SURVEY OF FIRE FIGHTING FOAMS AND ASSOCIATED EQUIPMENT AND TACTICS RELEVANT TO THE UK FIRE SERVICE
PART 1 - FIREFIGHTING FOAMS

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Survey of Fire Fighting Foams and Associated Equipment and Tactics Relevant to the UK Fire Service
Part 1 - Firefighting Foams

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ABSTRACT

This report is one of three constituting a survey of the field of firefighting with foam. It describes the various types of foam available and details their properties, uses and limitations. Application rates, the use of unaspirated foam and the relevance of the various standards, are considered in detail. The report identifies several areas where there are gaps in existing knowledge.

MANAGEMENT SUMMARY

The knowledge that exists on the subject of firefighting foams is extensive, but incomplete in certain significant respects. A large body of published reference material is available, and specific areas of expertise exist within foam manufacturing companies, industrial users, testing and research bodies and in fire brigades and mutual aid organisations. The objective of this study is to gather together the information from these sources, review, summarise, indicate where there are deficiencies and suggest how improvements could be made which would benefit the Fire Service. This particular report is the first of a series of four generated by this study and covers foam liquids and finished foams. The other three are:

Part 2 - Tactics and Equipment
Part 3 - Large Tank Fires
Part 4 - Management Summary

Fire fighting foams have developed over the last 40 years in two main groups, protein based and synthetic (surfactant based). As additives are introduced to improve performance the two groups are converging on a common goal - a foam which can be used on all class B fires in all circumstances. The report describes the development of each type, its properties, uses and limitations.

A wide range of properties are referred to in the literature on fire fighting foam. Some are of crucial importance, such as Recommended Minimum Application Rates, and others relatively obscure. The report discusses the main properties and their significance, indicating where existing knowledge is deficient or requires updating.

There has been considerable controversy over the use of AFFF as "unaspirated" foam. Since this term can be misleading it is redefined for clarity, and the advantages and disadvantages of "unaspirated" use are discussed. The report indicates that the effectiveness is at present unproven and sets out certain conditions which could be disadvantageous to its chances of extinguishing a tank fire.

A section is devoted to evaluation of the sources of information on foam which are available, and explains how they have been used in this study. Principally, information was obtained from meetings with organisations and individuals with specialised knowledge, a questionnaire to foam suppliers and use of various data bases to accumulate a reference library which was then reviewed.

Specifications and standards for foams are not directly comparable and test methods are frequently criticised for omitting to test critical factors, favouring one or other type of foam and for being unrepresentative of the real fire situation. These observations are explained and discussed. It is considered that more information should be available to those responsible for purchasing foam concentrates, particularly since cheap low specification foams are now available. There is a need for Fire Brigades to have available a specification for purchase of foams, and a test to support the specification.

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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 first 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 starts with a description of the information which has been gathered and which has formed a basis for the later sections (Section 2). This is followed by a descripton of the types of foam available and a brief summary of the main characteristics of each type (Section 3). Section 4 examines the Chemical and Physical properties of foam concentrates and finished foams indicating how significant these are in assessing the performance of the foam. The specific topic of aspiration versus non-aspiration of foam solution is covered in Section 5. The main specifications and standards relating to foam are examined in Section 6 including some of their drawbacks. Overall conclusions are presented in Section 7.

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

SECTION 2

INFORMATION AVAILABLE

2.1 GENERAL

Virtually all the data in these reports was and is available to the UK Fire Service but the experience gained while carrying out the survey demonstrated the difficulty and the time involved in gathering and accumulating the information.

Three main sources of information were used in gathering data for the preparation of this report and the three companion reports on the study. Meetings were held with individuals and organisations who have specialist knowledge of fire fighting foams, a literature search was conducted using available library facilities and information databases and a questionnaire was sent to manufacturers of foam concentrate and foam equipment.

The information collected has been used as a basis for all the report's sections, tables and appendices.

Despite the large quantity of information accumulated, there are areas of deficiency which are worthy of note.

- Information on major fires was sparse and poorly documented. Major oil companies claim for example that fires in floating roof storage tanks are infrequent but some would not release statistics and reports to corroborate this claim.

- Much information is not available in published form but can be obtained verbally from those with direct experience. For example the fire brigades in the USA quote numerous examples of floating roof tank fires.

- Manufacturers' information is not available on some crucial points, e.g. the distance of throw of nozzles and foams in combination.

- Research and testing information is variable in quality and there are many omissions, for example, tests on foam quality and working of foam - what effect do these properties have on fire extinguishment?

- There is a need for centralised collection and dissemination of data to the Fire Service. This is partially satisfied by the FEU Information Unit and the FINDS data base but should be extended into product information and testing.

2.2 QUESTIONNAIRE

The questionnaire reprinted in Appendix D was sent to 21 suppliers and manufacturers requesting information on their foam concentrates and foam equipment. The table in Appendix D shows that positive replies were received from 5 companies, one refused to contribute and the remaining 15 did not reply. The information provided by the companies that did reply has been most useful in preparation of the report, and their work is gratefully acknowledged.

Information in the questionnaires was compared with manufacturers' literature from responding and non-responding companies, giving rise to the following observations on the literature available to the purchaser;

- manufacturers select technical information presented to favour their product

- data is omitted in some cases, presumably for similar reasons

- demonstrations are represented (often by implication) as tests

- slightly different parameters are quoted making a direct comparison between products impossible

- different units are used making comparisons difficult

- trade names are used to create an enhanced image of the capabilities of certain products.

Whilst many of these practices are commonplace in the commercial world, consumers can take steps to improve matters.

In order to simplify the initial comparison of foam concentrates it is proposed that a series of data sheets should be devised for use by the Fire Service. Information could be gathered from suppliers in a similar way to the questionnaire for this study, but probably using a more simplified format. Data sheets could be circulated to all brigades to assist in countering the commercially slanted information which is often the only readily available source material to those responsible for making purchases.

2.3 MEETINGS

The study involved a series of meetings in the UK, USA, Holland, Belgium and France with individuals and organisations who are considered to be either expert or especially interested in one or more aspects of fire fighting foams.

Eight UK fire brigades were chosen to give a broad range of experience from highly industrialised to rural areas. For comparison overseas fire brigades were visited in the USA and France, and mutual aid organisations in the USA, Holland and France. Oil companies and petrochemical companies were considered to be amongst the most knowledgeable users of foam, and a representative sample was taken of views at both corporate and field levels.

Manufacturers played a major part in the meeting programme as well as in the questionnaire. Finally meetings were held with a sample of standards, testing, training and research facilities. The full list of contacts appears in Appendix C.

2.4 DATABASES

2.4.1 General

Databases were used during the study to identify published reference material. The types of information retrieved were standards, specifications, test results, research data, papers, articles and fire reports. There was much common material in all the databases used, but each also held a proportion of references unrecorded by the others.

The list of databases used is as follows:

FLAIR	- Fire Research Station Library Automated Information Retrieval System	

Pergamon Orbit

This system gave access to a number of further databases. Those examined were:

APIT	- American Petroleum Institute Abstracts	USA
Chemical Engineering	- Abstracts	USA
HSE Line		USA
Safety Science	- Abstracts	
NITIS		USA
PASCOL		ITALY

The search method was on a keyword basis.

From both the FLAIR and Pergamon Orbit databases lists of relevant abstracts were obtained. The more pertinent documents were obtained from the Fire Research Station Library for review.

2.4.2 FEU Information Desk

The information desk forms a part of the services provided by the Fire Experimental Unit. A microcomputer is employed to enable the staff concerned to cope with the increasing demand for information from the brigades.

In its present form there are three essential components which make up the FEU Information Desk Services;

- The FINDOUT database
- An individual search service
- A document procurement service.

Enquiries are dealt with initially by conducting a search of the FINDOUT database. If the information cannot be located in this way a number of alternative resources can be called upon;

- FEU and Home Office scientific and administrative staff
- Manufacturers and institutions
- Other databases
- FEU, FSC and other libraries
- Other brigades.

2.4.3 FINDS

CACFOA (Chief & Assistant Chief Fire Officers Association) in conjunction with Bradford University Research Ltd., are currently introducing a further information service called FINDS - Fire Information National Data Service. Fire Brigades belonging to this scheme will be able to contribute to and obtain information from FINDS through terminals linked to Bradford University Ltd.

2.4.4 Further Development

Further possibilities exist for improving information to the Fire Service. Purchasing of fire fighting equipment is the responsibility of individual

Fire Brigades. Along with that task comes the onus for researching the market, evaluating alternative suppliers and even joint development of equipment in conjunction with manufacturers. This can be a time consuming exercise if done thoroughly, and unless the task is tackled properly individual brigades can be susceptible to the intense commercial lobbying conducted by some supplers. Due to the many pressures imposed in an emergency service it would seem to be advantageous if market research and development work was carried out by a central facility with the results being made available to all the UK brigades. This practice should not be restricted only to fire fighting foams and equipment but would include all aspects of fire fighting equipment.

An subsequent extension of this system could be that the same central facility, or an independent organisation, could collect, store and make available the ideas and operating experience of all Fire Brigades regarding equipment, tactics and techniques.

2.5 COST INFORMATION

One specific area where information was sought from manufacturers was the cost of foam in terms that could be related to the cost of extinguishing a fire. Information was available on concentrate costs, and on the cost of finished foam, however, despite various early claims no firm information was forthcoming to relate these figures with efficiency of extinguishment.

The data is presented in the Table below in the form of ratios, with protein foam being the base unit of 1 (one).

2.6 LIST OF REFERENCES

The following reference numbers are sources used in this Section, and are listed in full in Appendix B: 1 .... 397.

	PROTEIN 3	PROTEIN 6	FLUOROPROTEIN 3	FLUOROPROTEIN 6	FFFP 3	FFFP 6	AFFP 1	AFFP 3	AFFP 6	AFFF AR 3	AFFF AR 6
COST RATIO OF LIQUID CONCENTRATE (average)	1		1.5	1.3	4.2	2.8	14.4	5.5	3.2	5.4	
COST RATIO OF FINISHED FOAM (by volume)	1		1.1	1.3	2.4	2.6	2.2	2.4	2.6	2.6	

APPROXIMATE RATIO OF FOAM COSTS

SECTION 3

TYPES OF FIRE FIGHTING FOAM

3.1 HISTORICAL DEVELOPMENT OF FOAM

It was a British scientist J. Johnson, who first patented a chemical foam in 1877. He recommended that a chemical foam produced by mixing two liquid solutions, one containing sodium bicarbonate and saponine and the other containing aluminium sulphate, be used for fighting petroleum fires. Later, a Russian engineer reported in 1904 during a meeting of the Technical Academy of Science in Petrograd that this chemical foam was first successfully used during an 11 metre diameter naphtha storage tank fire on the oil fields of Baku. This method of extinguishing fires necessitated the use of separate storage containers for the two solutions. In 1914, the Austrian engineers Stanzig and Konig developed the principle of producing foam by introducing a powder into running water which considerably reduced the labour required by the fire brigade. But the foam/powder system proved very expensive and therefore had a limited application. Subsequently, sulphuric acid was used as a constituent in producing chemical foam and the first "foam wagon" was developed using this method.

During the 1920's, it was discovered that a proteinaceous product which is easily dissolved in water could be extracted by chemical hydrolysis from organic by-products such as hoof and horn meal. It was quickly established that protein foam concentrate was far superior to chemical foam making substances. The foam concentrate was metered into a flowing water stream to form a foam solution, and air was entrained to produce a finished foam with an expansion of up to 10 times the volume of the solution. This led to the development of the first equipment for production and delivery of "mechanical" foam.

The 1930's saw extensive experimental work with mechanical foams and the first air injection systems were developed. Early experience proved that the water base of protein foams rendered them ineffective on alcohol fires. The water and alcohol would mutually dissolve rapidly destroying the foam. This led to the development of early chemical foams with alcohol resisting properties. Towards the end of this decade, the concepts of aspiration and proportioning had been developed for mechanical foam systems much as we know them today. At the same time, experimental work was started on synthetic types of foam, followed by the development of foam solutions which gave expansion ratios of up to 20:1.

During the Second World War a rapid extension of the market took place for both foam concentrates and delivery equipment. Fire fighting foams were in demand from industry and the armed forces, but were found to be particularly suitable for use on board ships.

Pre-war foam agents were restricted in the degree to which they could be concentrated without giving rise to heavy sedimentation. When additives were developed which allowed the concentrate volume to be reduced from 6% of the solution to 3%, there was an immediate demand for the new stronger concentrate. The advantages of reduced storage space, and reduced weight were, however, affected by the need to provide a new range of proportioning equipment, and this cost penalty ensured that there would be a continuing requirement for 6% concentrate for use with existing equipment.

In the 1950's further development work was carried out on synthetic foams containing detergents. Low, medium and high expansion foams could now be produced from a single synthetic foam concentrate. Temperature depressants were developed and added to 6% and 3% concentration protein foams which enabled the use of these foams down to -29°C. Also, the first polar solvent resistant mechanical foam was developed which had a superior performance to the earlier chemical alcohol resistant foams.

The 1960's saw the introduction of fluorochemical surfactants into both protein and synthetic foam compounds. This had the effect of improving both the flow and fuel tolerance properties of the existing foams. In the case of protein foam, the addition of fluorocarbon surfactants produced the fluoroprotein type foams, whereas in the case of synthetic foam AFFF (Aqueous Film Forming Foam) was produced. AFFF exhibited fast flowing and quick flame knockdown characteristics and was initially used for air crash rescue. Fluoroprotein foams, on the other hand, exhibited good fuel tolerance and sealing characteristics and its use led to the development of subsurface injection techniques for hydrocarbon storage tanks. This period also saw the development of polymeric type alcohol resistant foam which gave better separation between the foam layer and the liquid level, and avoided the problem of alcohol/water mixing.

Further development took place in the 1970's with alcohol resistant foam concentrate to produce multi-purpose foams for use with both hydrocarbons and polar solvents. The parallel use of fire fighting foams for suppression of vapour release was reinforced when "Hazmat" foams were specifically developed for the suppression of vapours from alkaline and acidic materials.

3.2 TYPES OF FOAM (See Tables 1 and 2 at the end of this Section)

The wide range of fire fighting foams available today is the result of forty years of development which has produced a steady improvement in performance. Additives such as bactericide, stabilisers and temperature depressants have been used to counteract specific deficiencies in the products, and a new family of foams have been introduced based on the use of surfactants rather than the established hydrolised proteins.

The types of foam within each family were originally developed to satisfy a particular need, but there is still a close similarity between them, and for some purposes, foams from the same family may be equally effective in practice. There has, however, been great pressure to find a foam which can extinguish as wide a range of fires as possible. This pressure has led to convergence of the two families. Developments of both protein based and synthetic based foams have been directed towards similar goals; fast knockdown, good security, wide usefulness (particularly against polar solvents like alcohols), a low weight of concentrate needed to produce a certain amount of finished foam, storage stability, and a wide temperature range.

This section reviews the main foam types and discusses their properties and main advantages. Further consideration of the properties of the foam is given in Section 4.

3.3 PROTEIN FOAM

Chemically, the modern protein foam concentrate is made up of hydrolised protein, solvent, sodium chloride, iron, calcium and preservatives in a neutral aqueous solution. The starting materials for production, which provide the protein can be; soya beans, corn gluten, animal blood, horn and hoof meal, waste fish products or feather meal. Protein foams extinguish primarily by blanketting, i.e. excluding flow of air to the liquid surface, and restricting the flow of vapour from the surface. Release of water is slow, and the bubble walls are reinforced by a skeletal protein structure which helps to maintain the foam bubbles even after loss of some water.

Protein foam was the first type of mechanical foam to be widely used. Over the last forty years additives have been incorporated to improve stability and shelf life. Originally 6% concentration was the lowest achievable without risk of sedimentation, but further development has resulted in 3% concentration.

The finished foams are characterised by being reasonably stable, with low liquid drainage rates, are relatively stiff, have excellent heat resistance and a low price. Their disadvantages are lack of fuel tolerance, slow fire knockdown performance and unsuitability for polar solvents. The stiffness of protein foams coupled with relatively high surface tension tends to restrict their ability to flow across a liquid surface. If the finished foam is forcibly applied the surface tension properties may allow the fuel to mix with the foam causing fuel to permeate the foam blanket and spread across its surface. This can result in a foam blanket which is capable of sustaining ignition. Storage life is limited, particularly at higher temperatures, for example above 40°C.

Uses are for class A and B fires, and in the past protein foam was widely employed by industry, fire brigades, the armed services and aviation authorities throughout the world. Protein type concentrates have now been largely superseded by fluoroproteins, although extensive stocks are still held, and protein concentrate still retains a price advantage over other foam types.

Manufacturers have indicated that all types of finished foam are compatible with all other finished hydrolised protein based foams and all fluorochemical foams. However, the concentrates are not compatible with alcohol resistant concentrates. Mixing of protein concentrates from different manufacturers, and protein with fluoroprotein is possible, but may produce a result exhibiting the "lowest common denominator" features of each. Manufacturers advice should normally be sought if mixing of concentrates is proposed. Only concentrates of the same strength should be mixed (e.g. 3% or 6%).

Protein foams generally do not contain corrosion inhibitors as the concentrate is not considered to be particularly corrosive. However, reports have indicated that some corrosion has taken place in unprotected carbon steel bulk storage containers, particularly within the UK fire service. It is therefore suggested that materials such as epoxy coated carbon steel, GRP and polyethylene should be used.

3.4 FLUOROPROTEIN FOAM (FP)

The chemical components of fluoroprotein foam concentrates are hydrolised protein, fluorosurfactants, solvent, sodium chloride, iron, magnesium, zinc and preservatives in a neutral aqueous solution. Fluoroprotein foams are derivatives of protein foams with the addition of fluorosurfactants to improve the fuel tolerance and fire knockdown performance. Since they still contain a large proportion of hydrolised protein they retain the properties of stability and heat resistance associated with protein foam. Because fluoroprotein foams flow more freely across fuel surfaces and around obstructions than protein foams they can give faster control and extinguishment, better self sealing and improved sealing against hot metal edges. Their main disadvantage is poor performance with polar fuels.

Fluoroprotein concentrates are available in 6% and 3% neutral aqueous solutions, to suit the type of foam proportioning equipment available. Tests have been carried out into the development of 1.5% concentrate which would further reduce handling and weight problems, but which would require a further range of proportioning equipment to be manufactured and distributed. Manufacturers have indicated that 1.5% concentrates have not yet been marketed because the demand is still uncertain.

Uses are widespread in the fire service, the petrochemical industry and armed services throughout the world. Fluoroproteins are primarily intended for low expansion use, but have proved effective at medium expansions. Manufacturers do not advocate its use at high expansion.

As with protein foams corrosion inhibitors are not usually included and ideally bulk storage containers should be of epoxy coated carbon steel, GRP or polyethylene. Compatibility of fluoroprotein with other finished foams and concentrates is similar to that of protein foam.

3.5 FILM FORMING FLUOROPROTEIN FOAM (FFFP)

The chemical components of FFFP are hydrolised protein, film forming fluorosurfactants, solvent, sodium chloride, iron, calcium, magnesium and preservative in a neutral aqueous solution. FFFP foams are based on fluoroprotein foams with the addition of film forming fluorosurfactants which produce a balance between the conventional AFFF and fluoroprotein foams. The foam produced contains no detergent materials, therefore its fuel tolerance is very good. It is more fluid than fluoroprotein and forms a vapour sealing aqueous film on the surface of hydrocarbon liquids. This can give protection against re-ignition and give resealing properties should the foam blanket be broken. In addition, the protein base gives FFFP good heat resistance and burnback properties that assist with sealing against hot metal surfaces and reduce the flame destruction of the foam blanket.

FFFP concentrates are available in 6% and 3% neutral aqueous solution, to suit the type of foam proportioning equipment available and are generally accepted throughout the fire protection industry, but they have not by any means superseded the use of fluoroprotein. Many tests have shown an improved performance of FFFP as compared with fluoroprotein but a number of brigades have indicated that the increase in price out-weighs the improvements over fluoroprotein (Ref 193). Also, since the advent of alcohol resistant FFFP as a multipurpose foam this has somewhat eclipsed the advantages of FFFP. It is questionable whether it is worth stocking FFFP when alcohol resistant FFFP is available.

Materials for bulk storage containers and concentrate/finished foam compatibility are similar to fluoroprotein foams.

3.6 SYNTHETIC FOAM

Synthetic foam concentrates were developed from early synthetic detergent foams and are based on a mixture of anionic hydrocarbon surfactants, solvents and foam stabilisers. Synthetic foams are versatile, as they can be used for low, medium and high expansion ratio applications. Nowadays, particularly in the UK, their use is limited to medium and high expansion ratios however, in Europe, countries such as Germany and Sweden use synthetic foam for low expansion applications. Heat resistance and fuel tolerance of the early synthetic foams were low and they were not widely accepted by the petrochemical world. However these properties have now been improved and synthetic foams are suitable for class A and B fires at low application rates, giving rapid control. Synthetic foams can be applied through medium expansion equipment and may be used for the control of liquified flammable gas fires and the suppression of vapour released from toxic liquid spillages.

In the high expansion form, synthetic foams find application for Class A fires in warehouses, basements, mine shafts, attics and other places that may be inaccessible to the fire fighter. The extinguishing mechanism is mainly exclusion of oxygen by smothering, with some small assistance from cooling by water released from the foam blanket and steam dilution. High expansion synthetic foam has also been used for the extinguishment of flammable liquid fires provided wind speeds are low, thermal updrafts are not too severe and sufficient quantities can be applied safely.

In addition, synthetic foams may be applied through medium expansion equipment for the extinguishment of class B fires. They may be used in open air situations which are too adverse for high expansion foam, for the control of liquified flammable gas fires and for the suppression of vapour released from toxic liquid spillages.

The disadvantages of medium and high expansion foams are that, unlike AFFF they do not release their water content quickly and therefore their cooling ability is limited, they are not film forming and do not flow well particularly in windy conditions. Their heat resistance and ability to seal against hot surfaces is also low.

Manufacturers have indicated that synthetic foam concentrate is not particularly corrosive but is slightly alkaline with a pH of between 7 and 8. Recent tests have been carried out at the FEU and reports have been received from the brigades that adverse corrosion effects occured on materials such as epoxy coated carbon steel, GRP and aluminium. Materials recommended for bulk storage containers and equipment for both concentrate and solution are 304 and 316 stainless steel or polyethylene. As a solution, the detergent additives contained in the synthetic foam make it highly searching.

3.7 AQUEOUS FILM FORMING FOAM (AFFF)

AFFF concentrates are slightly alkaline solutions of fluorocarbon surfactants, solvents, hydrocarbon surfactants and a low proportion of halide ions. The foams produced extinguish primarily by forming a vapour sealing aqueous film on the surface of hydrocarbon liquids. The low surface tension resulting from the surfactant content allows the solution to penetrate class A combustibles, acting as a wetting agent. AFFF foams drain rapidly and spread quickly over a hydrocarbon fuel surface giving rapid knockdown and initially rapid reseal of the film surface when broken. However, the fast drainage means that the foam blanket becomes rapidly depleted of film forming liquid and the ability to reseal quickly diminishes after application.

The dramatic fire knockdown capability of AFFF therefore comes at the expense of long term security against reignition. Properties associated with heat resistance are also diminished because the bubble structure is dependent on the low surface tension of the liquid and readily ruptures upon loss of fluid. Problems have been experienced when attempting to extinguish fires involving liquids with high vapour pressures, such as hexane and high octane petrol, where quantities of vapour have penetrated thin, low aspirated foam blankets. Also fuel pick-up has been found to lead to premature reignition which may be attributed to use of inferior fluorocarbon surfactants. AFFF can be effective when projected through equipment designed for water delivery such as conventional sprinkler heads and straight jet nozzles. In such cases a degree of aspiration is achieved at the discharge orifice, during the trajectory of the liquid and upon impact. Significant improvements in projection range can be achieved, but at the expense of a lower expansion ratio. In addition, reports have shown that AFFF will give better expansions through equipment originally designed for use with fluoroprotein foams. Expansions of up to 10:1 can be achieved, as less energy is required to aspirate the AFFF foam than with throprotein foams.

AFFF is generally accepted for crash rescue fire fighting uses and on fuels such as kerosene and diesel oil. It is widely used offshore for helideck protection at a concentration of 1%. AFFF is also used as a wetting agent additive by some fire brigades to extend the effectiveness of limited water supplies when tackling class A fires.

The concentrate is available in 6%, 3% and 1% foams and is supplied with freeze protection allowing use down to -20°C.

As with synthetic foams, AFFF is not particularly corrosive and contains no special corrosion inhibitors. The hydrocarbon surfactant content causes the concentrate and solution to be more searching than water and therefore marginally more corrosive. Recommended materials of storage and handling equipment are stainless steel, GRP, epoxy lined carbon steel and polyethylene.

3.8 ALCOHOL RESISTANT FOAMS (AR)

Alcohol resistant concentrates have been developed to deal with fires involving polar solvents, water miscible fuels such as alcohols and the continuing development of petrols containing up to 20% alcohol. Conventional foam blankets are broken down by the polar solvent or alcohol which mix freely with the water content of the foam. Early alcohol resistant foam concentrates were based on a modified protein compound which gave a structured foam formed from precipitation of solids within the foam bubble. It was capable of resisting the destructive effect of the polar liquid on the foam blanket but consequently had a very low drainage rate. These foams were very stiff and slow flowing and were susceptible to mechanical breakdown of the foam blanket and therefore required extremely gentle application techniques. Later, flow improvements were made by developing alcohol resistant fluoroprotein foams. Today two types of alcohol resistant foams have been developed: those based on synthetic detergent film forming foams and those based on film forming fluoroprotein foams. Further developments have been made with these foams in order to produce multi-purpose foams which may be used for hydrocarbon fires as well as flammable polar liquid fires. The same concentrate is used in both cases, but can be diluted with twice as much water for use on hydrocarbon fires. Thus multi-purpose foams are proportioned at 6% for use on polar liquids, but at 3% for use on hydrocarbons.

Alcohol resistant foams are primarily designed for low expansion applications. They may be used on hydrocarbon fuels as an aspirated or non-aspirated spray and through discharge outlets which deliver the foam forcibly onto the liquid surface causing agitation or by sub-surface injection. On polar solvents with a severe foam destroying action, however, application must be such that the foam blanket is delivered gently onto the liquid surface without submerging the foam or agitating the liquid surface. If some submergence and agitation is unavoidable, higher application rates may be required than those specified for fire extinction. Sub-surface injection on storage tanks containing polar solvents, however, cannot be used.

As alcohol resistant foam concentrates do not qualify under the U.S. Military Specifications for compatibility, checks should be made with manufacturers of other alcohol resistant concentrates before mixing is carried out. Contamination with any of the other types of foam concentrate will decrease the effectiveness of alcohol resistant foam. The recommended materials for bulk storage containers and equipment are carbon steel with bitumen or epoxy linings, G.R.P. and certain grades of stainless steel and polyethylene.

3.9 ALCOHOL RESISTANT AFFF

Alcohol resistant AFFF is a synthetic detergent based film forming foam which contains water soluble polymers. As the polar solvent extracts the water content of the foam blanket, the polysaccharide additives form a polymeric membrane at the interface between the foam and the solvent.

Contact between the solvent and the foam blanket is reduced and its destruction is retarded. Since the resulting finished foams are relatively fluid, they are capable of being more forcefully applied to water miscible fuels and provide fast fire extinction and good security (Ref 130). As an alcohol resistant foam they are available at 6% concentration and can also be used as a multi-purpose foam concentrate on hydrocarbon fuels by proportioning at 3%.

The disadvantages of alcohol resistant AFFF foams are that their fire security is not quite as good as FFFP alcohol resistant foams, they cannot be used in a premixed form and they are affected by repeated freeze/thaw cycles. However they can be stored at slightly higher temperatures than FFFP alcohol resistant foams. Development work is also taking place to produce a low temperature concentrate.

3.10 ALCOHOL RESISTANT FFFP

This is a film forming fluoroprotein foam which contains water soluble polymers. The polymer is present within the foam bubble and as with synthetic detergent based film forming foams, the initial water extraction by the solvent causes a polymeric membrane to form on the liquid surface which prevents further destruction of the foam blanket. The alcohol resistant FFFP foams are available at 6% concentration for flammable polar solvents and alcohols and may be used at 3% proportioning for hydrocarbon fuels as a multi-purpose concentrate.

In contrast to alcohol resistant AFFF foams the alcohol resistant FFFP foams can be used in a premixed form and are not affected by the repeated freeze/thaw cycle. However low temperature varieties are being developed for use at temperatures down to -15°C and will be available very shortly.

3.11 HAZMAT FOAMS

Many materials used in industrial and chemical processes release toxic vapours when in contact with the atmosphere. There is an increased danger of this occurring as many of these substances are transported over long distances by road and rail. If a spill occurs the hazard can be reduced by suppressing the released vapours until the spill can be neutralised and disposed of.

Some fire fighting foams may be used for vapour suppression on spills of flammable and combustible products and a certain amount of success has been achieved on toxic spills. Many chemicals destroy fire fighting foams by combining with surfactants, changing the pH or removing water from the foam by reaction or dissolution. Multi purpose foams are effective on water soluble liquids but other foams have been developed called Hazmat foams which are effective on products which destroy foams by changing the pH. At present, one Hazmat foam is available for use on alkaline materials such as anhydrous ammonia and methyl amines and another is available for acid materials such as hydrochloric acid.

3.12 WETTING AGENTS

Wetting agents are chemical compounds which when added to water in the required proportion, reduce the surface tension of the water and increase its penetrating and spreading abilities and may also provide emulsification and foaming characteristics.

It has been shown from test and experience that the extinguishing efficiency of water can be improved on Class A and B fires or a combination of these two. Wetting agents are not generally effective for polar solvents and in the form of a straight stream not recommended for Class C fires, although spray or fog application can be employed. Water with wetting agents should not be used on Class D fires.

Wetting agents added to water and aerated can produce a foam which retains the penetrating and spreading characteristics as well as providing an efficient smothering action for both Class A and Class B fires and will also provide exposure protection. This foam also contrasts with fire fighting foams in that it breaks down at approximately 80°C and returns to its liquid state retaining its wetting properties.

Apart from purpose made wetting agents which have low toxicity and low corrosive action, some AFFF foam concentrates may be used at low concentrations 0.5-1.0% as an effective wetting agent.

3.13 VAPOUR SUPRESSION

Foams restrict vapour release in three main ways. Firstly there is a temperature reduction of the liquid surface due to evaporation of water from the foam. The temperature reduction cuts down the vapour pressure of the fuel and reduces its evaporation rate. Secondly the vapour is trapped under a foam blanket, and can build up to sufficient concentrations where it is in equilibrium with the fuel. Without the foam blanket the vapour is removed by bulk air movements above the surface, and evaporation continues at a steady rate. This situation is closely analogous to loss of heat from the human body with, and without clothing. Finally, during the extinguishing process, the foam blanket cuts down the heat energy absorbed from any residual flames. The rate of evaporation of blanketted fuel is thus reduced.

The foam blanket formed by AFFF type foams also performs the function of acting as a reservoir of film generating liquid which feeds the film as it spreads across the fuel surface. In practice the film is thin, is easily evaporated and can only make limited progress ahead of the foam blanket when spreading towards a flame front. Exactly how far in advance of an AFFF foam blanket the film can extend remains an area of controversy.

The inhibition of vapour release by trapping vapour under a foam blanket works equally well in preventing evaporation of liquids which are not on fire. Hence, foam application can be used as a precaution on flammable liquid spills, or to suppress the evolution of toxic vapours.

3.14 LIST OF REFERENCES

The following reference numbers are sources used in this Section, and are listed in full in Appendix B: 4, 5, 6, 9, 12, 23, 28, 30, 32, 51, 69, 70, 72, 73, 77, 78, 99, 130, 131, 160, 163, 168, 173, 175, 176, 193, 225, 226, 227, 228, 319, 320, 321, 323, 325, 327, 341, 351, 380, 381.

MANUFACTURER		PROTEIN	PROTEIN (AR)	FLUOROPROTEIN	FLUOROPROTEIN (AR)	FFFP	FFFP (AR)
	L	Regular 3% & 6%		Plus F 3% - 4%			
Chubb	M	"		"			
	H						
	L	Nicerol	Polydol	FP70/FP570 3% 6%	Fluoropolydol	Petroseal 3% 6%	Alcoseal 3% 6%
Angus	M			"		"	"
	H						
	L						
3M	M						
	H						
	L	Foamousse 3 - 5%		Fluorofoamousse 3 - 5%	Fluorofoamousse 5%		
Sthamex	M						
	H						
	L	Aerofoam Regular 3% 6%		Aerofoam XL 3% 6%		Aerofilm	
National Foam	M	"		"			
	H						
	L	Regular 3% 6%		Fluoroprotein 3% 6%			
Ansul	M						
	H						

TYPE OF FIREFIGHTING FOAMS - PROTEIN BASED
TABLE 1

MANUFACTURER		SYNTHETIC	AFFF	AFFF (AR)
Chubb	L	Hex	Fluorafilm 1% 3% 6%	Masterfoam 3% 6%
	M	Hex	"	"
	H	Hex		
Angus	L	Expandol	Tridol S 1% 3% 6%	
	M	Expandol	"	
	H	Expandol		
3M	L		Light Water 1% 3% 6%	ATC 3% 6%
	M		"	"
	H		2	2
Sthamex	L	Sthamex AFFF 1% 3% 6%	Sthamex AFFF 3 - 5%	Moussol 3% 6%
	M	"	" " 5%	
	H	"		
National Foam	L	Syndet	Aero Water 3% 6%	Universal 3% 6%
	M	Syndet	"	"
	H	Syndet		
Ansul	L	Full - Ex 1% - 5%	Ansulite 1% 3% 6%	Ansulite (AR) 3% 6%
	M	"		
	H	"		

TYPE OF FIREFIGHTING FOAMS - SYNTHETIC BASED
TABLE 2

SECTION 4

CHEMICAL AND PHYSICAL PROPERTIES

4.1 INTRODUCTION

This section reviews the chemical and physical properties of fire fighting foams by first describing the extinguishing process and then describing how the properties of foam concentrates and finished foams provide the necessary extinguishing action and then the effect on the extinguishing process of varying these properties. Tabulated data is presented at the end of this section.

The following sections 5 and 6 give an analysis of the effect of the foam application equipment on the finished foam in terms of aspiration and the role of standards and specifications available to the fire service to ensure that foam concentrates and portable equipments perform effectively.

4.2 METHOD OF EXTINGUISHMENT

The use of fire fighting foams is essentially concerned with extinguishing class B fires. Certain high flash point hydrocarbon fires such as kerosene or fuel oils fires can be extinguished using only the cooling effect of water. Other low flash point hydrocarbon fires such as petrol and hexane fires cannot be extinguished by water alone as the temperature of the fuel cannot be lowered enough to prevent vapour being produced in sufficient quantities to ignite. Foam provides the necessary blanketting medium which is faster and more positive than water.

Foams extinguish fires primarily by excluding oxygen from the liquid surface and by restricting vapour release. Exclusion of freely circulating oxygen occurs both when a blanket of foam bubbles rests on a liquid surface and when a film of low surface tension surfactant/water mixture spreads over the fuel.

4.3 PROPERTIES OF FOAM CONCENTRATES

The main chemical and physical properties of foam concentrates which affect the performance of the finished foam are described as follows:

4.3.1 Specific Gravity

This is the weight per unit volume of foam concentrate compared with the weight of an equal volume of water, and is measured with a standard hydrometer. The acceptable limits of specific gravity are specified by the foam manufacturer and are between 1.0 and 1.2 depending on the type of foam concentrate and the temperature.

The specific gravity measurements can show whether the foam liquid has been diluted, or concentrated due to evaporation. Dilutions up to 5% are acceptable with most concentrates, but if more than 5% then further investigation may be necessary. Alcohol resistant concentrates are more sensitive to aqueous dilutions and care should be taken to prevent this.

Contamination by other materials may also lead to changes in specific gravity.

4.3.2 Viscosity

A low viscosity is desirable because it improves the flow characteristics of a foam concentrate. Viscosity varies between the types of foam and their concentration. Protein and synthetic based foams at 6% concentration tend to be the least viscous, followed by the 3% concentrations of the fluoroproteins and AFFF foams. The viscosity of 1% AFFF is still higher and 6% alcohol resistant foams are the most viscous currently in use. The lower the viscosity, the less energy is required for the concentrate to be proportioned into the water stream, particularly by induction. However, in the case of very viscous alcohol resistant concentrates, these are non-newtonian or thixotropic fluids, i.e. their viscosity varies with the shear rate and it is termed as shear thinning. As soon as this concentrate flows, its viscosity reduces to a more acceptable level and according to some foam manufacturers presents no problems with induction. However, other foam manufacturers have stated it will operate through inductors at about 90% of the efficiency of AFFF or fluoroprotein foam concentrates and that temperatures around 0°C may present problems of reduced induction rates.

The viscosity of foams will vary with temperature and may be affected by the age of the foam concentrate. This variation will affect the proportioning rate but should be within the tolerances stated in the draft BS and NFPA. Even alcohol resistant foams, which have been stated to operate at about 90% of the proportioning rate of other foams, should still operate within these tolerances. Worn, defective or maladjusted proportioning equipment may operate outside these tolerances and could cause problems as stated in 4.3.6 below.

4.3.3 Freezing Point

This property varies with the type of foam concentrate and is influenced by viscosity. Most protein, fluoroprotein, AFFF and FFFP concentrates are freeze protected for low temperature use. Alcohol resistant concentrates become very viscous at low temperatures and freeze protected varieties are not generally available. The concentrates cannot be used much below 0°C. Manufacturers have stated, however, that development work has been carried out and that freeze protected alcohol resistant concentrate will be available shortly for temperatures down to -15°C.

4.3.4 Undissolved Solids

Early types of protein foams exhibited high sedimentation and it was necessary to employ settling tanks and pumps to transfer the contents of one tank to another to leave the sediment behind. The foam concentrates produced today are very refined with undissolved solids contents of 0.1% by weight or less. A high level of undissolved solids may indicate a concentrate is deteriorating with age or high storage temperatures.

4.3.5 pH

This is an indication of acidity or alkalinity of a foam concentrate. Most foam concentrates are nearly neutral at between 7 and 8. If the value is lower than 7, it is acid; higher than 7, it is alkaline. The limits of pH are specified by the foam manufacturer and are determined in the laboratory by using an electrometric technique such as a pH meter.

Variation in pH outside manufacturers' limits may be due to the following:

(a) Contamination with water, chemicals, oils or mixtures of foam liquids.

(b) Degradation of foam concentration due to exposure to high temperatures, oxidation, or foreign substances that cause changes in stability.

(c) Biological decomposition due to breakdown of foam concentrate by micro-organisms which may occur from excessive water dilution or preservatives which are not effective.

4.3.6 Concentration Variation

The foam concentrations adopted throughout the industry are 6%, 3% and 1%. 6% was originally used for protein based foams as this was the maximum concentration that could be technically achieved using protein. Now, with improvements to the formulation, 3% can be achieved with fluoroprotein foam concentrates. Future developments may produce a 1.5% concentrate. Obviously, the higher the concentration the less foam concentrate that is required, which leads to space and weight saving and lower transportation costs.

One problem with higher concentrations is the increase in viscosity. This is particularly noticable with alcohol resistant concentrates with viscosities as high as 3250 centistokes at low temperatures.

Variations in the proportioning rates at the particular concentrations are specified in the draft BS and NFPA. They are: 6%±1%, 3%-0%+1%, 1%-0%+1%. Equipment should be manufactured within these tolerances. (Note: this means that 1% foam could legitimately be proportioned at 2%; this maximum is likely to be reduced to, say, 1.25% when the British Standard is formally published). Variations in the proportioning rates have shown that over-proportioning will result in excessive quantities of concentrate being used ineffectively and under-proportioning will result in longer extinguishing times and even not extinguishing the fire in the case of certain foams. A standard industrial refractometer may be used for measuring the concentration of foam solutions.

4.4 PROPERTIES OF FINISHED FOAMS

The performance of finished foams is measured and compared by testing and recording the behaviour of certain properties. These properties are influenced by the generic type of foam concentrate, namely, those based on protein and those based on synthetic detergents.

4.4.1 Protein Based Foams

When protein based foam concentrates are mixed with water and passed through a foam maker and aspirated, a low expansion foam is produced which consists of protein particles in the form of a physical/chemical structure in the bubble wall. This has a high surface tension and is therefore stable in the presence of hydrocarbon fuels. As there are no synthetic detergent compounds within the foam it retains its water content for a long period of time and is therefore very heat resistant. However, the result of this is that the finished foam tends to be stiff which reduces the spreading effect of the foam over the fuel surface. Forcible application of the foam to overcome this stiffness can cause mixing of the fuel and the foam blanket. In general with protein foams the fuel has a lower surface tension than the finished foam, the fuel can spread over the exposed surface of the foam and coat the surface of internal bubbles. This in turn can lead to re-ignition of the foam blanket.

4.4.2 Synthetic Based Foams

When synthetic based foam concentrates are mixed with water and passed through a foam maker, they produce a low expansion foam in the case of AFFF, or a medium and high expansion foam in the case of synthetic foam. The foam produced consists of synthetic detergent molecules which form a skeletal chemical structure in the bubble wall. The addition of fluorocarbon surfactants and other stabilisers produces a foam which is much more fluid than fluoroprotein foams and results in a very fast fire knockdown and extinction. Their fast drainage time and synthetic detergent base may however, result in a lower burnback resistance than protein or fluoroprotein foams. In the case of AFFF foams, the solution that drains out of the finished foam is capable of forming a floating film which spreads over the surface of hydrocarbon liquids. This film can for a limited period give protection against re-ignition and re-seal should the foam blanket be broken.

4.4.3 Extinguishing Time

This term is self explanatory as it is the time to achieve 100% fire extinguishment. It is, however, not easy to obtain repeatable times from fire tests. The ambient temperature will affect the temperature of the fuel and foam concentrate. As the fuel temperature rises, its vapour pressure increases, producing more flammable vapour which will be more difficult for the foam blanket to smother and cool. As the foam concentrate temperature rises, its viscosity decreases and the induction rate may increase, although induction systems are designed to take viscosity variations into account and still operate with the limits stated by NFPA. Wind will also affect the way foam is applied to the fuel surface and the quantity which actually reaches the fire. Most tests operate on a two-dimensional system, namely, the area of a test pan, and use manual application. The techniques used by different operators can considerably influence extinguishing times which again contribute to the inaccuracy of such tests. It is therefore of the utmost importance to monitor all these ambient conditions to ensure repeatability of tests and consideration should be given to testing indoors.

4.4.4 Control

This term is usually measured in two ways depending on whether the foam blanket is aspirated or not.

It is normally considered as 90% cover of the fuel surface with an aspirated foam blanket, or 90% extinguishment of the fire in the case of unaspirated application. In the first case an estimate has to be made of 90% of the fuel surface area which could be subject to many interpretations particularly in windy conditions or where fuels produce a lot of smoke. In the second case, an estimate has to be made of 90% of extinguishment which is highly subjective since no quantitative methods of measuring this state are used. Tests should be carried out to investigate the use of heat detecting sensors, such as, infra-red detectors and infra-red filming devices as a quantitative method of measuring "control".

4.4.5 Foam Flow

This term covers the ability of a foam blanket to cover a large distance from a single application point. It is critical to floating roof storage tanks and is important where foam is required to flow around obstacles in spill fires. Tests (as yet unpublished) have been carried out which examine the flow of various foams along narrow channels simulating the annular ring around the rim seal of a floating roof tank. These have indicated that fluoroprotein foams can cause a build up of drying foam preventing continued flow of the blanket and preventing full extinguishment. In the case of AFFF with lower expansion and faster drainage, the foam blanket continued to flow throughout the test and extinguishment was achieved. All other factors being equal good foam flow is an advantageous property of finished foams.

4.4.6 Film Formation

This term applies to AFFF and FFFP foams. These foams have the ability to produce an aqueous film which spreads over the surface of a hydrocarbon fuel cooling the burning fuel surface, reducing the hydrocarbon evaporation rate and depleting the supply of fuel vapour to the flames. It has been shown that this phenomenon is dependent on the spreading coefficient which in turn is related to the surface tension of the film and of the hydrocarbon liquid and the interfacial surface tension between them. Theoretically, a liquid will form a film on the surface of a second liquid, if the spreading coefficient, as calculated from surface tension measurements, is positive. The spreading coefficient is defined as:

$$S = \gamma_c - \gamma_u - \gamma_{IF}$$

where	S	=	spreading coefficient
	γ_c	=	lower liquid surface tension
	γ_u	=	upper liquid surface tension
	γ_{IF}	=	interfacial tension between the liquids

AFFF and FFFP solutions, although primarily water, contain fluorochemical surfactants that reduce the surface tension of water to such an extent that the spreading coefficient is positive with many hydrocarbon liquids. Tests have shown however, that spreading coefficients of aqueous AFFF solutions decrease with increase in fuel temperature and in the case of some low boiling point hydrocarbons become negative at temperatures above 60°C. This corresponds to a decrease in the ability of AFFF to reduce evaporation rates of these hydrocarbons. The inference is that film formation no longer takes place, and AFFF's then must rely only on their blanketting and cooling mechanisms to extinguish the fire. Consequently, larger quantities of foam are required to extinguish the fire and prevent reignition of the fuel. (Ref 277)

Other tests have been carried out comparing AFFF and FFFP extinguishing times with spreading coefficients on aliphatic and aromatic hydrocarbon fuels. The results indicated that, although, a high spreading coefficient was recorded with the aromatic toluene, extinguishing times were high. Conversely, low spreading coefficients were recorded with aliphatic heptane and extinguishing times were short. In the case of 4-star petrol which is a mixture of 30-50% aromatic and aliphatic hydrocarbons, this test resulted in long extinguishing times for the AFFF foams but relatively short extinguishing times for the FFFP foams. From this test it appears that perhaps the spreading coefficient is not the critical factor in determining the effectiveness of the aqueous film; there may be other factors involved, e.g. fuel temperature, fuel tolerance, and vapour pressure. Obviously, there is a need for further tests and research to determine exactly what influences the film forming phenomenon. (Ref 388)

4.4.7 Miscellaneous Properties

There are several obscure terms occasionally used which are neither precisely defined nor widely accepted. Such explanations as are available have been included below.

- **Ignition Assistance**

  A laboratory demonstration has reportedly been conducted where attempts were made under two sets of conditions to ignite liquid kerosene with a naked flame. In the first case the flame was extinguished. Several drops of AFFF concentrate were then applied to the kerosene surface and the flame reapplied, whereupon the kerosene ignited. The demonstration is not readily repeatable and if conditions vary slightly the effect does not occur. Discussion has taken place as to whether this shows that AFFF could promote a fire rather than extinguish it. However, it is generally considered to be an isolated example and of no significance to the practical usefulness of AFFF. It might be explained by a slight increase in vapour pressure of the kerosene/AFFF combination over that of pure kerosene.

- **Candling**

  This term is used in the U.L. test procedure and 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. It is though to result from vapour forcing its way into the foam so that a certain proportion of the bubbles become filled with a flammable mixture of gases. The U.L. test will still pass a foam that exhibits candling provided it is self extinguishing and the flames do not dwell in any one position.

Candling is considered to be of minor importance to the practical use of foam, and more a feature of certain test procedures, since foam is tested at the lower "critical" application rates, but used on real fires at the higher "minimum recommended application rates" (MRAR's).

- **Ghosting**

This is another term for candling.

- **Secondary Foaming**

When unaspirated AFFF solution is applied to a non burning pool of liquid hydrocarbon with a high vapour pressure, a film is initially spread across the fuel surface. However, after several minutes the film can become aspirated into bubbles of foam by the hydrocarbon vapour escaping from the liquid surface. This phenomenon has been called secondary foaming, but foam produced can be readily ignited and burned off. The circumstances of the observation are sufficiently remote from any practical situation that it is not normally considered to be of any significance.

- **Wicking Effect**

It is understood that this is another name for candling, but if so it may be a misleading one. It implies that fuel can be carried upwards through a foam blanket by the same mechanism as in a wick - i.e. surface tension and capillary effects.

4.4.8 Vapour Pressure and Rate of Evaporation

All combustion involving flames takes place in the vapour phase, and the rate of evaporation of vapour is effectively the rate of supply of fuel to the fire. Two principal factors affect the rate of evaporation; the vapour pressure of the liquid, and the rate at which heat is being supplied to the liquid surface.

For any particular liquid the vapour pressure varies with surface temperature alone (in fact it is related to absolute temperature °K), increasing with increasing temperature. If the vapour pressure is raised to equal the ambient atmospheric pressure, then the liquid boils. There is a relation between flash point and vapour pressure, but other factors such as explosive limits of concentration are also involved.

In practice, liquids with a high vapour pressure at ambient temperatures such as petrol, crude oil and Avgas, are harder to extinguish with foam than those with low vapour pressures such as diesel or lubricating oils. When a liquid is burning the surface is being supplied with heat at a high rate and vapour is being released rapidly.

Upon application of a foam blanket the heat input to the liquid surface is cut back, and as the surface cools the rate of evaporation is reduced. Equilibrium is often established with a saturated layer of vapour lying above the liquid under the foam blanket. With high vapour pressure liquids, however, the rate of generation can be sufficient to force vapour through a foam bed. This can happen particularly with thinner foam blankets such as aqueous film layers or unaspirated AFFF (see 4.4.7 above). In general the higher the vapour pressure the thicker the blanket needed to contain the vapour.

Where there is another source of heat to the liquid surface other than from the surface flame, then the rate of evaporation can remain high, for example hot metal surfaces at the side of a tank, or on a crashed vehicle.

4.4.9 Application Rates

The application rate of a foam onto a fire is defined as; the volumetric flowrate of foam solution divided by the area to be foamed. Normal units are litres per minute per square meter.

The fire fighting foam industry uses five different definitions for application rates, and it is important to distinguish between them.

- **Critical Application Rate**

This is the minimum application rate which will extinguish a fire under test conditions. Just sufficient foam is applied to overcome the rate of foam destruction by the fire, and comparisons between success or failure of various foams with different fuels can be made which would be obscured at higher application rates.

- **Recommended Minimum Application Rate (RMAR)**

These rates are recommended by various authorities for use in manual fire fighting and for application through fixed systems.

A comparison of the RMAR's for manual application recommended by the Manual of Firemanship, NFPA, Shell and BP is given in the Tables at the end of this Section. RMAR's are derived from Critical Application rates by the authority concerned using a scale up factor intended to compensate for loss of foam from fallout from the hose stream, wind losses and destruction of the foam passing through a fire plume, as well as a safety factor.

The RMAR is set at a level which will extinguish the fire concerned within the period recommended for the duration of foam supply. Establishing a suitable scale up factor is necessarily a matter of judgement reinforced by experience on real fires. The NFPA have conducted scale up tests on larger pan fires to establish a basis for extrapolation from the critical rates for small scale pan tests to the RMAR's needed in practice. Mobil and other oil companies have done similar testing.

The RMAR's in the Manual of Firemanship are significantly lower than those in the other standards. For the UK Fire Service a valuable research programme would be to carry out a series of tests to check the scale up factors and durations applied in the Manual of Firemanship, so that revisions can be made on a scientific basis if necessary. These RMAR's may also be too low for certain exceptionally high hazards, such as storage tanks for hydrocarbon liquids in excess of 45m diameter. (Ref 61)

In practice the RMAR is of greatest importance in planning the resources needed for a foam attack. It has a direct bearing on the quantity of concentrate, and water required, and also should dictate the amount of delivery equipment, i.e. appliances, monitors, branch pipes, proportioners and hoses.

- **Optimum Application Rate**

The optimum application rate is sometimes referred to as the most economical rate. It is the 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.

- **Overkill Rate**

In most practical cases where foam is used to extinguish fire the firefighters apply their own further margins of safety where sufficient resources of concentrate, water and equipment permit. This may appear wasteful of valuable foam concentrate, but in practice firefighters have reported that higher application rates can significantly reduce extinguishment times. (Ref 268)

This is not borne out by small scale pan tests which tend to indicate that the saving in foam concentrate obtained from achieving shorter extinguishment times is largely eroded by the additional quantities used in achieving the higher application rate. The Firemanship Manual shows a very sharp minimum in the foam quantity needed on a graph of extinction time against solution application rate. The implication is that there is a "most economical rate" and that higher rates of application are wasteful. (Ref 389)

These conclusions can be questioned on the ground that if the duration of foam application can indeed be reduced, then losses which are time dependent, such as wastage of foam from windage losses and destruction of foam by heat are also reduced. There may be a difference between the stiffer protein based foams and the more rapidly flowing synthetics which could perform relatively better at higher application rates. These factors would be more noticeable to the firefighter in a practical situation, and less so in standard test pan fires.

There are further reasons for increased application rates in air crashes and road crashes where life is in danger and reduction in extinguishment time becomes of overriding importance, and the cost of using excess concentrate should not be a factor.

For storage tanks over 45m diameter there are reports that increased application rates are also beneficial.

There appears to be a considerable variation in views on this topic, and it is a field where additional research is required, particularly since an increase in application rates is accompanied by improved reliability of achieving fire extinguishment.

Whilst the use of rates higher than RMAR's is a moot point there is little doubt that to attempt a foam attack with rates lower than RMAR's is at best wasteful of foam, and at worst may be totally futile. Firemen should be discouraged from "trying a little foam to see what happens".

- **Continued Application Rates**

  Various standards quote lower rates for continued application after a fire situation has been established. These rates should be sufficient to maintain the integrity of the foam blanket. (Ref 61)

4.4.10 Edge Sealing

This term relates to the effects of hot metal surfaces against a foam blanket and ensures that the fire is fully extinguished. Hot metal surfaces can cause breakdown of the blanket, increased vapour generation from the fuel and an inability of the foam to fully extinguish fires at this interface. Foams which have a good heat resistance exhibit good extinguishing times and burnback resistance and therefore should have good edge sealing properties, although, when really hot metal surfaces are encountered by the foam blanket, destruction of the foam blanket is inevitable and steps should be taken to cool these surfaces sufficiently to ensure edge sealing can take place.

4.4.11 Fuel Tolerance

This term indicates the resistance of a foam to formation of an intimate mixture with the fuel and relates to application of a hose stream where it is plunged directly into a flammable liquid. Depending on the type of foam used this method of application can result in partial destruction of the foam blanket and can cause fuel to be picked up by the foam.

Protein foams suffer from this problem when vigorously applied as the surface tension properties cause any fuel which mixes with the foam to spread over and within the blanket which can result in ignition being sustained. The addition of fluorocarbon surfactants which are oleophobic and have a very low surface tension resists this spread of fuel across the foam blanket and increases its fuel tolerance for both fluoroproteins and FFFP's.

In the case of synthetic detergent based foam the hydrocarbon surfactants tend to emulsify oils with water and cause the foam to pick up large quantities of fuel which is readily ignited. Fuel tolerance has been improved in the case of AFFF's and alcohol resistant AFFF's by the addition of a higher proportion of fluorocarbon surfactants to hydrocarbon surfactants. This reduced tolerance is particularly evident where the foam stream has created turbulence on the fuel surface during application and emphasises the need for gentle application techniques. (Ref 389)

4.4.12 Low Expansion

Low expansion foam is produced either by inducing air into the foam solution stream just upstream of the applicator or by inducing air into foam solution stream just as it leaves the applicator.

4.4.13 Medium and High Expansion

Medium and high expansion foam is produced by spraying foam solution onto a mesh screen or net through which air is induced by either the "Venturi" effect of the spray nozzle or a hydraulic or electric motor fan.

Various tests have been carried out on petrol fires which show that different types of foam at different expansion ratios can improve extinction times. (Ref 390) For example:-

(a) Protein foams at low expansions did not give fire extinction before the test fuel was exhausted.

(b) Fluoroprotein, fluorochemical and synthetic foams at low expansion ratios all gave satisfactory control and extinction.

(c) Synthetic foams at medium and high expansions gave satisfactory control and extinction.

(d) Synthetic foams at high expansion ratios of 400:1 and 700:1 give quickest control and extinction times under certain test conditions.

4.4.14 Drainage Time

This term is a measure of the rate at which water drains from a finished foam and indirectly of foam quality, i.e. the average bubble size. A high drainage time indicates that the finished foam is capable of maintaining its heat resisting and stability properties and is usually the case with most protein and fluoroprotein foams. These foams have similar drainage times but fluoroprotein is less stiff than protein foam with better flow characteristics. A low drainage time indicates that the finished foam losses its water content quickly and renders it vulnerable to high temperature flame and surfaces. Synthetic foams and AFFF's tend to have low drainage times which give them greater fluidity than protein and fluoroprotein foams but at the expense of heat resistance.

Drainage is usually expressed as 25% drainage time which is the time taken for 25% of the original water content (by weight) to drain from the finished foam. Some manufacturers quote a 50% drainage time and this is sometimes more suitable to synthetic based foams used for medium and high expansion applications. The property can be influenced by the same factors as expansion ratio and for comparitive test, a standard measurement technique must be used. NFPA 11 describe the usual test method and uses the same apparatus as the expansion test.

The drainage time associated with a particular type of finished foam will depend on the foam making equipment used. Equipment producing unrealistically high 25% drainage times of above 11 minutes should be avoided as, although, the foams will be very heat resistant, they will be excessively stiff and do not have good flow characteristics. Further tests should be carried out to optimise performance. (Ref 389) In addition, equipment producing very low 25% drainage times of less than 1 minute should again be avoided as their heat resistance is too low.

What does not appear to have been tested is that different foam types give different expansion ratios through the same equipment. Investigations should be carried out to find the operating characteristics of each type of applicator which includes fire performance and jet stability in wind conditions. In addition, tests should be carried out to examine the resulting foam expansions achieved using various foams through the same foam maker. For example, it has been stated that AFFF foams will give greater expansion ratios than fluoroprotein foams through the same equipment. Energy requirements for AFFF are less than for fluoroprotein foams therefore the same degree of aspiration and work imparted on the foam solution by a particular piece of equipment will produce more expansion.

The UL listing procedure circumvents this problem by only listing foam concentrates for use with particular application equipment, however, this is not generally applicable to UK Fire Service equipment.

4.4.15 Droplet Size of Foam Streams

This term is applied to the water droplet size in "unaspirated" foam streams. The term is not used in relation to aspirated foam where it is assumed that the majority of the foam solution has been converted into foam as it leaves the foam maker and water droplets of a significant size will not be present. The droplet size will vary depending on the type of foam making equipment used.

Most "unaspirated" foams (i.e. neither aspirated by primary nor secondary means see Section 5) are produced using straight jet equipment and it is thought that this equipment delivers streams containing large droplets. As with water stream through the same equipment, long throws can be achieved, together with good penetration of the thermal updraft when dealing with large storage tank fires, since the momentum of the stream and terminal droplet velocity is high. It is also thought, air entrained in an "unaspirated" stream can result in a low expansion of say up to 3:1. As a consequence, considerable feathering has been seen to take place in "unaspirated" streams and there may be extensive plunging of foam when the stream meets the liquid surface. Although, foam of some kind is delivered to the seat of the fire by this method, there is doubt about its extinguishing efficiency and very large quantities of foam may be required to counterbalance the reduced efficiency if plunging occurs. On the other hand use of unaspirated foam on helideck fires is reported to be highly effective.

It is apparent that further test work should be carried out to analyse the effects of droplet size on the droplet terminal velocity, updraft penetration, feathering of the foam stream, plunging on the liquid surface, effect on throw and the size and distribution of the footprint.

4.4.16 Critical Shear Stress

This term is a measure of the stiffness and the resistance of a finished foam to flow. It is measured by a paddle type torsion wire viscometer and typical values are:

(a) Protein of fluoroprotein 13-17 N/m^2
(b) Synthetics, AFFF & FFFP 4-5 N/m^2

4.4.17 Working and Foam Quality

"Working" refers to the action of the internal components of a foam making device on the solution stream and it passes through the device. It is the resistance created by impinging the foam solution stream onto obstructions and orifices within the foam maker. The more efficient the foam maker is at working the solution, the better quality of foam quality is produced in terms of densely packed small bubbles of uniform size within a narrow band of size distribution. This results in increased water retention or higher drainage times which improve heat resistance.

Ultimately, if the foam working is excessive, the foam becomes very stiff and losses its flow qualities.

4.4.18 Waterspray Tolerance

This term relates to the ability of a finished foam to perform satisfactory extinguishment after being subjected to extraneous water sprays.

A technique which is used today on storage tank fires to help penetrate the thermal updraft is to create a water spray shield through the flame wall and project the foam stream through this shield onto the fire. Although it has been reported that this method has successfully aided the control of tank fires, very little is known about the effects water sprays on the foam stream and on the finished foam blanket. Further tests should be carried out to investigate whether any degrading of the foam blanket occurs or whether extinguishing times are increased or application rates have to be increased to compensate for the effects of the water sprays.

4.5 WATER QUALITY

It has been shown by numerous tests that water quality can play an important part in determining the effectiveness of fire fighting foams. Certain water treatment chemicals have effect on foam properties and fire performance.

Cooling water dispersant does significantly degrade foam performance to the extent that very high levels of such additives could not be tolerated at even high foam application rates. Chlorine, on the other hand, appears to have little effect.

Where corrosion inhibitors are used in fire fighting water, such as sodium an d zinc chromate it was shown sodium chromate degrades foam even at low dosages whereas zinc chromate (50 ppm) does not. It was also shown higher application rates can compensate for foam degredation with a number of proteining commercial corrosion inhibitors.

Tests were also carried out with fire fighting water containing sodium fluoride, sodium chloride or synthetically hard water and it was doscovered that these solutions were not foam destructive. Sea water generally enhances foam quality and fire fighting performance whereas large quantities of sodium fluoride (13600 ppm) in brine was foam destructive. (Ref-75)

4.6 SCALE-UP TESTS AND COMPUTER MODELLING

Attempts have been made to correlate small scale laboratory tests to full scale fire tests. Test work was carried out, initially at Stanford University, California, then at the Maryland University lasting about 12 months, testing various foams and fuels. Laboratory tests were compared with a modified UL 162 test using 9.3 m^2 test pan.

Apparently there was very good correlation between the laboratory model and the full scale tests, particularly with synthetic foams such as AFFF and alcohol resistant types. In the case of protein foams there was, however, no correlation at all. There do not appear to be any test results available, so this could be another example of the need for further test work.

It may be possible to mathematically model the performance of fire fighting foams either simulating their performance under test, or perhaps eventually simulating how they can react on real fires. Existing computer models simulating find flow may be used, together with dimensional analysis for scale up comparisons and energy balances for loss and absorption of heat.

(Ref: Dr H Hickey - Maryland University)

4.7 LIST OF REFERENCES

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

12, 13, 22, 28, 30, 43, 68, 70, 73, 74, 75, 91, 116, 118, 119, 120, 122, 128, 129, 186, 189, 277, 291.

Authority	Foam Concentrate	Minimum Application Rates of Foam Solution 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	4.1	4.1		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

CONCENTRATE DATA	PROTEIN		PROTEIN (AR)	FLUOROPROTEIN		FLUOROPROTEIN (AR)	FFFP		FFFP (AR)
Solution Strength	3%	4%	6%	3%	4%	6%	3%	6%	6%
Specific Gravity @ 20°C	1.15	1.1	1.16	1.16	1.13	1.15	1.16	1.135	1.09
Viscosity 20°C mm^2/s	12	5	10	14	5	12	30	8	700 (1)
0°C "	30	10	24	28	9	25	102	18	400 (1)
-10°C "	54	17	37	55	14	40	245	54	Frozen (2)
Freezing Pt. °C	-12	-12		-15	-12		-18	-16	-7
Undissolved solids % by weight	<0.1	<0.1		<0.1	<0.1		<0.15	<0.15	<0.1
Cloud point temp. Upper °C	>60	>60	>60	>60	>60	>60	>60	>60	>60
Lower °C	<-10	<-10	<-15	<-15	<-10	<-15	<-18	<-16	<-7
Storage life	>10	>10	>7	>10	>10	>7	>10	>10	>10
Expectancy in ing. sealed containers (years) at average temps up to (°C)	40	40	40	40	40	40	50	50	50
Pour point (°C)	-10	-10	-15	-15	-10	-15	-18	-16	-4
pH at 20°C	7	7	9	7	7	9	7.8	7.8	7.5

(1) At shear rate sec^{-1}
(2) Low temperature grade available

PHYSICAL AND CHEMICAL PROPERTIES - 1
TABLE 3

CONCENTRATE DATA	SYNTHETIC	AFFF			AFFF (AR)
Solution Strength	1½%	1%	3%	6%	6%
Specific Gravity @ 20°C	1.0	1.06	1.0	1.01	1.0 - 1.02
Viscosity 20°C mm^2/s	7	14	3	5	2200
0°C "	15	35	6	8	3220 @ 4.4°C
-10°C "	-	62	Frozen[2]	Frozen[2]	-
Freezing point °C	-7	-20	-5	-5	-2
Undissolved Solids at per volume	13	20	8	4	
Cloud point temperature					
Upper °C	>60	>60	>60	>60	
Lower °C	<-5	<-18	<-5	<-5	
Storage life expectancy in orig sealed containers (years)	>10	>10	>10	>10	>10
at av. temps. up to (°C)	40	50	50	50	49
Pour point (°C)	-6	-20	-5	-5	1.6
pH	7	8	8	8	7.6 - 8.0

PHYSICAL AND CHEMICAL PROPERTIES - 2
TABLE 4

SOLUTION DATA	PROTEIN	PROTEIN (AR)	FLUOROPROTEIN	FLUOROPROTEIN (AR)	FFFP	FFFP (AR)
Solution strength	3% 4%	6%	3% 4%	6%	7% 6%	6%
Viscosity	Similar to water					
Surface tension at 20°C (dynes.cm)	45 45	40	23 23	17	17 17	17
Stability of premix (min)	OK OK	30	OK OK	30	OK OK	OK

OK - Indicates premix is stable but annual testing is recommended

PHYSICAL AND CHEMICAL PROPERTIES - 3

TABLE 5

SOLUTION DATA	SYNTHETIC	AFFF			AFFF (AR)
Solution strength	1½%	1%	3%	6%	6%
Viscosity			Similar to water		
Surface tension at 20°C (dynes/cm)	24	17	17	17	
Stability of premix (min)	10	OK	OK	OK	

PHYSICAL AND CHEMICAL PROPERTIES - 4

TABLE 6

FINISHED FOAM DATA	PROTEIN		PROTEIN (AR)	FLUOROPROTEIN		FLUOROPROTEIN (AR)	FFFP		FFFP (AR)
Solution strength	3%	4%	6%	3%	4%	6%	3%	6%	6%
Expansion (Def.specs)	7.3	8.0	8.0	8.5	8.5	7.8	8.5	8.5	8.5
25% drainage time (min)	8.5	7.4	20.0	5.0	5.0	9.3	5.0	5.0	12.5
Burnback resistance (Augas) (mins)	16	19	-	14	15	23	14	15	14
Bubble size (Def. Specs) (Branch Pipe)					Very finely textured				
Mix to JCDD28									
50% drainage time (mins)									
Bubble size (mm)									

PHYSICAL AND CHEMICAL PROPERTIES - 5

TABLE 7

FINISHED FOAM DATA	SYNTHETIC	AFFF			AFFF (AR)
Solution strength	1½%	1%	3%	6%	6%
Expansion (Def.Spec)	-	7.5	9.0	9.5	3 - 300
25% drainage time (min)	-	3.5	4.0	4.0	
Burnback moisture (Augas) (mins)	-	11	11	11	
Bubble size (Def.Specs) (Branch Pipe)	-	Very finely textured			
Hiex to JCDD 28	1000				
50% drainage time (mins)	15				
Bubble size (mm)	20				

PHYSICAL AND CHEMICAL PROPERTIES - 6

TABLE 8

SECTION 5

ASPIRATION

5.1 INTRODUCTION

AFFF foam concentrates were originally used "unaspirated" for air crash rescue where their property of fast fire knockdown was highly beneficial, coupled with the increased range of a "non-aspirated" foam stream when compared with aspirated foam.

It was also found that AFFF was extremely effective against most types of hydrocarbon fire when used aspirated to give a low expansion ratio. More recently unaspirated AFFF has been proposed for use on large oil storage tanks where the increased range achievable can be of crucial importance in reaching the seat of the fire.

This application of AFFF has been questioned regarding whether it is likely to be effective. In this section the main arguments for and against this particular use are examined together with the broader question of when should foams be used non-aspirated or aspirated.

5.2 TERMINOLOGY

There is some confusion over the use of the expression "aspirated" which can be clarified by a re-definition of terms. Traditionally an aspirated foam was produced by a nozzle with air inlet holes in the barrel or at the base. Air was sucked into the stream of solution and "worked", or mixed, within the liquid in the barrel of the nozzle during its passage to the tip where it was discharged as a stream of aspirated foam.

By default any foam solution which was discharged from a nozzle without air inlet ports was, and still is, commonly referred to as non-aspirated. This term is misleading since air can be mixed with the foam solution by other means, viz;

- certain nozzles use a system of impinging jets where foam solution is expelled from a device similar to a sprinkler head at the centre of an annular cylinder of water forming the jet. The impingement process causes a considerable amount of agitation, and air entrainment into the mixed stream takes place.

- a jet stream can be discharged at a slight cone angle which causes the jet to converge on itself at a point up to 3 or 4 metres beyond the nozzle. Known as the "vena contracta" this "necking" of a stream of solution acts in a similar way to a venturi and entrains air into the stream as it widens again after the narrowest point.

- frictional drag between the static air and a moving stream of foam solution will also induce air to be captured and carried with the stream as bubbles.

- impingement of a solution jet on a solid object again creates turbulence which incorporates further air into the solution.

The combined result of all or some of these effects can be to produce foam from a supposedly non-aspirated nozzle at expansion ratios of up to 6:1, particularly where foams requiring less energy to "work" are used, such as AFFF and AFFF (AR).

We propose that terminology should be borrowed from the physics of flame combustion, where primary air is induced through an aperture into a fuel stream before the burner tip, and secondary air is the term used for air drawn in as, or after, the fuel leaves the burner.

Thus, **primary aspiration** occurs when air is drawn into the nozzle through apertures, and **secondary aspiration** occurs at the tip and/or at the vena contracta. The term non-aspirated should be used with care or avoided since it can mean either foam solution liquid, or alternatively foam at 2-3:1 expansion which has been achieved by frictional drag and impingement of a jet of solution, or any intermediate degree of expansion.

5.3 ADVANTAGES AND DISADVANTAGES

Tests on fire brigade branchpipes used to extinguish test pan fires show that the addition of a clip-on aspirator can greatly improve the performance of all foams. The device used gave primary aspiration, and expansion ratios in the region of 7-10:1 could be achieved. A standard fire brigade branchpipe is not designed to give either primary or secondary aspiration, and would achieve expansion ratios of 2-3:1.

It is generally accepted that these results are applicable to practical fire fighting. Although AFFF can achieve rapid knockdown in spill fires without aspiration, it gains control more rapidly when used aspirated. Confusion can arise with the use of secondary aspirating nozzles, which can produce very effective foams from AFFF and AFFF (AR) concentrates at 5 to 6:1 expansion.

The main advantage of using monitors or nozzles that provide neither primary nor secondary aspiration is the increase in range of 20 to 30% that can be achieved. Secondly the foam stream is less likely to be affected by windage and will be more penetrating through a fire plume. Lack of range can be a major disadvantage with aspirated foams. The air resistance on a foam stream of 7 to 10:1 expansion can reduce the distance of throw to 60% of that of a water jet through similar equipment. Where range is particularly important is in fighting tank fires in the UK, where tank heights go up to 27m. If the further restriction is imposed that men and equipment should not be deployed within bunds, it becomes impossible to clear many tank walls with 7 to 10:1 expanded foam, using existing equipment.

Where wind resistance is important and jet plunging into a fuel bed is not expected "unaspirated" AFFF foams have found an application, particularly in helipad systems in the North Sea. Application rates are usually well above the MRAR's for life safety reasons.

On the other hand there may be disadvantages in using "unaspirated" AFFF at low expansion ratios of 2-3:1. Firstly there is no practical experience or test results which support the effectiveness of such foam for tank fires. This leaves the field open for speculation, but even here there are indications that the "unaspirated" AFFF may be less than fully effective:

- In tank fires "unaspirated" foams may plunge into the fuel more than aspirated foams, because of larger droplet size and higher terminal velocity.

- Heat resisting properties are poor, including burnback resistance, edge sealing and stability of the blanket.

- The foam would be very rapid draining limiting the depth of blanket that could be built up.

- Extinguishment of high vapour pressure fuels could be difficult, where a thick blanket is advantageous to suppress vapour release.

- Foam could be susceptible to breakdown from candling.

- No guidance is available on what application rates could be used to offset these disadvantages.

- AFFF is not suitable for polar fuel fires.

Further disadvantages arise in applications other than tank fires.

- The rapid draining properties imply that resealing capabilities of the blanket will be of short duration.

- It can be difficult for fire fighters to see where a surface film remains intact and where it has been broken.

- Higher rates of continued application after extinction may be required to compensate for the reduced durability of the foam blanket.

5.4 EXAMPLES OF USE

- Large oil tanks

One brigade in the U.K. has adopted use of "unaspirated" (2-3:1 expansion) AFFF to protect high sided storage tanks. A special monitor has been developed to enhance the range of the stream. The advantages and disadvantages listed above are applicable to this case. However, where the available methods of applying aspirated foam cannot reach the fire there is a strong rationale behind adopting such a less desirable but more practical alternative. Report No. 3 will cover specialist equipment which could provide further options for tackling fires in large oil tanks.

- Use as a wetting agent and for small class B fires

A UK fire brigade in a mainly rural area uses AFFF stored on the appliance and inducted at 1% into hose reels. This gives the capability of using AFFF unaspirated, as a wetting agent, or to speed the knockdown on small class B fires.

The use as a wetting agent is claimed to extend the extinguishing capacity of an appliance, which can be particularly valuable in areas where water is in short supply. Reduction in water damage is claimed as a secondary advantage, although in practice firefighters should place a higher priority in securing extinguishment rather than limiting water damage. Further tests would be needed to substantiate this claim.

The addition of a simple clip-on aspirator would greatly enhance the effectiveness of this equipment against small class B fires. No protection is provided by this system against polar solvent fires.

5.5 CONCLUSIONS

- Use of "unaspirated" AFFF on storage tank fires is unproven, but might be successful in favourable circumstances at higher application rates than normal. It is unlikely to be effective on fires which challenge aspirated foams, such as crude oil fires, large diameter tanks (over 45m diameter) and high vapour pressure fuels.

- All new methods and equipment for tackling fires should be evaluated independently of any commercial pressures by a centralised body within the fire service. Impartial advice on all available alternatives could then be imparted to all brigades.

5.6 LIST OF REFERENCES

The following reference numbers are sources used in this Section, and are listed in full in Appendix B: 7, 24, 28, 33, 71, 74, 75, 89, 106, 131, 132, 160, 167, 244, 384, 385.

SECTION 6

STANDARDS AND SPECIFICATIONS

6.1 GENERAL

There are a large number of specifications available against which foam quality can be measured, and effectiveness in fighting fires can be assessed. However, criticisms both in the literature and expressed at survey meetings stress a dissatisfaction with the main standards. Some of the main points raised are:

- standards do not test in repeatable conditions, e.g. wind, temperature and fuel vapour pressure may vary.

- tests involve subjective influences such as manual application and 90% control.

- tests do not use the most demanding conditions, or even realistic conditions. For example foam is not projected onto the liquid surface, but onto a backplate allowing gentler application than in real fires.

- scale up factors from test pan fires to full scale are considered too low in some cases, e.g. large tank fires.

- test nozzles can produce a foam quality significantly different from that produced by brigade equipment.

- the choice of test fuels favours some foams against others.

- products are tailored to tests by manufacturers.

- burnback test should be conducted separately from reignition tests.

6.2 PRINCIPAL STANDARDS FOR FOAM CONCENTRATE

Standards and specifications which are known and in current use within the UK Fire Service are:

- Underwriters Laboratories Inc. Standard for Air Foam Equipment and Liquid Concentrated UL.162.

- Federal Specification for Mechanical Fire Extinguishing Foam Liquid O-F-555C.

- Military Specification for Six-Percent Aqueous Film-Forming Foam Fire Extinguishing Agent for Fresh and Sea Water MIL-F-24385C.

- Ministry of Defence Standard. Fire Liquid Extinguishing 42-21 (Protein type) 42-22 (Fluoroprotein type) 42-24 (Fluorochemical type).

6.3 MAIN DIFFERENCES IN SPECIFICATIONS

The approach of the four documents is widely different to the extent that it is impractical to comment on all differences individually.

An attempt was made to compare each standard by the US-DOT which commissioned Underwriters Laboratories to carry out a series of over 600 fire tests on some 20 commercially available, non alcohol foam concentrates.

The programme compared results under the following headings:

- a resistance to breakdown against hot surface

- an ability to control and extinguish

- sealability of the foam blanket

- burnback resistance

- compatibility with fresh and sea water.

Results were obtained for each of these factors using the test procedures in each of the four standards. The analysis is presented in great detail, but emphasises the general lack of correlation of results obtained under the different test methods.

A briefer summary of differences in the test methods is provided in the table at the end of this section.

Some of the main differences of approach are discussed below.

- Listing of concentrates with delivery systems.

  UL only issue a listing to the components of a system, i.e. a particular foam concentrate when used with a specific piece of equipment. If this specified combination is not strictly observed, the listing becomes invalid.

  While at first this would seem to be a good idea, on further consideration it proves to create more problems than it solves. The main difficulty in practice arises when a user wishes to change his foam concentrate supplier, then the equipment may well have to be changed if the listing requirements are to be strictly adhered to.

- Test parameters

  The UL test procedure allows manufacturers to stipulate within certain limits some of the conditions under which the concentrates should be tested, for example, the test fuel is to be n-heptane (or, at the manufacturer's option, a more volatile fuel). The advantage of this approach is that it enables the testing authority to respond flexibly to new products introduced for specific purposes. The alternative approach of specifying in detail the range of values which will be met by the product is far more restrictive. However, the U.L. listings of concentrates become excessively complex as a result, and few users seem to take the trouble to ensure that the foam they are purchasing is listed for all the applications they envisage. This practice makes the U.L. listings difficult to compare with test results from the other three authorities.

- Different procedures for different foam types

The UL and FED Specifications do not differentiate between the protein and synthetic foams while the MIL specification is for aspirated AFFF only, and the DEF has a separate specification for Protein Fluoroprotein and AFFF. UL also cover uses of foam at any expansion ratio specified by the supplier, whereas the others generally apply to use of foams at low expansion only. This again gives rise to problems when attempting to make a comparison.

- Physical and chemical properties

On the question of physical and chemical properties the specifications vary. UL relies on the supplier setting them down, while the other three are quite detailed in their requirements. However differences in those requirements again make comparison difficult if not impossible, e.g. the pH value for the AFFF type foam range from 6-7 at the lower limit to 7.5-8.5 at the upper limit, but the protein foam requirements are consistant at a pH of 6-7.5. From these figures it can be seen that if an AFFF is to pass both the MIL and FED test a pH tolerance of between 6 and 7.5 is required but may be difficult to achieve.

Proteins and Fluoroproteins are tested with a non standard 5% solution under the DEF and FED specifications and AFFF is tested at 6% only under DEF and 5% under FED.

There are also considerable differences in the 25% drain times, the required values for viscosity and the stability limits.

- Quality assurance

Both the MIL F and the FED specifications address the subject of quality assurance and control while the DEF and the UL standards make no mention of it at all.

- Fire Tests

  In addition to the differences in specifications there are considerable differences in test procedures.

  UL is the only standard that makes provision for fire tests on both A&B class fires. The pan used by DEF and MIL tests is circular at 565mm and 1829mm dia. respectively and the FED and UL tests use a square pan measuring 3048mm square and 2156mm square respectively.

  The square pan has the advantage in so far as it will indicate the foams ability to flow and seal into corners, but it is easier to achieve final extinguishment by "cornering" the fire.

  The fuel used for the tests and foam application rates are quite different in each test.

  It can be seen that the DEF tests are on a much smaller scale and are carried out under cover which enables the results to be considered without the ever changing atmospheric conditions influencing the results.

  Burnback procedures are different for each specification with the DEF and MIL standards making use of a burnback pot while the UL and FED specification requires an opening in the foam to be made and ignited.

There have been significant improvements in foam quality since these standards and specifications were first published. Therefore there is a distinct need for updating. While this updating process may produce a more realistic series of standards in relation to the present generation of foams it is unlikely to make comparison and evaluation any easier.

6.4 POSSIBLE IMPROVEMENTS IN FIRE TESTING

The shortcomings of small scale pan fire tests appear to contribute to the difficulty experienced by those making a selection of which foam to purchase for general fire brigade use. It is virtually impossible to test foams repeatably on a full size scale because of cost and the many types of configuration that would be necessary.

It is possible, however, to extend and improve the pan test method to avoid some of the present criticisms. A detailed research project would be necessary to design an improved test, but it could be developed into a significant tool for advancing practical and theoretical knowledge of fire fighting foams.

Some features which could be included in an improved test are listed below for future consideration:

- The pan should be designed to allow foam to spread against a flame front. This could be achieved by either a long narrow pan, or a fan shaped pan. A long narrow pan would allow foam effectiveness to be judged by the distance the foam advanced against a standard fire. Burnback could be measured by cutting the foam supply when the blanket had reached a steady state and recording the time vs distance characteristics of the burnback.

  Such a test would be more representative of the real life use of foams. Both fluoroproteins, AFFF's and other foam types could be tested on the same apparatus since the advantages of good foam flow and good burnback resistance would both be demonstrable.

- Foam nozzles should be designed which can deliver a range of expansion ratios at constant flow rates. Foams should then be tested at fixed expansion ratios, with nozzle adjustments being made to compensate for the different expanding characteristics of each foam, giving a comparable basis for assessment.

- Foam should be delivered by a fixed or mechanically oscillating nozzle. Hand application should not be employed.

- The foam landing area within the test pan shuld be deeper than the remainder of the pan to allow plunging. Foam should be projected so that it falls directly into the fuel rather than by any other method of application which might artificially prevent plunging.

- Preburn time should be sufficiently long to allow the test tank walls to attain high temperatures in the region of 200°C to 300°C. Also the tank walls should be made of steel with a reasonable freeboard above the fuel level of at least 150mm to test the ability of the foam to extinguish in the presence of hot metal.

- Consideration should be given to monitoring radiation levels by instrumentation during fire tests rather than by manual estimation.

- If possible the tests should be conducted indoors to eliminate wind effects. If not, screens may be erected to reduce the effect of wind and strict standards should be set whereby tests are invalidated if annomometer readings exceed a preset level.

6.5 FURTHER STANDARDS

At various times during the survey, reference has been made to the standards that are in the course of preparation and are as yet only available in draft form -

1. BS 5306 Part 1
   Specification for the design and installation of Low Expansion Foam Systems.

2. ISO/TC21/SC5/WG5 N39
   Standard for the design and installation of Foam Systems.

3. BS 6535 Part 3
   Fire Extinguishing Foam concentrates.

4. ISO/TC21/SC6/WG4N59
   Fire Extinguishing media - Foam.

The BS (1.) and ISO (2.) relating to the design and installation of Foam Systems will be of considerable use for the design of fixed protection but they fall largely outside the scope of this report.

The BS (3.) and ISO (4.) relate to the Fire Fighting Foam Concentrates and will be of considerable use when they are complete and published, the date of which is not yet known.

There are a number of other specifications which may be worthy of consideration during the preparation of any new standard or data sheets, two of which are the Swedish "Nord Test Spec" and the German "DIN" which are at present only used by manufacturers exporting to those countries.

6.6 A STANDARDISED APPROACH FOR THE FIRE SERVICE

At present great reliance is placed on the integrity and the information provided by the manufacturers and suppliers when choosing foams. While in general the major suppliers give very sound information, there is doubt being expressed regarding the quality of some products entering the market from abroad at a considerably reduced price. There is, quite understandbly, pressure on the Brigades to purchase these products in the interests of economy.

For this reason, and the difficulties experienced in using the existing specifications and standards, there would seem to be a need for an alternative specification and quality control procedures for use by the Fire Service.

To prepare such a document would require a very much more detailed study of the standards and specifications reviewed in this report together with, perhaps, some of the lesser known standards in order to extract the most useful section from each.

Fire tests must be devised to produce more realistic and relevant information on the ability of modern foam to deal with the range of fuel and applications currently met.

6.7 PERIODIC TESTING OF FOAM CONCENTRATES

On the question of periodic testing for deterioration and ability to still put out a fire it would seem that it is not practical to do this at Brigade level. There are a number of alternatives for doing this which are:-

- Return a sample to the supplier.
- Send the sample to an independent laboratory or,
- Set up an independent testing facility.

There are precedents amongst oil companies for conducting in-house testing of foam concentrates. The organisations concerned consider that it is undesirable to rely on manufacturers tests when the manufacturer has a clear commercial interest in the outcome. Whilst there is no suggestion that any supplier has falsified results, it is always possible that an individual could act upon misplaced zeal at sometime in the future.

6.8 LIST OF REFERENCES

The following reference numbers are sources used in this Section, and are listed in full in Appendix B: 14, 17, 18, 19, 20, 21, 35, 37, 43, 48, 51, 63, 64, 71, 74, 116, 119, 157, 158, 159, 167, 197, 250.

FIRE TEST METHOD

	UK DEF	MLF 2485	UL 162	OF 555C
Test pan shape	Round	Round	Square	Square
Area m^2	.25	2.6	4.6	9.2
Height mm	146	127	305	914
Fuel Type	Not Spec.	Gasoline	N-Heptane	Gasoline
Fuel depth mm	25	17.5	51	30
Freeboard mm	122.5	110	152	610
Preburn Sec.	60	15	60	60
Application Method	Plunging	Fan Shaped Discharge	Plunging	Off back-board
Application				
Application rate - $1/m^2$	2.85	2.85	2.44	2.44
Application - duration Sec.	180	65	300	300
Control time Sec.	Not Spec.	Not Spec.	Not Spec.	240
Extinguishing time Sec.	180	65	300	300
Burnback area m^2	.01	.02	.02	.02
Max burnback area m^2	Total pan	.65	.37	.26
Burnback duration Sec.	Not Spec.	240	300	300

SECTION 7

DISCUSSION OF RESULTS

7.1 TYPES OF FOAM

The review of fire fighting foams available and their chemical and physical properties shows the development of each type of foam together with uses and limitations which have resulted in the further development of new and improved foams.

Protein based foams, for instance, have developed with improvements in chemical technology whereas synthetic based foam allowed a more radical approach to fire extinguishment with the introduction of film forming effects. Each type of foam has also had to be adapted to changes in use of certain products, such as hydrocarbon liquids, polar solvents and alcohol liquids.

In many ways the foams available today represent frozen stages in the historical development of mechanical airfoams. Many fire brigades and services have retained a particular part of this history. There are many reasons why this has taken place. Cost normally heads the list of reasons, followed by compatibility with existing equipment and compatibility with users stocks of foam.

Foam concentrate has a relatively long shelf life, up to 10 years or more. Foam making equipment lasts even longer and it might seem unreasonable to change either if a particular risk necessitating change does not apparently exist. Conversely some fire brigades and services have made positive efforts to keep up to date and have made quite radical changes to the type of foam and the equipment they use. Surveys have been carried out which indicate that the majority of fire brigades, services and refineries use fluoroprotein foams. They believe the combination of stability, heat resistance, fuel tolerance, reasonable fluidity and relatively low cost far outweigh the merits of other types of foam. An increasing number of fire brigades have been "converted" to the use of AFFF. These believe that the cost is justified by its fast fire control capability in the case of hydrocarbon spill fires from vehicle crashes and the long and high throws that can be achieved using straight jet monitors on hydrocarbon spill fires from vehicle crashes and the long and high throws that can be achieved using straight jet monitors on hydrocarbon tank fires. A small number of brigades still use protein foam as their main stock and may have to change to fluoroprotein when they replace their 6% proportioning equipment for 3% or variable equipment for use on alcohol resistant foams.

Most of the brigades visited in this survey had small stocks of alcohol resistant foam but this was usually if there was a fixed polar solvent or alcohol risk in their area.

What did not appear to be always taken into consideration was the mobile risk of polar solvent or alcohol through their area and therefore brigades should consider equiping themselves with adequate stocks of alcohol resistant foam concentrate.

The main reason for the low use of AFFF (AR) types of foam is the high price in the UK. Typically AFFF (AR) concentrates are five times the price of protein concentrates. It is possible that these prices could be reduced in the next few years to be more in line with prices in the USA where AFFF (AR) concentrates cost less than twice the price of protein concentrates.

There are specialist sections within main fire departments in the USA who deal with hazardous chemical spillages and are equipped with HAZMAT foams for vapour suppression. Consideration could be given within each fire brigade in the UK as to whether it is sufficiently equipped with specialist foams and trained in their use.

7.2 PROPERTIES OF FOAM

Certain foam properties appear to have a significant effect on the performance of foams in fires and yet are not given sufficient prominence in fire tests and manufacturers information;

- Foam flow is important in the ease with which a foam blanket can spread, and is particularly significant for rim seal fires.

- Vapour pressure of test fuel. Some commercial fuels such as petrol can very widely in vapour pressure, and this should be taken into account in fire tests.

- Aliphatic and Aromatic fuels. There is some evidence that certain foam types perform better on aliphatic fuels than aromatic.

- The application rates given in the Manual of Firemanship should be revised.

- There is a lack of experimental evidence on how and if foam films contribute to the extinguishment of liquid fuel fires.

7.3 ASPIRATION

On the subject of the aspiration versus non aspirated synthetic detergent foam it is not so much a question of whether to use a foam solution with little or no aspiration but rather where and how to use it.

It is generally accepted that where quick knock down of a fire involving hydrocarbons and rescue is of prime importance the use of non aspirated AFFF is very effective. In such a case securing the fire will be dealt with at the same time as rescue is taking place.

Where the prime need is the ability to project a foam over relatively large distances it may only be possible to achieve this with a solution having virtually no expansion. In such cases almost total reliance is placed on a rather fragile aqueous film to extinguish the fire and maintain security.

This is a subject that is in need of further investigation and research to determine the limitations of using foam in this way. At present it is not proven that "unaspirated" AFFF can be effective on storage tank fires.

7.4 INFORMATION AVAILABLE

Information on the subject of fire fighting foams is available through a large number of data bases and libraries which makes review and assessment a rather time consuming and expensive task.

There would seem to be a requirement for a single central information base for use by the fire service.

7.5 STANDARDS AND SPECIFICATIONS

There is a need for improved test methods which are more realistic in the way that they evaluate the capabilities of foams extinguishing fires. In certain cases, such as large tank fires, it may be necessary to conduct a full scale test programme to properly evaluate equipment and foam types. However, in the short term much can be done to improve smaller scale tests without committing the volume of resources that would be required for a full scale test programme. It is recommended that a programme to develop an improved medium scale test along the lines set out in 6.4 below should be undertaken.

There are a number of national and international specifications and standards all of which are structured to some degree in different ways and calling for varying standards and tests.

It would be advantageous to the fire service if a standard and data sheets were developed against which the brigades could more effectively evaluate the performance and costs of foam concentrates.

7.6 ACTIONS AND FUTURE RESEARCH

Throughout the text of this report references are made to areas for possible future research or improvements/modifications to existing procedures. These items are summarised below for reference purposes.

1. Foam applications rates in the Manual of Firemanship should be reviewed. This should initially be revised in line with MRAR's in

other international standards, but subsequently the result of future test programmes should be incorporated in future revisions.

2. A new medium scale fire test should be developed to more accurately reflect the performance of foams in use.

3. The centralised collection and dissemination of data on foam and other aspects of fire fighting should be continued and developed to assist fire brigades in making unbiased purchasing decisions. This could include production of foam data sheets and possibly be extended to cover equipment.

4. An independent programme should be established for performing periodic quality tests on existing foam stocks held by Fire Brigades.

5. Further pressure should be brought to bear on suppliers of foam concentrates to present technical data in a standard format to allow direct comparison between products. Information on the throw and footprint of nozzles and foams in combination would be a valuable addition to present data.

6. Hazmat foams should be investigated with a view to establishing whether certain brigades should be encouraged to hold stocks and train in their use.

7. The effectiveness of alcohol resistant AFFF should be investigated for use against road tanker fires of polar solvents. If the question of whether it can be effective when applied forcibly through standard brigade equipment is resolved in its favour, then consideration should be given to advising fire brigades on stockholding.

8. Further investigation is required into the subject of the effectiveness of "non-aspirated" AFFF for storage tank protection. It may require a large scale fire test to resolve the issue, but since at present reliance is being placed on an unproven technique, such a step is considered worthwhile.

9. Continued research into many aspects of fire fighting foams can provide much valuable data at present unavailable. The following topics are mentioned specifically:

the film forming process;
the significance of drainage time;
expansion ratios of various foams in the same equipment;
the effect of foam stream droplet size;
the effect of water sprays on foam blankets;
the effect of various properties of foam concentrates and finished foams;
compatibility of mixing concentrates and finished foams of various manufacturers and generic types;
use of medium and high expansion foams on flammable liquid fires;
the effectiveness of overkill rates of application;
the viability of 1.5% concentrates.

10. Means should be sought to obtain from oil companies information on the frequency and severity of fires in oil tanks, both fixed and floating roof. This information often exists but is not always freely released into the public domain.

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 describe 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
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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
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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.NULL
31	DILUTION OF FLAMMABLE POLAR SOLVENTS BY WATER FOR SAFE DISPOSAL.	P.F.THORNE
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33	TESTING OF FIRE FIGHTING FOAM	W.CAREY/M.SUCHOMEL
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44	THE NATIONAL INSPECTORATE OF FIRE SERVICES (SWEDEN)	SWEDISH BOARD OF RESCUE
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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
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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
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63	FOAM LIQUID FIRE EXTINGUISHING MECHANICAL SPECIFICATION	FEDERAL SPEC.
64	AIR FOAM LIQUID CONCENTRATES	UNDERWRITERS LABORTORIES
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66	ASSIGNMENT 65K2644 REPORT 19/10/65	UNDERWRITERS LABATORIES
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74	THE TESTING OF LOW EXPANSION FOAMS	TONY BRIGGS
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94	WHY WIDER GUIDANCE IS NEEDED (ARTICLE)	RON HIRST
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96	GERMAN TENDERS SENT TO BAHRAIN & BULGARIA	ARTICLE
97	LATEST EQIUPMENT 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.F.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 LAB 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.RYOERMANER
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 GRIGGS
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 MAY 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	G.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	LEAFLET
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	F.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 LIMITATIUN 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 GODEY WAY TO FIGHT A WAR (FLUROCARBON 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.HO[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.MELORUM/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 BIG 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.KILNER
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 HEPTANE 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.	C.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.