Central Fire Brigades Advisory Council
Scottish Central Fire Brigades Advisory Council

JOINT COMMITTEE ON FIRE RESEARCH

RESEARCH REPORT NUMBER 40

SURVEY OF FIRE FIGHTING FOAMS AND ASSOCIATED EQUIPMENT AND TACTICS RELEVANT TO THE UK FIRE SERVICE
PART 2 - TACTICS AND EQUIPMENT

1991

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Survey of Fire Fighting Foams and Associated Equipment and Tactics Relevant to the UK Fire Service
Part 2 - Tactics and Equipment

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ABSTRACT

This report is one of three constituting a survey of the field of firefighting with foam. It covers the tactics and equipment required for a wide variety of scenarios, and identifies areas where further development would be advantageous. It stresses the merits of preplanning, and identifies risks beyond the capabilities of normal Fire Service equipment.

MANAGEMENT SUMMARY

The tactics and equipment used by the UK fire service in connection with fire fighting foams have evolved over many years with piecemeal introduction of new methods, very often alongside the existing practices.

As a result of a wide ranging exercise in gathering information associated with this study it has been possible to examine tactics, techniques and equipment and suggest where new ideas, research, overseas practice or improved management could be developed to enhance the fire service capabilities. During the course of the study information was gathered from foam manufacturing companies, industrial users, testing and research bodies, fire brigades and mutual aid organisations. This particular report is the second in a series of four generated by this study and covers tactics and. equipment associated with fire fighting foams.

The other three are:

Part 1 - Fire Fighting Foam
Part 3 - Large Tank Fires
Part 4 - Management Summary

After first defining and explaining some the common types of fire encountered, an examination of various stylised fire scenarios illustrates some areas where use of foam, tactics and equipment could be improved. Main conclusions reached during the analysis of the scenarios and review of standards and equipment are summarised here.

In the case of road traffic accidents there is advocacy for equipping the first response appliance team with a substantial capability to deploy AFFF firefighting foam although alternatives have not been fully researched.

The logistical difficulties in fighting large storage tank fires, and large bund fires with conventional equipment are considerable. As the size of the tank at risk increases so do the complexities of the fire fighting operation. It is suggested that for tanks over 45 m in diameter other techniques are required (for further detail see Report No. 3).

When comparisons are made between the recommended minimum application rates given in the various standards and codes it becomes apparent that the Manual of Firemanship is considerably out of step with thinking elsewhere. An interim revision should take place at an early date to bring the manual more into line with international standards and where basic research is considered necessary to fully justify the new application rates it should be noted and a later revision issued to reflect these results.

Of the new and improved equipment reviewed the clip-on aspirating device for existing fire service branch pipes seems to give a substantial benefit for relatively small outlay. It has the further advantage of using simple, robust technology and should be relatively cost effective to develop and purchase.

Pre-planning for incidents at oil and petrochemical installations is hampered by unreliable and out of date information relating to site arrangements and tank contents. In this regard overseas brigades have demonstrated how direct-on-line updating facilities from the plant to the fire brigade can greatly improve the quality of information available to the officers and fire fighters when they respond to an alert. Fire Officers in charge of major incidents should have received recent training to prepare them for the organisational complexities of the task.

When tackling a fire in a flammable liquid storage tank resources of foam should not be used until sufficient concentrate is available to mount a full attack. Cooling water can be used more sparingly and on specific targets in many cases. This may be of crucial importance where water supplies are inadequate.

The report thus indicates areas where research is necessary, and indicates the analysis required to equip a fire brigade to tackle the fires where foam may be useful. The analyses presented are stylistic but with "local knowledge" they can be converted to realistic situations which will show any deficiences in the equipment and tactics used by any particular bridgade.

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SECTION 1

INTRODUCTION

In September 1987 Ewbank Preece Ltd., was commissioned by the Home Office, Scientific Research and Development Branch to perform a Survey of Firefighting Foam and Associated Tactics and Equipment relevant to the United Kingdom Fire Service. The Survey was conducted between October 1987 and March 1988 inclusive, and this report is the second in a series of three reports which present the findings, analysis and recommendations.

The original scope of the commission is presented in Appendix E, and calls for the production of reports on three main areas and a fourth summarising management report. The original three areas for reporting were Foam Types, Tactics and Equipment. Subsequent minuted discussions combined Tactics and Equipment into a single report and created a new third report on Large Tank Fires.

The four reports produced from the study are now:-

Part 1 - Firefighting Foam

Part 2 - Firefighting Foam
- Tactics and Equipment

Part 3 - Firefighting Foam
- Large Tank Fires

Part 4 - Firefighting Foam
- Management Summary

Three main methods were used to gather information, meetings with individuals and organisations who have specialist knowledge of fire fighting foams (a list of such contacts is provided in Appendix C); literature research (a list of references is provided in Appendix B); and a questionnaire to foam concentrate and equipment manufacturers (Appendix D).

This report covers the use of fire fighting foams by initially examining how they can be applied to the British Standard "Classes" of fire and to the different types of physical configurations in which fires occur. More specific information on tactics and equipment is related to certain stylised examples or "Scenarios" which represent some of the main fire situations in which foam is employed.

The various standards which recommend minimum application rates are reviewed and comments made on their suitability for practical firefighting. Finally the equipment currently used by brigades and some possible areas for improvement are examined.

The generous help received in the course of the study from all of the organisations and individuals contacted is gratefully acknowledged.

SECTION 2

FIRE CATEGORIES AND FIREFIGHTING FOAMS

2.0 INTRODUCTION

Any discussion of the uses which can be made of firefighting foam must be related to the wide variety of situations in which it may be applied, and the characteristics of the fires that are encountered by fire brigades. In this section the basic categories used to describe different types of fire are reviewed together with the general principles of extinguishment, particularly in relation to firefighting foams.

2.1 CLASSES OF FIRE

In the UK the standard classification of fire types is defined in BS 4547 which designates Class A as fires in carbonaceous solid materials, Class B as flammable and combustible liquids, Class C gases and liquified gases and Class D as combustible metals. Electrical fires are treated separately. Those who also deal with American standards should be aware that NFPA 10 (Portable Fire Extinguishers) uses a very similar but different system. Whilst the Class A is similar, ie ordinary combustible fires, the American Class B includes fires in flammable gases as well as flammable and combustible liquids. American Class C is reserved for electrical fires and Class D is again similar to the British Standard covering fires in combustible metals. In this report the British system has been used throughout.

2.1.1 Class A

Class A fires are those which involve solid materials usually of an organic nature such as wood, cloth, paper, rubber and many plastics.

In general AFFF or synthetic foams at concentration between 0.1% and 1% in either low, medium or high expansion form are capable of extinguishing Class A fires. Since water is also highly effective, and considerably cheaper, foam is not considered as a viable option except in a few specialised cases.

There are advantages in the use of surfactant based foams when fires become "deep seated;" meaning that glowing combustion occurs with little or no flame and air reaches the combustion zone by diffusion through capillary size passages rather than by bulk movement. In these conditions water can be slow to penetrate. A wetting agent that reduces the surface tension of the water can greatly improve penetration to the seat of the fire. When a wetting agent is employed the deep seated fire is predominantly extinguished by the cooling effect of the water rather than by the smothering effect of the foam.

Surfactant based foams display some wetting agent properties, but are more expensive that products sold purely for their wetting agent characteristics. A few brigades take advantage of these properties by using AFFF not only for Class B fires, but also to make better use of limited water supplies on Class A fires. It is claimed that the increased cost of the agent is often justified by reduced water damage to the property. Apart from specially designed demonstrations there is at present no independent evidence to corroborate this. The fire insurance records for the areas concerned would provide raw data which could be analysed for trends which could support the claim. This would be a valuable area for research since the results could be of financial significance.

Medium and high expansion foams have been advocated for indoor use on Class A fires. The confinement provided by building walls allows the foam to accumulate into a thick blanket which is protected from being broken up by the wind. The mechanism put forward for extinguishment is that the foam cuts down the bulk movement of air which supports the combustion. There is a cooling effect as water from the foam evaporates, and the steam generated will also tend to reduce the oxygen level in the air surrounding the fire. A sufficiently deep blanket exerts a hydrostatic pressure which will refill voids opened up when the foam is destroyed by the heat from the fire. Materials and structural members that would otherwise be exposed are shielded from heat radiation by the foam.

Although high expansion foam can be effective by the mechanisms described the main practical drawback is that firefighters cannot be sure whether or not the fire has been extinguished. It can be dangerous to enter a deep foam blanket to track down the seat of a fire since there is a chance of sudden exposure to heat and products of combustion. Under some conditions the fire can continue to burn for a considerable period at a reduced rate supported by the air released from the foam as it breaks down.

The use of medium expansion foam against indoor Class A fires, such as in warehouses, is in some ways more promising. It could be possible to restrict the application so that the area of origin of the fire is kept under observation whilst maintaining sufficient hydrostatic pressure to force the foam onto the fire. Since this is not normal brigade practice and little research appears to have been carried out, this is considered as a possible area where a suitably designed test programme would be of value.

2.1.2 Class B

Class B fires are those which involve flammable liquids, oils, greases, tars, oil based paints and laquers (ie flammable and combustible liquids). Combustion of these materials occurs entirely in the vapour phase above the liquid surface. From their requirements for fire fighting foam the Class B fires subdivide into three further categories viz, high flash point liquids, low flash point liquids and water miscible liquids (polar solvents).

(a) High Flash Point Liquids

High flash point liquids, or Class C petroleum liquids are those with a flash point above 55°C such as gas oils, diesel oils, heavy fuel oils and heavy lubricating oils. At normal ambient temperatures these liquids have sufficiently low vapour pressures that they do not generate flammable concentrations of vapour.

Water spray can be used to extinguish fires in high flash point liquids since the cooling effect of water is sufficient to reduce the generation of vapour to below the concentration needed to sustain combustion.

Firefighting foams are very effective against this type of fire giving rapid control and security against reignition, however, use of water spray can be perfectly satisfactory and far less expensive in many cases. The primary mechanisms by which foams extinguish high flash point liquid fires is by cooling the liquid surface and cutting out back radiation from the flames. The smothering action of foam plays a relatively insignificant role.

(b) Low Flash Point Liquids

Low flash point liquids, or Class A and B petroleum liquids have flash points below 21°C and 55°C respectively and include Class A petroleum liquids such as aviation gasoline, benzine, crude oil, hexane, toluene, petrol, etc and Class B petroleum liquids such as jet fuels and white spirit.

Spills or pools of low flash point liquids can produce flammable vapour under normal ambient temperatures, and flammable or explosive concentrations can accumulate at low level, since most of the vapours are heavier than air.

Water sprays are unsuccessful in extinguishing fires in low flash point liquids because vapour generation rate is not sufficiently reduced by the degree of cooling achieved. However, considerable reductions in flame height and radiation intensity can be achieved with water spray application.

Fire fighting foams are effective on low flash point liquids because they trap the vapour at, or just above the liquid surface. The trapped vapour then sets up an equilibrium with the bulk liquid which prevents further vapour generation. Where deep foam blankets can be formed such as in storage tanks with a large freeboard this process may be assisted by the increased hydrostatic pressure at the liquid surface although justification for this assortion is scant. Film forming foams may also inhibit liquid molecules passing through the liquid surface into the vapour phase. Additional benefits are that firefighting foams cool the liquid surface, reduce the vapour generation rate, obstruct back radiation from the flame and provide local steam dilution of the oxygen level at the flame/foam/surface interface. Low flash point liquid fires can only be extinguished by foam when the blanket covers the entire liquid surface.

(c) **Water Miscible Liquids**

Polar solvents and hydrocarbon liquids which are mutually soluble (wholly or partially) in water can tend to dissolve normal firefighting foams. Such liquids include gasohols, methyl and ethyl alcohol, acrylonitrile, ethyl acetate, methyl ethyl ketone, acetone, butyl alcohol, isopropyl ether, isopropyl alcohol, methyl isobutyl ketone and methyl methacrylate monomer.

Water miscible liquids which are also low flash point liquids can be extinguished either by increased application rates of foam to compensate for the rate of foam destruction or alternatively by use of alcohol resistant type of foam concentrates. These foams form a polymer membrane between the polar solvents and the foam blanket which arrests the destruction of foam and allows the functions of vapour suppression and cooling to continue. Alcohol resistant concentrates lose effectiveness unless they are applied gently to the surface of polar liquids avoiding plunging. Further research is needed to determine how much this affects foam performance.

2.1.3 Class C

Class C fires are those involving gases or liquefied gases.

In recent years liquefied flammable gases have become an increasingly important source of fuel in commerce and industry. Increased use brings increased tranportation of these liquids throughout the country by road, rail, and in UK coastal waters, which in turn increases the possibility of accidental spillage. The product group includes LPG (Liquefied Petroleum Gas, usually propane or butane) liquid ethylene, butadiene and LNG (Liquefied Natural Gas, ie methane). Boiling points are all low and in the event of spillage, rapid evaporation occurs. Due to the greater amounts of vapour produced and the low buoyancy of cold vapours, the dispersal of vapours produced from liquefied gas spills is more problematical than from spilled flammable liquids such as petrol. In still air conditions and where the ground is sloped or channelled these vapours can travel long distances from their source. Liquefied gas vapours have been known to travel 1,500 meters from a spilled pool of liquid whilst retaining a concentration above the lower flammability limit.

Medium and high expansion foams are suitable for liquefied gas spills both for fire extinguishment and vapour supression. The surface of the foam in contact with the liquid forms an icy slush which insulates and protects the upper layers of foam, and which in turn acts by reducing the evaporation rate from the liquid. A further important advantage is the relatively low amount of heat transmitted to the liquid by water draining from medium and high expansion foams. Low expansion foam is not suitable since it increases the rate of evaporation from the liquid. For a liquefied gas spillage any reduction in the rate of evaporation of the liquid is beneficial in that it limits the size of the flammable (or explosive) cloud generated and hence reduces the possibility of ignition.

2.1.4 Class D

Class D fires are those which involve combustible metals such as magnesium, titanium, zirconium, sodium, potassium and lithium. Firefighting foams should not be used with water reactive metals such as sodium and potassium, nor with other water reactive chemicals such as triethyl aluminium and phosphorous pentoxide. Other metal fires are treated as Class A fires, but in general the use of media other than foam or water is found to be more suitable.

2.1.5 Electrical Fires

Firefighting foams are unsuitable for use on fires involving energised electrical equipment. Other extinguishing media are available and that subject falls outside the scope of this report. Fires in de-energised electrical equipment are treated as either Class A or B as appropriate.

2.2 TYPES OF FIRE

The classes of fire discussed in the previous section have a strong bearing on the tactics and techniques of using firefighting foam, but they do not specify the physical environment of the fire which is particularly important in tackling Class B and C fires. Firefighters commonly refer to spill fires, pool fires and running fires and the variations in technique required for each. This section presents definitions of these terms which are used extensively in the later section on "Scenarios", and examines how the physical characteristics can affect the firefighting approach.

The definitions are idealised and in practice are unlikely to occur exactly as described, but nevertheless they illustrate the principles involved.

2.2.1 Spill Fires

Spill fires occur in shallow static unconfined areas of flammable, or combustible liquids. The liquid spreads under gravity flow to a depth of on average 25mm or less, although some variation and localised pools may occur due to surface irregularities.

The main characteristic of spill fires is their brief duration. If an average burn rate of 4mm/min is assumed then the major area of spillage will be consumed withing 7 minutes leaving only isolated pool fires in surface irregularities.

Such brief burn times rarely occur in practice. Flammable liquid may remain in the ruptured container and burn for a considerable time, or continuous leakage may replenish the spill.

(a) **Foam Selection**

From the information available there appears to be no ideal choice of foam for all spilled liquids that could be encountered by brigades. Generally AFFF gives rapid fire knockdown, but it is less effective on petrol fires than FFFP. The relative weakness of AFFF in terms of burnback resistance and security can be compensated for by re-application as necessary. All foams can give improved performance when applied aspirated rather than by equipment with no aspirating action. The available foam test data is mainly produced from pan fire tests which do not highlight the ability of a foam to spread across a spill, and which allow methods of application of the foam which do not match those used by brigades in practice. It may be possible to make a better assessment of foam performance if an improved medium scale fire test is introduced as recommended in Report No. 1 (Section 6.4).

Water spray would be suitable for small high flash point Class B fires, although skill is required (and usually available in the UK brigades) in the use of hose or branch lines. For larger fires of this type it is unlikely that extinguishment would be achieved by water alone within the time available. In addition use of water spray can succeed in spreading the fire by providing a larger volume of liquid which can cause flow further. However, it has a useful role in washing the flammable liquid away from a localised area, for example in establishing a rescue path to a crashed vehicle, although fire fighting foam is superior for this use in that it provides more security against burnback to protect firefighters.

(b) **Class B Fires**

For low flash point Class B fires water spray will not extinguish but foam will. High vapour pressure liquids can destroy a low expansion foam blanket or saturate it with vapour which can lead to reignition, making vigilance and periodic reapplication advisable. Polar solvents will render any normal foam less effective and use of an alcohol resistant foam concentrate would be preferable. It is at present unlikely that any brigade will carry alcohol resistant foams under normal operational circumstances, in which case higher application rates of other foams can be used with all but the most foam destructive chemicals. Medium expansion foams can also be used effectively against alcohol fires.

(c) **Class C Fires**

Where spillage is of LPG or a similar liquefied gas care must be taken to avoid ignition or inhalation of the gas cloud. Any gas leak or fire should be tackled from upwind. Even when an LPG spill fire is extinguished it will still generate vapour which will travel on the wind and collect in low lying areas of ground, ditches, etc. If a spillage has not been ignited it may be necessary to evacuate the down wind area in the path of a vapour cloud and eliminate any sources of ignition. LPG vapours can be dispersed by using water spray patterns from hose lines, and blanketting with high or medium expansion foam will suppress vapour generation and reduce the size of the flammable gas cloud. If there are hot surfaces or other sources of reignition the fire should not be completely extinguished, but reduced in size to a safer level by foam application. Explosive reignition is always a danger and tactics of approach must take account of this possibility.

2.2.2 Pool Fires

Pool fires may be generally described as static, confined spills which are deeper than 25mm but not as deep as storage tanks. The pool fire may cover a large area depending on the volume of the fuel source and the area of the confined space. It may take the form of a bunded area in a tank farm or a hollow pit or trench which has collected flammable liquid from a ruptured process vessel, road or rail tanker.

The difference between pool fires and spill fires is that pools may, depending on depth, continue to burn for a considerable period of time. As a result the firefighters are more likely to encounter a well developed fire burning evenly over a large area, rather than the more isolated, scattered fires which are characteristic of an unconfined spill. Foam may also be subject to more severe plunging during application, and techniques such as playing the foam stream against a solid surface and allowing the foam to run onto the fire may be both desirable and a practical possibility if suitable surfaces are available. The sustained high levels of heat output may demand more effort to be made in cooling exposed structures both to minimise damage during the fire and to prevent reignition after extinguishment.

The pool fire, therefore, requires a foam with a high fuel tolerance and heat resistance as well as fast flowing characteristics. Adequate post fire security is also required.

FFFP is likely to be the first choice of foam when available, as it combines the properties required as stated above.

2.2.3 Running Fires

Running fires may be described as un-confined spill or pool fires in which the product is being continuously supplemented by a spray, jet or stream from the ruptured tank or equipment. The continuous supply of product could result in burning liquid flowing into inaccessible areas, such as drainage systems and floor voids.

An early step in fighting a running fire is to stop the flow of product to the flames whenever possible. Water spray provides an excellent screen behind which to approach the fire and close the valve. Firefighters are trained in such operations as part of standard practice. Various suits are also available to give additional heat protection to trained firefighters.

Flow of product from a storage vessel can also be stopped by water displacement if there is sufficient freeboard above the source of the leak. This method has been successful in the case of a ruptured storage tank line. Water is pumped into the tank to raise the hydrocarbon liquid above the level of the outlet line so that water instead of product flows from the broken line.

If the product is a high flash point fuel the burn back rate may be less than the rate of discharge from the leak. In these circumstances the fire can be extinguished with a foam blanket or water spray in a similar fashion to a pool fire, the only additional precaution being to ensure that the level of fuel does not rise sufficiently to overspill the containment. Sand bagging, diversion channels and pumping out are all useful techniques to help prevent breakdown of containment.

If, on the other hand, burn back rate exceeds discharge rate then the discharging fuel jet will also be on fire. It may be necessary to use dry powder to extinguish fires in flowing jets of liquid or gas. Water sprays are effective in reducing the heat output from burning jets.

2.2.4 Flowing Fires

This term is less often used but refers to the case when a burning liquid is moving down a slope on a broad front. The situation is rare, but extremely hazardous because of the rapidity with which objects and people in the path of the flow can be enveloped. It is not possible to advise any course of action other than rapid evacuation from the oncoming flow. If monitors and hoses are immediately available they could provide sufficiently rapid knockdown. On many fuels AFFF is considered particularly effective at fast knockdown, although other foams can have similarly rapid effects. Another technique is to lay a band of foam at the lower end of the drainage path so that any pool that builds up will do so beneath a foam blanket. For this type of application fluoroprotein might be considered most suitable because of its stability, although other foams would also satisfactorily perform the task.

The main method of combatting flowing fires is by prevention. Firefighters must be aware of any potential for a pool fire to breach or overspill its containment. Firefighting efforts should be adjusted to reduce such a risk, for example minimising use of cooling water which could drain into the contained pool, monitoring the integrity of containing bund walls and evacuating in advance any area which could possibly become inundated.

2.2.5 Other Terms

Various other terms are used for different types of fire and explosion incident such as BLEVE (see Appendix A), vapour cloud explosion, gas flare, etc. These have not been covered separately since the use of firefighting foam is not directly involved.

2.2.6 Brigade Foam Purchasing Policy

Most UK fire brigades tend to standardise on one type of foam for their appliances and back up supplies. There are strong arguments in favour of this approach. A wider range of foam concentrates would normally imply higher overall stock holdings to maintain minimum stock levels of each type of foam. Specialist foams tend to be more expensive, and additional foam delivery equipment is often needed to get the best performance. Purchasing, testing and warehousing costs will all increase when a wider variety of foam stocks is purchased by a fire brigade. From an operational point of view the possibilities for using the wrong combinations of equipment and concentrate increase with the variety of foam types available to firefighters. Greater time is needed to train firefighters and greater care during fireground operations.

Despite these disadvantages it is considered unlikely that any UK fire brigade will be adequately served by stock of a single type of foam. There is no foam that can be regarded as suitable for all applications, and those that come nearest cost most. It is far more probable that at least two or three types will be required, with perhaps one of these selected for routine use and the others held in reserve for certain special risks. The selection of which foams should be bought for each brigade will depend on the types of risk most frequently encountered and upon the nature of any special risks in the brigade's area.

Material in this series of reports will provide useful background information to help aid foam selection. It is not possible to lay down hard and fast rules, and the final choice is best made by the senior officers of each fire brigade in order to take full account of local conditions and budgetary constraints.

SECTION 3

SCENARIOS

3.0 INTRODUCTION

In order to discuss the use of firefighting foams it is necessary to consider practical examples. The record of losses and published fire reports are of immense value to the industry in showing what can happen and the effectiveness or otherwise of various forms of fire attack. The published records have, however, disadvantages when it comes to selecting specific examples to illustrate the use of fire fighting foam. Very few published accounts contain comprehensive information in sufficient detail. The unpublished testimony of those present often fills many of the gaps, but events are still open to interpretation. Secondly in "real life" fires there often arise side issues which obscure the main principles. For example there may be uncertainty as to whether a particular foam attack was successful or if extinguishment occurred merely because the fuel supply burned out. Or in another case several different types of foam may have been used on the same fire so that it became unclear as to which had been successful.

In this section an attempt has been made to reconstruct from the many written and verbal reports available how typical fires would develop in a variety of practical situations, and how fire brigades could respond using various firefighting foams, equipment and techniques. Tables at the end of this section give the fire fighting foam and water requirements for storage tanks of 15, 30 and 45 m diameter.

In practice no two fires are exactly the same, and so any generalised description is bound to be a simplification. The descriptive scenarios below each start with a summary of some of the difficulties involved with each type of fire. The second part of the scenario is a brief description of an idealised fire and how it might be fought, particularly with reference to fire fighting foam.

Because the scenarios are simplified no allowance has been made for back-up or reserve capacity in the event of the first response not succeeding. Also no direct reference is made to the number of firefighters required. The number of appliances which attend will generally determine the manpower available. The numbers of appliances mentioned are those needed for direct fire attack. If additional manpower is required further appliances would be in attendance, but these would not form part of the equipment needs for the fire attack.

Such scenarios are a first step in pre-planning for a fire attack. The main difference is that the fire preplan is concerned with more detailed logistics and provides a sufficiently high level of response to cope with unforeseen difficulties and developments.

Before discussing the scenarios in more detail there are several general points on pre-planning which should be mentioned.

3.1 PREPLANNING

For smaller scale incidents much preplanning has been performed in the UK fire brigades over many years. The results of this work underpin the Manual of Firemanship, the basic and more advanced training courses and the selection of equipment that is carried on brigade appliances.

Formalised preplanning is usually reserved for larger incidents where the governing factors between success and failure may be: supply lines of material/equipment; fresh resources of men; clear decision making on the fire ground; or communications with third parties.

It is considered useful to extend the process of formalised preplanning to medium and small scale incidents, both as a training aid for firefighters and as a means of highlighting any deficiencies in existing methods, equipment and information.

There are two areas where other countries are in advance of the UK in preplanning, and consideration should be given to adapting their techniques for fire service use.

Firstly in the USA a software package has been developed for assisting fire departments in planning the foam requirements for specific risks. The input required includes the resources available from the fire site, and the output gives details of the application rates and equipment required. All parameters included in the programme conform with the requirements of the National Fire Protection Association (NFPA) Fire Codes, and United States units are used throughout. It is considered that a similar, although less elaborate programme in European/International units would be of great assistance to brigades in preplanning use of foam for major fire incidents.

Secondly in France certain petrochemical industries update changes in plant layout and liquid hydrocarbon storage tank contents automatically into computer based records held at the local headquarters of the Sapeur Pompier. By contrast in the UK site plans are updated intermittently and information on tank contents in particular is liable to be out of date.

Since any major preplanning exercise can be rendered futile by using out-of-date information, it is considered important to establish a more automatic routine for updating critical data from major petrochemical industries and other large risks.

Whilst pre-planning is of great importance in the successful handling of major incidents there are many situations where plans need to be changed at the last moment. This is particularly true when circumstances change rapidly, such as a change in wind direction.

This can place the senior officer in charge of a large fire in the difficult position of having to make many decisions and issue new orders at high speed. It can easily occur that the senior officer becomes a "bottleneck" in the command and control system when rapid changes are required.

There is also a strong argument for an expert support team drawn from both inside and outside the fire service to assist the senior officer in large scale complex firefighting operations. Such a team could include an engineer charged with assessing, for example, heat radiation effects and cooling water requirements, an expert on the tactics of using foam, and possibly a media spokesman. Equally it is of the utmost importance that all fire officers who could be placed in the position of either being in charge of a major fire incident, or responsible for its pre-planning and risk assessment, should have had recent realistic training in all aspects of this specialist work.

The objective of gaining experience in rapid changes of tactics could be achieved by training senior officers on an interactive video disc command and control simulator or by development of decision trees for use on the fireground.

3.2 SCENARIOS

The fire scenarios below set out the conditions which could pertain in a particular type of fire incident, and indicate how it could be assumed to develop. The effectiveness of the fire brigade response is discussed particularly in relation to the foam making materials, equipment and tactics required.

These scenarios are idealised cases and it is appreciated that the timing, aims and problems associated with each real fire incident will vary considerably. The use of these scenarios is to indicate the theoretical quantities of foam, water and equipment needed for direct fire attack. In practice greater resources are often committed because of the uncertainty as to how serious the incident may become, to provide a ready reserve capacity and to provide indirect support or relief to the main fire attack team. It is left to each individual brigade to interpret how the objectives would be achieved given their own mix of equipment, materials, philosophy, logistics, and manning policies.

3.2.1 Road Tanker Crash

A wide variety of flammable liquids and toxic chemicals is transported by road throughout the UK on urban and rural roads and motorways. The volume of this traffic is not known precisely, and the details of road tanker movements are not recorded, so fire brigades must rely on the hazard information carried in the vehicle and on the external hazard code plate. Lorries can carry up to 38 tonnes gross weight approximately equivalent to a maximum of 26m^3 of flammable liquid cargo. A number of incidents have occurred where the contents were discharged onto the road and the resulting fire caused loss of life.

When a road tanker is damaged in an accident it is unlikely to discharge all its contents at once onto the roadway. More usually liquid will steadily leak from breaks in the tank pipework or in the vessel itself (see Table No.1). Frequently not all the contents are discharged, and a substantial volume may remain inside the vessel. Spillage of flammable liquid may catch fire immediately or there can be a delay while the flammable vapour spreads far enough to contact a source of ignition.

There is thus a wide variety of fires that may face a brigade when it is called to attend a road tanker crash, from an extended spill fire, to a running fire, a tank fire, or a combination of all three.

In order to make an estimate of the foam resources that should be available on fire appliances a number of judgemental factors will need to be evaluated, but initially it is important to set the upper limit of what might be required by establishing a "theoretical worst case".

If it is assumed that most of the tanks contents are spilt, say a total of 24 cu.m, and they spread rapidly over a flat surface then a total area of 1000 sq.m could be covered to a depth of 25mm. Using the NFPA application rate of 4.1 lpm/m^2 for fifteen minutes duration a total of 61,000 litres of foam solution would be needed made from approximately 1,800 litres of 3% foam concentrate and over 58,000 litres of water.

In terms of equipment this would require the equivalent of nine 450 l/min branches, and three pumping appliances each supplying three of the branches. From a practical point of view it would be difficult to deploy this amount of equipment rapidly. Even if hydrants were available the time for laying hose would be considerable.

In taking a more practical view each brigade will need to assess the weight it gives to various mitigating factors.

Road surfaces are rarely flat. The road camber will tend to direct spillage into a more restricted area. Kerbs, banks and surface irregularities will tend to limit the spread of liquid, whilst rainwater drains will carry some away (with possible serious consequences of sewer explosions). It is suggested that because of these factors the foam requirement for first response could be reduced to 25% of the theoretical maximum i.e. 450 litres of foam concentrate and 13,000 litres of water, 3 branches and one pumping appliance. However, brigade experience and likely local conditions would need to be taken fully into account in setting such guidance for their first response capability second and subsequent responses and back up resources.

To illustrate some of the judgemental factors three cases are considered.

A tanker crash on a motorway may involve high speeds, high impact energy and therefore more rapid liquid discharge over a relatively flat surface. It is normal practice in some brigades to despatch a first response team of four appliances. Hydrants may be available on some motorways. The main objective in fire fighting is to extinguish fire around exposed vehicles prior to attempting rescue of trapped or stranded motorists. In these cases there are arguments for more than the 25% foam provision but the emphasis should be on very rapid deployment of the first attack. Supply of backup foam stocks and rapid access to further water supplies will need to be provided urgently since in a multiple pile-up secondary spills and fire are quite possible.

A rural tanker crash is likely to lead to a less extensive spill. Roads are narrower, more cambered and often flanked by banks or ditches. In these cases the brigade is more likely to be called upon to tackle a number of smaller isolated fires in accumulations of liquid, particularly since with longer response times shallow spills will have been burned off. There would be some justification for less than 25% of the theoretical foam supply figures, although water supplies are still likely to be a major problem, and additional water carrying capacity may be considered necessary.

An urban location for a tanker crash involves a further set of considerations. Water will be readily available, brigade response time rapid and flammable liquid leakage rates generally lower because of reduced impact speeds. However, there is a severe risk of secondary fires being started which may become life threatening. Whilst there are fewer physical factors calling for a large foam attack the exposure of human life can be severe and there may be more need than in rural areas for use of conventional water branches to extinguish secondary fires. There should be far less difficulty in an urban area in obtaining a strong and rapid backup response which will have sufficient resources to meet the demand. Other complications which need to be considered in preplanning are;

- local evacuation around the area possibly affected by a vapour cloud accumulation
- traffic control
- notifying of water authority and local media of explosion potential in sewers
- LEL measurement, flushing and venting of sewers.

The choice of foam concentrate has been discussed in 2.2 above.

If the foam supplied with the first response is not best suited to the flammable liquid involved then reserve stocks of a more compatible foam should be called up. In the meantime it is common practice to tackle the fire with whatever foam is available, and this must obviously continue to be brigade policy.

DISCHARGE TIMES FOR HORIZONTAL CYLINDRICAL TANK THROUGH A CIRCULAR ORIFICE ASSUMING ADEQUATE VENTING/BREATHING

Tank 26 m^3 Volume, 24m^3 Contents

Orifice Diameter	Time to Discharge (Seconds)
1" (25 mm)	7093 (1.97 hrs)
2" (50 mm)	1773 (29.5 mins)
4" (100 mm)	443 (7.4 mins)
6" (150 mm)	197 (3.3 mins)
8" (200 mm)	111 (1.8 mins)
12" (300 mm)	49
24" (600 mm)	12

TABLE NO. 1

3.2.2 Rail Tanker Crash

As with road transport, many flammable liquids and toxic chemicals are being transported by rail through urban as well as rural areas of the country.

There are two types of rail tank cars generally used. A two axle car of approximately 45m^3 and a bogie car of approximately 100m^3 capacity. Diesel locomotives can haul up to 1,500 tonnes, and hence trains of two axle cars could comprise as many as 22 cars.

The potential exists for a major incident arising from a rail crash. A wide range of risks are involved which require a variety of equipment and flexibility of approach from the fire brigades. If LPG or similar liquefied gases are being transported there is a risk of a BLEVE. In this case it may be unwise to expose fire fighters and a policy of evacuation of a wide area may be the only safe course of action. Even with ordinary flammable and combustible liquids exposed tanks can rupture suddenly and violently. If a passenger train is involved there is the possiblity of a major rescue operation in parallel with fire fighting activities. The speeds at which trains travel and their large momentum means that when a crash occurs strong forces can be brought to bear on the tankers, giving a high chance of major damage to the structure and rapid discharge of the contents. In urban areas the potential life exposure can be high and there is a possiblity of multiple secondary class A fires particularly where rail track is elevated above surrounding property or where buildings look down upon the track. In rural areas there can be severe problems of access and it may require time to lay on adequate water supplies.

In the hypothetical case of a single tanker spilling its contents rapidly over a flat surface, the area which could be covered to a depth of 25mm is 1,800m^2 for a 43m^3, and 4,800m^2 for a 100m^3 tanker. Using the NFPA application rates of 4.1 lpm/m^2 for AFFF over 15 minutes gives a solution demand of 16,400 lpm for the larger tanker and 7,400 lpm for the smaller.

This would require resources for the larger tanker of 246,000 litres of solution, 7,400 litres of 3% concentrate and 238,600 litres of water, 9 pumping appliances and 36 branches or nine 1,800 lpm monitors. For the smaller tanker the equivalent requirements would be 111,000 litres of solution, 3,300 litres of concentrate and 107,700 litres of water, four appliances, and 16 branches or four monitors.

In practice the surface around a rail crash is likely to be very uneven leading to a series of pool fires which will last longer than a spill fire but may require the same amount of foam delivery equipment because of their physical separation. If it is assumed that because of ground surface roughness the burning liquid surface is reduced to a quarter the area for a spill, and that a duration of 30 minutes would be required because of the deeper accumulations of liquid, then a practical estimate of first response capability is 50% of the theorectical figures in the previous paragraph.

There are many chances of complications with a rail tanker crash, and caution would lead most fire brigades to mobilise a considerably larger first response and rapidly arrange for support to be provided.

Tactics for such an incident require considerable flexibility. Water supplies may be restricted in the early stages, and the best use of limited quantities of water is to lay a foam blanket beneath exposed vehicles. A foam such as fluoroprotein with a good heat resistance would be preferable. Water will be required for Class A fires either in the surrounding area or in the interior of passenger coaches. Water monitors may also be needed for cooling exposed tanks, particularly if they are exposed to a flare fire. A further tank rupture must be expected and tactics set out with rapid re-deployment or retreat in mind.

In major incidents such as a rail tanker crash manpower may be a more critical factor than equipment. Fire fighters are needed for hose laying to water sources, rescue, relief, evacuation, maintaining supplies of foam concentrate and repositioning equipment. For such incidents it is common to mobilise more appliances than required for operational use to ensure adequate manpower is available.

3.2.3 Off-Airport Crash

In the case of the off-airport crash, a situation could arise where say a Boeing 747 crashes several miles from an airport in a rural area. The aircraft could be virtually fully laden with Jet A1 (aviation kerosene) which amounts to about $136m^3$.

It is believed that much of the spill would have burned or drained away within 10 to 20 minutes by the time the first appliances arrived at the scene of the incident. The initial crash/rescue teams to arrive would have to control and extinguish a large number of widespread Class A and Class B fires and would concentrate on rescuing any survivors of the aircraft or houses that were involved.

A relatively small amount of foam concentrate would be needed in the form of aspirated AFFF or fluoroprotein (at low or medium expansion) to deal with this situation. Again lack of water and difficulties of making a fast response would detract from any large scale firefighting exercise.

3.2.4 Marine Fires

The UK fire service is not responsible for combatting fires offshore in UK territorial waters, however it is likely that any fire service with coastal boundaries would exercise its power under the Fire Services Act 1947 to attend fires at sea outside its area, particularly where human life was endangered. The following section looks at three examples of marine fires where firefighting foams may be used.

(a) Engine Room

The example chosen is from a 2,000 tonne coastal tanker, although it is quite possible that fire brigades could be called to attend fires in any size of vessel from a yacht up to a bulk oil carrier of 200,000 tonnes or more. The principles of operation are similar for all steel construction vessels, but the complexity of the entry route, access to the engine room and size of the room itself would vary considerably.

A fire could occur from an oil fuel pipe breakage in the machinery space, with oil leaking onto the engine room deck which becomes ignited as a result of contact with hot metal surfaces. If the onboard CO_2 or inert gas systems and first aid firefighting fail to extinguish the fire then the fire brigade will be asked to attend.

In the first instance attempts should be made to isolate the flow of oil to the fire. It may be necessary to lay a blanket of low expansion AFFF or fluoroprotein to protect firefighters from deck level fires and provide water fog sprays to cool and protect as they enter enclosed spaces. Any means of venting the enclosed space by means of ducts, louvres, dampers or hatches should be carried out with the assistance of the ships chief engineer.

To achieve safe entry into a ship and perform a fire search is a challenging and hazardous operation even for skilled fire fighters. In addition to the usual problems of using breathing apparatus in dark confined spaces layers of hot gas may be encountered beneath deck levels, or thermal updrafts from shafts. Progress is inevitably slow and the steelwork is likely to be very hot in places. For such work one hour B.A. sets are preferable over the more standard 30 minute units. Reserve crews will probably be required to allow fire fighters to rest.

If low expansion foam does not reduce the level of the fire sufficiently to gain entry or if access is difficult it may be necessary to use medium or high expansion foam to control the fire and to cool heated steel plates to prevent damage to hoses and reignition. In addition cooling may be required to prevent heat transmission starting fires in the cargo or other areas of the ship. Foam induction must take place at deck level and if the fire is on the lower decks of a large ship it may be necessary to reduce pumping pressure.

The logistics of mounting a medium expansion foam attack involve considerable quantities of concentrate and there may be difficulties in providing this if the ship is at sea in rough weather. In this example the theoretical foam requirements are far lower than those needed in practice. When discharged into an environment with many hot metal surfaces the initial foam application will be largely destroyed. The resulting cooling effect is beneficial, but a further hazard to fire fighters arises from the steam generated.

Assuming a 10m x 10m engine compartment is to be filled with a 2m depth of medium expansion foam, the material and equipment for the theoretical foam requirements would be:

- $200m^3$ of medium expansion foam

- Assuming the use of 450 l/min (100 gpm) branch pipes, each with an output of $19.5m^3$/min of finished foam

- $200m^3$ would require one branch for 10 minutes or two branches for 5 minutes

More concentrate would be required to allow for foam burnoff and continued application. The extra allowance for foam burnoff is substantial but varies with the length of pre-burn and the mass of steel exposed. Further theoretical and practical reseach could provide a useful indication for fire fighters of the quantities to allow. Estimates of three times the theoretical application quantity have been proposed to allow for continued application after fire extinguishment, but in an area where the structure has a high thermal capacity, such as an engine room, this may be insufficient.

- The theoretical concentrate requirement is 2 x 450 l/min x 5 mins = 4,500 litres of solution.
  At 3% concentration; 4,500 x 3% = 13.5 litres of concentrate

This amounts to 7 drums of 22 litres capacity.

Allowing for burn off and re-application the concentrate required would be 6 to 10 times higher i.e. 42 to 70 drums of 22 litres capacity.

(b) **Deck Fire**

In the case of a similar sized coastal tanker a deck fire is considered originating from an oil leak in the deck pipework system.

Tankers normally carry their own onboard foam systems to cover the deck area which are operated by the crew, however if the fire brigade have been called this equipment may be out of service or inadequate for the purpose. Deck fires are more likely to be intense during pumped loading and unloading operations, in which case back-up support should be available from the adjacent jetty. However, various cleaning and transfer activities take place at sea and may give rise to a running/spill oil fire.

The fire fighters arriving on the scene must quickly assess the area of deck that could be affected by the spill and appropriate quantities of foam concentrate and branches should be ordered. If the fire is large and spillage of flowing oil extends into the sea, assistance from fire fighting tugs may be required. Communications and coordination should be maintained between the brigades, coastguard and the ship's master. Under normal conditions water is available direct from the ships hydrant system although booster pumps may be necessary in some cases. Low expansion foam, either AFFF or fluoroprotein would be suitable at the rate of 4.1 l/m^2 with at least double quantities of concentrate for continued application.

If possible, attempts should be made to shut off the flow of oil to the spill. Water fog sprays and low expansion foam streams may be necessary to ensure firefighters are protected whilst they reach the necessary isolating valves.

In addition, it may be necessary to close hatches and ventilation louvres to prevent burning oil from entering further into the ship.

Once sufficient foam stocks and branches have arrived, a concentrated low expansion foam attack can be mounted from a safe distance gradually laying foam onto the edge of the spill, working back to the source of the fire.

Additional water hoses may be required to cool hot steel surfaces to prevent re-ignition and possible spread of fire to the stored cargo.

(c) **Hold Fires**

If a hold fire has developed after a collision with a similar coastal tanker carrying fuel oil and the assistance of the local fire services has been requested by the ship's master, the firefighters must initially assess the requirements of foam concentrate and branches.

Where burning oil is spilling from a ruptured tank into the sea, it may be necessary for the firefighters to call for the assistance of fire tugs. Again the foam quantities depend on the area of the hold, and detailed advice is required from the ship's master.

In estimating the quantity of foam needed allowance should be made for burn off and re-application. Providing there is no possiblity of reignition from char (see below) three times the theoretical quantity of foam would probably be adequate. At least four times theoretical quantity should be allowed for both burn off and re-application, but as stated earlier such estimates are judgemental at present and further research is needed to give firmer guidance.

Once sufficient stocks of foam and branches have arrived, the foam attack should be concentrated at a safe distance from the windward side on each tank until the fire is controlled. If the updraught from the seat of the fire is too high for the foam streams to penetrate, other entrances should be found to apply the foam blanket.

When the tank fire has been extinguished, the foam application should be continued until the surrounding steel plates are sufficiently cool so as not to re-ignite the remaining oil.

Glowing char embers often remain adhering to the upper walls and roof on the inside of oil holds after extinguishment of the fire on the liquid surface. Unless extinguished or dislodged, these deposits can fall back into the cargo and cause reignition hours after first extinguishment.

3.2.5 Terminals - Jetties

The UK fire service is responsible for controlling and extinguishing fires on oil and gas terminals with jetties. Where jetties are sited in remote areas fire brigade response times may be high. On arrival the fire fighters will often be faced with restricted access and the need to carry equipment along jetties to reach the remote loading sections. In more populous river estuary sites there is the potential for exposure to the surrounding community, particularly from burning oil slicks on the water or burning vessels drifting from their moorings.

All these factors make the provision of adequate fixed fire protection facilities on jetties a high priority.

The majority of jetties should be equipped with the following:

- Onshore fire pumps providing fresh or sea water to the jetty hydrants and monitors.

- Twin outlet hydrants with hose connections along jetty approachway.

- Hose, branchpipes, monitors, inductors and foam concentrate.

- Water monitors, adjustable or remotely operated from the shore, which are fitted with jet/fog nozzles. These are arranged to provide a water curtain between the jetty and the ship.

- Four outlet hydrants along jetty deck, together with adaptors for international shore-ship connections.

- Open water spray nozzles installed at the ship side of the loading facility at various elevations.

- Foam monitors positioned at such an elevation that the jetty deck and the ship's deck are covered at all elevations. The foam monitors should be adjustable and may be fitted with remote hydraulic control from the shore.

- There should also be space at the jetty approach for any firefighting appliances and foam trailers.

If a fire occurs at a loading station on an oil terminal, the fixed equipment should be operated to maximum effect. This is to ensure that personnel can be evacuated quickly and safely and that the jetty is protected from exposure to the fire.

With this degree of fixed protection the need for intervention by the fire service with large amounts of equipment is greatly reduced. A first attendance of two fire appliances should be able to supplement the fixed systems in the event of minor sections failing to function. However the equipment handling problems may require considerable resources of manpower and the response should take this into account. The considerable potential for serious loss should mean that a strong second response backed up by fire tugs is provided. In the event of vessel impact on the jetty it may be necessary to isolate sections of the fixed fire protection system so that the undamaged portion near to the shore can remain in operation.

Isolated sections of jetty may well be dealt with by fire boats.

3.2.6 Boiler Rooms

Boiler rooms in commercial and industrial properties are a specific example of where fire brigades use firefighting foams on a routine basis. Most boilers in the UK are equipped with automatic shut-off valves on the fuel supply line at the point of entry to the boiler house. When the fire brigade arrives at the scene of a boiler room fire it is often difficult or dangerous to gain access and determine the extent of the potential fire.

The risk exists of an oil tank rupture leading to a major fire and possibly a boiler explosion. Since boiler houses are usually at the lower levels of buildings it is possible that damage to the supporting structure could occur and fire spread to the remainder of the building.

In a high rise building fire spread, structural damage or smoke logging could have particularly serious consequences.

External foam inlets are used to deliver low or medium expansion foam into the room and ventilation panels should be removed to clear smoke logging. At this stage it may be possible to enter the boiler room and isolate the source of the fuel leak.

When used in conjunction with a single hose inlet one branch would produce approximately $15m^3$/min of finished foam allowing for the restricting effect of the foam inlet. To achieve a 2m foam blanket over a $100m^2$ boiler room would require 13 minutes application and 5,800 litres of water with 175 litres of concentrate at 3%.

3.2.7 Warehouses

Interest has been shown in the use of medium expansion foam to combat warehouse fires particularly where a mixture of storage is involved producing a Class A fire with possible further Class B fires. High expansion foam is considered to have disadvantages for such fires (see 2.1.1 above) and there is insufficient test data on the use of medium expansion foam at present to do more than speculate on how it might be used effectively.

The potential advantages are that visibility can be retained with medium expansion foam, whereas it provides greater volumes of extinguishing agent than low expansion foam and possibly represents a better use of resources. The main disadvantages are; that the foam cannot easily be projected giving problems in delivery to the seat of the fire; it is unsuited to fires involving materials stored above 1m to 2m high; it may not be effective on deep seated fires; there is no research indictating suitable application rates; up to 3 times the theoretical quantity may be needed for re-application.

In conclusion very little information is available regarding the application rates and quantities of medium expansion foam and there may be circumstances when it can be used effectively to improve the extinguishing capabilities of the limited resources available.

3.2.8 Storage Tank Fires

Storage tanks for flammable and combustible liquids of up to 91m diameter and 25m high are used in the UK and it appears that there is a limit to the size of tank with a fully involved fire that can currently be dealt with by the UK fire service or by industrial fire teams. Opinion seems to indicate that this limit is in the order of 45m diameter and 15m high. This limit arises partly because of the delivery equipment currently available.

By far the most common problems with refineries and storage tank farms are;

- vehicular access, movement and parking
- space for hose distribution
- suitable locations for the development of delivery equipment
- inadequate water supply.
- performance limitation of existing equipment, particularly the range and height of monitor streams.

Access to and around storage tanks is often by means of a 3-4m wide road on top of the bund wall and in many cases this must meet the simultaneous needs of appliance movement, parking and operation.

Whilst the following section is primarily concerned with the tactics, equipment and materials needed to tackle a storage tank fire in such a major incident there would be a need for manpower to conduct support operations. This would be provided by fire fighters whose appliances would not be directly involved in the fire attack.

The figures quoted below are based on a fire incident involving a 45m diameter by 15m high crude oil storage tank with adjacent storage that will require exposure protection.

One of the major difficulties created by the often inadequate number of hydrant outlets available and the distance between them is the need for an excessive number of hose lengths.

Deployment of monitors should ideally be on, or better still outside, the bund wall. This is not always possible as the walls are quite often too far from the tank. The marshalling area for the pumps, foam supplies and foam induction should be as close as possible to the fire ground without putting either men or equipment at risk. Every effort should be made to avoid committing men and equipment inside the bund.

The following assumptions are made in order to demonstrate the size of the logistic problem;

- foam is applied at the National Fire Protection Association application rate of 6.5 litres/min/m^2 for a period of 65 min. (Note, there is provision in the NFPA to go up to 8.1 litres/min/m^2 for crude oil)

- hydrants available at 80m intervals with 4 x 70mm outlets

- it has been assumed that the hose layout will be idealised, i.e. the minimum number of hose lengths needed to cover the distances involved have been used

- exposure protection to adjacent storage to be at the rate recommended by the National Fire Protection Association of 10.2 litres/min/m^2

The tables at the end of this section indicate that;

- the water requirement is 10,032 l/min for the foam attack and 12,617 l/min for exposure protection (22,649 l/min total)

- Total Foam Concentrate Usage (3%) litres.	20,150
- Total Water Usage 65 minute attack, plus 4 hrs cooling (litres)	3,680,000
- Monitors (each 1,900 l/min)	13
- Pumps - (one per monitor)	13
- Hydrant Outlets (2 per monitor)	26
- Lengths of 70mm hose (each 25m)	96
- 3% Foam Concentrate (supply rate) l/min	310

Hose numbers are calculated on a regular 80m spacing between hydrants. For foam attack 6 monitors would be fed from 3 hydrants using 12 outlets and an estimated minimum of 20 lengths of 70mm hose to supply the pumps and 24 from pumps to monitors. For cooling water 7 monitors would be fed from 4 hydrants using 14 outlets and an estimated minimum of 24 lengths of 70mm hose to supply the pumps and 28 from pumps to monitors. Further details are given in Report No. 3.

At the Milford Haven incident it is known that 49,500 litres/min of water was available for exposure protection and a foam attack. Some of the tactics involved in fighting tank fires are discussed in 3.2.8 (a) and (b) below. Further details are provided in Report No. 3.

(a) **Floating Roof Storage Tank**

This description is of a scenario for a fully involved tank fire in a 45m diameter crude oil storage tank sharing a bund with a second crude oil tank of similar size 45m distant from the first tank.

It is likely that a floating roof storage tank fire would start by a source of ignition (a lightning strike or burning ember for example) setting fire to the rim seal area.

Floating roof storage tanks catch fire less often than fixed roof tanks with a flammable vapour space, but there have been a considerable number of such fires worldwide, and a larger number still of rim seal fires most of which are extinguished before they become more serious. Statistics are not released by the oil companies on the numbers of fires in floating roof tanks. The generalised statements above have been arrived at after discussion with fire brigades.

The alarm would be raised normally by visual sighting of the smoke, which could involve a considerable delay in a remote unmanned tank farm fire. Some floating roof tanks are equipped with automatic rim seal Halon systems, others with various detection systems.

Once the alarm was raised the plant fire brigade would respond and the local fire brigade would respond in support.

At this stage options depend on the equipment available. If rim seal foam pourers are provided these should be used. The NFPA provides for a supplementary foam hose to be attached to the foam pourer system so that the firefighters can infill any gaps in the foam coverage from the pourers by manual application from the wind girder.

Cases are quoted of rim seal fires being extinguished by foam hoses dragged up the external tank stairway and by large dry powder extinguishers being used from the wind girder. This last practice appears both uncertain and dangerous. The range of dry powder extinguishers is limited and if the floating roof is low it is unlikely that they would be effective at the distances involved. Furthermore with an exhaustible resource such as an extinguisher it is possible that it will run out whilst the firefighter is distant from the access stairway. If the rim seal fire should then burn back he could be cut off from the only means of escape without any firefighting resource to assist him.

The progress of a fire from the rim seal stage can be quite rapid. If floating pontoon sections are not fully air tight these may contain an explosive mixture of gas and air. An explosion in a pontoon section could rapidly sink or tilt the roof exposing the crude oil surface to spread of flame.

Once the tank becomes fully involved the full scale emergency plan should be brought into action. Decisions on the correct action need to be taken as events unfold, and flexibility of response together with close monitoring of developments is essential.

The following are some of the decision areas:

- **Cooling the involved tank**

It is only worthwhile cooling the freeboard area above the contents. This may be necessary if the tank freeboard begins to buckle. Excessive buckling could result in the rim curling inwards, touching the oil surface and preventing an eventual foam attack spreading over the entire liquid surface. Cooling is also necessary for a period before and during the foam attack to help reduce the temperature of the metal surface against which the foam is attempting to seal.

- **Cooling an exposed tank**

In the opinion of some practitioners much water is wasted in cooling activities at most tank fires. Atmospheric tanks beyond 1 diameter from the tank on fire probably do not require cooling unless the fire plume is blown towards them. Pressurised tanks, such as butane spheres should be cooled to avoid excessive operation of the safety relief valve and to maintain a temperature margin in case of a later flare or boilover. It is useful if a fire protection engineer is available with a radiation calculation software programme to make estimates of incident radiation and advise on cooling. Apart from pressurised vessels all cooling water can be switched to the foam attack if necessary.

- **Marshalling equipment and materials**

A preplan should be available showing the quantity of men, equipment and materials necessary to mount a foam attack. Calculations such as those earlier in this section show that in this case the following are required as minimum:

13 pumping appliances (2,270 l/min)
13 monitors (1,900 l/min)
96 lengths of hose (70mm, 25m)
20,200 litres of concentrate
7 foam dams
7 inductor systems for monitors

Ideally it should be possible to assemble and deploy this equipment with the required firefighting teams within 2 hours of the alarm. In practice the logistical problems probably make 4 hours a more realistic target. The foam attack should not be started until the full range of equipment and materials required is available on site. There are cases where resources have been wasted on premature piecemeal efforts.

- **Temperature monitoring**

It is important to monitor the progress of any hot zone formation in the tank on fire. This can give an early warning of potential boil over or froth over. A rough indication is provided by peeling paint on the tank side or by the steam generated when the tank side is wetted. More accurate indication can be obtained if a heat sensitive paint has been applied in a vertical line down the tank side.

- **Circulation**

If a hot layer is advancing to the level where it may encounter water it can be useful to attempt breakage or dispersion by means of tank stirrers (if fitted) or by injection of cold product, inert gas, air or other fluid. Base injection of foam will also induce this effect to some degree.

- **Pump out/Pump in**

The argument for pumping out product is both that the financial loss is curtailed to some extent and that the tank will take less long to burnout. If there is no possibility of mounting a foam attack this is a reasonable objective. There is a risk however that the tank rim will curl in when liquid levels are lowered impeding any eventual foam attack. In fact if there is confidence in the chance of success of a foam attack it can be argued that pumping product into the tank is a useful means of preventing tank curlover.

- **Mounting a foam attack**

Resources should not be wasted by "trying a little foam to see what happens". A foam attack should only be mounted when sufficient resources are available to maintain 6.5 litres/m^2/min uninterrupted for 65 minutes. If the attack has not succeeded or made significant progress by that time then there are probably other factors mitigating against the firefighters and the attack should be aborted and the situation reassessed. The only equipment permitted within the bund should be ground monitors where no other safer vantage point will allow them to reach the tank. Foam monitors should discharge in a narrow cone onto a single point on the liquid surface to maximise the chance of obtaining a "bite" ie. establishing a raft of foam on the liquid surface. A bite should be obtained with the first 30 minutes of a foam attack. It is possible that modelling techniques could be developed which would predict the way in which a foam succeeds in gaining hold on a flammable liquid fire. It would be of value to fire fighters to know which actions increase their chances of success.

- **Tricks of the trade**

Two techniques are advocated strongly by those who have fought such fires. Firstly the value of using waterspray above the foam blanket to cool the fire plume and take away some of the back radiation. If monitors run out of foam they should be raised to contribute to plume cooling. The water will largely evaporate in the plume and experience shows that at the right elevation this tactic does not disrupt the building of the blanket. It would be useful to confirm this field observation with some theoretical or practical research. Secondly it is said that the foam blanket can be spread over the surface more rapidly if a slow swirling motion is imparted by placing one of the monitors to land slightly off centre of the liquid surface. This technique is advocated in conjunction with any foam.

- **Emergency evacuation**

Some crude oils, dual component products or multicomponent products have the capability of forming a hot layer of high boiling constituents above the cooler bulk product. If this hot layer contacts water either held up in a half sunk floating roof, or layered in the tank contents or at the tank base rollover or a boilover can occur steam-lifting vast quantities of burning liquid over the tank walls and raising the size and intensity of radiation from the fire plume. The expelled liquid can be of greater volume than normal because of steam bubbles, causing a froth.

All deployment must be carried out with the prospect in mind of the need for a sudden evacuation of firefighters (and if possible of appliances) if a boilover should occur.

After extinguishment further foam will be required to keep the blanket intact and further cooling water needed to cool the tank to the point where reignition will not occur.

(b) **Fixed Roof Storage Tank**

A fully involved fire in a fixed roof storage tank is in many ways similar to the floating roof storage tank case in that deployment of large resources are required.

The first difference lies in the leadup to a fully involved fire. The vapour space above the liquid can contain a flammable gas air mixture when an atmospheric tank has been partially emptied. Faulty conservation vents or flame arrestors coupled with an ignition source, or simply a lightning strike can cause an explosion in the vapour space. In some cases the roof is blown clear of the tank, splitting at the weak roof-to-shell seam, in other cases a gash in the seam vents the explosion leaving a narrow aperture for fire to escape and firefighting agents to enter.

In terms of fixed equipment top pourers are useful if serviceable but tend to become damaged in any initial explosion. Base injection systems come into their own. There is not the same internal obstruction as with a partially submerged floating roof, and foam injected into the product inlet line or directly into the tank can generally rise through non polar contents and spread to a certain extent over the surface. With larger tanks of a diameter in the order of 45m there is still a need for over-the-top manual application of foam to support the base injection. For polar or waterlogged tank contents it may be necessary to rely entirely on over-the-top application, although semi-subsurface base injection (floating hose) systems may be appropriate.

Whilst fluoroprotein foam and its derivatives are no doubt effective on smaller diameter tanks, there is some question about their ability to spread over the greater distances required in tackling large tank fires. This subject is discussed in greater detail in Report No 3, but it is of relevance here to the case with fixed roof tanks where foam is being applied over-the-top through a restricted aperture, against a counter current flow of flame and hot gases. Under these circumstances there is little that can be done by manipulation of the jets and their landing area to aid foam spread, and the spreading characteristics of the foam may become a critical factor in determining how large a fire can be extinguished. For these reasons improved test methods are required which permit some evaluation of the ability of a foam to spread against a flame front across a flammable liquid. (See Report No. 1).

Firefighting through a restricted aperture also means greater heat radiation hazard for firefighters. The fire plume on leaving the tank can be deflected 60° or more from the vertical by the configuration of the aperture. Monitor teams will be positioned in the same tank quadrant as the fire plume is directed, in order to aim jets through the aperture. Special care should be taken that crews are well protected against sudden increases in heat radiation. One method used on certain specialist nozzles is to have the facility to switch a stream from jet to wide-angle spray with a quarter turn of a control handle. Reportedly this reduces radiation sufficiently to allow teams to hold their position during a brief flare, or to cover their retreat in a more prolonged surge in fire activity. This function would be useful to U.K. brigades and if it is as effective as is claimed, it would be a subject for further experimental work. Fire teams tackling tank fires through apertures also have little choice of their position relative to the wind, and adverse wind conditions could make most useful positions for ground monitors untenable.

In these cases it may be possible to deploy portable foam towers to discharge foam over the aperture lip to augment foam from monitors. Although not standard practice in the U.K. several organisations have used them in the U.S.A. For these special circumstances there is a prima facie case for their use if the materials of manufacture can withstand the heat exposure.

In the case of hydrocarbon liquids with a flash point above the storage temperature, tests have shown that the fire can be extinguished or at least its intensity reduced by rapidly rolling colder liquid from the lower part of the tank to displace the heated top surface. The most practical way of achieving this is to inject air into the bottom of the tank. As the air rises in the tank, it pushes colder oil to the surface. With refined high flash point product the heated surface layer has very limited depth regardless of the length of burning, and air agitation is one way of extinguishing the fire. In the case of high flash point crude oil, the agitation must be done before the heat wave has penetrated too deeply into the surface of the oil.

Low flash point products on the other hand cannot be extinguished by cooling alone. However, air agitation will reduce the intensity of the fire and will assist other forms of extinguishing such as foam or dry powder.

(c) **Bund Fire**

This example considers a fire in a bund area surrounding two 45m diameter petrol tanks, each 15m high. If the general tank farm separation distance is one diameter between all tanks, then the minimum bund dimension would be 170m long by 80m wide. (Allowance has been made for a 10m wide surrounding roadway on the bund walls) This would give a bund area of 13,600m^2 reduced to 12,000m^2 after deducting the area of the unaffected tank, or effectively 11,500m^2 allowing for a 45^o slope on the face of the bund walls. To provide 110% retention capacity bund height would be 2.2m giving a volume of 25,300m^3 as against an effective 23,000m^3 tank capacity.

Bund fires are very often limited in area and constitute running/spill fires. In these cases the brigade response is generally to lay foam and use water spray to allow access to isolation valves and to cut off the running fire element. The spill area is then calculated and a foam attack is mounted when sufficient men, material and equipment are available to provide 4.1 litres/min/m^2 and sustain application for 15 minutes. Tank cooling during the mobilisation period should be avoided if possible since the run-off water will tend to spread the burning liquid over a larger area, however, if tank contents are low and there is a direct flame impingement cooling may be necessary.

An area for particular attention in such small scale bund fires is any gas or liquid lines within the bund area which may be exposed to fire. If not fire proofed they will require protection with preferably a local foam blanket, or less desirably, with water spray.

In some bunds small retention walls are provided to assist in controlling limited spills. For example in cryogenic storage tank bunds the valve area is often provided with a small bund-within-a-bund draining to a small catchment pit in the corner of the main bund.

Fully involved bund fires following a major spillage are rare, but do occur, particularly as a result of boil overs, and sometimes following a terrorist, or military attack.

In this case the risk of rupture of the second tank is the major concern. If bund drainage facilities are adequate it may be possible to cool this tank with water spray whilst the foam attack is being prepared. When sufficient resources have been assembled to mount a foam attack the area around the unruptured tank should be tackled first. Tank walls can be used as back-plates to break the jet momentum and run foam onto the liquid surface whilst a blanket is simultaneously built up from the bund wall outwards.

To mount a 15 minute foam attack on the bund described above using 4.1 litres/min/sq m would require:

- $4.1\ l/min/m^2 \times 12{,}000m^2$ top of bund area
  = 49,200 litres/min

- for 49,200 litres/min x 15 mins = 738,000 litres of solution

- at 3% gives 738,000 litres x 3% = 22, 140 litres of concentrate.

This would require equipment to the extent of;

- 22 pumps and in excess of 400 lengths of hose and a water supply capable of providing 48,000 litres/min at 6 to 7 bars.

Shortage of hydrant outlets would necessitate more hose lengths per pump than in the floating roof tank fire case (above). No allowance has been made in these quantities for replenishing the foam blanket. Parking and layout of 70mm hose on this scale becomes a considerable practical difficulty, and alternative techniques are discussed in Report No 3.

If difficulties are encountered in projecting the foam to the centre of the bund then a longer duration of supply may be needed. Thus the dimensions, shape and access to a bund must be considered.

3.2.9 Vapour Suppression

This example illustrates the use of firefighting foams in vapour suppression. In the event of a collision between an LPG road tanker and other road vehicles, damage to the tank could result in discharge of the contents onto the highway.

When the fire services are alerted to the situation, the seriousness of the LPG spill is recognised and a series of emergency planning procedures are set in motion.

Several appliances are sent to the scene of the incident and approach is made from up-wind of the crash. After the leak is isolated, it is estimated that the spill could extend to about 2,000m^2 and it is calculated that 2 high expansion foam generators producing 153m^3/min at 7 bar could cover the spill in just over 6 minutes using about 60 litres of high expansion foam concentrate. Simultaneously to blanketing the spill with high expansion foam vapour dispersion/control measures would be taken as follows:

- The vapour cloud already formed would be visible by the condensed moisture as a white fog but this is not necessarily the limit of the gas cloud. To effectively monitor the cloud location, explosimeters would be required.

- Possible movement of the gas cloud is anticipated and the area of the probable path evacuated and sources of ignition eliminated.

- Dense curtains of water can be used to direct the gas cloud away from ignition sources that cannot be eliminated. Monitors and branches set in fixed positions enable firefighters to retreat from potentially dangerous situations where they might be exposed to the gas cloud.

- Once the gas cloud is dispersed such that its concentration is below the LEL a search should be made of all low lying areas to disperse other possible gas accumulations.

Use of high expansion foam will be affected by high winds, and further corroborative tests are required to verify those already performed over a range of ambient conditions.

3.2.10 Pressurised LPG Storage Tanks

LPG storage tanks are susceptible to heat radiation and unless care is taken to avoid excessive heating there is a potential for a BLEVE. The various main fire situations associated with LPG storage and transporation are outlined below:

(a) Pressure Relief Valve (Vapour) Fire

This type of fire condition is caused by ignition of a moderately high pressure vapour discharging through pressure relief valves or bursting discs fitted to industrial sized LPG storage tanks.

The resulting fire produces a high rate of heat input into the tank vapour space which will lead to further overpressures of the venting system.

When the flare from a relief valve fire is directed away from the tank shell it may be satisfactory to leave the vapour burning, with tank cooling, to avoid buildup of a vapour cloud. Extinguishment is recommended using dry powder if impingement occurs, and any ensuing vapour cloud should be dispersed.

(b) Radiant Heating Effects From a Remote Fire

An LPG storage tank may be exposed to incident heat fluxes from fires at other locations such as adjacent tankage, spills at unloading stations, or other types of flammable hydrocarbon fires.

If these fires are not controlled or extinguished (by use of foam or other means) an unprotected LPG tank will eventually develop a pressure relief valve vapour fire as described above. In the case of a spill from the LPG tank itself it may not be desirable to completely extinguish this type of fire to avoid creating a vapour cloud hazard. If the spill fire is not extinguished, it is necessary to provide water cooling for the LPG tank.

(c) **Direct Contact Heat Transfer From Spill Fire Flames**

Dykes or bunded areas which are arranged to prevent the spread of flammable liquid or vapour, can result in direct flame contact on the bottom and lower sides of an LPG storage tank with radiation on to the upper surfaces. Water cooling for the LPG tank is required.

(d) **High Pressure Impingement Fire Conditions**

This is the most dangerous type of fire and this is due to greatly increased heat fluxes particularly if flame impingement is on the vapour space or on an empty LPG storage tank which does not have the heat absorption capacity provided by the liquid contents of a full tank.

Such fires are experienced from the failure of an unloading pipe line or if a tanker car tips over and both liquid and vapour are released through the relief valve.

This type of fire situation requires the supply of liquid or vapour to be isolated as quickly as possible. The liquid spill should be contained to prevent further spread of fire and the vapour cloud if developed should be dispersed safely. Water cooling for the LPG tank is required.

(e) **Boiling Liquid Expanding Vapour Explosion (BLEVE)**

Failure of an LPG storage tank exposed to the various fire conditions as described previously, is related to the strength characteristics of the storage tank and is a function of temperature.

The strength of carbon steels used for LPG storage tank construction increases as the temperature increases up to between 315 and 455°C. At this point depending on the type of steel used the strength starts to decrease with further increase in temperature.

At 540°C the burst strength of the tank reduces to 20 bar and for a further increase to 595°C the strength reduces to between 14 and 15 bar.

During severe fire conditions such as direct exposure to spill fires or impinging pressure fires, the heat input is sufficient to cause a continued increase in the internal pressure of the tank. Further heat input to the tank steel not in contact with liquid causes an increase in the steel temperature. In time, a point is reached where the steel temperature in a localised area reduces the local burst strength below that maintained by the pressure relief system and a BLEVE will result.

LPG storage tank fixed protection is usually carried out by the operating company in the UK and can take the form of active cooling or passive fire protection.

TABLE 2

STORAGE TANK FIRES

TOTAL VOLUME OF CONCENTRATE REQUIRED

Tank Diameter	Top Area	Litres of 3% Concentrate			Litres of 6% Cocentrate		
		MOF	ESSO	NFPA	MOF	ESSO	NFPA
m	m^2	30 Min	90 Min	65 Min	30 Min	90 Min	65 Min
15	177	720	2340	2210	1440	4680	4485
30	707	2850	9360	8970	5730	18720	17875
45	1591	6450	21060	20150	12900	42120	40365

N.B. All the figures are rounded to the nearest integer. This leads to slight discrepancies between 3% and 6% figures, but the differences are not of a significant order of magnitude.

MOF - Manual of Firemanship

TABLE 3

STORAGE TANK FIRES

REQUIREMENTS FOR SOLUTION AND CONCENTRATE APPLICATION RATES

Tank Diameter	Top Area	Solution RMAR l/min			Concentrate 3% l/min			Concentrate 6% l/min		
		MOF	ESSO	NFPA	MOF	ESSO	NFPA	MOF	ESSO	NFPA
m	m^2	4.5	4.9	6.5						
15	177	797	867	1144	24	26	34	48	52	69
30	707	3182	3464	4589	95	104	138	191	208	275
45	1591	7160	7796	10342	215	234	310	430	468	621

MOF- Manual of Firemanship

RMAR Recommended Minimum Application Rate

N.B. All figures rounded to the nearest integer.

TABLE 4

STORAGE TANK FIRES
REQUIREMENTS FOR SOLUTION AND WATER

Tank Diameter m	Top Area m^2	Solution RMAR l/min MOF	Solution RMAR l/min ESSO	Solution RMAR l/min NFPA	Water RMAR l/min MOF	Water RMAR l/min ESSO	Water RMAR l/min NFPA
15	177	797	867	1144	773	840	1109
30	707	3182	3464	4589	3086	3360	4451
45	1591	7160	7796	10342	6945	7562	10032

MOF - Manual of Firemanship
RMAR - Recommended Minimum Application Rate
Concentration 3%

N.B. All figures rounded to the nearest integer.

TABLE 5

STORAGE TANK FIRES
COOLING WATER REQUIREMENTS

Tank Diameter	Top Area m^2	Height m	Vertical AREA m^2	Total AREA m^2	1/3 Total AREA m^2	1/3 Area x 10.2 $l/m^2/min$ litres/min	Total Water 65 min litres
15	177	15	707	884	295	3009	196 000
30	707	15	1414	2121	707	7211	469 000
45	1591	15	2121	3712	1237	12617	820 000

SECTION 4

APPLICATION RATES

4.1 INTRODUCTION

Report No 1 evaluated application rates associated with different types of foam concentrates, this section relates application rates to the techniques of extinguishing various types of fires. The various terms used for application rates are defined and the sources of Recommended Minimum Application Rates are reviewed and evaluated. Tables at the end of this section give a comparison of application rates and discharge times for the different standards authorities.

4.2 DEFINITIONS AND DESCRIPTIONS

4.2.1 Critical Application Rate

The critical application rate is usually determined by test and is the lowest rate that will repeatably extinguish the test fire within certain time limits. It gives an indication of the effectiveness of each type of foam on various flammable liquids, which would otherwise be obscured at higher application rates where good and bad foams could both easily extinguish the small test fires used.

4.2.2 Recommended Minimum Application Rates (RMAR)

The recommended minimum application rates are those provided by authorities such as, the Manual of Firemanship, NFPA, Shell, Esso, Draft BS 5306 and Draft International Standard. The RMAR's are derived from the Critical Application Rates by the authority concerned using scale up factors intended to compensate for loss of foam by fallout from the stream, wind losses and destruction of foam passing through a fire plume, as well as a safety factor.

4.2.3 Optimum Rate

The optimum rate is sometimes referred to as the most economical application rate. It is the application rate at which the minimum overall quantity of foam solution is needed to extinguish a fire. This rate usually lies between the critical rate and the RMAR.

4.2.4 Overkill Rate

The overkill rate is any application rate which is above the RMAR and according to current pass tests does not significantly reduce the extinction time. However, there have been reports from real fire situations that high application rates can considerably reduce extinction times.

4.2.5 Continued Application Rate

Many of the standards referred to quote lower rates for continued application after control of fire has been established. These reduced application rates should be sufficient to maintain the integrity of the foam blanket.

4.3 REVIEW OF SOURCES OF RMAR's

The table of application rates indicates that there is a wide difference of recommendation between the various authorities that give guidance on this subject. It is not only the application rates which vary but also the duration of application.

The Manual of Firemanship indicates that 5 lpm/m^2 is suitable for hydrocarbon spills and 4.5 lpm/m^2 is suitable for hydrocarbons in storage tanks, both for a duration of 30 minutes. This statement is without any differentiation between various hydrocarbon liquids or foam concentrates. The only exception is where it indicates that up to twice the application rate is required for alcohol resistant foam on polar solvents as compared with the rate for other foams on hydrocarbons.

By contrast the NFPA propose a variety of application rates for different types of foam, fire and fuel. It is interesting to note that NFPA indicate that for hydrocarbon spill fires the application rate can be reduced to 4.1 lpm/m^2 using AFFF whereas it has to be increased to 6.5 lpm/m^2 when using protein or fluoroprotein foams. This is in line with well documented evidence that AFFFs have better extinguishing times than protein and fluoroprotein foams. It should be noted that FFFP type foams are not specifically considered by design standards yet as they are a relatively new development. Another refinement in the NFPA is the longer application times that are recommended for lower flash point fuels. Flash points between 37.8°C and 93.3°C require 6.5 lpm/m^3 for a 50 minute duration whereas flammable liquids with flash points below 37.8°C require application for a minimum of 65 minutes. It also recognises that flammable liquids with a wide range of boiling points such as crude oils may develop a hot layer after prolonged burning and may require application rates in excess of 8.1 lpm/m^2.

In the case of gasohols and unleaded petrol with an alcohol content of less than 10% by volume, an application rate of 6.5 lpm/m^2 should be used with non-alcohol resistant foams (NFPA).

The application rate according to Shell and Esso appear to be somewhere between the other two authorities. Esso have opted for a lower application rate of 4.9 lpm/m^2 for spills and tanks over a duration of 90 minutes, whereas Shell prefer the high application rate of 6.0 lpm/m^2 for a shorter duration of 60 minutes.

With regard to the use of alcohol resistant foams, NFPA indicated that these should be applied at between 6.5 and 9.8 lpm/m^2 for a duration of 65 minutes depending on the type of polar solvent. In fact, it goes further by suggesting that some polar solvents may require even higher application rates.

The application rates quoted in the draft International Standard and the draft BS 5306 generally correspond with each other and are in line with NFPA 11. Some interesting points in the BS are the inclusion of protein foam for hydrocarbon spills, tank and bund fires and that alcohol resistant foams are not suitable for foam destructive liquids in tank and bund fires using monitors and branchpipe systems. In the draft International Standard reference is made to the use of protein and synthetic foam on hydrocarbon spill and tank fires. These references imply that protein and synthetic foams are still being used on this type of risk. Where the protein and synthetic foams are still held in stock their effectiveness should be reviewed against the more efficient foams now available. For any major risks or uses which present a challenge for foam to extinguish, e.g. bund fires, these foams should be replaced by foams with a higher performance specification.

4.4 DISCUSSION

After reviewing the sources of RMAR's, some interesting points emerge. NFPA 11 indicates certain limitations for the use of foam monitors and branches. It considers that monitors should not be used as the primary means of protection for fixed roof storage tank over 18m diameter and foam branches should not be the primary means of protection for fixed roof tanks over 9m diameter nor over 6m high. The NFPA goes on to say that although fires in tanks up to 39m diameter have been extinguished by using large capacity foam monitors, this success has been dependent on a number of other factors as follows.

The burning liquid level in the storage tank affects the amount of foam than can be applied to the tank and the position of the monitor spray foot print. If the burning liquid level is high, the foam stream has to be directed more at the liquid level than at the inside of the tank shell. This can result in greater submergence of the foam and it will therefore be less effective. Also, if the burning liquid level is too high and foams with rapid drainage times such as AFFF, are used this could quickly lead to a slopover situation. If the burning liquid has a high viscosity and is heated above 93.3°C or the temperature is above the boiling point of water, the use of foam with a low water content may cool the liquid slowly, but it may result in violent frothing and slopover of the tank contents.

Intensely burning liquids at high temperatures produce an updraught, due to the chimney effect around the tank. This may be very forceful and prevent sufficient foam from reaching the burning liquid surface to form a complete foam blanket. Also, high wind velocities may hinder projection of the foam stream and prevent proper formation of the foam blanket.

Also stated in the NFPA codes, is that recommended application rates are based on experience with tanks under 39m diameter. The requirements for foam protection on tanks above this are based on extrapolation of data from successful extinguishment in smaller tanks. Tests have shown that foam may travel effectively across 30m of burning liquid from fixed foam pourers and it is suggested that on fixed roof tanks of over 60m diameter subsurface injection may be used to reduce foam travel distances.

The above statements, clearly identify the need for increasing application rates and discharge times compared with those stated in the Manual of Firemanship and giving more details of different application rates and times for the various hydrocarbon liquids and polar solvents. Current tests have shown that an increase in application rate above the optimum rate will not necessarily extinguish the fire in less time. There is also the need to carry out further tests to determine the higher rates of application required by flammable liquids having a boiling point of less than 37.8^{O}C and the extent that foam will travel over a burning liquid.

4.5 LIST OF REFERENCES

The following reference numbers are sources used in this Section, and are listed in full in Appendix B: 23, 51, 99.

Authority	Risk	Equipment Type	Fuel Flash Point °C	Minimum Discharge Time Min
Manual of Firemanship	Any	Any	Any	30
NFPA 11	Hydrocarbon Spill	Any	Any	15
	Hydrocarbon Tank	Any	Any	50
			Below 40°C & Crude	65
	Polar solvent Tank	Any	Any	90
Esso Formula	Hydrocarbon Tank	Any	Any	90
	Hydrocarbon Spill	Any	Any	90
Shell DEP	Hydrocarbon Tank	Any	Any	60
	Hydrocarbon Spill	Any	Any	60
Draft BS 5306	Indoor & Outdoor Hydrocarbon Spills	Any	Any	15
	Tanks Containing Liquid Hydrocarbons	Any	Below 40°C	60
			Above 40°C	45
	Foam Destructive Liquids	Any using AR class foam	Any	15
	Bunds	Any	Any	60
Draft ISO Standard	Spills	All	All	15
	Hydrocarbon Tank	All	Below 40°C	60
			Above 40°C	45

MINIMUM DISCHARGE TIMES FOR MONITOR AND BRANCHPIPE SYSTEMS

TABLE 6

		Minimum Application Rates of Foam Solution			
Authority	**Foam Concentrate**	**Spill Fires lpm/m²**	**Tank Fires lpm/m²**	**Bund Fires lmp/m²**	**Flammable Liquid**
Manual of Firemanship	Any	5.0	4.5		Hydrocarbon
NFPA 11	AFFF	4.1	6.5		Hydrocarbon
	P or FP	6.5	6.5		Hydrocarbon
			8.1		Low & wide range of boiling points
	AR		6.4 - 9.8		Polar solvent
Esso Formula	Any	4.9	4.9		Hydrocarbon
Shell DEP	Any	6.0	6.0		Hydrocarbon
Draft BS 5306	AFFF	4.0	6.5		Hydrocarbon
	FFFP	4.0	6.5	2.0	"
	FP	5.0	6.5		"
	P	6.5	8.0	2.0	"
	AR	Test	-		Foam Distinctive Liquid
Draft ISO Standard	FP or AFFF	4.0	6.5		Hydrocarbon
	P	6.5	8.0		"
	S	6.5	8.0		"
	AR	6.5	-		Methyl & Ethyl alcohol, acrylonitrile, ethyl acetate, methyl ethyl ketone (MEK)
	AR	10.0	-		Acetone, butyl alcohol

MINIMUM APPLICATION RATES FOR MONITOR AND BRANCHPIPE SYSTEMS

TABLE 7

SECTION 5

EQUIPMENT

5.0 INTRODUCTION

Equipment used throughout the UK fire service varies in detail, but follows a broadly similar pattern. There are many legitimate reasons for variation including;

- the state. of the art of appliances and equipment at the time of purchase
- budgetary constraints
- priorities for spending within individual brigades
- the type and size of the risks that may be encountered
- the needs of adjoining county brigades in the event of assistance being required
- officer preference.

Most brigades tend to standardise on one or other type of foam for their appliances and backup supplies. There are strong arguments in favour of this because of the possiblity of confusion between foam concentrates and equipment in the stress of an emergency. This section attempts to describe the typical equipment operated by the UK fire service and to review the types of foam induction equipment available.

5.1 VEHICLES

5.1.1 Fire Appliances

Pumping appliances in use at the present time are defined by their pump capacity and are generally either 4,500 l/min or more usually 2,270 l/min. An average pumping appliance at this size will carry 900-1,800 litres of water for immediate use.

In addition to the water application equipment specialist foam making equipment carried would typically consist of;

- induction/proportioning devices
- foam making branches and devices for low expansion and/or medium expansion and possibly high expansion foam
- a limited quantity of liquid foam concentrate

Foam tenders and carriers vary in their type and function and can include any of the following types;

- tankers with fixed or detachable pods
- tankers provided with fixed or portable pumping units
- Water carriers are usually available with a capacity of about 9,000 litres. These carriers may be used to transport foam concentrate by draining the water and refilling with concentrate from fixed storage tanks.
- flat back transporters to receive either pods, $1m^3$ containers or any containers and equipment.

Specialist foam equipment may be transported separately in dedicated vehicles. This equipment would be for use in conjunction with the pumping appliances and the foam tenders at the larger and more serious incidents.

The equipment must obviously be compatible with the foams that may be used on any anticipated risk.

5.2 INDUCTION EQUIPMENT

5.2.1 General

Report No 1 makes reference to allowable variations in proportioning rates at particular concentrations as specified in BS 5306 Section 6.1.

- 6% concentration -1% + 1% ie between 5% and 7%
- 3% concentration -0% + 1% ie between 3% and 4%
- 1% concentration -0% + .25% ie between 1% and 1.25%

Induction devices must therefore be manufactured to proportion within these limits.

However a device that proportions at the upper limit of these tolerances may in fact use between 17 to 33% more foam concentrate than is required.

Quite apart from the effect this under or over proportioning may have on the times to extinguish a fire, over proportioning, if not taken into account when calculating foam requirements may well result in insufficient foam being available at fire and the depletion of stocks.

This would suggest that calculations for foam concentrate requirements should be based on either:

- 1.25% instead of 1%
- 4% instead of 3%
- 7% instead of 6%

Manufacturers suggest that no problem will be experienced when proportioning alcohol resistant type foams through standard proportioning equipment. However there is a body of opinion that believes independent tests should be carried out to confirm this opinion particularly in relation to induction at low temperatures. Reference to this subject is made in report number one.

Concern has been expressed by one of the testing authorities that induction devices, particularly inline inductors, are very seldom tested for accuracy of proportioning. A programme of maintenance and testing should be set up to ensure that these units are returned to manufacturers to confirm that they perform within the required tolerances.

5.2.2 Inline Inductors

An inline inductor is a device that can be fitted in the delivery hose to introduce foam concentrate into the fire water stream at a maximum distance of 60 metres from the foam branch pipe and enables the branchman to have complete freedom of movement. The principle of operation is that water under pressure is fed to the inlet of the inductor and through a jet to a throat-passage at high velocity. This action creates a vacuum in a chamber located between the jet and the throat to a degree that foam concentrate will be induced into the stream by means of a pick-up tube. The solution then passes through the delivery hose to the branchpipe or monitor where it is made into finished foam.

Inline inductors may be of the fixed or variable proportioning type.

Advantages of inline induction are;

- simple, robust equipment with few moving parts

- reasonably accurate proportioning (within the required tolerance) over a wide pressure range

- quick deployment/redeployment on the fire ground.

The disadvantages of inline induction are;

- the inductor must be matched with the discharge nozzle

- pressure losses through the inductor of 25-35% can be expected at the normal working pressure range.

5.2.3 Round the Pump Proportioning

This method of proportioning is achieved by the use of an inductor that works on a similar principle to that of the inline inductor but the induction rate can be adjusted by varying the position of the throat in relation to the nozzle. A hand actuated control moves the throat by means of a rack and pinion to vary the flow of foam concentrate.

The inductor unit can be fitted to a fire pump as a temporary or permanent feature.

Water to the fire pump is supplied from either hydrant, tank or open water sources. If hydrant pressure is so high that the required suction to delivery pressure ratio of 1:3 cannot be met then a means of pressure control must be used.

Water passes through a suction adaptor to the fire pump. On the delivery side of the pump a small proportion of the water is diverted by means of a delivery adaptor to the round the pump inductor where a preset quantity of concentrate is induced by mean of the pick-up tube.

A concentrate rich solution is formed and fed via the inductor to the suction adaptor at the suction side of the pump. Here the correct proportion of foam concentrate to water is achieved and the solution is fed through the pump to the foam making equipment.

The advantages of this method of induction are;

- variable induction rate
- quick and simple settings
- can be used as a fixed or portable system
- wide operating pressure range
- able to supply a premix solution over extended lengths of hose dependant on pump pressure.

The disadvantages of this system are;

- premix solution is passed through the pump. A number of brigades but by no means all, express concern regarding the subject of pump corrosion.
- where the equipment feeds more than one branch there is the need to match the pump output to the number of branches in use at any one time. This is achieved either by manually altering a setting on the pump, or on some models automatically via a flow measurement device.

5.2.4 Pressurised Foam Supply

Many brigades employ a system of pumping foam concentrate through hose from bulk storage direct to the delivery equipment. This is achieved by utilising the pumping unit on the foam tender to convey the foam concentrate to the induction device which may take the form of an inline inductor or a constant flow valve.

5.2.5 Inline Foam Injection (Pelton Wheel)

Attention has been drawn to the very high pressure losses experienced when using inline (venturi type) inductors. The loss through these units is in the order of 30%. It is not unusual for this loss together with hose, monitor and nozzle loses to add up to a total frictional loss that makes the performance of some pieces of equipment ineffective, particularly in terms of throw.

An alternative system is to make use of a pelton wheel driven positive displacement pump which will introduce foam from a storage tank or foam dam into the delivery hoses through a regulating valve. This valve can be adjusted to suit the injection rate required and once set will inject at the required percentage regardless of pressure fluctuations from the pumping appliance. The units can be supplied with either fixed or adjustable induction rates to suit the circumstances. Reference is made elsewhere regarding the allowable tolerance on proportioning and this must be taken into account when this injection unit is set up.

5.2.6 Pre-induction (Double Sucker)

This system employs two induction units.

A pre-induction unit is installed near a hydrant and draws concentrate from a reservoir to produce a concentrate rich solution which is fed to a specially designed nozzle into which is built a second inductor. At this second stage the required rate of induction is achieved.

By using two stages of induction and making use of the power from a separate hydrant a much lower pressure loss is experienced.

This system is not in general use in the U.K., but it should be evaluated under controlled conditions against the techniques currently employed by the fire service.

5.3 LARGE NOZZLES

The use of large volume/discharge nozzles on monitors must be considered.

These have been used with some success although there is very little documented evidence giving details of their performance. Discharge rates of up to 15,000 l/min are available.

While these large volume nozzles go some way to solving the problem of delivering the foam onto the large tanks it seems that there is still room for research into their use in order to obtain performance figures to assist in selection and use.

At least one oil company is making use of this type of nozzle both in conjunction with ground monitors and by elevating them on cranes.

5.4 HOSE LAYING

It will be seen from the figures produced indicating the water requirements for fighting large tank fires (Report No 3) and in this report that a very large number of hoses would be needed from the fire main to the pumpers and from the pumpers to the delivery equipment. It is quite evident that the exclusive use of large numbers of 70mm hoses to supply foam delivery equipment is impractical. Systems and equipment must be developed to employ 100mm and 150mm diameter hoses that are necessary if large volume monitors and nozzles are used.

Some advantages may be gained by the use of hose laying vehicles for both standard and large hoses where large numbers and distances are involved.

5.5 STANDARDISATION

The Fire Service Act calls for brigades to provide support to adjoining county brigades. Their ability to perform this task would be much improved if equipment and foam concentrates are compatible, particularly when there is a likelihood that two or more brigades will attend the same major incident.

Foam concentrates and proportioning systems vary considerably which creates difficulties in the event of a major incident such as;

- methods of induction can be any of those described in the previous sections

- some equipment and methods of induction are not variable between 1%, 3% and 6% concentrate

- delivery equipment may not be provided with the facility to receive concentrate from a pressurised supply.

5.6 LIST OF REFERENCES

The following reference numbers are sources used in this Section, and are listed in full in Appendix B: 1, 2, 3, 7, 8, 10, 168, 194, 195, 196.

SECTION 6

NEW AND IMPROVED EQUIPMENT

6.1 MODIFICATION TO EXISTING EQUIPMENT

The great majority of the time the Fire Service employs water delivery equipment to tackle fires but they are also obliged to carry foam making and delivery devices for use in the event of a call to a Class B fire.

The foam making equipment is divided into three general groups depending on the requirement for either low, medium or high expansion finished foam. Most extensive use is made of low expansion foam which may be used through both hose reels and main hose streams.

Whilst the majority of the delivery equipment carried by the Fire Brigade is for use with water only, some developments have taken place with regard to modifying water branches and nozzles to make them suitable for foam delivery. A particular example of this is the development by one Fire Brigade of a clip on foam aspirator attachment for fitting to the nozzle at a hose reel branch.

A similar device is available to fit a range of twist pattern mushroom type jet spray nozzles for use with 45mm and 70mm hoses. This will effectively convert the unit from a water branch to a foam maker producing a good quality finished foam.

Some overseas manufactures are producing add on aspirators for use with large capacity monitor nozzles.

These devices are very good examples of the way that by relatively simple means standard water delivery equipment carried by the Fire Brigade can be effectively and cheaply converted to produce and deliver finished foam.

6.2 FIRE PUMP CONTROL

A subject that is receiving attention at the present time is the automatic control of appliance fire pumps for foam proportioning. The purpose of the research is to simplify the workload of the pump operator. Simplification of operation is of prime importance in the early stages of an incident when there are other tasks to perform.

Automatic control would give the pump the added ability to respond immediately to changes in demand thereby providing greater safety for the branchman.

Some overseas brigades have had automatic pump control systems in use for a number of years. Two levels of automatic control are available;

- basic auto-control
- remote auto-control.

Basic auto-control requires that the pump operator and branchman would employ current practice to obtain the required conditions and then engage the auto-control which will maintain the branch condition irrespective of fluctuations of inlet or outlet pressures. The foam proportioning percentage can be set on a dial, and an automatic servo-controlled valve system ensures that the required percentage of concentrate is mixed regardless of changes in pressure or demand.

In the case of remote auto-control the pressure/flow at the branch would be controlled by the branchman without the need to communicate with the pump operator or be subject to the limitations of the basic system.

6.3 ELEVATING EQUIPMENT

Method of elevating foam delivery equipment would benefit from further research. Considerable benefits derive from elevated delivery in some fire situations. For example tackling storage tank fires where accurate projection of a foam stream against metal surfaces can improve the efficiency of formation of the foam blanket, or where a foam stream needs to be directed through a small aperture.

6.4 HIGH EXPANSION FOAM EQUIPMENT

High expansion foam has been used by the fire service for many years.

Doubts have been expressed that until recently the type and range of equipment available did not allow high expansion foam to be used to its full potential. One drawback is that it requires a different foam concentrate from most of the more generally used low expansion foams.

Tests indicate that high expansion foam is very effective on petrol pool fires when wind conditions permit but if special purpose tenders are to be employed it will only be used as a last resort when other forms of attack have failed to extinguish the fire. In practice the U.K. brigades use high expansion foam very little. In some cases the specially designed lightweight generators are no longer kept as standard appliance equipment.

6.5 SURVEILLANCE EQUIPMENT

During the course of the survey reference was made to the use of surveillance devices as an aid to fighting storage tank fires. The devices mentioned would take the form of;

- closed circuit television (CCTV)
- infra red heat detection.

It must be said that little seems to be known about the practical capabilities of either system. Further investigations would be necessary to comment on the practicability of using these techniques.

Consideration should be given to the use of closed circuit television with the camera mounted on elevated platforms, at the top of foam towers or on the jib of a crane.

With the aid of remote control it should be possible to view the development and control of a fire within the storage tank. With this degree of information available to the firefighters it should enable them to direct the foam attack with much greater accuracy.

A similar system is operated on a smaller scale at the testing facility of one of the overseas oil companies.

The use of infra red detection to monitor the movement of the heatwave in a crude oil storage tank fire has been suggested. The equipment would need to be directional and very selective in order to differentiate between the heatwave in the tank and the heat from the fire generally. Both of these systems would be of great benefit to the fire service. A simpler method may be the use of heat sensitive paint. Its use, durability and effectiveness should be researched independently to establish whether it has a role either in the protection/detection materials provided by operators, or uses within the fire service.

An investigation into the effectiveness of these methods of surveillance in connection with oil storage fires would be an advantage. Based on the findings of the investigation a research programme should be set up to develop the subject further.

6.6 LIST OF REFERENCES

The following reference numbers are sources used in this Section, and are listed in full Appendix B: 147, 150, 163, 255, 257, 239, 230, 268, 382, 383.

SECTION 7

DISCUSSION OF RESULTS

7.0 INTRODUCTION

The various points for action, discussion or research which have been raised in this report are briefly summarised for reference. There is a certain amount of interrelation between the results derived from this report and from other reports in this series. A full collation of the points raised in the first 3 reports is provided in Report No. 4.

7.1 USE OF MEDIUM EXPANSION FOAM

(see 2.1.1)

There are potential savings in equipment and in the use of foam concentrate by employing medium expansion foam for certain types of Class A and Class B fires.

However, further research is required to determine the additional quantities of medium expansion foam needed for security in such circumstances. A research programme could be devised that would be able to provide improved guidance for fire brigades as to where medium expansion foam could be used to advantage and the application rates/security required.

7.2 FOAM REQUIREMENTS FOR FIRST RESPONSE TO VEHICLE CRASHES

(Section 3.2)

There is a case for reviewing the equipment, material and policy on use of aspirated foam which are presently used in the first response team to vehicle crashes in urban, rural and motorway settings. Several types of foam may be required in the brigades stocks, including fluoroprotein, AFFF, and FFFP.

There may be a case for adopting the alcohol resistant forms of AFFF or FFFP for such use, but research is needed into whether the requirement that this type of foam should be gently applied is a serious obstacle to its more general use. Section 3.2 provides an outline of how foam requirements can be estimated and what considerations need to be taken into account.

7.3 FOAM PURCHASING

(Section 2.2.6)

Concern has been expressed in several quarters (both by interested parties and financially disinterested) that brigade purchasing policies do not provide an adequate means of differentiating between good quality and lower quality foam products, and between different types of foam which may be beneficial for certain applications. In this area brigade purchasing should give weight to well established manufacturers with a track record in the UK above products imported from organisations with little or no technical record or back-up support.

7.4 PROTEIN AND SYNTHETIC FOAMS FOR TANK FIRE USE

(Section 4.3)

Use of protein and non-fluorinated foams should be discontinued for fighting flammable and combustible storage tank fires and substituted by more effective foams which are now available.

Tank fires can pose a considerable challenge to fire fighting foams and the use of the more advanced types of foam is advised.

7.5 FOAM APPLICATION RATES - MANUAL OF FIREMANSHIP
(Section 4.3)

An area where insufficient data is presently available is on the amount of spread that can be expected from fire fighting foams over the surface of burning flammable and combustible liquids. Research on this subject coupled with an improved test method (see report No. 1, 7.6 item 1) would provide data for an independent review of the foam application rates presented in the Manual of Firemanship. As stated in Report No. 1 interim revision to align the manual more closely to international standards is necessary.

7.6 FORMAL PRE-PLANNING
(Section 3.1)

There are training and operational benefits in conducting formal pre-planning excercises for medium and small size incidents as well as major disaster plans. Much is already being done in this area, but this activity is considered of great benefit in operational effectiveness and it is considered worthy of further emphasis. Training aids are now available which will greatly enhance the impact of this work, such as interactive videos. Further research data would also assist in constructing realistic training exercises.

7.7 FOAM USE PRE-PLANNING SOFTWARE
(Section 3.1)

Consideration should be given to development of a European/International standard version of the foam planning software programmes used in the U.S.A.

7.8 DIRECT ON-LINE UPDATING OF MAJOR HAZARD CHANGES

(Section 3.1)

Consideration should be given to direct-on-line updating of tank contents and site plans by major chemical, petrochemical users to the fire brigade. This is already done in certain areas of France, and the present methods of updating used by UK fire brigades do not appear to provide sufficiently current information.

7.9 CONTROL OF MAJOR INCIDENTS

(Section 3.1)

Those senior fire officers who are likely to take charge of major fire incidents should be specifically trained in the organisation, control, logistics and techniques of major incident management. Use of expert advisers, software programmes and decision trees should be incorporated into this training process.

7.10 ROUTINE TESTING AND MAINTENANCE OF FOAM PROPORTIONING EQUIPMENT

(Section 5.2.1)

At present there appears to be little attention paid to the accuracy of proportioning obtained from equipment. However, where such equipment is performing out of tolerance it can greatly affect the calculations of foam concentrate required to tackle a particular fire. A routine testing and maintenance programme should be operated by each fire brigade for such equipment.

7.11 RESEARCH INTO THE CHARACTERISTICS OF LARGE FOAM MONITORS

(Section 5.2.7)

Research is required into the performance characteristics of the new large flowrate foam monitors. The jet throw, wind susceptibility, fallout and footprint are areas where insufficient data is currently available.

7.12 RESEARCH INTO ELEVATED PLATFORMS FOR FOAM DELIVERY
(Section 6.3)

There are considerable advantages to be gained by elevated delivery of fire fighting foam on certain risks, e.g. storage tank fires. Ad hoc experiments have been performed at some refineries and some commercial equipment is available. The subject requires further study to determine whether equipment currently available on the market is suited for these purposes in the UK or whether there is a need for development of a revised equipment specification.

7.13 SURVEILLANCE EQUIPMENT
(Section 6.5)

The subject of remote surveillance of fire conditions by CCTV or infra red techniques is being developed, but applications to tank fire fighting are seen as promising and worthy of further study.

7.14 CLIP-ON FOAM ASPIRATORS
(Section 6.1)

There are considerable advantages to be gained in the selective use of clip-on attachments to standard branchpipes which convert them to generate aspirated low expansion foam. Further development is required to produce a commercial product for general use, but it is considered that development effort spent in this area will yield a valuable improvement to current capabilities.

7.15 FIRE PUMP CONTROL
(Section 6.2)

This development is directed at providing a method of foam proportioning that is easier to control and gives improved levels of safety for the branchman. Counter arguments that appliance equipment should be kept as mechanically and electrically simple as possible have some validity.

However, auto-control systems have been developed and are in service in other countries, so a practical step to keep abreast of developments would be to conduct an evaluation of the in service record and of the costs and benefits.

7.16 ECONOMIC ANALYSIS OF AFFF AS A WETTING AGENT
(Section 2.1.1)

Research should be performed into the property damage savings that may be achieved by using wetting agents or foams with wetting agent properties in fighting Class A fires.

7.17 STANDARDISATION
(Section 5.3)

There is a need for standardisation between adjoining county fire brigades on the types of foam stocks and proportioning equipment used so that full mutual support can be provided when required. This is a complex subject, but one which requires attention to fully meet the requirements of the Fire Services Act.

7.18 USE OF ALCOHOL RESISTANT AFFF AND FFFP
(Section 2.1.2)

Tests should be performed to establish the sensitivity of this foam to other than "gentle" methods of application, and advice disseminated to brigades on how to employ the foam to best effect, on alcohol type fuels.

7.19 FOAM BURNOFF AND REAPPLICATION RATES
(Section 3.2.1)

The effects of large quantities of steelwork in enclosed spaces on the volumes of fire fighting foam required should be investigated. Guidance will be of use in ship fires, offshore installations, and other enclosed fires.

7.20 MODELLING THE FOAM "BITE".

(Section 3.2.8)

Techniques are available to model the way in which foam obtains a hold on a flammable liquid fire. Such work would give valuable insight into the extinguishing mechanisms and tactical options.

7.21 FIRE PLUME COOLING

(Section 3.2.8)

The tactic of cooling a fire plume from a tank fire with water projected above a foam blanket should be investigated. Superficially the technique appears valuable, but guidance would be needed to fire fighters to avoid disrupting the foam blanket.

7.22 USE OF WIDE ANGLE SPRAY PATTERNS

(Section 3.2.8)

These are claimed to have value in protecting fire fighters from rapid heat flux increase. Research into available equipment is required to confirm this point.

APPENDIX A

GLOSSARY OF TERMS

This appendix gives a number of definitions referred to in the text of the report.

APPENDIX A

GLOSSARY OF TERMS

The following terms are used throughout the chapters of this report and should be interpreted as illustrated by the definitions that are given.

Accelerated Ageing - Storage of foam concentrate for short periods at high temperatures, to indicate long term storage properties of the foam concentrate at ambient temperatures.

AFFF (Aqueous Film Forming Foam) - A synthetic foam concentrate containing detergents and fluorocarbon surfactants that control the physical properties of water so that it may be able to float and spread across the surface of some liquid hydrocarbon fuels.

Alcohol Resistant Foam Concentrate - A specially formulated foam concentrate for use on alcohol and other water miscible risks.

Application Rate - The rate at which a foam solution is applied to a fire. Usually expressed as litres of foam solution per square metre of fire area exposed per minute.

Aspirated Foam - A general term to indicate expanded foam which has an expansion ratio typically 4:1 or more.

Aspiration - The addition or entrainment of air into the foam solution.

Balanced Pressure Proportioning - A foam concentrate induction system designed to inject automatically the correct quantity of foam concentrate into a water stream over a wide range of variable flows and pressures.

Base Injection - The introduction of expanded finished foam beneath the surface of certain flammable and combustible hydrocarbons, to effect fire extinguishment.

Boiling Liquid Expanding Vapour Explosion (B.L.E.V.E.) - Explosive fire balls caused by the rapid escape of flammable gas, discharging from sealed pressurised containers, which have ruptured/failed due to adverse heat exposure.

Boil Over - Violent ejection of flammable liquid from its container, caused by vaporisation of a water layer beneath the body of the liquid. It will generally only occur after a length burning period, in wide flashpoint range products, such as crude oil.

Branchpipe - A hand-held foam maker and nozzle.

Burn Back Resistance - The ability of a foam blanket to resist direct flame and heat impingement.

Bund Area - A dyked area surrounding a storage tank, which is designed to contain the liquid product in the event of a tank rupture.

Candling - Refers to the thin intermittent flames that can move over the surface of a foam blanket even after the main liquid fuel fire has been extinguished.

Chemical Foam - A foam produced by mixing two or more chemicals. The bubbles are typically caused by carbon dioxide released by the reaction.

Classification of Fire

CEN System (UK and Europe) - Used in this report

Class 'A' Fire - A fire in materials such as wood and paper where the cooling effect of water is of paramount importance in extinguishing the risk.

Class 'B' Fire - A fire involving a flammable liquid or liquefiable solid where a blanket or smothering effect is of major importance in extinguishment.

Class 'C' Fire - A fire involving a flammable gas or gases.

Class 'D' Fire - A fire involving a metal such as magnesium, sodium, lithium and potassium etc.

US Classification (NFPA 10-1984) - Alternative System used in the U.S.A.

Class 'A' Fire - Fires which occur in ordinary combustible materials, i.e. wood, paper, rubber and certain plastics etc.

Class 'B' Fire - Fires which occur in flammable liquids, oils, tars, lacquers etc., and including flammable gases.

Class 'C' Fire - Fires involving energised electrical equipment where the electrical non conductivity of the extinguishing agent is particularly important.

Class 'D' Fire - Fires which occur in metals such as magnesium, zirconium lithium and potassium etc.

Combustible Liquid - Any liquid having a flashpoint at or above 37.8°C (100°F).

Critical Application Rate - The minimum rate at which foam solution can be applied to a given fire in order to achieve extinction.

Drainage Rate - The rate at which water drains from an expanded finished foam.

Dual Agent - See Twin Agent Method.

Eductor - American term for Inductor (q.v.).

Expansion Ratio - The ratio of total foam volume to the volume of foam solution.

Film Forming Foam - A foam that can produce a spreading, vapour securing, thin aqueous film on the surface of certain hydrocarbon fuels.

FFFP (Film Forming Fluoroprotein Foam) - A protein based foam concentrate with film forming characteristics.

Flammable Liquid - Any liquid having a flashpoint below 37.8°C (100°F).

Flashback - Re-ignition of flammable liquid caused by exposure of its vapours to a source of ignition such as a hot metal surface or a spark.

Flashpoint - The lowest temperature at which a flame can propagate in the vapours above a liquid.

Fluoroprotein Foam Concentrate - A foam concentrate based on hydrolised protein with surface active fluorocarbon concentrates added.

Finished Foam - The homogeneous blanket obtained by mixing water, foam concentrate and air.

Foam Generator - See Foam Maker.

Foam Maker - A device designed to introduce air into a pressurised foam solution flow.

Foam Pourer - A device designed to deliver expanded foam gently onto a burning liquid.

Foam Solution - A homogeneous mixture of water and foam concentrate.

Foam Water Sprinkler - An open air aspirating delivery head whose water discharge pattern closely resembles those for standard sprinklers.

Foam Water Spray Nozzle - An open air aspirating delivery head whose discharge pattern is specific to the individual nozzle.

Friction Loss - The loss of pressure in a pipe line resulting from resistance to flow imposed by the inside of the pipe and by changes in flow direction such as elbows and T-pieces. Friction losses are greater with expanded foams than with foam solutions.

GRP - Glass reinforced plastic used for construction of some storage tanks and equipment.

Hazmat - A proprietary trade name used to describe special types of foam which can be used on certain alkaline and acid materials.

High Back Pressure Generator (Forcing Foam Maker) - HBPGs introduce air into the foam solution to produce expanded foam in a base injection system.

High Expansion Foam (HEX) - Foam of expansion ratio between 200-2000:1.

Hydrocarbon Fuel - Fuels based exclusively on chains or rings of linked hydrogen and carbon atoms. Hydrocarbon fuels are not miscible in water.

Inductor (Eductor) - A device used to introduce foam concentrate into a water line. A venturi is fitted to suck foam concentrate into the water stream.

Induction Rate - The percentage of foam concentrate mixed or introduced into the water supply line.

Inline Inductor - An Inductor used in a hose line.

Knockdown - The ability of a foam to quickly control flames. Knockdown does not necessarily mean extinguishment.

Low Expansion Foam - Foam of expansion ratio between 2-20:1.

Mechanical Foam - Foam produced by a physical agitation of a mixture of water, foam concentrate and air.

Medium Expansion Foam - Foam of expansion ratio between 20-200:1.

Monitor - A large throughput branchpipe and nozzle which is normally mounted on a vehicle or on a fixed or portable pedestal.

NFPA - Standards for foam systems published in America by the National Fire Protection Association.

Non-Aspirated Foam - Foam of expansion ratio typically between 0-2:1. Only Film Forming Foam Concentrates are suitable for non aspirating applicators.

Oleophobic - Oil repellent.

pH - Measurement of acidity and alkalinity on a scale of 1-14. Neutral de-ionised water has a pH value of 7.

Polar Solvent - This term is generally used to destribe any flammable liquid which destroys standard foams, although it actually refers to liquids whose molecules possess a permanent dielectric charge e.g. alcohols, ketones. Polar solvents are generally miscible with water.

Premix Solution - A mixture in correct proportions of a foam concentrate and water. Use of this term generally implies that the foam is stored in premix form, as in a portable foam fire extinguisher.

Proportioner - A device where foam concentrate and water are mixed to form a foam solution.

Protein Foam Concentrate - Substance containing organic concentrates derived from natural vegetable or animal sources. Hydrolised products of protein provide exceptionally stable and heat resistant properties to foams.

Security - The ability of a foam to seal around hot objects and prevent reignition.

Stability (of Concentrate) - Ability to be stored for long periods without separating out.

Stability (of Finished Foam) - Ability to retain shape and form in the presence of heat, flame and/or other liquids.

Static Pressure - The pressure existing in a line at no flow. This pressure is always considerably higher than under flowing conditions.

Sub Surface Injection - Another term referring to base injection.

Specific Gravity - The specific gravity of a material is a measure of the density of the material in relationship to the density of water. The specific gravity is calculated as:

$$S.G. = \frac{\text{Density of Material}}{\text{Density of Water}}$$

Twin Agent Method - A technique where Dry Chemical Powder is used to knockdown flames quickly, and AFFF is also applied to seal over a fuel spill. Used mainly for rescuing people from crashed aircraft.

Unaspirated Foam - See Non-Aspirated Foam.

Vapour Seal Box - A unit fitted on the outside of a fuel storage tank which will pass expanded foam through it, but will not allow vapours from the fuel in the tank to escape into the atmosphere. Normally fitted with a glass seal which is broken by the foam.

Venturi - A constricted portion of a pipe or tube which will increase water velocity, thus momentarily reducing its pressure. It is in this reduced pressure that foam concentrate is introduced. The pressure difference across the venturi can be used to force foam concentrate into the water.

VFP (Variable Flow Proportioner) - A foam proportioning device that will automatically adjust the pressure of the foam concentrate to match the water mains pressure thus giving the desired induction rate regardless of variation in flow.

APPENDIX B

LIST OF REFERENCES

This is the full list of references. Some of these have been reviewed in abstract form only.

At the end of each section of the report the appropriate references have been listed by number.

1	PILOT STUDY ON LOEX FOAM MAKING BRANCH PIPES	B.F.JOHNSON/P.L.PARSONS
2	TRIALS OF METHODS OF FOAM DISP.FOLLOWING USE OF HIEX FOAM	F.E.SMITH
3	BRIGADE TRIALS OF A COMPACT HIEX.FOAM GENERATOR 1982-1984	J.A.FOSTER
4	TRIALS OF MEDIUM AND HIGH EXPANSION FOAMS ON PETROL FIRES	P.L.PARSONS
5	TRIALS OF FOAM ON PETROL FIRES AT THE FIRE SERVICE TECH.COLLEGE	P.L.PARSONS
6	EVALUATION OF FIRE FIGHTING FOAMS.(ALCOHOL CONTAINING FUELS)	USA PETROLEUM INSTITUTE.
7	ADDITIVES FOR HOSEREEL SYSTEMS:TRIALS OF FOAM ON PETROL FIRE	J.A.FOSTER
8	A COMPACT HIGH EXPANSION FOAM GENERATOR	P.L.PARSONS
9	TRIALS OF FOAMS ON HYDROCARBON FIRES IN THE E.E.C.	F.E.SMITH
10	TESTS OF INLINE INDUCTORS FOR USE WITH A COMPACT HIEX GENERATOR	J.FOSTER/ B.P.PARSONS
11	TESTS OF 2 COMPACT HIEX FOAM GEN.PRODUCED BY SYMTOL ENG.1982	J.A.FOSTER.
12	ADVANCES IN PROTECTION OF POLAR TYPE FLAMMABLE LIQUID HAZARD	L.DI'MARIO/P.CHIESA/M.S.OTT
13	PROPERTIES OF FIRES OF LIQUIDS	D.RASBASH/Z.ROGOWSKI/G.STARK
14	EVALUATING FOAM FIRE EQUIPTMENT AIRCRAFT RESCUE & FIRE FIGHTING VEHICLES	N.F.P.A
15	TESTS - POWDER EXTINGUISHING	HOME OFFICE STANDARD
16	NFPA 18 - STANDARD ON WETTING AGENTS 1986	NFPA (ANSI)
17	SPEC.FOR MANUFACTURE & UNIFORMITY OF FOAM LIQUID FIRE EXTINGUISHING (FLUROCHEMICAL TYPE)	DEFENCE STANDARD
18	SPEC.FOR MANUFACTURING & UNIFORMITY OF FOAM LIQUID FIRE EXTINGUISHING (FLUROPROTEIN TYPE)	DEFENCE STAN
19	WEST GERMAN STANDARD FOR FIRE FIGHTING FOAM EQUIP.(BRANCH PIPES & MONITORS)	DIN 14
20	SPEC.FOR MANUFACTURING & UNIFORMITY OF FOAM LIQUID FIRE EXTINGUISHING (PROTEIN TYPE)	DEFENCE STANDARD
21	NFPA 11C -STANDARD FOR MOBILE FOAM APPARATUS 1986	NFPA
22	EVALUATION ABILITIES OF FOAM AGENTS TO POLAR TYPE LIQUIDS(ABSTRACTS)	M.HOSHI/K.HAYSHI
23	MODERN DEVELOPMENTS IN FOAM SYSTEMS	BFPSA LTD.
24	EVALUATION OF A NON ASPIRATING NOZZLE	L.DI'MAIO/R.LANGE/F.CONE
25	EVALUATION TEST FOR FOAM AGENT EFFECTIVNESS	J.PIGNATO JNR.
26	TESTING OF FOAM AS A FIRE EXTINGUISHING MEDIUM FOR POLAR SOLVENT & PETROL FIRES	A.RYDERMAN
27	TECHNIQUE PLAYS A MAJOR ROLE IN APPLYING FOAM CONCENTRATES	D.WALTERS
28	SELECTION & USE OF FOAMS TO MEET CHALLANGES OF FLAMMABLE LIQUID FIRES	SGT.G.BROWN
29	MANAGEMENT OF FLAMMABLE LIQUID STORAGE TANK FIRES	GEORGE.R.HER,
30	EVALUATING THE USE OF FIRE FIGHTING FOAMS	GREG.NOLL
31	DILUTION OF FLAMMABLE POLAR SOLVENTS BY WATER FOR SAFE DISPOSAL.	F.F.THORNE
32	TESTS INTO THE COMPATABILITY OF FLUROPORTEIN FOAMS WITH ALCOHOL BLENDS.	G.FERRONI/S.ANTINCENDI/Y.LEV
33	TESTING OF FIRE FIGHTING FOAM	W.CAREY/M.SUCHOMEL
34	FOAM EQUIPMENT SUPPLIERS	
35	FEDERAL SPECIFICATION/FOAM LIQUID/FIRE EXTINGUISHING/MECH.	U.S.A. SPECI
36	DRAFT REPORT-PIOLT STUDY LOW EXPANSION BRANCH PIPES	D.J.MUSS

37	D.I.N. CATALOGUE 1981-HOW TO USE IT	DIN
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40	EXPERIMENTAL STUDY ON TRANSPORTATION OF HIEX FOAM THROUGH FLEXIBLE DUCTS	ROKURO NII
41	FIRE RESEARCH NOTE NO.1056-200L/MIN STANDARD FOAM BRANCHPIPE	J.G.CORRIE
42	TRIALS OF FOAM ON PETROL FIRES AT THE FIRE SERVICE TECH.COLLEGE	P.L.PARSONS
43	FILM FORMING FOAM(AFFF)LIQUID CONCENT.FOR FRESH & SEA WATER	MILITARY SPECIFICATION
44	THE NATIONAL INSPECTORATE OF FIRE SERVICES (SWEDEN)	SWEDISH BOARD OF RESCUE
45		
46	UL STANDARD 162- FOAM EQUIPMENT & LIQUID CONCENTRATES	UNDERWRITERS LABORATORIES INC
47	THE INFLUENCE OF ALCOLOL CONCENTRATION ON THE EFFECTIVNESS OF PROTEIN FOAMS IN EXTING. FIRES IN GAS/ALC.MIX.	D.FITTES/D/RICHARDSON
48	SWEDISH DEFENCE SPECIFICATION-FOAM COMPOUND WITH A MOISTENING AGENT BASE FOR PRODUCTION OF MECHANICAL FOAM.	ANGUS FIRE ARMOUR
49	FOAM:EC WGF (LETTER)	P.L.PARSONS
50	FOREIGN PUBLICATIONS (FRENCH & JAPANESE)	VARIOUS
51	ISO/TC 21/SC 5/WG 5 N 39 (LISTING)	
52	CHEMICAL TANKER	FPA CASEBOOK
53	FIREFIGHTING - VERY LARGE FLAMMABLE LIQUID STORAGE TANKS	BEVERELY FIRE STATION 7/5/87
54	JUNIOR OFFICERS ADVANCEMENT COURSE -FIRE PROTECTION & FIREFIGHTING IN THE PETROCHEMICAL INDUSTRY	FIRE SERVICE COLLEGE
55	PEROLCHEMICAL MODULE (OPERATIONS)	JUNIOR OFFICERS COURSE
56	LOADING & UNLOADING BULK FLAMMABLE LIQUIDS & GASES AT HARBOURS.GUIDANCE NOTE	HEALTH & SAFTEY EXECUTIVE
57	SPECIFICATION	UNKOWN
58	NATIONAL FOAMSTAT PREPLANNING HAZARD ANALYISS & RECORDATION	FILE NAME TLB.HAZ
59	NATIONAL FOAMSTAT PREPLANNING HAZARD ANALYSIS & RECORDATION	FILE NAME TANK.HAZ
60	FACTORY MUTUAL APPROVAL GUIDE 1982	UNKNOWN
61	NFPA 11 STANDARD FOR LOW EXPANSION FOAM & COMBINED AGENT SYSTEMS	NFPA
62	FLUORPROTEIN FOAM 'A PROVEN SUCCESS' IN USE ON TANK FIRES	R.C. PARAMOR
63	FOAM LIQUID FIRE EXTINGUISHING MECHANICAL SPECIFICATION	FEDERAL SPEC.
64	AIR FOAM LIQUID CONCENTRATES	UNDERWRITERS LABORTORIES
65	FIRE FIGHTING PROPORTIONER	H. S. CONTROLS
66	ASSIGNMENT 65K2644 REPORT 19/10/65	UNDERWRITERS LABATORIES
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68	FOAM FIRE PROTECTION SEMINAR	NATIONAL FOAM
69	A GUIDE TO FIRE PREVENTION-THE USE OF FOAM LIQUID CONCENTRATES	CHUBB FIRE
70	FIRE FIGHTING FOAMS FOR FLAMMABLE LIQUIDS	D.HIRD
71	RELEVANCE OF FOAM LIQUID TESTING FOR RELIABILITY IN CASE FIRE BREAKS OUT.	J.DOWLING
72	HALOFOAM (R) (LETTER)	M.A.PYSDEN.MANAGING DIRECTOR

73	THE EFFECTIVNESS OF FIRE FIGHTING FOAMS	A.F.ACKLAND
74	THE TESTING OF LOW EXPANSION FOAMS	TONY BRIGGS
75	WATER QUALITY & ITS EFFECTS ON FIRE FIGHTING FOAM	L.DI'MARIO/R.LANGE
76	SALT WATER COOLING AND FIRE FIGHTING	UNKNOWN
77	FIRE EXTINGUISHANTS (HISTORY PROPERTIES & USE)	J.OKE/R.ANTHONY/A.STEVENS
78	CLASSIFICATION OF FIRES (LOOSELEAF PAGES)	UNKNOWN
79	FOAM AND ITS SPECIFIC APPLICATIONS	A.RODRIGUEZ
80	AWP-THE DEVELOPMENT OF FILM FORMING LIQUID FOAM COMPOUNDS	E.SZONYI
81	PROPORTIONING SYSTEMS FOR FIXED SYSTEMS	
82	THE CHOICE OF GASEOUS EXTINGUISHING AGENTS	D.R.WALKER
83	FOAM WATER SPRINKLER SYSTEMS USING AQUEOUS FILM FORMING FOAM	E.BAYLEY (OFFICE CORRESP.)
84	MAINTENANCE AND TESTING OF HIGH EXPANSION FOAM SYSTEMS	P.FITZGERALD (OFFICE CORRESP)
85	MODERN DEVELOPMENTS IN FOAM SYSTEMS	SYMPOSIUM NOTES
86	FIXED FOAM EXTINGUISHING SYSTEMS	J.L.EVANS
87	FIRE EXTINGUISHING SYSTEMS (SECTION 4 FOAM SYSTEMS)	DRAFT COPY
88	THE ESSENTIALS OF FOAM EXTINGUISHING SYSTEMS	P.NASH
89	TESTS SHOW UNFOAMED AGENTS CAPABLE OF INCREASING FIRE POTENTIAL IN FUELS	C.COUSIN /A.BRIGGS
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91	GASOHOL - A NEW FIRE CHALLENGE	L.DI'MARIO
92	TESTING CONCLUDES PETROL CAN REDUCE THE EFFECTIVNESS OF SOME FOAMS	A.BRIGGS/J.WEBB
93	SPECIAL HAZARDS PROTECTION - MANUFACTURERS & EQUIPMENT	NAME LISTINGS
94	WHY WIDER GUIDANCE IS NEEDED (ARTICLE)	RON HIRST
95	SPECIAL APPLIANCES (ARTICLE)	MANUAL OF FIREMANSHIP
96	GERMAN TENDERS SENT TO BAHRAIN & BULGARIA	ARTICLE
97	LATEST EQUIPMENT DEMONSTRATED	ARTICLE
98	PRACTICAL FIRE FIGHTING	MANUAL OF FIREMANSHIP
99	LESSONS LEARNED FROM THE AMOCO FIRE (ARTICLE)	ROGER PARAMOR
100	TWO-BLAZE TASK FOR THAMES-SIDE FIRE-FIGHTERS	ARTICLE
101	SECOND FATAL EXPLOSION AT BP GRANGEMOUTH	ARTICLE
102	SUMMIT TUNNEL:THE LESSONS	ARTICLE
103	FIRE FIGHTING METHODS & EQUIPMENT IN THE MIDDLE EAST	ARTICLE
104	DRY POWDER FIRE EXTINGUISHING FOAM COMPATIBLE	DEFENCE SPEC.
105	FUEL STORAGE PROTECTION	A.RAINE
106	THE USE OF AQUEOUS FILM FORMING FOAM	DR.C.A.SMITH
107	IMPORTANCE OF EXTINGUISHANT IN AIR CRASH WORK	ARTICLE
108	FOAM SYSTEM PROJECT CREATES WIDE INTEREST	ARTICLE

109	PROJECT DESIGN TO SOLVE PROBLEMS OF HELICOPTER DECK FIRE PROTECTION.	D.MITCHELL
110	USING THE RIGHT FOAM IS CRITICAL TO ACHIEVING TARGET RESPONSE TIME	W.MERTENS/D.COOK (ARTICLE)
111	AFFF.ITS APPLICATION TO THE PROTECTION OF AIRCRAFT HANGERS	MERROL FIRE PROTECTION LTD
112	STORAGE OF FOAM COMPOUND	H.O.SUPPLY & TRANSPORT BRANCH
113	STORAGE OF FOAM COMPOUND AT 28/02/71	H O SUPPLY & TRANSPORT BRANCH
114	FOREST FIRE FIGHTING WITH FOAM	M.INGOLBY/R.SMITH
115	HAZARDOUS MATERIALS - ARE YOU REALLY PREPARED?	LT.E.VASIL
116	MEASURING THE SHEAR STRESS OF FIRE-FIGHTING FOAM	J.G.CORRIE
117	TESTS OF THE EFFECT OF HOSE KINKING ON THE COMPACT GENERATOR	J.FOSTER/G.JOHNSON
118	THE FIRE RESEARCH FOAM VISCOMETER ITS CONSTRUCTION & USE	J.G.CORRIE
119	METHOD FOR MEASURING DRAINAGE RATE OF FIRE FIGHTING FOAMS	S.BENSON/K.MORRIS/J.CORRIE
120	EFFECT OF TEMPERATURE ON FOAM IN THE 5 L/MIN BRANCHPIPE	S.P.BENSON
121	A 200 LITRE PER MINUTE FOAM BRANCHPIPE	J.G.CORRIE
122	EFFECT OF FOAM PRODUCED IN THE STIRRED JAR	S.P.BENSON
123	A 5 LITRE PER MINUTE STANDARD FOAM BRANCHPIPE	S.BENSON/D.GRIFFITHS/J.CORRIE
124	FOAM BRANCH DESIGN	S/BENSON/D.GRIFFITHS/D.TUCKER
125	BREAKDOWN OF HIGH EXPANSION FOAM USING ANTIFOAMING AGENTS	P.TONKIN/C.BERLEMONT
126	A STIRRED JAR FOR PRODUCTION OF STANDARD FOAM IN THE LAB.	J.G.CORRIE
127	THE APPLICATION OF HIGH EXPANSION FOAM TO WOOD CRIB FIRES	P.THORNE/R.YOUNG
128	EFFECT OF FOAM JETS ON CONTROL & EXTING. OF LAG FIRES	D.TUCKER/D.GRIFFITHS/J.CORRIE
129	THE POSSIBILITIES OF APPLYING EXTINGUISHING FOAM IN ACCIDENTS INVOLVING DANGEROUS MATERIALS	J.JEULINK
130	USE OF FOAM AS AN EXTING.AGENT FOR POLAR & PETROL FIRES	A.RYDERMANER
131	FIGHTING FIRES WITH FOAMS	A.F.ACKLAND
132	USE OF 1% CONCENTRATE A.F.F.F.	DAVID SMITH
133	BRIGADE DESIGNS LOW COST FOAM INJECTION SYSTEM ON APPLIANCES	DCFO R.CURRIE
134	H.O.MEMO-SAFE WORKING WITH HIGH EXPANSION FOAM	HOME OFFICE
135	H.O.MEMO-TRIALS OF FOAM ON PETROL TRAY FIRES	HOME OFFICE
136	H.O.MEMO- PLANNING FOR THE USE OF BULK FOAM STOCKS	HOME OFFICE
137	MISC.MEMORANDUM	K.L.HOLLAND
138	H.O.MEMO-TRAINING IN THE USE OF HIGH EXPANSION FOAM.	HOME OFFICE
139	LETTER	CHIEF FIRE OFFICER
140	LETTER	HOME OFFICE
141	OPERATIONAL USE OF HIGH EXPANSION FOAM EQUIPMENT	HOME OFFICE
142	STOCKS OF PROTEIN COMPOUND	HOME OFFICE
143	MISC. MEMORANDUM	HOME OFFICE
144	OPERATIONAL USE OF HIGH EXPANSION FOAM	HOME OFFICE

145	STOCKS OF FOAM COMPOUND (LETTER)	HOME OFFICE
146	MISC MEMORANDUM	HOME OFFICE
147	HOME OFFICE FIRE EXPERIMENTAL UNIT	FIRE RESEARCH NEWS
148	FIREFIGHTING WITH FOAM EQUIPMENT EVALUATION	FIRE RESEARCH NEWS
149	TRIALS OF FOAMS ON PETROL TRAY FIRES	FIRE RESEARCH NEWS
150	FIRE SERVICE EXPERIMENTAL UNIT AT MORETON	FIRE RESEARCH NEWS
151	FIRE RESEARCH NEWS	CATALOGUE
152	A STUDY OF VARIATIONS IN FIRE FIGHTING TACTICS	HOME OFFICE
153	TECHNICAL RESEARCH & DEVELOPMENT IN THE HOME OFFICE	SIR RONALD MASON
154	FIRE PROTECTION & FIREFIGHTING IN THE PETROCHEMICAL INDUSTRY	SPEC.
155	GERMAN STANDARDS	DIN 14 366 PT.2
156	GERMAN STANDARDS	DIN 14 366 PT.1
157	GERMAN STANDARDS	DIN 14 272 PT.1
158	GERMAN STANDARDS	DIN 14 272 PT.2
159	MECHNICAL FIRE EXTINGUISHING FOAM LIQUID	FEDERAL SPEC
160	"A.F.F.F. - TECHNIQUES FOR TOMORROW?"	SPEC.
161	ASSESMENT OF THE USE OF A REFRACTOMETER FOR MEASURING FOAM SOLUTION CONCENTRATION	H O.SCIENTIFIC ADVISORY BRANCH
162	TESTS WITH A WORMALD SILVEX CONCENTRATE	B.J.JONES
163	BRIGADE DESIGN LOW COST FOAM INJECTION SYSTEM ON APPLIANCES	ROBIN CURRIE
164	FOAM TRANSPORT TRIALS PROVE SUCCESSFUL	SPEC.FIRE MAGAZINE 1980
165	FIRE FIGHTING FOAM RESEARCH & DEVELOPMENT PROPOSALS	BP PETROLEUM DEVELOPMENT
166	FOAM MAKING CONCENTRATES:AN ASSESMENT OF TODAYS PRODUCTS	G.RUSSELL(ARTICLE FIRE MAG.)
167	SINGLE FOAM AGENT PROVIDES PROTECTION AT OIL & GAS TERMINALS	D.SMITH (ATRICLE FIRE MAG)
168	FINAL CONCLUSIONS FROM THE INKINE CONDUCTOR TESTS	SPEC.
169	FOAM TESTS	TONY BRIGGS
170	LORCON SILVEX FOAM APPLICATION FOR FOREST FIREFIGHTING	UNKNOWN
171	BRIGADES FIRST USE OF BULK FOAM SUCCESSFUL AT TRAIN CRASH SALFORD	UNKNOWN
172	METHOD FOR MEASURING CONCENTRATION OF FOAM COMPOUNDS IN WATER	I.LUSTIG
173	COMPACT ISO HIGH EXPANSION FOAM GENERATOR	SYMTOL
174	EEC WORKING GROUP ON FIRE 7TH MEETING 24/25 MAT 1986	SPEC.
175	TESTS INTO COMPATABILITY OF FLUROPROTEIN FOAMS WITH ALC/PET	G.FERRONI /Y.LEV
176	ACTIVITIES ON FIRE RESEARCH & DEVELOPMENT IN THE NETHERLANDS	SPEC.
177	FOAM PROPERTIES & PERFORMANCE FOR MED/HIEX FOAM GENERATORS	A.FELLERMAN/R.JEWSBURY
178	FIRE INFORMATION - NATIONAL DATA SERVICE	CACFOA
179	DISPOSAL OF FOAM COMPOUND & FOAM MAKING EQUIPMENT	FIRE SERVICE CIRC. NO.44/1976
180	A STUDY OF METHODS OF FOAM INDUCTION	A.C.WOODLEY

181	DEFENCE STANDARD TESTS ON CENTRIFOAM 906	ARTICLE
182	AWG-FOAM.HALON.& POWDER PISTOL NOZZLE	CATALOGUE
183	ELECTRONIC FOAM INDUCTION SYSTEM	HARRIER MARKETING
184	BOILOVERS	DAVID WHITE
185	CORROSION EFFECTS OF FOAM ADDITIVES ON FIRE APPL.& ASS.EQUIP	AMTAC LABATORIES
186	FIRE SERVICE COLLEGE-PROGRAMME OF COURSES 1988	SPEC.
187	HOME OFFICE CORRESPONDANCE - FOAM STUDY	M.THOMAS
188	TANKER CRASH -ARTICLE-FIRE MAGAZINE	UNKNOWN
189	BRIGADE QUESTIONNAIRES	UNKNOWN
190	REPORT ON TRIALS OF LIGHT WATER AT THE AFDFS CENTRE	S.S.HARRISON
191	EVALUATION OF STANDARD PROTEIN/FLUROPROTEIN/SYNTHETIC FOAMS	HEAD OF SERVICE (RAF)
192	AIRPORT RESCUE & FIRE FIGHTING SERVICES - IDENT.CATEGORIES	NATO STANAG 3712
193	TRIALS ANGUS PETROSEAL FILM FORMING FLUOROPROTEIN LIQUID	E.L.CHILD
194	TESTS ON THE WARDASH FOAM INDUCTOR SYSTEM	J.A.FOSTER
195	TESTS ON THE CHUBB INDUCTOR SYSTEM FOR USE WITH HOSE REELS	J.FOSTER/J.PURILL
196	TESTS ON A GALENA FOGFOAM AUTOMATIC IN-LINE INDUCTOR SYST.	B.P.JOHNSON
197	BRITISH STANDARD DRAFT 5306	P.D.O'CONNEL
198	COMPUTER LISTING	UNKNOWN
199	CHIEF INSPECTOR OF FIRE SERVICES REPORTS ON 1986 (ARTICLE)	CHIEF INS.IF FIRE SERVICES
200	PERGAMON INFOLINE /ORBIT INFORMATION TECHNOLOGIES	CATALOGUE
201	M1272 DEGRADED & CONTAMINATED FOAM	ARTICLE
202	M1267 FIRE PREVENTION & FIRE FIGHTING IN SHIPS IN PORT	ARTICLE
203	ONCE MORE INTO THE BREACH	ARTICLE
204	HI-LIFT TWIN STAGE FOAM INDUCTION NOZZLE	CATALOGUE
205	DEBUT OF NEW FOAM NOZZLE SYSTEM	ARTICLE FIRE MAG NOV.87
206	GUIDES FOR FIREFIGHTING IN & AROUND PETROLEUM STORAGE TANKS	API PUB 2021
207	WELDED STEEL TANKS FOR OIL STORAGE	API STANDARD 650
208	A GUIDE TO THE CONTROL OF INDUSTRIAL MAJOR ACCIDENT HAZARD REGULATIONS 1984	UNKNOWN
209	TACOA STORAGE TANK	ARTICLE FIRE ALMANAC 1984
210	STRATEGIC PLAN FOR H.O.FIRE RESEARCH 1987/80-1991/92	UNKNOWN
211	GENERAL RULES FOR FOAM APPLICATION	UNKNOWN
212	OPERATIONAL & TRAINING INSTRUCTIONS PART-1 APPLIANCE & EQUIPMENT	UNKNOWN
213	HOW TO FIGHT HYDROCARBON FIRES	FIRE PROTECTION MANUAL
214	THE PROBLEMS ASSOCIATED WITH VAPOUR SUPPRESSION	ARTICLE
215	DISCUSSION RECORD NOTE -MILFORD HAVEN TANK FIRE	MINUTES OF MEETING
216	FIREFIGHTING-VERY LARGE FLAMMABLE LIQUID STORAGE TANK	D.D.GEORGE

217	BP ENGINEERING CODE OF PRACTICE CP 15-ACTIVE FIRE PREVENTION	
218	FIREFIGHTING SYSTEMS	DEP.80.47.10.11.
219	REQUIREMENTS FOR FIRE PROTECTION IN ON-SHORE OIL & GAS PROCESSING & PETROCHEMICAL INSTALLATIONS	DEP.80.47.10.30
220	PORTABLE & MOBILE EQUIPMENT FOR FIREFIGHTING	DEP.80.47.10.32
221	FIREFIGHTING VEHICLES & FIRE STATIONS	DEP.80.47.10.33.
222	CYCLE FIRE TEST & DRAFT STANDARD COMMENTS	
223	ELKHART FIRE FIGHTING EQUIPMENT CATALOGUE	CATALOGUE
224	AKRON CATALOGUE NO.105	CATALOGUE
225	FOAM-MAKING CONCENTRATES :AN ASSESSMENT OF TODAYS PRODUCTS	G.RUSSELL
226	A GUIDE TO THE USE OF FOAM LIQUID CONCENTRATES	UNKNOWN
227	FOAM AND ITS APPLICATION	A.ACKLAND
228	LIGHT WATER AFFF IMPROVES JETTY SAFTEY	ARTICLE
229	THE EXTINGUISHING POWER OF FOAM	DR.STHAMER
230	HOSEREEL SYSTEM ADDITIVES PUT TO THE TEST	H.O.FIRE DEPT
231	FOAM OFFSHORE	ARTICLE
232	FOAM DEMONSTRASTION SPARKED OFF THOUGHTS ON HOW TO TACKLE OIL REFINERY FIRES.	R.CAVANAGH
233	INTRODUCTION TO FOAM	NATIONAL FOAM
234	AT NATIONAL FOAM FLAMMABLE LIQUID FIRE PROTECTION IS A FULL TIME JOB	LEAFLET
235	GETTING THE BEST PROTECTION NOW COSTS LESS WITH OUR NEW REMOTE CONTROL HYDRAULIC MONITOR SYSTEM	LEAFLET
236	FIGHTING FIRE WITH FOAM:BASICS OF EFFECTIVE SYSTEMS	D.N.MELDRUM
237	MODEL HMG-4 REMOTE CONTROL HYDRAULIC MONITOR SYSTEM	LEAFLET
238	MINI-PRO FOAM SYSTEM FOR THE MUNICIPAL FIRE SERVICE	LEAFLET
239	FOAM LIQUIDS AND EQUIPMENT FOR MUNICPAL AND VOLUNTEER FIRE DEPARTMENTS	LEAFLET
240	CONSULTING SERVICES	LEAFLET
241	PER HOUR COST OF FIRE IN PRODUCT LOSS	DATA INFORMATION
242	NOZZLE AND FOAM LIQUID TEST DATA	DATA INFORMATION
243	GASOHOL AND UNLEADED GASOLINE	L.DiMARIO
244	PERFORMANCE AND TESTING OF FOAMS FOR AIRCRAFT CRASH - FIRE FIGHTING PAST.PRESENT AND FUTURE	D.MELDRUM / K.POLLARD
245	THE RIGHT FOAM FOR THE JOB	LEAFLET
246	PROVEN PERFORMANCE...NOT JUST PROMISES	LEAFLET
247	THINK TANKS	LEAFLET
248	INTRODUCING A NEW FOAM SYSTEM FOR FLOATING ROOF TANKS	LEAFLET
249	DAMAGED TANK DRAINED WITHOUT INCIDENT	LEAFLET
250	NATIONAL FOAM HAS THE MOST COMPREHENSIVE SET OF UL LISTINGS OF ANY FOAM FIRE PROTECTION COMPANY	LEAFLET
251	RED ALERT DOES DOUBLE DUTY	LEAFLET
252	ETHANOL - A NEW MARKET FOR FARMERS.A NEW HAZARD TO PROTECT	LEAFLET

253	FOAMSTAT - PREPLANNING AND EMERGENCY SOFTWARE FOR FLAMMABLE LIQUID FIRE PROTECTION	[illegible]
254	PROTECTING THE PANAMA CANAL	LEAFLET
255	PRODUCING OIL IN THE NORTH SEA	LEAFLET
256	FIRE SCHOOL REPORT	LEAFLET
257	KODAK PARK - INDUSTRIAL FIRE PROTECTION AT ITS FINEST	LEAFLET
258	HAZMAT NF - HAZARDOUS VAPOR MITIGATING FOAMS	LEAFLET
259	'OVER THE TOP DELIVERY' (GASOLINE AND CRUDE OILS)	DATA INFORMATION
260	FIRE PROTECTION EQUIPMENT DIRECTORY	UNDERWRITERS LABORATORIES
261	EVALUATION OF FILM FORMING FLUROPROTEIN FOAM	T.MILLER
262	INFORMATION PACK	UNDERWRITERS LABORATORIES
263	STANDARDS FOR SAFTEY	UNDERWRITERS LABORATORIES
264	REVISED DP 7076 - FOAM SYSTEMS	D.FISHER
265	STORING AND HANDLING ETHANOL AND GASOLINE - ETHANOL BLENDS AT DISTRIBUTION TERMINALS AND SERVICE STATIONS	AMERICAN PETROLEUM INSTITUTE
266	COMPUTERS AND INCIDENT SIMULATION	R.F.CAREY
267	CONOCO WORLD	NEWS SHEET
268	FIRE EXTINGUISHANT AND HAZARDOUS SITUATION CONTOL	CATALOGUE
269	MOBIL TRAVEL GUIDE	MOBIL OIL CO-OPERATION
270	PETROLEUM PROPERTIES AND CHEMICAL PLANTS	PHILADELPHIA FIRE DEPT
271	LNG/LPG EMERGENCIES	PHILADELPHIA FIRE DEPT.
272	FIRE EXTINGUISHING AGENT.AQUEOUS FILM-FORMING FOAM (AFFF) LIQUID CONCENTRATE.FOR FRESH SEA AND WATER	MILITARY SPEC.
273	FOAM LIQUID.FIRE EXTINGUISHING.MECHANICAL	FEDERAL SPEC.
274	FIRE PROTECTION ENGINEERING	UNIVERSITY OF MARYLAND
275	TOP POURING FOAM EQUIPMENT FOAM POURER	CATALOGUE
276	PRE-FIRE PLAN FOLLOWED IN SETTING UP PUMPER RELAY FOR SUPERHIGHWAY FIRE	J.D.FEIGE
277	AFFF SPREADING PROPERTIES AT ELEVATED TEMPREATURES	A.WOODMAN/H.RICHTER/A.ADICOFF
278	A TECHNIQUE FOR THE EVALUATION OF AFFF SEALING CHARACTERISTICS	P.NICHLOSON/D.ARTMAN
279	THE USE OF AFFF SPRINKLER SYSTEMS	R.DURFORD
280	HANGAR FIRE PROTECTION WITH AUTOMATIC AFFF SYSTEMS	D.DREEN
281	AUTOMATED SURFACE AND INTERFACIAL MEASURMENTS OF AFFF'S.	D.ELLIOTT/P.CHIESA
282	FIRE TESTS AT ZURICH AIRPORT	ARTICLE
283	LIGHT WATER AFFF IMPROVES JETTY SAFTEY	ARTICLE
284	ENHANCEMENT OF FIRE PROTECTION WITH DIRECTIONAL COOLING SPRAY NOZZLES BY USE OF AFFF	J.PIGNATO
285	CONTROL FLAMMABLE LIQUID FIRES BY 'PREMIXING'	R.GIBSON
286	FIRE-FIGHTING FOAMS FOR LIQUID HYDROCARBON FUELS	ARTICLE
287	TANK FIRE: A CASE STUDY HISTORY	P.FOX
288	ANGUS INTRODUCE PETROSEAL 'FFFP' IN HOLLAND	ARTICLE

289	SELECTION AND USE OF FOAMS TO MEET CHALLANGES OF FLAMMABLE LIQUID FIRES	G.BROWN
290	LIQUEFIED GAS FIRES: WHICH FOAM?	L.BROWN
291	FIRE OUT: MAKING WATER MORE EFFECTIVE	A.SALY
292	TESTING OF FIRE FIGHTING FOAM	W.CAREY
293	MEDIUM AND LIGHT FOAMS FOR FIRE EXTINGUISHING	GERMAN STANDARD DIN 14272
294	PROTEIN BASED FOAMING AGENTS: TECHNICAL CONDITIONS OF SUPPLY	FIRE RESEARCH STATION
295	FOAM BRANCHPIPES: PART 1: PORTABLE FOAM BRANCHPIPES	DIN 14 366:PART 1:DRAFT
296	TEST METHOD FOR FOAM LIQUIDS	H.PERSSON/A.RYDERMAN
297	FOAM AND DRY POWDER SYSTEMS	FIRE PROTECT.ASSN.SOUTH AFRICA
298	FOAM AND DRY POWDER SYSTEMS	AUSTRALIAN FIRE ASSN
299	FOAM FOR AIRCRAFT CRASH FIRES	H.HIRD/R.FRENCH/P.NASH
300	THE RELATION BETWEEN CRITICAL SHEAR STREE AND '25 PER CENT DRAINAGE TIME'OF AIR-FOAM	N.SAVAGE
301	A MECHANICAL FOAM GENERATOR FOR USE IN LABATORIES	J.FRY/R.FRENCH
302	THE ABSORPOTION OF RADIANT HEAT BY FIRE FIGHTING FOAM	P.THOMAS
303	THE APPLICATION OF HIGH EXPANSION AIR FOAM TO 2 TYPES OF FIRE	P.TONKIN/D.TUCKER
304	NOTES ON THE USE OF HIGH EXPANSION AIR FOAM IN FIRE FIGHTING	P.THORNE/D.TUCKER/D.RASBASH
305	AIR FOAM IN THE CONTROL AND EXTINCTION OF PETROL FIRES BY SURFACE APPLICATION	R.FRENCH/D.HIRD
306	THE USE OF FOAM MAKING EQUIPMENT AGAINST BACK PRESSURES	R.FRENCH
307	SUITABLE FOAM COMPOUNDS FOR THE PRODUCTION OF HIGH EXPANSION FOAM FOR FIRE FIGHTING	G.STARK/P.FIELD
308	EXTINCTION OF INDUSTRIAL FIRE BY FOAM	P.NASH/D.FITTES
309	A 50 LITRE PER MINUTE STANDARD FOAM BRANCHPIPE	S.BENSON/J.CORRIE
310	EVALUATION OF NOZZLES TO BE USED WITH AFFF AND THE COAST GUARD IN-LINE PROPORTIONER	R.RICHARDS
311	COMPARATIVE EVAULATION OF FIREFIGHTING FOAM AGENTS	G.GEYER/T.NERI/C.URBAN
312	PLANNING FOR THE USE OF BULK FOAM STOCKS	S.GILBERT
313	FIRE EXTINGUISHING EFFECTIVNESS OF A SYNTHETIC SURFACTANT FOAM	D.McDANIEL
314	REVISED DRAFT SPECIFICATION FOR 'HIGH EXPANSION 'FOAM LIQUIDS	P.THORNE
315	A PRELIMINARY EXAMINATION OF A NOVEL FOAM LIQUID	D.TUCKER/D.GRIFFITHS/J.CORRIE
316	FIGHTING FIRES IN OIL STORAGE TANKS USING BASE INJECTION OF FOAM	P.NASH/J.WHITTLE
317	A NEW FOAM RHEOMETER FOR STUDYING FIRE FIREGHTING FOAMS	D.ELLIOTT/P.CHIESA
318	EXTINCTION OF LABORATORY HYDROCARBON FIRES WITH A SYNTHETIC FOAM	J.CORRIE/D.GRIFFITHS
319	TRIALS OF FOAM ON PETROL POOL FIRES	A.WELLS
320	PRELIMINARY REPORT OF FOAM TRIALS ON PETROL POOL FIRES	FIRE MAG
321	THE USE OF FOAM FOR LNG FIRE FIGHTING	Y.LEV
322	INVESTIGATION INTO LIMITATION OF EVAPORATION OF LIQUIDS BY MEANS OF FIRE FIGHTING FOAM.PT3.MEASUREMENT RESULTS	D.NIEVERGELD/W.SULITALU
323	NEW LIQUID FOAM TO FIGHT FOREST FIRES IN FRANCE	S.SZONYI
324	ACTION AND RESULT OF HEAT ON EXTINGUISHING FOAM	S.SZONYI

325	COMBATING FOREST FIRES WITH FOAM REQUIRES A REASSESSMENT OF TACTICS	R.SMITH
326	NEW FOAM EXTINGUISHING AGENTS	R.JAIHESSER
327	BREAKTHROUGH CLAIMED FOR FOAM SOLUTIONS	ARTICLE
328	KWV'S ADVANCES IN FOAM APPLICATION	AARTICLE
329	SIMULTANEOUS APPLICATION OF FOAM AND DRY POWDER ON AIRCRAFT FIRES	F.ANSART
330	THE GOOEY WAY TO FIGHT A WAR (FLURDCARBON FOAM)	ARTICLE
331	FOAMS AND FOAM SYSTEMS	P.NASH
332	COULD AFFF'S ACCERLATE THE IGNITION OF AVTUR? A PRELIMINARY INVESTIGATION	A.BRIGGS/C.COUSIN
333	APPLICATION OF FOAM IN THE PETROLEUM INDUSTRY	ARTICLE
[illegible]	TEST BURN FOR NEW FIRE FIGHTING FOAM	ARTICLE
335	LIGHT FOAM - LITERATURE COMPLIATION AND RESEARCH REQUIREMENTS	G.[illegible]
336	A RHEOLOGICAL MODEL FOR A LIQUID GAS FOAM	J.CALVERT/K.NEZHATI
337	OF SEA AND FOAM :OFFSHORE AND MARINE FIRE PROTECTION	S.ROWSELL
338	DEVELOPMENTS IN SHIP FIRE FIGHTING PROCEDURES	T.HAYWARD
339	EXTINCTION TESTS OF FLAMMABLE LIQUIDS	S.NICOLETTI
340	COMPARSION OF FOAMS FOR AIRCRAFT CRASH FIRES	A.RODRIGUEZ
341	FIRE PROTECTION OF SYNFUELS	D.MELDRUM/L.DIMARIO
342	THE EXPERIMENTAL STANDARD AND A4P EXTINGUISHING AGENT	S.SZONYI
343	RIYDAH DISASTER UNDERLINES PROBLEMS OF AIRCRAFT FIRES	J.HORSFALL
344	TESTS FOR PROTECTION FOR THE OPTIMIZATION OF FIRE PROTECTION IN B16 TANK FARMS	R.FIALA
345	TESTS IN LIQUID FUEL FIRES	I.TIEZZI/A.IRACE/G.AMATO
346	AIRCRAFT FIRE PROTECTION CAN START OR FINISH IN A HANGAR	J.MACDONALD
347	FRS INVESTIGATES METHODS OF DEALING WITH GASHOL FIRES	A.BRIGGS
348	OFFSHORE OIL PLATFORM INSTALLATIONS.PT2 FIRE AND EXPLOSION DETECTIONAND FIXED FIRE FIGHTING SYSTEMS	L.HEAVYSIDE
349	THE PROTECTION OF AIRCRAFT HANGARS	J.SIDDLE
350	GASOLINE SPILL - 4000 GALLONS ON THE GROUND	J.BRADSISH
351	GASHOL: GASOLINE OR ALCOHOL ?	R.CANAVAN
352	SEVERE LABORATORY FIRE TEST FOR FIRE FIGHTING FOAMS	P.CHIESA/R.ALGER
353	HELICOPTER AND BUCKET TRIALS COULD PROVIDE NEW FOREST FIRE TECHNIQUE	W.SHAND
354	LESSONS FORM THE PAST.NO.3:ONE OF BRITAIN'S WORST OIL FIRES	T.KLETZ
355	A MAJOR FIRE IN A FLOATING ROOF CRUDE OIL STORAGE TANK	C.MUMMFORD
356	THE USE OF A SUSPENSION OF FULLER'S EARTH IN WATER AS A PROTECTION AGAINST THERMAL RADIATION	I.EMSON
357	FIRE PROTECTION AND FIRE FIGHTING IN SHIPS	D.MURRAY SMITH/A.WILLENS
358	A COMPARATIVE TESTING STUDY OF FIRE EXTINGUISHING AGENTS FOR SHIPBOARD MACHINERY SPACES	E.PATTERSON/H.TUVE
359	EXPERIMENTAL METHODS FOR THE STUDY OF FIRE FIGHTING FOAMS	J.CORRIE
360	PROBLEMS WITH THE USE OF FIRE FIGHTING FOAMS	J.CORRIE

361	FIRE OFFICER'S GUIDE TO EXTINGUISHING SYSTEMS	C.EAHME
362	PRINCIPLES OF FIRE PROTECTION CHEMISTRY	R.TUVE
363	TNAKER FIRE CONTAINED	W. WARD
364	'AIRCRAFT ON FIRE.......RUNWAY 6'	P.DITZEL
366	HEXANE TANKER BURNS ON FREEWAY	ARTICLE
367	MUTUAL AID AT TANK FARM FIRE	C.DEKTAR
368	ANALYSIS OF EXPERIENCES COVERING MINERAL OIL FIRES	P.BOHL
369	DRAINAGE TIME AND THE CEILING FIRE TEST	D.TUCKER
370	A REVIEW OF FUTURE TRENDS OF FIRE PROTECTION FOR TANKERS	L.ERRIKSSON
370	DRIANAGE LAWS FOR FIRE FIGHTING FOAMS	P.THORNE
371	TWO NEW TECHNIQUES SUCCESSFUL AT SHIP FIRE IN LONDON DOCKS	J.MILNER
372	THE FIRE PROTECTION OF FLAMMABLE LIQUID RISK BY FOAMS	J.CORRIE
373	ADVANCES IN PROTECTION OF POLAR-TYPE FLAMMABLE LIQUID HAZARDS	L.DIMARIO/P.CHISEA/M.OTT
374	MATHEMATICAL MODEL FOR ANALYZING THE TRADE-OFFS IN AIRCRAFT HANGAR DELUGE SPRINKLER SYSTEMS DESIGN	D.SHPILBERG
375	GASOLINE FIRE AT TANK FARM FOUGHT 7HOURS WITH HELP OF MUTUAL AID COMPANIES	E.VAN DUSEN
376	TO ASPRIATE OR NOT TO ASPIRATE AFFF? TESTS.ADVICE HLEP ANSWER QUESTION	J.BOWEN
377	RUNWAY FOALING - A CONTROVERSIAL FIRE FIGHTING TECHNIQUE	N.ANDERSON
378	GENERATION OF ELECTROSTATIC CHARGE IN FUEL HANDLING SYSTEMS:A LITERATURE SURVEY	J.LEONARD
379	PLANNING PAYS OFF IN TANKER CRASH	H.EISNER
380	FIGHTING FIRES WITH THE RIGHT FOAM	ARTICLE
381	SAFTEY CODES IN DOUBT AFTER BRITAIN'S LARGEST POST WAR REFINERY FIRE(OIL REFINERY MILFORD HAVEN)	ARTICLE
382	PRESSURE CONTROL FOR FIRE FIGHTING SYSTEMS	R.VAUX
383	MOBILE FOAM TOWER	ARTICLE
384	ISSUES RAISED BY FOAM FIRE TESTS	A.A.BRIGGS
385	CAMBRIDGESHIRE IS 'COMMITTED TO AFFF' FOR FIRE FIGHTING	D.McCALLUM
386	FOAM FILLER FIRE AT SUMMIT TUNNEL	ARTICLE
386	AMOCO FIRE	DYFED COUNTY FIRE COUNCIL
387	MANUALS OF FIREMANSHIP	HOME OFFICE
388	SPREADING OF AFFFS AND FIRE EXTINCTION	A.A. BRIGGS
389	COMPARATIVE EVALUATION OF FIREFIGHTING FOAM AGENTS	F.A.A.
390	DGMK - PROJECT 230-01	DGMK
391	WHAT IS THE RELEVANCE OF MEPTANE TO FIRE-FIGHTING FOAM QUALITY	A.A. BRIGGS
392	TO ASPIRATE OR NOT TO ASPIRATE	J. E. BOWEN
393	A REVIEW OF DATA RETRIEVAL FACILITIES AND THEIR USEFULNESS TO FIRE BRIGAES.	L.J. TARR
394	SUPPLY OF FOAM CONCENTRATES	DU PONT
395	AFFF SYSTEM	CAMB FIRE & RESCUE SERVICE

396	FOAM EQUIPMENT & LIQUID CONCENTRATES	U. L.
397	LARGE SCALE BRANCH PIPES-COMPARISON OF FOAM PROPERTIES	A.A. BRIGGS

APPENDIX C

The attached appendix the people and organisations consulted during the UK and overseas visit which include Brigades, Testing/Standards authorities, Suppliers and Industrial users.

APPENDIX C

LIST OF CONTACTS

The list of contacts below are the people who were consulted during the course of the study, between October 1987 and March 1988. They include:

Officers of the U.K. Fire Service
Equipment and Concentrate Manufacturers
Major oil industry and petrochemical users
Mutual Aid Organisations
Testing Authorities
Research Establishments
Overseas Fire Brigades
Home Office Fire Experimental Unit

Meetings were held in the U.K., Europe and United States of America.

APPENDIX C

Angus Bentham Lancaster	M. Hough D. Ross D. Mulligan
Avon F.B. Bristol	DCFO P. Aris DO B. Townley
Boots & Coots Port Neches Texas	L. Williams D. Williams
BP Petroleum Development Ltd Aberdeen	G. Dalzel
Cambridgeshire F.B. Huntingdon	DCFO A.E. Best
Chubb Fire Security Feltham Middlesex	E. Allen
Cleveland County F.B. Hartlepool Cleveland	CFO B. Cooney ACO J.W. Watson
Conoco Inc. Houston Texas USA	R. Barresi
Cynamid BV Rotterdam Holland	A. Van Bedaf R. Garvelink

Du Pont de Nemours (Netherlands) Dordrecht Netherlands	A. Ciggar
Dyfed County F.B. Carmarthen	DCFO M.J. Knowles DC R. Oldacres DO M. George
Eau et Feu France	A. Balthazard Y. Lequeux
Essex County FB Brentwood Essex	DCFO J. Sherrington SSO B. Unger DO T. Lilliot
Esso Petroleum Refinery Fawley Southampton	B. Browning
Exxon Florham Park New Jersey USA	R. Murphy
Fire Experimental Unit Moreton-in-Marsh Gloucestershire	Dr M. Thomas DO R. Lock ADO M. Currey DO J. Kitchen
Fire Service College Moreton-in-Marsh Gloucestershire	DO D. Hopkins ADO A. Doig
Gloucestershire F.B. Cheltenham	CFO A.R. Currie
Hampshire F.B. Eastleigh Hants	CFO J. R. Pearson ACO D. M. Pain

Houston Fire Dept Houston Texas	DC M. McRae B. Hand
Le Havre F.B. Le Havre France	Lt. Col. J. Bernhaert Comm. Taconet
3M UK PLC Bracknell Berkshire	D. M. Smith
3M Antwerp Belgium	W. Mertens
Mobil Research and Development Paulsboro New Jersey	M. Hicks T. Miller E. Andester
National Foam UK Aylesbury Bucks	N. Ramsden
National Foam USA Lionville USA	B. Robinson D. Cochran B. Schofield W. Woodson
Norfolk County F.B. Norwich	DFCO Smith
Shell International Petroleum Maatschappij BV The Hague Netherlands	R. Kok L. Latter
Shell Oil Co/Shell Chemical Co Deer Park USA	J. Oliphant

Texas A&M University College Station Texas USA	J. Donovan J. Hubaeek Jr B. Paricor
Total Le Havre France	L.P. Le Signor
Underwriters Laboratories Northbrook Illinois USA	E. Misichko D. Nelson
University of Maryland College Park Maryland USA	F. Mowrer Dr H. Hickey

APPENDIX D

QUESTIONNAIRE AND RESPONSE

This questionnaire was sent to the manufacturers and suppliers indicated requesting information regarding their foam concentrate and equipment.

Although the response was disappointing the information that was received was most useful.

APPENDIX D

FOAM STUDY QUESTIONNAIRE RESPONSE

Company	Questionnaire Returned
British Fire Protection Systems Association Ltd., Kingston Upon Thames Surrey	-
Angus Fire Armour Ltd., Morecambe, Lancs	14/12/87
National Foam System UK Aylesbury Bucks	-
Chubb Fire Security Ltd., Sunbury on Thames Middlesex	16/2/88
John Kerr & Co. Ltd., Liverpool	Request declined
Walter Kidde Plc South Ruislip Middlesex	-
Macron Fire Protection Ltd., Aylesbury	-
Gilmat Engineering Ltd., Preston Lancs	-

Company	Questionnaire Returned
Silvani Antincendi S.p.A. Milan Italy	
3M (UK) Plc Bracknell Berks	1/12/87
Wood Group Fire Protection Great Yarmouth	
Angloco Limited Batley West Yorks	
Amendola Engineering Ltd., Birmingham	10/12/87
Symtol Engineering Ltd., Blyth Northumberland	
Sabo Spa Lavate Italy	
Preussag AG West Germany	
Rockwood Systems Corporation South Portland U.S.A.	
Sicli Ltd., Maidstone Kent	

Company	Questionnaire Returned
Dr. Sthamer, Liebigstr. 5 W. Germany	
Hoechst (UK) Ltd., Hounslow	
Ansul Slough	28/1/88

APPENDIX D

FOAM CONCENTRATE DATA

GENERAL

Foam Name/Identification?

Foam Type?

Country of Origin/Manufacture?

Budget Cost per 25 1 drum?

PHYSICAL PROPERTIES

Specific Gravity?

Viscosity at 0 deg C? at 10 deg C? at 20 deg C?

Freezing Point (deg C)?

Undissolved solids before aging,
% by weight?

CHEMICAL PROPERTIES

Constituents and Additives
(N.B. A formulation for the product
is **not** requested)?

pH?

Suitable for mixing with which types of water?
Potable/Fresh/Sea/Brackish

Please comment on suitability or finished
foam for supervision of vapours from
hazardous/toxic materials other than vapours
from 'normal' flammable liquids?

TOXICITY/ENVIRONMENTAL DATA

LD (please supply method of determination)?

Bio-degradability, half-life in soil and water?

Recommendations for dispersal of spilled concentrate and finished foam?

APPROVALS/TESTING

Please quote any approvals or certification issued by national or international bodies?

Please supply reports of testing or certification by other independent bodies?

COMPATIBILITY WITH OTHER MATERIALS

Recommended materials for storage tanks? (Please include any results of tests on materials which have influenced this recommendation)

What known contaminants will substantially decrease the effectiveness of this concentrate, either in contact or in solution (Please supply any relevant test results)?

Which other foam concentrates (of different manufacture or type) will substantially decrease the effectiveness if mixed, up to 50% by volume, either in store concentrate or as finished foam?

STORAGE/ROUTINE TESTING

Recommended materials for bulk storage containers?

Maximum and minimum recommended storage temperature? (deg C)

MAX MIN

Does a repeated freeze/thaw cycle
significantly affect foam properties?

YES/NO

Shelf life in original containers at 10 deg C?

Shelf life in bulk storage container of
recommended materials at 10 deg C?

Shelf life in lined mild steel tank
at 10 deg C? (Please specify lining)

Do original containers identify date of production?

Yes-Directly/Yes-By Code/No

Recommendations for routine testing?
(Properties tested and frequency)

USE

Range of Usable expansion rates
(numerical values; upper and lower limits)

Recommended proportioning rate
(% v/v with fresh water; please quote
reasons if more than one rate)

Maximum and minimum proportioning rates which do not cause significant loss of performance?

Please quote application rates (litres/minutes/sq. m) -

Material	Recommended Rate	Minimum Rate
Crude Oil	-	-
Diesel Fuel	-	-
4-Star Petrol	-	-
Hexane	-	-
Heptane	-	-
Methyl Ethyl Ketone (MEK)	-	-
Acetic Acid	-	-

Is non-standard foam making equipment necessary for use of this concentrate?

No/Yes-Please indicate types

QUALITY CONTROL PROCEDURES

Please attach copy of quality schedule and procedures

STRATEGIC STOCKS

Please list locations of depots which can be guaranteed to carry some stock of this form?

Location	Normal Stock	Maximum Stock	Minimum Stock

CASE HISTORIES

Please attach any case histories which show the performance of this foam in real-life situation.

PROPORTIONERS - VENTURI TYPE

Name/Description?

Please provide technical data sheet and quality control procedures

Materials of construction?

Connections (Inlet and Outlet)?

Nominal proportioning rate(s)
(% concentrate/water)? 1%/3%/6%/other _____

Method of achieving variable proportioning?

Accuracy of proportioning rate (guaranteed)?

Water pressure/flow range at inlet?

Water pressure loss across proportioner?

Water back pressure limit?

Limitations on usable foam concentrate
(e.g. S.G., Viscosity)?

Maximum suction lift for concentrate or
required concentrate pressure at concentrate
inlet?

PROPORTIONERS - NOT VENTURI TYPE

Name/Description?

Please provide technical data sheet including schematic diagram of control arrangements, and quality control procedures

Materials of construction of water and foam chemicals?

Materials of construction of housing (if applicable)?

Inlet and outlet connections?

Suitable for portable use or fixed mounting only (including vehicle mounting)?

Nominal proportioning rate(s)
(% concentrate/water)? 1%/3%/6%/other _____

Method of ahieving variable proportioning?

Accuracy of proportioning rate (guaranteed)?

Water pressure/flow range at inlet?

Water pressure loss across proportioner?

Water back pressure limit?

Limitations on usage foam concentrate (e.g. S.G., Viscosity)?

Maximum suction lift for concentrate
or required concentrate pressure at
concentrate inlet

Have you identified any concentrates
for which this equipment is
inappropriate (i.e. does not function
or functions significantly poorly)?

Recommendations on maintenance and cleaning?

MONITOR DATA

(N.B. This concerns the fixed waterways leading into a nozzle)

Monitor name/description?

Please attach technical data sheet

For use with which nozzle(s)?

Materials of construction?

Please supply copy of quality control procedures

Method of remote control (if appropriate; please quote water usage if driven by water motor)?

Hydraulic/Pneumatic/Electric/Water Motor

Recommended uses?

Vehicle of Trailer method/Ground Mounted/Portable

Usable Inlet Pressure/Flow Range?

Pressure Drop through monitor?

Connections (inlet and outlet)?

Rotational/Positional Limitations?

Optional Extras?

Recommended Maintenance and Cleaning?

NOZZLE/FOAM GENERATOR DATA

(N.B. This section of question is aimed at a description of nozzles only. Some equipment, e.g. bipod monitors and HI-EX Generators, have integral proportioners and/or monitors. If the equipment described here has such integral parts please also complete the proportioner or monitor questionnaires as appropriate).

Nozzle name/description?

Please attach technical data sheet, and quality control procedures

Materials of construction?

Connection types available?

Suitable for use with -
Monitor/Lay Flat Hose/Hose Reel

Recommended situations for use -

Flammable liquid spill (unconfined)/Tank Fire/Bund Fire/General Purpose

What limitations on types of foam concentrate?

Operating pressure? MAX _____ MIN _____ Recommended _____

Operating flow rates? MAX _____ MIN _____ Recommended _____

Method of aeration?

Range of expansion produced?

Variable expansion method
(other than water flow dependent)?

Nozzle length after aeration?

Nozzle discharge foot print -

Elevation	Flow Rate	Throw	Height	Spread
30				
60				
45				

Are operational additions/extension to the nozzle available, if so what?

Recommendations for maintenance and cleaning?

Budget Price. Ex-works, UK?

APPENDIX E

BRIEF

This brief is a copy of the original document on which the study was structured.

Changes were made to the format as the study progressed and it will be noted that the contents of each report is now different.

APPENDIX E

TERMS OF REFERENCE

SURVEY OF FIREFIGHTING FOAM AND ASSOCIATED TACTICS AND EQUIPMENT RELEVANT TO THE UNITED KINGDOM FIRE SERVICE

1. INTRODUCTION

1.1 The Fire Experimental Unit of the Home Office Scientific Research and Development Branch (FEU) are undertaking research into the use of foam for firefighting in the Fire Service. In the context of these Terms "Fire Service" will be used to describe all United Kingdom Local Government Fire Brigades.

1.2 The Fire Service use a wide variety of foam but as most of their work dues not require the use of foam it is difficult for them to build up expertise in this area. More expertise is available in specialist industries and internationally. The research is directed towards assessing the present state of art, and identifying areas where the Fire Service would benefit from further research.

1.3 As a first step therefore, FEU require a Survey of the advice and expertise which is available. This Survey will then form the basis for an assessment by the FEU of future research areas.

1.4 These Terms of Reference define the scope of the Survey which is to be undertaken by the Contractor.

2. SCOPE OF THE SURVEY

2.1 The Contractor shall address three main areas:-

1. The types of firefighting foam which are or could be made available to the Fire Service; their chemical and physical properties including the effects of high temperatures; the specifications which they are required to satisfy; the suitability of these specifications; possible alternative specifications or quality controls suitable for use by the Fire Service; the advantages and disadvantages of the various types of foam; the information available on the various products on the market.

2. The tactics to be adopted in using foam for fire fighting; foam application rates for different types of fire; the relative merits of non-aspirated and aspirated foam; techniques for delivering the foam to the base of the fire; the logistic problems of fighting large fires.

3. The suitability of existing Fire Service foam delivery equipment; the foam delivery equipment required to deal with fires attended by a small number of Appliances (an "Appliance" is a fire fighting vehicle owned by any fire brigade); the maximum size fire which can be tackled by a single fire brigade; the possiblility of there being fires which a Brigade cannot handle; existing specialist foam delivery equipment required by the Fire Service; the possibility that new specialist equipment is required.

2.2 The Contractor shall obtain his information from as wide a range of sources as possible. These shall include:

1. The FEU, who have access to computer data systems, can provide copies of relevant reports which they hold and will arrange contacts with the Fire Service.

2. The Fire Research Station at Borehamwood, Hertfordshire WD6 2BL.

3. The petro-chemical industry.

4. Overseas fire services.

5. Firefightng foam manufacturers.