Fire Service Manual

Volume 2

Operational

Firefighting Foam

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Preface

This manual, Volume 2, Fire Service Operations – Firefighting Foam, deals with the production of foam, categories of fires and foams, application rates and the operational use of foam. Specific practical scenarios are also discussed.

A second manual is also to be provided under Volume 1, Fire Service Technology, Equipment and Media. This will deal with the technical aspects of foam concentrates, standards and equipment.

These books will replace:

Dear Chief Officer Letter 2/97 – Foam Application Rates.

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Firefighting Foam

Chapter 1 – Introduction

Firefighting foams have been developed primarily to deal with the hazards posed by liquid fuel fires.

Water is used for most firefighting incidents, however it is generally ineffective against fires involving flammable liquids. This is because water has a density that is greater than most flammable liquids so, when applied, it quickly sinks below their surfaces, often without having any significant effect on the fire. However, when some burning liquids, such as heavy fuel oils and crude oils, become extremely hot, any water that is applied will begin to boil. The resulting rapid expansion as the water converts to steam may cause burning fuel to overflow its containment and the fire to spread – this event is known as a slop-over. Also, the water that sinks below the fuel will collect in the container and, should the container become full, this will result in the fuel overflowing.

Finished firefighting foams, on the other hand, consist of bubbles that are produced from a combination of a solution of firefighting foam concentrate and water that has then been mixed with air. These air-filled bubbles form a blanket that floats on the surface of flammable liquids. In so doing, the foam suffocates the fire and can lead to the knockdown and extinction of the flames.

The low density of firefighting foam blankets also makes them useful for suppressing the release of vapour from flammable and other liquids. Special foam concentrates are available which allow vapour suppression of many toxic chemicals.

Water-miscible liquids, such as some polar solvents, can pose additional problems for firefighters. These quickly attack finished foams by extracting the water they contain. This rapidly leads to the complete destruction of the foam blanket. Consequently, special firefighting foams, generally known as ‘alcohol resistant’ foam concentrates, have been developed to deal with these particular types of liquid.

Some firefighting foams have also been developed specifically for use against class A fires.

The main properties of firefighting foams include:

- Expansion: the amount of finished foam produced from a foam solution when it is passed through foam-making equipment.
- Stability: the ability of the finished foam to retain its liquid content and to maintain the number, size and shape of its bubbles. In other words, its ability to remain intact.
- Fluidity: the ability of the finished foam to be projected onto, and to flow across, the liquid to be extinguished and/or protected.
- Contamination resistance: the ability of the finished foam to resist contamination by the liquid to which it is applied.
- Sealing and resealing: the ability of the foam blanket to reseal should breaks occur and its ability to seal against hot and irregular shaped objects.
- Knockdown and extinction: the ability of the finished foam to control and extinguish fires.
- Burn-back resistance: the ability of the finished foam, once formed on the fuel, to stay intact when subjected to heat and/or flame.
The performance of firefighting foams can be greatly influenced by:

- The type of foam-making equipment used and the way it is operated and maintained.
- The type of foam concentrate used.
- The type of fire and the fuel involved.
- The rate at which the foam is applied.
- The quality of the water used.
- The length of pre-burn.

The most effective and efficient use of firefighting foam can only be achieved after full consideration has been given to all of the above factors.

This Volume of the Manual describes all aspects of the operational use of firefighting foam and in particular its use against class B liquid fuel fires. Topics covered include recommended minimum application rates and application techniques; practical scenario considerations; and the logistics involved in dealing with fires in storage tanks.

The section on firefighting foams in Volume I of the Manual describes the technical aspects of firefighting foam and discusses the types of equipment typically used by the fire service to produce it. Topics covered include the properties of foam concentrates, finished foams and foam equipment; application rates; and the classes of, and types of, fire for which foam can be used. However, the more important operational aspects included in Volume I are also summarised in Chapters 2, 3 and 4 of this Volume. At the rear of this Volume, there is a glossary of terms used in this Manual and other terms that may be used in connection with firefighting foams.

It must be stressed that this Manual only gives general information on the use of firefighting foams. Incidents requiring the use of foam are varied and preplanning in support of an effective risk assessment at the commencement of an incident is of the utmost importance to ensure that the correct foams, equipment and tactics are selected and employed.

Chapter 2 – Production of Finished Foam

2.1 General

Finished foam is produced from three main ingredients: foam concentrate, water and air. There are usually two stages in its production. The first stage is to mix foam concentrate with water to produce a foam solution. The foam concentrate must be mixed into the water in the correct proportions (usually expressed as a percentage) in order to ensure optimum foam production and firefighting performance. This proportioning is normally carried out by the use of inductors (or proportioners) or other similar equipment. This results in the production of a 'premix' foam solution. In other words, the foam concentrate and water have been mixed together prior to arriving at the foam-making equipment. Occasionally, premix solutions are produced by mixing the correct proportions of water and foam concentrate in a container, such as an appliance tank, prior to pumping to the foam-making equipment. In addition, some types of foam-making equipment are fitted with a means of picking up foam concentrate at the equipment; these are known as 'self-inducing' with the mixing taking place in the foam-making equipment itself.

The second stage is the addition of air to the foam solution to make bubbles (aspiration) to produce the finished foam. The amount of air added depends on the type of equipment used. Hand-held foam-making branches generally only mix relatively small amounts of air into the foam solution. Consequently, these produce finished foam with low expansion (LX) ratios, that is to say, the ratio of the volume of the finished foam produced by the nozzle to the volume of the foam solution used to produce it, is 20:1 or less. Other equipment is available which can produce medium expansion foam (MX) with expansion ratios of more than 20:1 but less than 200:1, and high expansion foam (HX) with expansion ratios of more than 200:1 and possibly in excess of 1000:1.
The following Sections describe in more detail some of the important factors of foam production that were introduced above.

2.2 Percentage Concentration
All foams are usually supplied as liquid concentrates. These must be mixed with water, to form a foam solution, before they can be applied to fires. They are generally supplied by manufacturers as either 6%, 3%, or 1% foam concentrates. These have been designed to be mixed with water as follows:

- 6% concentrates
  6 parts foam concentrate in 94 parts water,
- 3% concentrates
  3 parts foam concentrate in 97 parts water,
- 1% concentrates
  1 part foam concentrate in 99 parts water.

1% concentrate is basically six times as strong as 6% concentrate, and 3% concentrate is twice as strong as 6% concentrate. However, the firefighting characteristics of finished foam produced from 1%, 3% and 6% concentrates of a particular type of manufacturer's foam should be virtually identical.

The lower the percentage concentration, the less foam concentrate that is required to make finished foam. The use of say 3% foam concentrate instead of 6% foam concentrate can result in a halving of the amount of storage space required for the foam concentrate, with similar reductions in weight and transportation costs, while maintaining the same firefighting capability. Not all foam concentrates are available in the highly concentrated 1% form, e.g. alcohol resistant and protein based foam concentrates. This is because there are technical limits to the maximum usage concentrations of some of the constituents of foam concentrates.

It is extremely important that the foam induction equipment used is set to the correct percentage. If 3% concentrate is induced by an induction system set for 6% concentrate, then twice the correct amount of foam concentrate will be used creating a foam solution rich in foam concentrate. Not only will this result in the foam supply being depleted very quickly and an expensive waste of foam concentrate, but it will also lead to finished foam with less than optimum firefighting performance, mainly due to the foam being too stiff to flow adequately. Alternatively, using 3% foam concentrate where the system is set for 1% will result in a solution with too little concentrate to make foam with adequate firefighting performance.

It is also very important to have compatibility of foam-making equipment and induction equipment, and just as importantly, foam induction equipment must be checked regularly to ensure that it is operating correctly and giving an accurate rate of induction.

2.3 Aspiration
Once the correctly mixed foam solution has been delivered to the end of a hose line, there are a number of forms in which it can be applied to the fire. Generally, foam application is referred to as being either 'aspirated' or 'non-aspirated':

- Aspirated foam is made when the foam solution is passed through purpose designed foam-making equipment, such as a foam-making branch. These mix in air (aspirate) and then agitate the mixture sufficiently to produce uniformly sized bubbles (finished foam).
- 'Non-aspirated' implies that no aspiration of the foam solution has taken place.

Consequently, the term 'non-aspirated foam' is often used incorrectly to describe the product of a foam solution that has been passed through equipment that has not been specifically designed to produce foam, such as a water branch. However, the use of this type of equipment will often result in some aspiration of a foam solution. This is because air is usually entrained into the jet or spray of foam solution:

- As it leaves the branch.
- As it travels through the air due to the turbulence produced by the stream.
- When it strikes an object. This causes further turbulence and air mixing.

There is sufficient air entrained by these processes to produce a foam of very low expansion (often with an expansion ratio of less than 4:1).

To more accurately describe the different types of finished foam produced, the terms 'primary' or 'secondary' aspirated are preferred:

- Primary aspirated foam - finished foam that is produced by purpose designed foam-making equipment.
- Secondary aspirated foam - finished foam that is produced by all other means, usually standard water devices.

Secondary aspirated foams generally have an expansion ratio of less than 4:1.

2.4 Foam Expansion Ratios
(a) General
As mentioned previously, finished foam is usually classified as being either low, medium or high expansion. The expansion, or more strictly the expansion ratio, of a foam is the ratio of the volume of the finished foam to the volume of the foam solution used to produce it.

Typical firefighting foam expansion ratio ranges are:

- Low expansion
  less than or equal to 20:1
- Medium expansion
  greater than 20:1 but less than or equal to 200:1
- High expansion
  greater than 200:1

Secondary aspirated low expansion foams are usually produced by using purpose designed foam-making branches or mechanical generators.

Secondary aspirated low expansion foams are usually produced by using standard water delivery devices. Some purpose designed large capacity monitors have also been produced for this particular type of application (see Chapter 8, Section 3).

Medium and high expansion foams are usually primary aspirated through special foam-making equipment. This equipment produces foam by spraying the foam solution on to a mesh screen or net. Air is then blown through the net or mesh either by entrainment caused by the spray nozzle, or by an hydraulic, electric or petrol motor driven fan.
(c) Foam Concentrates

The amount that a foam solution can be aspirated not only depends on the equipment, but also on the foam concentrate that is used. For instance, synthetic detergent (SYNDET) foam concentrates are the only type that can be used to produce low, medium and high expansion foams; protein foam concentrates can only be used to produce low expansion foam and the remaining commonly used foam concentrates (i.e. AFFF, AFFF-AR, FP, FFFP and FFFP-AR), are mostly intended for use at low expansion, although they can also be used to produce medium expansion foam.

For flammable liquid fuel fires, effective secondary aspirated foam can only be produced using a film-forming foam concentrate.

(d) Typical Uses and Properties of Low, Medium and High Expansion Finished Foams

The various expansion ratios are typically used for the following applications:

- **Primary Aspirated Finished Foams**

  **Low expansion**
  - Large flammable liquid fires (i.e. storage tanks, tank bunds)
  - Road traffic accidents
  - Flammable liquid spill fires
  - Vapour suppression
  - Helidecks
  - Aircraft crash rescue
  - Portable fire extinguishers

  **Medium expansion**
  - Vapour suppression
  - Flammable liquid storage tank bunds
  - Small cable ducts
  - Small fires involving flammable liquids, such as those following road traffic accidents
  - Transformer protection

- **Secondary Aspirated Finished Foams**

  Large flammable liquid fires (i.e. storage tanks, tank bunds)
  - Helidecks
  - Aircraft crash rescue
  - Portable fire extinguishers

  Low expansion finished foams can be projected over reasonably long distances and heights making them suitable in many situations for use against fires in large storage tanks.

  Medium expansion finished foam can only be projected over small distances. However, with expansions of between 20 and 200, large quantities of foam are produced from relatively small quantities of foam solution. This, combined with its ability to flow relatively easily, makes medium expansion foam ideal for covering large areas quickly.

  High expansion finished foam flows directly out of the foam-making equipment and is not projected over any appreciable distance. Its coverage of large areas can also be slow but the immense quantity of foam produced (expansion ratios are sometimes in excess of 1000:1) can quickly fill large enclosures. Often, flexible ducting is required to transport the foam to the fire. Due to its volume and lightness, high expansion foam is more likely than low and medium expansion foam to break up in moderately strong wind conditions (Reference 1).

  The equipment used to produce secondary aspirated foam is often standard water type branches and nozzles although there are some specifically designed nozzles available. The foam produced in this way is not well worked, has a very low expansion ratio and short drainage time, and tends to be very fluid. These properties, combined with the film-forming nature of the foam concentrates used, can result in a finished foam blanket that can quickly knockdown and extinguish fires of some liquid hydrocarbon fuels. This ability can make them ideal for use in certain firefighting situations such as aircraft crash rescue. However, the foam blanket tends to collapse quickly, so providing very poor security and resistance to burnback.

Secondary aspirated foam can be thrown over a greater distance than is possible with primary aspirated low expansion foam. This has resulted in equipment being designed specifically to project secondary aspirated foam into large storage tank fires (see Chapter 5, Section 2b (iv) and Chapter 8, Section 3). Manufacturers of this equipment recommend the use of film-forming foam concentrate types for such applications. They claim that the finished foam produced usually has an expansion ratio of less than 4:1.
Chapter 3 – Categories of Fire and Firefighting Foam

3.1 Classes of Fire

In the UK the standard classification of fire types is defined in BS EN 2 : 1992 as follows:

Class A: fires involving solid materials, usually of an organic nature, in which combustion normally takes place with the formation of glowing embers.

Class B: fires involving liquids or liquefiable solids.

Class C: fires involving gases.

Class D: fires involving metals.

Electrical fires are not included in this system of classification (see this Chapter, Section 2).

In the following Sections, the general principles of extinguishment, particularly in relation to firefighting foams, are reviewed for each of the above classes of fire.

(a) Class A fires

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

Some manufacturers of AFFF, AFFF-AR, FFFP, FFFP-AR and SYNDET foams state that their products may be used as wetting agents at between 0.1% and 3% concentration to assist in the extinction of class A fires. For these fires, AFFF, AFFF-AR, FFFP and FFFP-AR may be used at low and medium expansion while SYNDET foams may be used at low, medium or high expansion.

There are said to be advantages in the use of wetting agents when fires become deep seated. In these conditions, water can be slow to penetrate. A wetting agent that reduces the surface tension of water is claimed to greatly improve penetration to the seat of these types of fire. When a wetting agent is employed, a deep seated fire is predominantly extinguished by the cooling effect of the water mix rather than by the smothering effect of any foam that may be produced.

Surfactant based foams display some wetting agent properties, but are more expensive than products sold purely for their wetting agent characteristics. From time to time, a few brigades take advantage of these wetting agent properties by using AFFF not only for class B fires (see (b) below), but also, they claim, to make better use of limited water supplies on Class A fires. It is claimed that the increased cost in agent is often justified by reduced water damage to the property.

Tests have indicated that in some circumstances the addition of some foam concentrates to water can help in reducing the severity of a Class A fire when compared to the use of water alone (Reference 2). In particular, when applied by spray to wooden crib fires, secondary aspirated AFFF, and to a slightly lesser extent, EFFF, AFFF-AR and SYNDET, performed significantly better than water. Several wetting agents were also tested but they did not perform much better than water. These results seem to indicate that wetting properties may not alone quickly and effectively deal with Class A fires involving wood. The smothering characteristics of the foams may also be helping. (In fact, this is the principle under which American ‘Class A’ foams have been developed).

During these tests, because of the size and shape of the fires, some areas of the cribs were not adequately reached by the spray. Consequently, tests were also performed using jet applications of water, primary aspirated AFFF and secondary
Class B fires are those which involve flammable based paints and lacquers (i.e. flammable and force the foam onto the fire.

(b) Class B Fires

class A fires, such as in warehouses, could be a consideration whilst maintaining sufficient foam flow to prevent the fire from being extinguished (see Chapter 5, Section 4). It can be dangerous to enter a deep foam blanket to track down the seat of the fire since there is a chance of sudden exposure to heat and products of combustion. Under some conditions, the fire can continue to burn for a considerable period at a reduced rate supported by the air released from the foam as it breaks down.

The use of medium expansion foam against indoor class A fires, such as in warehouses, could be a more effective and efficient use of foam. It should be possible to restrict the foam application so that the area of origin of the fire is kept under observation whilst maintaining sufficient foam flow to force the foam onto the fire.

(b) Class B Fires

(i) General

Class B fires are those which involve flammable liquids, liquefiable solids, oils, greases, tars, oil based paints and lacquers (i.e. flammable and combustible liquids). Combustion of these occurs entirely in the vapour that is present above the surface of the liquid. For firefighting purposes, Class B liquids can be subdivided into three categories, each requiring different properties from firefighting foams in order to achieve effective and efficient fire control and extinguishment.

The categories are:

- high flash point water-immiscible Class B liquids;
- low flash point water-immiscible Class B liquids;
- water-miscible Class B liquids;

Some high flash point liquid hydrocarbon fires, such as those involving fuel oils, can, under very controlled conditions, be extinguished using only the cooling effect of water.

However, most low flash point hydrocarbon fires, such as those involving petrol, cannot be extinguished by water alone as the fuel cannot be lowered to a temperature where the quantity of vapour produced is too small to sustain burning. In addition, water is generally much denser than liquid hydrocarbons, consequently, when applied during firefighting, it immediately sinks below the liquid surfaces without having any beneficial effect, in firefighting terms, on the fire. In fact, the application of water may cause the surface area of the fire to increase and spread to previously unaffected areas.

Firefighting foams are effective on low flash point liquids because they trap the vapour at, or just above, the liquid surface, trapping the fuel vapour, and prevent further vapour generation. Where deep foam blankets can be formed, such as in storage tanks or large warehouses, this process may be assisted by the increased pressure exerted by the heavier blanket. Film-forming foams produce a thin film on the surface of some of these class B liquids which may also prevent vapour escaping.

Additional benefits of using firefighting foams on these liquids are that they cool the liquid surface, reduce the vapour generation rate, obstruct radiation from the flame to the liquid surface and reduce the oxygen level, by the production of steam, where the foam, flame and liquid surface meet.

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

Large scale fire tests have been carried out in the UK to establish whether lead-free petrol, conforming with current British and European standards, would present any problems to the fire service using their standard low expansion foam equipment and techniques (Reference 3). The results showed that providing brigades follow the Home Office recommended minimum application rates (see Chapter 4), no problems would be expected when using good quality AFFF or FFFP against petrol formulations permitted by current and likely future standards. However, FP gave poor extinction performances against lead-free petrol containing oxygenates although its burnback performances were better than either AFFF or FFFP.

(iv) Water-miscible Class B Liquids

Polar solvents and hydrocarbon liquids that are soluble in water (water-miscible) can dissolve normal firefighting foams. Such liquids include some petrol/ethanol mixtures (see above), methyl and ethyl alcohol, acrylonitrile, ethyl acetate, methyl ethyl ketone, acetone, butyl alcohol, isopropyl alcohol and many others.

Water-miscible class B liquids, such as some polar solvents, require the use of alcohol resistant type foam concentrates for firefighting and for vapour suppression. These foams form a polymer membrane between the water-miscible and the foam blanket which virtually stop: the destruction of the foam and allows vapour suppression and cooling to continue. Alcohol resistant foam concentrates lose effectiveness unless they are applied gently to the surface of polar liquids, avoiding plunging (see Chapter 2, Section 2).

(c) Class C Fires

Class C fires are those involving gases or liquefied gases.

In recent years liquefied flammable gases have become an increasingly important source of fuel in commerce and industry. Increased use brings increased transportation of these liquids throughout the country by road, rail, in UK coastal waters, which in turn increases the possibility of accidental spillage. The product group includes LPG (Liquefied Petroleum Gas, usually propane or butane) liquid ethylene and LNG (Liquefied Natural Gas, i.e. methane).

Boiling points for these liquefied gases are low and so in the event of spillage, rapid vapour production occurs. Due to the greater amounts of vapour produced and the low buoyancy of cold vapour, the dispersal of this vapour is more problematic than from spilled flammable liquids such as petrol. In still air conditions, and where the ground is sloped or channelled, this vapour can travel long distances from its source. Liquefied gas vapour has been known to travel 1,500 metres from a spilled pool of liquid whilst retaining a concentration above the lower flammability limit.

Medium and high expansion foams are suitable for liquefied gas spills both for fire extinction and vapour suppression. The surface of the foam in contact with the liquid forms an icy slush which insulates and protects the upper layers of foam, and which in turn acts by reducing the evaporation rate from the liquid. A further important advantage is the relatively low amount of heat transmitted to the liquid by water draining from medium and high expansion foams.

Low expansion foam is not suitable since it increases the rate of evaporation from the liquid. For a liquefied gas spillage any reduction in the rate of evaporation of the liquid is beneficial in that it limits the size of the flammable (or explosive) cloud generated and hence reduces the possibility of ignition.

(d) Class D Fires

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

3.2 Electrical Fires

Firefighting foams are unsuitable for use on fires involving energised electrical equipment. Other extinguishing media are available. Fires in de-energised electrical equipment are treated as either class A or B as appropriate (see this Chapter, Section 1).

3.3 Types of Liquid Fuel Fire

(a) General

The classes of fire discussed in the previous Section have a strong bearing on the tactics and techniques of using firefighting foam. However, the size, shape and general appearance of a fire is also of particular importance when tackling class B or class C fires. Firefighters often refer to spill fires, pool fires and running fires and the variations in firefighting technique required to tackle each. This Section describes these types of fire and how their characteristics can affect the approach to firefighting.

These descriptions relate to ideal conditions which in practice are unlikely to occur exactly as described and in some situations, such as incidents involving aircraft, more than one of these situations may occur simultaneously. Even so, they illustrate the principles involved.

(b) Spill Fires

Spill fires occur in unconfined areas of flammable, or combustible liquids with an average depth of around 25mm or less. There is often variation in the depth of the spill due to unevenness of the surface on which the liquid stands. Because it is unconfined, a spill fire may cover a very large area.
The main characteristic of spill fires is their relatively short burning times. If an average burn rate of 4mm of the depth of fuel per minute is assumed, then most of the fuel involved in a spill fire will have burnt away within 7 minutes of ignition. Such brief burn times are, however, unlikely to occur in practice. Flammable liquid may remain in a ruptured fuel container and burn for a considerable time, continuous leakage may replenish the spill or numerous deep localised burning pools of fuel may form over a large area.

(c) Pool Fires

Pool fires occur in confined pools of flammable, or combustible, liquids which are deeper than 25mm but not as deep as the contents of storage tanks. A pool fire may cover a large area depending on the volume of the fuel source and the area of the confined space. It may take the form of a banded area in a tank, farm or a hollow pit or trench within which flammable liquid has collected from a ruptured process vessel, road or rail tank.

The difference between pool fires and spill fires is that pools may, depending on depth, continue to burn for a considerable period of time. As a result, firefighters are more likely to encounter a well developed fire burning evenly over a large area, rather than the more isolated, scattered fires which are characteristic of an unconfined spill. Foam may also be subject to more fuel contamination if forceful application is used due to the depth of the fuel. Consequently, techniques such as playing the foam stream against a solid surface and allowing the foam to run onto the fire, may be both desirable and a practical possibility if suitable surfaces are available (see Chapter 5, Section 2).

The sustained high levels of heat output may demand more effort to be made in cooling exposed structures, both to minimise damage during the fire and to prevent reignition after extinguishment. It should be remembered that if water is used for cooling, it will break down any existing foam blanket in that area, allowing any remaining flames to burn back and preventing further blanket formation until the water application ceases.

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

(d) Spreading Fires

Spreading fires can be described as unconfined spill or pool fires in which the liquid fuel is being continuously supplemented by a spray, jet or stream from a ruptured tank or equipment. The continuous supply of fuel often results in burning liquid flowing into inaccessible areas, such as drainage systems and floor voids.

An early step in fighting a spreading fire is to stop the flow of product to the flames whenever possible. Water spray provides an excellent screen behind which to approach the fire and close leaking valves for instance. The flow from a storage vessel can also be stopped by water displacement if there is sufficient ullage above the source of the leak. This method has been successful in the case of a ruptured storage tank line. Water is pumped into the tank to raise the liquid fuel above the level of the outlet line so that water, instead of product, flows from the broken line.

If the flammable liquid is a high flash point fuel, the burn back rate of flames through the spray, jet or stream of fuel leaking from the container may be less than the rate at which the fuel is discharged from the leak. In this situation, the discharging fuel will not be on fire. Consequently, the fire can be extinguished with a foam blanket or water spray in a similar fashion to a pool fire, the only additional precaution being to ensure that the level of fuel does not rise sufficiently to over spill the container. Sand bagging, diversion channels and pumping out are all useful techniques to help prevent drowning of containment.

(e) Running Fires

This term refers to the case when a burning liquid is moving down a slope or a broad front. The situation is rare but extremely hazardous because of the rapidity with which objects and people in the path of the flow can be enveloped. It is not possible to advise any course of action other than rapid evacuation from the oncoming flow. If monitors and hoses are immediately available they could provide sufficiently rapid knockdown.

On some fuels, film-forming foams are considered particularly effective at fast knockdown, although other foams can have similarly rapid effects. Another technique is to lay a band of foam at the lower end of the path of flow so that any pool that builds up will do so beneath a foam blanket. For this type of application fluoroprotein or film-forming alcohol resistant foams might be considered most suitable because of their stability, although other foams would also satisfactorily perform the task.

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

(f) Other Terms

Various other terms are used for different types of fire and explosion incident such as BLEVE (see Glossary of Terms - Firefighting Foams, at the rear of this Volume), vapour cloud explosion, gas flare, etc. These have not been covered separately since the use of firefighting foam is not directly involved.
Chapter 4 – Recommended Minimum Application Rates

4.1 General

The application rate of a foam onto a fire is normally expressed as the amount of foam solution, in litres per minute, to be applied to every square metre of the total area to be covered with foam.

The Recommended Minimum Application Rate is the minimum rate at which foam solution is recommended to be applied to a fire. The rate assumes that all of the foam made from the foam solution actually reaches the surface of the burning fuel.

The recommended minimum application rate includes a ‘safety margin’ to help to take into account factors such as:

- variations in the quality of foam concentrate;
- variations in the quality of finished foam produced;
- some of the detrimental effects of forceful application.

The Home Office recommended minimum application rates for use by the UK fire service for fires involving water-immiscible class B liquids are given in Section 2 below. Advice is given concerning the application rates for fires involving water-immiscible class B liquids in Section 3 below.

4.2 Fires Involving Water-immiscible Class B Liquids

Tables 4.1 and 4.2 give the minimum application rates of foam solution recommended by the Home Office for use by the UK fire service when using manual firefighting equipment to apply low and medium expansion foam to fires involving water-immiscible class B liquids. Also, recommended durations of foam application are included in the tables.

It should be noted that the figures given in Tables 4.1 and 4.2 relate to minimum foam solution application rates and times and assumes that all of the finished foam produced from the foam solution actually reaches the surface of the liquid on fire. These rates should not be considered as being definitive; allowances must be made to compensate for losses due to circumstances such as fall out of finished foam from the foam stream, adverse weather conditions, breakdown of foam due to flames before it reaches the fuel surface, and loss of foam due to the thermal convection currents caused by the fire. For storage tank fires, these rates need to be increased by up to 60% to account for foam losses.

In addition, it is recommended that application rates should be reviewed if, after 20–30 minutes application, there has been no noticeable reduction in the intensity of the fire.

In practice, the recommended minimum application rates are of great importance in pre-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, branches, proportioners and hoses.

4.3 Fires Involving Water-miscible Class B Liquids

Application rates for water-miscible fuels vary considerably depending on the following factors:

- the type of fuel;
- the depth of fuel;
Table 4.1: Home Office Recommended Minimum Application Rates Of Foam Solution For the Production of Low Expansion Foam For Use on Liquid Hydrocarbon Fuel (Class B) Fires

<table>
<thead>
<tr>
<th>Foam Type</th>
<th>Minimum Application Rate of Foam Solution (lpm/m²)</th>
<th>Minimum Application Time (Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spill/Bund D&lt;45m</td>
<td>Tanks D=45m</td>
</tr>
<tr>
<td>Protein</td>
<td>6.5</td>
<td>NR</td>
</tr>
<tr>
<td>Fluoroprotein</td>
<td>5.0</td>
<td>8.0</td>
</tr>
<tr>
<td>AFFF</td>
<td>4.0</td>
<td>6.5</td>
</tr>
<tr>
<td>FFFP</td>
<td>4.0</td>
<td>6.5</td>
</tr>
<tr>
<td>AFFF-AR</td>
<td>4.0</td>
<td>6.5</td>
</tr>
<tr>
<td>FFFP-AR</td>
<td>4.0</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Notes to Table 4.1:
- < = less than or equal to
- > = more than or equal to
- D = Diameter of tank
- m = metre
- NR = Not Recommended for this use

Table 4.2: Home Office Recommended Minimum Application Rates Of Foam Solution For the Production of Medium Expansion Foam For Use on Liquid Hydrocarbon Fuel (Class B) Fires

<table>
<thead>
<tr>
<th>Foam Type</th>
<th>Minimum Application Rate of Foam Solution (lpm/m²)</th>
<th>Minimum Application Time (Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spill/Bund</td>
<td>Spill</td>
</tr>
<tr>
<td>SYNDET</td>
<td>6.5</td>
<td>15</td>
</tr>
<tr>
<td>Fluoroprotein</td>
<td>5.0</td>
<td>15</td>
</tr>
<tr>
<td>AFFF</td>
<td>4.0</td>
<td>15</td>
</tr>
<tr>
<td>FFFP</td>
<td>4.0</td>
<td>15</td>
</tr>
<tr>
<td>AFFF-AR</td>
<td>4.0</td>
<td>15</td>
</tr>
<tr>
<td>FFFP-AR</td>
<td>4.0</td>
<td>15</td>
</tr>
</tbody>
</table>

Note to Table 4.2:
lpm/m² - litres per minute of foam solution per square metre of burning area of fire

Due to the large number of water-miscible fuels in use, and the varying firefighting performance of different foams on each of them, information on the recommended application rates for a particular water-miscible risk should be obtained from the manufacturer of the alcohol resistant foam concentrate to be used.

Typical recommended foam application rates for water-miscible liquid fires range between 4 and 13 litres per minute per square metre. However, it is recommended that the minimum application time for a spill of water-miscible fuel should be 15 minutes and for tanks involving these fuels it should be a minimum of 60 minutes.

On water-miscible liquids, application must be such that the foam blanket is delivered gently onto the liquid surface without submerging the foam or agitating the liquid surface (see Chapter 5, Section 2). If some submergence and agitation is unavoidable, the foam blanket will be destroyed at a high rate and much higher application rates and application times will be required.

- the type of foam;
- the manufacturer of the foam;
- the method of foam application.

Some of the most widely used water-miscible liquids include:

- Alcohols (e.g. Methanol, Ethanol, Isopropyl alcohol)
- Ketones (e.g. Acetone, Methyl Ethyl Ketone)
- Vinyl Acetate
- Acrylonitrile
Chapter 5 – Operational Use of Foam on Class B Liquid Fuels

5.1 General

This Chapter mostly concerns the main fire service operational use of foam, that is on class B liquid fuels.

When using foam operationally, there are a number of basic, common sense procedures that need to be followed to help to ensure success, these are:

- **Objective of Foam Application:** On arrival at an incident, an immediate decision needs to be made on whether foam needs to be used and, if so, what is the objective that is hoped to be achieved by its application. For instance, is the objective to provide a temporary break in order to attempt a rescue or close a valve, or is the objective to totally extinguish the fire?

- **Collect Sufficient Resources:** Before commencing foam application, ensure that enough resources of foam, water, equipment, personnel etc. are collected together to enable the objective of foam application to be carried out successfully. Home Office recommended minimum foam application rates (see Chapter 4) should, where possible, be used as the basis for calculations. If a fire is to be totally extinguished, then running out of foam concentrate during application will probably result in a complete re-involvement of the fire and complete wastage of the resources already used.

- **Wind Direction:** Obviously, foam can only be effective when it reaches the intended target. Wherever possible, the foam stream should be directed downwind in order to project the foam over the maximum possible distance. In fire situations, this will not only mean that the firefighters will be able to stand as far away from the fire as is possible but, also, the wind will cause the fire plume to angle away from them and so further reduce the radiant heat being experienced by them.

- **Correct Operation of Equipment:** The foam-making equipment must be used under the correct operating conditions of flow and pressure. Inductors and foam-making branches must be matched and the correct foam concentrate for the fuel and the correct foam induction rate must be chosen. Care should be taken not to cover the air inlet holes of the foam-making branch because this will result in poor quality foam being produced.

- **Gentle Foam Application:** Foam application should be as gentle as possible. Forceful application, which is applying foam directly to the surface of a fuel, will generally result in fuel contamination of the foam, increased breakdown of the foam, and increased flame intensity and radiated heat from the area of application due to vigorous disturbance of the surface of the fuel. The overall effect will be a dramatic reduction in the effectiveness of the foam. In addition, forceful application to an existing foam blanket may cause breaks which reveal the underlying fuel. If complete extinction has not been achieved when this occurs, then a significant amount of burnback could result.

- **Continuous Foam Application:** Once foam application has commenced, it should continue without interruption until at least the objective of the foam application has been achieved. Interruptions in foam application...
will result in wasted resources. The foam application should at least be maintained at the Home Office recommended minimum application rate (see Chapter 4).

- **Edge Fires**: Long after the main bulk of a fire has been extinguished, flames are likely to persist around the edges of the foam blanket where it meets and attempts to seal against objects, such as hot metal container walls. These last flames are likely to require a great deal of time and foam to extinguish. If stocks of foam run out at this stage, the fire may burn back completely. Application should continue to be as gentle as possible, with consideration being given to using medium expansion foam if access and equipment permit. It is often better to reinforce the foam blanket near to persistent flames so that it flows over the area of its own accord. Using water to cool the external walls of a metal container around the area of flame can help to reduce the rate of vaporisation of the fuel, and hence the intensity of the flames. In addition, the cooler the metal walls of a container, the easier it will be for a foam blanket to seal against them, suffocating the remaining flames as it does so.

- **Maintaining the Foam Coverage**: Once a fire has been extinguished or a toxic/flammable fuel has been covered with a foam blanket, foam application should continue until a thick foam blanket has been built up. However, the foam blanket will break down and lose its water content with time. Consequently it is important that the foam blanket is regularly replenished in order to ensure continued protection from re-ignition or vapour release. Where possible, the use of water jets or sprays should be avoided in the vicinity of a foam blanket as these can also cause the foam to break down.

- **Maintain Foam-making Capability**: Even after the fire has been extinguished (or the vapour from flammable and/or toxic material has been suppressed) and a thick foam blanket has been built up, a significant hazard still remains. Consequently, the foam-making capability should be maintained, resources replenished and remain ready for immediate use until all hazards have been removed or neutralised.

- **Beware of Ignition of the Foam Blanket**: Even with a thick foam blanket in place, operations involving possible ignition sources, such as hot cutting, should be carried out with great care. Fuel contamination of foam can occur during application and the vapour from some fuels will penetrate the foam blanket. Complete involvement of the foam blanket in flame can happen in seconds if a contaminated foam blanket is ignited – this can occur with all types of foam concentrate. Foam production capability must be maintained throughout any such operations. Further discussion of these basic and other procedures follows with particular reference to the type of finished foam (i.e. low, medium or high) being used.

### 5.2 Low Expansion Foam

**General**

Low expansion foam-making branches throw their foam over much longer distances than medium or high expansion foam-making equipment. This length of throw is generally enough to allow firefighters to tackle large, open, liquid fuel fires while standing at a distance from the fire where the radiant heat is bearable.

Ideally, the application of the foam to the surface of the fuel should be as gentle as possible in order to achieve the most effective performance from the foam.

**Forceful Application**

Forceful application of the foam, such as when aiming a foam stream directly onto the surface of a burning fuel, causes the foam to impact heavily on, and penetrate below, the surface of the fuel ('Plunging'). This leads to a considerable amount of mixing of the foam with fuel causing the foam to become contaminated. Inevitably, some of the fuel within this contaminated foam will burn off, causing the partial destruction of the foam blanket as it does so.

In addition, when the foam stream hits the burning fuel, it causes a great deal of disturbance to the fuel surface which results in a considerable increase in flame intensity and hence radiant heat. This will cause the partial breakdown of any existing foam blanket and also makes it very uncomfortable for the firefighters to maintain their position.

**Gentle Application**

There are several gentle foam application techniques available which will reduce the impact velocity of the foam stream. These are:

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**Gentle Application**

There are several gentle foam application techniques available which will reduce the impact velocity of the foam stream. These are:
using the full trajectory of the foam stream. This reduces the impact velocity of the foam due to the loss of speed of the foam stream as it travels through the air and the dispersion of the foam in the stream during transit.

Another similar method is known as the ‘rain-down’ technique. This involves directing the foam stream almost vertically up into the air so that when the foam stream reaches its maximum height, it breaks up and the resulting chunks of foam ‘rain down’ onto the fire. This has two potentially serious drawbacks; the first is that any thermal updraft from the fire plume is likely to carry the foam upwards and away from the surface of the fuel; the second is that the technique requires the foam-making branch, and the firefighter, to be positioned relatively near to the fire.

- Front surface indirect application involves foam being rolled or pushed onto the surface of the fuel by aiming the foam stream at a point in front of the fuel and allowing the foam to build up. With further applications of foam to this area, a raft of foam will begin to gently flow across the surface of the fuel. This method leads to very little fuel contamination of the foam.

- Wall/object indirect application involves aiming the foam stream at a surface behind the fire (such as a storage tank) or at an object in, or to the side, of the fire. By positioning the branch at a suitable distance away from the object, the foam stream will have lost much of its energy by the time it hits the object. Further energy will be lost on impact with the object with the result that the foam will slide slowly down the object and gently onto the surface of the fuel. A raft of foam will form which, with further application of foam to the object, will increase in size and spread over the surface of the burning fuel. This method has the additional advantage that it can be used to cool hot metal objects which might otherwise cause edge sealing problems.

- Finger/hand deflection application involves the firefighter placing his hand or fingers directly in front of the outlet nozzle of the foam-making branch so that the foam issues as a spray rather than a jet, greatly reducing the impact velocity of the foam. This method is most suited to extinguishing small residual fires from very close range. One drawback of this method is that it may disturb the existing foam blanket and reveal some of the underlying fuel.

Suitable hand protection must be worn. This technique is not acceptable for use with large through-put foam-making branches where fingers may be bent back by the force of the foam stream. Care should also be taken when using long foam-making branches to ensure that the firefighter is not put off balance by trying to use this technique. ‘Blabber-mouth’ foam-making branches have flaps that can be opened and closed at the outlet end of the nozzle. These deflect the foam stream in such a way as when using this method of foam application.

(iv) Single Point of Application

In order to achieve a quick flame knockdown with the minimum of foam with a single branch, foam should only be applied to one point and the branch should be held still. This will allow a foam raft (or ‘bite’) to form which will then spread over the surface of the fuel.

Moving the branch will result in many smaller applications of foam which will not sufficiently cool the fuel locally or suppress the fire to allow an adequate foam blanket to form. This will lead to a great deal of foam destruction, and hence wastage, of the finished foam.

When using more than one branch, a single point of application should still be used wherever possible.

However, it should be noted that foam will only flow over a liquid fuel a maximum distance of 30 metres from the edge of the foam application area (see Chapter 7, Section 5b)(x)). Consequently, where the fire area is very large, several foam application points, and hence branches, will be required. In such cases, the number of application points should be kept to the absolute minimum that allows the foam blanket to cover the whole of the fire area.

One method of assisting in the spreading of foam over the surface of a fuel once a bite has been achieved is by producing a swirling motion in the whole surface area of the fuel. This can be done by moving the branch or branches so that the stream(s) lands slightly off centre of the liquid surface (see Chapter 7, Section 5b (xi)).

(v) Assistance Required to Apply Foam Accurately

Usually, when applying low expansion foam, the firefighter at the foam-making equipment will be unable to see where the foam stream is landing. Consequently, the firefighter may require help from someone standing to the side who can see where the foam is being applied and can indicate, perhaps by the use of a radio or arm signals, what movements to the foam stream the firefighter must make in order to ensure the required application can be achieved.

(vi) Extinction of Residual Flames

As mentioned previously, the extinction of any residual flames should, where possible, be by:

- the use of medium expansion foam;
- foam applied using the finger/hand deflection application technique;
- the gentle application of foam to the surrounding foam blanket in order to allow existing foam to flow over the flames.

Some combination foam-making branches are available that allow the operator to easily switch from low expansion to medium expansion foam, these have obvious applications here. However, tests carried out by the Home Office FRDG on one combination 225 litre per minute foam-making branch indicated that it produced very poor low expansion foam which was unable to sufficiently control a 55m² petrol fire. Consequently, the firefighter was unable to get close enough to the fire in order to use the medium expansion capability.

(vii) Continued Application After Extinction

Foam application should always continue after extinction in order to produce a very thick protective foam layer. It can take less than 4 minutes for half of the liquid content of a foam blanket to drain out. This may not have any effect on the appearance of the blanket but the loss of this amount of water will make the blanket less resistant to burn-back, less able to seal any breaks that may occur in the blanket, more likely to allow vapour to percolate through it, and make it more susceptible to being blown away by wind. Consequently, it is essential that the foam blanket is replenished at regular periods in order to maintain its effectiveness.

When replenishing, care should be taken to avoid applying water initially to the foam blanket. Applying water will break down the foam blanket, cause gaps in the blanket to reveal the underlying fuel and, in some situations, may produce a static discharge that could reignite the fire.

(viii) Precautions to Prevent Ignition of the Foam Blanket

Precautions should be taken to ensure that an ignition source does not come into contact with the foam blanket. Rescue operations that take place within the foam blanket will inevitably lead to much disturbance of the foam blanket and further fuel contamination. Should foam that has been contaminated with fuel ignite, then large areas of the foam blanket are likely to become involved in intense flames within seconds. These flames will probably die down relatively quickly but leaving the upper layer of foam badly damaged. Generally, the shorter and more forceful the foam application, the more severe any resulting fire is likely to be.
There have been several reports of floating roof tank fires that may have been ignited by the disconnection of foam from refined hydrocarbon liquids (e.g. naphtha) by the over-the-top application of water and/or foam should be applied via the sides of the tank. This gentle application method will allow foam to flow down on to the surface of the fuel and form a continuous raft of foam. Islands of foam that are not attached to the main raft should be avoided as this may produce a static discharge.

(iii) Limitations of Use

The expansion of secondary aspirated foam is very low, generally less than 5. On some fuels fires, its use can result in very quick control and extinguishment. However, tests have indicated that secondary aspirated film-forming foams can take up to twice as long to extinguish a petrol spill fire as that taken by the same film-forming foams when used primarily aspirated (Reference 4).

The impact of water or foam streams directly on the tank contents should also be avoided as this may produce a static discharge.

(b) Secondary Aspirated Foams

(i) General

At low expansion, film-forming foams (e.g. AFFF, AFFF-AR, FFFP, FFFP-AR) can be applied primarily aspirated, with the techniques described above, or they can be applied secondary aspirated. Only film-forming foams can be applied secondary aspirated, non film-forming foams such as P, FP and SYNDENT must not be applied in this way.

(ii) Application Techniques

Film-forming foams can be applied secondary aspirated by using standard water-delivery branches set to wide angle spray or fog. The use of spray or fog produces a relatively gentle application and, on some fuels, this will allow a film to form on the surface of the fuel.

Application should be made directly to the surface of the burning fuel. This requires the firefighter to get very near to the fire although a suitable spray pattern should provide sufficient protection from radiant heat. The method of application generally recommended is to spray the secondary aspirated foam across the burning fuel with a sweeping action, back and forth.

See Section (iv) below regarding the application technique when using purpose designed secondary aspirated foam making branches.

(iv) Use in Specialised Firefighting Equipment

Some purpose designed secondary aspirated foam making branches have been designed for use in process areas and/or for incidents involving large storage tanks. This equipment is claimed to throw foam across the burning fuel with a sweeping action, back and forth. This technique has now been mostly rejected in favour of applying large quantities of foam to fully involved large storage tank fires requiring a number of foam-making monitors to be positioned around the tank, each applying foam to a small area. This technique was known as ‘surround and drown’.

This required long periods of foam application before sufficient cooling of the fuel and knockdown of the flames occurred to allow small areas of foam to become visible on the surface of the fuel. This technique has now been mostly rejected in favour of applying large quantities of foam to a small area of the burning fuel surface. This provides a very high localised foam application rate which relatively quickly results in the localised knockdown of flames and the formation of a raft of foam (or “bite”) in the foam application area. Once formed, this raft of foam gradually enlarges and spreads across the surface of the fuel. The maximum distance this will spread is 30 metres in all directions (see Chapter 7, Section 5b(x) from the edge of the foam application area. Consequently, when fighting fires with large fuel surface areas, more than one main foam application point will be required.
needed in order to ensure that the rafts of foam formed meet and hence cover the whole of the area of fuel. The number of monitors this requires will obviously depend on their capacity but should also take into account the maximum foam spread distance of 30 metres. The aim should be to use the minimum number of foam application points possible and, where necessary, several monitors can be positioned to apply foam to the same point on the fuel surface.

Once a bite has been achieved, the spread of foam across the surface of the fuel can be aided by causing the fuel to slowly swirl around the tank. This movement can be achieved by allowing the stream from a monitor to land slightly off centre of the fuel surface (see Chapter 7, Section 3b) (x).)

5.3 Medium Expansion Foam

(a) General

Medium expansion foam can have relatively low stability and poor burnback resistance and it is the sheer volume of foam produced, combined with its inherent gentle application, that makes it an efficient and effective firefighting medium. For example, MX foam has a much greater volume than low expansion foam. From the same amount of foam solution, a medium expansion foam generator producing finished foam with an expansion ratio of 100:1 creates 10 times more finished foam than a low expansion foam-making branch producing foam of an expansion of 10:1. Typically, medium expansion foam-making equipment produces foam of expansions of between 50 and 100:1.

In order to make medium expansion foam, large quantities of air need to be mixed with the foam solution. This mixing takes place within the foam-making equipment and this greatly reduces the speed at which the foam emerges from it. As a result, using medium expansion foam against large fires can require firefighters to approach very close to the flames, exposing them to dangerous levels of radiated heat. The risk to firefighters can be reduced by the use of floor standing medium expansion foam generators which, once in position, can be left unattended. It should be noted that hand-held medium expansion foam-making generators should not be put on the ground while operating because they may suck in debris which could block or break the internal foam-making mesh.

The very gentle application characteristics and high volume output of medium expansion foam makes it particularly useful for rapid vapour suppression of hydrocarbon liquids (and water-miscible liquids when using alcohol resistant film-forming foam concentrates). It can also be used to fill, up to a maximum height of around 3 metres, small volumes such as those found in engine test cells and transformer rooms.

Medium expansion foam is among the reasons why it cannot be used to fight large storage tank fires.

Medium expansion FP foam has been successful in controlling crude oil band fires with long pre-burn times. The disadvantage of using medium expansion foams in these circumstances is that they do not release their water content quickly and therefore their cooling ability is limited. Other disadvantages of the use of medium expansion foam are that they do not flow well, particularly in windy conditions and their heat resistance and ability to seal against hot surfaces is also poor.

(b) Application Technique

To achieve the best possible fire knockdown, medium expansion foam should be applied in front of a liquid pool fire and an initial foam raft ('bite') should be formed with little movement of the branch. Further application of foam should then be used to widen the raft to allow it to spread over the surface of the fuel. This further application of foam should be to the edges of the raft, it should not be to the flames in front of the raft.

(c) Use as a Fire Break

The Forestry Commission has experimented with the use of MX foam in laying a barrier to grass, heath and brush fires. Providing there is not too much wind, the foam remains in position and, besides the direct effect of stopping flames, the drainage helps to create a wet surface to impede any creeping fire. Application should be made not less than 5 minutes nor generally more than 60 minutes before the fire front hits the barrier.

5.4 High Expansion Foam

(a) General

High expansion foam is produced from SYNDET synthetic detergent concentrate. The finished foam has an expansion ratio that can range from 200:1 to 2000:1 although the high expansion foam generating equipment used by the fire service normally produces finished foam of expansion ratios between 300:1 and 1200:1. High expansion foam can be effective in extinguishing fires in a wide range of solid and liquid fuels.

From the same amount of foam solution, fire service high expansion foam generating equipment can produce, in terms of volume, in excess of 10 times more finished foam than medium expansion foam-making equipment and 100 times more finished foam than low expansion foam-making equipment.

The high expansion foam is very slow-moving and is poured on to a fire rather than projected. It is mainly intended for use to totally 'flood' enclosed areas such as basements, warehouses, machinery spaces and ships' holds. It has also been used in hazardous areas where it can be unsafe to send personnel, such as refrigerated rooms, mine shafts and cable tunnels. Due to the large volume of foam produced from small amounts of foam solution, high expansion foam can also be used in instances where there is a limited water supply and where water damage needs to be kept to a minimum.

High expansion foam can be very effective outdoors but only if the wind speed is very low. Outdoor uses include vapour suppression and, at lower expansions of the range, e.g. 300:1 to 500:1, in controlling fires in spillages of hydrocarbon fuels. Obviously, due to its density and the way that it is produced, high expansion foam can only be applied very gently.
The major disadvantages of using high expansion foam for firefighting are:

- the release of the water content of the foam is very slow and therefore this provides only limited cooling, particularly for deep seated fuels in combustible solids;
- the foam does not flow well, consequently the foam will be at its lowest depth at the furthest point away from the generator;
- its poor flowing characteristics may also lead to large air pockets in the foam where combustion can continue even after the compartment has apparently been completely filled;
- due to large expansion ratios, high expansion foam is very light and can be blown away by even a minor breeze and by the up-draughts caused by fires;
- the foam cannot be projected and so the foam generating equipment must be positioned very close to fires. However, in certain situations, flexible ducting can be used to transport the foam to the required application area.
- High expansion foam should not be used to fight fires involving chemicals which generate enough oxygen to sustain their own combustion, e.g. cellulose nitrate.

The slow release of water from the foam is beneficial when used for the vapour suppression of LPG and other similar liquefied gases.

Before the production of high expansion foam begins, as much information as possible must be obtained about any compartment that is about to be flooded, i.e. its nature, size, layout and contents. If the contents of the compartment are stacked or placed up to or near the ceiling, it must be realised that the foam blanket may not extinguish all of the fire, and preparations must be made to attack this later. It must also be understood that the use of high expansion foam will inhibit the use of any other firefighting technique and may make it more difficult to commit firefighters into the compartment at a later stage.

(b) Planning Resource Requirements

Although the size of the compartment is known, it will be possible to calculate approximately how much foam concentrate will be needed to adequately fill it. For compartments containing combustible solids, sufficient foam should be injected to ensure a depth of at least 1 metre above the highest fire affected object. For flammable liquids, the fill height should be considerably more than 1 metre above the fuel surface.

To calculate the fill height, the approximate foam output of the particular high expansion foam generator in use will need to be known in m³/min at the required expansion ratio as well as its consumption of foam concentrate in litres per minute.

A simple table kept with the generator would help, but allowances must be made for the initial fast breakdown of foam that will occur due to the effects of heat, flame and hot objects. Holes in the compartment walls and the need to regularly ‘top-up’ the foam for a time after control of the fire has been achieved, will also need to be taken into account.

The minimum requirement should be to have sufficient high expansion foam generated to lift the height of the foam in the compartment by at least 1 metre per minute, with total filling of the compartment to the required height taking no more than 8 minutes. Resources should be made available to ‘top-up’ the foam for at least a further 30 minutes. In order to allow for the losses due to the breakdown of the foam, at least a total of twice the amount of resources (i.e. foam concentrate and water) required to fill the compartment to the required height should be made available before filling commences. If high expansion foam is to be used outdoors, then further allowances will need to be made for foam that is likely to be blown away.

(c) Positioning of High Expansion Foam Generators

High expansion foam generators should always, where possible, be placed in the open air, as products of combustion of the fire could otherwise affect the volume output and stability of the foam.

Ducting can be used on the outlet of a generator to enable it to operate in fresh air while effectively transporting the foam to the required area. This ducting should be kept as short as possible, without kinks, and any opening used must be larger in area than the ducting, to cut down back-pressure and to ensure that the maximum possible output can be generated. Doorways, hatches etc. may be usable as they are, but, in some incidents, openings may have to be made or improved.

The further high expansion foam has to travel through ducting or other areas in order to reach the fire, the more breakdown of the foam that will take place. Ideally, the foam generator should be positioned as near to the fire as it is as safe and practical to do so. Tests have been carried out using lay-flat polythene ducting on the outlet of a high expansion foam generator. Using an 8 metre length of this ducting, the volume of the foam produced by the generator fell by more than 50%. However, even though this is a big reduction in the foam volume output, even less foam is likely to reach a fire affected area 8 metres away from a foam generator if ducting is not used.

There are various kinds of high expansion foam ducting, but a heat-resistant type must obviously be used if the conditions demand it.

(d) Level of Injection

If HX foam can be injected at the floor level of the compartment, it will not have to contend with heated currents of air to penetrate the area. However, operational conditions nearly always require it to be injected at a higher level, and this will work provided that the injection is kept going steadily. There will probably be an initial fast breakdown of the finished foam but the sheer volume should soon penetrate.

(e) Ventilation

If a large volume of foam is to penetrate a compartment, it must displace the air in that compartment. Also, when the foam first attacks the fire, a
and the application of high expansion foam into the compartment should not be stopped, without good reason, until the fire is extinguished. Deep seated fires in some materials may require the maintenance of a foam blanket for a considerable length of time before being completely extinguished.

(g) Entering the Compartment
All personnel entering a high expansion foam filled compartment should wear BA, and the BA procedures should be rigorously applied. Firefighters should take in a hosereel or 45 mm hose line ready to extinguish with water any small pockets of fire still remaining, taking care that fire does not break out behind them.

(h) Hazards in High Expansion Foam – Safety of Personnel
High expansion foam, even in a relatively well-known environment, has a very claustrophobic effect. In an unknown compartment this effect can be heightened. Other hazards encountered are:

- there is a general loss in effectiveness of vision, hearing and sense of direction, i.e. disorientation;
- penetration of light from torches and equipment is severely affected;
- audibility of speech, evacuation signals, low-pressure warning whistles and distress signal units is also severely restricted;
- transmission of heat is reduced and the location and travel of fire are therefore harder to determine. Thermal image cameras are also ineffective. Damage to structural features above and around may not be visible, with the danger of ceilings etc. collapsing onto firefighters;
- the compartment may contain trapped gases which, with the introduction of fresh oxygen, could result in backdraught conditions;
- openings, machinery, electric cables etc. will all be harder to discern, and progress must therefore be even more careful than usual. Guide lines and communications equipment should always be fully used if firefighters need to be totally immersed in HX foam.

One of the factors that should be assessed is where the compartment can be safely ventilated. Due regard should be given to the risks of flashover and backdraught when venting a fire (see Fire Service Manual Volume 2 – Compartment Fires and Tactical Ventilation).

Should conditions be safe to do so, the best place for a vent is diametrically opposite the generator(s), at the highest level. To be most effective, low-level openings may need to be blocked and suitable openings may need to be made at a high level in order to ensure that the compartment is filled with HX foam as quickly as possible. Opening up a ceiling or roof would be ideal, but in some cases the highest available opening may be several feet below the top of the compartment. To facilitate ventilation, smoke extractors could be employed in the openings; high expansion foam generators can be adapted for this purpose. The officer-in-charge must station crews with hand-controlled branches or hose-reels at all the ventilation openings to cover any fire which might appear there. Under no circumstances should any of this water be injected into the compartment, however, as this would break down the foam.

(f) Maintaining Foam Production
Changes in the colour of the smoke issuing from the fire will give a good indication of whether the foam is achieving control of the fire. As mentioned above, there will be a degree of breakdown of the foam, and the application of high expansion foam into the compartment should not be stopped, without good reason, until the fire is extinguished. Deep seated fires in some materials may require the maintenance of a foam blanket for a considerable length of time before being completely extinguished.

(i) Clearing/Collapsing the Foam
The removal of HX foam from a compartment is not easy. Tests have been carried out using various methods (Reference 6) and, of these, the following gave the best performance:

- a high-pressure hose-reel branch;
- a dry powder extinguisher;
- a high expansion foam generator in suction mode, using semi-rigid ducting.

All of these methods have disadvantages, and the operational situation will largely determine which method is used. A high-pressure hose-reel is efficient but will cause further water damage. A dry powder extinguisher is also extremely efficient but leaves a combined powder/water residue which will have to be cleaned by a salvage team. A high expansion foam generator works well, provided that the water residue is led away by hose and the ducting is not too long but, to clear all of a compartment, the ducting will have to be moved around like a vacuum cleaner. This will be difficult where the compartment is large or where there is machinery, stacked goods, racks etc.

One obvious point which firefighters should remember is that the longer the high expansion foam is left, the easier it is to break down. Drainage from the foam weakens the bubble walls and, in the tests using breakdown by water, it took less water to complete the job after a 30-minute waiting interval than after a 15-minute interval.
6.1 General

In order to discuss the use of firefighting foams it is necessary to consider practical examples.

In this Section, information is given on how typical fires may develop in a variety of practical situations, and how the fire service could respond using various firefighting foams, equipment and techniques.

In practice, no two fires are exactly the same and so any generalised description is bound to be a simplification. The descriptions that follow each start with a summary of some of the difficulties involved with each type of fire. The second part of the scenario is a brief description of a typical fire and how it might be fought, particularly by the use of firefighting foam.

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

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

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

6.2 Preplanning

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

Formalised preplanning is usually carried out for larger incidents where the following factors need to be fully considered and arrangements put in place before the event occurs:

- risk assessment;
- supply lines of material/equipment;
- fresh resources of personnel;
- clear decision making on the fire ground;
- communications with third parties.

It can be very useful to use formalised preplanning for medium and small scale incidents, both as a training aid for firefighters and as a means of highlighting any deficiencies in existing methods, equipment and information.

6.3 Scenarios

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

These scenarios are idealised cases and it is appreciated that the timing, aims and problems
associated with each real fire incident will vary considerably. The use of these scenarios is to indicate the likely quantities of foam, water and equipment needed for direct fire attack.

In practice, greater resources are often committed because of the uncertainty of how serious the incident may become, to provide a ready reserve capacity and to provide indirect support or relief to the main fire attack team. It is left to each individual brigade to interpret how the objectives would be achieved given their own mix of equipment, materials, philosophy, logistics, and personnel policies.

(a) Road Tanker Crashes

A wide variety of flammable liquids and toxic chemicals is transported by road throughout the UK on urban and rural roads and motorways. Lorries can typically carry 38m$^3$ of flammable liquid cargo. A number of incidents have occurred where the contents of road tankers have been discharged onto the road and the resulting fire has caused loss of life.

When a road tanker is damaged in an accident it is unlikely to discharge all its contents at once onto the roadway. More usually, liquid will steadily leak from breaks in the tank pipe-work or in the vessel itself. Frequently, not all the contents are discharged, and a substantial volume may remain inside the vessel. Spillage of flammable liquid may catch fire immediately or there can be a delay while the flammable vapour spreads far enough to contact a source of ignition.

Consequently, there are a wide variety of fires that may face firefighters when they attend a road tanker crash. These can range from an extended leak from breaks in the tank pipe-work or in the vessel itself. Spillage of flammable liquid may catch fire immediately or there can be a delay while the flammable vapour spreads far enough to contact a source of ignition.

In terms of equipment, this would require the equivalent of fourteen 450 lpm foam-making branches and induction, and approximately four pumping appliances to supply the branches.

From a practical viewpoint, it would be difficult to deploy this amount of equipment rapidly. Even if hydrants were available, the time for laying hose would be considerable. In addition, assuming a fuel burning rate of around $4 \text{mm} \text{per minute}$, the fire would have burnt itself out in just over 7 minutes if no firefighting took place.

In taking a more practical view, there are many other factors that could be taken into consideration. Road surfaces are rarely flat. The road camber will tend to direct spillage into a more restricted area. Kerbs, banks and surface irregularities will tend to limit the spread of liquid, whilst rainwater drains will carry some away (with possible serious consequences of sewer fires and explosions). In addition, tankers are generally compartmentalised, and it would be highly unusual, although not unknown, for all of the compartments to be breached.

Perhaps, because of these factors the foam requirement for first response could be reduced to 25% of the "worst case", e.g. 684 litres of 3% film-forming foam concentrate, 22,116 litres of water and a foam solution flowrate of 1520 litres per minute. This would require four 450 lpm foam-making branches and one pumping appliance. However, experience and likely local conditions would need to be taken fully into account in setting such guidance for the first response capability, second and subsequent responses and back up resources.

Using the Home Office recommended minimum foam application rate for film-forming foams of 4 lpm/m$^2$ for fifteen minutes duration, a total of 91,200 litres of foam solution would be needed at a foam solution flowrate of 6080 litres per minute. This would require 2,736 litres of 3% film-forming foam concentrate and more than 88,000 litres of water.

(ii) Rural Tanker Crash

A rural tanker crash is likely to lead to a less extensive spill. Roads are narrower, more cambered and often flanked by banks or ditches. In these cases the brigade is more likely to be called upon to tackle a number of smaller isolated fires in accumulations of liquid, particularly since with longer response times shallower spills will have been burnt off. There would be some justification for less than 25% of the calculated foam supply figure, although water supplies are likely to be a major problem.
There should be far less difficulty in an urban area and there may be more need than in rural areas for mable liquid leakage rates generally lower because of reduced impact speeds. However, there is a severe risk of secondary fires being started which forces can be brought to bear on the tankers, giving a high chance of major damage to the structure and rapid discharge of the contents. In urban areas the potential life exposure can be high and there is a possibility of multiple secondary class A fires, particularly where the rail track is elevated above surrounding property or where buildings look down upon the track. In rural areas there can be severe problems of access and it may require time to lay on adequate water supplies.

(b) Rail Tanker Crash

As with road transport, many flammable liquids and toxic chemicals are transported by rail through urban and rural areas of the country. There are two types of rail tanker car generally used. A two axle car of approximately 45m³ (45,000 litres) capacity, and a bogie car of approximately 100m³ (100,000 litre) capacity. Diesel locomotives can haul up to 1,500 tonnes, and trains of two axle cars could comprise of as many as 22 cars.

The potential exists for a major incident arising from a rail crash. A wide range of risks are involved which require a variety of equipment and flexibility of approach from the fire service.

If LPG or similar liquefied gases are being transported there is a risk of a BLEVE. Depending on the result of an operational risk assessment at such an incident, it may be considered that the policy of evacuation of a wide area may be the only safe course of action.

Even with ordinary flammable and combustible liquids, exposed tanks can rupture suddenly and violently. If a passenger train is involved, there is the possibility of a major rescue operation in parallel with firefighting activities.

The speeds at which trains travel and their large momentum means that when a crash occurs, strong forces can be brought to bear on the tankers, giving a high chance of major damage to the structure and rapid discharge of the contents. In urban areas the potential life exposure can be high and there is a risk of explosion potential in sewers; flushing and venting of sewers; LEL (Lower Explosive Limit) measurement.

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

An urban location for a tanker crash involves a further set of considerations. Water will be readily available, brigade response time rapid and flammable liquid leakage rates generally lower because of reduced impact speeds. However, there is a severe risk of secondary fires being started which may become life threatening. Whilst there are fewer physical factors calling for a large foam set of considerations. Water will be readily available, brigade response time rapid and flammable liquid leakage rates generally lower because of reduced impact speeds. However, there is a severe risk of secondary fires being started which may become life threatening. Whilst there are fewer physical factors calling for a large foam...
There are many chances of complications with a rail tanker crash, and caution would lead most fire brigades to mobilise a considerably larger first response and rapidly arrange for support to be provided.

Tactics for such an incident require considerable flexibility. Water supplies may be restricted in the early stages, and the best use of limited quantities of water is to lay a foam blanket beneath exposed vehicles. FP or an alcohol resistant foam would be preferable because of their good heat resistance and stability. Water will be required for class A fires either in the surrounding area or in the interior of passenger coaches. Water monitors may also be needed for cooling exposed tanks, particularly if they are exposed to a flare fire. A further tank rupture must be expected and tactics set out with rapid redeployment or retreat in mind. Care would need to be exercised to ensure that any foam blanket in the area is not broken down and that liquid fuel, especially if already burning, is not spread over a wider area by the application of water.

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

(c) Aircraft Crash

Generally at aircraft incidents on airports or airfields the Local Authority Fire Brigade augment the airport fire service. The attendance time for the airport fire service to any incident that occurs anywhere on their airfield is normally less than two minutes although regulations state it must be less than 3 minutes. The airport fire service will have emergency plans for most eventualities and it is likely that they will have been put into action well before the arrival of the Local Authority Fire Brigade.

In addition, the airport fire service must attend incidents up to 1000 metres from the runway threshold but, for incidents further afield, they may attend in a reduced capacity, depending on the distance from the airport.

In an off-airport crash incident, a situation could arise where say a Boeing 747 crashes, after take-off, several miles from an airport. Such an aircraft could be virtually fully laden with Jet A1 (aviation kerosene) which amounts to about 156m³ (136,000 litres).

If ignition takes place, it is possible that much of the spill would have burned or drained away within 10 to 20 minutes of the incident and probably by the time the first Local Authority Fire Brigade appliances arrived at the scene of the incident. The initial crash/rescue teams to arrive might have to control and extinguish a large number of widespread class A fires and class B pool fires whilst assisting any survivors from the incident or from involved buildings, vehicles etc. In addition, flammable vapours would be given off from any unburnt fuel for several hours after the incident and this, too, would need to be dealt with. Problems of adequate water supply and access are likely to hamper any large scale firefighting exercise and therefore it is unlikely that large amounts of foam concentrate would be required.

Not all aircraft crashes will result in fire. There have been occasions where aircraft have crash landed at low speed and from low altitude. In such situations, the aircraft may have broken into several large parts without bursting into flames. It is possible that there could be many survivors.

In these circumstances, there is a risk of fire from free fuel flowing out of broken fuel tanks and fuel lines. This fuel should be immediately covered with a thick layer of foam. Frequent replenishment of the foam blanket would be required in order to ensure continued protection. At all times, foam application should be as gentle as possible in order to minimise fuel contamination of the foam. Even when a suitable foam blanket has been applied, sufficient firefighting equipment should be deployed, with firefighters in constant attendance, in case a fire breaks out within or around the foam blanket (see Chapter 5, Section 2(a) (viii)).

Should a large fire break out, then a mass application of foam would be required in order to suppress the fire. Given the limited resources likely to be available, the main objective of the attack should be to keep the fire away from any survivors and rescue personnel without obstructing their escape route.

Foam branches should be positioned as closely as possible to the fuselage, the initial discharge being directed so that the foam drives the fire outwards and away from the wreckage. If possible, fire should be kept at least 15 metres away from an intact fuselage.
Great caution should be used when applying foam near to wreckage as there is a risk of flushing fuel under or into the fuselage where it can present a far more serious hazard. Similar care should be taken to avoid the possibility of a water jet disturbing any foam blanket already laid on a liquid fuel surface.

In addition, there may be areas where firefighting foam will not penetrate and so other suitable extinguishants such as CO₂ and dry powder should be made available. The use of these back-up agents should be confined to spreading and running liquid fuel fires, the inhibition of enclosed spaces such as wing voids, or to deal with special fires such as engine nacelles or undercarriage assemblies.

(d) Marine Fires

The UK fire service is not responsible for combating fires offshore in UK territorial waters. However, any fire brigade with coastal boundaries may exercise its power under the Fire Services Act 1947 (as amended by the Merchant Shipping and Maritime Security Act 1997, Section 3), to attend fires at sea outside its areas particularly where human life was endangered. The following Section looks at three examples of marine fires where firefighting foams may be used.

(i) Engine Room

The example chosen is from a 2,000 tonne coastal tanker, although it is quite possible that fire brigades could be called to attend fires in any size of vessel from a yacht up to a ultra large crude carrier (UL/CC) of 400,000 tonnes or more. The principles of operation are similar for all steel construction vessels, but the complexity of the entry route, access to the engine room and size of the room itself would vary considerably.

A fire could occur from an oil fuel pipe breakage in the machinery space, with oil leaking onto the engine room deck and being ignited as a result of contact with hot metal surfaces. If the on board suppression systems (e.g. CO₂ or inert gas systems) and first aid firefighting fail to extinguish the fire, then the fire service will be asked to attend.

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

To achieve safe entry into a ship and perform a fire search is a challenging and hazardous operation even for skilled firefighters. In addition to the usual problems of using breathing apparatus in dark confined spaces, layers of hot gas may be encountered beneath deck levels, or thermal updrafts from shafts. Progress is inevitably slow and the steel work is likely to be very hot in places. Reserve crews will probably be required and protracted working should be expected.

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

The logistics of mounting a medium expansion foam attack involve considerable quantities of foam concentrate and there may be difficulties in providing this if the ship is at sea in rough weather.

When discharged into an area with many hot metal surfaces, the initial foam application will be largely destroyed. The resulting cooling effect is useful, but steam generation can be a further hazard to firefighters. For this reason, the foam requirements calculated in the following example are probably far lower than those needed in practice.

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

- 200m³ of medium expansion foam;
- Assuming the use of 450 lpm MX foaming branches with an output of 19.5m³ of finished foam per minute;
- 200m³ would require one branch for approximately 10 minutes or two branches for approximately 5 minutes;
- the foam solution requirement for two branches is 2 x 450 lpm x 5 minutes = 4,500;
- at 3% concentration, 4,500 x 3% = 135 litres of 3% foam concentrate is required;
- this is equivalent to 7 x 20 litre drums of 3% foam concentrate.

More foam concentrate and foam solution than that calculated above would be required to allow for foam burn off and continued application. The extra allowance for foam burn off is substantial but varies with the length of pre-burn and the mass of steel exposed.

Estimates of up to three times the initial calculated application quantity could be used to allow for burn off and a further three times the initial estimate for continued application after fire extinguishment. However, in an area where the structure has a high thermal capacity, such as an engine room, even this may not be enough. Allowing for foam burn off and continued application in such a situation could result in as much as 10 times the amount of foam concentrate calculated above being required. That is 1,350 litres of 3% foam concentrate, the equivalent of 68 drums.

(ii) Deck Fire

In the case of a similar sized coastal tanker, this example considers a deck fire originating from an oil leak in the deck pipe work system. Tankers normally carry their own on board foam systems to cover the deck area. These are normally operated by the crew, however, if the fire service have been called, this is probably as a result of the equipment being out of service or of it being inadequate for the purpose.

Deck fires are more likely to be intense during pumped loading and unloading operations, in which case back-up support should be available from the adjacent jetty. However, various cleaning and transfer activities take place at sea and may give rise to a running/spill oil fire.

The firefighters arriving on the scene must quickly assess the area of deck that could be affected by the spill and appropriate quantities of foam concentrate and branches should be requested. If the fire is large and spillage of flowing oil extends into the sea, assistance from firefighting tugs may be required. Communications and co-ordination should be maintained between the fire service, coast guard and the ship's master.

Low expansion foam, either a salt water compatible film-forming or FP foam would be suitable at the Home Office recommended minimum application rates and minimum application times for spill fires. However, in reality, conditions at sea are likely to result in higher application rates, application times and hence greater quantities of foam concentrate being required.

Under normal conditions, water is available direct from the ships hydrant system although booster pumps may be necessary in some cases.

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

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

Once sufficient foam stocks and branches have arrived, a concentrated low expansion foam attack can be mounted from a safe distance gradually laying foam onto the edge of the spill, working back to the source of the fire.
Additional water hoses may be required to cool hot steel surfaces to prevent re-ignition and possible spread of fire to the stored cargo. However, care should be taken to ensure that foam blankets are not broken down and that liquid fuels, and liquid fuel fires, are not spread by cooling water.

(iii) Cargo Tank Fires

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

Where burning oil is spilling from a ruptured tank into the sea, it may be necessary for the firefighters to call for the assistance of firefighting tugs. The quantities of foam concentrate required depend on the area of the cargo tank and here advice is required from the ship's master. Further quantities of foam concentrate would also be required for the spill fire. Low expansion foam, either a sea water compatible film-forming or FP foam, would be suitable at the Home Office recommended minimum application rates and minimum application times for spill fires or for tank fires (see Chapter 4), depending on the depth of fuel and the size of the cargo tanks. In estimating the quantity of foam needed in the cargo tank, further allowance should be made for burn off and re-application. This may involve up to four times the calculated amount of foam for each of burn off and re-application.

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

When the tank fire has been extinguished, the foam application should be continued until the surrounding steel plates are sufficiently cool so as not to reignite the remaining oil. Glowing char embers often remain adhering to the upper walls and roof on the inside of oil cargo tanks after extinguishment of the fire on the liquid surface. Unless extinguished or dislodged, these deposits can fall back into the cargo and cause reignition hours after the first extinguishment.

(e) Terminals – Jetties

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

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

The majority of jetties should be equipped with the following:

- Fire pumps providing fresh or sea water to the jetty hydrants and monitors.
- Multi outlet hydrants with hose connections along the jetty approach way.
- Hose, branches, monitors, inductors and foam concentrate.
- Water monitors, adjustable or remotely operated, which are fitted with jet/fog nozzles. These may be arranged to provide a water curtain between the jetty and the ship, or for cooling the ship loading manifold area or the jetty head area.
- Multi outlet hydrants along the jetty deck, together with adapters for international shore-ship connections.
- Open water spray nozzles installed at the ship side of the loading facility at various elevations.
- Foam monitors positioned at such an elevation that the jetty deck and the ship's deck are covered at all elevations. The foam monitors should be adjustable and may be fitted with either hydraulic or electronic remote controls.
- There should also be space at the jetty approach for firefighting appliances and bulk foam vehicles.

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

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

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

(f) Boiler Rooms

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

The risk exists of an oil tank rupture leading to a major fire and possibly a boiler explosion. Since boiler houses are usually at the lower levels of buildings, it is possible that damage to the supporting structure and fire spread to the remainder of the building could occur. In a high rise building, fire spread, structural damage or smoke logging could have particularly serious consequences.

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

When used in conjunction with a single hose inlet, one 450 lpm MX branch would produce approximately 15m³/min of finished foam (this figure allows for a reduction in the expansion of the foam due to the restricting effect of the foam inlet).

For a boiler room fire, a 2m foam blanket should be produced. To achieve this in a boiler room of floor area 100m² would require the following foam resources:

- Total amount of finished foam required
  = Height of room × floor area
  = 2m × 100m²
  = 200m³
- Total foam application time
  = Total amount of finished foam
  = Branch output per minute
  = 200m³
  = 15m³/min
  = 13 minutes 20 seconds
- Total amount of foam solution required
  = Branch flow × Total foam application time
  = 450 lpm × 13 minutes 20 seconds
  = 6,000 litres
(g) Warehouses

Medium expansion foam can be effective in combating low-level storage warehouse fires, particularly where a mixture of storage is involved producing a class A fire with possible involvement of class B liquid fuels.

The potential advantages of using medium expansion foam in such situations are:

- visibility can be retained – unlike when using high expansion foam;
- it provides greater volumes of extinguishing agent than low expansion foam and possibly represents a better use of resources.

The main disadvantages are:

- the foam cannot be projected as easily as low expansion foam giving problems in delivery to the seat of the fire, especially in large warehouses;
- it is unsuited to fires involving materials stored above 2m high;
- it may not be effective on deep seated fires;
- there has been no research into determining suitable application rates;
- up to 3 times the theoretical quantity may be needed for re-application and for burn off in warehouse fires.

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

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

(h) Vapour Suppression

This example illustrates the use of firefighting foams in vapour suppression. In the event of a collision between an LPG road tanker and other road vehicles, damage to the tank could result in discharge of the contents onto the road. When the fire services are alerted to this type of situation, the seriousness of an LPG spill is recognised and a series of emergency planning procedures are set in motion.

Several appliances are sent to the scene of the incident and their approach is made from up-wind of the crash. After the leak is isolated, it is estimated that the spill could extend to about 2,000m² and it is calculated that 4 high expansion foam generators each producing 133m³/min of finished foam at 7 bar from 225 lpm of foam solution, could cover the spill, with an average blanket thickness of around 2 metres, in approximately 8 minutes. This would require approximately 108 litres of SYNDET foam concentrate when used at 1.5% concentration.

The above calculations represent the absolute minimum application that could be expected for such an incident. No allowances have been made for re-application during a prolonged incident or for replacing foam blown away from the spill by wind. Due to the poor flow characteristics of high expansion foam, problems may also be experienced in covering areas of the spill furthest away from the foam generators.

Simultaneously to blanketing the spill with high expansion foam, vapour dispersion/control measures should be taken as follows:

- The vapour cloud already formed would be visible as a white fog due to condensed moisture. However, this is not necessarily the limit of the gas cloud. To effectively monitor the cloud location, explosimeters are required.
Chapter 7 – Storage Tank Fires

7.1 Introduction

In this Chapter, the use of conventional fire service equipment to tackle storage tank fires is discussed.

Areas covered include fire development, the particular problems that can be posed by these fires, the facilities available at refinery and storage tank farms, the logistical problems that can occur due to the large amount of conventional equipment and supplies needed to fight these fires and the firefighting tactics that could be used. These aspects are illustrated in several fire scenarios. As with the scenarios described in Chapter 6, these are idealised cases and it is appreciated that the timing, aims and problems associated with real fires will vary considerably from incident to incident.

Whilst the fire scenarios are primarily concerned with the tactics, equipment and materials needed to tackle storage tank fires, there would also be a need for personnel to conduct support operations. This would be provided by firefighters whose appliances would not be directly involved in the fire attack. The support operations are not considered in these scenarios.

7.2 Common Problems With Refineries and Storage Tank Farms

By far the most common problems with refineries and storage tank farms are as follows:

- vehicular access, movement and parking;
- space for hose distribution;
- suitable locations for the deployment of delivery equipment;
- inadequate water supplies;
- performance limitation of existing equipment, particularly the maximum range and height of monitor foam streams.
Access to and around storage tank bunds is often by means of a 3–4m wide road near to the outer base of the bund wall and in many cases this must meet the simultaneous needs of monitor placement and operation, and appliance movement, parking and operation.

Deployment of monitors should ideally be on, or better still outside, the bund wall. This is not always possible as the walls may be too far from the tank.

The predetermined marshalling area for the pumps, foam supplies and foam induction equipment should be as close as possible to the fire ground without putting either personnel or equipment at risk from the fire or potential spread of the fire. Every effort should be made to avoid committing personnel and equipment inside the bund although this may sometimes be necessary (see this Chapter, Section 5 (b) (x)).

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

7.3 Tank Size

(a) General

Storage tanks for flammable and combustible liquids in excess of 91m diameter and 27m high are used in the UK. Tanks in the range 45m to 91m diameter tend to be predominantly of the floating roof design although some fixed roof tanks of over 45m diameter do exist. The 27m high tanks are of older design and can generally be found in congested refineries and depots that are in traditional industrial areas such as along the North Thames Estuary. Where space is available, tank heights can be as low as 15m.

(b) Tank Diameter

The effect of increased tank diameter on the severity of storage tank fires is well recognised in standards. Standards for tank installations give guidelines intended to show when fixed firefighting protection measures should be considered. These standards consider that tanks up to a limit of around 9m diameter can have hand-held branch lines as a primary means of protection and tanks up to a limit of approximately 20m diameter can rely on portable foam monitors. If this equipment is not available, or if tanks are greater than 20m in diameter, then fixed systems are recommended as the primary means of fire protection.

In general, those who have had experience in fighting tank fires agree with the standards that conventional equipment can be used successfully in "over-the-top" applications to tanks with diameters of up to 20m (an over-the-top application refers to a foam that has been projected over the sides of a storage tank and on to the surface of the fuel). In addition, many experienced firefighters maintain that conventional equipment can be used successfully for fighting fires in tanks of up to 45m in diameter; above 45m diameter, they believe that conventional equipment cannot be successful. In addition, the logistics of using conventional equipment for these larger fires are said to be far too difficult. However, there are even significant problems involved in tackling fires in tanks between 18m and 45m.

(c) Tank Height

The height of storage tanks can pose severe problems when using conventional equipment. Many foam monitors are unable to project foam over tank walls in normal circumstances. In addition, when the distance of the bund wall from the tank sides is taken into account, often in the order of 50 metres, the limited throw of conventional foam equipment can pose even more problems.

7.4 Fire Development

(a) Ignition

The first phase of any tank fire is ignition and development to the stage where the tank is fully involved in fire. Ignition can occur from many different sources, for example, lightning strikes, static electricity or burning embers from flare stacks.

(b) Fire Plume

The fire plume from a fully involved tank fire can be several hundreds of metres in height. The rapidly rising flame and smoke can radiate heat to the surroundings and draw fresh air in at the base creating, in some cases, strong artificial winds at ground level. In some circumstances, these incoming winds can help to cool the area around a burning tank making working conditions more bearable.

Local wind conditions can incline the angle of the column so that it closely approaches, or in some cases impinges directly upon, nearby structures including other storage tanks. If the tank on fire is partially empty, then the exposed ullage may begin to distort and collapse inwards towards the surface of the burning liquid. This process may happen suddenly, or may develop over a period of hours, leading to a situation where the wall of the tank can be scoured over and touching the surface of the burning liquid. This is a further complication for firefighters since the scoured wall can shield a large area of burning liquid from direct foam attack.

(c) Fuel

Crude oil, unrefined products and mixtures of flammable liquids, can be more difficult to extinguish in storage tank fires compared with single boiling point liquid fires. The presence of volatile "light ends" in these types of fuel tends to cause disruption to any foam blanket that has already been applied. If the foam blanket is not sufficiently deep, vapour can permeate the foam and ignite so greatly reducing its resistance to heat and flames. Foams that "pick-up" fuel when applied (i.e. where the foam blanket mixes and becomes contaminated with fuel) can also cause a similar breakdown of the foam blanket.

The Home Office recommended minimum application times (see Chapter 4) are longer for applications to fuels that have a flash point below 40°C, this is a consequence of their increased volatility.

Flammable liquid tank fires will eventually burn to extinction although this is likely to take many hours or even days. However, severe problems can occur during this time due to slop-overs and boil-overs (see this Chapter, Section 5 (b) (xii)). Also, the cost of the product in the tank involved in the fire can make it desirable, from an owners point of view, for the fire to be extinguished. In addition, further losses may occur if other nearby tanks are damaged or even ignited by the radiant heat due to the spacing between tanks being inadequate or due to unfavourable wind conditions. The environmental impact of a major storage tank fire is considerable. Concerns of air pollution alone could build up public pressure against a policy of "let it burn".

The liquid fuel contained within a tank will be consumed at a burn rate which will vary according to the type of fuel and the conditions (e.g. wind strength, air temperature, surface area of fire) but a rate of 4nm of liquid depth per minute is often quoted as an average for hydrocarbons such as petrol. For crude oils, burning rates have been estimated to be as low as 0.2 mm per minute and as high as 15mm per minute depending on the type of crude.

In the case of single boilling point liquid fuels, the surface temperature of the liquid will never rise above the boiling point of the liquid no matter how much heat is generated by the fire. Evaporation from the surface cools the liquid and hence the greater the heat absorbed by the liquid surface the faster liquid vapourises, and the more intense is the fire.

With flammable liquid mixtures, such as crude oils and partially refined products, there may be very hot layers of high boiling point residue at or near the surface, or even crusts of coke may form on the burning surface.

Water-miscible fuels require higher application rates due to their destructive effects on foams. Alcohol resistant type foams should always be used for these types of applications.

Problems are experienced with fully involved cryogenic storage tank fires such as ethylene, LPG or other similar liquefied gases. To apply water or low expansion foam to the liquid surface would cause it to warm up which in turn would increase the evaporation rate and intensify the fire. High expansion foam can be applied to pool fires of these fuels when held in retention bands, however, this is not the case for tank fires because this type of foam cannot be projected any appreciable distance. There is generally little alternative in these cases other than to pump out as much of the tank
contents as possible, cool the tank to avoid collapse and allow the fuel to burn out under control.

### 7.5 Practical Scenarios

#### (a) Example of Resources Required For A Storage Tank Fire

The figures quoted below are based on a fire incident involving a 45m diameter by 15m high crude oil storage tank with nearby storage tanks that would require water cooling. The following assumptions are made in order to demonstrate the size of the logistic problem when using conventional equipment:

- a 3% alcohol resistant film-forming foam is applied at the Home Office recommended minimum application rate of 7.3 litres/min/m² for a period of 60 minutes. This application rate assumes that all of the foam produced is being projected onto, and reaching, the surface of the fire. This application rate, water requirements, foam concentrate requirements and hence the number of pumps, monitors and associated equipment, may all need to be increased by up to 60% to take into account foam that does not reach the fire due to losses caused by the effects of foam stream fall-out, wind, thermal updraughts etc. (see Chapter 4, Section 2);

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

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

- exposure protection to an adjacent storage tank of similar size to be at the maximum rate of 10.2 litres/min/m² (see this Chapter, Section 5 (b) (ii) for discussion of cooling rates for adjacent tanks - 2 litres/min/m² may be more appropriate), the storage tank is approximately 1 tank diameter away from the burning tank;

- it is assumed that cooling of the adjacent storage tank is required for a total of 4 hours to allow enough time for resources to be collected and the fire to be fought. Tank cooling continues during the firefighting period.

From this information, the following can be calculated:

**Firefighting Foam and Water Requirements**

- **Surface area of the top of the tank**
  \[ \pi r^2 \text{ (where } \pi = 3.142 \text{ and } r = \text{ tank radius)} \]
  \[ = 3.142 \times (22.5m)^2 \]
  \[ = 1,591 \text{ m}^2 \]

- approximately 1,600 m² tank surface area

- **Total quantity of foam solution required**
  \[ \text{application rate} \times \text{application time} \times \text{tank top surface area} \]
  \[ = 7.3 \text{lpm/m}^2 \times 60 \text{ minutes} \times 1,600 \text{ m}^2 \]
  \[ = 700,800 \text{ litres} \]

- approximately 701,000 litres of foam solution

- **Total amount of foam concentrate required**
  \[ \text{Total foam solution} \times \text{foam concentration} \]
  \[ = 701,000 \text{ litres} \times \frac{3}{100} \]
  \[ = 21,030 \text{ litres} \]

- approximately 21,100 litres of foam concentrate (more than 1050 drums, each containing 20 litres)

- **Total amount of water required for foam production**
  \[ = \text{Total amount of foam solution} \]
  \[ \text{– Total amount of foam concentrate} \]
  \[ = 701,000 \text{ litres} - 21,100 \text{ litres} \]
  \[ = 679,900 \text{ litres} \]

- approximately 680,000 litres of water for foam making

**Cooling Water Requirements For Adjacent Storage Tank**

- **Total surface area of adjacent tank**
  \[ = \text{area of tank top} + \text{area of tank sides} \]
  \[ = 1,600 \text{ m}^2 + (\text{tank height} \times \text{tank circumference}) \]
  \[ = 1,600 \text{ m}^2 + (15m \times (2 \times \pi \times 15m)) \]
  \[ = 1,600 \text{ m}^2 + 1,312 \text{ m}^2 \]
  \[ = 3,712 \text{ m}^2 \]

- approximately 3,800 m² total surface area of adjacent tank

- **Total cooling water required for adjacent tank**
  \[ = \frac{1/3 \times \text{total area of tank} \times \text{water application rate} \times \text{cooling time}}{100} \]
  \[ = \frac{1/3 \times 3,800 \text{ m}^2 \times 10.2 \text{lpm/m}^2 \times 240 \text{ minutes}}{100} \]
  \[ = 3,100,800 \text{ litres} \]

- approximately 3,101,000 litres of cooling water

(*1/3 is assumed to be the proportion of the surface area of the tank subject to direct heat radiation from the fire, see this Chapter, Section 5 (b) (iii))*

The figures above are for a 60 minute foam application period and a 4 hour water cooling period. During the firefighting period, assuming that cooling of the adjacent tank continues, the water flows required would be approximately 11,500 lpm for foam production and approximately 13,000 lpm for cooling the adjacent tank making a total of 24,500 lpm. In addition, the 3% film-forming foam concentrate supply would be approximately 360 litres per minute making the total amount of liquid required during the firefighting phase of this incident nearly 25,000 lpm.

To supply this would require the following examples of firefighting equipment:

- Monitors = 14
  (each 1900 lpm, 7 foam monitors, 7 water monitors)

- Pumps = 14
  (one per monitor, each pump 2250 lpm)

- Hydrant outlets = 28
  (2 per monitor)

- Lengths of 70mm hose (each 25m)
  = 104 (2.6 km)

For the foam attack, 7 monitors would be fed from 4 hydrants using 14 outlets and an estimated minimum of 24 lengths of 70mm hose to supply the pumps and 28 from pumps to monitors.

For the cooling water, 7 monitors would be fed from 4 hydrants using 14 outlets and an estimated minimum of 24 lengths of 70mm hose to supply the pumps and 28 from pumps to monitors.

Table 7.1 contains information on the minimum total volumes of 3% and 6% foam concentrates that are required for tanks of diameter 15m, 30m and 45m when using the Home Office recommended minimum application rates.

The following Sections discuss typical tank fire scenarios, the decision areas and the techniques that could be used to deal with them.
(b) Techniques and Decision Areas
When Tackling Storage Tank Fires

(i) General

The following Sections outline some of the possible complications that can occur when fighting storage tank fires and the decision areas that need to be considered. Ideally, many of these problem areas would have been considered and decisions made in the preplanning that should have taken place in anticipation of storage tank incidents occurring. Information is also given on special techniques that could assist firefighting operations when using foam to extinguish storage tank fires.

(ii) Cooling the Involved Tank

It is only worthwhile cooling the ullage area of the tank involved in fire (i.e., the area of the tank edge above the level of the burning fuel). This may be necessary if the tank begins to buckle. Excessive buckling could result in the rim curling inwards, touching the fuel surface and preventing an eventual foam blanket spreading over the entire liquid surface. Cooling water should be sprayed as evenly as possible around the rim. This will help to avoid uneven cooling which may cause even more distortion of the tank rim.

Cooling of the ullage of the involved tank is necessary during the foam attack to help reduce the temperature of the metal surface against which the foam is attempting to seal.

Oscillating water monitors will provide a wider area of cooling water coverage around the ullage of the burning tank than is possible with fixed monitors. They are preferred in instances where cooling needs to be carried out from within the bund because they can be left unattended.

Care should always be taken to ensure that cooling water does not enter the tank because this will break down the foam blanket and may speed the onset of slop-overs and boil-overs (see Section (xiii) below).

(iii) Cooling an Exposed Tank

NFPA (US National Fire Protection Association) recommend a water cooling rate for direct flame impingement of exposed adjacent LPG pressure vessels of 10.2 lpm/m² when using fixed protection water spray systems.

Generally, the NFPA cooling requirement is also often used as a guide for the use of portable monitors in tank cooling applications and has been used in the calculations in this Chapter and in Chapter 8. However, this water cooling rate is considered by many experienced firefighters and petrochemical organisations to be excessive for the protection of atmospheric hydrocarbon storage tanks where they are more likely to be subject only to radiated heat. They see this as diverting resources of organisations, time, equipment and water from a possible foam attack, and contributing to difficult ground conditions in the area surrounding the fire.

If tank spacing of adequate, cooling can normally be kept to a minimum and resources should be concentrated on making a successful foam attack even if cooling water requirements are cut back in proportion to the scale of the fire. This will almost certainly be the case when adjacent tanks are completely unburned. The use of too much cooling water for adjacent tanks is likely to generate steam from hot surfaces and not to totally flood the adjacent tank and bund area.

The area of an adjacent tank that requires cooling due to exposure to heat and flame is often estimated at between 25% and 50% of the tanks total surface area depending on its separation from the burning tank. For instance, for adjacent tanks at only 1 diameter spacing, an estimate of 1/3 of the tank surface requiring cooling is reasonable. For tanks that have closer separations, more of the surface area of the exposed tank would require to be cooled.

The quantities of water that can be successfully delivered by portable monitor nozzles to adjacent tanks will vary depending on wind speed, wind direction, nozzle type, pressure, distance of throw, monitor position and so on. In addition, portable monitors tend to deliver water in a less even pattern than fixed spray nozzles. However, it is possible to use direct portable monitors more precisely towards the areas of adjacent tanks most affected by the heat and flames of a burning tank. Alternatively, oscillating water monitors will provide a wide and even area of cooling water.

Obviously, the amount of water and equipment required for cooling can increase dramatically if a tank fire backs over. In this situation, not only are flames likely to get nearer to, or engulf tanks within the same bund, but the heat from the flames may also begin to affect tanks in other, adjacent bunds.

Pressurised tanks, such as butane spheres should be cooled to avoid excessive operation of the safety relief valve and to maintain a temperature margin in case of a later boil-over. Many pressurised tanks have fire protection cladding or fixed spray protection systems. This should be confirmed with the refinery management to ensure that the most appropriate cooling action is taken.

It is useful if a fire protection engineer is available with a radiation calculation software programme to make estimates of incident radiation and advise on cooling.
Apart from pressurised vessels, all cooling water can be switched to the foam attack if necessary in order to achieve the required application rate.

(iv) Water Supply

The total volume of water used for cooling can be far in excess of that required for the foam attack due to the longer duration that can be involved in waiting for resources to arrive. Where there is a need for extended periods of cooling, it is usually necessary to complement or replenish any on-site water supply system with a water relay from an estuary, lake or other natural "unlimited" water source.

In some cases, the on-site fire pumps and mains capacities at UK refineries are sufficient to meet these high demands and in others they are not. The most common deficiency seems to be the under-sizing of fire mains in storage tank farm areas which are often remote from the fire pumps. Hydrant mains should be capable of supplying the maximum flowrates required at a residual pressure in excess of 2 bars with a single section of main out of service in the hydraulically least favourable position.

In some areas, fire brigade pre-planning exercises have highlighted deficiencies in supply which have been remedied by plant/refinery management. Fire hydrants should ideally be of the above ground type with four gated 70mm outlets and a single 100mm, 125mm or 150mm outlet. In addition, the fire main should ideally be below ground, with below ground isolation valves, to provide blast protection. Some UK refineries have large capacity transportable pumps, with capacities of up to 23,000 lpm, which can be used to supplement any short falls from the fire main.

Brigades should try to ensure that, on at least a yearly basis, all plant/refinery mains are thoroughly flushed through and all outlets are checked for correct operation.

(v) Marshalling Equipment and Materials

A pre-plan should be available showing the quantity of firefighters, equipment and materials necessary to mount a foam attack. Calculations such as those earlier, in Section 5(a), show that for a 45m diameter by 15m high crude oil storage tank the following are required as a minimum during a 60 minute foam attack and simultaneous cooling of an adjacent tank:

- 14 pumping appliances (each 2,250 lpm)
- 14 monitors (each 1,900 lpm, 7 water, 7 foam)
- 104 lengths of hose (70mm, 25m)
- 21,100 litres of 3% concentrate
- 7 foam dams
- 7 inductor systems for foam monitors

It is assumed that cooling water is applied to the adjacent tank at a rate of 10.2 lpm/m² over one third of the surface area of that tank (2 lpm/m² may be a more appropriate rate, see this Chapter Section 5(b)(iii) for further information). The calculations do not include the equipment and water necessary to cool the ullage of the burning tank. It should also be noted that the application rate (7.3 litres/minute/m²), water requirements, foam concentrate requirements and hence the number of pumps, monitors and associated equipment, may all need to be increased by up to 60% to take into account foam that does not reach the fire due to losses caused by thermal up-draughts etc. (see Chapter 4, Section 2).

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

(vi) Foam Types

A review of the various types of foam concentrates available, and the characteristics and properties of finished foams are discussed in Volume 1. Ideally, primary aspirated foams for tank fire application should be used at an expansion ratio of 6:1 or more and should give a 25% drainage time in excess of 2 minutes in order to have effective heat resistance properties.

FP foams exhibit good heat resistance properties, such as edge sealing and burn back resistance but are less effective at lower expansions than AFFF, AFFF-AR, FFFP and FFFP-AR.

The AFFF and FFFP group of products only form aqueous films on certain hydrocarbon fuels. In large tank fire situations, the types of fuel stored and the way in which they burn, generally prevents these foams from forming films on the surface of the fuel although the ability of these foams to readily flow across the fuel surface can produce quicker flame knockdown.

FP, FFFP and FFFP-AR foams tend to form crusted where the foam blanket is directly exposed to heat. This reduces their ability to flow and may produce sealing problems at the tank edges.

AFFF and FFFP foams drain much quicker than the alcohol resistant versions of these and FP foams; this can be seen as both an advantage and a disadvantage. This faster drainage is believed to contribute to rapid flame knockdown but may also reduce the protection offered by the foam blanket. As a result, constant replenishment of the foam blanket will be required during the fire as will frequent re-application after extinguishment to assist in preventing reignition. For fuels such as crude oils, faster draining foams may help to cool the fuel quicker but are also more likely to cause slope-overs and boil-overs.

(vii) Temperature Monitoring

For tanks containing burning crude and heavy oils, it is important to monitor the progress of any hot layer formation. This can give an early warning of potential boil-over (see Section (xii) below). A rough indication is provided by peeling paint on the tank side or by the steam generated when the tank is wetted. More accurate indications can be obtained by the use of thermal image cameras or from heat sensitive paint if it has been applied in a vertical line down the tank side. However, it must be stressed that these methods will only give an indication of the formation of hot layers, they may not be uniform in cross-section and may only be formed in the centre of the tank giving little or no indication at the outer edges. (see also sub-section xii below)

(viii) Circulation

If a hot layer is advancing down to the level where it may encounter water, it can be useful to attempt breakage or dispersion by means of tank stirrers (if fitted) or by injection of cold product, inert gas, air or other fluid. However, the possible need for circulation will not arise until an advancing hot layer has been formed which is likely to be several hours after ignition.

Circulation will disrupt the surface of the burning fuel. Consequently, in order to allow a foam blanket to be formed and to spread evenly and quickly across the surface of the fuel, circulation should be stopped prior to the application of foam.

Base injection of foam will also induce circulation to some degree.

(ix) Pump out/Pump in

The argument for pumping out product is both that the financial loss is reduced to some extent and that the tank will burnout in a shorter time. If there is no possibility of mounting a foam attack, this is a reasonable objective. There is a risk however that the tank rim will curl in when liquid levels are lowered, impeding any eventual foam attack. However, if there is confidence in the chance of the success of a foam attack, it can be argued that pumping product into the tank is a useful means of preventing the tank from curling over.

(x) Mounting a Foam Attack

Resources should not be wasted by "trying a little foam to see what happens". A foam attack should only be mounted when sufficient resources are available to maintain it at the required application rate continuously for at least 60 minutes. Stopping foam application before the fire has been completely extinguished will probably lead to a rapid burnback and destruction of the whole of the foam
blanket with a complete waste of the resources already committed.

Care should always be taken when fighting tank fires to ensure that there is sufficient ullage in the tank to contain prolonged applications of firefighting liquid. Pumps that put some of the contents of the tank may need to be considered (see this Chapter, Section 5 (b) (xi)).

When applying foam to a storage tank fire, the stream from the monitors should be aimed at the darkened area just above the rim of the tank, and below the flames in the fire plume, where air is being sucked in to the fire. This will help to ensure that the foam is applied directly to the surface of the fuel and not taken up by the thermal updraft of the fire as may be the case if the foam were applied directly into the fire plume. If possible, the rear of the foam landing area should be positioned within 25 metres of the back edge of the tank. In any case, the momentum of the foam stream as it strikes the burning fuel will push the foam blanket towards this direction. All of this will assist in forming a bite which will be supplemented once foam spreads to, and begins to build up from, the back edge of the tank. Cooling of the ullage at the rear of the tank will assist in quickening the formation of a foam blanket here.

On larger storage tanks, foam monitors may need to be positioned to have overlapping foam landing areas in order to ensure that a high enough local application rate is achieved in order to form a 'bite' (see Chapter 5, Section 2 (a) (iv)) and that all areas of the fuel surface can be covered by the flowing foam. The most difficult area of the tank to extinguish will be the area at the front of the tank, nearest to the monitors. Due to the long fuel burning time in this area, the tank rim will be extremely hot and cooling of the ullage here will help the foam blanket to form a seal. However, it is likely that by the time the edge of the foam blanket has flowed against, and across, the burning fuel to reach the tank sides in this area, it will have seriously degraded and will not be immediately capable of forming a seal. Consequently, further foam application is required in order for a fresh wall of foam to be pushed in to that area to make a final seal.

It has been estimated that foam, when applied to the surface of a burning hydrocarbon liquid, can spread from the edges of its landing area a maximum distance of 30m although a maximum of 25m may be a better approximation to use operationally. Obviously, the spreading distance depends on the type of foam used. The more fluid foams, such as the film-forming types, are more likely to spread over these distances than the stiffer P and FP foams. Tactics which produce a circular movement in the foam blanket on the surface of a foam blanket have also been reported as assisting in foam spread (see this Chapter, Section 5 (b) (xi) below).

A substantial bite should be obtained within the first 20 to 30 minutes of a foam attack. If the attack has not succeeded or made significant progress by this time (i.e. a bite has not been formed) then there are probably other factors mitigating against the firefighters and the attack should be reassessed. In particular, application rates and tactics should be reviewed. If necessary, the foam application should be stopped in order for further resources to be gathered together before attempting a further foam attack. The resources used during this initial 20 to 30 minute attack will also need to be replaced.

The only equipment permitted within the bund should be ground monitors where no other safer position will allow their streams to reach the tank. It is important that firefighters are not allowed to remain in the bund due to the risks from boil-overs, slop-overs or a split in the tank. If possible, monitors in the bund should be mounted above ground level so that any liquid collecting in the bund does not affect their operation.

(xii) Special Firefighting Techniques

Two techniques are strongly suggested by those who have fought large tank fires. Firstly, the value of using water spray above the foam blanket to cool the fire plume and take away some of the back radiation. If monitors run out of foam they should be raised to contribute to plume cooling. The water will largely evaporate in the plume and experience shows that, at the right elevation, this tactic does not disrupt the build-up of the foam blanket.

Secondly, it is said that the foam blanket can be spread over the surface more rapidly if a slow swirling motion is imparted by placing one of the monitors to land slightly off centre of the liquid surface. This technique is advocated in conjunction with any foam.

Reducing the Distance From Pump to Monitor

Pressure drops through the hose used to connect pumps to monitors can greatly reduce the pressure at the monitor and hence reduce its throw. Reducing the length of these hose runs will reduce these pressure drops as well increasing the hose diameter.

Higher Capacity Monitors

Manufacturers quote improvements in range with increasingly higher capacity nozzles. For instance, one manufacturer quotes a range of 50m and a maximum height of 18m for a 1,820 litre per minute nozzle and a 54m range and 22m height for a 2,700 litre per minute. Both are of the same design with a recommended operating pressure of 7 bar.

Minimal Obstructions in Nozzle Waterways

Some foam-making monitors include baffles and gauzes to increase the amount of air mixing of the foam solution that takes place. This can significantly reduce the throw of these monitors although more consistent quality finished foam is produced.

Changing Foam Induction Method

In-line venturi inducers generally cause pressure drops of at least 30% and are sometimes in the region of 40 to 50%. The pressure drops can be greater than this, and the inducers may fail to pick-up foam concentrate, if the inducers are not correctly matched to the monitors. There are other methods of foam induction available that cause much smaller losses in pressure in the delivery line to the monitors (see Volume 1).

Elevation of Monitors

Elevating monitors above ground level can obviously assist in applying foam over tank walls.
Whilst elevated platforms and cranes can achieve the best means of doing this, significant advantages can be gained by mounting monitors on bunds or bund extensions. A 3m high bund can make at least a 10% improvement on the height of the jet trajectory. However, elevating monitors may cause further throw problems due to head pressure drops. In some cases, such as with venturi type in line inducers, these pressure drops may prevent the induction system from operating correctly.

(xiii) Boil-overs, Slop-overs and Froth-overs

If there is water in a fuel storage tank, either in the form of a stratified layer of moisture (crude oils may contain up to 5% by volume of water) or, as is often the case, up to a metre or so of water in the base, or even trapped higher up in a pocket created by a sunken floating roof, then there exists the possibility of sudden violent steam generation. The resultant rapid expansion as the water is converted into steam can result in the phenomenon known as boil-over, i.e. the burning contents of the tank will be thrown out. This may occur after a tank fire has been extinguished with the risk continuing until all of the contents of the tank have been cooled to below 100°C.

Boil-overs are very large events, during which substantial quantities of flammable liquid, possibly even the full contents, are ejected from an open tank and onto the surrounding area. The radiated heat produced during a boil-over is extremely intense.

Boil-overs only happen after long pre-burn periods in wide range flashpoint fuels such as crude oil. They occur when a hot layer of residue forms at the top of the tank and, due to its density, sinks below the un-burnt contents of the tank. This hot layer can be at temperatures ranging between approximately 150°C and 300°C. The hot layer is not even and may have deeper waves travelling down from it. The rate at which the hot layer travels down the tank varies depending on the type of crude product but can range from 0.75m to 1.25m per hour. For most crude oils, the rate of travel down the tank is generally between 0.3m and 0.6m per hour. Thermal image cameras can be used to track the progress of travel of a hot layer, as can observing where water is flashing to steam off the sides of a burning tank. However, it must be stressed that these methods will only give an indication of hot layer formation, the zone may not be uniform in cross-section and may only be formed in the centre of the tank giving little or no indication at the outer edges.

Once the hot layer reaches water further down the tank, a steam explosion can occur where the water flashes to steam and the volume of the water expands by approximately 1700:1. This violently propels the burning liquid above it upwards and outwards from the tank.

It has been estimated that a steam explosion can propel the contents of a tank to a height of 10 times the diameter of the tank. Incidents have occurred where the tank contents have been estimated to have been projected to heights of up to 300m.

The presence of steam in the ejected oil can increase its volume temporarily by several multiples to form a ‘froth’ allowing rapid spread of up to 7 tank diameters away from the tank. It is likely that this ejected oil would flow over the containment bunds of the tank.

Boil-overs can occur with very little warning and their far reaching effects should be taken into account when positioning personnel and equipment. During 1982, a storage tank fire in Venezuela burned for 6 hours before boil-over and killing more than 150 people; 40 of them firefighters.

(xiv) Continued Application After Extinction

After extinction of the fire, foam application should continue in order to keep the foam blanket intact and to help to cool the contents of the tank.

Crude oil that has been burning for several hours will be very hot and will bubble through the foam blanket. In addition, liquid draining from the foam blanket will cool the crude down to reduce bubbling and prevent reignition. Foam application made need to continue for at least 1 hour in order to keep the foam blanket intact and to help to cool the contents of the tank.

Slop-overs occur when some burning liquids, such as heavy fuel oils or crude oils, become extremely hot, any applied water may begin to boil on contact with the fuel, the resulting rapid expansion as it converts to steam may cause burning fuel to overflow its containment and the fire to spread.

Froth-overs are where a non burning flammable liquid overflows from a tank due to the thermal expansion of the liquid or violent boiling on top of, and within, the upper layers of the liquid due to the presence of small quantities of water. This boiling may produce a sufficient increase in the volume of the flammable liquid for a froth-over to occur. Froth-overs will generally only occur in wide flashpoint range products, such as heavy crude oils and bitumen type products.

Boil-overs, slop-overs and froth-overs can all result in hot, often burning, fuel being ejected from a storage tank and into the surrounding bund. Consequently, all deployment must be carried out with the need in mind for a sudden evacuation of firefighters (and if possible of appliances and other equipment) if a boil-over, slop-over, froth-over or a split tank should occur. Not only is there a risk from the heat radiation from any burning fuel but also from the wave of expelled liquid which could flow over the bund walls.

(c) Floating Roof Storage Tank Fire Scenario

This description is of a scenario which develops in to a fully involved tank fire in a 45m diameter crude oil storage tank sharing a bund with a second crude oil tank of similar size, 45m (1 tank diameter) distant from the first tank.

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

Floating roof storage tanks catch fire less often than fixed roof tanks with a flammable vapour space, but there have been a considerable number of such fires world-wide, and a larger number still of rim seal fires most of which are usually extinguished before they become more serious.

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

Once the alarm was raised the plant fire brigade would respond and the local fire brigade would respond in support. At this stage, it may not be immediately apparent from ground level whether the fire is contained to the rim seal area or involves the full fuel surface. Obviously, the extent of the incident must be determined immediately on arrival.

The options then depend on the equipment available. If rim seal foam pourers are provided these should be used. Some installations provide for a
supplementary foam hose to be attached to the foam pourer system so that the firefighters can in fill any gaps in the foam coverage from the pourers by manual application from the wind girders.

Cases are quoted of rim seal fires being extinguished by foam hoses dragged up the external tank stairway and by large dry powder extinguishers being used from the wind girders.

The progress of a fire from the rim seal stage can be quite rapid or it may develop very slowly. If the rim seal fire should then burn back he could be cut off from the only means of escape without any firefighting resource to assist him. The dangers of vapours on the roof should also be taken into consideration.

However, combined dry powder/water (or secondary aspirated foam) hand-held branches are available. These enable dry powder to be fired down the centre of the water/foam stream when required, increasing the reach of the dry powder by 3 or 4 times (around 12 metres). This equipment may be suitable for this type of application although large dry powder extinguishers would need to be positioned relatively near to the branch (often within 30 metres). In addition, the problems in dragging two hoses (one water/foam, one dry powder) up an external tank stairway would need to be considered.

(d) Fixed Roof Storage Tank Scenario

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

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

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

While FP foam is effective on smaller diameter tanks, there is some question about its ability to spread over the greater distances required in tackling larger tank fires. This is of particular concern here because in cases where only restricted apertures are available for foam application, there is little that can be done by manipulation of the jets and their landing area to aid foam spread, and the spreading characteristics of the foam may become a critical factor in determining how large a fire can be extinguished. Even with film-forming foam concentrates, the absolute maximum spreading distance from the edge of the foam landing area is estimated to be in the region of 30 metres although a maximum of 25 metres is more likely.

Firefighting through a restricted aperture also means a greater heat radiation hazard for firefighters. The fire plume on leaving the tank can be deflected by 60° or more from the vertical by the size and position of the aperture. Monitor teams will need to be positioned in the same tank quadrant as the fire plume is directed in order to aim jets through the aperture. Special care should be taken that crews are well protected against sudden increases in heat radiation. One method used on certain specialist nozzles is to have the facility to switch a stream from jet to wide-angle spray with a quarter turn of a control handle. This may reduce radiation sufficiently to allow teams to hold their position during a brief flare, or to cover their retreat in a more prolonged surge in fire activity.

Fire teams tackling tank fires through apertures also have little choice in their position relative to the wind, and adverse wind conditions could make most useful positions for ground monitors unusable. In such cases it may be possible to deploy hydraulic platforms and transportable foam towers to discharge foam over the aperture lip to augment foam from monitors.

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

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

(e) Storage Tank Bund Fire Scenario

This example considers a fire in a bund area surrounding two, 45m diameter petrol tanks, each 15m high. If the separation distance is one diameter between the tanks, then the minimum bund dimension would be 170m long x 80m wide. This would give a bund area of 13,600m² reduced to 12,000m² after deducting the area of the unaffected tank, or effectively 11,500m² allowing for a 45° slope on the face of the bund walls.

To provide the recommended 110% retention capacity of the largest tanks' contents, the height of the bund would be 2.1m giving a total bund volume of 25,300m³ compared with the maximum 23,000m³ capacity of one of the tanks.

Bund fires are very often limited in area and constitute spreading/running/spill fires. In these cases the response is generally to lay foam and use water spray to allow access to isolation valves and to cut off the spreading/running fire element. The spill area is then calculated and a foam attack is mounted when sufficient firefighters, material and equipment are available to provide 4 to 6.5 litres/min/m² (depending on the foam concentrate in use) and sustain application for 60 minutes (see Chapter 4). Tank cooling during the mobilisation period should be avoided if possible since the run-off water will tend to spread the burning liquid over a larger area. However, if the tank contents are low, and there is direct flame impingement, cooling may be necessary.

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

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

Fully involved bund fires following a major spillage are rare, but do occur, particularly as a
result of boil-over, and sometimes following a terrorist, or military attack. In these cases, the risk of rupture of the second tank is the major concern. If bund drainage facilities are adequate, it may be possible to cool this tank with water spray whilst the foam attack is being prepared. When sufficient resources have been assembled to mount a foam attack, the area around the un-ruptured tank should be tackled first. Tank walls can be used as back-plates to break the jet momentum and run foam onto the liquid surface whilst a blanket is simultaneously built up from the bund wall outwards.

To mount a 60 minute foam attack on the bund described above using 4 lpm/m² of a film-forming foam would require:

- **Foam solution requirement per minute**
  \[4 \text{ lpm/m}^2 \times 12,000 \text{m}^2 \text{ surface area of bund} = 48,000 \text{ lpm}\]

- **Total foam solution requirement**
  \[48,000 \text{ lpm} \times 60 \text{ minutes} = 2,880,000 \text{ litres}\]

- **3% foam concentrate requirement**
  \[2,880,000 \text{ litres} \times 0.03 = 86,400 \text{ litres}\]

This would require equipment to the extent of at least:

- 22 x 2250 lpm pumps;
- in excess of 400 lengths of hose (10km);
- a water supply capable of providing 48,000 lpm at 6 to 7 bars.

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

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

Further information and guidance will be found in Fire Service Manual, Volume 2, Fire Service Operations – Petrochemicals.

In Chapter 7, information was given on the practical aspects of dealing with storage tank fires when using conventional fire service equipment. Particular reference was made to fighting fires in tanks of up to 45m in diameter.

This Section examines, in more detail, the resources and logistics involved in a typical deployment of conventional fire service equipment to deal with storage tanks of 45m and beyond in diameter. This is followed by a discussion of other, larger equipment, that is available and the reduction in logistical problems that the use of these can bring.

8.1 Introduction

In Chapter 7, information was given on the practical aspects of dealing with storage tank fires when using conventional fire service equipment. Particular reference was made to fighting fires in tanks of up to 45m in diameter.

This Section examines, in more detail, the resources and logistics involved in a typical deployment of conventional fire service equipment to deal with storage tanks of 45m and beyond in diameter. This is followed by a discussion of other, larger equipment, that is available and the reduction in logistical problems that the use of these can bring.

8.2 Conventional Fire Attack

(a) General

The logistical problems of using conventional fire service equipment to tackle large tank fires are significant. Although some brigades and petrochemical plants possess specialist equipment to deal with these types of fire, in many instances, only standard fire service equipment is available.

This Section highlights the difficulties faced when using conventional equipment to fight flammable liquid storage tank fires of 45, 60, 75 and 90 metre in diameter. Tables 8.1 to 8.11 provide the following estimates for each of these tank sizes:

- total quantity of foam concentrate required for 60 minute foam attack;
- number of monitors required;
- number of fire service pumps required;
- number of hydrants required;
- lengths of 70mm hose required.

The main items of conventional fire service equipment assumed to be available are:

- 1,900 lpm monitors;
- 2,250 lpm pumping appliances;
- 70mm hose in 25m lengths;
- venturi type in-line inductors.

It should be noted that the deployment of equipment shown in the tables is theoretical and approximate, they are based on the Home Office recommended minimum application rates (see Chapter 4) and do not represent practical experience. There are few instances where storage tank fires of diameter 45m to 90m have been successfully extinguished. Those claimed have been achieved with the use of specialist equipment (see this Chapter, Section 3).

The tables should be used purely as a means of comparing the practicalities of conventional deployment as against use of specialist equipment, rather than as a model for strategic planning. It should be noted that 1,900 lpm monitors may not have sufficient range to project foam into tanks of this size.
The tables do not take account of the number of firefighters required to deploy equipment. For large fire incidents, many more personnel may be required than would be provided with the minimum number of appliances shown. Relief crews may be required, and many firefighters may be deployed in establishing a chain of foam concentrate supply, or in setting up hose runs to draw suction from natural water courses. It is recognised that these firefighters will be transported in fire appliances, but these appliances would not necessarily form part of the attack team.

It is also assumed that firefighting depends entirely on over-the-top projection of foam by fire brigade monitors. There are cases where fixed systems around the tank rim or for base injection of foam will be available and could be used to advantage, but such provision is by no means certain. Even if these fixed installations are available, they may have been incorrectly maintained or may have been damaged during the incident thus making them ineffective.

The other assumptions made when producing these tables are discussed below.

(b) Cooling Water

The NFPA recommended cooling rate of 10.2 lpm/m² (see Chapter 7, Section 5 (b) (iii) for discussion of cooling rates; a rate of 2 lpm/m² may be more appropriate) has been used in the calculations presented in Tables 8.1 to 8.11 in order to represent a 'worse case' situation in terms of cooling water resources needed. Water can also be used to cool the external ullage of the tank on fire during foam application (see Chapter 7, Section 5 (b) (ii)). The water requirement for this additional cooling has not been specifically included in the calculations presented in Tables 8.1 to 8.11 but should be more than covered by the resource requirements calculated from the 10.2 lpm/m² cooling water application rate.

(c) Bund, Hydrants and Hose

In order to give an indication of the quantities of hose required, it has been necessary to make some idealised assumptions about the tank, bund and mains layout. It has been assumed that the bund configuration allows space at the corners of bunds for vehicles and fire appliances to stand during operations, whilst leaving bund roadways clear. Road widths are assumed to be 10m to permit both hose laying and vehicle passage at the same time. Bund extensions are assumed to be in place, 10m wide and projecting halfway towards the tank. These extensions would provide a safe vantage point to place monitors during a foam attack and an escape route if necessary. In practice, the facilities available would probably fall short of this, and additional fire brigade equipment would be required to compensate.

Hydrant spacing is taken as 80m, each hydrant being equipped with four 70mm outlets. Tables 8.6 and 8.10 show the derivation of the lengths of hose required.

It has been assumed that water supplies in the hydrant main are at sufficient pressure. The hydrant main should be capable of providing the full foam and cooling water demand at a residual pressure of not less than 2 bar to ensure a reliable supply to the pumps.

(d) Limitations of Conventional Fire Attack

One of the main limitations of using conventional equipment for fighting large storage tank fires is the range and trajectory height that can be achieved by foam monitors. Methods of increasing these are discussed in Chapter 7, Section 5 and include:

- Reducing the expansion ratio of the foam.
- Increasing the pump pressure.
- Reducing the distance from pump to monitor.
- Larger capacity monitors.
- Changing foam induction method.
- Elevation of monitors.

Tables 8.1 and 8.2 show that even under favourable conditions very large quantities of conventional equipment are required.

The organisation of resources for a major incident involving a large tank fire is a very complex task in itself. Sources of foam concentrate must be identified and transported to the fireground, replacement fire crews, messing, first aid, and control of the public are a few of the ancillary activities which require organisation.

The conclusion that it is intended should be drawn from this Section is that any ways that can be found to reduce the quantities of equipment required to tackle large tank fires is well worthwhile.
### Table 8.1: Large Storage Tank Fires, Conventional Deployment
Summary of Foam Attack and Cooling Water Requirements

<table>
<thead>
<tr>
<th>Tank Diameter (15m high)</th>
<th>45m</th>
<th>60m</th>
<th>75m</th>
<th>90m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water For Cooling (lpm)</td>
<td>13,300</td>
<td>20,400</td>
<td>28,600</td>
<td>36,800</td>
</tr>
<tr>
<td>Water For Foam Attack (lpm)</td>
<td>11,400</td>
<td>20,600</td>
<td>31,900</td>
<td>50,300</td>
</tr>
<tr>
<td>Total Water Usage (litres)</td>
<td>3,880,000</td>
<td>6,140,000</td>
<td>8,550,000</td>
<td>11,860,000</td>
</tr>
<tr>
<td>60 Minute Foam Attack, 4 Hours Cooling Adjacent Tank</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3% Foam Concentrate (lpm)</td>
<td>360</td>
<td>640</td>
<td>990</td>
<td>1,600</td>
</tr>
<tr>
<td>Total Concentrate Usage (litres)</td>
<td>21,100</td>
<td>38,200</td>
<td>59,200</td>
<td>93,400</td>
</tr>
<tr>
<td>Foam Solution (lpm)</td>
<td>11,700</td>
<td>21,200</td>
<td>32,900</td>
<td>51,900</td>
</tr>
<tr>
<td>Total Foam Solution Usage (litres)</td>
<td>710,000</td>
<td>1,280,000</td>
<td>1,980,000</td>
<td>3,120,000</td>
</tr>
<tr>
<td>Foam Monitors (each 1900 lpm)</td>
<td>7</td>
<td>12</td>
<td>18</td>
<td>28</td>
</tr>
<tr>
<td>Pumps (one per monitor)</td>
<td>7</td>
<td>12</td>
<td>18</td>
<td>28</td>
</tr>
<tr>
<td>Hydrant Outlets (2 per pump)</td>
<td>14</td>
<td>24</td>
<td>36</td>
<td>56</td>
</tr>
<tr>
<td>Hydrants (4 outlets per hydrant)</td>
<td>4</td>
<td>6</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>Lengths of 70mm Hose (each 25m)</td>
<td>48</td>
<td>88</td>
<td>148</td>
<td>288</td>
</tr>
</tbody>
</table>

Notes to Table 8.1:

a. The water cooling rate of the adjacent tank used for these calculations is 10.2 lpm/m² of 1/3rd of the tank surface area. This rate could be reduced to 2 lpm/m² (see Chapter 7, Section 5 b) (iii)).

b. The foam application rates used for these calculations are the Home Office recommended minimum application rates (see Chapter 4). The calculations assume 3% alcohol resistant film-forming foam concentrate is being used.

c. No allowance has been made for any additional foam concentrate requirements as a result of an increased foam application rate during firefighting due to losses, or for continued application after extinction. Losses could add as much as 60% to these requirements with associated increases in foam attack water and equipment (see Chapter 4).

d. All numbers are approximate.

### Table 8.2: Large Storage Tank Fires, Conventional Deployment
Summary of Resource Requirements For 60 Minute Foam Attack

<table>
<thead>
<tr>
<th>Tank Diameter (15m high)</th>
<th>45m</th>
<th>60m</th>
<th>75m</th>
<th>90m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water For Foam Attack (lpm)</td>
<td>11,400</td>
<td>20,600</td>
<td>31,900</td>
<td>50,300</td>
</tr>
<tr>
<td>3% Foam Concentrate (lpm)</td>
<td>360</td>
<td>640</td>
<td>990</td>
<td>1,600</td>
</tr>
<tr>
<td>Foam Solution (lpm)</td>
<td>11,700</td>
<td>21,200</td>
<td>32,900</td>
<td>51,900</td>
</tr>
<tr>
<td>Total Water (litres)</td>
<td>681,000</td>
<td>1,240,000</td>
<td>1,920,000</td>
<td>3,020,000</td>
</tr>
<tr>
<td>Total 3% Foam Concentrate (litres)</td>
<td>710,000</td>
<td>1,280,000</td>
<td>1,980,000</td>
<td>3,120,000</td>
</tr>
<tr>
<td>Foam Monitors (each 1900 lpm)</td>
<td>7</td>
<td>12</td>
<td>18</td>
<td>28</td>
</tr>
<tr>
<td>Pumps (one per monitor)</td>
<td>7</td>
<td>12</td>
<td>18</td>
<td>28</td>
</tr>
<tr>
<td>Hydrant Outlets (2 per pump)</td>
<td>14</td>
<td>24</td>
<td>36</td>
<td>56</td>
</tr>
<tr>
<td>Hydrants (4 outlets per hydrant)</td>
<td>4</td>
<td>6</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>Lengths of 70mm Hose (each 25m)</td>
<td>48</td>
<td>88</td>
<td>148</td>
<td>288</td>
</tr>
</tbody>
</table>

Notes to Table 8.2:

a. The foam application rates used for these calculations are the Home Office recommended minimum application rates (see Chapter 4). The calculations assume 3% alcohol resistant film-forming foam concentrate is being used.

b. No allowance has been made for any additional foam concentrate requirements as a result of an increased foam application rate during firefighting due to losses, or for continued application after extinction. Losses could add as much as 60% to these requirements with associated increases in foam attack water and equipment (see Chapter 4).

c. All numbers are approximate.

### Table 8.3: Large Storage Tank Fires, Conventional Deployment
Foam Solution and 3%/6% Foam Concentrate Requirements Per Minute

<table>
<thead>
<tr>
<th>Tank Diameter</th>
<th>Surface Area of Top of Tank (m²)</th>
<th>3% Foam Concentrate (lpm)</th>
<th>6% Foam Concentrate (lpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(m)</td>
<td>Foam Solution</td>
<td>FP</td>
</tr>
<tr>
<td>45</td>
<td>1,600</td>
<td>14,400</td>
<td>11,700</td>
</tr>
<tr>
<td>60</td>
<td>2,900</td>
<td>26,100</td>
<td>21,200</td>
</tr>
<tr>
<td>75</td>
<td>4,500</td>
<td>40,500</td>
<td>32,900</td>
</tr>
<tr>
<td>90</td>
<td>6,400</td>
<td>64,000</td>
<td>51,900</td>
</tr>
</tbody>
</table>

Notes to Table 8.3:

a. The foam application rates used for these calculations are the Home Office recommended minimum application rates (see Chapter 4).

b. No allowance has been made for any additional foam concentrate or foam solution requirements as a result of an increased foam application rate during firefighting due to losses, or for continued application after extinction. Losses could add as much as 60% to these requirements (see Chapter 4).

c. All numbers are approximate.
### Table 8.4: Large Storage Tank Fires, Conventional Deployment
**Total 3%/6% Foam Concentrate Requirements For a 60 Minute Foam Attack**

<table>
<thead>
<tr>
<th>Tank Diameter (m)</th>
<th>Surface Area of Top of Tank (m²)</th>
<th>3% Foam Concentrate (litres)</th>
<th>6% Foam Concentrate (litres)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>FP</td>
<td>Film-forming</td>
</tr>
<tr>
<td>45</td>
<td>1,600</td>
<td>26,000</td>
<td>21,100</td>
</tr>
<tr>
<td>60</td>
<td>2,900</td>
<td>47,000</td>
<td>38,200</td>
</tr>
<tr>
<td>75</td>
<td>4,500</td>
<td>72,900</td>
<td>59,200</td>
</tr>
<tr>
<td>90</td>
<td>6,400</td>
<td>116,000</td>
<td>93,400</td>
</tr>
</tbody>
</table>

Notes to Table 8.4:
- The foam application rates used for these calculations are the Home Office recommended minimum application rates (see Chapter 4).
- No allowance has been made for any additional foam concentrate requirements as a result of an increased foam application rate during firefighting due to losses, or for continued application after extinction. Losses could add as much as 60% to foam concentrate requirements with associated increases in foam attack water and equipment (see Chapter 4).
- All numbers are approximate.

### Table 8.5: Large Storage Tank Fires, Conventional Deployment
**Water Requirements For a 60 Minute Foam Attack**

<table>
<thead>
<tr>
<th>Tank Diameter (m)</th>
<th>Surface Area of Top of Tank (m²)</th>
<th>Water (lpm)</th>
<th>Total Volume of Water (litres)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>FP</td>
<td>Film-forming</td>
</tr>
<tr>
<td>45</td>
<td>1,600</td>
<td>14,000</td>
<td>11,400</td>
</tr>
<tr>
<td>60</td>
<td>2,900</td>
<td>25,400</td>
<td>20,600</td>
</tr>
<tr>
<td>75</td>
<td>4,500</td>
<td>39,300</td>
<td>31,900</td>
</tr>
<tr>
<td>90</td>
<td>6,400</td>
<td>62,100</td>
<td>50,300</td>
</tr>
</tbody>
</table>

Notes to Table 8.5:
- The foam application rates used for these calculations are the Home Office recommended minimum application rates (see Chapter 4).
- No allowance has been made for any additional foam concentrate requirements as a result of an increased foam application rate during firefighting due to losses, or for continued application after extinction. Losses could add as much as 60% to these requirements with associated increases in foam attack water (see Chapter 4).
- All numbers are approximate.

### Table 8.6: 70mm Hose Requirements For a Foam Attack – Hydrants to Pumps

<table>
<thead>
<tr>
<th>Tank Diameter (m)</th>
<th>Surface Area of Top of Tank (m²)</th>
<th>No. of Hydrants Needed (4 outlets per hydrant)</th>
<th>Distance From Hydrants to Pumps (m)</th>
<th>No. of Hydrants Runs for Each Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>1,600</td>
<td>7</td>
<td>2&lt;25m</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2&lt;30m</td>
<td>8</td>
</tr>
<tr>
<td>60</td>
<td>2,900</td>
<td>12</td>
<td>2&lt;25m</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2&lt;30m</td>
<td>8</td>
</tr>
<tr>
<td>75</td>
<td>4,500</td>
<td>18</td>
<td>2&lt;25m</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2&lt;30m</td>
<td>8</td>
</tr>
<tr>
<td>90</td>
<td>6,400</td>
<td>28</td>
<td>2&lt;25m</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6&lt;50m</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6&lt;125m</td>
<td>8</td>
</tr>
</tbody>
</table>

Notes to Table 8.6:
- 6<125m means six hydrants are located less than 125m from the pump that they supply.
- No allowance has been made for any additional equipment requirements as a result of an increased foam application rate during firefighting due to losses, or for continued application after extinction. Losses could add as much as 60% to these requirements with associated increases in foam attack water and equipment (see Chapter 4).
- All numbers are approximate.
Table 8.7: Large Storage Tank Fires, Conventional Deployment 70mm Hose Requirements For a Foam Attack – Pumps to Monitors And Total For Foam Attack

<table>
<thead>
<tr>
<th>Diameter of Tank to be Cooled (m)</th>
<th>Height of Tank to be Cooled (m)</th>
<th>Water For Cooling (lpm)</th>
<th>Total Water Required For 4 Hours Cooling (litres)</th>
<th>Water Monitors (each 1900 lpm)</th>
<th>Pumps (per pump)</th>
<th>Hydrant Outlets (2 per pump)</th>
<th>Hydrant Outlets (4 outlets per hydrant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>15</td>
<td>13,300</td>
<td>2,200,000</td>
<td>7</td>
<td>7</td>
<td>14</td>
<td>5</td>
</tr>
<tr>
<td>45</td>
<td>20</td>
<td>15,300</td>
<td>3,680,000</td>
<td>9</td>
<td>9</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>45</td>
<td>15</td>
<td>20,400</td>
<td>4,900,000</td>
<td>10</td>
<td>10</td>
<td>16</td>
<td>7</td>
</tr>
<tr>
<td>75</td>
<td>15</td>
<td>27,600</td>
<td>6,680,000</td>
<td>11</td>
<td>11</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>90</td>
<td>15</td>
<td>27,600</td>
<td>8,840,000</td>
<td>15</td>
<td>15</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

Notes to Table 8.7:
- a. The water cooling rate of the adjacent tank used for these calculations is 10.2 lpm/m² of 1/3rd of the tank surface area. This rate could be reduced to 2 lpm/m² (see Chapter 7, Section 5 b) (iii)).
- b. All numbers are approximate.

Table 8.8: Large Storage Tank Fires, Conventional Deployment
Summary of Resource Requirements for the Cooling Water of an Adjacent Tank

<table>
<thead>
<tr>
<th>Diameter of Tank to be Cooled (m)</th>
<th>Height of Tank to be Cooled (m)</th>
<th>Water For Cooling (lpm)</th>
<th>Total Water Required For 4 Hours Cooling (litres)</th>
<th>Water Monitors (each 1900 lpm)</th>
<th>Pumps (per pump)</th>
<th>Hydrant Outlets (2 per pump)</th>
<th>Hydrant Outlets (4 outlets per hydrant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>15</td>
<td>13,300</td>
<td>2,200,000</td>
<td>7</td>
<td>7</td>
<td>14</td>
<td>5</td>
</tr>
<tr>
<td>45</td>
<td>20</td>
<td>15,300</td>
<td>3,680,000</td>
<td>9</td>
<td>9</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>45</td>
<td>15</td>
<td>20,400</td>
<td>4,900,000</td>
<td>10</td>
<td>10</td>
<td>16</td>
<td>7</td>
</tr>
<tr>
<td>75</td>
<td>15</td>
<td>27,600</td>
<td>6,680,000</td>
<td>11</td>
<td>11</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>90</td>
<td>15</td>
<td>27,600</td>
<td>8,840,000</td>
<td>15</td>
<td>15</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

Notes to Table 8.8:
- a. The water cooling rate of the adjacent tank used for these calculations is 10.2 lpm/m² of 1/3rd of the tank surface area. This rate could be reduced to 2 lpm/m² (see Chapter 7, Section 5 b) (iii)).
- b. All numbers are approximate.
Table 8.11: Large Storage Tank Fires, Conventional Deployment
70mm Hose Requirements For Cooling of Adjacent Tank – Pumps to Monitors and Total Required For Cooling

<table>
<thead>
<tr>
<th>Tank Diameter (m)</th>
<th>Tank Height (m)</th>
<th>No. of Water Monitors Needed (each 1900 lpm)</th>
<th>Total No. of Hose Runs From Pumps to Monitors</th>
<th>Length of Each Run (m)</th>
<th>Total No. of 25m Lengths of Hose Required From Pumps to Monitors</th>
<th>Length of Hose Required For Cooling (m)</th>
<th>Overall No. of Monitors</th>
<th>Overall No. of Runs Of 25m Lengths Of Hose</th>
<th>Overall Length Of Hose Required For Cooling (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>15</td>
<td>7</td>
<td>14</td>
<td>average 50m</td>
<td>28</td>
<td></td>
<td>48</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>20</td>
<td>8</td>
<td>16</td>
<td>average 50m</td>
<td>32</td>
<td></td>
<td>56</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>25</td>
<td>10</td>
<td>20</td>
<td>average 50m</td>
<td>40</td>
<td></td>
<td>72</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>15</td>
<td>11</td>
<td>22</td>
<td>average 50m</td>
<td>44</td>
<td></td>
<td>80</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>15</td>
<td>15</td>
<td>30</td>
<td>average 50m</td>
<td>60</td>
<td></td>
<td>112</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>15</td>
<td>20</td>
<td>40</td>
<td>average 50m</td>
<td>80</td>
<td></td>
<td>176</td>
<td>4.4</td>
<td></td>
</tr>
</tbody>
</table>

Note to Table 8.11:
- All numbers are approximate.

8.3 Technical Options

(a) General

This section looks at some of the specialist equipment and facilities that can be used to tackle large scale tank fires. Their use would reduce many of the problems highlighted in the previous section concerning the use of conventional fire service equipment to tackle these fires. However, before modifying facilities and employing such equipment, there is a need for thorough assessments to be made in order to quantify advantages and disadvantages and to evaluate the performance characteristics of equipment in realistic operating conditions.

(b) Large Nozzles

Several large capacity nozzles are available. These range in capacity with the biggest in the order of 50,000 litres of foam solution per minute. Table 8.12 provides some manufacturers performance information for these larger nozzles.

The advantages in the use of large capacity nozzles are:
- Larger nozzles have a longer range than smaller nozzles when used at the same operating pressure.
- The larger jets are more resilient to the heat and updraft effects involved when penetrating the fire plume of a burning storage tank.
- The localised application of a large quantity of finished foam when using larger monitors makes it easier to achieve a "bite" on the fire than when using smaller monitors.
- Smaller numbers of monitors are required.
- They can be readily used with large diameter hose.
- They have been claimed to have been used successfully against large tank fires.

The disadvantages are:
- Some of them, especially the very large capacity nozzles, can only be used for very few specialised tasks i.e. fighting large tank fires.
- There is a high cost involved in both buying this equipment and training firefighters to use it.
- They are heavy and difficult to manoeuvre, although the larger ones are mounted on purpose designed trailers or on appliances.
- Some large monitor designs have shorter ranges than would be expected, primarily because of internal obstructions in the bore designed to produce improved foam working.
- Technical information on some of the monitors is sparse, particularly regarding range, trajectory, foam ground pattern, feathering (fallout from the stream) etc.

(c) Large Pumps

Larger sized pumps, such as those on 4,500 litre per minute pumping appliances or skid mounted pumps of similar or larger capacity, have many advantages. These include a reduction in the
number of crews required for a foam attack, reducing the amount of space required for appliances, and reducing the logistical complexities discussed above. Pump sizes could be selected to match the capacity of the supply requirements of some of the smaller monitors (e.g. one pump per monitor or one pump per two monitors). Such pumps would provide the opportunity to use large sizes of suction hose, as well as large delivery hose.

The obvious disadvantages of using larger pumps are similar to those of using large monitors and include in particular cost, specialist use and additional training requirements.

Vehicle mounted or trailer mounted pumps with capacities in excess of 23,000 litres per minute are available.

(d) Large Hose

Use of large diameter hose is considered vital to enable control and flexibility on the fireground. One 150mm diameter suction hose and one 150mm diameter discharge hose is more than sufficient to supply a single 3,800 litre per minute monitor, compared with four 70mm hoses. In addition, hose laying vehicles should be considered to rapidly deploy and retrieve hose lengths. Where long runs of hose are required, as may well be the case with storage tank fires, the time saved in deployment by such a vehicle, at speeds of up to 30 mph if necessary, can be of crucial importance.

Where possible, large diameter suction hose should be connected directly, or via a junction coupling, into the large diameter outlet at a site hydrant. Where these do not exist, 4 to 1 adapter heads (sometimes referred to as phantom pumper collecting breechings) can be fabricated to enable 70mm outlets to be coupled to 150mm suction hose.

150mm diameter lay flat delivery hose is widely available and sizes in excess of 250mm are in production for specialist applications. It should be remembered that the couplings are the most expensive part of large diameter hoses and so hose lengths should be chosen with care.

(e) Bund Architecture

Typical storage tank bunds in the UK consist of 3m high sloping sided earth banks. Access to and around storage tank bunds is often by means of a 3-4m wide road near to the outer base of the bund wall. Little or no provision is generally made for vehicle marshalling or hose runs. The following are suggestions for features of designs which could be considered for new constructions or refurbishment of existing facilities:

- Marshalling points for fire appliances.
- 10m wide roadways to allow hose runs and vehicles to pass.
- Bund extension piers. Where it is difficult to project foam over tank walls from the surrounding bund wall, such extensions would provide a suitable platform for monitors by reducing the range and increasing the elevation above the bund floor. In addition, there is a considerable degree of safety for firefighters in being able to tend and train monitors outside of the bunded area. In the event of a boil-over, froth-over or slop-over their elevation would provide additional time to effect an escape, and they would be on a paved exit route where vehicles could be readily used.
- Concrete faced bund walls to prevent erosion by weather and by water from burst hoses etc. Special care should be taken in bund maintenance to ensure no points of weakness develop (for example around pipework that penetrates the bund walls). When a bund is full of liquid, any leakage can lead to rapid erosion and loss of containment.
- For liquefied gases, lower diversion walls can be provided within the main bund to channel small spills to a catchment pit away from the tank and close to the main bund wall for ease of extinguishment.
- Facilities for drainage of bunds should be provided under the control of an isolation valve.

(f) Fixed Equipment

The role of fixed fire protection is of great importance in minimising the extent of manual firefighting required. For floating roof tanks, top pourers are usually designed for rim seal protection only and are likely to be damaged in fully involved tank fires. Similarly, with fixed roof tanks, top pourers are often damaged during the ignition phase.

Subsurface injection systems are not normally damaged during tank fires. These can be particularly useful for fixed roof tank fires where there is no obstruction in the form of a sunken roof structure. However, the extent of spread from sub-surface injection is limited, probably to less than 30m in any one direction, so for larger tanks, over-the-top application is still essential to achieve extinguishment. The use of both base injection systems and over-the-top application can be the most effective combination available for large tank fires.

In determining the requirements of equipment and materials for manual firefighting, no account should be taken of fixed protection since it can be out of service when required and cannot be regarded as a common protection feature on storage tanks.

For tanks over 45m diameter, which present a considerable challenge to any manual system of foam application, it is recommended that fixed base injection systems should be provided.

(g) Elevated Equipment

By elevating monitors it may be possible to direct the foam to the required point on the fuel surface which could be particularly useful as a method of assisting the foam to flow the whole way across the burning fuel in a tank by:

- Advancing the foam landing zone as the foam front progresses.
- Directing the foam stream at the foam blanket near the side of the tank to encourage a circular movement.

Foam delivery equipment can be elevated by:

- Purpose made foam towers.
- Mounting the monitor/nozzle on an elevating platform.
- Fixing the monitor/nozzle to the jib of a crane.

Care must be taken in the case of the elevating platform as the jet reaction may affect the stability of the unit.

In all methods of elevating equipment, some method of remote control would be a distinct advantage.

(h) Implications of Use of Specialist Equipment

Tables 8.13 to 8.19 show the development of the logistics of firefighting with specialist equipment in direct comparison to the use of conventional equipment.

There is no immediately obvious saving in the quantities of water or concentrate required but the percentage savings in foam equipment compared with conventional deployment are as follows:

<table>
<thead>
<tr>
<th></th>
<th>3,800 lpm</th>
<th>7,600 lpm</th>
<th>15,000 lpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitors and Pumps</td>
<td>43–50%</td>
<td>71–75%</td>
<td>82–86%</td>
</tr>
<tr>
<td>Pumps</td>
<td>43–50%</td>
<td>71–75%</td>
<td>82–86%</td>
</tr>
<tr>
<td>Hose lengths</td>
<td>71–75%</td>
<td>87–91%</td>
<td>83–90%</td>
</tr>
</tbody>
</table>

In addition, the transportation of foam concentrate can be greatly simplified by the use of far fewer large foam concentrate containers (i.e. foam drums, foam tankers, bulk containers etc.).

The numbers of firefighters involved directly in the foam attack can be reduced along with the reduction of equipment, with a corresponding lower requirement for standby crews and logistic support. It is far easier to re-deploy the foam attack when needed since less items of equipment need to be moved. There is also a better chance of
extinguishing the fire when using specialist equipment because deployment can be achieved earlier and because large nozzles should be more effective in penetrating the fire plume and getting a "bite" on the fire.

Although not illustrated here, the application of cooling water can also be simplified by the use of large suction hose, large pumps and large delivery hose to distribution headers. However, smaller water monitors, such as those with a 1,900 litre per minute capacity, would still be useful for cooling because a smaller number of large monitors may distribute the water less evenly, and there are not the same problems with monitor range when projecting water.

It can be expected that the use of specialist equipment would increase the sizes of storage tank fires that could be successfully tackled and extinguished. For fires in tanks of less than 45m, it would greatly simplify the logistics and the process of extinguishment. For larger storage tanks, it may be possible to extinguish fires that are beyond the capabilities of present equipment.

<table>
<thead>
<tr>
<th>Tank Diameter (15m high)</th>
<th>45m</th>
<th>60m</th>
<th>75m</th>
<th>90m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water For Foam Attack (lpm)</td>
<td>11,400</td>
<td>20,600</td>
<td>31,900</td>
<td>50,300</td>
</tr>
<tr>
<td>3% Foam Concentrate (lpm)</td>
<td>170</td>
<td>360</td>
<td>640</td>
<td>990</td>
</tr>
<tr>
<td>Foam Solution (lpm)</td>
<td>11,700</td>
<td>21,200</td>
<td>32,900</td>
<td>51,900</td>
</tr>
<tr>
<td>Total Water (litres)</td>
<td>681,000</td>
<td>1,240,000</td>
<td>1,920,000</td>
<td>3,020,000</td>
</tr>
<tr>
<td>Total 3% Foam Concentrate (litres)</td>
<td>21,100</td>
<td>38,200</td>
<td>59,200</td>
<td>93,400</td>
</tr>
<tr>
<td>Total Foam Solution (litres)</td>
<td>710,000</td>
<td>1,280,000</td>
<td>1,980,000</td>
<td>3,120,000</td>
</tr>
<tr>
<td>Foam Monitors (each 1,900 lpm)</td>
<td>7</td>
<td>12</td>
<td>18</td>
<td>28</td>
</tr>
<tr>
<td>Pumps (one per monitor)</td>
<td>7</td>
<td>12</td>
<td>18</td>
<td>28</td>
</tr>
<tr>
<td>Hydrant Outlets (2 per pump)</td>
<td>14</td>
<td>24</td>
<td>36</td>
<td>56</td>
</tr>
<tr>
<td>Hydrants (4 outlets per hydrant)</td>
<td>4</td>
<td>6</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>Lengths of 70mm Hose (each 25m)</td>
<td>48</td>
<td>88</td>
<td>148</td>
<td>288</td>
</tr>
<tr>
<td>Foam Monitors (each 3,800 lpm)</td>
<td>4</td>
<td>6</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>Pumps (3,800 lpm, one per monitor)</td>
<td>4</td>
<td>6</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>Hydrant Outlets (1 × 150mm per pump)</td>
<td>4</td>
<td>6</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>Hydrants (each 1 × 150mm outlet)</td>
<td>4</td>
<td>6</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>Lengths of 150mm Hose (each 25m)</td>
<td>14</td>
<td>22</td>
<td>37</td>
<td>72</td>
</tr>
<tr>
<td>Foam Monitors (each 7,600 lpm)</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Pumps (7,600 lpm, one per monitor)</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Hydrant Outlets (1 × 150mm per pump)</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Hydrants (each 1 × 150mm outlet)</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Lengths of 150mm Hose (each 25m)</td>
<td>6</td>
<td>10</td>
<td>18</td>
<td>26</td>
</tr>
<tr>
<td>Foam Monitors (each 15,000 lpm)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Pumps (15,000 lpm, one per monitor)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Hydrant Outlets (2 × 150mm per pump)</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Hydrants (each 1 × 150mm outlet)</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Lengths of 150mm Hose (each 25m)</td>
<td>6</td>
<td>14</td>
<td>22</td>
<td>30</td>
</tr>
</tbody>
</table>

Notes to Table 8.13:
a. The foam application rates used for these calculations are the Home Office recommended minimum application rates (see Chapter 4).
b. No allowance has been made for any additional foam concentrate requirements as a result of any increased foam application rate during firefighting due to losses, or for continued application after extinction. Losses could add as much as 60% to the foam concentrate requirements with associated increases in foam attack water and equipment (see Chapter 4).
c. All numbers are approximate.
### Table 8.14: Large Storage Tank Fires, Specialist Equipment Deployment – 150mm Hose Requirements For a Foam Attack – Hydrants to Pumps, Pumps and Monitors 3,800 lpm

<table>
<thead>
<tr>
<th>Tank Diameter (m)</th>
<th>Surface Area of Tank (m²)</th>
<th>No. of Foam Monitors/ Pumps Needed (each 3,800 lpm)</th>
<th>No. of Hydrants Needed (1 outlet per hydrant)</th>
<th>Distance from Hydrants to Pumps (25m) Length (km)</th>
<th>No. of 25m Hose Runs for Each Distance</th>
<th>No. of 25m Hose Lengths Required (150mm Diameter) (km)</th>
<th>Total No. of Lengths of 25m Hose</th>
<th>Total Hose Length of 25m Hose (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>1,600</td>
<td>4</td>
<td>4</td>
<td>2&lt;25m</td>
<td>2</td>
<td>2</td>
<td>6</td>
<td>0.2</td>
</tr>
<tr>
<td>60</td>
<td>2,900</td>
<td>6</td>
<td>6</td>
<td>2&lt;25m</td>
<td>2</td>
<td>2</td>
<td>10</td>
<td>0.3</td>
</tr>
<tr>
<td>75</td>
<td>4,500</td>
<td>9</td>
<td>9</td>
<td>2&lt;25m</td>
<td>2</td>
<td>2</td>
<td>19</td>
<td>0.5</td>
</tr>
<tr>
<td>90</td>
<td>6,400</td>
<td>14</td>
<td>14</td>
<td>2&lt;25m</td>
<td>2</td>
<td>2</td>
<td>44</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6&lt;25m</td>
<td>6</td>
<td>6</td>
<td>18</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Notes to Table 8.14:

a. The number of monitors required has been calculated by dividing the foam solution rate requirement for film-forming foam (see Table 8.13) by the capacity of the foam monitors (3,800 lpm).

b. 6<125m means six hydrants are located less than 125m from the pump that they supply.

c. No allowance has been made for any additional foam concentrate requirements as a result of an increased foam application rate during firefighting due to losses, or for continued application after extinction. Losses could add as much as 60% to the foam concentrate requirements with associated increases in foam attack water and equipment (see Chapter 4).

d. All numbers are approximate.

### Table 8.15: Large Storage Tank Fires, Specialist Equipment Deployment – 150mm Hose Requirements For a Foam Attack – Pumps to Monitors, Pumps and Monitors 3,800 lpm

<table>
<thead>
<tr>
<th>Tank Diameter (m)</th>
<th>Surface Area of Tank (m²)</th>
<th>No. of Monitors Needed (each 3,800 lpm)</th>
<th>No. of Hose Runs Needed</th>
<th>No. of 25m Hose Lengths Required (150mm Diameter) (km)</th>
<th>Total No. of Lengths of 25m Hose</th>
<th>Total Hose Length of 25m Hose (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>1,600</td>
<td>4</td>
<td>4&lt;50m</td>
<td>8</td>
<td>14</td>
<td>0.4</td>
</tr>
<tr>
<td>60</td>
<td>2,900</td>
<td>6</td>
<td>6&lt;50m</td>
<td>12</td>
<td>22</td>
<td>0.6</td>
</tr>
<tr>
<td>75</td>
<td>4,500</td>
<td>9</td>
<td>9&lt;50m</td>
<td>18</td>
<td>37</td>
<td>1.0</td>
</tr>
<tr>
<td>90</td>
<td>6,400</td>
<td>14</td>
<td>14&lt;50m</td>
<td>28</td>
<td>72</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Notes to Table 8.15:

a. <50m means less than 50 metres.

b. No allowance has been made for any additional foam concentrate requirements as a result of an increased foam application rate during firefighting due to losses, or for continued application after extinction. Losses could add as much as 60% to the foam concentrate requirements with associated increases in foam attack water and equipment (see Chapter 4).

c. All numbers are approximate.
Table 8.16: Large Storage Tank Fires, Specialist Equipment Deployment – 150mm Hose Requirements For a Foam Attack – Hydrants to Pumps, Pumps and Monitors 7,600 lpm

<table>
<thead>
<tr>
<th>Tank Diameter (m)</th>
<th>Surface Area of Top of Tank (m²)</th>
<th>No. of Foam Monitors Needed (each 7,600 lpm)</th>
<th>No. of Hydrant Outlets Needed (1 outlet per hydrant)</th>
<th>Distance From Hydrants to Pumps (m)</th>
<th>No. of Hose Runs for Each Distance</th>
<th>No. of 25m Hose Lengths Required (150mm Diameter)</th>
<th>Total No. of 25m Hose Lengths</th>
<th>Total Length of Hose (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>1,600</td>
<td>2</td>
<td>2</td>
<td>2&lt;25m</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0.1</td>
</tr>
<tr>
<td>60</td>
<td>2,900</td>
<td>3</td>
<td>3</td>
<td>2&lt;25m</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>0.1</td>
</tr>
<tr>
<td>75</td>
<td>4,500</td>
<td>5</td>
<td>5</td>
<td>2&lt;25m</td>
<td>2</td>
<td>2</td>
<td>8</td>
<td>0.2</td>
</tr>
<tr>
<td>90</td>
<td>6,400</td>
<td>7</td>
<td>7</td>
<td>2&lt;25m</td>
<td>2</td>
<td>2</td>
<td>12</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Notes to Table 8.16:

a. The number of monitors required has been calculated by dividing the foam solution rate requirement for film-forming foam (see Table 8.13) by the capacity of the foam monitors (7,600 lpm).
b. 2<25m means two hydrants are located less than 25m from the pump that they supply.
c. No allowance has been made for any additional foam concentrate requirements as a result of an increased foam application rate during firefighting due to losses, or for continued application after extinction. Losses could add as much as 60% to the foam concentrate requirements with associated increases in foam attack water and equipment (see Chapter 4).
d. All numbers are approximate.

Table 8.17: Large Storage Tank Fires, Specialist Equipment Deployment – 150mm Hose Requirements For a Foam Attack – Pumps to Monitors, Pumps and Monitors 7,600 lpm

<table>
<thead>
<tr>
<th>Tank Diameter (m)</th>
<th>Surface Area of Top of Tank (m²)</th>
<th>No. of Monitors Needed (each 7,600 lpm)</th>
<th>No. of Foam Monitors Needed</th>
<th>Length of Runs</th>
<th>No. of 25m Hose Lengths Required (150mm Diameter)</th>
<th>Total No. of 25m Hose Lengths From Hydrants to Pumps to Monitors</th>
<th>Total Hose Length From Hydrants to Pumps to Monitors (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>1,600</td>
<td>2</td>
<td>2</td>
<td>&lt;50m</td>
<td>4</td>
<td>6</td>
<td>0.2</td>
</tr>
<tr>
<td>60</td>
<td>2,900</td>
<td>3</td>
<td>3</td>
<td>&lt;50m</td>
<td>6</td>
<td>10</td>
<td>0.3</td>
</tr>
<tr>
<td>75</td>
<td>4,500</td>
<td>5</td>
<td>5</td>
<td>&lt;50m</td>
<td>10</td>
<td>18</td>
<td>0.5</td>
</tr>
<tr>
<td>90</td>
<td>6,400</td>
<td>7</td>
<td>7</td>
<td>&lt;50m</td>
<td>14</td>
<td>26</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Notes to Table 8.17:

a. <50m means less than 50 metres.
b. No allowance has been made for any additional foam concentrate requirements as a result of an increased foam application rate during firefighting due to losses, or for continued application after extinction. Losses could add as much as 60% to the foam concentrate requirements with associated increases in foam attack water and equipment (see Chapter 4).
c. All numbers are approximate.
### Table 8.18: Large Storage Tank Fires, Specialist Equipment Deployment – 150mm Hose Requirements For a Foam Attack – Hydrants to Pumps, Pumps and Monitors 15,000 lpm

| Tank Diameter (m) | Surface Area of Top of Tank (m²) | No. of Monitors Needed (each, 15,000 lpm) | No. of Hydrants Needed (each, 150mm Diameter) | Distance From Hydrants to Pumps (25m Hose) | No. of No. of 25m Hose Lengths Required (150mm Diameter) | No. of No. of Total No. Total Hose Length of Total Distance (each, 25m) | No. of Total of Total | No. of Total | No. of Total | No. of Total | No. of Total | No. of Total | No. of Total | No. of Total | No. of Total | No. of Total | No. of Total | No. of Total | No. of Total |
|------------------|----------------------------------|------------------------------------------|-----------------------------------------------|------------------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|
| 45               | 1,600                            | 1                                        | 2                                             | 2                                        | 2                             | 2                             | 0.1                           | 4                             | 6                             | 0.2                           | 0.1                           | 4                             | 6                             | 0.2                           | 0.1                           | 4                             | 6                             | 0.2                           | 0.1                           | 4                             | 6                             | 0.2                           | 0.1                           |
| 60               | 2,900                            | 2                                        | 4                                             | 2                                        | 2                             | 6                             | 0.2                           | 8                             | 14                            | 0.4                           | 0.2                           | 8                             | 14                            | 0.4                           | 0.2                           | 8                             | 14                            | 0.4                           | 0.2                           | 8                             | 14                            | 0.4                           | 0.2                           |
| 75               | 4,500                            | 3                                        | 6                                             | 2                                        | 2                             | 10                            | 0.3                           | 12                            | 22                            | 0.6                           | 0.3                           | 12                            | 22                            | 0.6                           | 0.3                           | 12                            | 22                            | 0.6                           | 0.3                           | 12                            | 22                            | 0.6                           | 0.3                           |
| 90               | 6,400                            | 4                                        | 8                                             | 2                                        | 2                             | 14                            | 0.4                           | 16                            | 30                            | 0.8                           | 0.4                           | 16                            | 30                            | 0.8                           | 0.4                           | 16                            | 30                            | 0.8                           | 0.4                           | 16                            | 30                            | 0.8                           | 0.4                           |

#### Notes to Table 8.18:

a. The number of monitors required has been calculated by dividing the foam solution rate requirement for film-forming foam (see Table 8.13) by the capacity of the foam monitors (15,000 lpm).
b. <50m means four hydrants are located less than 50m from the pump that they supply.
c. No allowance has been made for additional foam concentrate requirements as a result of increased foam application rate during firefighting due to losses, or for continued application after extinction. Losses could add as much as 60% to foam concentrate requirements with associated increases in foam attack water and equipment (see Chapter 4).
d. All numbers are approximate.

### Table 8.19: Large Storage Tank Fires, Specialist Equipment Deployment – 150mm Hose Requirements For a Foam Attack – Pumps to Monitors, Pumps and Monitors 15,000 lpm

<table>
<thead>
<tr>
<th>Tank Diameter (m)</th>
<th>Surface Area of Top of Tank (m²)</th>
<th>No. of Monitors Needed (each, 15,000 lpm)</th>
<th>No. of Hydrants Runs Required (150mm Diameter)</th>
<th>Length of Runs (25m Hose)</th>
<th>Total No. of 25m Hose Lengths From Hydrants to Pumps to Monitors</th>
<th>Total Hose Length (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>1,600</td>
<td>1</td>
<td>2</td>
<td>&lt;50m</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>60</td>
<td>2,900</td>
<td>2</td>
<td>4</td>
<td>&lt;50m</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>75</td>
<td>4,500</td>
<td>3</td>
<td>6</td>
<td>&lt;50m</td>
<td>12</td>
<td>22</td>
</tr>
<tr>
<td>90</td>
<td>6,400</td>
<td>4</td>
<td>8</td>
<td>&lt;50m</td>
<td>16</td>
<td>30</td>
</tr>
</tbody>
</table>

#### Notes to Table 8.19:

a. <50m means less than 50 metres.
b. No allowance has been made for any additional foam concentrate requirements as a result of an increased foam application rate during firefighting due to losses, or for continued application after extinction. Losses could add as much as 60% to foam concentrate requirements with associated increases in foam attack water and equipment (see Chapter 4).
c. All numbers are approximate.
References


Further Reading

   - Part 1 : Firefighting Foams
   - Part 2 : Tactics and Equipment
   - Part 3 : Large Tank Fires


**Glossary of Terms: Firefighting Foams**

*(Note: Not all of these terms have been used in this Manual of Firemanship but they have been included here for completeness)*

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerated ageing</td>
<td>Storage of foam concentrate at high temperatures to indicate long term storage properties of the foam concentrate at ambient temperatures.</td>
</tr>
<tr>
<td>Acidity</td>
<td>See pH.</td>
</tr>
<tr>
<td>Alcohol resistant foam concentrates</td>
<td>These may be suitable for use on hydrocarbon fuels, and additionally are resistant to breakdown when applied to the surface of water-miscible liquid fuels. Some alcohol resistant foam concentrates may precipitate a polymeric membrane on the surface of water-miscible liquid fuels.</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>See pH.</td>
</tr>
<tr>
<td>Application rate</td>
<td>The rate at which a foam solution is applied to a fire. Usually expressed as litres of foam solution per square metre of the fire surface area per minute (lpm/m²).</td>
</tr>
<tr>
<td>AFFF concentrate</td>
<td>Aqueous film-forming foam. AFFFs are generally based on mixtures of hydrocarbon and fluorinated surface active agents and have the ability to form an aqueous film on the surface of some hydrocarbon fuels.</td>
</tr>
<tr>
<td>Aspiration</td>
<td>The addition or entrainment of air into foam solution.</td>
</tr>
<tr>
<td>Aspirated foam</td>
<td>Foam that is made when foam solution is passed through purpose designed foam-making equipment, such as a foam-making branch. These mix in air (aspirate) and then agitate the mixture sufficiently to produce finished foam. (see also primary aspirated foam and secondary aspirated foam).</td>
</tr>
<tr>
<td>Base injection (Subsurface injection)</td>
<td>The introduction of fuel-tolerant primary aspirated finished foam beneath the surface of certain flammable and combustible hydrocarbons, to effect fire extinguishment. Usually used for the protection of fixed roof hydrocarbon fuel storage tanks.</td>
</tr>
<tr>
<td>Bite</td>
<td>The formation of an initial area of foam blanket on the surface of a burning liquid fuel.</td>
</tr>
</tbody>
</table>
Boiling liquid expanding vapour explosion (BLEVE)

The catastrophic failure of a tank containing pressure liquefied gas (PLG) due to mechanical damage or adverse heat exposure will result in a BLEVE. A BLEVE will produce blast and projectile hazards. If the contents of the tank are toxic, then health and exposure hazards may occur. If the contents are flammable, then a fireball may occur with associated thermal radiation and fire engulfment hazards.

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 lengthy burning period in wide flashpoint range products, such as crude oil. The water layer may already have been in the container before the fire began or may be the result of the inadvertent application of water (perhaps during cooling of the container walls), or from the drainage of foam solution from finished foam applied to the fire. (see also froth-over and slop-over).

Bund area (Dike area)

An area surrounding a storage tank which is designed to contain the liquid product in the event of a tank rupture.

Branch

A hand-held foam maker and nozzle.

Burnback resistance

The ability of a foam blanket to resist direct flame and heat impingement.

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 finished foam produced by mixing two or more chemicals. The bubbles are typically caused by carbon dioxide released by the reaction.

Classes of Fire

In the UK the standard classification of fire types is defined in BS EN 2:1992 as follows:

- Class A: fires involving solid materials, usually of an organic nature, in which combustion normally takes place with the formation of glowing embers.
- Class B: fires involving liquids or liquefiable solids.
- Class C: fires involving gases.
- Class D: fires involving metals.

Electrical fires are not included in this system of classification.

Cloud point

The lowest temperature at which a liquid remains clear. Usually only applicable to high expansion foam concentrates.

Combustible liquid

Any liquid having a flashpoint at or above 37.8°C (100°F).
| **Finished foam** | The foam as applied to the fire. It will consist of a mixture of foam solution that has been mixed with air. The foam may be primary aspirated or secondary aspirated. |
| **Flammable liquid** | Any liquid having a flashpoint below 37.8°C (100°F). |
| **Flashback** | The re-ignition of a flammable liquid caused by the exposure of its vapour 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 vapour above a liquid. |
| **Flow requirement (low and medium expansion)** | The nominal supply rate of foam solution required by a foam branch, measured in litres per minute. |
| **Fluoroprotein (FP) foam concentrate** | A hydrolysed protein based foam concentrate with added fluorinated surface active agents. |
| **Foam** | The result of mixing foam concentrates, water and air to produce bubbles. |
| **Foam concentrate** | The foam as supplied by the manufacturer in liquid form; this is sometimes referred to as 'foam compound', 'foam liquid' or by trade or brand names. |
| **Foam, dry** | Foam with a long drainage time, i.e. the liquid content of the foam takes a long period of time to drain out of the foam; the foam is very stable. |
| **Foam generator (high expansion)** | A mechanical device in which foam solution is sprayed onto a net screen through which air is being forced by a fan. |
| **Foam generator (low expansion)** | Similar to a foam-making branch, but inserted in a line of hose so that the finished foam passes along the hose to a discharge nozzle. |
| **Foam-making branch (foam-making branchpipe, FMB)** | The equipment by which the foam solution is normally mixed with air and delivered to the fire as a finished foam. |
| **Foam monitor** | A larger version of a foam-making branch which cannot be hand-held. |
| **Foam solution** | A well mixed solution of foam concentrate in water at the appropriate concentration. |
| **Foam, wet** | Foam with a short drainage time, i.e. the liquid content of the foam takes a short period of time to drain out of the foam; the foam breaks down quickly. |
| **Freeze point** | The highest temperature at which a material can exist as a solid. |
| **Froth-over** | Overflow of a non-burning flammable liquid from a container due to the thermal expansion of the liquid or violent boiling on top of and within the upper layers of the liquid due to the presence of small quantities of water. (see also boil-over and slop-over) |
| **Hazmat** | A proprietary trade name used to describe special types of foam which can be used to suppress the vapour production of certain hazardous materials (toxic, odorous and/or flammable). |
| **Heat resistance** | The ability of a foam blanket to withstand the effects of exposure to heat. |
| **High expansion foam (HX)** | Finished foam of expansion ratio greater than 200:1 |
| **Hydrocarbon fuel** | Fuels based exclusively on chains or rings of linked hydrogen and carbon atoms. Hydrocarbon fuels are not miscible with water. |
| **Induction** | The entrainment of foam concentrate into the water stream. |
| **Inductor (Eductor)** | A device used to introduce foam concentrate into a water line. |
| **Induction rate (pick-up rate)** | The percentage at which foam concentrate is proportioned in to water by an inductor in order to produce a foam solution. Normally this is 1%, 3% or 6%. |
| **Inline inductor** | An inductor inserted in to a hose line in order to induce foam concentrate prior to the water reaching the foam-making branch. |
| **Knockdown** | The ability of a foam to quickly control flames. Knockdown does not necessarily mean extinguishment. |
| **Low expansion foam (LX)** | Finished foam of expansion ratio of less than or equal to 20:1. |
| **Mechanical foam** | Foam produced by a physical agitation of a mixture of water, foam concentrate and air. |
| **Medium expansion foam (MX)** | Finished foam of expansion ratio greater than 20:1 but less than or equal to 200:1. |
| **Minimum use temperature** | The lowest temperature at which the foam concentrate can be used at the correct concentration through conventional equipment such as inline inductors and other proportioning devices. |
| **Monitor** | A large throughput branch (water or foam-making) which is normally mounted on a vehicle, trailer or on a fixed or portable pedestal. |
Multipurpose foam concentrates

Another name given to alcohol resistant foam concentrates.

Newtonian liquids

The viscosity of Newtonian liquids remains the same no matter how quickly or slowly they are flowing (see also non-Newtonian pseudo-plastic liquids). Most non-alcohol resistant foam concentrates (such as AFFF, FFFP, FP, P and SYNDELT) are Newtonian liquids.

Non-aspirated (Unaspirated)

The application, by any appropriate means, of a firefighting liquid that does not mix the liquid with air to produce foam (i.e. aspiration does not occur). The term “non-aspirated foam” is often used incorrectly to describe the product of a foam solution that has been passed through equipment that has not been specifically designed to produce foam, such as a water branch. However, the use of this type of equipment will often result in some aspiration of a foam solution. This is because air is usually entrained into a jet or spray of foam solution as it leaves the branch, as it travels through the air due to the turbulence produced by the stream and/or when it strikes an object. This causes further turbulence and air mixing. There is sufficient air entrained by these processes to produce a foam of very low expansion (often with an expansion ratio of less than 5:1). Consequently, the term secondary aspirated foam is preferred in these cases (see also primary aspirated and secondary aspirated foam).

Non-Newtonian pseudo-plastic liquids

As the rate of flow of non-Newtonian pseudo-plastic liquids increases, their viscosity decreases and so they flow more easily. Consequently, getting them to flow initially can be difficult, but once flowing, their viscosity reduces to a more acceptable level. Many alcohol resistant foam concentrates (such as AFFF-AR and FFFP-AR) are considered to be non-Newtonian pseudo-plastic liquids.

Oleophobic

Oil repellent.

Over-the-top foam application

The application of foam by projecting it over the sides of a storage tank and directly on to the surface of the contained fuel.

pH (Acidity/Alkalinity)

Measurement of the acidity to alkalinity of a liquid on a scale of 1 to 14. A pH of 7 is neutral (like that of pure water); a pH of 1 is very acidic, a pH of 14 is very alkaline.

Polar solvent

This term is generally used to describe any liquid which destroys standard foams, although it actually refers to liquids whose molecules possess a permanent dielectric discharge e.g. Alcohols, ketones. Most polar solvents are water-miscible.

Pour point

The lowest temperature at which a foam concentrate is fluid enough to pour. This is generally a few degrees above its freezing point.

Preburn time

The time between ignition of a fire and the commencement of foam application.

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 a premix form, as in a portable foam fire extinguisher or as foam solution in a fire appliance water tank.

Primary aspirated foam

Finished foam produced from foam solutions that are passed through purpose designed foam-making equipment. (See secondary aspirated foam).

Proportioner

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

Protein (P) foam concentrate

Protein foam concentrate contains organic concentrates derived from natural vegetable or animal sources. Hydrolysed products of protein provide exceptionally stable and heat resistant properties to foams although they lack fuel tolerance and have slow knock-down performance.

Relative density

see Specific gravity

Secondary aspirated foam

Finished foams that are produced from foam solutions that are applied other than by purpose designed foam-making equipment, usually standard water devices. (See primary aspirated foam).

Security

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

Shear strength

The measurement of the stiffness of a finished foam sample when measured with a foam viscometer. Units of measurement are Newtons per square metre (N/m²).

Stop-over

When some burning liquids, such as heavy fuel oils or crude oils, become extremely hot, any applied water may begin to boil on contact with the fuel, the resulting rapid expansion as it converts to steam may cause burning fuel to overflow its containment and the fire to spread (see also boil-over and froth-over).

Solution transit time

The time taken for foam solution to pass from the point where foam concentrate is introduced in to the water stream to when finished foam is produced.

Specific gravity

The specific gravity of a material is a measure of the density of the material in relation to the density of water. The specific gravity is calculated as:

Specific Gravity = Density of material / Density of water
A liquid with a specific gravity of less than one will float on water (unless it is water-miscible); a specific gravity of more than one indicates that water will float on top of the liquid.

**Water-immiscible liquid**
A liquid that is not soluble in water.

**Water-miscible liquid**
A liquid that is soluble in water. Polar solvents and hydrocarbon liquids that are water-miscible can dissolve normal firefighting foams (see also alcohol resistant foam concentrates).

**Wetting agent**
A chemical compound which, when added to water in correct proportions, materially reduces its surface tension, increases its penetrating and spreading abilities and may also provide foaming characteristics.

A flammable liquid fire having an average depth of not more than 25mm.

**Spill fire**

The ability of a finished foam to retain shape and form particularly in the presence of heat, flame and/or other liquids. The 25% drainage time is often used as a measure for stability.

**Stability**

See base injection.

**Subsurface injection**

A chemical ingredient of some foam concentrates. Finished foams is stabilised by the addition of surface active agents (or surfactants) which promote air/water stability by reducing the liquids surface tension. Most surface active agents are organic in nature and common examples are soaps and detergents.

**Surface active agents**

These are based upon mixtures of hydrocarbon surface active agents and may contain fluorinated surface active agents with additional stabilisers. They are multipurpose foams in that they can be used at low, medium and high expansion.

**Synthetic detergent (SYNDET) foam concentrate**

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.

**Venturi**

This is a measure of how well a liquid will flow. Liquids are generally classed as either being non-Newtonian or Newtonian. A low viscosity is often desirable because it improves the flow characteristics of a foam concentrate through pick-up tubes, pipework and induction equipment.

Viscosity will also vary with foam concentrate type and with concentration. AFFF foam concentrates at 3% and 6% concentrations tend to be the least viscous, closely followed by P, FP and FFFF foam concentrates at 6%. AFFF at 3% and SYNDET foams, P, FP and FFFF foam concentrates at 3% concentration are appreciably more viscous than these. The alcohol resistant foams are often the most viscous although recent developments have dramatically reduced the viscosity of some products.

In addition, the viscosity of all foam concentrates will vary with temperature and may be affected by the age of the foam concentrate. Manufacturers often state the viscosity of their products when measured at 20°C; lower temperatures will result in higher viscosity.

**Viscosity**