NFPA 1081 Standard

Incipient Industrial Fire Brigade Member

NFPA 1081 contains no Incipient Industrial job performance requirements for this chapter.

Advanced Exterior Industrial Fire Brigade Member

6.3.4* Extinguish an ignitable liquid fire operating as a member of a team, given an assignment, a handline, personal protective equipment, a foam proportioning device, a nozzle, foam concentrates, and a water supply, so that the correct type of foam concentrate is selected for the given fuel and conditions, a correctly proportioned foam stream is applied to the surface of the fuel to create and maintain a foam blanket; fire is extinguished, re-ignition is prevented, and team protection is maintained.

(A) Requisite Knowledge. Methods by which foam prevents or controls a hazard; principles by which foam is generated; causes for poor foam generation and corrective measures; difference between hydrocarbon and polar solvent fuels and the concentrates that work on each; the characteristics, uses, and limitations of fire-fighting foams; the advantages and disadvantages of using fog nozzles versus foam nozzles for foam application; foam stream application techniques; hazards associated with foam usage; and methods to reduce or avoid hazards.

(B) Requisite Skills. The ability to prepare a foam concentrate supply for use, assemble foam stream components, master various foam application techniques, and approach and retreat from fires and spills as part of a coordinated team.

Interior Structural Industrial Fire Brigade Member

7.3.4* Extinguish an ignitable liquid fire operating as a member of a team, given an assignment, a handline, personal protective equipment, a foam proportioning device, a nozzle, foam concentrates, and a water supply, so that the correct type of foam concentrate is selected for the given fuel and conditions, a correctly proportioned foam stream is applied to the surface of the fuel to create and maintain a foam blanket; fire is extinguished, re-ignition is prevented, and team protection is maintained.

(A) Requisite Knowledge. Methods by which foam prevents or controls a hazard; principles by which foam is generated; causes for poor foam generation and corrective measures; difference between hydrocarbon and polar solvent fuels and the concentrates that work on each; the characteristics, uses, and limitations of fire-fighting foams; the advantages and disadvantages of using fog nozzles versus foam nozzles for foam application; foam stream application techniques; hazards associated with foam usage; and methods to reduce or avoid hazards.

(B) Requisite Skills. The ability to prepare a foam concentrate supply for use, assemble foam stream components, master various foam application techniques, and approach and retreat from fires and spills as part of a coordinated team.

Additional NFPA Standards

NFPA 11 Standard for Low, Medium, and High-Expansion Foam
NFPA 600 Standard on Industrial Fire Brigades

Knowledge Objectives

After completing this chapter, you will be able to:

• Understand foam terms.
• Describe how foam works.
• Understand the foam tetrahedron.
• Describe expansion rates.
• Explain the different types of foam concentrate.
• Describe foam characteristics.
• Describe foam percentages and their importance.
• Explain foam guidelines and limitations.
• Identify various foam proportioning devices.
• Recognize the causes of poor foam quality delivery.
• Calculate the application rates for a spill fire.
• Calculate the application rates for a diked fire.
• Calculate the application rates for a tank fire.

Skills Objectives

After completing this chapter, you will be able to perform the following skills:

• Assemble the correct foam stream components.
• Perform the roll-on method of applying foam.
• Perform the bounce-off method of applying foam.
• Perform the rain-down method of applying foam.
You are responding to a plant alarm with a report of a running spill in a partially diked area. When you arrive, the area operator tells you that the source of the leak hasn’t been determined; the liquid spill could be a light hydrocarbon blend, methanol, or a combination of both. You are carrying aqueous film-forming foam (AFFF) in your foam tank. A second engine carrying “alcohol foam” is 5 minutes away. You decide to begin foaming operations to prevent the vapors from reaching an ignition source. A few minutes after foam application has started, you observe that the foam blanket is remaining on the fuel’s surface and spreading out, reducing the release of vapors.

1. What are the six categories of foam concentrates that are commonly used in the fire service?
2. What type of foam concentrate is required for polar solvent fuels?
3. Was the fuel spill hydrocarbon or methanol?

Introduction

Brigade members are faced with a wide variety of flammable and combustible liquid risks. Successful control and extinguishment requires not only the proper application of foam on the fuel surface, but also an understanding of the physical characteristics of foam production. A thorough knowledge of the chemistry of the variety of foam concentrates that are available today is necessary to ensure brigade member safety and fire control.

Firefighting foam is divided into two basic classifications: Class A or Class B. Class A foams are used to fight ordinary combustible material (wood, textiles, and paper). Often referred to as “wetting agents,” Class A foams are very effective because they improve the penetrating effect of water and allow for greater heat absorption. Class A foams are most commonly used by municipal, rural, and wildland fire departments, but are being increasingly used by industrial fire brigades. Class B foam is used on Class B flammable and combustible liquid fires. This chapter will discuss Class B foams that are widely used in the petrochemical industry.

Foam is not a “one size fits all” extinguishing agent. The liquid fuel involved will determine the type of foam concentrate required as well as the volume and the duration necessary to extinguish the fire and control the vapors.

How Foam Works

Hydrocarbon fuels have a lower surface tension than water. When fuel and water are mixed, the two fluids quickly separate; the fuel rises to the top and the water remains on the bottom. When foam concentrate is mixed with water, the surface tension is reduced, allowing the foam/water mix to float on the surface of the fuel.

Foam extinguishes flammable or combustible liquid fires in four ways (Figure 17-1):
- It prevents air from mixing with the vapors on the fuel surface. The foam blanket provides a physical barrier on the fuel surface.
from hazardous chemicals. Mid-range expansion ratios of 30:1 and 55:1 produce an effective foam blanket for vapor suppression on low boiling point organics and chemicals that are highly water reactive.

High Expansion Foams

High expansion foams, which have an expansion ratio from 200:1 to approximately 1000:1, are used for a variety of confined space firefighting situations. The synthetic, detergent type foam is used in basements, ships, aircraft hangars, and mines.

Foam Concentrates

Foam concentrates are divided into six categories commonly used in the fire service:

- Protein foam
- Fluoroprotein foam
- Film-forming fluoroprotein foam (FFFP)
- Aqueous Film-Forming Foam (AFFF)
- Alcohol-resistant aqueous film-forming foam (AR-AFFF)
- Synthetic detergent foam

Protein Foam

Protein foams are limited to use on hydrocarbon fires only. They form a tough stable foam blanket with excellent heat and burnback resistance as well as good drainage rate characteristics. Although protein foams provide slower knockdown than other concentrates, they provide a long-lasting foam blanket after the fire is extinguished. Protein foams can be used with salt water or fresh water. These foams require good air aspiration through a foam nozzle; they cannot be properly aspirated through a structural fog nozzle. Mechanical protein foams were first developed between the late 1930s and mid 1940s, and came into nonmilitary
use after World War II. These foams are produced from hydrolyzed keratin protein (such as hoof and horn meal or chicken feathers) with stabilizing additives and inhibitors to prevent corrosion and control viscosity.

**Fluoroprotein Foam**

Fluoroprotein foams contain fluorochemical surfactants, which improve the performance with better resistance to fuel pickup, faster knockdown, and compatibility with dry chemical agents. These foams are used on hydrocarbon fuels and some oxygenated fuel additives. Fluoroprotein foams have excellent heat and burnback resistance, and maintain a good foam blanket after extinguishment. The addition of surfactants makes the foam more fluid, which increases the knockdown rate and provides better fuel tolerance than protein foam.

**Film-Forming Fluoroprotein Foam (FFFp)**

A derivative of fluoroprotein and AFFF, this foam has performance characteristics similar to protein and fluoroprotein foams. Knockdown performance is improved because this foam releases an aqueous film on the surface of the hydrocarbon fuel. The overall performance of FFFp lies between fluoroprotein foam and AFFF. The foam does not have the quick knockdown of AFFF on a spill fire. When used on a fuel in depth fire, FFFp does not have the burnback resistance of fluoroprotein foam.

**Aqueous Film-Forming Foam (AFFF)**

Commonly referred to as AFFF, this foam has the fastest knockdown on hydrocarbon fuels. Since AFFF is very fluid, it quickly flows around obstacles and across the fuel surface. AFFF can be used as a premixed solution; it is compatible with dry chemical agents and can be used with fresh or salt water. Although AFFF can be used through non-aspirating nozzles, maximum performance can be achieved only through aspirating foam nozzles.

AFFF is composed of synthetic foaming agents and fluorochemical surfactants. AFFF extinguishes fire by forming an aqueous film on the fuel surface. The film is a thin layer of foam solution, which quickly spreads across the surface of a hydrocarbon fuel, creating an extremely fast fire knockdown. Surfactants reduce the surface tension of the foam solution, which allows it to remain on the surface of the hydrocarbon fuel. The aqueous film is formed by the action of the foam solution draining from the foam blanket.

**Alcohol-Resistant Aqueous Film-Forming Foam (AR-AFFF)**

Alcohol-resistant AFFFs are a combination of synthetic detergents, fluorochemicals, and high molecular weight polymers. Polar solvents (water miscible fuels) are not compatible with non-alcohol-resistant foams. Common polar solvents include alcohols (isopropyl, methanol, ethanol), esters (butyl acetate) amines, ketones (methyl ethyl ketone), and aldehydes. When non-alcohol-resistant foam is applied to the surface of a polar solvent, the foam blanket quickly breaks down into a liquid and mixes with the fuel. AR-AFFF performs as a conventional AFFF on hydrocarbon fuels, forming an aqueous film on the fuel surface. When applied to polar solvents, the foam solution forms a polymeric membrane on the fuel surface. This tough membrane separates the fuel from the foam and reduces destruction of the foam blanket.

AR-AFFF is one of the most versatile types of foam. It provides good knockdown and burnback resistance, and has a high fuel tolerance on polar solvent and hydrocarbon fires.

**Synthetic Detergent Foam (High Expansion)**

This foam group is most commonly used on Class A fires. High expansion foam is highly effective in confined space firefighting or in areas where access is limited or entry is dangerous to brigade members. These areas include basements, shipboard compartments, warehouses, aircraft hangars, and mine shafts. High expansion foams can be used in fixed generating systems and portable foam generators.

Rapid smothering and cooling achieve fire control and extinguishment. High expansion foams have a tremendous smothering and steam generation effect because the water is divided into such fine particles (bubbles), which enhance the heat absorption quality of the water. Care must be taken with
regard to electrical power sources in the area when foam is applied.

Foam Characteristics

Good foam must contain the right combination of physical characteristics to be effective. Knockdown speed and flow are the time required for a foam blanket to spread out across a fuel surface. The foam must also be able to flow around obstacles in order to achieve complete extinguishment and vapor suppression.

Foam must have good heat resistance to avoid breakdown from the effects of direct flame contact of burning fuel vapors or heat generated from metal objects. Fuel resistance is foam’s ability to minimize fuel pickup. This oleophobic quality reduces the amount of fuel saturation in the foam.

Foam must produce a good vapor-suppressing blanket. A vapor-tight foam blanket reduces the generation of flammable or combustible vapors above the fuel surface and minimizes reignition.

When used on polar solvent fuels, foam must be alcohol resistant. Because alcohol readily mixes with water and since foam is mostly water, a foam blanket that is not alcohol resistant will quickly dissolve into the fuel and be destroyed.

A comparison of the properties of the various foam types is shown in Table 17-1.

Foam Percentages

Foam concentrates are designed to be mixed with water at specific ratios. Foam concentrate ratios vary from 1% to 6%. The amount of concentrate varies depending on the manufacturer, the type of application, and the type of fuel.

A 3% concentrate is mixed at a ratio of 97 parts water to 3 parts foam concentrate. For example, each 100 gallons of foam solution would contain 97 gallons of water and 3 gallons of foam concentrate. A 6% solution would require 6 gallons of concentrate mixed with 94 gallons of water to produce the same 100 gallons of foam solution. When mixed with water (proportioned), the 100 gallons of solution have virtually the same performance characteristics. A 3% concentrate is twice as concentrated as a 6% concentrate.

It is important to understand that foam concentrates must be proportioned at the percentage listed by the manufacturer. If you want to produce a 3% foam solution, you cannot use half the amount of a 6% concentrate, you must use the concentrate at the percentage listed on the container. Foam concentrates are manufactured at different percentages for a variety of reasons. The chemical make-up of the concentrate, freeze protection additives, military use specifications (Mil-Specs), and cost are some of the basic factors that determine the percentage.

The trend in industry is to reduce foam concentrate percentages as low as possible. Lower proportioning rates mean less bulk storage for the user. Lower percentage rates also mean that you can increase your firefighting capacity by carrying the same volume of foam concentrate or you can reduce your foam supply without reducing your suppression capabilities. Lower proportioning rates can also reduce the cost of fixed foam system components and concentrate transportation costs. Historically, foam concentrates were manufactured at 3% and 6%. Today, foam concentrates are produced for use at rates as low as 1% and as high as 6%, depending on the liquid fuel and how the foam is to be used.

AR-AFFFs are effective on both hydrocarbon and polar solvent fuels. The most common concentrate in use is labeled “AR-AFFF 3%–3%”. This means that the foam can be used at 3% concentration on hydrocarbons and polar solvents. There are also concentrates on the market that are used at different proportioning percentage rates depending on the type of fuel. Concentrates labeled as 3%–6% are still common and have been used for many years. Concentrates labeled as 1%–3% are seeing increased use as the chemical technology improves.

<table>
<thead>
<tr>
<th>Property</th>
<th>Protein</th>
<th>Fluoroprotein</th>
<th>AFF</th>
<th>FFFP</th>
<th>AR-AFFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knockdown</td>
<td>Fair</td>
<td>Good</td>
<td>Excellent</td>
<td>Good</td>
<td>Excellent</td>
</tr>
<tr>
<td>Heat resistance</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Fair</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Fuel resistance</td>
<td>Fair</td>
<td>Excellent</td>
<td>Moderate</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Vapor suppression</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Alcohol resistance</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Excellent</td>
</tr>
</tbody>
</table>
The lower percentage rate is used for most hydrocarbons. It is important to review manufacturers’ data sheets when determining which foam best meets your needs. A concentrate that is labeled 1% for hydrocarbons may require proportioning at 3% for some blended gasoline; this information should be contained in the product data sheet. The higher percentage rate is used for polar solvents. The higher proportioning percentage must be used to produce the polymeric membrane on the fuel surface. If the lower percentage rate is used on a polar solvent fuel, the foam will quickly be destroyed. An important consideration when using foams at 1% concentration is that the foam proportioner must be extremely accurate in order to ensure that a true 1% solution is being delivered to the fuel surface.

Because so many types of foam concentrates are available, selecting the right concentrate can be a challenge. The key is to identify the type of exposure that is to be protected and the type of foam delivery system that will be used. A foam concentrate that provides excellent performance characteristics for hydrocarbon storage tank and containment dike fires using monitors may not be as effective for warehouse protection utilizing a foam sprinkler system. Good hazard evaluation as a part of the overall preplanning process will ensure that the correct foam concentrate is selected.

**Foam Production**

Finished foam is a combination of water, foam concentrate, air, and mechanical agitation. When these four elements are brought together in the correct proportions, foam is produced. The simplified diagram in Figure 17-5 shows how foam is produced through a typical proportioning system.

**Foam Proportioners**

Foam proportioners are designed to supply the correct percentage of foam concentrate into the water stream. A variety of proportioning devices and systems are available to the industrial fire service today. Proportioning equipment ranges from simple in-line eductors used in hose systems to “around-the-pump” and “balanced pressure” systems, found on mobile fire apparatus. This equipment is discussed in detail later in the chapter.

**Foam Guidelines**

Proper storage is critical to foam shelf life. Foam concentrates have temperature limitations that prevent degradation. The concentrates are stored in sealed containers to prevent air contact that causes evaporation and chemical breakdown. Manufacturers’ guidelines will list the storage requirements to ensure concentrates are ready for service after many years of storage.

Foam concentrates in general tend to be more stable when used with moderate water temperatures. Although foam liquids will perform with water temperatures that exceed 100°F, preferred water temperatures are 35°F to 80°F. Foam concentrates can be used with either fresh water or seawater. Water that contains contaminants such as detergents, certain corrosion inhibitors, or oil residues may adversely affect foam quality.

Ideal nozzle pressures range between 50 and 200 pounds per square inch (psi). When a proportioner is used, proportioner pressure should not exceed 200 psi. Higher pressures will cause foam quality to deteriorate, while lower pressures will reduce the reach of foam streams.
When flammable or combustible liquids have been spilled, prompt coverage with a foam blanket can prevent ignition. Additional foam application may be required periodically to maintain the blanket for extended periods until the spill has been cleaned up.

Foam should be considered the same as water when used on or near electrical fires and is not generally recommended in those circumstances. Electrical systems should be de-energized before applying foam.

Foam is not recommended for use on products that are stored as liquids but are normally vapor or gas at ambient conditions, such as propane, butane, and vinyl chloride. Foam is not recommended on water-reactive materials such as magnesium, titanium, lithium, potassium, and other combustible metals.

**Foam Equipment**

A basic foam equipment system consists of a water supply hose, a foam proportioner to mix foam concentrate into the water stream, a foam source, and a hose line with either a standard fog stream nozzle or an air aspirating foam nozzle. There are a variety of proportioning systems; the appropriate type and size of the system required is determined by the anticipated size of the exposure or fire risk and the capacity of the water supply. Small volume, low flow portable equipment is suitable for small Class B spill fires or for Class A fires in relatively small structures. Large spill fires, tank fires, and large structures are more effectively protected by fixed systems or proportioning systems integrated into industrial fire apparatus.

**Foam Proportioning Systems**

A foam proportioner is the device that mixes foam concentrate into a water stream in the correct percentage. Foam eductors and injectors are the two types of proportioners. Proportioners are manufactured in a range of proportioning percentages from 0.5% to 6% and vary in delivery capacity from as little as 60 gpm to over 14,000 gpm.

**Foam Eductors**

A foam eductor functions by flowing water through a venturi, which causes an increase in the velocity of the

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**Brigade Member Safety Tips**

Extinguishing flammable or combustible liquid fires is not listed as an Incipient Industrial Fire Brigade Member job performance requirement in NFPA 1081. A liquid fire that cannot be extinguished with either portable fire extinguishers or 1/2" foam hand lines is beyond incipient-stage firefighting.
Our refinery’s emergency dispatch center was contacted by the assistant chief of the municipal department, who stated that his department was fighting a fire in a 120-foot asphalt tank in a terminal facility on the outskirts of the city. The municipal department was requesting additional foam resources. The assistant chief informed me that they had used all available on-site foam resources (numerous 5-gallon buckets) but that the fire was continuing to grow. Our refinery agreed to respond with a foam engine, a foam tender, and two quick-attack vehicles. Each vehicle was staffed with a full crew.

Upon our arrival at the incident, we noted that the tank was fully involved and that only exposure protection operations were being conducted. I quickly completed the calculations for the required foam extinguishment and noted there were insufficient water supplies to support both exposure protection and firefighting operations. This information was relayed to the command staff; they informed our crews that the tactical units would remain in a defensive operation and that they planned to allow the tank to burn out.

Our apparatus was released from staging and returned to the refinery. Approximately 8 hours later, the municipal department again contacted the refinery and requested that our resources return to the scene. The department staff had decided they would attempt extinguishment of the fire before daybreak. We contacted the command post and informed personnel there of the water supply we would require to complete extinguishment. The command staff informed us they had contacted additional resources and that they would have additional large-diameter hose lays in place by the time the refinery apparatus arrived on the scene.

A refinery quick-attack truck with a 2000-gpm monitor was set up on the northwest corner of the tank, and dual 5-inch supply lines for the monitor were stretched to Foam Engine 3 (a 3000-gpm foam pumper with a 1850-gallon tank). Engine 3 was set up 150 feet north of Quick Attack 1. Two 5-inch supply lines and one 4-inch supply line were redirected from other operations to supply Engine 3. Foam Tender 1 (a 4000-gallon tender) was set up adjacent to Engine 3, and a foam resupply system was established using a portable foam-transfer pump.
Foam extinguishment operations were started using a 3 percent foam application from a rapidly sweeping stream from the 2000-gpm deck gun on Quick Attack 1. Within 15 minutes of the application, significant fire and smoke knockdown could be seen. The west side of the tank area could not be reached owing to an overhang from the failed sidewall. A portable monitor (1250 gpm) with a foam tube was fed with two 3-inch supply lines to supplement extinguishment in the western portion of the tank. After 45 minutes, no visible flame or smoke could be seen. Foam operations were slowed, such that they used intermittent flows from the 2000-gpm and 1250-gpm monitors. The fire was deemed secure, and cooling operations were turned back over to the municipal department.

This incident highlighted the importance of proper foam-application rates and techniques. Ironically, this same tank caught fire approximately one month later as the terminal staff was trying to de-inventory the tank. The refinery resources were again requested, and they extinguished the fire in an even shorter timeframe using the same tactical plan.

Rick Haase
ConocoPhillips Wood River Refinery
Roxana, Illinois
It is important to verify the manufacturer’s recommendation for the length of time that a foam concentrate can remain premixed with water.

Water, creating a low-pressure area on the discharge side of the venturi. The low pressure creates a vacuum, drawing foam concentrate through the pickup tube into the water stream. Eductors are manufactured with either fixed percentage or adjustable percentage.

A commonly used portable eductor is the in-line eductor (also referred to as a line proportioner, inductor, or ratio controller). Portable eductors are a common choice when limited use is expected, when flammable liquid fires are relatively small in size, or when it is difficult to justify the expense of high capacity proportioning systems. Because in-line proportioners are portable, they are easy to set up and can be operated some distance from the apparatus or fixed water source.

Most eductor systems have operating requirements and limitations. The flow rate of the eductor must be matched with a nozzle of the same flow rate. A 95-gpm eductor must be operated with a 95-gpm nozzle in order to deliver an effective foam stream. Mismatching nozzles and eductors is a common cause of proportioning problems. Mismatches can cause a poor quality foam solution or cause the foam concentrate pickup to shut down.

Eductors typically require a fairly high inlet pressure. Most eductors develop their rated flow at 200-psi inlet pressure, although some eductors are designed to operate at lower pressures. In-line eductors will not operate properly if there is excessive back pressure. Total back pressure cannot exceed 65% of the inlet pressure. An eductor operating at 200 psi is limited to a total of 130-psi back pressure. Excessive back pressure may be caused by:

- Nozzle flow that is rated lower than the eductor.
- A nozzle shut-off valve that is not fully open.

**Foam Injectors**

Foam injectors, which are typically found on apparatus, provide foam to the water stream under pressure. A metering system senses the pressure and flow rate of the water and adjusts the injection rate to ensure the correct percentage of foam concentrate is supplied to the water stream. Injection proportioners are effective over a broad range of water flow rates and pressures.

To place a foam line in service, use the following steps:

1. Ensure all foam system components are available. This includes the water supply hose, the foam eductor, foam concentrate, attack hose line, and an air aspirating nozzle or foam nozzle.
2. Connect the water supply line to the water source and to the inlet side of the eductor.
3. Connect the attack line to the discharge side of the eductor.
4. Place the foam concentrate container(s) next to the eductor.
5. Set the metering device on the eductor to match the concentrate percentage on the container.
6. Place the eductor pickup tube into the foam concentrate container.
7. Charge the hose line with water, ensuring the minimum required inlet pressure at the eductor.
8. Flow water through the hose line until foam solution begins to flow from the nozzle.
9. Apply foam from the upwind side using the appropriate application technique (bank in, bounce off, or rain down).

**Batch Mixing**

Foam concentrate can be poured directly into the booster tank on apparatus that is not equipped with a foam proportioning system. Batch mixing can be used either with foam concentrates that are designed for premixed systems or when the manufacturer states that the concentrate can be batch mixed for a short period of time. A booster tank with a volume of 1,000 gallons would require 30 gallons of 3% concentrate or 60 gallons of 6% concentrate. Once the concentrate has been added, the solution should be mixed.
Premixed systems are discharged from stored pressure in the extinguisher or from an inert gas source, which pressurizes a pressure-rated tank. The systems are easy to use and provide quick delivery of the agent on the fire. They are limited to a single use and must be emptied and recharged afterward.

**Foam Tactics**

Successful foam operations require an effective size-up before firefighting starts. It is not enough to arrive on scene and start applying foam on a flammable or combustible liquids fire. You have to know the type of fuel you are dealing with, the size of the area involved, the required application rate, and the required application duration. Once you begin foam operations, you must be able to sustain foam application until the fire is out.

**Spill Fires**

Spill fires are those where the average depth of the fuel is 1” or less. NFPA 11 defines a spill fire as "nondiked spill areas where a flammable or combustible liquid spill might occur, uncontained by curbing, dike walls, or walls of a room or building. A spill fire is bounded only by the contour of the surface on which it is lying."

**Spill Fire Tactical Elements**

Because a spill fire is not contained, an important tactical consideration is the topography of the spill area. You must take into consideration the path that the liquid will follow and any additional hazards caused by migrating fuel. Additional firefighting resources may be needed to protect exposures from potential spill migration. All spill fires should be fought from the uphill, upwind side. This provides safety for personnel and helps carry the foam across the fuel surface.

The type of fuel involved is another tactical consideration. Polar solvent fuels cannot be extinguished with protein, fluoroprotein, or AFFF. Alcohol-resistant foam must be used. The foam concentrate must be matched to the liquid fuel involved.

The next tactical consideration is spill size. The size of the spill area must be calculated to ensure an adequate foam supply. Estimate the length and width of the spill to determine the square footage. Spills tend to be irregular in shape, so it is easier to estimate the area at its largest point. This allows for quicker calculations, and although the actual spill area is smaller than what is calculated, it provides a margin of safety and ensures an adequate foam application rate.

The minimum application rate will vary depending on the type of foam concentrate used. In all cases, the minimum application time for a spill fire is 15 minutes. The minimum application rates and discharge times for...
portable foam nozzles and monitors are shown in Table 17-2. Based on the table, a 1,000 square foot hydrocarbon spill using AFFF requires an application rate of 0.1 gallons per minute (gpm)/square foot (sq ft), which equates to a 100-gpm foam solution flow. The 15-minute application time requires a total solution flow of 1,500 gallons. Foam proportioned at 3% would require a total of 45 gallons of concentrate and 1,455 gallons of water.

It is important to remember that before flammable or combustible liquid firefighting begins, adequate foam concentrate supply, a sustained water supply, and adequate personnel and equipment must be staged at the scene. If foam firefighting cannot be sustained, it should be delayed until the required resources are available. If foam operations begin on a spill fire and must be shut down before the fire is extinguished, the fire will break down and consume the foam that has been applied. Much of the fire area that was extinguished before the operation was shut down will have to be extinguished again when operations are resumed. The end result is that foam concentrate is wasted, additional firefighting time is required, and little was gained by starting the operation without adequate resources.

Three-Dimensional Fires

Three-dimensional fires involve liquid fuel dripping, pouring, or running from one or more horizontal surfaces. These fires can be challenging because the vertical burning liquid provides a constant ignition source to the liquids on each level below. Successful extinguishment requires proper foam application in the correct sequence. Three-dimensional fires can be relatively small, such as those involving with piping that operates at low pressure, or they can be large and difficult to fight, such as when a burning storage tank is pouring fuel into a ground fire. The fuel source supply must be shut off as soon as possible to limit the surface area and depth of the fuel.

Three-Dimensional Fire Tactical Elements

A key tactic is to extinguish the fire at the lowest level first. If the fire at this lower level is not extinguished, it provides a continuous ignition source, in the form of heat and flame to the fuel at the upper level. Even when the fire at the lower level has been completely extinguished, there is the strong probability that a small fire will persist where the burning liquid falls from above and breaks up the foam blanket. The size of the fire at the lower level and the rate at which that size increases over time will determine when and if additional foam application is required to keep the fire area to a minimum while the fire at the upper level is being extinguished.

After the fire is extinguished at the lowest level, foam can be applied to the next horizontal liquid fire. The foam flow should reach the fuel surface as gently as possible. Gentle application will minimize the amount of fuel that splashes onto the areas below. If the foam flow volume is excessive and the containment volume is minimal, a large amount of burning fuel may be pushed over the side of the containment and increase the size of the fire on the lower level.

<table>
<thead>
<tr>
<th>Foam Type</th>
<th>Minimum Application Rate (gpm/ft²)</th>
<th>Minimum Discharge Time (min)</th>
<th>Anticipated Product Spill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein and fluoroprotein AFFF, FFFP, AR-AFFF, and AR-FFFP Alcohol-resistant foams</td>
<td>Consult manufacturer (typically 0.2)</td>
<td>15</td>
<td>Hydrocarbon Polar solvent</td>
</tr>
</tbody>
</table>
As each successive horizontal fire is extinguished, the volume of vertical burning fuel should decrease. A large-volume, foam-compatible dry chemical extinguisher may be effective in extinguishing these vertical fuel fires. Success in extinguishment depends on the volume and volatility of the fuel and fire fighters’ ability to reach the burning fuel with an adequate amount of dry chemical.

When the source of the fuel is from a flange, valve, or piping break, fire fighters can partially control the fire by “capturing” it with a power cone or modified fog water stream. The water stream pattern should be adjusted so that the fire and fuel are contained inside the water pattern. Capturing will reduce both the amount of fire at the source and the amount of ground fire below it. This technique also allows crews to keep the fire away from piping, tanks, and vessels that might otherwise create an exposure hazard.

Small leaks near the ground can be controlled by handlines when such an approach does not put brigade members in danger of operating from a position in the fuel on the ground or under an elevated leak source. Ground monitors or aerial monitors can be used to control large leaks that cannot be controlled by handlines or that are too far away for handline streams to be effective. A spotter with a clear view of the leak and fire stream may be needed to direct the positioning and shape of the stream so as to provide optimal control and capture.

When foam and water operations are conducted in the same location, the streams must be closely coordinated to minimize the destruction or disturbance of the foam blanket that is protecting unburned fuel. Reduction of the ground fire to a manageable size may allow foam operations to be run intermittently. This strategy saves foam supplies, extends the amount of time crews can operate foam lines, and facilitates the logistics required to replenish the foam concentrate.

**Diked Fires**

Diked or contained fires are defined by NFPA 11 as “areas bounded by contours of land or physical barriers that retain a depth of fuel greater than 1 inch.” Diked fires, also referred to as spill fires in depth, require greater resources and present potential tactical challenges that may not exist in spill fires. Fixed discharge outlets and fixed or portable monitors commonly protect large diked areas. Diked areas can also be protected by foam hose lines, but this is often impractical due to the high application rates and extended discharge times that are required.

**Diked Fire Tactical Elements**

Successful extinguishment of a diked fire depends on good preplanning, applying the correct amount of foam for the required time, and proper application technique. The area of a dike can vary greatly depending on the volume of the tank or tanks inside the dike. A properly designed dike will hold the volume of the largest tank plus 10%. Because a dike has a known area, preplanning will ensure that the required resources, application rate, and application duration are identified. The worst possible time to start making calculations is when your world is on fire.

**Preplanning**

Preplanning provides the opportunity to identify exposures and potential problems that are unique to the area. Exposed piping, flanges, fittings, pumps, and meters can create additional problems that must be addressed before an event if the tactical plan is to be successful.

Protection of these exposures should be an early tactical consideration. Heat from a fire can quickly cause flanges and fittings to fatigue. Flange gaskets can fail causing additional fuel to leak into the diked area. Any mechanical connection inside the dike has a high potential for failure and is a potential source of uncontrolled fuel flowing into the dike.

In diked areas that provide containment to more than one tank, multiple failures in piping connections may cause the release of fuel volumes that are in excess of the capacity of the dike. If the dike overflows, you are faced with the potential of a running spill fire that could put personnel and equipment in danger. Fuel burning outside of the dike may also cut off access routes and prevent personnel from operating foam equipment from the most effective position. Applying foam to the fuel surface under pipe fittings will help to maintain their integrity.

**Application Rate and Duration**

Application rates and discharge times for fixed foam application on hydrocarbon liquids are shown in ▶ Table 17-3 ◀. Class I hydrocarbons are those fuels with a flash point of less than 100°F; class II hydrocarbons are fuels with a flash point greater than 100°F. Application rates and discharge times are not shown for fuels (polar solvent group) that require alcohol-resistant foams. The characteristics of the fuels within this group vary widely. The manufacturers’ recommendations should be followed. These recommendations are based on listings or approvals for specific products and foam-making devices. In all cases, the minimum application time is 30 minutes.

**Application Techniques**

The minimum application rates and discharge times assume that the foam discharge is reaching the fuel’s surface. The key to successful foam firefighting is putting foam on the fuel surface in the most efficient and effective manner. Gentle foam application is very important. One of the reasons that foam application rates are higher for handline and monitor application is the potential for foam being plunged into the fuel, which reduces its effectiveness. Foam applied from handlines and monitors can also be carried away by wind and thermal columns from the fire. Foam that does not reach the fuel surface cannot extinguish the fire. It is
important to understand that the minimum discharge times may not be adequate because wind, thermal updraft, or plunging into the fuel will reduce the amount of foam reaching the fire. Foam not only extinguishes the fire but also prevents or reduces reignition by suppressing fuel vapors.

Water streams that are used for cooling operations must be coordinated to prevent disrupting the foam blanket. Personnel should avoid walking in areas where foam has been applied. This breaks up the foam blanket, creating the potential for reignition, and puts fire crews at risk. Small areas of fuel may continue to burn where the foam stream breaks up the foam blanket. This can be corrected by moving the foam stream away and allowing the blanket to reseal, thus extinguishing the remaining fire. Foam should be reapplied as necessary to maintain an effective foam blanket depth.

Three methods of applying foam to the fuel surface are **roll on**, **bounce off**, and **rain down**. Their effectiveness depends on the size of the area obstructions and the amount of time that the fuel has been burning.

**Roll On**
Roll on, also referred to as bank in and sweep, is most effective on spill fires and small dike fires (Figure 17-12). In this technique the foam is applied to the ground in front of the spill, allowing it to build up at the edge of the spill. The energy of the stream pushes the foam blanket out across the fuel surface. Gentle sweeping of the nozzle from side to side in a horizontal motion will cause the foam blanket to spread out across the fuel surface. It may be necessary to change location to ensure the entire area is covered.

To perform the roll-on method, follow the steps in Skill Drill 17-2:

1. Open the nozzle away from the spill until foam is flowing.
2. Move into a safe distance on the upwind side of the spill and open the nozzle.
3. Direct the foam stream onto the ground just in front of the edge of the spill.
4. Allow the foam to pile up and roll out across the top of the fuel until the area is completely covered.
5. Change position as necessary to ensure the foam has covered the entire area.

**Bounce Off**
Bounce off, also referred to as bank shot and bank down, is an effective method of gently applying foam when an object such as piping, a vessel, or a wall is available (Figure 17-13). The bounce-off method allows foam to strike the object and run down onto the fuel surface and spread out. This method is especially effective when using...
a straight stream to apply foam. It may be necessary to bounce the foam off several points to ensure complete foam coverage.

To perform the bounce-off method, follow the steps in **Skill Drill 17-3**:

1. Open the nozzle away from the spill until foam is flowing.
2. Move into a safe distance on the upwind side of the spill and open the nozzle.
3. Direct the foam stream onto an object such as a wall or tank so that the foam is directed off the object and onto the fuel surface.
4. Allow the foam to flow across the fuel surface until the area is completely covered. The foam stream may have to be bounced off several areas of the object to ensure complete coverage and extinguishment.

**Rain Down**

In the rain down method the nozzle is raised up at a sharp angle so that the foam stream is directed into the air (Figure 17-14). This allows the foam stream to reach a height where the stream will break into smaller drops and fall gently back onto the fuel surface. The nozzle angle may have to be adjusted to ensure that the foam pattern effectively reaches the fuel area. The rain-down method can provide an effective and fast knockdown. However, the foam stream may be carried away from the fuel surface in high wind conditions or if the fuel has had an extended preburn, creating a strong thermal column. When these conditions exist, this technique may be ineffective.

To perform the rain-down method, follow the steps in **Skill Drill 17-4**:

1. Open the nozzle away from the spill until foam is flowing.
2. Move into a safe distance on the upwind side of the spill and open the nozzle.
3. Direct the foam stream into the air so that the foam stream breaks up and falls onto the fuel surface.

**Tank Fires**

Tank fires are some of the most dramatic and intense incidents that can occur. Tank fires also require a great amount of preplanning and resource management. A thorough knowledge of tank construction and the fire effects on different construction types will help reduce the number of surprises during an incident. Effective protection systems, resources, and proper strategy and tactics will result in more efficient and effective fire ground operations. The foam requirements for tanks vary depending on the type of tank, the size of the area involved, and the type of product in the tank. Typical application rates are:

- 0.10 gpm/sq ft for hydrocarbon fixed systems
- 0.30 gpm/sq ft for fixed system seal protection
- 0.10 gpm/sq ft for subsurface injection
- 0.10 to 0.16 gpm/sq ft for hydrocarbon spills—portable equipment
- 0.16 gpm/sq ft hydrocarbon storage tanks—portable equipment
- 0.20 gpm/sq ft polar solvent storage tanks—portable equipment

NOTE: Industry recommends an application rate of 0.18 to 0.20 gpm/sq ft for tanks larger than 140'.

**Preplanning**

Tank emergencies and fires require a level of preplanning that exceeds the elements of spill fires and smaller dike fires because of the volume of fuel, the size of tanks, and the volume of foam and water resources required to bring the incident under control.

There are different issues and challenges to be addressed. Fires in diesel tanks, gasoline tanks, and crude oil tanks are not the same. Extinguishing times are different, and they pose different hazards to responding personnel.

The geography of the area is a critical element of the preplan. Access and egress points determine how and if you can get close enough to a tank to operate effectively. Egress addresses the question, can I evacuate quickly enough if the incident gets worse and puts personnel in danger? Dirt roads that will support the weight of fire equipment may be inadequate after heavy rains. Facility drainage is another factor to be considered. It is important to evaluate not only drainage capacity for the dike system around the tanks, but also drainage direction if the dike should overflow and the flow direction of the tank contents if the tank should fail.

How is the facility staffed? If the brigade is fully staffed during the day shift, but only a skeleton crew is in the plant at
other times, the response is going to be delayed until adequate personnel are on scene. Delays in starting firefighting operations could result in a longer firefight.

Tank data in the preplan is essential. Critical questions can be addressed if the information is in the preplan. The type of tank construction, tank capacity, height, diameter, and the capacity of piping systems should not be left to memory at 2 o’clock in the morning.

Knowing the characteristics of the dike will prevent unwanted surprises. Having the capacity of the dike, drain valve locations, and the drain volume rates readily available in the preplan will reduce the chance of overfilling the dike when foam and water are added to the volume released by the tank or process piping.

The exposures at the scene will determine the type and capacity of support activities and personnel required. Tanks, piping, process units, and structures pose different challenges. These exposures require different strategies and tactics and affect the priority order of the incident.

Tank fires are large and complex. Water requirements may exceed the capacity of a plant water system. Water is needed for extinguishment and exposure protection. If the water requirements can’t be met, and additional water cannot be brought to the scene, the tank will burn out or exposures will be lost, possibly both.

Large tanks or multiple tanks can require tremendous volumes of foam. Foam flow calculations for every tank and the associated dike should be calculated and easily retrievable from the preplan. The question “do I have enough foam on hand?” is answered by having this information before the incident. Preplanning of foam requirements will also identify the need for mutual aid or regional foam supplies.

Application Rate and Duration

The firefighting tactics determine application rates and application duration. Over-the-top foam application requires higher rates and longer application times than fixed systems. Foam application from ground monitors and apparatus also requires more personnel. A 120’ cone roof diesel storage tank has a total surface area of 11,500 sq ft. Over-the-top or topside foam stream operations require 0.16 gpm/sq ft or 1,850 gpm application rate for a minimum of 50 minutes. The same tank protected by a fixed system would require higher rates and longer application times than the cone roof system. Adequate foam supplies and an uninterrupted water source must be available before operations begin. The minimum application rate and application duration assume that all the foam is reaching the fuel surface continuously. The actual extinguishing time for a tank fire can vary greatly. Although tanks have been extinguished in under an hour, other tanks have required days to extinguish because of their size, inadequate water or foam supplies, and the time required to establish enough delivery capability.

Crude Oil Tanks

Crude oil storage tanks present unique challenges and hazards that are not present in other flammable or combustible liquid storage tanks. One of the major differences between crude oil and other products is water. Crude storage tanks contain a layer of water in the tank bottom, and some crude oils may contain small and fairly thin stratified areas of water at various levels.

Crude oil is a mixture of light and heavy hydrocarbons that burn off and separate as the fire progresses. As the crude oil continues to burn, the cold crude oil below the fire warms up, this causes more of the light product to rise to the surface and feed the fire. The heavier products in the crude
Oil start to build up and begin to fall down through the crude oil below. This heavy layer, called a heat wave, warms up the crude oil and sends more light fuel to the surface. As this process continues, more fuel is warmed up, creating a layer of superheated fuel just below the surface. The heat wave gets thicker and heavier as it moves toward the bottom of the tank. Three different events can occur during crude oil firefighting.

As the crude oil burns, the layer of preheated fuel below the surface is hot enough to boil water and can cause water droplets to flash to steam. This causes a frothover of hot burning crude oil. If foam is properly applied, the froth will usually stay in the tank. If foam or cooling water is not properly applied, the froth may float burning fuel over the top of the tank. The burning crude oil will spread out in the dike and down ditches. This is another reason to avoid plunging foam into the fuel, to stay out of dike areas and, whenever possible, to operate uphill.

As the heat wave continues to fall and contacts small layers or pockets of water, a small steam explosion creates a slopover. Slopovers tend to be relatively small in intensity. The steam explosion creates a burp of burning crude oil. The frequency and size of slopovers are determined by the volume and number of water layers in the crude oil column. There could be many of these water pockets or none at all, depending on the crude oil.

A boilover is the most serious and potentially deadly incident at a crude tank fire. During the burning of the crude oil, the heat wave continues to build up, getting thicker and heavier. During this process the fire and smoke on the fuel surface show little or no change in appearance. If the fire has not been extinguished or if it has not been possible to drain the water bottom in the tank, a boilover will occur. When the heat wave comes in contact with the water bottom, the water is immediately heated well above 212°F. The water flashes to steam with an expansion ratio of 1,700 to 1 and the resulting steam explosion ejects the entire contents of the tank in seconds. Without knowing how much water is in the bottom of the tank, it's not possible to determine how big the fireball will be. The fireball can easily be up to 10 times the tank's diameter. A relatively small 120-ft diameter tank could create a fireball over 1,000 ft.

Playing a water stream up and down the side of the tank can indicate the level of the heat wave because the water will either change to steam or rapidly evaporate. Proper tactics, adequate resources, and properly trained personnel can help avert a crude tank fire disaster.
Foam is a fundamental flammable and combustible liquids firefighting tool. Understanding the chemistry of foam helps ensure brigade member safety and fire control. Foam is an effective tool for vapor suppression and fire control of hydrocarbon and polar solvent liquids. Effective firefighting foam requires the correct mix of concentrate, water, air, and mechanical agitation. The correct foam type must be matched to the hazard. Foam characteristics differ with the type of foam concentrate and the performance required. Correct foam proportioning must be matched to the type of hazard. Correct foam application and duration is necessary to extinguish a fire or suppress vapors. Safety must be the top priority; equipment and tanks can be replaced.

Batch mixing Pouring foam concentrate directly into the booster tank of an apparatus.
Boilover Violent ejection of fuel from a tank when hot heavy hydrocarbons contact water in a tank bottom, causing a steam explosion.
Bounce off Foam application utilizing an object to bounce foam off of to gently flow onto the fuel surface.
Burnback resistance The ability of a foam blanket to resist direct flame impingement.
Drainage rate The rate at which solution drains from the foam blanket. For foam quality test purposes, it is the time it takes for 25% of the solution to drain from the foam blanket.
Eductor A foam proportioner that operates as a venturi to draw foam concentrate into the water stream.
Finished foam The homogeneous blanket obtained by mixing water, foam concentrate, and air.
Fluorochemical surfactant A chemical compound containing fluorine that is used to reduce surface tension when dissolved in a solution.
Foam concentrate The foaming agent that is mixed with the appropriate amounts of water and air to produce mechanical foam.
Foam proportioner The device that mixes foam concentrate into a water stream in the correct percentage.
Foam solution A homogeneous mixture of water and foam concentrate in the correct proportions.
Frothover A frothing of burning crude oil caused when water contacts superheated fuel and flashes to steam.
Heat wave A build-up of heavy hydrocarbons that collect as crude oil burns.
Hydrolyzed Decomposition of a chemical compound by reaction with water.
Miscible Readily mixes with water.
Oleophobic Oil hating; having the ability to shed hydrocarbon liquids.
Oxygenated To treat, combine, or infuse with oxygen.
Polymer A naturally occurring or synthetic compound consisting of large molecules made up of a linked series of repeated simple monomers.
Premixed foam Mixed foam and water used in portable extinguishers and dual agent systems.
Rain down Foam application method to apply a raised foam stream to allow the foam to gently fall onto the fuel surface.
Roll on Foam application method of applying foam at the front edge of the fuel and allowing the foam to flow across the fuel surface.
Slopover Burps of crude oil caused by steam explosions when the heat wave contacts small areas of water in the fuel column below the surface.
Surface tension The attractive force exerted upon the surface molecules of a liquid by the molecules beneath.
Thermal column Heated air that rises above a burning fuel.
Vapor pressure The pressure exerted by a vapor.
Venturi A tube with a constricted throat that causes an increase in the velocity of water, creating a low-pressure area.
Viscosity The degree to which a fluid resists flow under an applied force. The lower the viscosity, the easier a fluid will flow.
You arrive at the scene of a contained methanol spill fire. Another engine has already begun to apply foam to the fire. You observe that the fire crew is not making any progress in knocking the fire down even though you see a good foam discharge. The brigade leader orders your crew to start applying foam and shuts down the other engine crew’s operations. After a few minutes the size of the fire is reduced and your foam blanket is flowing out across the fuel surface, extinguishing the fire.

1. What is the likely cause of the other engine’s lack of success?
   A. The wrong type of foam concentrate was being used.
   B. The water pressure was too low.
   C. The proportioning percentage was too high.
   D. The chief didn’t give the other crew enough time.

2. When applied to polar solvents, what type of foam forms a polymeric membrane on the fuel surface?
   A. Synthetic foam
   B. Alcohol-resistant Aqueous Film-Forming Foam (AR-AFFF)
   C. Aqueous Film-Forming Foam (AFFF)
   D. Fluoroprotein Foam

3. What is the proportioning percentage required for this fire using AR-AFFF 3%–6% concentrate?
   A. 1%
   B. 3%
   C. 6%
   D. You can use either; AR-AFFF is effective at any percentage.

4. What type of foam concentrate is most commonly used on Class A fires?
   A. Protein foam
   B. Synthetic detergent foam
   C. Fluoroprotein foam
   D. Film-Forming Fluoroprotein Foam (FFFP)