
7	*Water*	*5:30*	*3:15*	*1:50*
8	*AFFF*	*5:30*	*3:23*	*1:46*
9	*Expandol*	*5:30*	*4:05*	*2:11*
10	*Silv-ex*	*5:30*	*4:30*	*2:20*
11	*Forexpan*	*5:30*	*4:33*	*1:57*
12	Control A	5:30	2:50	1:49
13	*1st Defense*	*5:30*	*lost suction*	
14	1st Defense	5:30	2:17	1:03
15	Phirex +	5:30	3:12	1:52
16	Ecofoam	5:30	3:46	1:58
17	Cold Fire	5:30	2:53	1:31
18	Water	5:30	3:23	1:51
19	Chemguard	5:30	3:14	1:45
20	Phos-Chek	5:30	3:47	1:17
21	*Fire Out I*	*5:30*	*4:20*	*2:14*
22	*Chubb 1%*	*5:30*	*4:23*	*2:42*
23	*Fuel Buster*	*5:30*	*3:47*	*2:27*
24	JJD	5	1:52	1:23
25	Forexpan	5	2:32	1:44
26	AFFF	5	2:08	1:00
27	*Expandol*	*5*	*3:15*	*1:42*
28	1st Defense	5	3:16	1:52
29	Silv-ex	5	2:20	0:56
30	Water	5	2:45	1:42

Table 8 : Firefighting time and time of the last major flame - 1995 tests
Rows that are shaded grey and written in italics are invalid results - either because of stack collapses, or because the pump lost suction during the test.

Firefighting time and the time when the last major flame was extinguished are both calculated from the start of firefighting.

Test no.	Additive	Preburn time (min:sec)	Time to achieve 90% reduction in radiated heat output[1] (seconds)	Time to achieve 95% reduction in radiated heat output[1] (seconds)	Maximum radiated heat during preburn (kW/m^2)
7	*Water*	*5:30*	*60*	*103*	*15.2*
8	*AFFF*	*5:30*	*83*	*101*	*15.5*
9	*Expandol*	*5:30*	*47*	*96*	*20.6*
10	*Silv-ex*	*5:30*	*84*	*110*	*18.3*
11	*Forexpan*	*5:30*	*49*	*92*	*22.0*
12	Control A	5:30	68	86	14.8
13	*1st Defense*	*5:30*		*Not calculated*	
14	1st Defense	5:30	52	60	13.9
15	Phirex +	5:30	106	113	14.6
16	Ecofoam	5:30	111	118	13.6
17	Cold Fire	5:30	70	89	14.5
18	Water	5:30	107	114	13.3
19	Chemguard	5:30	67	104	15.5
20	Phos-Chek	5:30	70	79	14.3
21	*Fire Out I*	*5:30*	*122*	*129*	*15.5*
22	*Chubb 1%*	*5:30*	*140*	*160*	*14.5*
23	*Fuel Buster*	*5:30*	*120*	*140*	*16.6*
24	JJD	5	60	82	13.6
25	Forexpan	5	103	108	13.0
26	AFFF	5	58	67	13.2
27	*Expandol*	*5*	*63*	*101*	*16.0*
28	1st Defense	5	102	109	14.8
29	Silv-ex	5	53	62	12.0
30	Water	5	57	104	12.7

Table 9 : Radiometer results - time to achieve 90% and 95% reduction in radiated heat output and the maximum radiated heat output during the preburn - 1995 tests

Rows that are shaded grey and written in italics are invalid results - either because of stack collapses, or because the pump lost suction during the test.

Notes to Table 4

[1] *The lower the value, the better the additive performed*

		Area under curve[1]			% reduction in area under the curve[2]	
Test No.	Additive	First minute of firefighting	Second minute of firefighting	First two minutes of firefighting	First minute of firefighting	First two minutes of firefighting
7	*Water*	*28.77*	*4.31*	*33.1*	*57*	*76*
8	*AFFF*	*34.29*	*7.48*	*41.8*	*56*	*74*
9	*Expandol*	*25.60*	*3.83*	*29.4*	*59*	*76*
10	*Silv-ex*	*28.48*	*6.90*	*35.4*	*53*	*71*
11	*Forexpan*	*22.87*	*2.86*	*25.7*	*63*	*79*
12	Control A	35.87	3.48	39.4	44	69
13	*1st Defense*	*Not calculated*			*Not calculated*	
14	1st Defense	21.92	1.96	23.9	52	98
15	Phirex +	34.54	8.37	42.9	45	66
16	Ecofoam	38.19	12.50	50.7	41	61
17	Cold Fire	34.42	3.71	38.1	46	70
18	Water	38.83	8.81	47.6	39	63
19	Chemguard	38.31	4.19	42.5	41	67
20	Phos-Chek	37.81	3.96	41.8	40	67
21	*Fire Out I*	*39.84*	*13.01*	*52.8*	*46*	*91*
22	*Chubb 1%*	*36.46*	*12.36*	*48.8*	*42*	*61*
23	*Fuel Buster*	*32.53*	*11.63*	*44.2*	*51*	*74*
24	JJD	32.27	2.77	35.0	51	74
25	Forexpan	31.52	12.64	44.2	49	65
26	AFFF	32.30	2.55	34.9	50	73
27	*Expandol*	*32.50*	*4.70*	*37.2*	*52*	*74*
28	1st Defense	30.42	7.01	37.4	52	70
29	Silv-ex	30.86	2.15	33.0	52	74
30	Water	30.63	4.83	35.5	52	72

Table 10 : The area under the normalised radiated heat output curve and the percentage reduction in the area under the curve - 1995 tests

Rows that are shaded grey and written in italics are invalid results - either because of stack collapses, or because the pump lost suction during the test.

Notes to Table 5

[1] *The lower the value, the better the additive performed*

[2] *The higher the value, the better the additive performed*

Test No.	Additive	Pump pressure (bar)	Firefighting solution Temp (°C)
7	*Water*	*9.5*	*17.7*
8	*AFFF*	*9.7*	*17.8*
9	*Expandol*	*10.0*	*19.0*
10	*Silv-ex*	*13.0*	*20.3*
11	*Forexpan*		*20.3*
12	Control A	8.9	20.0
13	*1st Defense*	*Not recorded*	
14	1st Defense	8.3	18
15	Phirex +	9.5	21.0
16	Ecofoam	13.5	21.6
17	Cold Fire	13.7	22.4
18	Water	12.2	23.8
19	Chemguard	14.1	22.6
20	Phos-Chek	13.6	21.5
21	*Fire Out I*	*5.9*	*22.4*
22	*Chubb 1%*	*5.9*	*23.1*
23	*Fuel Buster*	*5.9*	*21.6*
24	JJD	11.8	22.9
25	Forexpan	10.7	22.8
26	AFFF	12.8	22.1
27	*Expandol*	*12.6*	*20.0*
28	1st Defense	13.6	20.3
29	Silv-ex	13.8	19.5
30	Water	13.8	20.7

Table 11 : The pump pressure and firefighting solution temperature - 1995 tests

Rows that are shaded grey and written in italics are invalid results - either because of stack collapses, or because the pump lost suction during the test.

Test No.	Additive	Additive concentration with water (%)	Preburn time (min:sec)	Expansion ratio
7	*Water*		*5:30*	
8	*AFFF*	*3*	*5:30*	*3.4*
9	*Expandol*	*3*	*5:30*	*2.7*
10	*Silv-ex*	*0.5*	*5:30*	*2.0*
11	*Forexpan*	*0.5*	*5:30*	*2.4*
12	Control A	0.5	5:30	1.8
13	*1st Defense*	*1*	*5:30*	
14	1st Defense	1	5:30	3.1
15	Phirex +	1	5:30	1.4
16	Ecofoam	1	5:30	2.0
17	Cold Fire	3	5:30	1.5
18	Water		5:30	
19	Chemguard	0.5	5:30	2.8
20	Phos-Chek	1	5:30	3.7
21	*Fire Out I*	*0.3*	*5:30*	*1.4*
22	*Chubb 1%*	*1*	*5:30*	*2.7*
23	*Fuel Buster*	*1*	*5:30*	*1.4*
24	JJD	0.025	5	1.3
25	Forexpan	0.5	5	3.0
26	AFFF	3	5	7.1
27	*Expandol*	*3*	*5*	*3.9*
28	1st Defense	1	5	5.2
29	Silv-ex	0.5	5	2.6
30	Water		5	

Table 12 : The foam property results - 1995 tests

Rows that are shaded grey and written in italics are invalid results - either because of stack collapses, or because the pump lost suction during the test.

Test No.	Additive	Additive concentration with water (%)	Mean wood moisture content (%)	Air Temp (°C)	Humidity (% RH)
31	Water		13.7	16	73
32	Silv-ex	0.5	14.1	17	67
33	Control A	0.5	13.3	14	75
34	*Water*		*13.5*	*15*	*74*
35	Water		13.9	15	69
36	Phirex +	1	13.8	15	71
37	Forexpan	0.5	13.9	16	70
38	AFFF	3	14.2	15	71
39	Phos-Chek	1	14.1	16	67
40	1st Defense	1	15.0	15	74
41	Chubb 1%	1	15.5	16	62
42	Chemguard	0.5	14.1	15	68
43	*Fire Out I*	*0.3*	*16.0*	*16*	*58*
44	Ecofoam	1	13.6	14	64
45	Expandol	3	14.4	14	64
46	Fuel Buster	1	13.8	15	60
47	JJD	0.025	14.0	14	64
48	Water		14.1	14	59
49	AFFF	3	14.4	14	58
50	Phos-Chek	1	14.2	13	74
51	Silv-ex	0.5	14.4	14	72
52	Chemguard	0.5	14.7	14	69
53	Control A	0.5	15.6	13	82
54	Phirex +	1	14.6	14	81
55	Ecofoam	1	15.0	14	84
56	Forexpan	0.5	14.4	13	77
57	1st Defense	1	14.1	14	75
58	JJD	0.025	14.4	14	73
59	Fire Out I	0.3	14.0	13	82
60	Fuel Buster	1	14.2	14	82
61	Expandol	3	14.9	14	83
62	Chubb 1%	1	13.8	13	83
63	Control A	0.5	13.2	14	82
64	Water		14.8	14	83
65	Fire Out I	0.3	14.9	11	75
66	*Fuel Buster*	*1*	*14.3*	*12*	*74*

Table 13 : The wood moisture content and ambient conditions - 1996 tests

Rows that are shaded grey and written in italics are invalid results.

Test No.	Additive	Firefighting time (min:sec)	Time last major flame was extinguished (min:sec)
31	Water	04:45	02:03
32	Silv-ex	05:32	03:12
33	Control A	05:43	03:04
34	*Water*	*18:54*	*Not recorded*
35	Water	02:51	01:16
36	Phirex +	08:18	01:09
37	Forexpan	07:15	02:14
38	AFFF	09:53	08:35
39	Phos-Chek	05:18	02:35
40	1st Defense	06:00	03:56
41	Chubb 1%	05:52	02:57
42	Chemguard	04:48	03:41
43	*Fire Out I*	*04:27*	*Not recorded*
44	Ecofoam	05:42	03:26
45	Expandol	04:18	03:08
46	Fuel Buster	04:46	03:18
47	JJD	05:34	03:24
48	Water	06:01	03:39
49	AFFF	05:18	03:21
50	Phos-Chek	04:48	03:13
51	Silv-ex	05:01	03:10
52	Chemguard	05:52	03:40
53	Control A	04:36	03:22
54	Phirex +	04:48	03:18
55	Ecofoam	06:35	03:29
56	Forexpan	03:50	03:41
57	1st Defense	04:57	03:35
58	JJD	05:33	03:32
59	Fire Out I	06:54	03:57
60	Fuel Buster	05:35	03:34
61	Expandol	05:36	03:37
62	Chubb 1%	05:00	03:42
63	Control A	06:19	03:53
64	Water	04:51	03:21
65	Fire Out I	04:26	03:07
66	*Fuel Buster*	*04:46*	*03:12*

Table 14 : Firefighting time and time of the last major flame - 1996 tests

Rows that are shaded grey and written in italics are invalid results.

Test No.	Additive	Maximum radiated heat during preburn (kW/m^2)	Area under the curve over the first 4 minutes of firefighting[1]
31	Water	10.3	34.3
32	Silv-ex	10.1	39.1
33	Control A	9.7	32.9
34	*Water*	*11.0*	*41.5*
35	Water	9.8	30.1
36	Phirex +	10.7	30.5
37	Forexpan	10.2	36.0
38	AFFF	9.9	38.0
39	Phos-Chek	9.8	29.0
40	1st Defense	9.2	26.2
41	Chubb 1%	8.5	34.8
42	Chemguard	9.6	36.3
43	*Fire Out I*	*8.7*	*19.1*
44	Ecofoam	10.0	29.5
45	Expandol	10.0	27.0
46	Fuel Buster	9.6	49.2
47	JJD	9.3	33.2
48	Water	9.4	38.1
49	AFFF	9.6	33.3
50	Phos-Chek	9.3	43.5
51	Silv-ex	9.5	40.5
52	Chemguard	10.2	43.4
53	Control A	9.2	32.3
54	Phirex +	9.0	34.4
55	Ecofoam	9.0	40.3
56	Forexpan	9.3	32.6
57	1st Defense	9.1	30.9
58	JJD	10.0	31.0
59	Fire Out I	9.7	36.2
60	Fuel Buster	9.4	31.3
61	Expandol	9.7	42.0
62	Chubb 1%	9.5	35.0
63	Control A	9.7	33.9
64	Water	9.3	36.8
65	Fire Out I	9.3	26.7
66	*Fuel Buster*	*10.3*	*41.2*

Table 15 : The area under the normalised radiated heat output curve and the maximum radiated heat output during the preburn - 1996 tests

Notes to Table 10 : [1] *The lower the value, the better the additive performed*
Rows that are shaded grey and written in italics are invalid results.

Test No.	Additive	Pump Pressure (bar)	Firefighting Solution Temp. (°C)	Expansion Ratio
31	Water	11.3	24	
32	Silv-ex	12.4	23	1.9
33	Control A	11.5	20	1.8
34	*Water*	*10.6*	*19*	
35	Water	10.9	20	
36	Phirex +	11.0	23	1.2
37	Forexpan	10.6	20	2.2
38	AFFF	9.8	21	3.3
39	Phos-Chek	10.2	20	1.6
40	1st Defense	9.2	20	2.2
41	Chubb 1%	9.9	20	2.2
42	Chemguard	13.0	22	1.9
43	*Fire Out I*	*12.0*	*22*	*1.5*
44	Ecofoam	13.9	23	1.6
45	Expandol	14.2	24	2.1
46	Fuel Buster	12.7	22	1.4
47	JJD	13.2	23	1.2
48	Water	10.4	22	
49	AFFF	14.3	25	2.7
50	Phos-Chek	12.2	21	1.9
51	Silv-ex	13.6	22	1.4
52	Chemguard	14.4	22	1.6
53	Control A	13.4	22	1.5
54	Phirex +	12.1	21	1.3
55	Ecofoam	13.7	22	1.6
56	Forexpan	14.1	21	1.6
57	1st Defense	13.6	22	2.6
58	JJD	14.8	22	1.3
59	Fire Out I	14.4	23	1.4
60	Fuel Buster	14.1	22	1.3
61	Expandol	14.7	23	1.9
62	Chubb 1%	14.4	22	2.0
63	Control A	14.2	22	1.5
64	Water	12.7	21	
65	Fire Out I	14.1	20	1.5
66	*Fuel Buster*	*14.6*	*23*	*1.4*

Table 16 : Pump pressure, firefighting solution temperature and foam expansion ratio results - 1996 tests

Rows that are shaded grey and written in italics are invalid results.

Additive type	Probability that the additive is making no difference to the performance of water (%)
1st Defense	11
AFFF	80
Chemguard	22
Chubb 1%	98
Control A	44
Ecofoam	99
Expandol	97
Fire Out I	44
Forexpan	86
Fuel Buster	65
JJD	37
Phirex +	46
Phos-Chek	87
Silv-ex	14

Table 17 : The results of statistical tests on the values for the area under the graph for the first 4 minutes of firefighting - 1996 tests

The difference may represent an improvement or a reduction in performance. The lower the value, the more different the results are to the results of firefighting using water alone.

Figure 1 : The smoke hood in the Still Air Facility at RAF Little Rissington

C148/1996

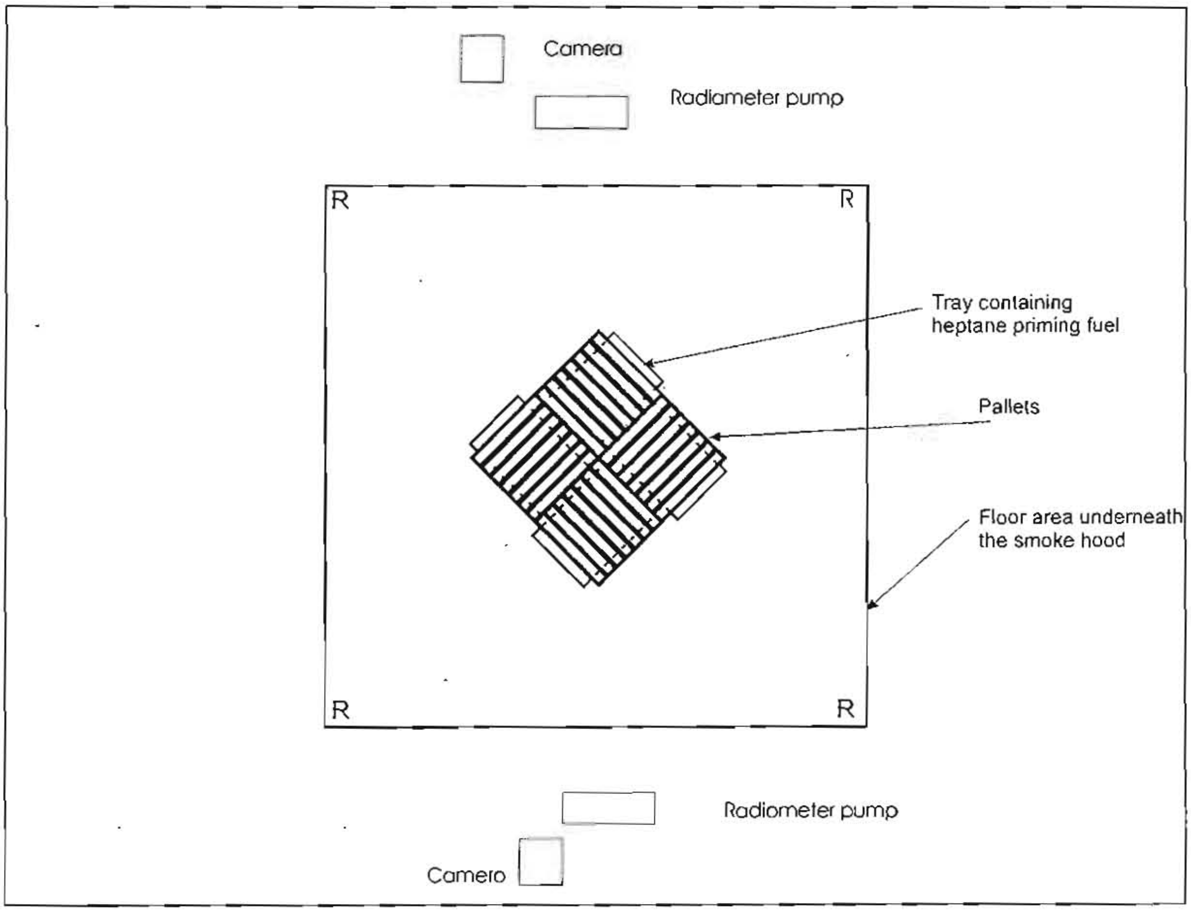

Figure 2 : Plan view of the area under the smoke hood showing the orientation of the pallets and the position of the radiometers (marked R)

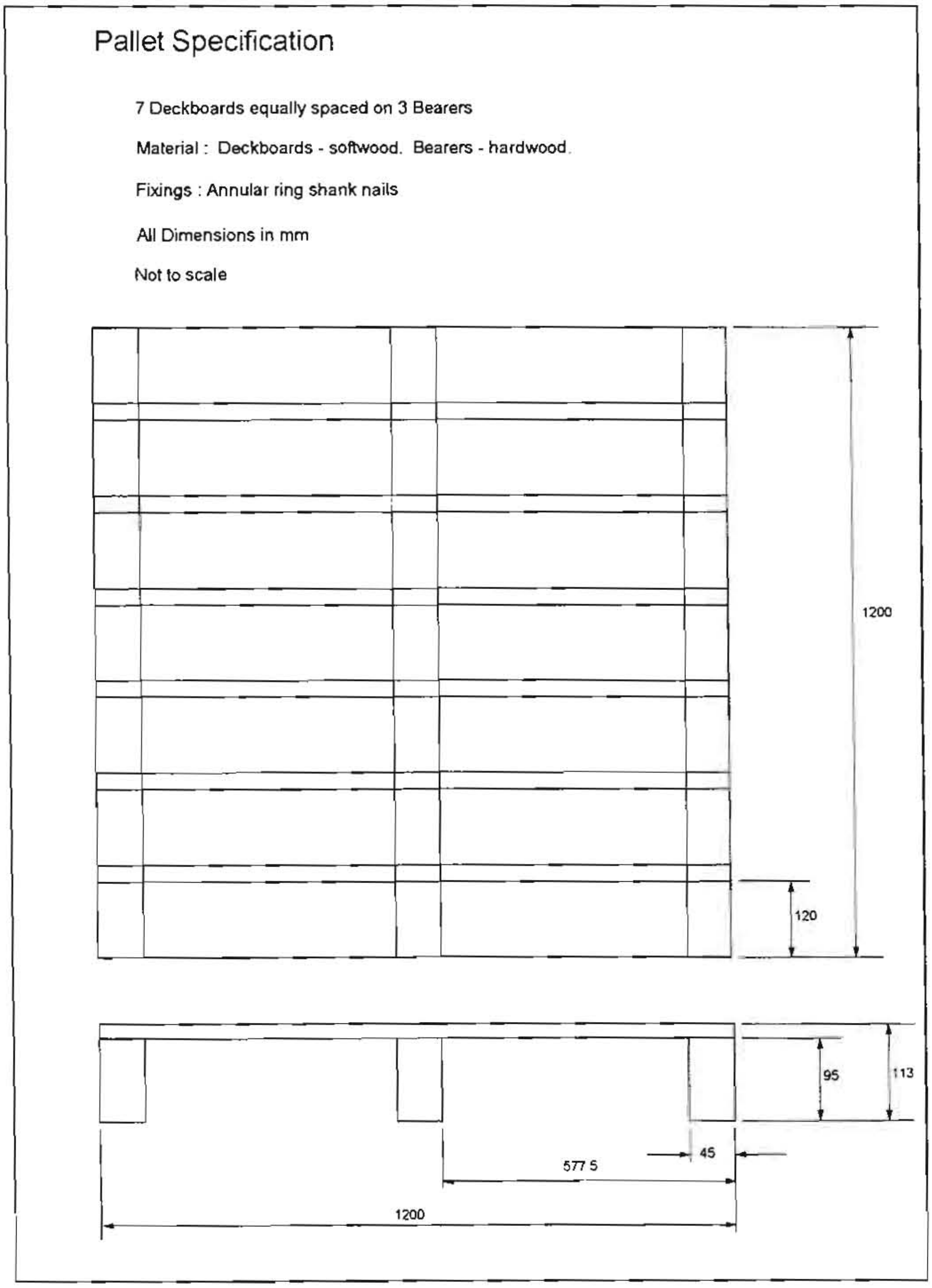

Figure 3 : Pallets 1.2 m square

Figure 4: The Test Rig and Priming Fuel Tray C414/97

Figure 5: The Pallets arranged in a square formation under the smoke hood C412/1995

Figure 6 The priming fuel trays arranged underneath the test rigs
C639/1995

Figure 7: Radiometer positioned on a bracket clamped to a stanchion
C641/1995

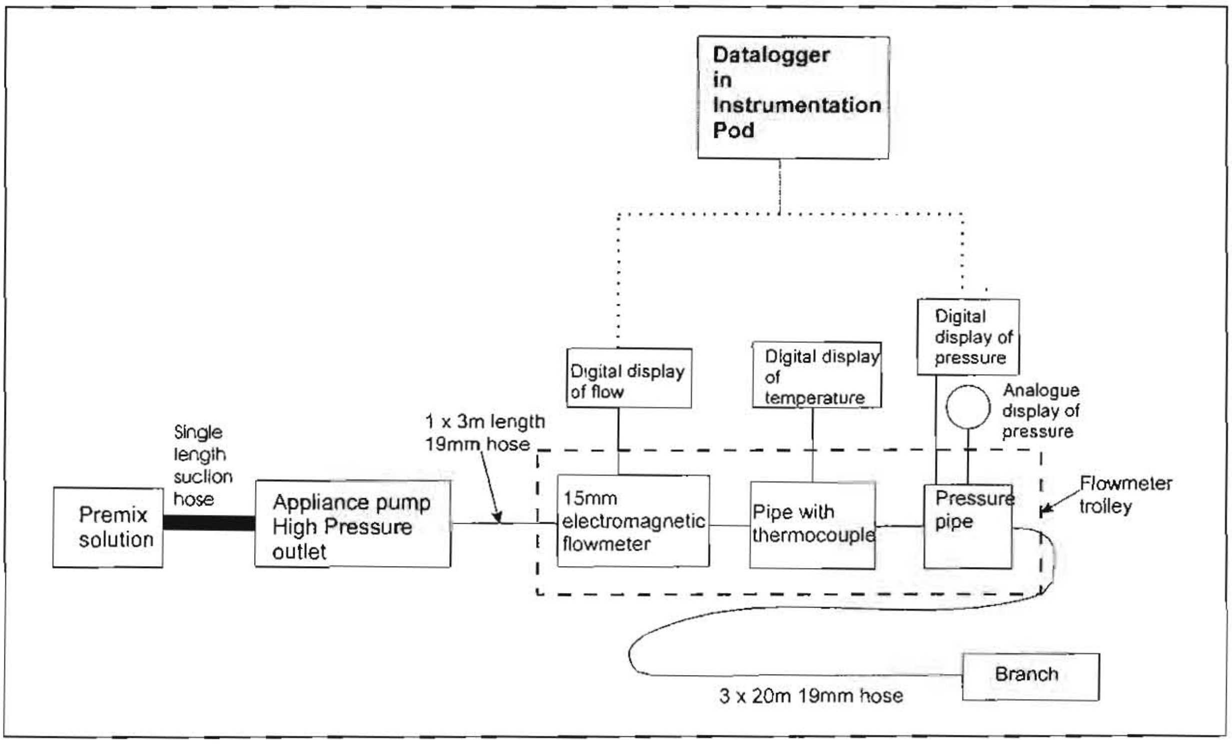

Figure 8 : Hydraulic arrangement for the 1995 and 1996 fire tests

Figure 9 : Elkhart SFS 'Select-O-Stream' hosereel branch

C692/84

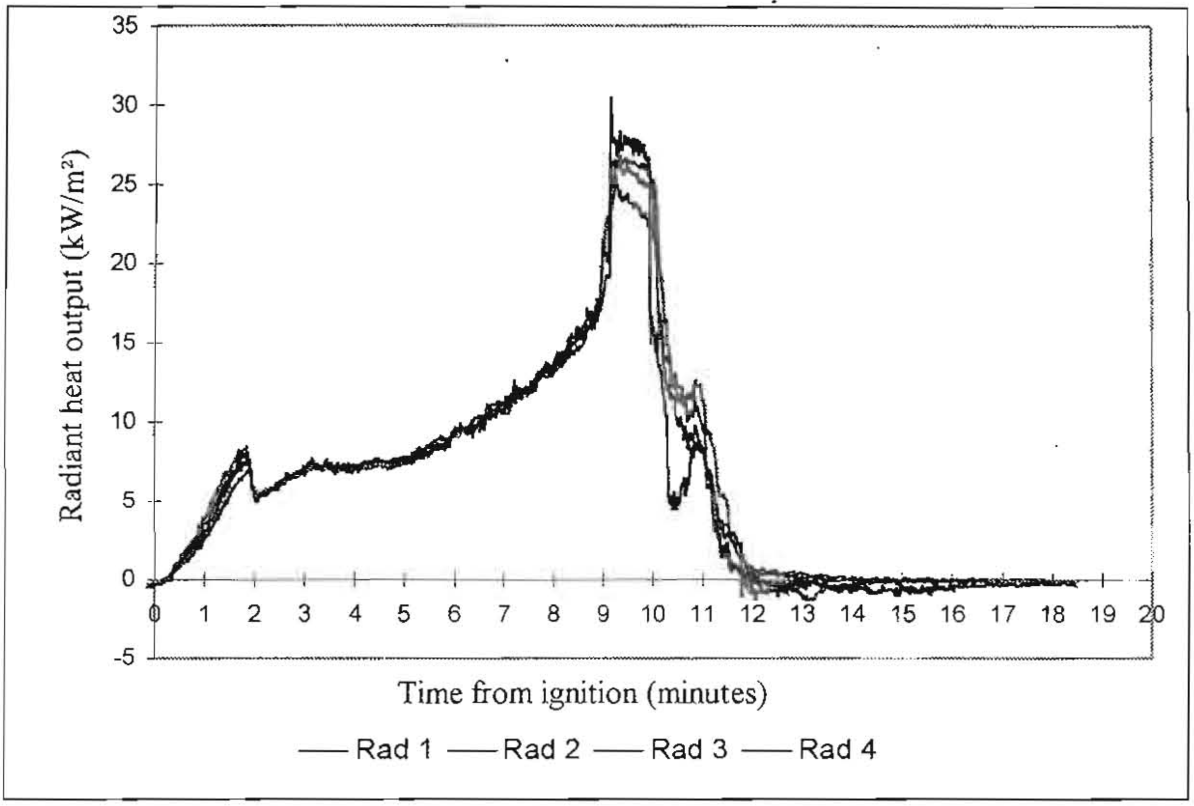

Figure 10 : The radiometer results of the preliminary fire.

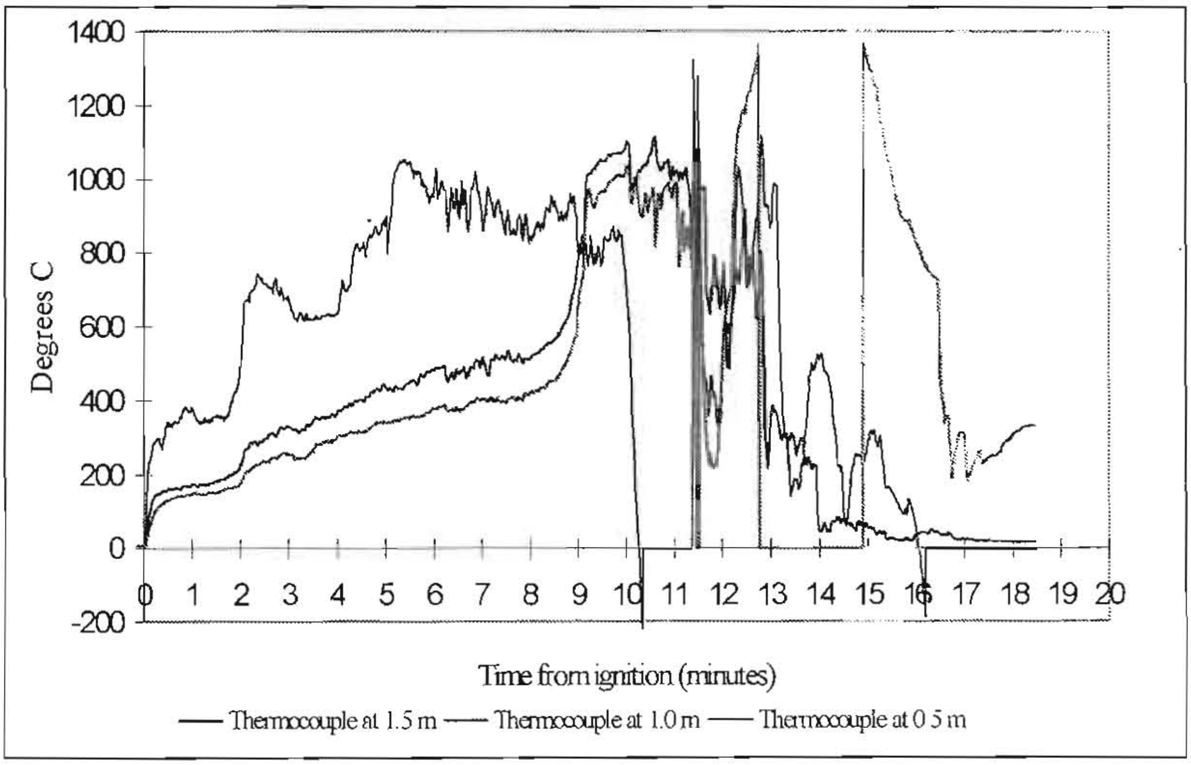

Figure 11 : The thermocouple results of the preliminary fire.

Note: when the thermocouples become damaged, they give spurious readings, hence the negative values after 10 minutes from ignition.

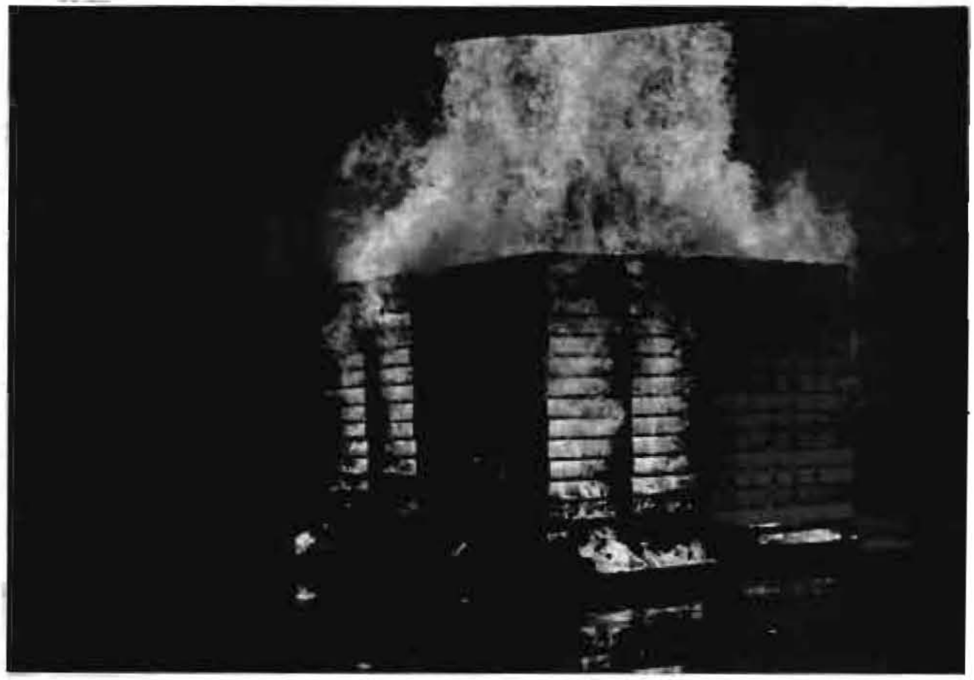

Figure 12: The fire approximately 2 minutes into the preburn - 1995 tests
C414/97

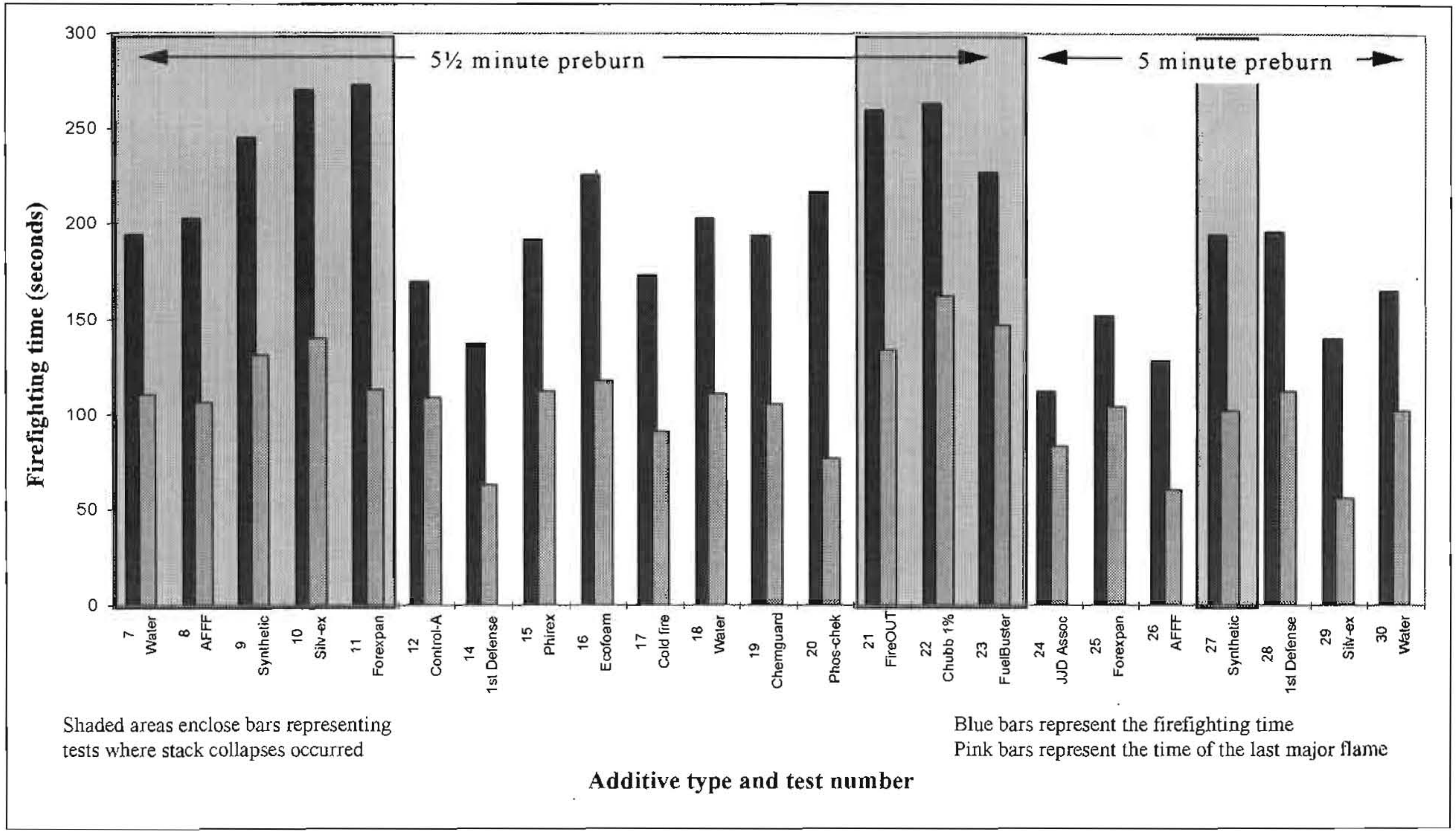

Figure 13 : Bar chart of the firefighting time and the time of the last major flame - 1995 tests

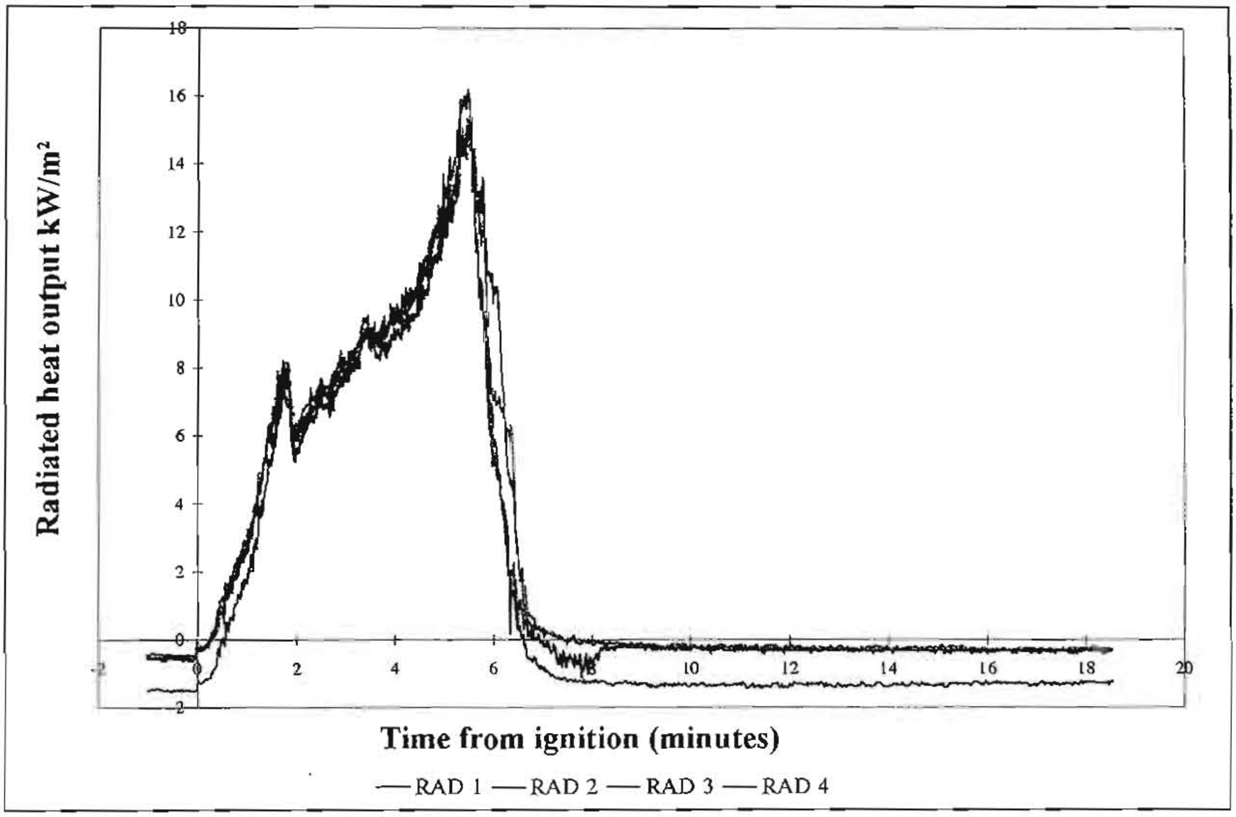

Figure 14 : A typical radiant heat output graph in which there were no stack collapses - 1995 tests

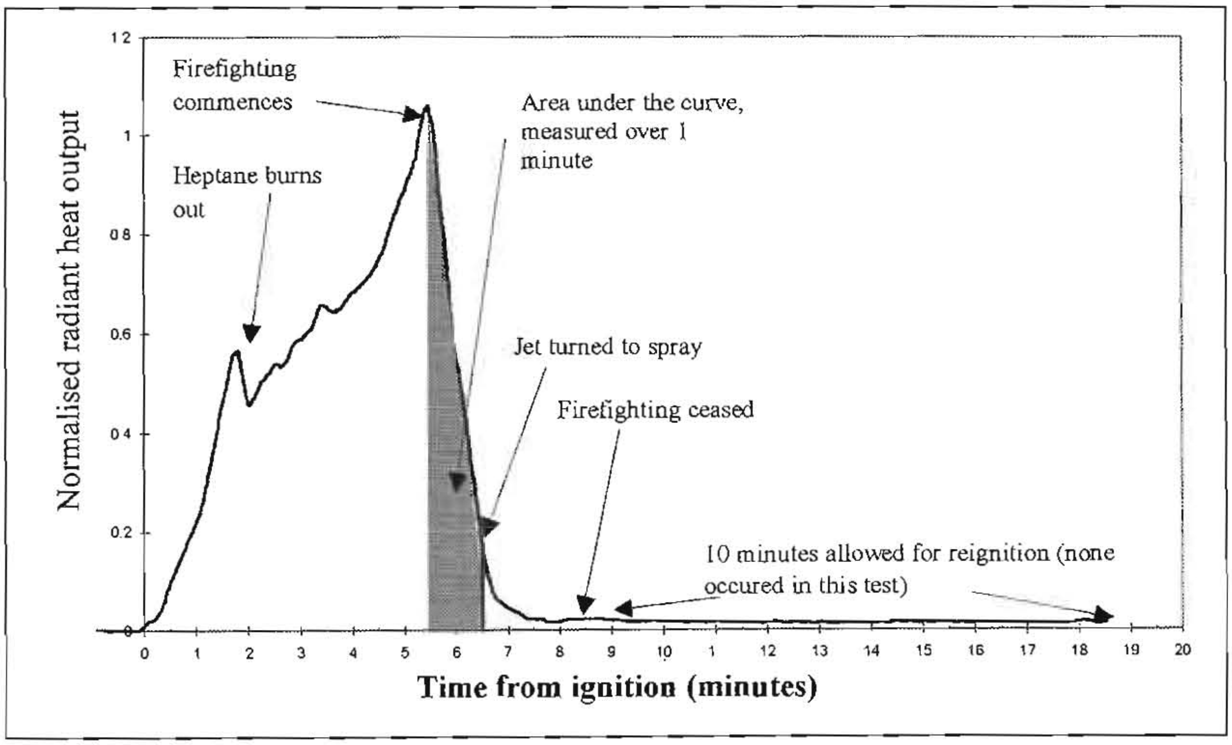

Figure 15 : A typical mean, normalised, radiant heat output graph with notes - 1995 tests

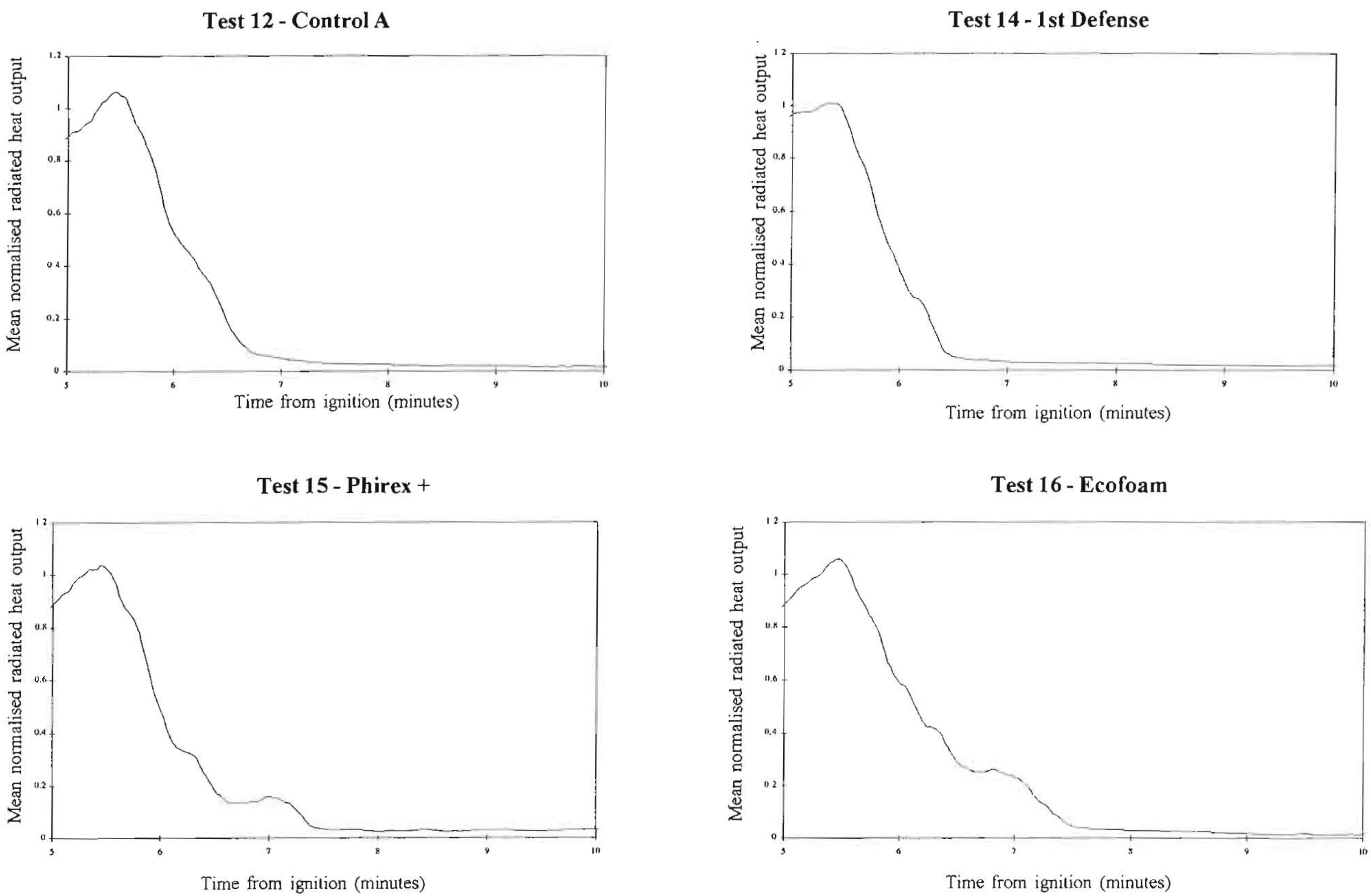

Figure 16 : The mean normalised radiant heat output of tests with a 5½ minute preburn - 1995 tests

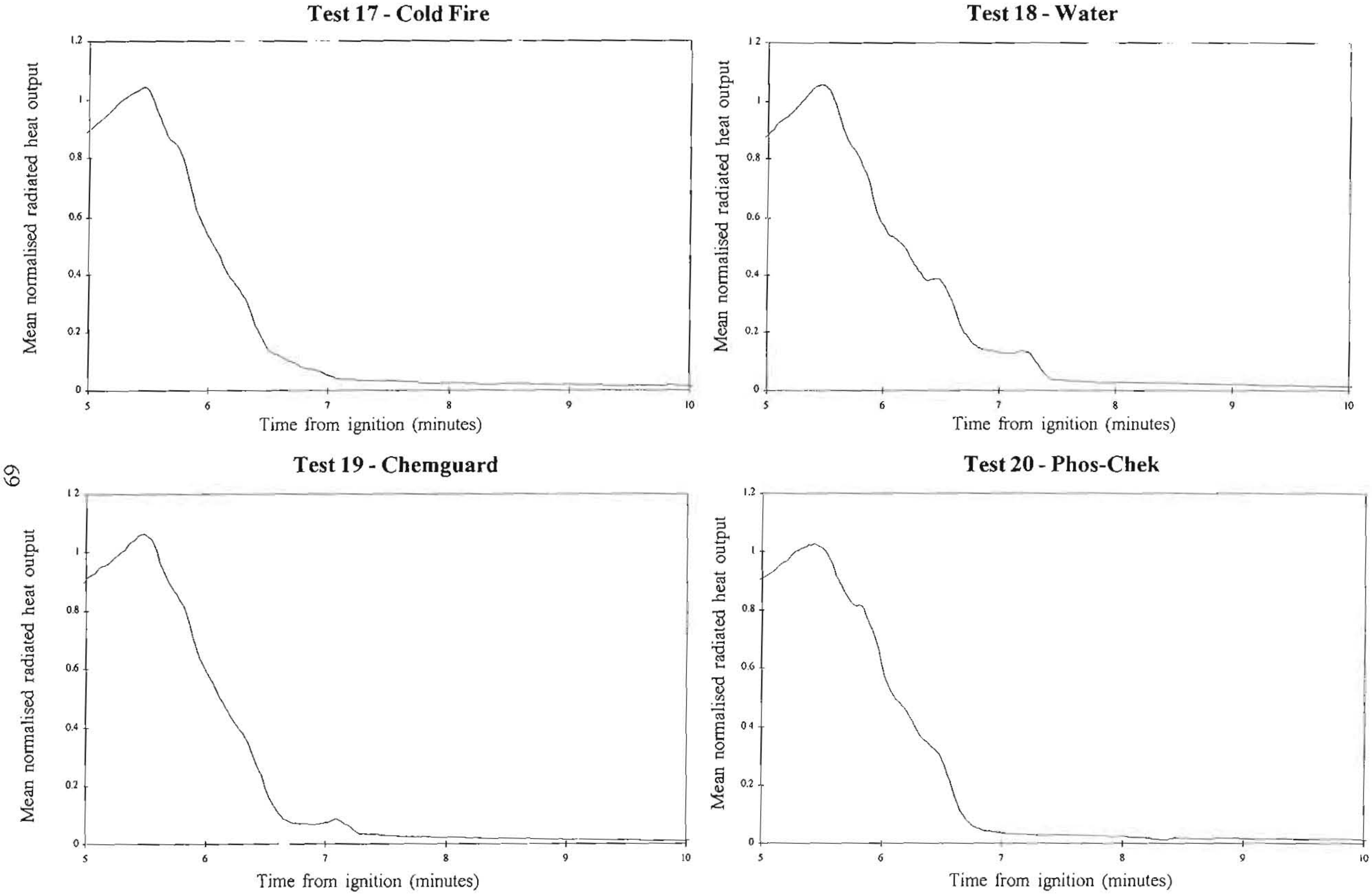

Figure 16 : The mean normalised radiant heat output of tests with a 5½ minute preburn - 1995 tests

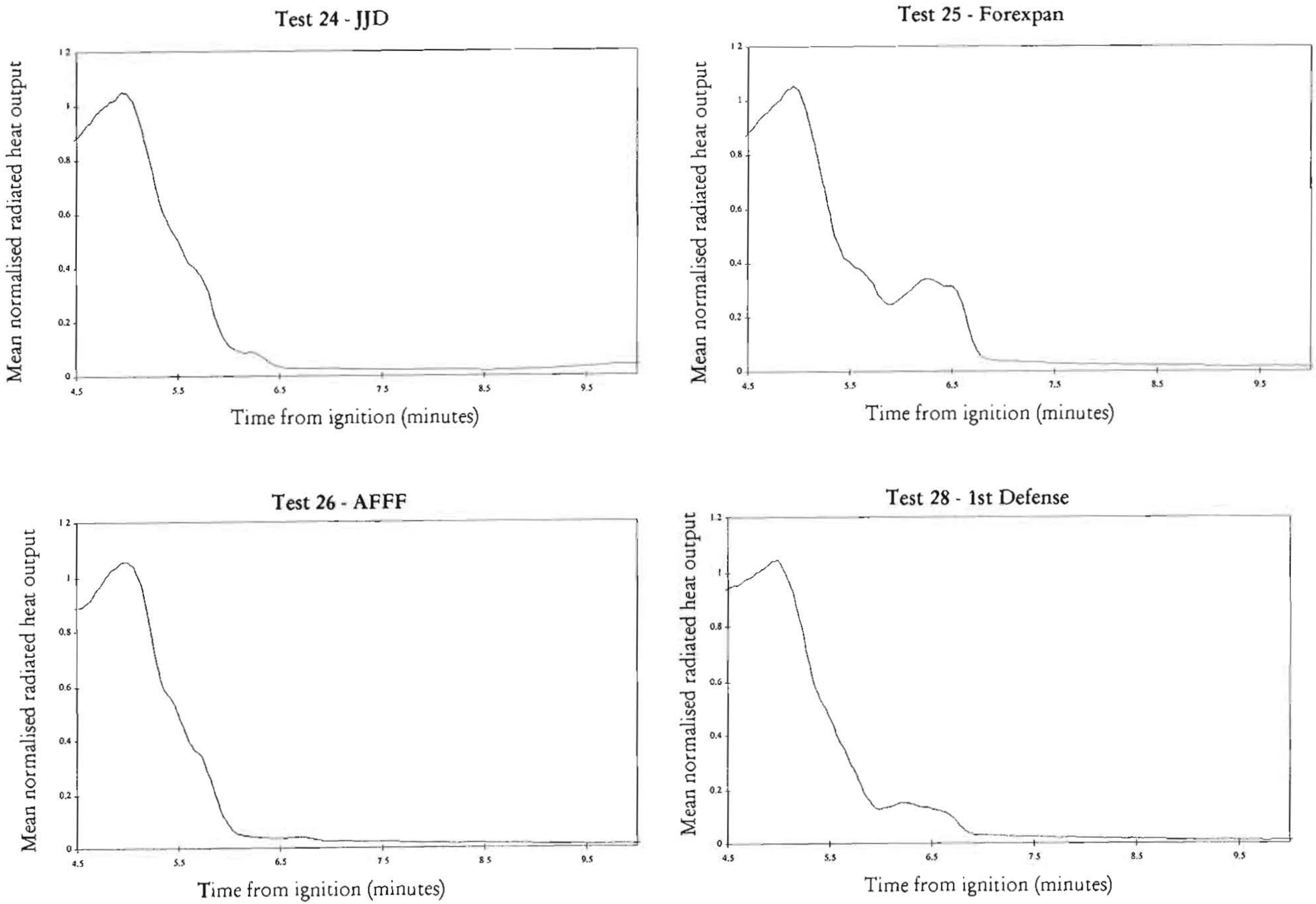

Figure 17 : The mean normalised radiant heat output of tests with a 5 minute preburn - 1995 tests

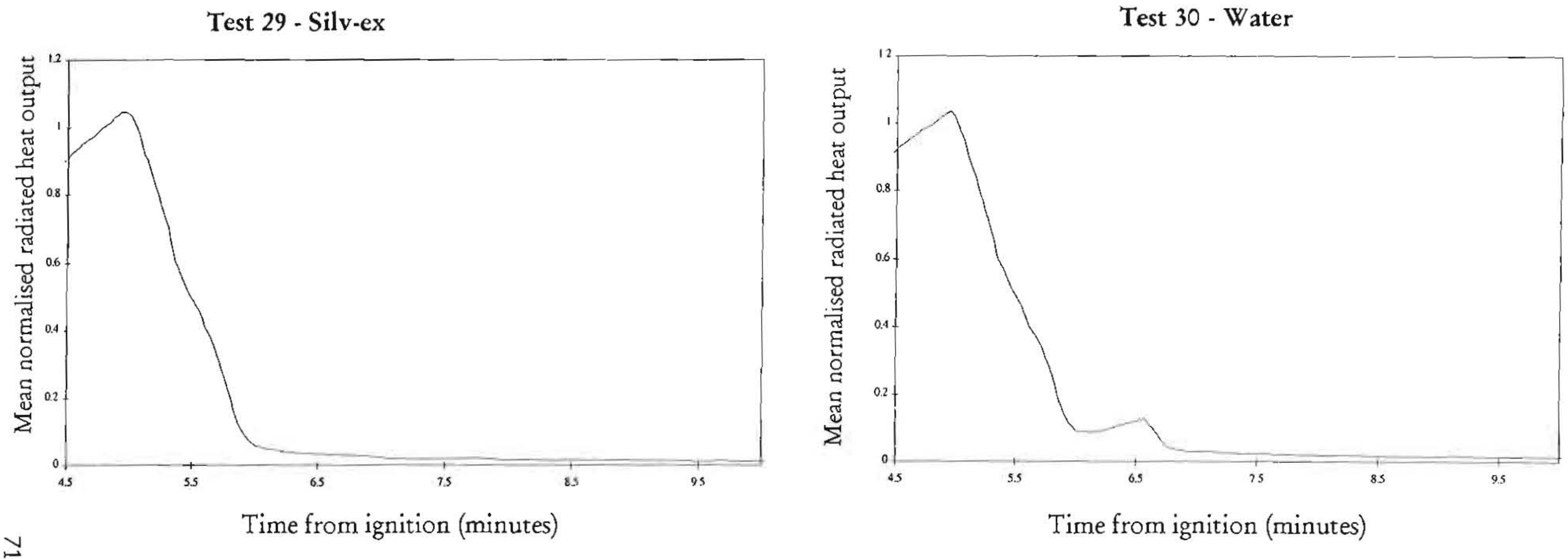

Figure 17 : The mean normalised radiant heat output of tests with a 5 minute preburn - 1995 tests

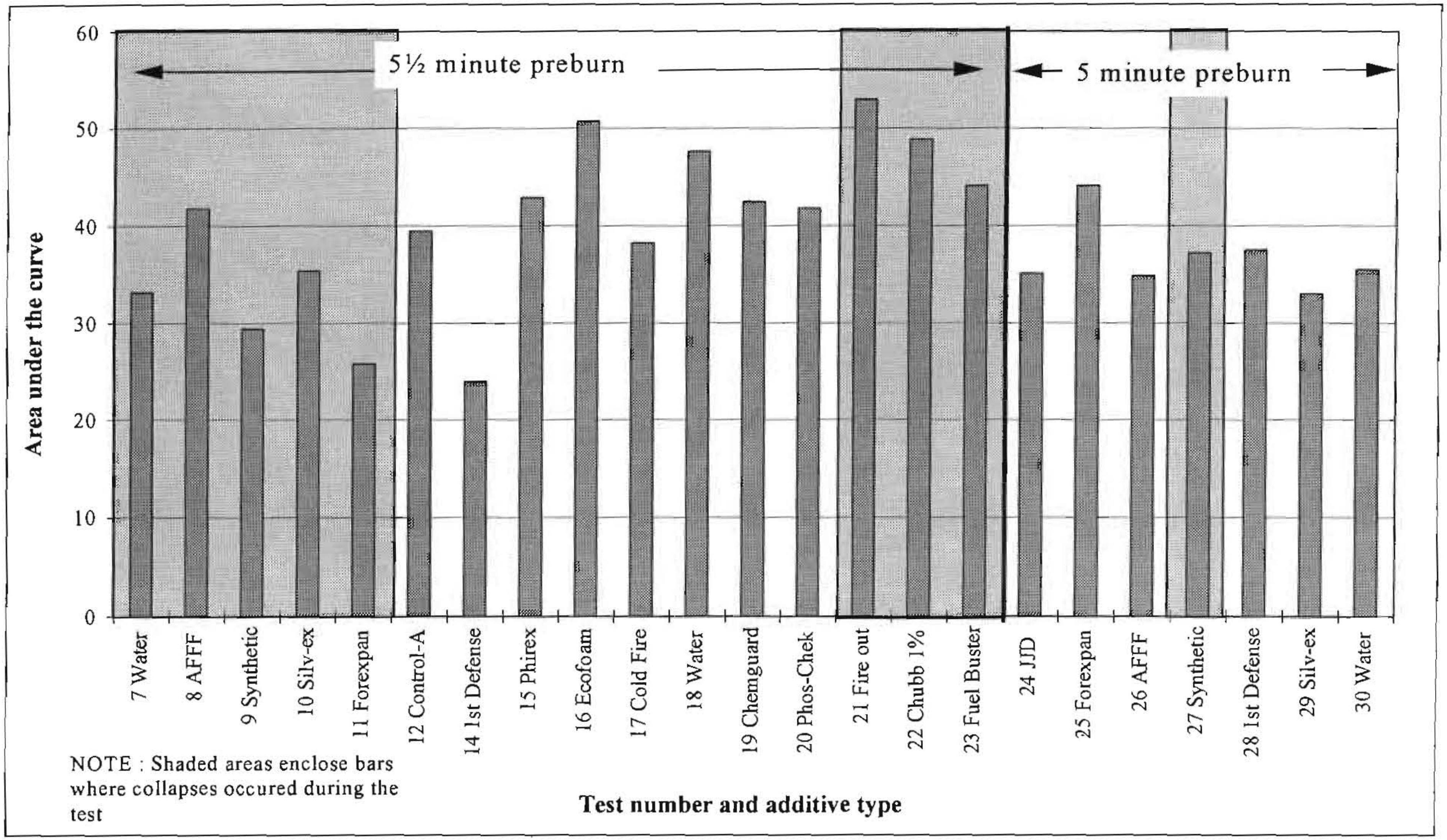

Figure 18 : Bar chart of the area under the curve over the first minute of firefighting - 1995 tests.
Note: the smaller the area, the better the additives performed.

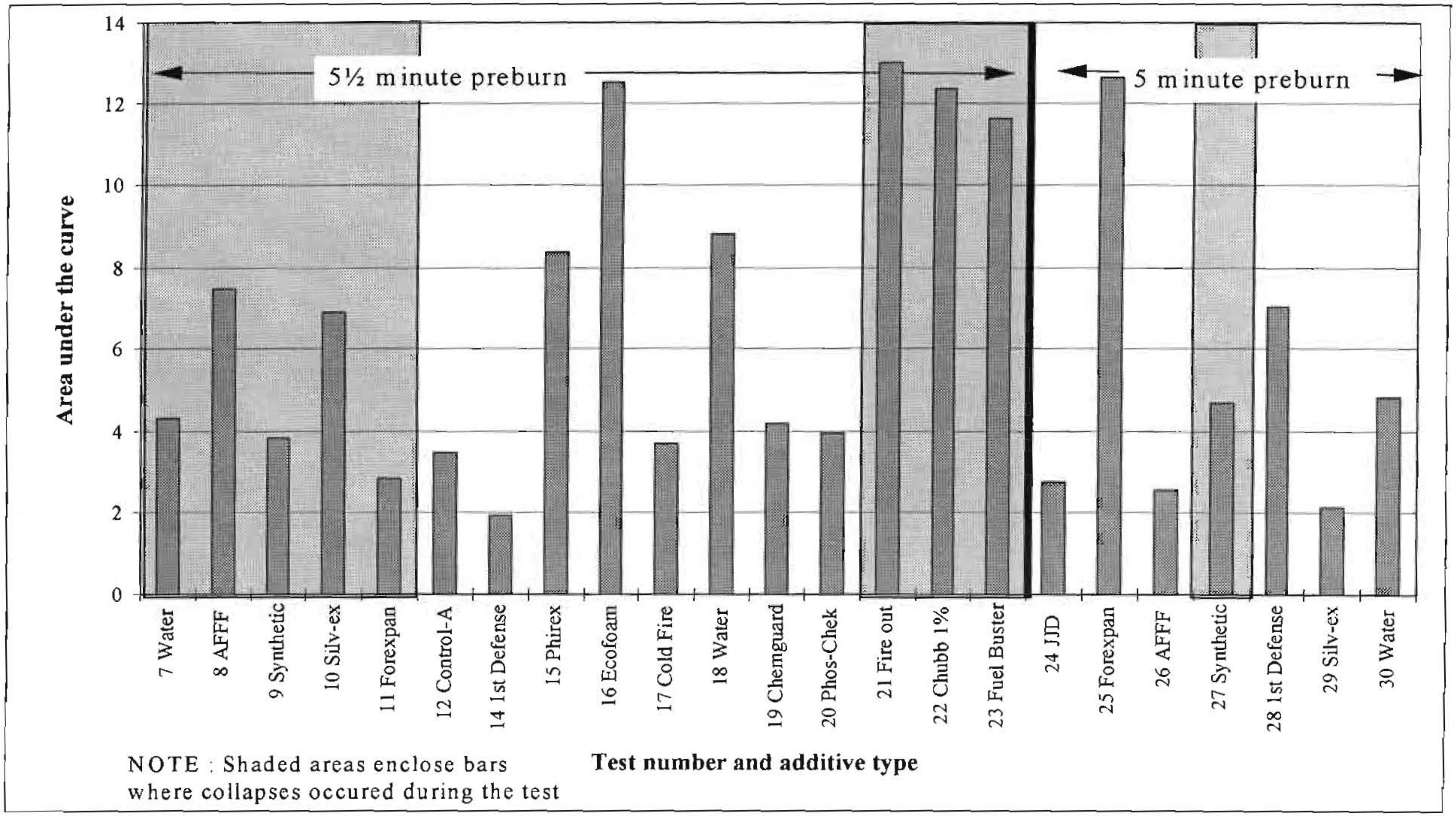

Figure 19 : Bar chart of the area under the curve over the second minute of firefighting for the 1995 tests.
Note: the smaller the area, the better the additives performed.

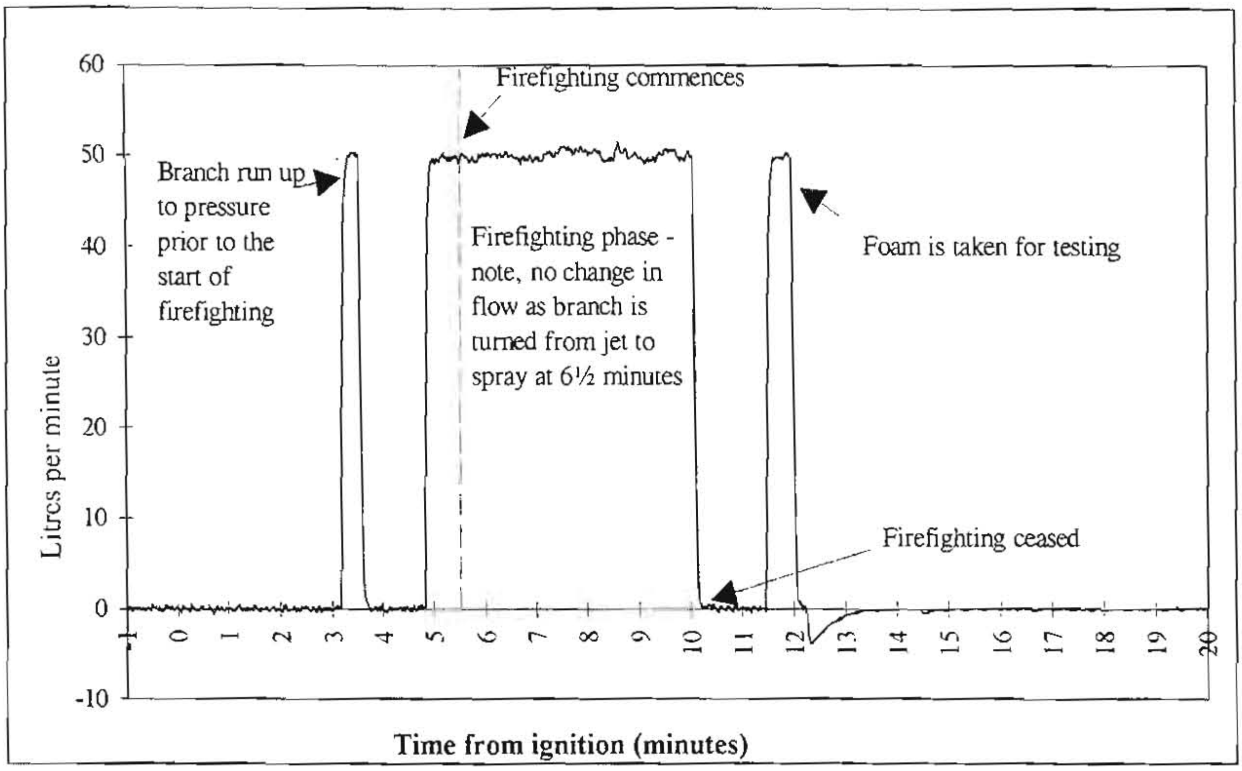

Figure 20 : Graph of the flow rate from a typical test fire - 1995 tests

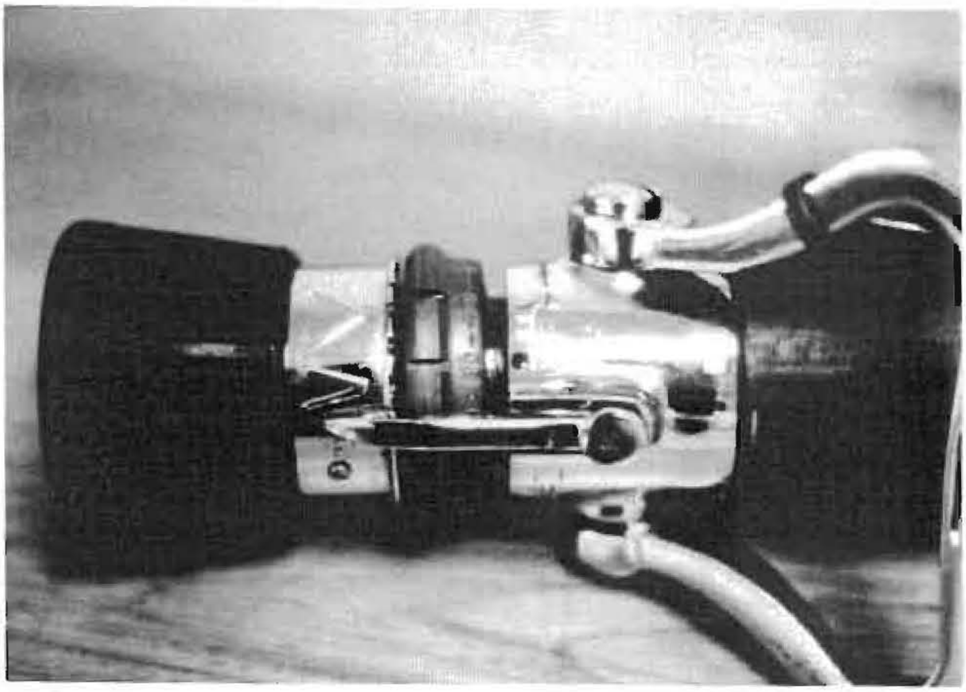

Figure 21 : Details of the firefighting branch

Figure 22: The pallets for the 1996 tests during conditioning prior to testing
C253/1996

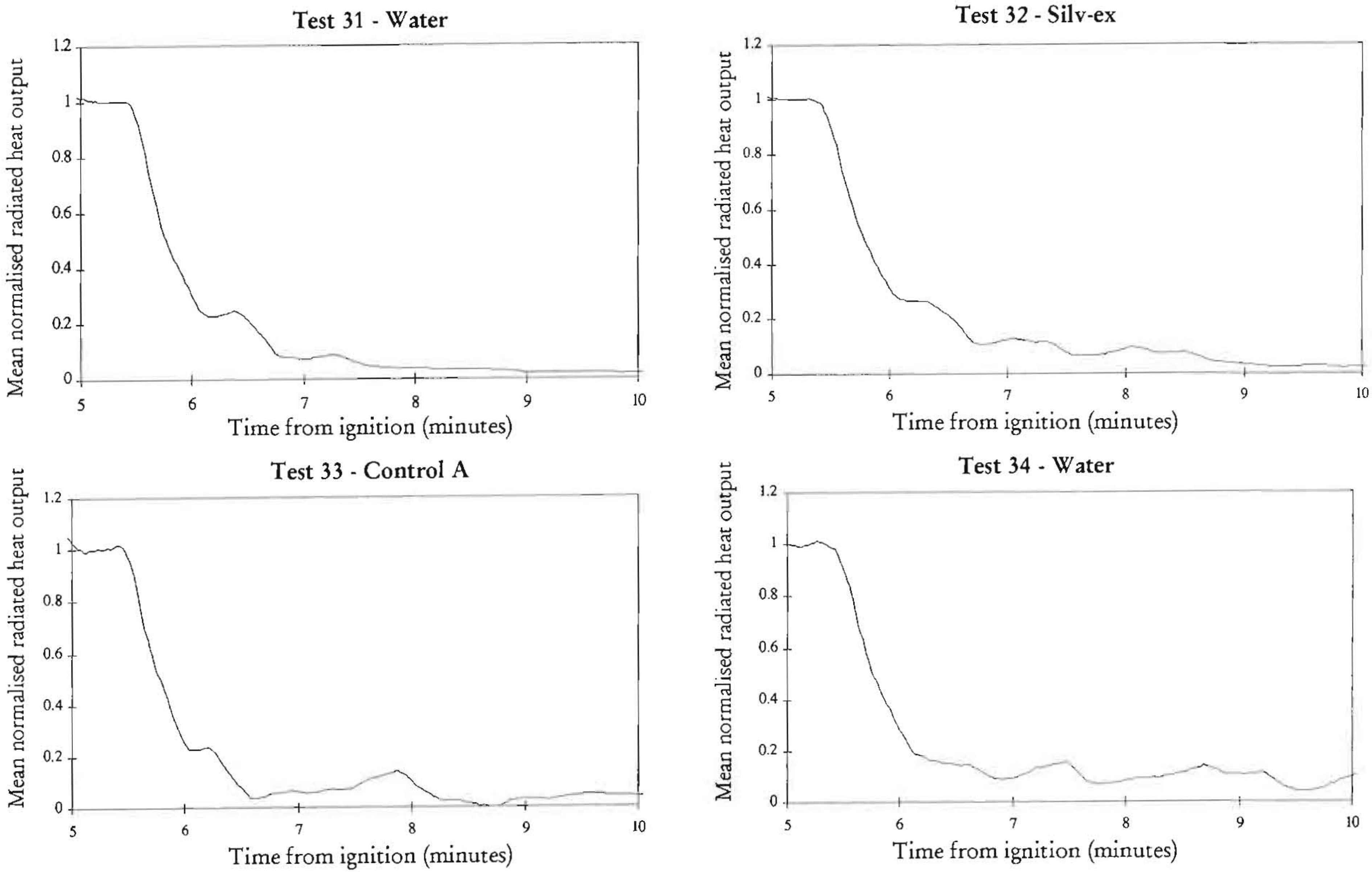

Figure 23 : The mean normalised radiant heat output graphs - 1996 tests

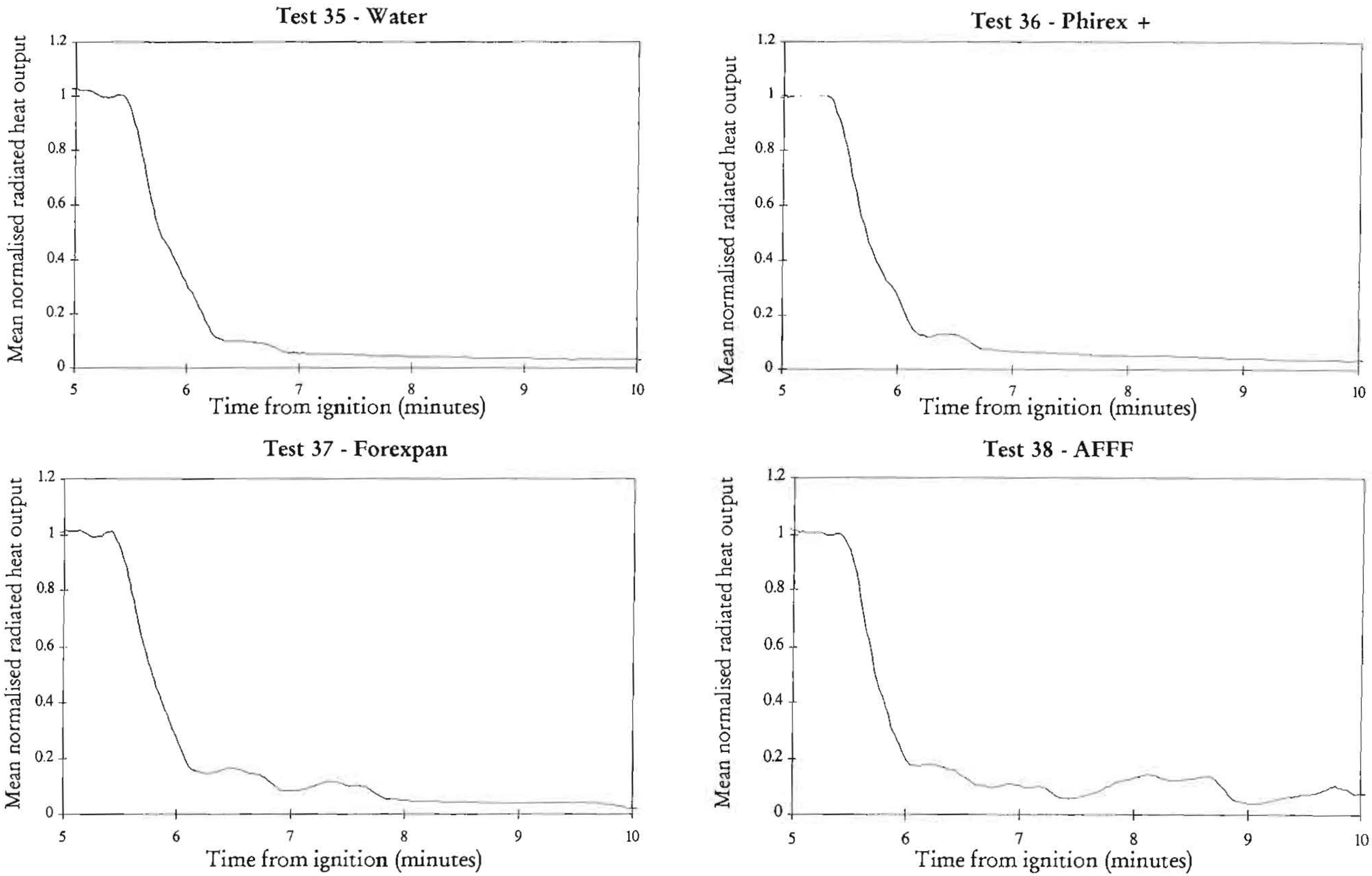

Figure 23 : The mean normalised radiant heat output graphs - 1996 tests

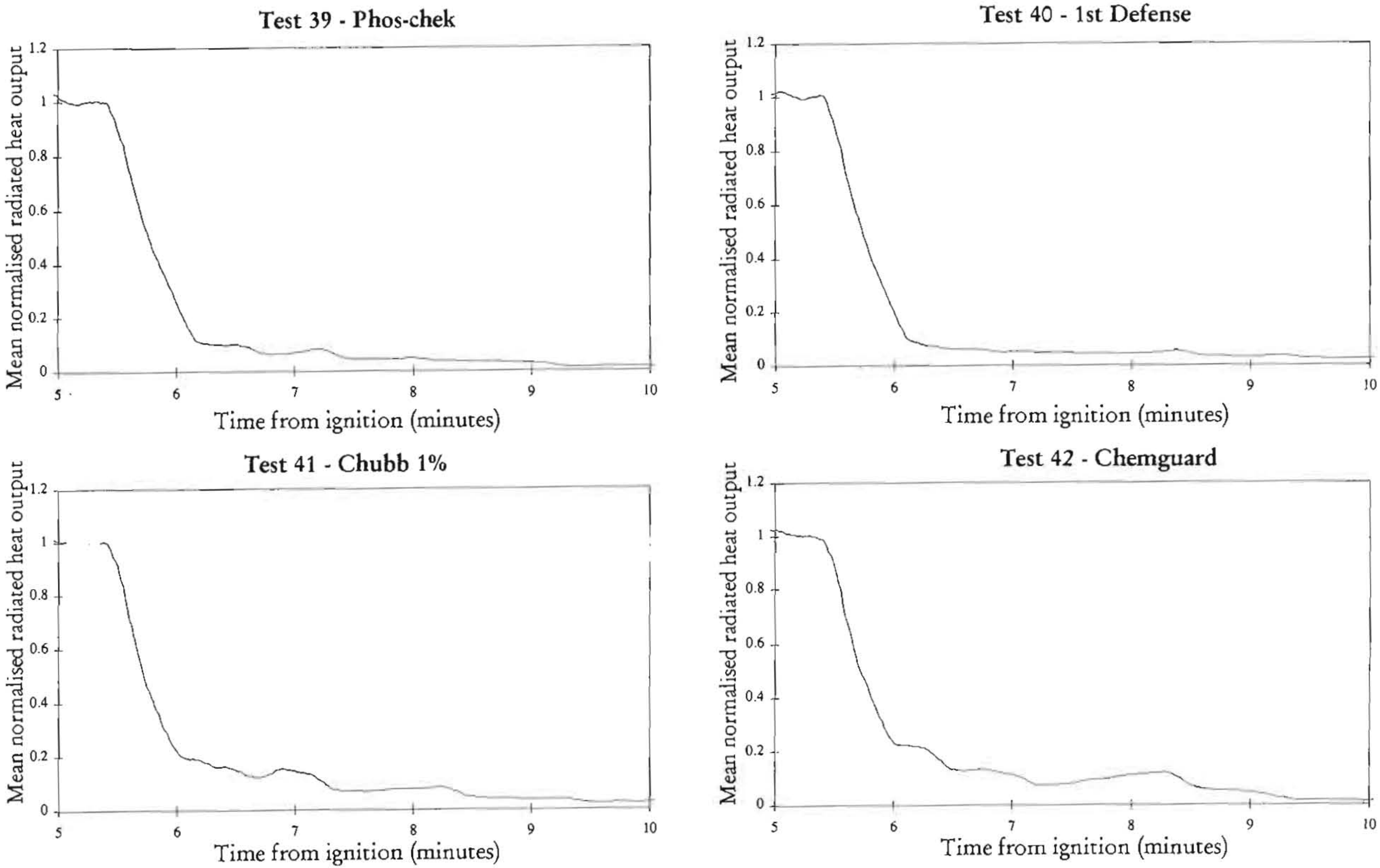

Figure 23 : The mean normalised radiant heat output graphs - 1996 tests

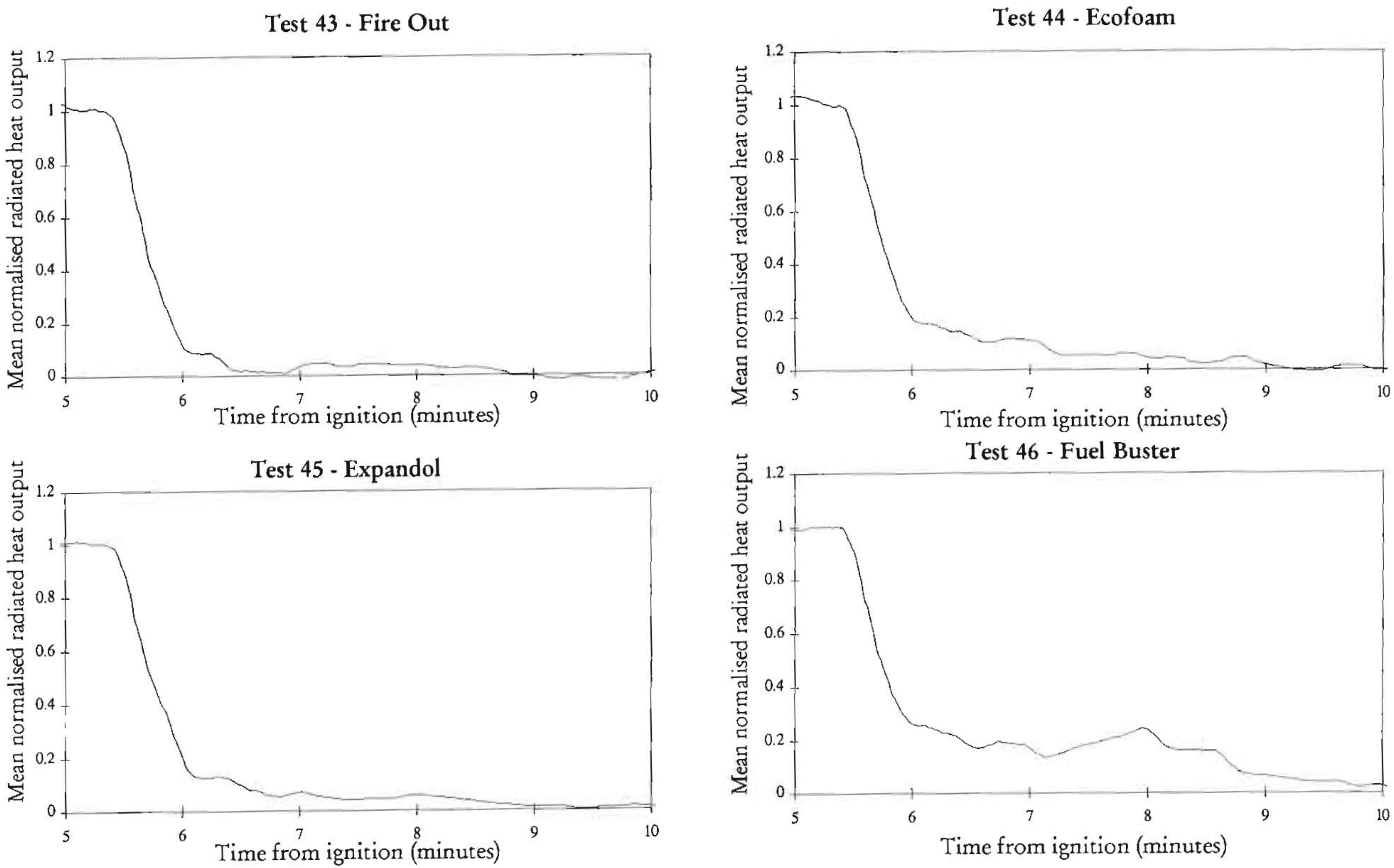

Figure 23 : The mean normalised radiant heat output graphs - 1996 tests

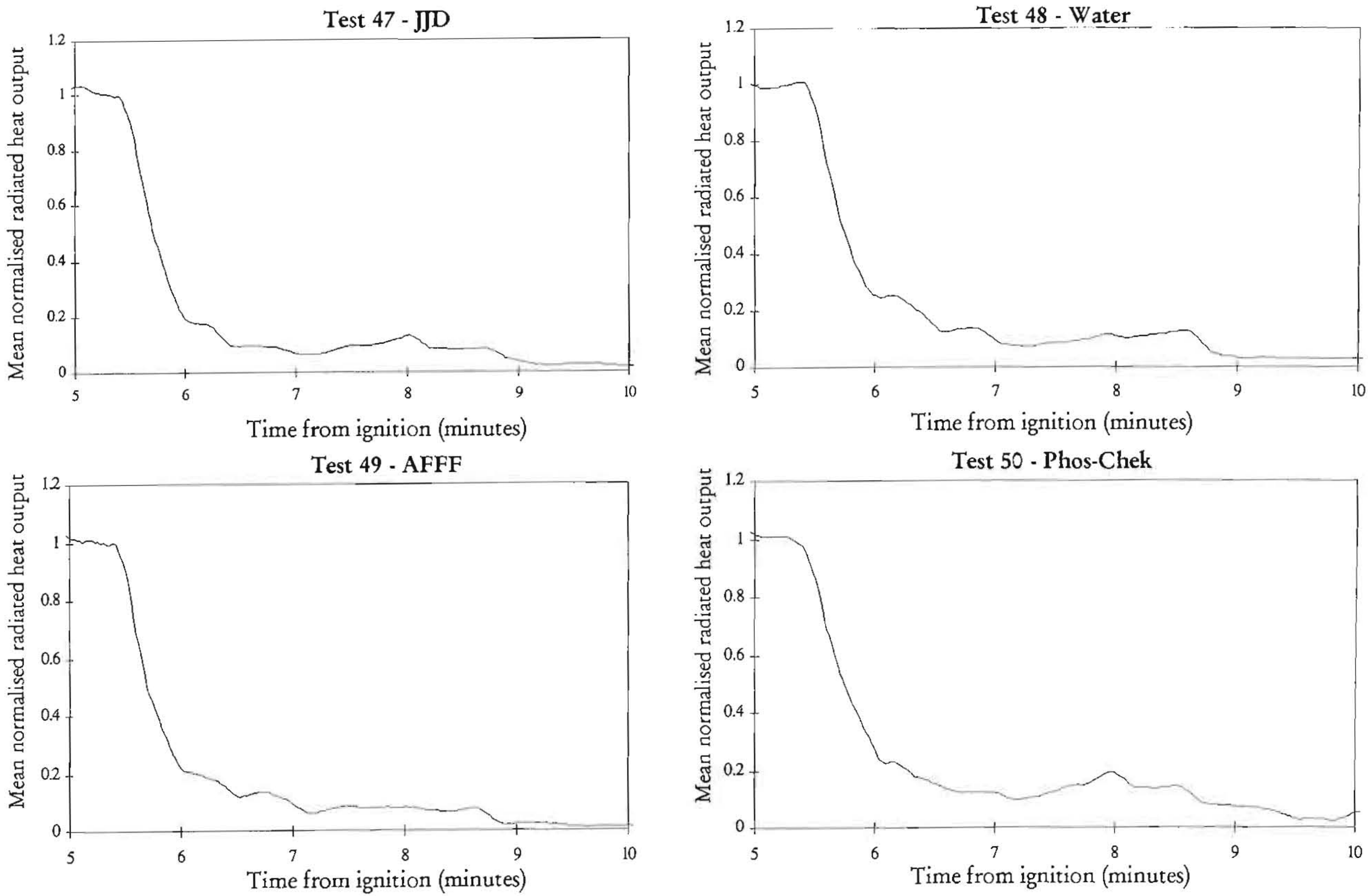

Figure 23 : The mean normalised radiant heat output graphs - 1996 tests

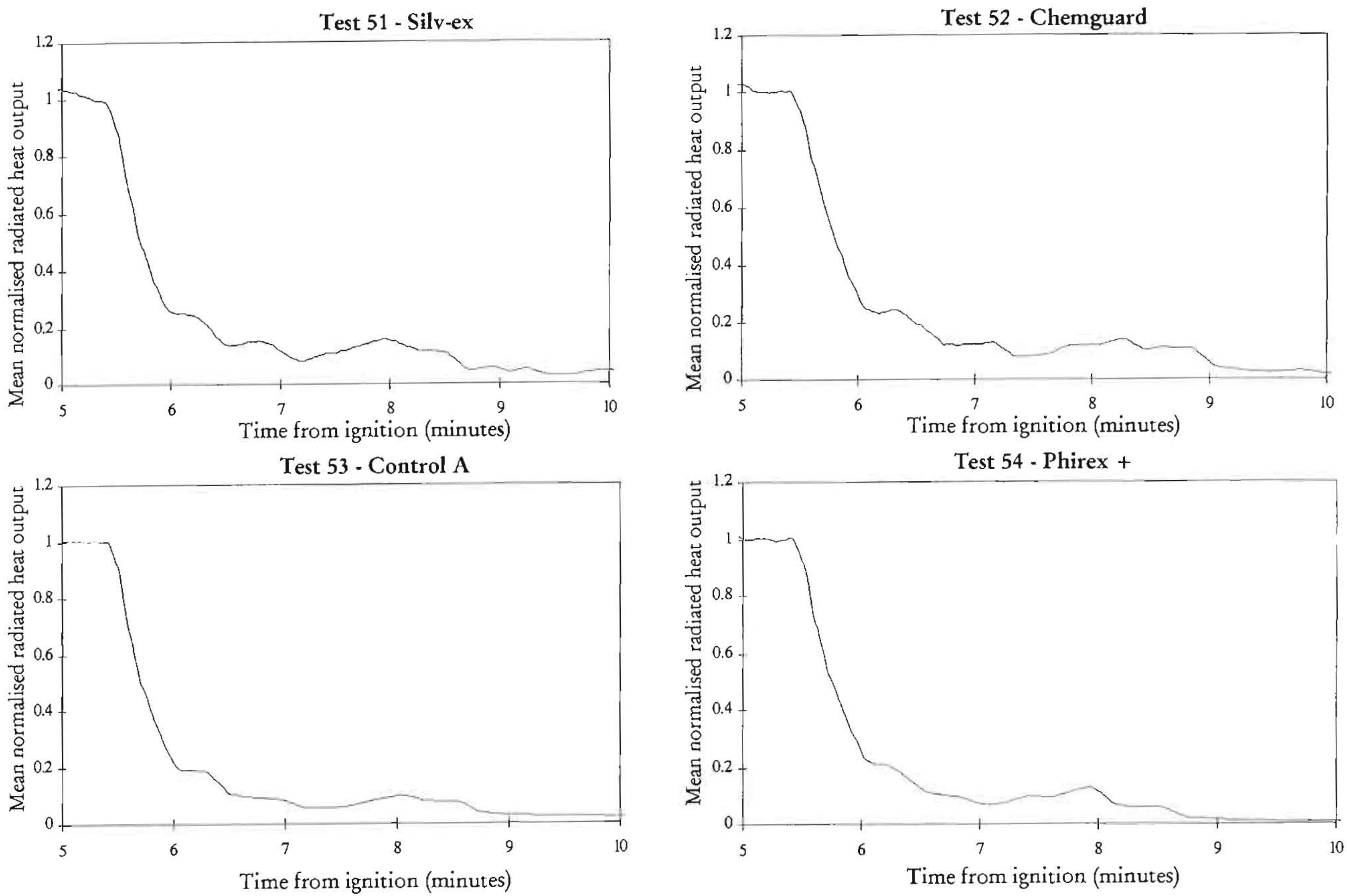

Figure 23 : The mean normalised radiant heat output graphs - 1996 tests

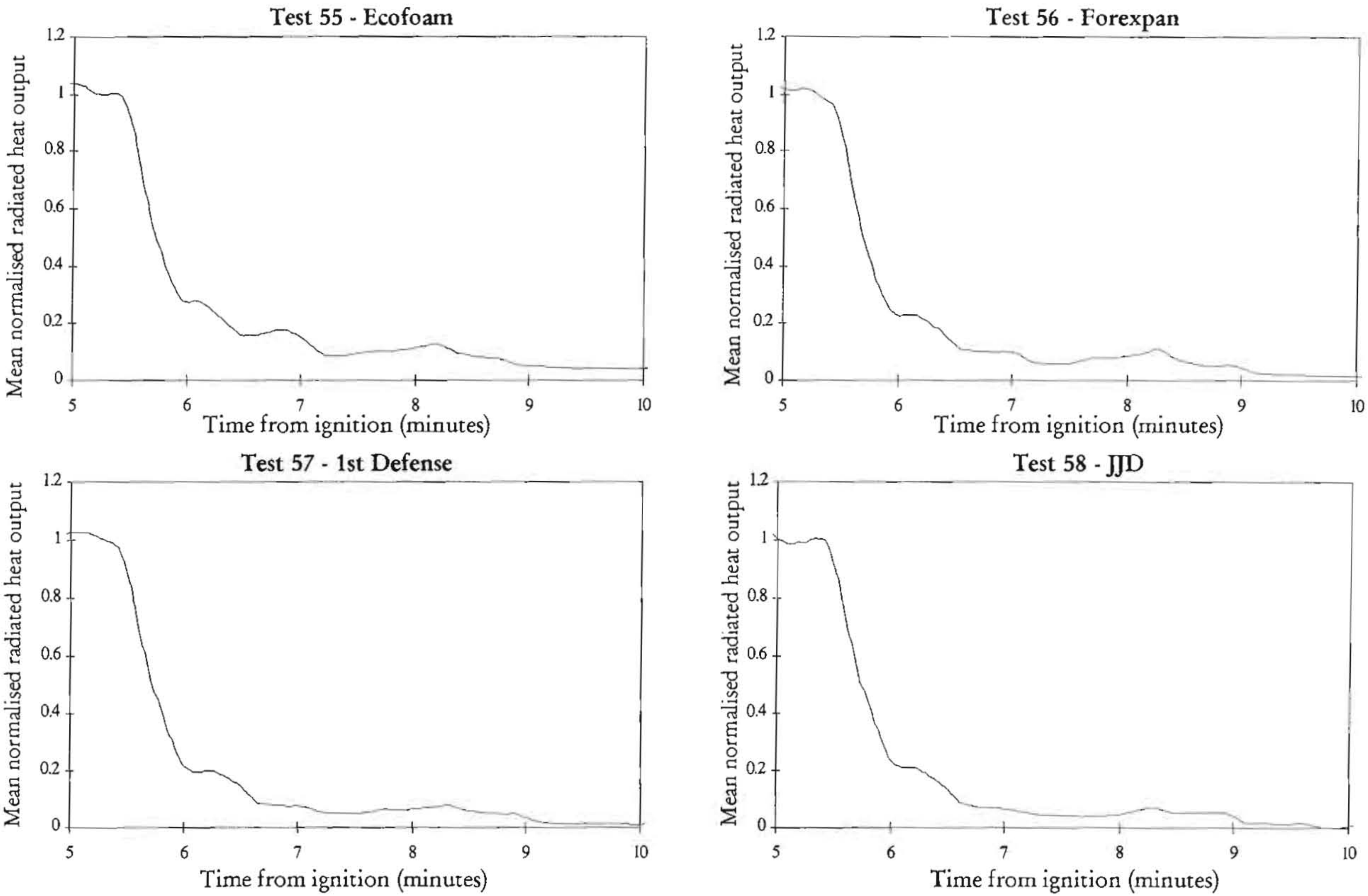

Figure 23 : The mean normalised radiant heat output graphs - 1996 tests

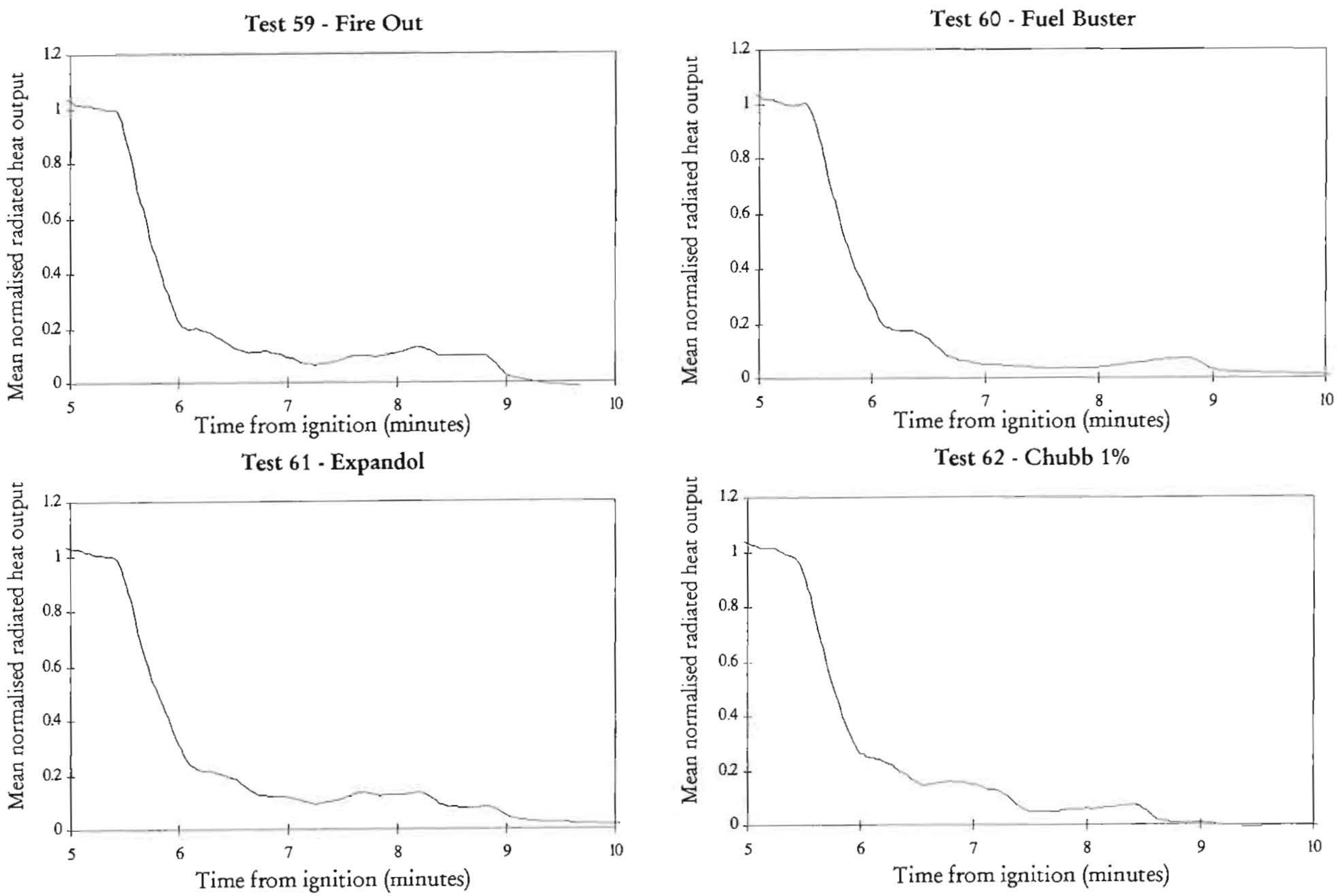

Figure 23 : The mean normalised radiant heat output graphs - 1996 tests

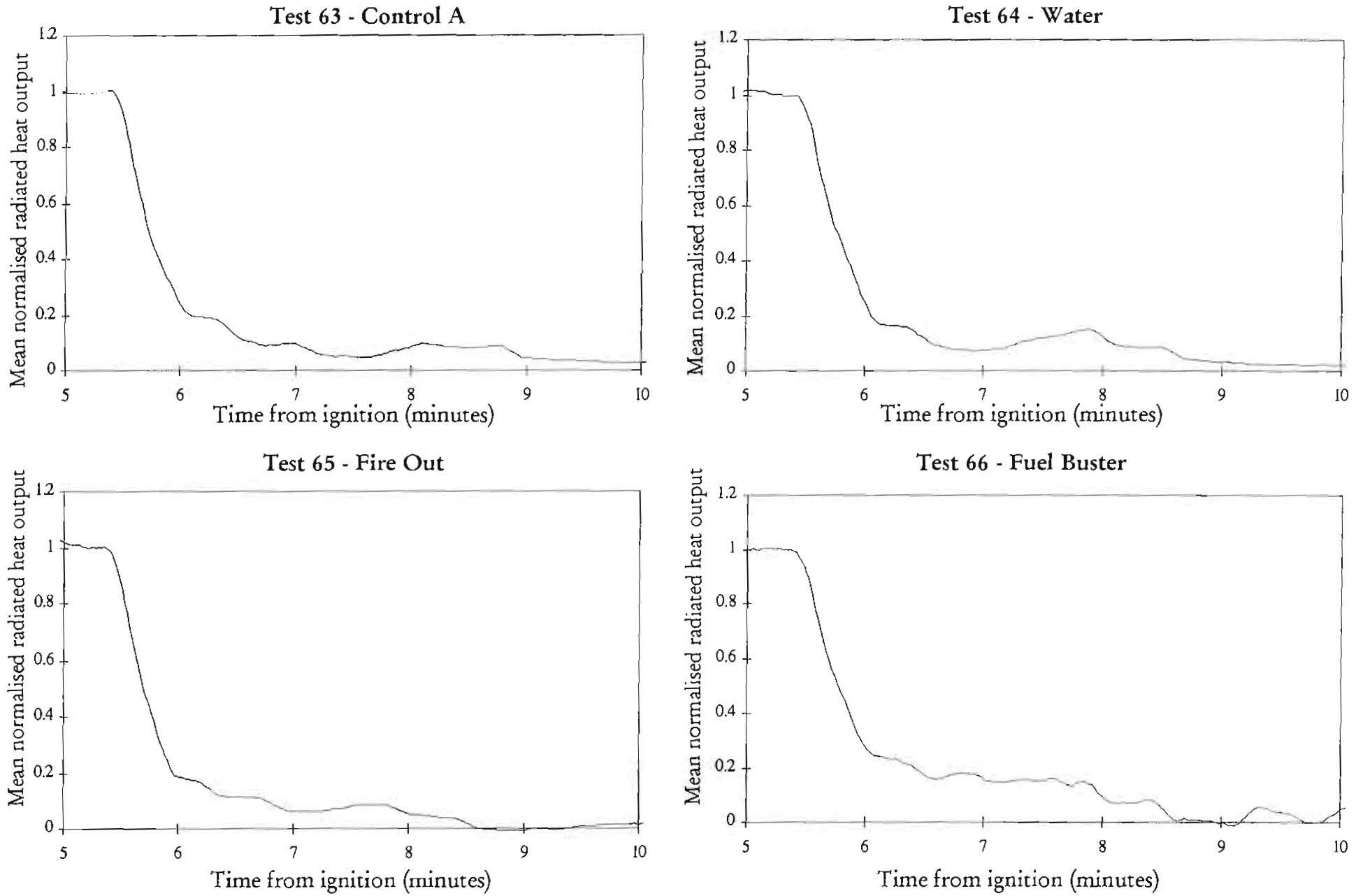

Figure 23 : The mean normalised radiant heat output graphs - 1996 tests

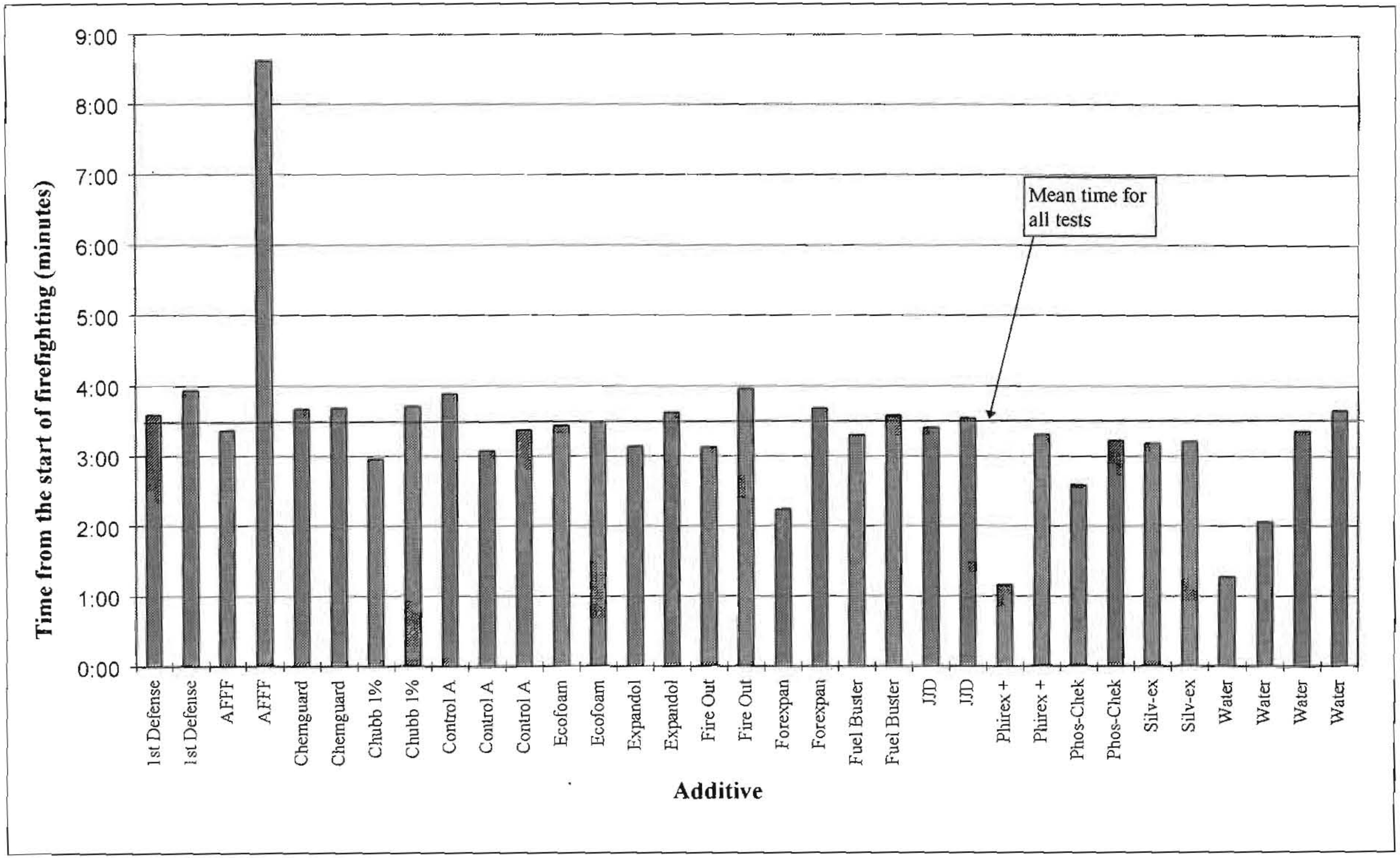

Figure 24 : The times of the last major flames - 1996 tests

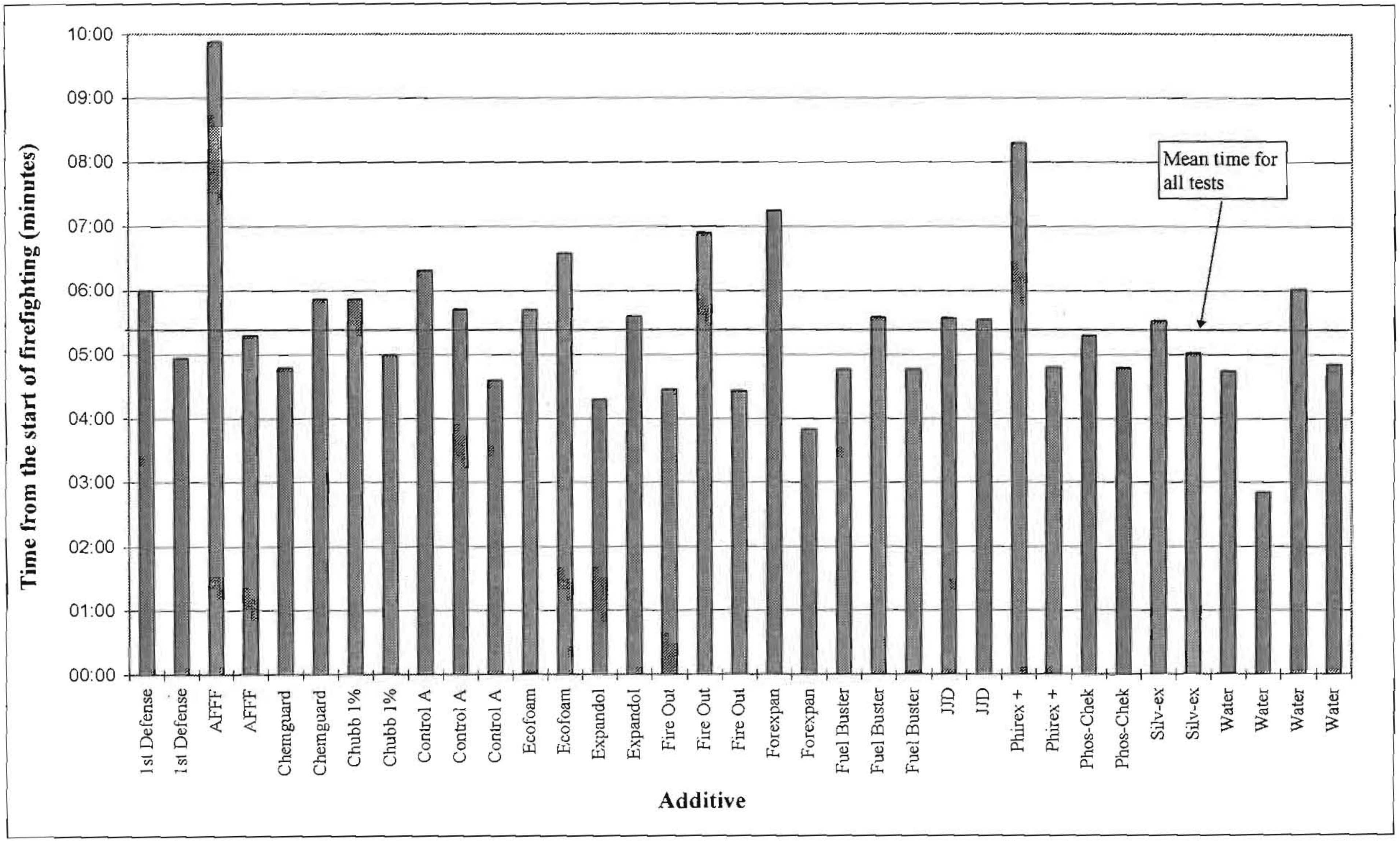

Figure 25 : Firefighting time - 1996 tests

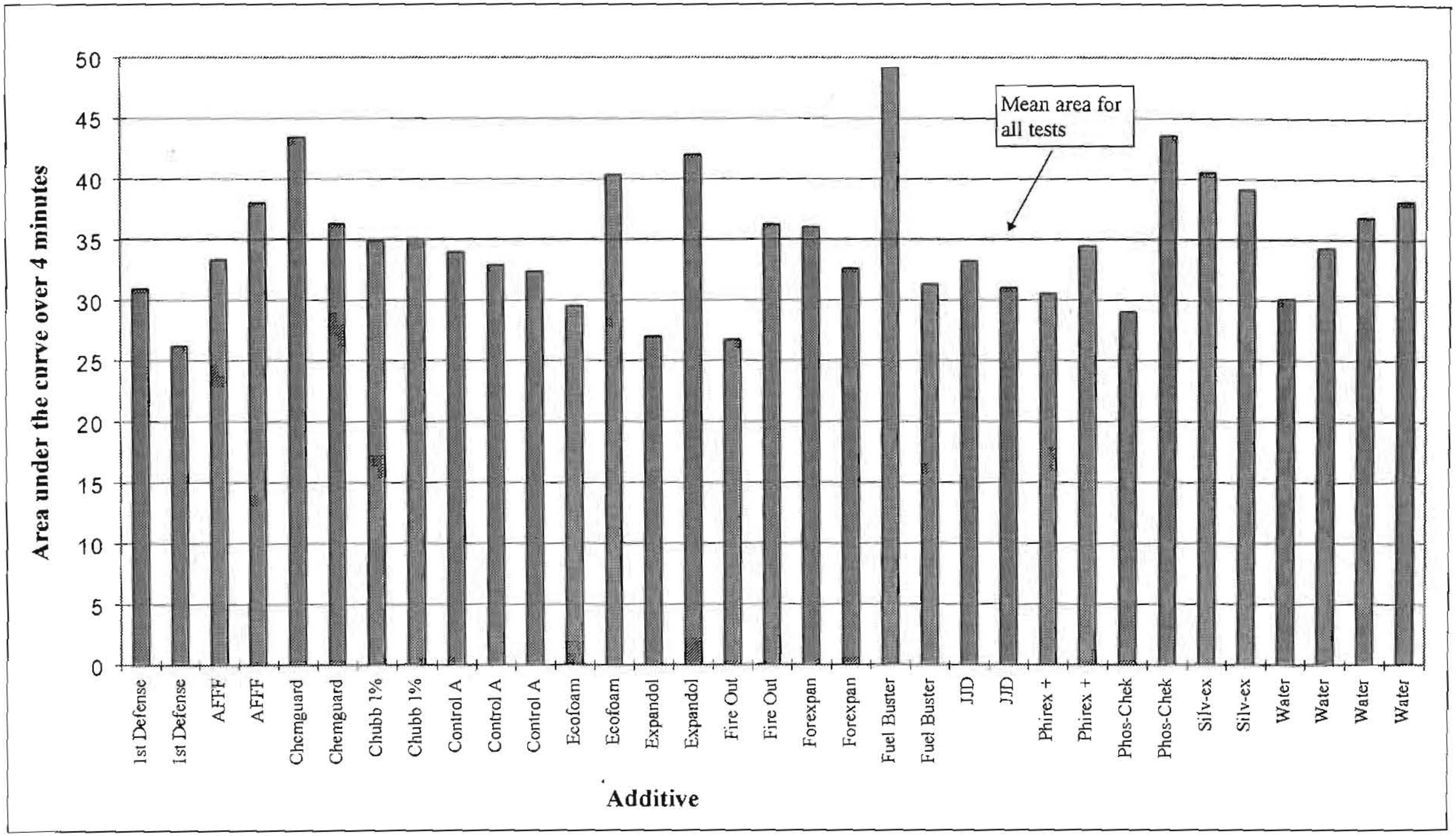

Figure 26 : A bar chart of the results of the analysis of area under the curve - 1996 tests

The lower the value, the better the additive performed

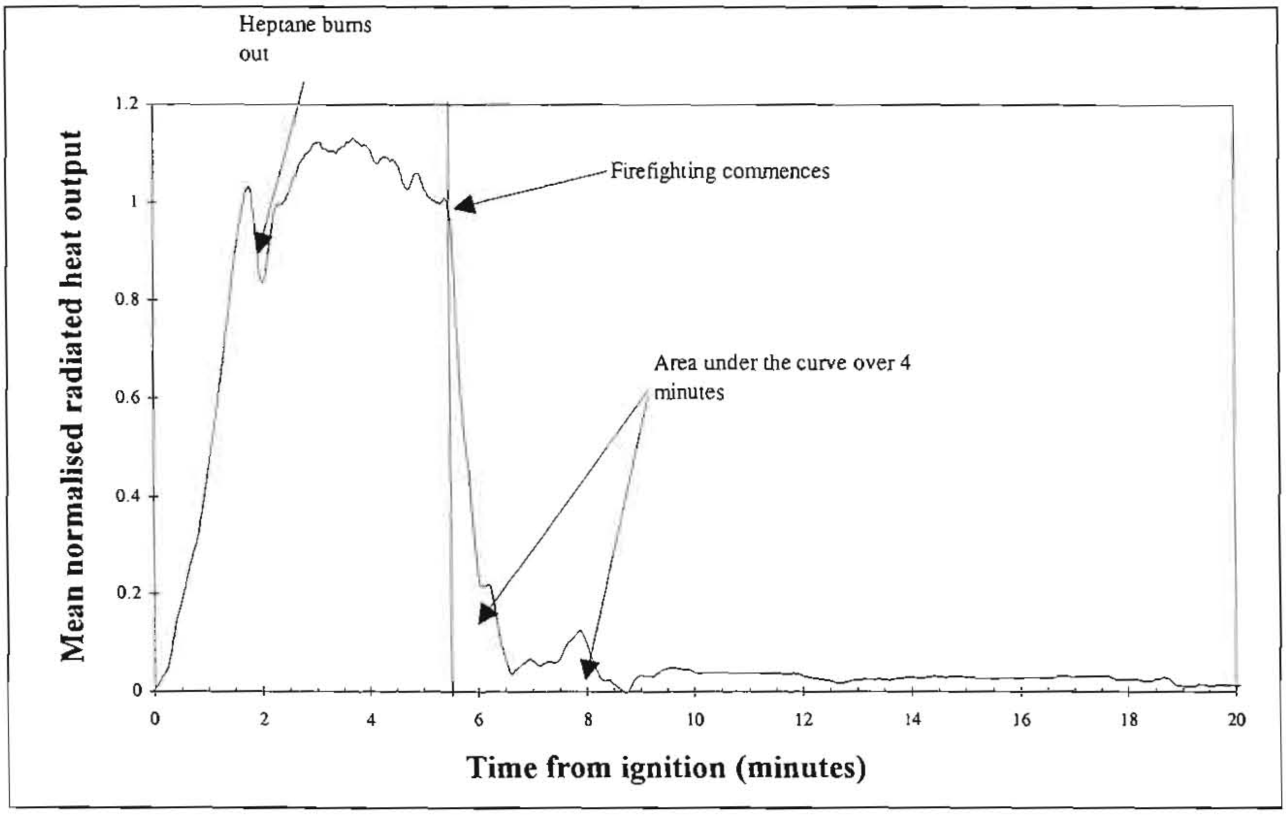

Figure 27 : A typical graph of a mean normalised radiated heat output - 1996 tests

APPENDIX A

Details of the Class A Additives Used

The instructions contained in this appendix were copied from the containers of additives. In some cases full instructions and contents were given on the containers, while in others this information was less complete. Material safety data sheets and test certificates were also supplied with the additives, although these have not been included here.

Product	**LIGHT WATER** **AFFF** **FC 203**	3M Chemical Group 3M House 28 Jackson Street Manchester M15 4P
Cont:	Diethylene glycol, monobutyl ether, ethylene glycol	
LOT#:	002376	3% Concentration

May cause eye and skin irritation
Avoid contact with eyes
Avoid prolonged or repeated contact with skin
In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. After contact with skin, wash with soap and water.
If swallowed, drink two glasses of water and immediately call a physician.

Instructions for use: see Technical data sheet. Data bulletin «AFFF» Aqueous Film Forming Concentrate.

Please ensure before using our product that it is suitable for your intended use.

All questions of liability relating to this product are governed by the terms of the sale, subject, where applicable, to the prevailing law.

Supplier:

Fireater Ltd.
Fireater House
South Denes Road
Great Yarmouth
Norfolk
NR30 3QP

Product	JJD ASSOCIATES LTD CLASS A CONCENTRATE (wetting agent)	Spumifer American Company PO Box 3267 St Augustine Florida USA 32085-3267

Cont: NOT LISTED

This concentrate is intended for Class A fires where water penetration is of primary importance.

Any structural, brush, forestry, or similar incident will benefit from application of this concentrate resulting in very considerable savings of water while achieving fire control very quickly and subsequently giving a rapid knock down.

Class A concentrate may be added to the booster tank, applied through any eductor system or any type of proportioning system. There is no need for any special equipment, even foam nozzles are not required. Since this class A concentrate does not rely on generation of foam for its efficiency any water nozzle can be used with excellent results. In particular very substantial water savings will come during the fire overhaul.

Class A concentrate is a combination of surface tension modifiers which, when mixed with water, permit deep penetration of porous Class A fuels. Even stubborn tyre fires which are normally very difficult to extinguish become easy to control.

Class A concentrate can be added to water in booster tanks at the rate of about 1 or 2 quarts (32 or 64oz) to 1,000 gallons - actual amount will depend on characteristics of water or type of incident. Another suggested method of application is the use of any inline educator: add about 10oz of Class A concentrate to 5 gallons of water and induce at 3% or less. Please make sure that both educator and the nozzle used are of matching flow, i.e. 45 and 45 gallons

Class A concentrate is packaged in 10oz, 32oz (1 qrt.), 128oz (1gal), 5gal or 55gal containers.

Should you have any questions please call us at 1 800 446 1551

Supplier:

Spumifer American Company
PO Box 3267
St Augustine
Florida
USA
32085-3267

Product	**PHIREX +** CLASS A and B firefighting agent & dispersant	Phirex + UK Ltd. 60 Queensway Building 506 IMI Witton Works Witton Birmingham B6 7UQ
Cont:	NOT LISTED	

Product safety information:

Phirex + is a non-toxic, biodegradable, fuel dispersant and flammable/combustible liquid firefighting agent. This product contains no hydrocarbons, alcohol, nor oxides. Phirex + contains no carcinogens or fluorocarbons.

Product uses:

Phirex + may be used to disperse all hydrocarbon spills on land or water. It may be used to neutralise common acids such as sulphuric and hydrochloric. In firefighting it may be used on all types of petroleum and will extinguish petroleum fires at 1 gal per sq.ft. of water and 3% agent or less. Metered agent rate to water may be 3 or 6%.

Firefighting nozzle operations. Phirex + in solution with water should be applied in a dispersed or fog pattern, unless at a very long range. Air aspiration is recommended for the best foam making results.

Application rates and procedures:

1 Major oil spill, deep water, thin oiling

A. Meter at 3% to fresh or sea water

B. Apply solution at 1gal per sq.ft. or less

2 Major oil spill, deep water, several mm thick

A. Meter at 6% to fresh or sea water

B. Apply solution at 1gal per sq.ft. or less

3 Major oil spill, inland waterway & dock areas

A. Meter at 6% to water and apply solution at 1gal per sq.ft. or less of affected surface area

4 Minor oil spills, inland waterway.

A. Meter at 3% to water and apply solution at 1gal per sq.ft. or less of affected surface area

5 Land hydrocarbon spills

A. Meter rate: Meter at 6% to water apply solution at 1gal per sq.ft. or more if long term emulsification is required.

B. Small quantities: Concentrated agent from portable sprayers, when herding is required

C. Flammable vapour: Where vapours cause ignition, use high pressure spray or air aspirated nozzles to produce foam. Metered rate to water at 3% apply at 1gal per sq.ft.

D. Sewer and storm drains: Use Phirex + at 3% metered rate to water with air aspirated nozzles to ensure that foam is generated with this application.

Supplier:

Phirex + UK Ltd.
60 Queensway
Building 506
IMI Witton Works
Witton
Birmingham
B6 7UQ

Product	**DREXEL** **CONTROL A** Class A fire control foam concentrate	Drexel Chemical Company 1700 Channel Avenue PO Box 13327 Memphis TN 76063 USA
Cont:	Non-ionic Surfactants, Alkyl Sulfate Glyc__, Glycol	
LOT: #		0.1% to 1.0% proportioning

Control A - is a fire control concentrate. It is carefully formulated for use on all Class A fires, including wood, paper, plastics, textiles, rubber and coal. Diluted to use concentrations with water, CONTROL A is not toxic to fish or wildlife, nor does it affect the growth of plants. It is biodegradable in soils and sewage treatment facilities. CONTROL A is non-corrosive, and is compatible with plastic, rubber, aluminium, brass and steel.

CONTROL A - significantly reduces water consumption and control time on Class A fires. When applied as a protective barrier it will provide added protection to uninvolved structures and minimise fire and water damage.

CONTROL A- reduces flow resistance in pumps, hoses and nozzles, thus improving stream distance and lessening pump wear. CONTROL A - acts by improving the penetration and spreading of water, thus providing a cooler environment and reducing exposure to toxic fumes for firefighters. It mixes easily in booster pump tank or tanker shuttle, or it can be metered into the flow stream easily with an eductor.

Directions for use

Control A - fire control liquid is a synthetic based concentrate for use by dilution with fresh or sea water in firefighting foam-generating equipment. For ground firefighting use typical Class A firefighting nozzles, mix 0.3 parts CONTROL A to 99.7 parts water. For other Class A fire applications, a proportioning rate of 0.1% to 1.0% should be used depending upon type of fuel and foam generating equipment. CONTROL - A may also be diluted at the rate of 2.5 gallons to 500 gallons fresh water for ready-to-use storage as a premix solution.

Temperature storage ranges

Minimum 5°F (-15°C) to maximum 120° F (49°C). Storage of CONTROL -A in temperatures outside the ranges set forth above may adversely effect the performance of the extinguishing agent.

NOTICE - not intended for use on water soluble fuels - do not mix with other Class A foam agents.

If eyes become irritated by contact with agent, immediately flush with large amounts of flowing water for 15 minutes. If irritation persists consult a physician.

LIMITS OF WARRANTY - CONDITION OF SALE

This product is believed to be highly effective aid in suppression or reduction of the hazards of fire when used according to the directions for use. However, DREXEL has no control over the customer's use of the product or the applications for which it is employed. Because of the many variables associated with fire, DREXEL does not warrant that this product will suppress or extinguish every fire.

DREXEL CHEMICAL COMPANY WARRANTS that the product conforms to the chemical description on the label and is reasonably fit for the purpose as referred to in the directions for use as modified by the above. DREXEL makes no other warranties, expressed or implied, including FITNESS OR MERCHANTABILITY. In no case shall DREXEL or the Seller be liable for consequential, special or indirect damages resulting from the use of handling of this product. The foregoing is a condition of sale by DREXEL CHEMICAL COMPANY and is accepted as such by the buyer.

Supplier:

Chiltern Fire and Chemicals
11 High Street
Thornborough
Buckingham
MK18 2DF

Product	**FUEL BUSTER**	FSI FUEL BUSTER 256 Commerce Drive Suite 475 Peachtree City GA 30269 USA
Cont:	**Not listed**	Phone (404) 487 - 2969 Fax (404) 487 - 5474
LOT #:		

Designed for petroleum fires for fire departments, industry, marinas and commercial use.

Helps in prevention of fuel and oil related fire and explosions

Non corrosive, non toxic, non flammable

Locks up hydrocarbons and dispersed petroleum distillate based spills

Completely miscible in water in all proportions

Minimise flammable vapours

Reduces fire hazards by emulsifying, dispersing and diluting flammable liquids

Will not support combustion

Contains tracing dyes

Easy to use

CAUTION:

Keep out of reach of children, Avoid prolonged contact with skin.

Do not get in eyes.

In case of contact, flush with plenty of water. Get medical attention

Notify EPA on water spills

Refer to MSDS for additional information

IMPORTANT:

This product does not make petroleum spills non-flammable until thoroughly agitated with water.

All normal caution should be used.

FSI Fuel Buster will make the spills water soluble so they may be easily rinsed away.

Supplier:

Omega Global Networks,
34, St Stephens Garden
London
W2 5QX

Product **CHUBB FIRE**
CLASS A CONCENTRATE

Chubb Fire Engineering
Lancaster Road
Cressex Industrial Estate
High Wycombe
Bucks HP12 3QF

U.K. Emergency Response
Number 0932 785588.

NOTE: The information on this container was as for Chubb training foam. However the foam inside was Class A Concentrate. The instructions and information therefore have not been reproduced

Product	**NATIONAL FOAM** **1ST DEFENSE** **CLASS A FOAM** **Liquid foam concentrate for Class A fires**	National Foam Inc. 150 Gordon Drive PO Box 270 Exton PA 19341 - 1350 USA Tel 215 363 1400 Fax 215 524 9073

LOT: # 167586208

Properties

Mix ratios: 0.1% to 0.7% by volume

Aerial Application: 4 to 7 gallons concentrate to 1000 gallons water (4 to 7 litres concentrate to 1000 litres water).

Ground Application: 1 to 5 gallons concentrate to 1000 gallons water (1 to 5 litres concentrate to 1000 litres water)

Note Add 1st Defense concentrate AFTER loading water. Avoid excessive stirring or aeration of foam concentrate/water mixture. 1st Defense can be added with inline eductors in injectors.

Density: 8.52lbs per gallon (1.022 kg/litre)

Compatibility. Product is compatible with fresh, brackish & sea water. Usable temperatures; Minimum 47°F (4°C); maximum 125°F (52°C)

Storage Containers Store in polyethylene or polyethylene-lined containers

Storage 1st Defense foam is not affected by freezing and thawing

Environment: Product is biodegradable and has minimum impact on the environment. Avoid introduction of concentrate into watercourses.

Cleanup: Spills of 1st Defense foam concentrate should be physically removed using sand or other absorbent material to facilitate removal. Direct application of water may result in excessive foaming. Water can be used for final cleanup after concentrate is removed. Cleanup should be done in accordance with all government regulations.

Handling: Shipping data : 5 gallon pails (18.9 litres) 55 gallon drums (208 litres)

Hazards: Non hazardous composition
Non flammable

Mixing: Avoid skin and eye contact when mixing concentrate. Persons handling 1st Defense concentrate should wear goggles and gloves.

Wash thoroughly after handling.

First Aid: In case of eye contact immediately flush eyes with large amounts of water for at least 15 minutes. Call a physician. Flush skin with water.

Notice to customer/user: This product can be a highly effective aid in the suppression and control of the hazards of fire when used in accordance with NF's instructions. However, since NF has no control over the customer's selection of application equipment and maintenance of same and the many variables associated with fire, hazards to be protected etc. NF cannot and does not warrant that this product will suppress and extinguish any fire. Customer/user should be aware that the dilution, or contamination with any other substance or storage outside the recommended storage temperature range shown on this label may render this product ineffective for its intended use. Ref 6o NF data sheets and bulletins for information on shelf life and storage requirements. Before using customer/user shall determine the suitability of the product for its intended use and user assume all risk and liability whatsoever in connection therewith. Neither Seller nor NF shall be liable in tort or in contract for any loss or damage, direct, incidental or consequential arising out of the use of or the inability to use this product.

Supplier:

Chubb Fire Engineering
Lancaster Road
Cressex Industrial Estate
High Wycombe
Bucks HP12 3QF

Product | **CHEMGUARD CLASS A PLUS Foam Liquid Concentrate**

Chemguard Inc.
204 South 6th Avenue
Mansfield
TX USA 76063
(817) 473 9964

Cont: Not listed

Instructions for use:-

Chemguard Class A plus foam is formulated to be premixed or proportioned for use between .1% and 1% depending upon application.

The type of equipment used to develop the foam and the type of foam desired will determine the required use level. When using Compressed Air Foam Systems, the range of proportioning is normally between 0.1% and 0.8% depending on degree of foam expansion required. Air aspirating nozzles generally use .2% to 5% mixtures. Helicopters with buckets or fixed tanks generally use .2% to 5% solutions. Lower concentrations may be used in "mop-up" operations and higher concentrations on flash or high intensity fires where longer drainage times are necessary. Fixed wing aircraft should use .6% solutions when dropping on open fuels. If canopy penetration is required a reduced concentration of approximately .3% should be used to reach ground fuels with larger percentage of the product.

CHEMGUARD CLASS A PLUS FOAM is non-corrosive, non-toxic, nor harmful to the environment.

CAUTION Avoid use on electrical fires or fires involving chemicals that react dangerously to water. This material may cause skin and eye irritation. Avoid skin and eye exposure.

FIRST AID In the case of eye contact, flush with water immediately and obtain emergency medical attention. In the case of skin contact wash with soap and water.
Supplier:

Chemguard Inc.
204 South 6th Avenue
Mansfield
TX USA 76063
(817) 473 9964

Product	**FIRE OUT I** **Concentrated fire control additive**	Thermal Science & Technology PO Box 426 Monroe VA24574 (808) 385 4441
Cont:	A nonylphenyl ether (CAS NO. 2607-38-3), biodegradable surfactants & corrosion inhibitors Suggested hazards rating: HMIS: Health =1; Fire = 0; Reactivity = 0 NFPA: Health =1; Fire = 0; Reactivity = 0	
LOT: #	Shipping Instructions: shipped as Compounds, Cleaning Liquid, N.O.S. No specific hazards labelling required	

Instructions for use:

Read the MSDS prior to using this product. FIRE OUT I is specifically formulated as a highly concentrated surfactant mixture for use in a wide variety of firefighting situations. The product functions by causing the water dilutant to become a superior heat sink and by also breaking down at the high temperature fuel/fire interface to form a vapour cloud which aids in choking off oxygen feeding the fire. This dual action has proven very effective in class "A" and "C" fires as well as in various class "B" fires which have a high enough temperature at the burning interface. For use, the product is normally inducted into the flowing water stream at a concentration of 0.2% by utilising the special eductor designed specifically for this purpose.

Caution

Keep out of the reach of children. May be toxic by ingestion. Keep containers tightly closed when not in use. Do not take internally. The concentrate is an eye irritant. The use of safety glasses is recommended when handling. If clothing is contaminated, remove and wash before reuse.

First Aid

If ingested, drink several glasses water to dilute and induce vomiting. Get immediate medical attention. For eyes, flush with clear water for 15 minutes. Get medical attention if irritation persists. For skin, wash with soap and water.

Keep container closed when not in use. Do not contaminate water, food or feed by storage or disposal of this material or its container. Open dumping is prohibited. Triple rinse container and offer for recycling or recondition. Thoroughly rinsed containers may be disposed of in an incinerator or properly approved landfill. Consult Federal State or local disposal authorities for approved alternative procedures such as limited open burning.

The seller warrants that this product conforms to its chemical description and is reasonably fit for the purposes stated on this label when used in accordance with directions under normal conditions of use. The seller does not make and does not authorise any agent or representative to make any other warranties of fitness or merchantability, guarantee or representation express or implied, concerning this material. This product is sold only on the basis that the buyer assumes all risks of use, handling or storage which result in loss or damage and which are beyond the seller's control. No claim of any kind shall be greater in amount than the purchase price of the material in respect of which such claim is made in no event shall the seller or the manufacturer be liable for special, indirect or consequential damages resulting from the use, handling, storage or disposal of this material or its container.

Supplier:

Thermal Science & Technology
PO Box 426
Monroe
VA24574
USA
(808) 385 4441

Product	**PHOS-CHECK WD881** **Fire Retardant Compound**	Monsanto Antwerp, Belgium (32) 3.568.51.11 (32) 2.7614600

LOT #: 3H1/Y - 1.2/150/92
F-BVT 222512 - AP

Irritating to eyes, respiratory system and skin
Avoid contact with skin and eyes
Do not breathe vapour
Supplier:
Monsanto p.l.c.
Chineham Court
Chineham
Basingstoke
RG24 8AG

Product **ECO-FOAM 2004TM**

Phirex + U.K. Ltd
60 Queensway
IMI Witton Works
Witton
Birmingham B6 7UQ
Tel: 0121 331 4838
Fax 0121 331 4868

Cont: Not listed

LOT: #

Eco-Foam 2004 is a new state-of-the-art very low toxicity and biodegradable firefighting foam specifically designed for application on Class A and Class B fires. Eco-foam 2004 can be deployed through all standard/normal firefighting appliances, including fixed sprinkler systems, hand held portables and wheel mounted foam units. Eco-Foam 2004 is UL Listed.

Applications and uses:

1 **Class A (fibrous) materials:**

Meter agent at 0.5% - 3% in fresh water and apply foam solution onto fire. Suitable for all types of fibrous combustibles, e.g. wood, textiles, paper, plastics, rubber, cloth etc. For bush fires, meter agent at 0.5% - 1% in solution in water and apply to cover fires.

2 **Class B (hydrocarbon) Liquids:**

Flammable hydrocarbon fires can easily be extinguished by using Eco-Foam 2004 at 3% to 6% in solution in fresh or salt water. Aspirated or non-aspirated nozzles can be used. Where highly flammable or volatile fuels are encountered, use of aspirated nozzles is strongly recommended. Extinguishment can be accomplished at 0.04% to 0.06% density or less (depending on fuel types encountered).

Where potential for ignition of flammable vapours exists, meter at 6% solution with aspirated nozzles and ensure adequate foam blanket coverage is provided at all times.

3 **Equipment:**

All standard/normal firefighting appliances including fixed monitors, sprinklers and portable delivery systems can be used. Aspirated or non-aspirated nozzles may be used for successful results.

4 **Special Handling Precautions:**

None specified, however it is recommended to wear rubber gloves and face shield when handling or transferring agent to prevent splashing of agent onto skin or introduction into the eyes. Wash agent off with soap and water should skin contact occur, consult physician, if ingested, seek medical advice.

5 **Precautions:**

Not recommended for use on alkaline substances or Class D (metal fires). When in doubt, contact manufacturer and/or refer to technical manuals.

Supplier:

Phirex + U.K. Ltd
60 Queensway
IMI Witton Works
Witton
Birmingham B6 7UQ
Tel: 0121 331 4838
Fax 0121 331 4868

Product	**SILV-EX** **Class A Fire Control** **Concentrate**	ANSUL Fire Protection One Stanton Street Marinette WI 54143-2542 715-735-7411
Cont:	HMIS 2-1 O/Butyl Carbitol, Ether Sulfates, Glycol Ether/Irritant "Class A" Fire Control Concentrate (0.1% to 1.0% Proportioning)	
LOT#:	US6401	Shipping Assembly Part No. 75451 5 gallon canister

NOTICE; Not intended for use on water soluble fuels

Temperature Storage Ranges: Minimum 20°F(-7 °C) to maximum 120 °F(49 °C). Storage of Silv-ex foam concentrate in temperatures outside the ranges set forth above may adversely affect the performance of the extinguishing agent.

Do not mix with any other "Class A" foam concentrates without consulting Ansul Fire Protection for compatibility. If eyes become irritated by contact with agent, flush with water.

Instructions for Use:

Ansul SILV-EX "Class A" fire control liquid is a synthetic based concentrate for use by dilution with fresh or sea water in firefighting foam-generating equipment. For ground firefighting using typical "Class A" firefighting nozzles, mix 0.3 parts concentrate to 99.7 parts water. When used for aerial application with fixed wing aircraft, or helicopters, mix 0.6 part concentrate to 99.4 parts water. For other "Class A" fire applications, a proportioning rate of 0.1% to 1.0% should be used dependent upon the type of fuel and foam generating equipment. SILV-EX foam concentrate can also be diluted for ready-use storage as a premix solution with fresh water.

Limits of Warranty and Remedy:

This product is believed by Ansul to be a highly effective aid in suppression or reduction of the hazards of fire when used according to the instructions for use. Since, however, Ansul has no control over the customers use of the product or the applications to which it is employed and because of the many variables associated with fire, Ansul cannot and does not warrant that this product will suppress or extinguish every fire. Before using, user shall determine the suitability of the product for his intended use and user assumes all risk and liability whatsoever in connection herewith.

Ansul warrants that this product conforms to its technical specifications for a period of one year after the date of sale by Ansul provided that the product is maintained in a container or equipment approved by Ansul;; stored within a temperature range of **(20°F (-7 °C) to maximum 120 °F (49 °C);** and not mixed with foreign substances. Ansul's only obligation and the purchaser's sole remedy for breach of this warranty shall be to replace quantities of the product which in Ansul's opinion do not meet Ansul's specifications within the warranty period.

ANSUL MAKES NO OTHER WARRANTY OF ANY KIND, WHETHER EXPRESS OR IMPLIED INCLUDING THE WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, UNDER NO CIRCUMSTANCES SHALL SELLER OR ANSUL BE LIABLE FOR ANY CONSEQUENTIAL, SPECIAL OR SIMILAR DAMAGE, ARISING OUT OF THE USE OF THIS PRODUCT.

Supplier:

Grinnell Manufacturing Co Ltd
Stockport Trading Est.,
Yew Street
Stockport, SK4 2JW

Product	**ANGUS FOREXPAN**	Angus Fire Armour Ltd

ANGUS FOREXPAN
Forestry Foam Concentrate

Angus Fire Armour Ltd
11 Curity Avenue
Toronto
Ontario M4B 1XF

Cont:

For use at 0.10-1.0% INDUCTION

LOT#:

Recommended minimum storage temperature -10°C
Maximum storage temperature 50°C

Advice to Users:

Avoid Ingestion

Avoid contact with eyes, accidental splashes in the eye should be washed out immediately with fresh water

Avoid prolonged skin contact

Wash after skin contact

The manufacturer makes no warranties for this product express or implied. The manufacturer agrees to replace such quantity of the product that proves to be defective. The manufacturer shall not be liable for injury, loss or damage direct, incidental or consequential arising out of the use of or the inability to use this product. The product is designed for use only by qualified professionals who shall determine the suitability of the product for its intended use, shall assume all risk and liabilities whatsoever in connection therewith. The product should not be mixed with other liquids except as specified in the instructions. These provisions may not be altered except by written agreement executed by an officer of the manufacturer

Supplier:

Angus Fire
Thame Park Road
Thame
Oxfordshire
OX9 3RT

Product

ANGUS EXPANDOL
Synthetic Foam Concentrate

Angus Fire
Thame Park Road
Thame
Oxfordshire
OX9 3RT

Cont:

LOT#:

For use at 1 - 3%
INDUCTION

Storage Temperatures Min. -5°C
Maximum 49°C

Advice to Users:

Avoid ingestion

Avoid contact with eyes, accidental splashes in the eye should be washed out immediately with fresh water

Avoid prolonged skin contact

Wash after skin contact

Supplier:

Angus Fire
Thame Park Road
Thame
Oxfordshire
OX9 3RT

APPENDIX B

Safety Notes

F 23.20.1 Class A Firefighting Foam

Fire Tests

INTRODUCTION

Following the preliminary fire test that was held at Rissington on April 27th, the main series of pallet fires is to be held, again at Rissington, at the beginning of June. Each test load will consist of 56 pallets stacked in 4 piles together. They will be stacked on the test rigs as before.

The preliminary fire has indicated that a maximum of two fires a day should be possible. Labourers will be hired for clearing the site after a fire and rebuilding the next stack. 17 to 20 fires will be held.

Test	Additive	Purpose
1 - 2	Water	To confirm the test method and provide a control result using water (if the method requires too much modification, further fires may be needed to provide the control information)
3	AFFF	Control information
4	Expandol	Control information
5	Class A foam	Practise class A foam application
6 - 17	Test foams	Class A foam tests proper

14 types of Class A additive have been ordered so far. A maximum of 20 tests will be held.

Test Procedure

The area under the hood will be cleared before each test by labourers. Charred wood will be placed into skips provided outside the hangar. The fuel trays and stands will be cleaned and all additive solution from any previous test will be cleared away. The rigs will be positioned centrally under the hood and the pallets stacked on top of them. Enough water will be put into the trays to cover the bottom surface.

The radiometers will be checked, the moisture content of the wood will be checked and noted.

200 litre drums of heptane will be stored in the fuel store outside the Still Air Facility. While the area under the hood is being cleared, 6.25 litres of heptane will be transferred into each of 4 smaller, flammable liquid containers. These smaller containers will be placed on a hand trolley which will be positioned in the coned off area inside the Still Air Facility.

The detonators will be connected to the firing box by a system of two core cable and ceramic connectors. This system will be set up and checked before fuel transfer and then removed during fuel transfer. The detonators will be connected in parallel. Each detonator will be wired with a shorting link for safety. During all operations involving the detonators, the safety key will be removed from the firing box and will be in the possession of the person responsible for detonator handling.

1500 litres of water will be measured into a large tank and the foam concentrate will be mixed in. The tank will be located on platform scales to enable the volume of water to be measured. The additive will be measured using measuring cylinders. The pump will be run up to deliver 100 lpm of solution.

When all personnel are clear of the area under the hood, the trolley containing the four cans of priming fuel will be moved over to the hood and the fuel will be transferred into the trays. The fuel temperature will be noted in each of the trays. The detonators, in their brackets, will be placed over the edge of the tray and the shorting links will be cut. The safety key will then be handed to the project officer and placed in the firing box. Three tones will be sounded over the PA system and the clocks will be started (preset to 99:00). After 1 minute, with the clocks reading 00:00, the detonators will be fired.

A preburn (probably of 6 minutes) will be allowed. During the final 90 seconds of the preburn the pump will be run up to the required operating conditions (flowrate 100 lpm). At the end of the preburn firefighting will commence. Firefighting will cease when the project officer deems that the fire is sufficiently extinguished. After firefighting has ceased measurements of expansion ratio and drainage time of the foams will be made. If the fire reignites firefighting will recommence until it is completely extinguished.

After a test is over (i.e. the fire is extinguished and the project officer has confirmed that the test is complete) the roller shutter doors will be opened to allow any smoke to clear. When the smoke has cleared and the fire is cool, casual labourers will start to clear the area.

Safety Notes

The following instructions concern the safety aspects of these tests. These instructions must be adhered to throughout.

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

Personnel Directly Involved in the Fire Test

Kirsty Bosley - Project officer and observer and fire safety cover

Bryan Johnson - Fuel handler, detonator handler, observer, safety fire cover during trials

John Price - Pump operator and flowmeters

Guy Roberts - Instrumentation, video, foam measurement

Gary Pearson - Firefighter, fuel handler, fuel igniter (if the detonators fail), fire safety cover

Pete Snowden (later replaced by a local authority firefighter) - Fire safety cover, firefighting assistance

John Foster - Pump operator and flowmeters when John Price is not available.

Casual Observers

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

Project Officer

1. The project officer responsible for this work is Kirsty Bosley. In the first instance , all matters of safety during this test are her responsibility.

No Smoking

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

Fuels

3. The fuel to be used as the ignition fuel during these trials will be :
Commercial Heptane (Solvent 50) - also known and sold as Exxsol Heptane

6.25 litres of fuel will be used in each fire tray, making a total of 25 litres of fuel for each fire test.

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

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

Foam Concentrates

5. The following foam concentrates will be used during these trials:

Manufacturer	Foam Type(s)	Concentration
3M	Lightwater (AFFF)	3%
Angus	Forexpan S Expandol (Synthetic)	0.5% 3%
Ansul	Silv-ex	1%
Chubb (National Foam)	Chubb Class A 1% 1st Defense	1% 1%
Chemguard	C-111	0.5%
Drexel	Control A	0.5%
F.I.R.E.OUT	F.I.R.E.COOL	1%
Fire Safety Services	Cold Fire	3%
Fuel Buster	Fuel Buster	1%
Monsanto	Phos-Chek	1%
JJD Associates	Water Stretcher	0.25%
Phirex +	Phirex + Ecofoam	1% 1%
Spumifer American Co.	Class A Concentrate	0.025%

The Health and Safety Data Sheets for each type of foam concentrate will be stored in the Health and Safety Data Sheet Library in the Information Desk and in a file to be kept in the instrumentation pod in the Still Air Facility. The sheets will be placed in the Library as soon as they arrive - usually when the foam is delivered. **ALL PERSONNEL INVOLVED IN THIS TRIAL SHOULD CAREFULLY READ THESE SAFETY DATA SHEETS**. In particular, gloves and goggles should be worn when pouring out and handling these concentrates.

6. The test additive will be mixed in solution in a tank prior to each test. If there is solution left at the end of a test, it will be discharged into the hangar drain system. This system will be switched to collect liquid from the hangar into the waste storage tank throughout the period of testing.

Fuel Handling

7. The person handling or measuring out the fuel will be dressed in a fleet suit, safety fire boots and wearing a protective helmet with integral face visor and flame resistant protective gloves, or full local authority fire kit. All operations that involve the handling of fuels will be overseen by a second person standing at a safe distance and holding a fully charged dry powder fire extinguisher. This second person will be dressed in non-flammable clothing and have experience in the use of fire extinguishers.

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

9. The measuring out of fuels will be performed within the flammable liquid stores external to Hangar 97, or in the designated area near the small fuel store inside the Still Air Facility. This area will be designated by cones and flammable liquid signs. All of the doors of the flammable store in use (including the safety door) must be open during this operation and the entry ramp will be down. The doors of the store that is not in use must be closed.

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

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

12. When the fuel is transferred from the smaller flammable liquid containers into the trays, one person will pour the fuel while another provides safety cover with a dry powder extinguisher. Both will be dressed as in 7. above. A charged hosereel will also be available.

Fuel Ignition

13. The fuel will be lit by detonators. Prior to pouring the fuel into the trays, the detonators will be placed in brackets over the edge of the trays. This will be done by a person wearing protective clothing, including helmet and visor. The detonators will be connected, via the ceramic blocks, to the two core cable. Shorting links will be added across the ceramic block. The detonators will then be removed from the trays.

14. The fuel will be poured into the trays as specified in 12. above. The person transferring the fuel will also measure the temperature of the fuel in the tray with an intrinsically safe thermocouple probe and indicator or with a mercury in glass thermometer.

15. When the fuel is in the trays, the detonators in their brackets, will be placed over the tray edge by person in possession of the safety key of the firing box. The shorting links will then be cut. The safety key will then be handed over to the project officer.

16. The firing box will be located in the instrumentation pod.

17. When the detonators are in place, the project officer will ensure that all personnel are at their designated places and that no one is standing in the area under the hood before the last connection is made to the firing box using the safety key.

18. Three tones will be sounded by the project or instrumentation officer prior to ignition of the fuel.

19. In the event of a failure of the detonators, the fuel will be lit with a flaming lance. The person lighting the fuel will be dressed as specified in 7. above and will be provided with fire safety cover.

20. Only 1 litre of fuel will be placed in a measuring cylinder for use with the lance. This measuring cylinder will be placed within the designated safe area. This area will be designated by cones and flammable liquid signs. This fuel must be transferred to a safety container at the end of the day.

21. Ignition of the lance will take place in a tray which is a safe distance from the fuel handling area and fuel trays.

22. The lance must be extinguished immediately after use.

Electrical Equipment

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

24. Only 110v equipment will be used around the trials site. 240v to 110v transformers will only be used at the electrical supplies at the hangar walls. 240v equipment may be used within the instrumentation cabin via the cabins own 240v supply. All cabling must be placed to avoid trip hazards as far as is possible; in particular no cabling should run along the floor under the hood.

Casual Observers

25. Casual observers will not be allowed under the smoke hood during a fire test. (A fire test commences at the point at which fuel is poured into the trays and ends when the fire has been completely extinguished.) They will wear safety helmets at all times in the hangar.

Exits

26. All hangar doors will be closed and remain closed during a fire test to minimise the effect of wind on the test fire. However, the personnel doors at the North and the South ends of the hangar will be unlocked and may be used in the event of an emergency. The centre door, nearest to the fire appliance, will not be locked and may also be used as an emergency exit.

Additional Fire Cover

27. Several AFFF and dry powder extinguishers will be positioned around the fire test area.

28. A small bore, main line water branch will be connected directly to a fresh water hydrant supply with sufficient hose lengths to allow it to be used to cover all fuel operations and the fire tests.

29. The fire appliance will have connected to it a main line (70mm) water branch, and a foam making branchpipe with inductor and foam concentrate. The appliance will be connected directly to a fresh water hydrant supply. The appliance will be started prior to, and left running throughout, each fire test.

30. A hosereel will be used in the tests and will be available in case of emergency.

FEU Firefighter

31. The FEU firefighter and the back up firefighter will be dressed in full brigade issue firefighting clothing. The back up firefighter will assist firefighting operations and be available in case of an emergency. Secondary safety cover will be given by a member of FEU staff during all firefighting operations. This will be provided by someone dressed as in 7. above.

Firefighting Equipment

32. All of the firefighting equipment used during this trial must be handled with care. Any damage caused to any item of equipment must be reported to the Project Officer immediately. When in operation, nozzles must not be pointed at, or in the vicinity of, staff or visitors.

Emergency Procedures

33. A telephone will be available in the pod to summon assistance if necessary.

Filtered Air Supply

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

Pallet Clearance

35. After a fire the charred wood must be completely extinguished before it is placed in the skip. Suitable gloves and footwear must be worn to avoid nails and hot spots in the wood.

36. The additives used in these tests are likely to leave the floor slippery; care should be taken at all times. As much as possible of the foam from previous tests shall be washed away prior to commencement of the next test.

APPENDIX C

A Check List for the Test Procedure - 1995

• Call brigades to inform them of a 'controlled burn'
• Zero clocks (to 99:00)
• Change test numbers
• Measure fuel
• Check radiometers
• Stack pallets
• Check and record pallet moisture content
• Water in trays
• Mix firefighting solution
• Record air temperature and humidity
• Set up detonators and remove them
• Pour heptane into trays
• Record fuel temp
• Replace detonators
• Start instrumentation (datalogger and video recorders)
• START
• Run up the pump
• Commence firefighting and back up
• STOP - firefighting ceases
• Measure foam
• Wait 10 minutes from Stop time for burnback
• Stop datalogging
• Extinguish fire
• Cool
• Clear debris to skip, clear and wash area
• Trays and rigs into position
• Check trays and rigs
• Clean firefighting solution tank
• Call brigades to inform them the 'controlled burn' is over

A check list for the 1995 test procedure

APPENDIX D

1995 Radiometer Results - Data Processing

1995 Radiometer Results - Data Processing

The raw data from the radiometers was transferred from the datalogger into an Excel spreadsheet. 5 columns of data were imported into the spreadsheet. An additional column which contained the start signal (a pulse triggered when the clocks were started) was imported and used to identify the start of the test, but was not saved on the spreadsheet.

Datalogger time code	Radiometer reading 1	Radiometer reading 1	Radiometer reading 1	Radiometer reading 1
stored in serial code	*data in kW/m²*			

The datalogger time code was converted into time from ignition in minutes. Data was saved from 1 minute prior to ignition (-1.0 minutes). Any data that had been imported from the datalogger before this time was not saved on the spreadsheet.

The radiometer results of the tests were considered in various ways, Section 6.3 of the main report summarises the processing that was carried out on the raw data. This appendix contains details of the processing and examples of the Excel code used.

Percentage Reduction in Radiated Heat Output

Firstly the data was reduced following a procedure given in the BS ISO standard for foam concentrates for use on Class B fires (Reference 16, main report). This procedure calculates the time that the radiated heat of the fire takes to reduce by 90% or 95% of its maximum. Table D1 shows a sample of a processed spreadsheet. Table D2 shows the Excel codes that were used to calculate the values in Table D1. Cell references in the following paragraphs refer to both Tables.

Calculations were carried out as follows:

1. Calculate the background radiation using the mean of the values from 10 seconds to 5 seconds prior to ignition. These background values are stored in cells C1 to F1.

2. Subtract the background radiation from all the original radiometer readings. The results of this calculation are stored in columns G to J.

3. Calculate the mean of the two opposing radiometers i.e. calculate the mean of columns G and I (radiometer readings of Radiometers 1 and 3), and of H and J (radiometer readings of Radiometers 2 and 4).

4. Calculate the maximum radiated heat at the end of the preburn for each pair of radiometers i.e. the mean of the values from 10 seconds to 5 seconds prior to the commencement of firefighting. The results of these calculations are stored in cells K1 and L1.

5. Normalise the radiated heat by dividing the mean radiometer values (columns G to J) by the maximum radiated heat (K1 and L1), so that each fire test gives a heat output

equal to 1 prior to the start of firefighting. Store the results in columns M and N.

6. Smooth the curve by calculating a running average over 10 seconds (columns O and P).

7. Find the time at which the values reduced to less than 0.2, 0.1 or 0.05 (this represents the normalised radiated heat reducing by more than 80%, 90% or 95% of the maximum radiated heat).

Although these figures were calculated, there were drawbacks to its use in these tests because the nature of the firefighting resulted in several reductions and regrowths of the fire. As the firefighter reached Stack D, the fire was regrowing in Stack A and vice versa, therefore the curve passed through 0.2, 0.1 or 0.05 more than once.

Graphs were produced of the radiated heat minus the background radiation and of the smoothed, normalised radiated heat.

Area under the Radiated Heat Output Curve

It was decided to consider the area under the mean radiated heat curve. The area under this curve gives an indication of how quickly the fire was reduced and how well it recovered while firefighting continued on the other side of the fire.

The procedure described above was carried as far as normalising the values (to the end of step 5), then the following steps were taken:

1. Average the two normalised columns of data to give a single mean value i.e. calculate the mean of columns O and P. Write the result in column Q.

2. Add together the figures from the start of firefighting over a given timescale (1, 2, 4, and 5 minutes were tried, and the time between one and two minutes from the start of firefighting). This approximates to the area under the curve, each point being 1 second apart.

Percentage Reduction in Radiated Heat Output Over Time

Following on from calculating the area under the curve, the percentage heat reduction was calculated. This involved the following steps. For simplicity, the steps describe the calculation over the first minute of firefighting, with a 5 minute preburn; alternative figures are included in brackets.:

1. Find the value of the mean, normalised, radiated heat (column Q) at the start of firefighting (or at the start of the second minute of firefighting).

2. Multiply this value by 60 to give the area that could have been bounded by the curve if the heat continued to be radiated at this rate (or multiply by 120 if the reduction is to be calculated over 2 minutes).

3. Divide the actual area under by the curve (as established earlier) by the potential value (as established by step 2). Subtract the value from 100. This gives the amount by which the radiant heat has reduced in per cent.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	KBA12R	Background Radiated Heat	-1.502	-0.418	-0.547	-0.550		Maximum radiated heat during preburn			14.822	14.874				
2			Raw data				Radiation minus background				Mean radiated heat		Normalised mean radiated heat		Smoothed normalised radiated heat	
3	Time code	Time from ignition	RAD1	RAD2	RAD3	RAD4	RAD1	RAD2	RAD3	RAD4	Rads 1 & 3	Rads 2 & 4	Rads 1 & 3	Rads 2 & 4	Rads 1 & 3	Rads 2 & 4
4	35080	-1.000	-1.48	-0.39	-0.56	-0.50	0.022	0.028	-0.013	0.050	0.004	0.039	0.000	0.003		
5	35081	-0.983	-1.52	-0.42	-0.52	-0.50	-0.018	-0.002	0.027	0.050	0.004	0.024	0.000	0.002		
6	35082	-0.967	-1.48	-0.42	-0.52	-0.50	0.022	-0.002	0.027	0.050	0.024	0.024	0.002	0.002		
7	35083	-0.950	-1.48	-0.42	-0.56	-0.50	0.022	-0.002	-0.013	0.050	0.004	0.024	0.000	0.002		
8	35084	-0.933	-1.48	-0.39	-0.56	-0.50	0.022	0.028	-0.013	0.050	0.004	0.039	0.000	0.003		
9	35085	-0.917	-1.45	-0.37	-0.54	-0.50	0.052	0.048	0.007	0.050	0.029	0.049	0.002	0.003	0.001	0.003
10	35086	-0.900	-1.46	-0.36	-0.54	-0.50	0.042	0.058	0.007	0.050	0.024	0.054	0.002	0.004	0.001	0.003
11	35087	-0.883	-1.46	-0.36	-0.56	-0.50	0.042	0.058	-0.013	0.050	0.014	0.054	0.000	0.004	0.002	0.003
12	35088	-0.867	-1.46	-0.37	-0.52	-0.50	0.042	0.048	0.027	0.050	0.034	0.049	0.002	0.003	0.002	0.003
13	35089	-0.850	-1.46	-0.38	-0.52	-0.50	0.042	0.038	0.027	0.050	0.034	0.044	0.002	0.003	0.002	0.003

Table D1 : A sample of the values contained in a typical results table after processing

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	File-name	Back-ground Radiated Heat	=average (C54:C59)	=average (D54:D59)	=average (E54:E59)	=average (F54:F59)			Maximum radiated heat during preburn		=average (K374:K389)	=average (L374:L389)				
2							Radiation minus background				Mean Radiated Heat		Normalised mean radiated heat		Smoothed normalised radiated heat	
3	Time code	Time from ignition	RAD1	RAD2	RAD3	RAD4	RAD1	RAD2	RAD3	RAD4	Rads 1 & 3	Rads 2 & 4	Rads 1 & 3	Rads 2 & 4	Rads 1 & 3	Rads 2 & 4
4	Raw data	=((A4 - A4) /60)-1	Raw data				=C4-C1	=D4-D1	=E4-E1	=F4-F1	=(G4+I4) /2	=(H4+J4)/2	=(K4)/$K $1	=(L4)/$ L$1		
5																
6																
7																
8																
9															=average (M4:M14)	=average (N4:N14)
10																
11																
12																

Table D2 : A sample of the code used to process radiometer results
Shaded cells are headings only. Other cells contain Excel code.

APPENDIX E

Statistical Analysis

The Effects of Individual Variables

Initially it was important to ensure that the results of the tests were not significantly affected by any factors except the extinguishing medium. Statistical checks were carried out on the following five factors to find out whether these factors affected each other.

The table below show the results of calculating the correlation coefficients of various, independent variables associated with the 1996 fire tests. Each section in the table shows the correlation coefficient, the number of results that were tested and the probability (P) of those results occurring by chance (i.e. the lower P, the more likely that the results were in some way connected).

Thus the P values in the table below indicate where there is relationship between the two factors; a value of $P < 0.05$ suggests a significant relationship between the two factors, $P > 0.05$ gives no indication of such a relationship. For example, the air temperature and the humidity in the Still Air Facility give a P value of 0.007, indicating a high probability that they are related. The wood moisture content and the area under the curve over 4 minutes gave a P value of 0.994, indicating a very low probability that they are related.

-- Correlation Coefficients --

	Wood Moisture Content	Humidity	Air Temp	Max radiated heat during preburn	Area under the radiant heat curve over 4 mins
Wood Moisture Content		.1557 (33) P= .387	-.0882 (33) P= .625	-.5390 (33) P= .001	-.0013 (33) P= .994
Humidity	.1557 (33) P= .387		-.4631 (33) P= .007	-.1904 (33) P= .288	-.0264 (33) P= .884
Air Temp	-.0882 (33) P= .625	-.4631 (33) P= .007		.3556 (33) P= .042	.1566 (33) P= .384
Max radiated heat during preburn	-.5390 (33) P= .001	-.1904 (33) P= .288	.3556 (33) P= .042		-.0195 (33) P= .914
Area under the radiant heat curve over 4 mins	-.0013 (33) P= .994	-.0264 (33) P= .884	.1566 (33) P= .384	-.0195 (33) P= .914	

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

The Effects of All Additives
t-tests for Independent Samples of Class A additive or Water

Taking all the Class A additive results as one group and all the water results as another group, is there a significant difference in performance between them?. The results of the area under the curve over 4 minutes for the 1996 tests were analysed using t-tests.

Variable	Number of Cases	Mean	SD	SE of Mean
Area under the curve over first 4 mins				
Additives	29	34.7931	5.507	1.023
Water	4	34.8250	3.523	1.761

Mean Difference = -.0319

Levene's Test for Equality of Variances: F= .903 P= .349

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	-.01	31	**.991**	2.852	(-5.848, 5.784)
Unequal	-.02	5.30	**.988**	2.037	(-5.180, 5.116)

The 2 tailed significance of 0.99 indicates that the two sets of results have a probability of 99% that they come from similar groups of results i.e. there is very little likelihood of being a genuine difference between these two groups.

The Effects of Each Additive
t-tests for Independent Samples of each additive individually in comparison to water.

The results of the area under the curve over 4 minutes from the 1996 tests were subjected to t-tests. Each additive individually was compared with water. The 2 tailed significance results of these t-tests were used to calculate the figures in Table 12 of the main report.

Variable	Number of Cases	Mean	SD	SE of Mean
Area under the curve after first 4 mins				
1st Defense	2	28.5500	3.323	2.350
Water	4	34.8250	3.523	1.761

Mean Difference = -6.2750

Levene's Test for Equality of Variances: F= .042 P= .848

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	-2.09	4	.105	3.009	(-14.628, 2.078)
Unequal	-2.14	2.21	.154	2.937	(-17.841, 5.291)

Variable	Number of Cases	Mean	SD	SE of Mean
Area under the curve after first 4 mins				
AFFF	2	35.6500	3.323	2.350
Water	4	34.8250	3.523	1.761

Mean Difference = .8250

Levene's Test for Equality of Variances: F= .042 P= .848

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	.27	4	.797	3.009	(-7.528, 9.178)
Unequal	.28	2.21	.803	2.937	(-10.741, 12.391)

Variable	Number of Cases	Mean	SD	SE of Mean
Area under the curve after first 4 mins				
Chemguard	2	39.8500	5.020	3.550
Water	4	34.8250	3.523	1.761

Mean Difference = 5.0250

Levene's Test for Equality of Variances: F= .472 P= .530

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	1.47	4	.216	3.421	(-4.474, 14.524)
Unequal	1.27	1.52	.365	3.963	(-18.338, 28.388)

Variable	Number of Cases	Mean	SD	SE of Mean
Area under the curve after first 4 mins				
Chubb 1%	2	34.9000	.141	.100
Water	4	34.8250	3.523	1.761

Mean Difference = .0750

Levene's Test for Equality of Variances: F= 3.518 P= .134

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	.03	4	.979	2.643	(-7.262, 7.412)
Unequal	.04	3.02	.969	1.764	(-5.519, 5.669)

Variable	Number of Cases	Mean	SD	SE of Mean
Area under the curve after first 4 mins				
Control A	3	33.0333	.808	.467
Water	4	34.8250	3.523	1.761

Mean Difference = -1.7917

Levene's Test for Equality of Variances: F= 3.603 P= .116

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	-.85	5	.437	2.120	(-7.242, 3.659)
Unequal	-.98	3.41	.390	1.822	(-7.215, 3.631)

Variable	Number of Cases	Mean	SD	SE of Mean
Area under the curve after first 4 mins				
Ecofoam	2	34.9000	7.637	5.400
Water	4	34.8250	3.523	1.761

Mean Difference = .0750

Levene's Test for Equality of Variances: F= 4.249 P= .108

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	.02	4	.987	4.233	(-11.677, 11.827)
Unequal	.01	1.22	.991	5.680	(-47.604, 47.754)

Variable	Number of Cases	Mean	SD	SE of Mean
Area under the curve after first 4 mins				
Expandol	2	34.5000	10.607	7.500
Water	4	34.8250	3.523	1.761

Mean Difference = -.3250

Levene's Test for Equality of Variances: F= 13.114 P= .022

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	-.06	4	.954	5.298	(-15.036, 14.386)
Unequal	-.04	1.11	.973	7.704	(-77.700, 77.050)

Variable	Number of Cases	Mean	SD	SE of Mean
Area under the curve after first 4 mins				
Fire Out I	2	31.4500	6.718	4.750
Water	4	34.8250	3.523	1.761

Mean Difference = -3.3750

Levene's Test for Equality of Variances: F= 2.492 P= .190

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	-.86	4	.439	3.930	(-14.285, 7.535)
Unequal	-.67	1.29	.605	5.066	(-42.090, 35.340)

Variable	Number of Cases	Mean	SD	SE of Mean
Area under the curve after first 4 mins				
Forexpan	2	34.3000	2.404	1.700
Water	4	34.8250	3.523	1.761

Mean Difference = -.5250

Levene's Test for Equality of Variances: F= .472 P= .530

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	-.18	4	.862	2.840	(-8.409, 7.359)
Unequal	-.21	3.11	.843	2.448	(-8.167, 7.117)

Variable	Number of Cases	Mean	SD	SE of Mean
Area under the curve after first 4 mins				
Fuel Buster	2	40.2500	12.657	8.950
Water	4	34.8250	3.523	1.761

Mean Difference = 5.4250

Levene's Test for Equality of Variances: F= 22.076 P= .009

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	.89	4	.423	6.084	(-11.468, 22.318)
Unequal	.59	1.08	.652	9.122	(-92.340, 103.190)

Variable	Number of Cases	Mean	SD	SE of Mean
Area under the curve after first 4 mins				
JJD	2	32.1000	1.556	1.100
Water	4	34.8250	3.523	1.761

Mean Difference = -2.7250

Levene's Test for Equality of Variances: F= 1.283 P= .321

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	-1.00	4	.374	2.727	(-10.295, 4.845)
Unequal	-1.31	3.98	.260	2.077	(-8.502, 3.052)

Variable	Number of Cases	Mean	SD	SE of Mean
Area under the curve after first 4 mins				
Phirex +	2	32.4500	2.758	1.950
Water	4	34.8250	3.523	1.761

Mean Difference = -2.3750

Levene's Test for Equality of Variances: F= .251 P= .642

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	-.82	4	.459	2.899	(-10.425, 5.675)
Unequal	-.90	2.70	.439	2.628	(-11.292, 6.542)

Variable	Number of Cases	Mean	SD	SE of Mean
Area under the curve after first 4 mins				
Phos-Chek	2	36.2500	10.253	7.250
Water	4	34.8250	3.523	1.761

Mean Difference = 1.4250

Levene's Test for Equality of Variances: F= 11.804 P= .026

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	.28	4	.796	5.166	(-12.919, 15.769)
Unequal	.19	1.12	.877	7.461	(-72.411, 75.261)

Variable	Number of Cases	Mean	SD	SE of Mean
Area under the curve after first 4 mins				
Silv-ex	2	39.8000	.990	.700
Water	4	34.8250	3.523	1.761

Mean Difference = 4.9750

Levene's Test for Equality of Variances: F= 2.045 P= .226

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	1.86	4	.137	2.677	(-2.456, 12.406)
Unequal	2.62	3.74	.063	1.895	(-.433, 10.383)