Fighting Fires in and Around Flammable and Combustible Liquid Atmospheric Storage Tanks

API PUBLICATION 2021
THIRD EDITION, JANUARY 1991

American Petroleum Institute
1220 L Street, Northwest
Washington, D.C. 20005

Fighting Fires in and Around Flammable and Combustible Liquid Atmospheric Storage Tanks

Safety and Fire Protection Department

API PUBLICATION 2021
THIRD EDITION, JANUARY 1991

American Petroleum Institute

SPECIAL NOTES

1. API PUBLICATIONS NECESSARILY ADDRESS PROBLEMS OF A GENERAL NATURE. WITH RESPECT TO PARTICULAR CIRCUMSTANCES, LOCAL, STATE, AND FEDERAL LAWS AND REGULATIONS SHOULD BE REVIEWED.

2. API IS NOT UNDERTAKING TO MEET THE DUTIES OF EMPLOYERS, MANUFACTURERS, OR SUPPLIERS TO WARN AND PROPERLY TRAIN AND EQUIP THEIR EMPLOYEES, AND OTHERS EXPOSED, CONCERNING HEALTH AND SAFETY RISKS AND PRECAUTIONS, NOR UNDERTAKING THEIR OBLIGATIONS UNDER LOCAL, STATE, OR FEDERAL LAWS.

3. INFORMATION CONCERNING SAFETY AND HEALTH RISKS AND PROPER PRECAUTIONS WITH RESPECT TO PARTICULAR MATERIALS AND CONDITIONS SHOULD BE OBTAINED FROM THE EMPLOYER, THE MANUFACTURER OR SUPPLIER OF THAT MATERIAL, OR THE MATERIAL SAFETY DATA SHEET.

4. NOTHING CONTAINED IN ANY API PUBLICATION IS TO BE CONSTRUED AS GRANTING ANY RIGHT, BY IMPLICATION OR OTHERWISE, FOR THE MANUFACTURE, SALE, OR USE OF ANY METHOD, APPARATUS, OR PRODUCT COVERED BY LETTERS PATENT. NEITHER SHOULD ANYTHING CONTAINED IN THE PUBLICATION BE CONSTRUED AS INSURING ANYONE AGAINST LIABILITY FOR INFRINGEMENT OF LETTERS PATENT.

5. GENERALLY, API STANDARDS ARE REVIEWED AND REVISED, REAFFIRMED, OR WITHDRAWN AT LEAST EVERY FIVE YEARS. SOMETIMES A ONE-TIME EXTENSION OF UP TO TWO YEARS WILL BE ADDED TO THIS REVIEW CYCLE. THIS PUBLICATION WILL NO LONGER BE IN EFFECT FIVE YEARS AFTER ITS PUBLICATION DATE AS AN OPERATIVE API STANDARD OR, WHERE AN EXTENSION HAS BEEN GRANTED, UPON REPUBLICATION. STATUS OF THE PUBLICATION CAN BE ASCERTAINED FROM THE API AUTHORING DEPARTMENT [TELEPHONE (202) 682-8000]. A CATALOG OF API PUBLICATIONS AND MATERIALS IS PUBLISHED ANNUALLY AND UPDATED QUARTERLY BY API, 1220 L STREET, N.W., WASHINGTON, D.C. 20005.

FOREWORD

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any federal, state, or municipal regulation with which this publication may conflict.

Suggested revisions are invited and should be submitted to the director of the Safety and Fire Protection Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

CONTENTS

Page

SECTION 1—GENERAL
1.1 Introduction 1
1.2 Scope and Objectives 1
1.3 Definition of Terms 1
1.4 Referenced Publications 2

SECTION 2—FIRE-FIGHTING AGENTS
2.1 General 2
2.2 Water 3
2.3 Foams 3
2.3.1 General 3
2.3.2 Protein Foam Concentrates 4
2.3.3 Fluoroprotein Foam Concentrates 4
2.3.4 Aqueous-Film-Forming Foams 4
2.3.5 Alcohol-Resistant Foam Concentrates 4
2.3.6 Film-Forming Fluoroprotein Foams 5
2.3.7 Chemical Foams 5
2.4 Dry Chemicals 5
2.4.1 General 5
2.4.2 Regular Sodium Bicarbonate 5
2.4.3 Foam-Compatible Sodium Bicarbonate 5
2.4.4 Potassium Bicarbonate 5
2.4.5 Potassium Chloride 5
2.4.6 Monoammonium Phosphate 5
2.4.7 Potassium Carbamate 6
2.4.8 Potassium Sulfate 6
2.5 Aqueous-Film-Forming Foam Combined With Dry Chemical 6
2.6 Halogenated Hydrocarbons 6
2.6.1 Halon 1301 6
2.6.2 Halon 1211 6
2.6.3 Halon 2402 6

SECTION 3—FIRE-FIGHTING OPERATIONS IN AND AROUND PETROLEUM STORAGE TANKS
3.1 General 7
3.2 Strategy 7
3.3 Assessment of the Fire 7
3.4 Strategy and Tactics Applicable to All Tank Emergencies 8
3.4.1 General 8
3.4.2 Passive Tactics 8
3.4.3 Defensive Tactics 8
3.4.4 Offensive Tactics 9
3.5 Protecting Adjacent Tanks 10
3.6 Tank Vent Fires 10
3.6.1 Yellow-Orange Flame With Black Smoke 10
3.6.2 Snapping Blue-Red, Nearly Smokeless Flame 10
3.7 Fighting Ground Fires Around Tanks 11

SECTION 4—CONTROLLING AND EXTINGUISHING TANK FIRES
4.1 General 11
4.2 Cooling Water 11

Page

4.3 Extinguishing the Fire 12
4.4 Tanks 12
4.4.1 General 12
4.4.2 Cone-Roof Tanks 12
4.4.3 Cone-Roof Tanks Containing Crude Oil and Other Materials With Boilover Potential 13
4.4.4 Open-Top Floating-Roof Tanks 15
4.4.5 Covered Floating-Roof Tanks 15
4.4.6 Large Tanks 16
4.4.7 Frangible or Weak-Seam Roofs 16
4.4.8 Vertical, Low-Pressure Fixed-Roof Tanks 16
4.4.9 Bolted- and Riveted-Seam Tanks 16
4.5 Motor Fuel Lead Blending—Blending Tanks and Storage Tanks 16
4.6 Other Additives 17
4.7 Overhaul 17

APPENDIX A—BIBLIOGRAPHY 19
APPENDIX B—PREINCIDENT PLANNING 21
APPENDIX C—INCIDENT DATA SHEET 27
APPENDIX D—CRUDE OIL TANK BOILOVER, SLOPOVER, OR FROTHOVER 29
APPENDIX E—FOAM FRICTION LOSS DATA 31

Figures
1 — Cone-Roof Tank 12
2 — Boilover of a Cone-Roof Tank 14
3 — Open-Top Floating-Roof Tank 15
4 — Covered Floating-Roof Tank 15
E-1— Static Head Conversion 32
E-2 —Foam Friction Losses (2½-, 3-, 4-, 6-, 8-, and 10-Inch Pipe) 32
E-3 —Foam Friction Losses (12-, 14-, 16-, 18-, 20-, and 24-Inch Pipe) 33
E-4 —Foam Velocity Versus Foam Rate: Schedule 40 (2½-, 3-, 4-, 6-, 8-, 10-, 12-, and 14-Inch Pipe) 33
E-5 —Foam Velocity Versus Expanded Foam Rate: Schedule 40 (14-, 16-, and 18-Inch Pipe) 34
E-6 —Foam Velocity Versus Expanded Foam Rate: Schedule 40 (20- and 24-Inch Pipe) 34

Tables
B-1 —Application Method for Fixed Chambers or Monitors 25
B-2 —Minimum Application Time and Minimum Number of Hose Streams Required for a Given Tank Size 25

Fighting Fires in and Around Flammable and Combustible Liquid Atmospheric Storage Tanks

SECTION 1—GENERAL

1.1 Introduction

Surveys conducted by API show very few petroleum storage tank fires compared with the thousands of tanks used in all phases of petroleum operations.

In view of the low number of tank fires on record, relatively few people have had direct experience with fighting tank fires. This guide was prepared to satisfy that need.

Prefire planning must include consideration of federal, state, and local laws and ordinances (see 1.4 and Appendix A). Proper training at regular intervals is essential to fighting fires effectively in and around storage tanks. The type of fire protection that is developed will vary with the nature of the plant, its size, and its complexity. In a medium-size plant, the position of fire chief may be a part-time function of one of the plant personnel. Other plant personnel, who can leave their normal work during an emergency, may be trained to serve in assigned fire crew duty. Assistance may be furnished by still others in the plant, depending on the availability of personnel. Small plants would follow this plan as far as is practical but will have to depend more on mutual aid and assistance from the public fire department. The larger plants may have a full-time fire chief and one or more full-time fire fighters who supervise assigned fire crews or brigades. These full-time fire fighters normally inspect and maintain fire equipment and perform training, along with fire fighting. They may also make fire prevention inspections, conduct gas tests, and issue hot-work permits.

1.2 Scope and Objectives

The scope and principal value of this publication is to teach interested fire fighters about various kinds of aboveground atmospheric storage tanks and methods that could be used to fight flammable and combustible liquid tank fires. It includes emergency planning and mutual aid so that a total plan for tank fire fighting can be developed. It includes flammable and combustible liquids with low flash points, such as gasoline, and those with high flash points, such as lube oil and asphalt.

This publication presents practical tank fire-fighting guidelines based on industry experience concerning the following:

a. Prefire planning for fighting fires involving horizontal and vertical atmospheric storage tanks.
b. Precautions and guidance in strategy and tactics for fighting fires in and around flammable and combustible liquid atmospheric storage tanks.
c. Fire-fighting agents useful on fires in and around storage tanks.

This publication specifically excludes consideration of the following:

a. Personal protective equipment.
b. Pressurized gases.
c. Nonmetallic tanks.

Fire prevention technology and types of fire protection equipment and maintenance data are outside the scope of this publication. They are covered in publications such as NFPA 11, NFPA 30, and API Publication 2005 (see 1.4 and Appendix A).

It should be understood that this document provides basic guidelines. Its application must remain flexible to relate to conditions as they occur.

1.3 Definition of Terms

1.3.1 *Aqueous-film-forming foam (AFFF) concentrates* are based on fluorinated surfactants plus foam stabilizers and are generally diluted with water to a 3- or 6-percent solution by volume, depending on the type of concentrate. The foam formed acts as a barrier to exclude air or oxygen and develops an aqueous film on some fuel surfaces that suppresses the evolution of fuel vapors.

1.3.2 The *class of a fire* is determined by what type of fuel is involved in the fire. *Class A fires* involve ordinary combustibles such as wood, cloth, paper, and rubber. *Class B fires* involve flammable or combustible liquids and gases.

1.3.3 *Control* is a reduction in fire intensity of approximately 90 percent.

1.3.4 *Film-forming fluoroprotein (FFFP) concentrate* is composed of a combination of protein and film-forming surfactants. The foam formed acts as a barrier to exclude air or oxygen and develops an aqueous film on some fuels that suppresses the evolution of fuel vapors. Concentrates are diluted with water to a 3- or 6-percent solution by volume, depending on the type of concentrate.

1.3.5 *Fluoroprotein (FP) foam concentrate* is a foam concentrate with a protein base and a synthetic fluorinated surfactant additive. In addition to an air-excluding foam blanket, it may also deposit a vaporization-preventing film on the surface of a liquid fuel. Concentrates are diluted with water to a 3- or 6-percent solution by volume, depending on the type of concentrate.

1.3.6 The *foam application rate* is a measure of the quantity of foam applied per unit of time per unit of area. It is usually based on the amount of foam solution (in gallons or liters) per unit of time (in minutes) per unit of area (in square feet or square meters); for example, gallons per minute per square foot.

1.3.7 The *foam expansion value* is defined as the ratio of final foam volume to original foam solution volume before adding air. It is also the numerical value of the reciprocal of the specific gravity of the foam.

1.3.8 *Foam quality* is a measure of a foam's physical characteristics, expressed as the foam's 25-percent drain time, expansion value, and burn-back resistance.

1.3.9 The *minimum application rate* is the rate that is sufficient to cause extinguishment and demonstrate satisfactory stability and resistance to burn-back (see NFPA 11).

1.3.10 A *polar solvent* is a flammable liquid partially or totally miscible with water. Alcohol, ketones, aldehydes, and ethers are common organic polar solvents.

1.3.11 *Protein foam concentrates* consist primarily of products from a protein hydrolysate plus stabilizing additives and inhibitors to reduce the freezing point, prevent corrosion of equipment and containers, resist bacterial decomposition, control viscosity, and otherwise assure readiness for use in an emergency. Concentrates are diluted with water to form 3- or 6-percent solutions, depending on the type of concentrate.

1.3.12 *Subsurface injection* is a method of fighting hydrocarbon tank fires in which foam is fed into the tank at a point below the surface of the burning fuel. The foam rises to the surface and blankets the fuel vapor at the surface.

1.3.13 *Topside application* is a method of foam discharge in which the foam is applied to the surface of the burning fuel.

1.3.14 *Twenty-five-percent drain time* is the time required for 25 percent of the liquid contained in the foam to drain.

1.3.15 A *Type I discharge outlet* is a device that conducts and delivers foam onto the burning surface of a liquid without submerging the foam or agitating the surface; for example, a foam trough.

1.3.16 A *Type II discharge outlet* is a device that delivers foam onto the burning liquid, partially submerges the foam, and produces restricted agitation of the surface; for example, a foam chamber.

1.3.17 A *Type III discharge outlet* is a device that delivers foam so that it falls directly onto the surface of the burning liquid in a manner that causes general agitation; for example, lobbing with a foam nozzle.

1.4 Referenced Publications

Note: See Appendix A for further sources of information on fire protection for petroleum facilities.

The following standards and publications are cited in this publication:

API

Std 620	*Design and Construction of Large, Welded, Low-Pressure Storage Tanks.*
Std 650	*Welded Steel Tanks for Oil Storage*
Publ 2005	*Service Station Safety*
Publ 2300	*Evaluation of Firefighting Foams as Fire Protection for Alcohol Containing Fuels*

NFPA[1]

11	*Low Expansion Foam and Combined Agent Systems*
12A	*Halon 1301Fire Extinguishing Systems*
12B	*Halon 1211 Fire Extinguishing Systems*
17	*Dry Chemical Extinguishing Systems*
30	*Flammable and Combustible Liquids Code*

[1]National Fire Protection Association, Batterymarch Park, Quincy, Massachusetts 02269.

SECTION 2—FIRE-FIGHTING AGENTS

2.1 General

This section describes fire-fighting agents that are useful in fighting ground fires that could involve storage tanks and fires in storage tanks that contain flammable and combustible liquids. Only agents and equipment designed specifically for the purpose of fighting liquid fires should be used. These items should be used by personnel qualified for fighting liquid fires.

2.2 Water

Water is used universally as a fire-fighting agent. It serves as a cooling, quenching, smothering, emulsifying, diluting, and displacing agent. Water has the greatest heat-absorbing properties of any common material and is usually the most readily available and plentiful. It is used to cool equipment, structures, and tank shells that are exposed to a fire, thus preventing or reducing both heat damage to equipment and overpressure that results from overheating of vessel contents. When used as a fog or spray stream, water is effective for cooling. Extinguishment will result if the fuel surface can be cooled below its flash point, which is the temperature at which the fuel will give off enough vapor to support combustion. When properly applied in spray form, water may be suitable for extinguishing small fires in liquid hydrocarbon fuels with flash points above 38°C (100°F).

Water spray applied lightly to burning viscous liquids with flash points above 93°C (200°F) can produce a layer of froth on the liquid surface that acts like foam and smothers the fire. Fighting a small-diameter hot asphalt tank fire is an example.

Flammable liquids that are soluble in water may, in some instances, be extinguished by dilution. The percentage of dilution necessary to effect extinguishment varies with the product. For example, a solution of 75 percent water and 25 percent ethyl alcohol will barely support combustion. In case of tank fires, it may be impractical to achieve sufficient dilution.

Water is frequently used as a displacement medium in leaking hydrocarbon lines, or it may be used to float the liquid hydrocarbons above a leak in a tank to interrupt product leakage. Check valves should be used to prevent backflow into the fire-protection system. Before the check valve will open, the water pressure must be greater than the product pressure. Water, however, cannot be used to displace refrigerated liquefied petroleum gas or liquefied natural gas from a leaking pipeline because the product temperature is below 0°C (32°F). The low temperature will cause the water to freeze and possibly break a line, thus increasing the magnitude of the incident.

Water spray is particularly useful for dispersing escaping gases and vapors. It may also be used to protect operating personnel and fire fighters from radiant heat or contact with flame.

Water is the principal ingredient in fire-fighting foam, the agent most commonly used in extinguishing large flammable and combustible liquid fires.

Water can be used effectively to control, but not to extinguish, fires in low-flash-point fuels.

2.3 Foams

2.3.1 GENERAL

Foams for fire protection are an aggregate of gas-filled bubbles that will float on the surface of a flammable liquid. They are commonly made from an aerated solution of water and a small percentage of foam concentrate. They are used principally to form a cohesive floating blanket on the fuel surface that extinguishes the fire by smothering and cooling the fuel. Foam also prevents reignition by averting formation of combustible mixtures of vapor and air above the fuel surface. Foams are particularly suited for extinguishing two-dimensional (flat) flammable liquid fires that result from spills or involve storage tanks. The foam forms a vapor-sealing blanket that extinguishes the fire and secures the area.

To have a good-quality foam blanket, the water quality must be good. Water may be hard or soft, fresh or salt, but it must be of suitable quality so that it does not have an adverse effect on foam formation or foam stability. Corrosion inhibitors, emulsion-breaking chemicals, or any other additives must not be used without prior consultation with the foam concentrate supplier. Recycled water from skim ponds or separators is generally not acceptable, because trace amounts of oil can affect the quality of the foam blanket.

In fires involving jetting or falling fuel (such as a ruptured tank or line), foam is effective only on the part of the fire that involves fuel spills or on pools that form flat surfaces. Three-dimensional fires can be extinguished by securing the pool fire with foam and then extinguishing the falling fuel with dry chemical or Halon 1211 or by shutting off the source of fuel that is feeding the fire. Three-dimensional or falling-fuel fires involving combustible liquids with flash points above 60°C (140°F) can usually be extinguished by using water or foam spray after the pool fire is extinguished.

To extinguish tank fires or liquid fires in depth, continuous foam application at the required rate is critical. The fire will not be extinguished unless the foam is continuously applied at the recommended application rate for the specified minimum time. Once the foam blanket is in place it must be maintained on the liquid surface until a sealing, cohesive foam blanket is established. The integrity of the blanket should be monitored and maintained for the safety of personnel and to maintain extinguishment.

When foam is applied by handlines or monitors over the rim of a tank, wind and thermal updrafts frequently carry much of it away. As specified in

NFPA 11, foam must be applied at a higher application rate to replace this loss.

Foam is not suitable for extinguishing fires that involve flammable gases, liquids that contain large amounts of liquefied petroleum gas, or any liquid that has a vapor pressure above atmospheric pressure (14.7 pounds per square inch at sea level). Gases will boil off the liquid surface and blow through the foam blanket. The fire will then continue to burn on the top side of the foam blanket.

Foam is made by turbulent mixing of atmospheric air into the foam solution (water and foam concentrate). This turbulence may be produced by air induced into the solution by venturi action, such as by using a foam maker.

Many types of foam concentrate are available for use as 3- or 6-percent solutions by volume. Concentrates for use at 3 percent are normally preferred to those for use at 6 percent because of their efficiency in use, storage, and handling. The equipment used to proportion and distribute the foam must be compatible with the concentrate being used.

Foam concentrates of different types or from different manufacturers should not be mixed unless it has been established that they are completely compatible. For requirements and limitations, see NFPA 11.

2.3.2 PROTEIN FOAM CONCENTRATES

Protein foam concentrates were introduced in about 1935 and have been used widely for petroleum-spill and tank fires. They consist primarily of hydrolyzed proteins plus stabilizing additives and inhibitors to lower the freezing point, prevent corrosion of equipment and containers, resist bacterial decomposition, control viscosity, and assure readiness for use in emergencies.

2.3.3 FLUOROPROTEIN FOAM CONCENTRATES

Fluoroprotein foam (FP) concentrates are very similar to protein foam concentrates but have a synthetic, fluorinated surfactant additive. They form an air-excluding foam blanket and may also deposit a film to prevent evaporation on the surface of a liquid fuel. They were introduced around 1965 to improve the capabilities of protein foam. These foams are usually compatible with current dry-chemical extinguishing agents when used simultaneously on a fire, but this should be verified by the manufacturers or by tests. Compared with protein foam, FP foam has a much better resistance to fuel entrainment when submerged in the liquid fuel and can therefore withstand rougher application. This characteristic makes FP foam suitable for subsurface injection into tanks containing nonpolar liquid hydrocarbons or for monitor or hose stream application over the rim of a tank. When used on petroleum fuels, protein and FP foams generally have greater stability and resistance to burn-back than do other types of foams. For requirements and limitations, see NFPA 11.

2.3.4 AQUEOUS-FILM-FORMING FOAMS

Aqueous-film-forming foams (AFFFs) consist of synthetic fluorinated surfactants, hydrocarbon surfactants, solvents, and water. AFFFs act as a barrier to exclude air and also develop an aqueous film on the fuel surface capable of suppressing the evolution of fuel vapors from most petroleum fuels. The foam blanket produced should be applied thickly enough to be visible before fire fighters rely on the aqueous film as a vapor suppressant. Monitoring for flammable mixtures should be performed. Without a visible foam blanket to replenish it, the film may or may not be present. Therefore, the film alone cannot be relied upon to provide a tenacious vapor seal. AFFF concentrates may be used in conventional foam-making devices suitable for producing protein foams. However, protein foam-proportioning equipment should not be converted for use with AFFF concentrates without consultation with the manufacturer. Additionally, a thorough flushing of the complete system, including the foam tank, is usually required.

The foam produced with AFFF concentrate is compatible with dry chemicals and is suitable for combined use with them. Protein and FP foam concentrates may be incompatible with AFFF concentrates and should not be mixed in the same proportioning system. Foams separately generated with these concentrates are compatible and can be applied to a fire in sequence or simultaneously. AFFFs are available for use at 1–6-percent concentration.

AFFFs are generally faster draining and more fluid than other foams, resulting in rapid knockdown and extinguishment. Topside application by fixed, semifixed, or portable methods is a typical strategy. Some AFFFs are also suitable for subsurface injection into tanks containing ordinary hydrocarbons. Regular AFFF is not suitable for topside application or subsurface injection into tanks containing water-miscible fuels or polar solvents. For requirements and limitations, see NFPA 11.

2.3.5 ALCOHOL-RESISTANT FOAM CONCENTRATES

For fighting fires in liquids that are water miscible or that chemically destroy protein, FP, or AFF foams, special foaming concentrates are available that form an insoluble barrier between the fuel surface and the foam blanket. Commonly called alcohol or polar solvent foams, they vary considerably in chemical composition, acceptable methods of proportioning, useful concentration limits, and other operational parameters. They are usually available only as concentrates for use at 6 percent on polar solvents but may be approved for use at 3 percent on petroleum products.

Some of these concentrates produce AFFFs on petroleum products. Systems that use these agents require special design considerations. Different alcohol-resistant foam concentrates should not be mixed, nor should they be mixed with other types of concentrate unless their compatibility has previously been established. These agents are used only for topside application to water-miscible liquids. They are not suitable for subsurface application into water-miscible liquids. For requirements and limitations, see NFPA 11.

2.3.6 FILM-FORMING FLUOROPROTEIN FOAMS

Film-forming fluoroprotein (FFFP) foam combines the characteristics of AFFF and FP foam. It is a combination of protein and film-forming surfactants. It acts as a barrier to exclude air and can develop an aqueous film on the fuel surface that is capable of suppressing the evolution of fuel vapor. Like standard FP foams, FFFP foams have good resistance to fuel entrainment when submerged in the liquid fuel and can therefore withstand rougher application. This makes FFFP foam suitable for subsurface injection into tanks or from monitors over the rim into a tank. It is similar to AFFF when applied to spill fires.

The foam produced with FFFP foam concentrate is compatible with dry chemicals. FFFP foams are available as concentrates for use at 3 percent and as concentrates for use at 6 percent.

FFFP foam concentrates have been developed that are effective in combating fires involving water-miscible and polar liquids as well as ordinary hydrocarbons. These agents have components that react chemically with polar solvents to form a plasticlike film. They can be used in conventional foam-making devices. It should be noted that higher concentrations or higher application rates may be required for water-miscible products.

2.3.7 CHEMICAL FOAMS

Chemical foams are formed by a chemical reaction between two powders that contain alkaline and acidic salts. These foams are inferior to current foams with respect to ease of handling, installation, and equipment maintenance. For these reasons, chemical foams should not be used.

2.4 Dry Chemicals

2.4.1 GENERAL

Dry chemicals are highly efficient in extinguishing fires involving flammable liquids. Fast extinguishing action is achieved when the agent is applied to all fire areas without interruption. The finely divided chemical initiates a chain-breaking reaction to inhibit the oxidation process within the flame. Dry chemicals do not secure the fuel against reflash if it is again exposed to ignition sources. For additional information concerning dry chemicals, see NFPA 17.

Dry chemicals have been used, either alone or in combination with foam, to extinguish fires in the seals of floating-roof tanks when a large area of the seal is burning. They are also effective on small spill fires involving jetting or falling fuel. If there is risk of reignition from embers or hot surfaces, these ignition sources should be quenched or cooled with water and secured with foam, or the source of fuel should be shut off before extinguishment is attempted.

Several types of dry chemical are available that contain additives to produce free flow and water repellency.

2.4.2 REGULAR SODIUM BICARBONATE

Sodium bicarbonate is commonly referred to as "ordinary" or "regular" dry chemical. It is not compatible with protein foams because it contains metallic stearate additives, which are antifoaming agents that cause breakdown of protein foams. Regular sodium bicarbonate should not be used before, during, or after the use of protein foams.

2.4.3 FOAM-COMPATIBLE SODIUM BICARBONATE

Foam-compatible sodium bicarbonate has been treated with silicone polymer to make it suitable for use simultaneously with foam. Only foam-compatible dry chemicals should be used where follow-up with foam is expected.

2.4.4 POTASSIUM BICARBONATE

Potassium bicarbonate (purple K) is usually available in a foam-compatible form. It has greater extinguishing capability on Class B fires than does sodium bicarbonate (see 2.4.2 and 2.4.3). It may be compatible with protein foams, depending on the manufacturer's process and its listing.

2.4.5 POTASSIUM CHLORIDE

Potassium chloride, a foam-compatible dry chemical, has about the same extinguishing capability as does potassium bicarbonate (see 2.4.4). It is compatible with all types of foam but is usually corrosive to metals such as steel and aluminum. It is not generally used in the United States.

2.4.6 MONOAMMONIUM PHOSPHATE

Monoammonium phosphate (or a mixture of monoammonium and diammonium phosphates), a multipurpose dry chemical, is the only dry chemical that is effective on Class A combustible fires and Class B flammable liquid and gas fires. It is more effective on Class B fires than sodium bicarbonate but is less effective than potassium bicarbonate. It may be compatible with protein foams, depending on the manufacturer's process and its listing.

2.4.7 POTASSIUM CARBAMATE

Potassium carbamate, a foam-compatible dry chemical, is formulated from a reaction produced from potassium bicarbonate and urea. It is completely foam compatible and is more effective than potassium bicarbonate on flammable-liquid or gas fires.

2.4.8 POTASSIUM SULFATE

Potassium sulfate, a foam-compatible dry chemical, is available in Europe but is not used in the United States. It is about as effective as sodium bicarbonate on flammable-liquid and gas fires.

2.5 Aqueous-Film-Forming Foam Combined With Dry Chemical

Hose reels equipped with twinned hoses and twinned nozzles, and turrets equipped with twinned nozzles, have been developed for simultaneous or alternating application of AFFF and dry chemical by one fire fighter. AFFF and potassium bicarbonate are usually the two agents used, although multipurpose dry chemical and water with a wetting agent are available. The AFFF concentrate is usually premixed in solution with water and stored in a container that can be pressurized with nitrogen for instantaneous use, similar to a dry chemical extinguisher. Combined-agent storage containers vary in size from 50 to 200 gallons (189 to 757 liters) of premixed AFFF solution and from 500 to 3000 pounds (227 to 1361 kilograms) of dry chemical. This design permits use against both three-dimensional pressure or leak fires and spill fires. The AFFF secures against reflash, as the fire fighter uses dry chemical for fast knockdown and extinguishment (see NFPA 11).

2.6 Halogenated Hydrocarbons

Halogenated hydrocarbons, commonly referred to by the trade name Halon, are fully halogenated methane or ethane derivatives. They are colorless, odorless, and electrically nonconductive. Like dry chemicals, Halons initiate a chain-breaking reaction that inhibits oxidation within the flame, thus providing rapid extinguishment of Class B fires. Rapid extinguishment of Class A combustible, non-deep-seated fires may also be obtained. Halogenated hydrocarbons are particularly effective for flammable liquid or gas fires and are also effective for extinguishment of Class C fires where a clean agent is desired.

There are three halogenated-hydrocarbon extinguishing agents presently available:

a. Halon 1301 (bromotrifluoromethane).
b. Halon 1211 (bromochlorodifluoromethane).
c. Halon 2402 (dibromotetrafluoroethane), which has limited application because of its higher toxicity.

2.6.1 HALON 1301

Halon 1301 boils at –58°C (–72°F) and vaporizes close to the nozzle during discharge. Its primary application is in total flooding systems, in which it is superpressurized with nitrogen to either 2482 kilopascals (360 pounds per square inch gauge) or 4137 kilopascals (600 pounds per square inch gauge). Storage temperatures for the agent range from 55°C (130°F) to –29°C (–20°F). Total flooding systems can be designed either to extinguish a fire or to produce an inert atmosphere in a protected, enclosed area (see NFPA 12A).

2.6.2 HALON 1211

Halon 1211 boils at –3.3°C (26°F) and affords reasonably rapid coverage. Halon 1211 is generally used in hand-portable fire extinguishers where a clean agent is desired. Some companies are installing automatic systems that use Halon 1211 to extinguish rim fires on floating-roof tanks. However, these systems may allow flashbacks. (Flashbacks have occurred in actual fires.) It is also difficult to maintain the required concentration for the required duration (see NFPA 12B).

2.6.3 HALON 2402

Halon 2402 boils at 47.2°C (117°F). At normal ambient temperatures, it discharges and distributes as a liquid. Because of its higher boiling point, discharge equipment can be recharged without the use of special transfer equipment. Other than in specialized explosion-suppression systems, the general use of Halon 2402 has not been established in the United States. It is unsuitable for use in total flooding of occupied areas because of its toxicity.

SECTION 3—FIRE-FIGHTING OPERATIONS IN AND AROUND PETROLEUM STORAGE TANKS

3.1 General

Tank fires are complex events; fighting them requires planning and proper organization of resources. Multiple tank fires and fires in tanks of very large diameter (more than 150 feet) pose extraordinary logistical and coordination problems. The incident commander must supervise his own force and coordinate activities with mutual aid departments, plant operating staffs, and others.

Large fires may require many hours of preparation for emergency operations before the incident can be resolved.

Experience shows that safe and successful fighting of tank fires requires proper planning (see Appendix B). A workable and safe strategy should be developed, tactics should be implemented, and progress should be monitored. If the plan is not achieving the desired results, the plan should be changed accordingly.

3.2 Strategy

Strategy relates to planning. A general strategic plan includes the following components:

a. Goals—the items to be accomplished and the results desired.
b. Resources—the items needed to achieve the desired results.
c. Organization—assignment of personnel to implement the plan.
d. Strategy and tactics—formulation of an action plan and communication of the plan and the results.
e. Feedback—evaluation of the plan's progress and implementation of any needed modifications.

In general, the strategy for fighting tank fires should be developed in advance, as part of the facility emergency action plans.

3.3 Assessment of the Fire

Assessment is the ongoing process of gathering information related to the emergency.

As in any fire-fighting situation (after turning in the alarm), the first action to be taken by the responding incident commander is to assess the situation. Information should be gathered quickly to develop the most effective and safe strategy to fight the fire. Some of the elements to consider and their priorities are as follows:

a. Rescue—the need for rescue of any injured people.
b. Exposures—the probability or possibility of extension, including the following:
   1. Status of tank and dike valves.
   2. Surface drainage.
c. Life hazard—the potential need for evacuation of personnel and inhabitants of the surrounding area.
d. Situation—the types of tanks involved and their characteristics, including the following:
   1. Pertinent data from the facility plan.
   2. Whether the tanks have open-top or internal floating roofs or cone roofs.
   3. Whether the tanks have weak roof seams.
   4. The tank size and diameter.
   5. The position and condition of roof drain valves.
   6. The number and type of roof seals.
e. Type of fire:
   1. Seal fire.
   2. Full involvement.
   3. Overfill (spill) fire.
   4. Combination (tank and dike) fire.
   5. Multiple-tank fire.
   6. Vent fire.
   7. Seam fire.
   8. Piping-connection fire.
f. Characteristics of tank contents, including the following:
   1. The product involved.
   2. The possibility of boilover.
   3. The volume of product in the tank.
   4. The depth of water bottoms in the tanks.
   5. The boiling point of the contents.
   6. The toxicity of the contents.
g. Condition of tank roof, shell, piping, and fixed fire systems.
h. Possibility of pumping out contents of atmospheric storage tanks if extinguishment will be difficult.
i. Need for cooling water for metals exposed to flame.
j. The immediate need for coordinating emergency efforts with operating personnel. Such efforts may include the following:
   1. Shut fuel off.
   2. Initiate product transfer.
   3. Stop product mixers because of their detrimental effect on the foam blanket.
   4. Stop all pumping into the tank.
k. Fire-fighting capabilities, including the following:
   1. The availability of trained personnel.
   2. The availability of foam.
   3. The availability of water, including amount and pressure.
   4. Proportioning equipment.

5. Vehicle access.
l. Weather conditions.

3.4 Strategy and Tactics Applicable to All Tank Emergencies

3.4.1 GENERAL

Strategy relates to planning; tactics are the physical acts that accomplish the goal. Basically, three types of strategy may be used to combat a tank fire. Each category requires different tactics and thus different types of action and different priorities to obtain a safe resolution of the incident without injury or loss of life. Ideally, damage to the tank and its contents is minimized and both are economically salvageable. When the incident is resolved, fire-fighting personnel should have tangible results to compare with the strategic plan. An important tool for this purpose is the incident data sheet, which is discussed in Appendix C.

The tactics used at a tank fire should implement the strategic plan in detail. Examples of tactics are proper use of manpower and equipment, shutting off of pumps, coordination with other involved groups (operations, mutual aid, regulatory agencies, and others), and a plan of attack for control or suppression.

The incident commander responsible for implementing a strategy through the tactical plan should have a thorough understanding of fire behavior, fire control and suppression techniques, risk analysis, and loss prevention.

A passive strategy should be used when there is little chance of extinguishing the tank fire and the area may have to be evacuated because of the possibility of a boilover or for other reasons.

A defensive strategy should be used when there is little chance of extinguishing the tank fire but the area will not have to be evacuated. The fire fighters should remain and take action to confine the fire within the tank and minimize exposure damage. However, if additional personnel and equipment become available, the strategy should probably shift to an offensive one.

An offensive strategy should be used when sufficient foam supplies, equipment, and personnel are available to give a reasonable chance of extinguishing the fire.

3.4.2 PASSIVE TACTICS

The key thought is, "Become part of the solution, not part of the problem." Passive tactics should be considered if fighting the fire would jeopardize personnel unjustifiably. The following are examples of situations that dictate a passive strategy:

a. Not enough personnel and materials (foam and water) are available for a safe and complete extinguishment attempt.
b. Recommended application rates and times cannot be met.
c. There is imminent danger of a boilover, tank failure, or other life-threatening occurrence, dictating immediate evacuation of the area.

3.4.3 DEFENSIVE TACTICS

Defensive tactics are considered when intervention cannot immediately and safely influence the outcome of the incident. Factors to be considered when using these tactics include the following:

a. The status of all dike and tank-roof drain valves. In most situations, these valves should be closed to localize the incident.
b. Flame impingement and heat load on adjacent or nearby tanks. This situation may require immediate action to prevent the involvement of additional tanks. Protective cooling streams, foam attacks, and transfer of products to safe tanks should be considered.
c. Product characteristics, product levels, and levels of water bottoms. These data should be readily available. Times until vessel failure or other adverse events, such as boilover or rupture, should be estimated. Evacuation to a safe area, according to the emergency plans, should be considered. (Large-diameter tanks may require pulling back 2000 feet or more from the incident.)
d. The status of product-transfer or isolation valves.
e. Mutual aid. Requesting mutual aid should be considered, and the proper authorities (engineering management, regulatory agencies, and so forth) should be notified.
f. Whether the incident can be contained with available resources without jeopardy to life or further jeopardy to property, that is, that steps can be taken to preserve a controlled burn while minimizing losses by operations. (For example, a temporary measure such as protecting exposures might be taken while waiting for additional help. On its arrival, an aggressive offensive attack to effect extinguishment would begin.)
g. Whether the scope of the incident does not reasonably justify the risk associated with an aggressive attack. These incidents are sometimes referred to as *plot limit incidents*. Fire-fighting efforts should center on preventing further losses and salvaging assets until additional resources become available.
h. Whether it is advisable to exercise basic loss control philosophies and accept a controlled burn, in which exposures are protected and losses are minimized.

Examples of defensive tactics include the following:

a. Preserve the integrity of fixed fire-fighting systems, including foam lines and chambers, sprinklers, and fire isolation valves. Cool until attempts can be made to extinguish or control the fire.

b. Cool flame impingements immediately, with the following priorities:

1. Exposed pressurized tanks. Cool the area exposed to flame or heat above the liquid level to maintain structural integrity and lower the vessel's internal pressure. At points of flame impingement, apply cooling agent as quickly as possible to prevent vessel failure and the resulting boiling-liquid expanding-vapor explosion (BLEVE). BLEVEs have been documented to occur in about 10 minutes. Cool areas of direct flame impingement on vessels that may be caused by flames from pressure-relieving devices.

2. Exposed atmospheric tanks. Protect by cooling the roof and the tank shell above the liquid level. Try to maintain container integrity to prevent loss of product. The size of the fire is directly proportional to the surface area of the contents. An alternative priority would include cooling the area of flame impingement above the liquid level. (Liquid acts as a heat sink.) The prefire plan should include calculations of the quantities of water required.

3. Exposed product line valves and flanges. Bolted flanges and repair clamps have exposed bolts that lengthen when exposed to flame impingements or high heat loads. Gaskets exposed to high heat often fail, which can result in the release of additional quantities of fuel. Cooling of these areas should be coordinated with extinguishment efforts. Product pipeline valves must be protected from the outset because they may have to be operated (opened and closed) during fire-fighting operations. This is especially important if a product pump-out or subsurface injection through the product line is to be attempted.

4. Exposed product piping. If product piping is blocked in, it can fail when exposed to flame impingement or high heat loads. Maintain flow through piping, if possible, to carry away heat and reduce risk of failure.

c. Use appropriate tactics for radiant heat. Radiant heat exposures (without direct flame impingement) are not as urgent as the fire service has believed in the past. A rule of thumb is to stop cooling a radiant heat exposure if a cooling stream produces no steam or quick flash-off of cooling water. This test should be made periodically to verify the heat load on the vessel or structure in question. Water walls and water curtains should not be used because they waste water and are of questionable effectiveness. To mitigate the effects of radiant heat, water must be applied directly to the surface requiring protection. Radiant heat protection is generally not a high priority. One or two handlines are usually sufficient to supply protection if they are played back and forth over the exposed area.

3.4.4 OFFENSIVE TACTICS

Offensive strategy and aggressive tactics should be considered in the following situations:

a. When life is in imminent jeopardy—rescue should be attempted if the risks are consistent with the potential for success.
b. When adequate personnel and materials are immediately available for a safe and complete extinguishment.

Offensive tactics (attack techniques) are generally used when adequate personnel and materials are immediately available. They include attacking the fire, removing the fuel source, and other actions intended to put out the fire completely. Fire-fighting personnel must be familiar with the equipment, agents, and procedures. To extinguish the fire, recognized application rates must be effectively delivered by trained personnel for the required duration.

The following factors should be considered when an offensive attack on a tank fire is contemplated:

a. Adequate foam supplies and equipment should be available to apply foam at the recommended rates. Foam should never be applied at rates below those recommended. This will not extinguish the fire, and will only waste the foam.
b. Weather conditions should permit extinguishment. (Wind and rain destroy foam blankets and limit the reach of fire streams.)
c. Cooling streams should be applied with a sweeping motion to distribute the greatest quantity of water over the largest exposed area.
d. When foam is applied to a hot burning liquid (for example, a crude oil fire), a slopover should be expected and planned for. See Appendix D.
e. When there is a dike fire as well as a tank fire, the dike fire should typically be extinguished before extinguishment of the tank fire is attempted.
f. When there are multiple tank fires, the first priority should be to extinguish the fires that can most easily be extinguished (for example, the smallest) or ones that pose the greatest hazards to life or property (for example, a potential BLEVE or boilover).
g. During the application of fire-fighting agents, the effectiveness of the attack should be judged so that it may be altered, if needed.
h. After a reasonable period of time has passed in a foam application attempt, a check should be made to determine whether the fire's intensity has decreased recognizably or whether the smoke's color has changed. If not, reevaluation of the tactics may be in order. Using the application rates and times specified in NFPA 11, this change should occur in 20–30 minutes.
i. If the goal is extinguishment, consideration should be given to what to do with a damaged tank partially full of a

volatile product. Usually, foam blankets have to be renewed periodically until the tank contents can be salvaged. Hot metal causes a foam blanket to deteriorate rapidly, exposing volatile vapors to potential sources of ignition. Incident commanders should be aware of the potential for reignition of vapors due to the static-generating potential of fire streams. Salvage can take many days. Are adequate foam supplies available? Are conditions being supervised and controlled to prevent reignition of the tank contents?

j. When fighting seal fires, extreme care should be exercised not to overload and sink the roof with the weight of foam and water. Handlines are the preferred method of foam application for these fires. The indiscriminate use of master streams should be avoided. Fires with small surface areas are much easier to extinguish than those with large surface areas.

WARNING: Personnel must exercise extreme caution and pay full attention to the flammability hazard when entering an area containing spilled fuel. If the foam blanket is disrupted, reignition may injure personnel inside the spill area. Personnel should not walk into a foam blanket that is covering fuel.

In most tank fires, a cookbook solution, or flowchart approach, has not proven successful. For most incidents there are several tactical approaches that can lead to a safe, effective extinguishment. By the same token, mistakes and oversights can complicate fire-fighting efforts and increase risk to life and property.

3.5 Protecting Adjacent Tanks

Depending on tank spacing and wind, cooling of adjacent tanks is typically unnecessary unless there is direct flame contact or sufficient radiant heat to scorch the paint.

If there is a question about the temperature and heat absorption of tank shells not directly exposed to flame, frequent checks should be made with water spray from long-range water streams to see whether steam is produced. If steam is generated, cooling water should be applied until steaming stops. When tanks require cooling, water streams should be fanned on the sides and roofs for best results; this does not apply to the roofs of floating-roof tanks.

Although radiant heat does not seriously damage tank shells below the liquid level, two factors must be kept in mind that may dictate the need for cooling adjacent tanks:

a. Heat on shells of tanks that contain combustible liquid stocks may bring the vapor space of the tank within the flammable range.

b. Heat on shells of tanks that contain low-flash-point stocks may cause the tank pressure to rise and expel flammable vapor that may ignite and cause tank failure. Tanks constructed in accordance with API Standard 650 have a weak roof-to-shell seam that serves as an emergency vent. Likewise, floating-roof tanks may leak vapor in the seal area.

A common error in fighting tank fires is using too much cooling water on exposures. This not only robs volume and pressure from the water supply but can overtax sewers and drainage ditches and make fighting the fire difficult. Also, empty or near-empty tanks may float from their foundations. These factors should be considered in prefire planning so that water is not indiscriminately used. Care must be exercised during the simultaneous application of cooling water and foam to ensure that the cooling water streams do not disrupt the foam blanket. There have been many instances in which indiscriminate use of water has disrupted or washed away foam blankets and hindered extinguishing efforts. This not only prolongs the extinguishing efforts but also wastes foam.

3.6 Tank Vent Fires

3.6.1 YELLOW-ORANGE FLAME WITH BLACK SMOKE

A fire at a tank vent that is burning with a yellow-orange flame and emitting black smoke indicates that the vapor/air mixture in the tank is above its flammable or explosive limits. This type of fire has been extinguished with dry chemical.

3.6.2 SNAPPING BLUE-RED, NEARLY SMOKELESS FLAME

A fire at a tank vent that is burning with a snapping blue-red, nearly smokeless flame indicates that the vapor or air mixture in the tank is flammable or explosive. As long as the tank is breathing out through the pressure–vacuum valve, the flame cannot flash back into the tank because of the high-velocity flow through the valve. However, any attempt to extinguish with dry chemical should be accomplished quickly to avoid flashback into the tank if heat damages the pressure–vacuum valve. This type of fire can be handled in one of the two following ways if other methods prove to be ineffective:

a. A pressure reduction in the tank (caused by cooling) will snuff out the fire when the pressure–vacuum valve closes. When the tank is exposed to fire, this can be accomplished by applying cooling water to the tank roof and shell. If pumping into the tank causes overpressure, a pressure reduction can be obtained by pumping or switching product out of the tank.

b. A positive pressure is maintained in the tank by introducing fuel gas. When a vapor-rich condition is indicated by change of flame character (see 3.6.1), extinguishment may be accomplished with dry chemical.

3.7 Fighting Ground Fires Around Tanks

When fighting ground fires around tanks, cooling water should be applied to all flame-exposed metal as soon as possible. Extinguishment of the ground fire should then be attempted by isolating the source of fuel in one of the following ways:

a. Closing pertinent valves under the cover of water spray streams when needed for personnel protection.
b. Displacing enough product with water to produce a water leak rather than a product leak. If this method is used, the water pressure must be greater than the product pressure in the line or tank. Care must be exercised to avoid overfilling the tank.

Dike valves, roof drain valves, and water bottom drain valves are important means of isolating fuel. It is thus a high priority to gain control of these valves.

When a tank containing a high-flash-point product is exposed to ground fires, personnel must be aware of the possibility of a flammable mixture being created in the tank that can be ignited by the hot metal of the tank shell.

Although it is possible to extinguish some fires involving a leak of fuel gas or liquefied petroleum gas, this should only be done by shutting off the fuel source. Unless there is sufficient wind to dissipate the leak, the leak may become dangerous if extinguished without fuel shutoff. For detailed information on controlling these fires, refer to API Publications 2510 and 2510A concerning fighting fires in and around pressure vessels.

Small ground fires involving liquid products may be extinguished with dry-chemical extinguishers, provided the product is not exposed to reflash or the shadow effect and the fire fighters are not forced to walk in pooled product. In some cases it may be possible to use water to flush the product to a safe location where extinguishment or control may be easier. Reignition is likely if sources of ignition have not been eliminated.

WARNING: Personnel should never enter areas of a liquid spill because of the serious danger of being trapped if the vapor ignites.

The typical strategy for extinguishing a large ground fire is to apply a foam blanket.

Products with flash points well above 38°C (100°F) or, specifically, above the temperature of the water used, may be extinguished with water spray. Radiant heat from the flame heats the surface of such products, causing vaporization. Evaporation of the water spray droplets first extracts heat from the flame, reducing the flame size. Further application of water cools the hot product surface below its flash point. When vaporization of the product ceases, the fire goes out.

Three-dimensional fires involving flange leaks, mixer fires, and so forth, generally have to be extinguished with an agent such as dry chemical or Halon 1211 unless sufficient foam or water can overwhelm the fire and cool the metal, preventing reignition. Foam should be used to extinguish large ground fires or ground fires that could endanger personnel attempting to use dry-chemical extinguishers. Where monitors and handlines are used, a study of the most favorable tactics should be made assuming the whole dike is involved. The necessary numbers, sizes, and range of the equipment should be matched to the risk. The procedure for fighting fires in diked areas is to extinguish and secure one area and then move on to extinguish the next section within the dike. This technique should be continued until the complete diked area has been extinguished. In establishing the required delivery rate for the foam solution, it is not necessary to consider applying foam to cover the total diked area simultaneously. Ground fires around tanks should be controlled or extinguished before an attempt is made to extinguish tank fires.

SECTION 4—CONTROLLING AND EXTINGUISHING TANK FIRES

4.1 General

This section relates to the types of storage tanks most frequently used in the petroleum industry. Adoption of the guidelines presented should include the applicable data described in Section 3. These guidelines are not intended to replace good fire-fighting judgment or other methods of proven merit. Many variables are present in every emergency and sound on-the-spot judgment must be exercised in choosing a proper course of action.

4.2 Cooling Water

The first inclination of fire fighters confronted with a tank fire is to immediately deluge and cool all adjoining tanks. This practice is usually needless and can adversely affect attempts to extinguish the fire. Wind conditions may affect the situation, however.

If there is doubt about the heat radiated to tank shells not directly exposed to flame, it is possible to check for heat by playing a water stream on the shell. If steam is produced, cooling water should be applied until the steaming stops. The cooling water stream should be fanned directly on the tank sides exposed to the flame and onto the roof, except in the case of floating-roof tanks, where water should be played onto the sides only. If there is any direct flame impingement on exposed tanks, they must be cooled immediately.

4.3 Extinguishing the Fire

Some tactics are applicable to fires in all types of storage tanks and should be considered:

a. All dike and ground fires in the vicinity of the burning tank should be extinguished before attempting to fight the tank fire; otherwise reignition of the tank may occur.
b. Cooling water streams should be directed at the exposed shell above the liquid level of the burning tank. This will help keep the shell erect and prevent it from folding inward and preventing foam or dry chemical from reaching the product surface. It also assists the foam blanket in sealing against the shell. However, a balance between cooling and foam blanket dilution must be maintained.
c. When there are simultaneous atmospheric tank fires, foam should be applied only to the tanks that can be attacked at the recommended foam rates for at least the recommended period of time. This will decrease the possibility of failing to extinguish any of the tank fires as a result of an insufficient application rate or depletion of foam supplies.
d. If the burning tank is fitted with fixed foam connections, they should be protected with cooling streams to keep them intact until foam can be applied.
e. Pumping out tank contents while preparing for foam application will help salvage some of the product but will damage more of the tank shell. If the chances of extinguishment are good, the additional task of pumping out probably should not be undertaken.
f. In some situations, it may be impractical to fight a tank fire because of insufficient water, foam, fire fighters, or foam-producing equipment. Accepting a burnout while protecting adjacent exposures may be the best solution in these instances. Under these conditions, pumping out the tank to recover the contents is recommended.

4.4 Tanks

4.4.1 GENERAL

The methods and foam agents needed to extinguish the fire depend on the product involved (hydrocarbon or polar solvent) and the construction of the tank roof. Application methods in terms of roof construction and product types are covered in 4.4.2 through 4.4.9.

4.4.2 CONE-ROOF TANKS

Typical combustible volatile liquids (for example, liquids with flash points greater than 100°F) are stored in cone-roof tanks (see Figure 1). However, this is not always the case, and on occasion liquids with lower flash points, including crude oils, polar solvents, and contaminated combustible liquids, are stored in such tanks. These tanks have a vapor space between the liquid surface and the underside of the roof. If vapor space is in the explosive range at the time an ignition source is introduced, an explosion will occur. If the tank is constructed in accordance with API Standard 650, the roof may separate from the shell joint. The roof may separate in one piece or in fragments, the latter sometimes traveling considerable distances. Sometimes the roof will lift into the air and fall back into the tank. On other occasions, only pieces of the separated roof may remain intact on top of the tank. The resulting fire usually involves the entire surface area of the tank. When the product involved is a hydrocarbon, there are two options for extinguishing the fire: topside application or subsurface injection of foam. Topside application is limited to protein foam, FFFP foam, FP foam, and alcohol-resistant foams or common AFFFs approved for the purpose. Subsurface injection is limited to FP foam, FFFP foam, AFFF, and alcohol-resistant AFFFs specifically approved for this use. If the fire involves a polar solvent, the extinguishing technique is limited to topside application with alcohol-resistant foams.

When topside application is indicated on hydrocarbon, several methods of application are open to consideration. Among them are fixed systems, foam towers, high-capacity foam monitor nozzles, and elevated platform devices fitted with foam nozzles.

Subsurface injection into hydrocarbon storage tanks has proven successful on numerous occasions. Injection must be above any water bottom in the tank. A water bottom

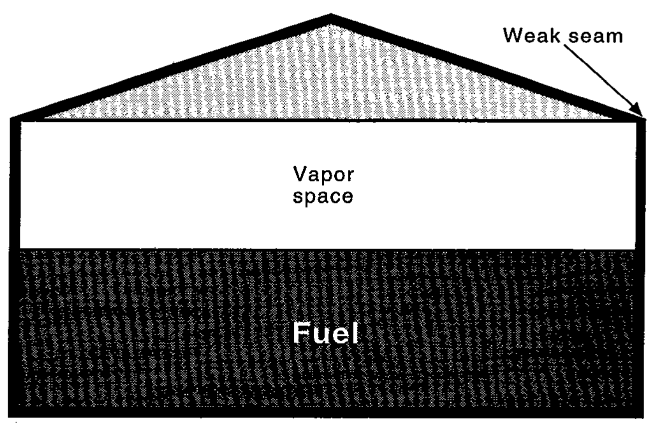


Figure 1—Cone-Roof Tank

will be created during subsurface injection and may require special procedures for water withdrawal before and during subsurface injection. Special high-backpressure foam makers are required for subsurface injection, and hydraulic calculations are necessary. Depending on its design, the foam maker will generally tolerate from 20 percent to 40 percent of its inlet pressure in backpressure against the discharge of the foam maker. The pressure generally consists of the head pressure in the tank and the friction loss of the finished foam in the piping between the foam maker and the injection point (see NFPA 11). Elevated platforms can sometimes provide a view into the tank to better evaluate fire-fighting progress. Subsurface injection usually extinguishes the center of a tank fire first and the rim last. Observation from grade level will show a great deal of flame, which is the fire in the shell area.

The flow velocity of the foam in the inlet piping to the tank is also critical. In the case of flammable liquids, this velocity should not exceed 10 feet per second, based on the expanded volumetric rate. Combustible liquids will tolerate a velocity of up to 20 feet per second. Graphs indicating friction loss characteristics and inlet velocities for various pipe sizes are given in Appendix E.

Subsurface injection may require multiple injection points depending on the product involved and the diameter of the tank. NFPA 11 provides application information. All of these factors should be examined and calculated before any commitment is made to using subsurface injection. Ideally, the information should be obtained during prefire planning.

Topside Type II application to cone-roof tanks containing polar solvents is effective only with alcohol-resistant foams that are approved or tested for such use. These include approved alcohol-resistant AFFFs or FFFP. The older protein-based, alcohol-resistant foam agents require special equipment that provides very gentle application (NFPA Type I) to the surface of the polar solvent. Application rates on polar solvents vary with the solvent and the type of foaming agent used. The foam manufacturer should be consulted regarding the recommended application rates for polar solvents because these rates are generally much higher than those required for hydrocarbon products. Subsurface application has proven ineffective on polar solvents because the foam dissolves.

Before foam is applied to a tank, the minimum quantities recommended in NFPA 11 should be available on site.

4.4.3 CONE-ROOF TANKS CONTAINING CRUDE OIL AND OTHER MATERIALS WITH BOILOVER POTENTIAL

Special tactics are needed when fighting tank fires that involve crudes and other oils that can produce a boilover (see Figure 2). The incident commander must understand this behavior and be alert to a hazard not encountered with other fuels.

Certain factors are necessary for boilover to occur:

a. A major fire involving all or most of the surface of the liquid. A fire in a floating-roof seal will not produce a boilover as long as the roof is floating.
b. A wide range of boiling points in the components of the crude oil. As the crude burns, the light volatile fractions are cracked or distilled off and burn. The unvaporized hot (300°F and above) residue is denser than the cold crude oil and begins to sink below the surface. As the fire progresses, the lighter fractions continue to distill at the interface between the hot residue layer and the cold crude below. The burning vapor supplies the heat that continues the distillation. As the residue layer increases in depth, the interface moves downward at a rate 2 to 3 times that of the burn-off at the oil surface. This hot residue is called the *heat wave layer* and the interface is called the *heat wave front*. The heat wave layer settles at a rate of 1–4 feet per hour.
c. Water or oil-in-water (wet) emulsion bottoms, which are normally present in crude oil tanks. Water may also be inadvertently introduced into the tank from the fire-fighting efforts, or there may be layers or lenses of wet emulsion in the product. When the hot interface reaches the water or emulsion in the bottom of the tank, it flashes the water into steam. At 400°F the expansion factor from water to a frothy steam mixture is about 1700 (see Appendix D).
d. A high enough content of residue to produce a steam/oil froth of tough consistency. Very light crudes may not contain enough residue to make a tank froth. Some heavy crudes, asphalts, and heavy fuels may not contain enough light fractions to produce a sharp heat wave layer. However, there have been cases in which heavy fuel oil residue containing light material has boiled over. Typical medium-weight crudes are the most likely to boil over violently, whereas other crudes may have less severe boilovers.

Cone-roof tanks in crude oil service require special fire-fighting tactics. Foam application has the best results if it is begun within about 30 minutes of the fire starting. The proper agent may be applied either subsurface or topside.

If, for any reason, it is not possible to extinguish a burning cone-roof crude oil tank, the strategy must be changed. All unnecessary personnel and equipment should be removed from the area. The progress of the heat wave front as it moves lower into the tank should be checked frequently. To estimate the time of the boilover, water should be applied to the tank shell and the location of the interface should be determined by the steam generated above the heat wave front.

An imminent boilover is generally indicated by an increase in flame height and brightness. This is sometimes accompanied by a change in the sound of the fire, such as

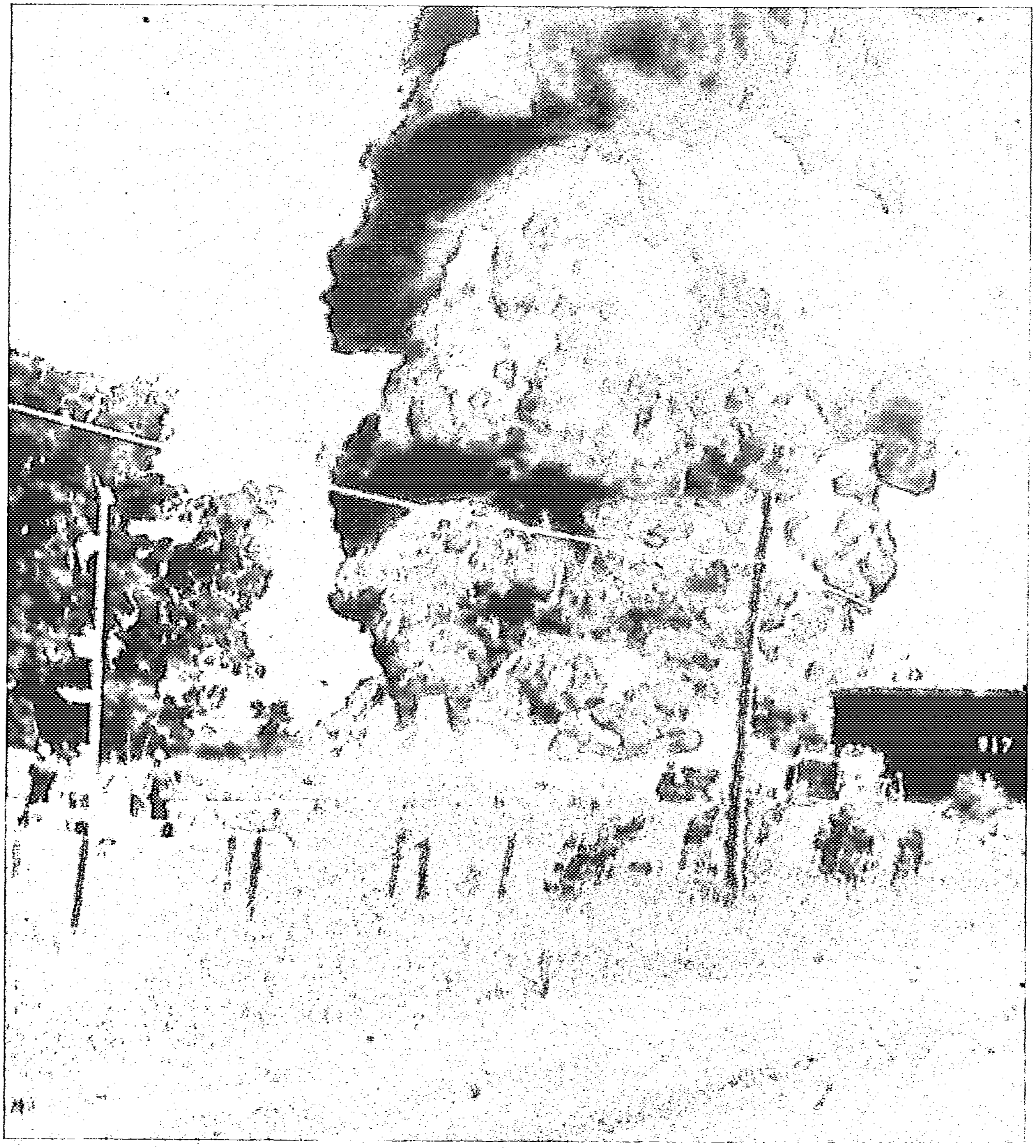


Figure 2—Boilover of a Cone-Roof Tank

a pronounced "frying" sound. Large blobs of burning froth may be projected up a few feet and may be visible from some distance.

The temperature should also be monitored after the fire is extinguished. The heat wave generated while the material was burning may continue downward and may have enough energy to cause a boilover when it reaches the water bottom. A boilover at this time would still be a personnel hazard and, if an ignition source exists, may be a fire hazard. If a boilover is anticipated, personnel should be evacuated to a safe area. Large-diameter tanks may require pulling back 2000 feet or more from the incident. (For notes on other fuels, see NFPA 30.) It may also be appropriate to install additional earthen berms downstream of diked areas.

4.4.4 OPEN-TOP FLOATING-ROOF TANKS

Fires in open-top floating-roof tanks (see Figure 3) are generally confined to the annular seal area between the floating roof and the tank shell. If fixed foam protection is not provided for the seal area (a foam dam and foam makers, as specified in NFPA 11), it will be necessary to fight the fire with mobile and portable equipment.

Foam hose streams may be directed into the seal area from the wind girder or the roof. When large portions of the seal area are involved, it is preferable to have at least two hose streams working around the wind girder in opposite directions. Personnel must be aware of the potential of falling from the wind girder and be protected from this hazard. If it is the practice to use the wind girder for fighting seal fires, handrails should be provided to protect fire fighters.

If the seal area is burning beneath the stairway platform and prevents access, foam can be applied to the area by portable foam towers, foam monitors, or hose streams from elevated platforms. Handlines can be used to dissipate the heat while foam is directed onto the seal area so that fire-fighting personnel can gain access to the platform. Caution must be exercised, however, to prevent excessive amounts of foam from flowing onto the roof and sinking it. Ideally, someone should be watching the foam application from an elevated position. If the seal fire has been burning for some time, it may be necessary to apply cooling water to the outside of the tank shell. The need for cooling water will be indicated by blistering or discoloring of the shell paint.

Directing large straight streams of foam or water into the flammable product at the damaged roof seal should be avoided. This can splash product onto the roof and increase the fire's intensity. Also, regardless of the type of foam concentrate being used, good foam-making air-aspirating nozzles should be used. Water nozzles will not generally produce optimum results, even with AFFF.

Large crude tanks are typically of floating-roof design. Should only a seal fire develop, no boilover will result. If the roof sinks, however, there is a possibility of a boilover.

4.4.5 COVERED FLOATING-ROOF TANKS

Covered or internal floating-roof tanks (see Figure 4) are cone-roof tanks with a weak roof-to-shell joint and an internal floating roof or pan. They are easily identified from the exterior by the vents located around the tank shell, usually just beneath the roof joint. The vapor space in these tanks is usually free from ignitable mixture except during periods of initial fill and for 18–25 hours thereafter, depending on the volatility of the product. These tanks have an excellent fire safety record. However, there have been a few instances of fires in this type of tank, and such fires are extremely difficult to extinguish unless the tank is equipped with a fixed system in accordance with NFPA 11. Seal or rim fires in a covered floating-roof tank are virtually impossible to fight with portable equipment. The side vents are too small to permit access by foam streams directed from ground level. On some occasions, the cone roofs have blown partially open or off, thus involving the entire surface area when the pan sinks.

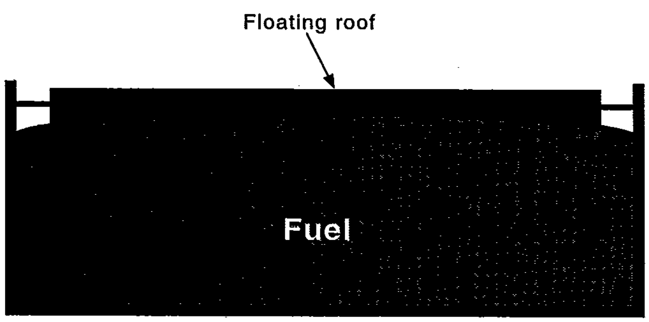


Figure 3—Open-Top Floating-Roof Tank

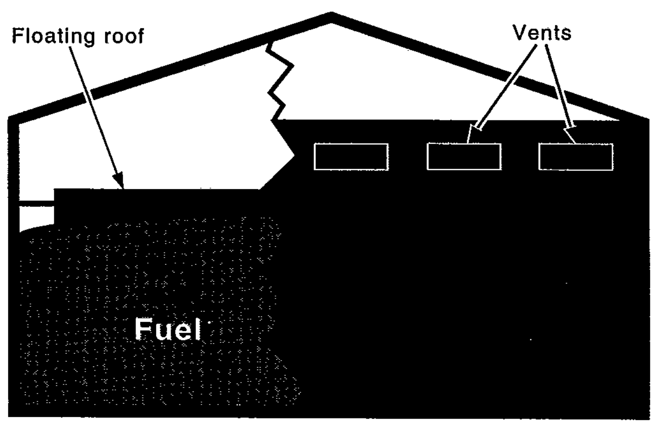


Figure 4—Covered Floating-Roof Tank

In these instances, the fire should be treated as a cone-roof tank fire and extinguished by monitor nozzles or other topside application. It should be noted that the sunken roofs will probably obstruct foam travel from subsurface systems; however, if all else fails, subsurface injection may be attempted and, in rare cases, this has been successful. Some companies have installed fixed foam protection to cover the total surface area of tanks constructed in accordance with NFPA 11, which have roofs that are more susceptible to sinking.

4.4.6 LARGE TANKS

Extinguishment becomes more difficult as the diameter of the tank increases. The largest tank fire known to have been extinguished was in a tank 150 feet in diameter. One hundred feet is generally accepted as the maximum distance that foam will flow on a burning surface before the water dropout is excessive and the foam loses its fire-extinguishing ability. Therefore, the largest cone-roof tank that should be protected with shell-mounted foam chambers is one about 200 feet in diameter. However, fires in tanks more than 200 feet in diameter could probably be extinguished with a combination of shell-mounted foam chambers and subsurface foam application for the center area or by a subsurface system alone. It should be pointed out that the expansion rate and inlet velocity are critical for subsurface application so that not too much product is entrained as the foam rises through it. All subsurface systems should be designed in strict accordance with NFPA 11.

Recent studies of successful tank fire extinguishments have shown that high-capacity foam monitors are effective when several streams are concentrated in one small area in the initial attack. This technique allows the foam to overwhelm the fire in a small area, reducing the heat degradation and thermal updraft effect, and allows the foam blanket to establish itself on the surface.

4.4.7 FRANGIBLE OR WEAK-SEAM ROOFS

It is normally recommended that weak roof seams or frangible roofs be installed on cone-roof tanks and on the fixed roofs of tanks with internal floating roofs. In case of an internal explosion or other overpressure, the roof-to-shell joint will fail instead of the shell-to-bottom joint. There have been cases in which the tank failed at the bottom, releasing the entire contents and spreading the fire over a large area. See API Standard 650 for the design of frangible roofs. It should be noted that small tanks (less than 50 feet in diameter) require special attention to be sure that the roof is, in fact, frangible. For small tanks, the weight of the shell may be inadequate to counteract the uplifting force caused by tank overpressure. This problem has not been widely recognized, and special design features may be required to prevent failure of the shell-to-bottom joint.

4.4.8 VERTICAL, LOW-PRESSURE FIXED-ROOF TANKS

4.4.8.1 Tanks Without Weak Seams

Tanks without weak seams are tanks designed and constructed in accordance with API Standard 620 and are operated with metal temperatures not exceeding 93°C (200°F) and with pressures not exceeding 1 kilogram per square centimeter (15 pounds per square inch gauge).

Fires involving these tanks are generally attributable to leaks or spread of fires from other sources. If an internal explosion should occur (which is rare), the tank ruptures at its weakest point. This can be at the bottom-to-shell seam and can cause the tank to rocket out of the area, resulting in a severe flash fire followed by a large ground fire (see Figure 2). Prefire planning should include consideration of this factor so that fire fighters can be alerted and injuries prevented.

4.4.8.2 Tanks With Nonfrangible Roofs or No Emergency Vents

Tanks with nonfrangible roofs or no emergency vents should be identified in the prefire plan and on the tank in the field. The fire-fighting principles and practices pertaining to such tanks are similar to those in other sections of this publication, depending on the type of fire.

4.4.9 BOLTED- AND RIVETED-SEAM TANKS

Bolted- and riveted-seam tanks have a potential for three-dimensional fires. Fuel leaking from the seams may burn and run down the tank shell. These fires must be overwhelmed with extinguishing agent.

4.5 Motor Fuel Lead Blending—Blending Tanks and Storage Tanks

For fires around tanks that contain antiknock compounds, cooling water is essential to prevent the metal surfaces in the vapor space of the tanks from reaching temperatures high enough to initiate surface decomposition of the lead compounds and to keep the temperature of lead liquids in the tanks below the critical bulk temperature. Once decomposition of the liquid begins, violent rupture of the vessel is imminent.

Many variables are present in every emergency, and sound judgment must be exercised in deciding the course of action to be taken. The following are recommended precautions and procedures in the event of fire in the area:

a. Stop transfer and blending operations.
b. Use proper personal protective equipment.

c. Apply cooling water to the tanks immediately. Use a manual, fixed water-spray system or check operation of the automatic system if there is one.
d. If a fire endangers the blending installation, initiate and follow regular plant fire procedures and regulations. Also, notify the nearest representative of the supplier of the antiknock compound immediately.
e. Extinguish hydrocarbon fires in the area.
f. Use dry chemical to extinguish vent fires or fires involving flowing hydrocarbons.
g. In case of a prolonged fire in the area, supplement the cooling water system by using portable monitor nozzles to play additional water streams on the tank.

In general, the safety of personnel fighting fires in a blending plant depends on keeping the antiknock compound below its critical bulk temperature. If the antiknock compound tank has ruptured, skin contact with tank contents or inhalation of any fumes must be avoided.

Water has been found effective for extinguishing burning antiknock compounds. Unlike its behavior with oil or gasoline fires, water collects on the surface of the high-density antiknock material, effectively separating the fuel vapor from air and preventing reignition. To ensure maximum effectiveness of the water layer, every effort should be made to add the water in a way that minimizes turbulence. Inhalation of combustion products should be avoided.

When a fire occurs in an antiknock storage tank area, the time available before fire fighters or other personnel are endangered depends on the amount of compound in the storage tank and on the prompt application of cooling water in adequate quantities.

The following examples include time factors (based on experience) that can be used to estimate the time available for extinguishing fires before the heat input causes the compounds to reach their critical bulk temperatures:

a. A total of 4500 kilograms (10,000 pounds) of antiknock compound is in the tank (regardless of tank total capacity). There is a gasoline fire in the pit, the tank vent is closed, and the cooling water system is inoperative. The time available is about 15 minutes in which to set up portable monitor nozzles to cool the tank or, if that fails, to evacuate personnel from the area.
b. A total of 11,000 kilograms (24,250 pounds) of antiknock compound is in the tank (regardless of tank total capacity). There is a gasoline fire in the pit, the tank vent is closed, and the cooling water system is inoperative. The time available is about 25 minutes in which to set up portable monitor nozzles to cool the tank or, if that fails, to evacuate personnel from the area.
c. A total of 45,000 kilograms (100,000 pounds) of antiknock compound is in the tank (regardless of tank total capacity). There is a gasoline fire in the pit, the tank vent is closed, and the cooling water system is inoperative. The time available is about 60 minutes in which to set up portable monitor nozzles to cool the tank or, if that fails, to evacuate personnel from the area.

CAUTION: Allowance should be made for any lapse of time before the fire was reported and for other factors specific to the age and condition of the installation or magnitude of the emergency.[2]

4.6 Other Additives

Gasoline has traditionally been fortified by the addition of tetraethyl lead to increase octane ratings. Environmental considerations in the United States and other countries are leading to the gradual replacement of tetraethyl lead with other additives intended to act as octane boosters and volume extenders. These fuels are marketed as unleaded gasolines.

In an attempt to increase the available supply of automotive fuel, refiners have turned to the agriculture industry. Ethanol (grain alcohol) has been added to automotive fuel as a gasoline extender, and methanol is also currently under study. Tertiary butyl alcohol and methyl tertiary butyl ether are also being used as octane boosters.

Because polar solvents, particularly the lower alcohols, are known to be destructive to foams, API sponsored a research program to evaluate the effectiveness of currently available foam concentrates in extinguishing fires that involve fuels containing these materials. API Publication 2300 provides a complete report on this test project.

Briefly stated, the tests showed that the additives made extinguishment more difficult when simulated handline application at reduced foam application rates was used. However, the research confirmed that fires in all the gasolines tested could be extinguished at the application rates specified in NFPA 11.

4.7 Overhaul

The final stage in any fire-fighting evolution is overhaul. Overhaul is the practice of ascertaining that the fire has been completely extinguished and that the area is safe from reignition. Overhaul of a tank fire consists of disposing of the remaining product and preventing its reignition. Care must be exercised to avoid all possibilities of ignition sources in the vicinity of an extinguished tank. Volatile product may remain in the tank, and as the foam blanket dissipates, vapors will be released. A foam blanket should be maintained over the surface until the product has been safely removed. Alert fire watch crews should be on standby with the proper foam equipment in position until this exercise has been completed.

[2]For additional information, refer to *Thermal Characteristics of Motor Fuel Antiknock Compounds Containing Tetraethyl Lead, Methylethyl Lead, Tetramethyl Lead* published jointly by Ethyl Corporation and E. I. du Pont de Nemours and Company.

APPENDIX A—BIBLIOGRAPHY

Note: There are many sources of information on fire protection in petroleum facilities. Although the following list includes a number of useful publications, it should not be considered a complete bibliography of all pertinent information.

A.1 Standards, Codes, and Regulations

API

- Spec 12B *Specification for Bolted Tanks for Storage of Production Liquids*
- RP 2001 *Fire Protection in Refineries*
- Publ 2015 *Cleaning Petroleum Storage Tanks*

IFSTA[3]

- 210 *Private Fire Protection*

NFPA

- 11A *Medium and High Expansion Foam Systems*
- 11C *Mobile Foam Apparatus*
- 12 *Carbon Dioxide Extinguishing Systems*
- 325M *Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*
- *Fire Protection Handbook;* Section 4, Chapter 4; Section 10, Chapter 5; and Section 18, Chapter 4
- *Fire Protection Guide on Hazardous Materials*
- *Flammable and Combustible Liquids Code Handbook,* Chapter 2

OSHA[4]

- 29 *Code of Federal Regulations* Subpart L, "Fire Protection," and 1910.120

[3]International Fire Service Training Association, Oklahoma State University, Stillwater, Oklahoma 74078.

A.2 General References

Bryan, J. L. (Ed.), *Fire Suppression and Detection Systems* (2nd ed.), Chapters 3–4, Macmillan, New York, 1982.

Thermal Characteristics of Motor Fuel Antiknock Compounds Containing Tetraethyl Lead, Methylethyl Lead, Tetramethyl Lead, Ethyl Corporation and E. I. du Pont de Nemours and Company.

Hazardous Materials for First Responders, Fire Protection Publications (Division of IFSTA), Stillwater, Okla., 1988.

Herzog, G. R., *Management of Flammable Liquid Storage Tank Fires*, Ansul Fire Protection, Dallas, Texas.

Langenkamp, R. D. (Ed.), *Illustrated Petroleum Reference Dictionary,* (3rd ed.), PennWell, Tulsa, Okla., 1985.

Meidl, J. H., *Flammable Hazardous Materials* (2nd ed.), Chapters 2–4, Macmillan, New York, 1978.

Meyer, E., *Chemistry of Hazardous Materials,* Chapters 2, 4, and 10, Prentice-Hall, Englewood Cliffs, N.J., 1977.

Note: In addition to the references listed above, the manufacturers of fire-fighting foams and related equipment publish materials regarding their products. Fire departments that use specific types of foam or equipment should not hesitate to seek out this information (for example, on the capabilities, limitations, and applications of a fire-fighting foam) and incorporate it into regular training sessions.

[4]Occupational Safety and Health Administration, U.S. Department of Labor. The *Code of Federal Regulations* is available from the U.S. Government Printing Office, Washington, D.C. 20402.

APPENDIX B—PREINCIDENT PLANNING

B.1 General

The importance of preincident planning with respect to petroleum storage facilities cannot be overemphasized. Concise, comprehensive information should be available to an incident command staff.

B.2 Storage Tank Considerations

Tank construction fits into this planning in the same way that building construction type and features fit into typical fire service planning.

Important items of concern include the following:

a. Type of construction.
b. Dimensions (diameter, liquid surface area, height).
c. Capacity, in barrels or gallons (1 barrel equals 42 gallons).
d. Type and properties of products in storage.
e. Product piping and attached equipment, including emergency devices.
f. Exposures (type, distance, other products).
g. Time required to pump out product (for salvage purposes).
h. Drains (in diked areas, on open-top floating roof).
i. Surface area (including any diked area for calculating foam needs).
j. Attached (fixed) fire protection devices.

B.3 Fire Protection Considerations

B.3.1 ASSESSMENT

Before an incident, a complete assessment of fire protection considerations should be completed. Factors to be considered are described in B.3.2 through B.3.4.

B.3.2 WATER SUPPLY AND DISTRIBUTION SYSTEM

The following items should be considered:

a. Capacity and type.
b. Total flow available, in gallons per minute.
c. Length of hose lays.
d. Compatibility of system threads with fire service hose threads.
e. Alternative sources.
f. Pumps, if available, and their source of power (if electric, the presence or absence of a backup pump or system). Since water is the main ingredient in fire-fighting foam, if water supplies are deficient, proper application of foam will be impossible.
g. Pressure of the system.

Since water is the main ingredient in fire-fighting foam, if water supplies are deficient, proper application of foam will be impossible.

B.3.3 FOAM SUPPLY AND DISTRIBUTION SYSTEM

As is already known, fire-fighting foams are the principai agents for extinguishing flammable and combustible liquid fires. Unless the foam is applied at the correct rate and for the recommended length of time, extinguishment will not occur. For this reason, an assessment of foam supplies and application systems and equipment is critical.

The following information should be obtained and documented before an incident:

a. Quantity and type of foam concentrate immediately available.
b. Method of transporting foam concentrate from an onsite stockpile to the incident location.
c. Practical fire water flow available from the semifixed system (if one is present).
d. Location and availability of other sources of foam concentrate (other industry facilities, other fire departments, and foam manufacturer's emergency stockpiles).
e. Number and type of fire protection devices, both fixed and portable. Intelligent and effective strategic and tactical decisions cannot be made unless the incident commander and staff are aware of and understand the use of the appliances installed on or operable around petroleum storage tanks.
f. Availability of other extinguishing agents (for example, dry-chemical extinguishers for use on fires in floating roof seals).

B.3.4 DRAINAGE AND RUNOFF

Consideration should be given to the drainage and runoff of surface water from the incident area. Controlling the amount of flow and the direction of the flow are important considerations.

The following information should be obtained and documented before an incident:

a. Availability of equipment to move dirt and other materials to direct the flow away from the incident area.
b. Knowledge of the natural drainage, including direction of flow and collection points.
c. A plan for controlling the flow of incident runoff. The plan should include holding areas and a means of disposing of the collected runoff.
d. A list of the appropriate authorities and organizations available to manage anticipated spills and cleanup.

B.4 Command Post and Communications

As with any major fire incident, the establishment of a proper command post and on-scene communications center is an absolute necessity. In addition to its usual fire-ground functions, this location should be used by the incident commander and staff, other key fire service personnel, and representatives from the facility to formulate tactics and strategies and to coordinate all outside resources.

The command post should be able to communicate with all operating units on the fire ground. Radio equipment on a common frequency is preferable and should be provided. If this equipment is not available, other means of maintaining contact with units should be employed (for example, an adequate number of message runners). Also, telephone lines in the command center may help eliminate problems or delays in contacting outside resources.

All information about the facility and storage tanks (incident plans, maps, standard operating procedures, and so forth) should be on hand for use by the command staff.

The use of incident command and control charts has been a standard practice of fire-ground officers for a number of years. They serve not only as a "things-to-consider" checklist but also as a convenient, organized place to record important data. These charts, or some other functional system, are easily developed and adaptable for use during incidents at petroleum facilities.

Up to this point in the planning process, a great deal of information and material has been collected about the resources and particulars of the storage facility. Once problem areas have been identified, fire service capabilities can be evaluated.

B.5 Operational and Logistical Considerations

Some of the following factors appear insignificant when compared with the magnitude of the fire problem that may be encountered. However, lack of adequate attention to any one of the following could easily interrupt an otherwise smooth operation:

a. Entry into the facility should be possible, day or night, for both the initially assigned unit and additional alarm units. In large complexes, units unfamiliar with the area will probably require assistance in getting to assigned positions.
b. The location of clearly recognizable staging areas should be considered during planning. Standard operating procedures should designate a staging area and a staging officer responsible to the command center.
c. Transportation of foam concentrate supplies to the location of an incident may become a serious problem during large-scale operations. This is a concern that will result in failure of the extinguishment effort if not resolved during the planning phase.
d. During long-term pumping operations, fire apparatus will require refueling. A refueling plan should be in place.
e. If the operation requires the use of self-contained breathing apparatus, a plan should be formulated for the supply of breathing air, for example, provision of spare bottles, cascade system, or air supply unit.
f. Large-scale operations take their toll on working personnel. Adequate personnel are necessary to provide a sufficient number of relief periods. (This is especially critical in extreme weather conditions.) Appropriate areas must be set up to accommodate and feed resting fire fighters.

B.6 Other Resources

Many service agencies and companies other than fire services can provide valuable assistance during a major incident. These should be included or contacted at some point in the planning process. Examples of such organizations include the following:

a. Industry. Neighboring petroleum facilities may be able to provide additional foam concentrate, fire-fighting equipment, and technical expertise (possibly under an existing mutual aid plan).
b. Foam manufacturers. Some of these companies offer 24-hour emergency phone numbers that can be used to obtain additional foam concentrate and appliances from stockpiles located strategically around the United States.
c. Law enforcement agencies. Since spectacular incidents draw large numbers of spectators, cooperation from the responsible police departments is essential. They will be needed for crowd and traffic control, especially when special apparatus or extra foam concentrate is on the way. The police may be able to escort mutual aid units who are unfamiliar with the area, assist with any evacuations that become necessary, or even provide a helicopter for an aerial view of the fire ground.
d. News media. In some instances, the news media may be used to keep local residents informed of the situation or to broadcast the order to evacuate, should evacuation become necessary.
e. Airport and military fire departments. These stations may be able to provide specialized apparatus and equipment to assist in the extinguishment of flammable-liquid fires.

B.7 Preincident Plan Information and Training

Once planning activities have been completed, the information must be entered and maintained in a filing system from which it can be readily accessed. The best and most complete job of planning is useless if the data cannot be quickly referenced during the course of an operation.

Current facility maps should be maintained with the other materials to ensure availability at an incident. Depending on the complexity and scale of the maps obtained from a facility, it may be advisable to draw fire service versions, indicating routes, fire protection features, terrain, and so forth. If this is done, however, both sets of maps should be provided in the command post to ensure that complete and accurate information is available.

The complete and finalized plan data (a book or other system, maps, and so forth) should then be incorporated in regular training sessions. Also, periodic walk-through tours should be conducted by fire department personnel to maintain familiarity with the installation and promote good relations with the local fire brigade and management.

B.8 Determining Foam Concentrate Requirements

B.8.1 GENERAL

Fire-fighting operations at petroleum storage facilities require the expenditure of thousands of gallons of water and foam concentrate, especially if several atmospheric storage tanks are involved.

The following equations can assist fire departments in determining their foam and water requirements for handling storage tank fires. In accordance with NFPA 11, fire protection for tanks consists of (a) primary protection through fixed systems and (b) supplemental protection, generally through portable application devices.

B.8.2 PRIMARY PROTECTION REQUIREMENTS

Foam concentrate requirements are determined by the following equation:

$$C = RSTF$$

Where:

C = concentrate required, in gallons.
R = application rate, in gallons per minute per square foot.
= 0.10 gallon per minute per square foot for hydrocarbon product.
= 0.16–0.20 gallon per minute per square foot for portable application.
S = liquid surface area, in square feet. S is determined by the following equations:
$3.14r^2$ for circular tanks.
lw for rectangular areas.
r = radius, in feet.
l = length, in feet.
w = width, in feet.
T = application time, in minutes (see NFPA 11).
F = foam concentrate, percent.

B.8.3 SUPPLEMENTAL PROTECTION REQUIREMENTS

For protection in addition to the requirements listed above, the following equation is used:

$$C = NLTF$$

Where:

C = concentrate required, in gallons.
N = nozzle application rate, in gallons per minute.
L = number of lines needed at 50 gallons per minute per hose line (see NFPA 11).
T = application time, in minutes (see NFPA 11).
F = foam concentrate, percent.

B.9 Examples

B.9.1 EXAMPLE 1

B.9.1.1 Problem

A cone-roof tank 48 feet high and 60 feet in diameter contains kerosene with a flash point of 120°F. The tank is protected by a fixed foam chamber on the shell. In accordance with NFPA 11, the application rate is 0.01 gallon per minute per square foot and the duration of discharge is 30 minutes.

B.9.1.2 Primary Protection

The primary protection requirement is calculated as follows:

Foam solution flow rate
= area × application rate
= 2828 square feet × 0.1 gallon per minute per square foot
= 283 gallons per minute

Foam concentrate flow rate
= 283 gallons per minute × 0.03
= 8.5 gallons per minute

Concentrate supply
= 8.5 gallons per minute × 30 minutes
= 255 gallons

B.9.1.3 Supplemental Protection

The supplemental protection requirement is calculated as follows: One hose stream is available that can furnish water at a rate of 50 gallons per minute for 20 minutes.

Foam concentrate flow rate
= 50 gallons per minute × 0.03
= 1.5 gallons per minute

Concentrate supply
= 1.5 gallons per minute × 30 minutes
= 45 gallons

B.9.1.4 Total System Supply

The total system supply is 255 + 45 = 300 gallons.

B.9.2 EXAMPLE 2

B.9.2.1 Problem

A cone-roof tank 48 feet high and 60 feet in diameter contains kerosene with a flash point of 49°C (120°F). The tank is protected by a monitor nozzle. In accordance with NFPA 11, the application rate is 0.16 gallon per minute per square foot and the duration of discharge is 50 minutes.

B.9.2.2 Primary Protection

The primary protection requirement is calculated as follows:

Foam solution flow rate
= area × application rate
= 2828 square feet × 0.16 gallon per minute per square foot
= 453 gallons per minute

Foam concentrate flow rate
= 453 gallons per minute × 0.03
= 13.6 gallons per minute

Concentrate supply
= 13.6 gallons per minute × 50 minutes
= 680 gallons

B.9.2.3 Supplemental Protection

No supplemental protection is required because the monitor fills the need.

B.9.2.4 Total System Supply

The total system supply is 680 gallons.

B.9.3 EXAMPLE 3

B.9.3.1 Problem

A floating-roof tank 56 feet high and 150 feet in diameter contains gasoline with a flash point of –45°F. The tank is not protected by a fixed system. In accordance with NFPA 11, the application rate is 0.16 gallon per minute per square foot and the duration of discharge is 65 minutes.

B.9.3.2 Primary Protection

The primary protection requirement is calculated as follows:

Foam solution flow rate
= area × application rate
=17,671 square feet × 0.16 gallon per minute per square foot
= 2827 gallons per minute

Foam concentrate flow
= 2827 gallons per minute × 0.03
= 85 gallons per minute

Concentrate supply
= 85 gallons per minute × 65 minutes
= 5525 gallons

B.9.3.3 Supplemental Protection

No supplemental protection is required because the monitor fills the need.

B.9.3.4 Total System Supply

The total system supply is 5525 gallons.

B.10 Incident Command and Prefire Plan Data Sheet

An incident command and prefire plan data sheet is a fairly simple way to organize the data acquired in the initial stages of an operation and from the plans. It also provides a convenient means of keeping track of assignments given to specific units on the fire ground. There are many different types and features of command charts, and many varieties have been adapted to serve the needs of departments around the country.

The sample chart is intended to illustrate the kinds of information an incident commander may wish to have at hand as the incident develops.

The information blocks on a chart can be arranged in any order, or expanded to any size, to accomplish the desired objectives. (The sample chart has been reduced in overall size to fit on a page.)

Note: The data sheet provided is not currently in use by any specific department).

The data sheet has the following features:

a. Incident. Space for the location, time, date, and other pertinent information.
b. Exposures. Space for listing exposures (type, products, and so on) to the involved tank or tanks.

c. Staging area. Space for listing the apparatus in the staging area, the location of the area, and related data.
d. Fire brigade (if applicable). Space to allow inclusion of such items as equipment, personnel requirements, radio frequencies, and the name of the officer in charge.
e. Storage tank. Space for the features of the storage container itself. Information on pump-out time may be useful in determining attack, salvage, or burnout strategy.
f. Product. Space for data regarding the involved flammable or combustible liquids.
g. System. Space to record information about the water and foam distribution system supplying the facility.
h. Tank devices. Space for recording information about installed fire protection devices. The status of these devices (for example, the need for cooling streams as a result of flame impingement) should be included.
i. Other devices. Space to record information about the type and number of portable devices.
j. Foam concentrate. Space to note any details about the concentrate, its sources, and the available supply. (Much of this should already have been addressed in the preincident plans.)
k. Unit assignments. Space to note assignments and the time of issue of orders to specific units.
l. Additional information. Space for a list of reminders, specialized equipment, or other information. (This varies according to locality.)
m. Any remaining space can be used for additional unit assignments, notes, or drawings of the incident scene.

Table B-1—Application Method for Fixed Chambers or Monitors

Product	Time (minutes)	
	Type II Application	Handlines
Water insoluble		
Flash point above 200°F (lube oils)	25	35
Flash point 100°F–200°F (kerosenes)	30	50
Flash point below 100°F (gasoline)	55	65
Crude oil	55	65
Water soluble		
Polar solvents	55[a]	65[a]

[a]Only when the foam is listed by the manufacturer for Type II application and at their application time but never less than 30 minutes.

Table B-2—Minimum Application Time and Minimum Number of Hose Streams Required for a Given Tank Size

Tank Size (feet)	Minimum No. of Hose Streams	Minimum Application Time Per Hose Stream (minutes)
< 35	1	10
35–65	1	20
65–95	2	20
95–120	2	30
>120	3	30

INCIDENT COMMAND AND PREFIRE PLAN DATA SHEET FOR PETROLEUM STORAGE FACILITIES

Page 1 of 1

Incident

1. Location ______
2. Date and time ______
3. Other information ______
4. Exposures: 1. ______ 2. ______ 3. ______ 4. ______

Staging Area

5. Apparatus in the staging area ______
6. Location of the area ______

Fire Brigade

7. Equipment ______
8. Personnel Requirements ______
9. Radio frequencies ______
10. Officer in charge ______

Storage Tank

11. Type ______
12. Diameter ______
13. Liquid surface area ______
14. Attached equipment ______
15. Drains ______
16. Time to pump out ______

Product

17. Name ______
18. Flash point ______
19. Specific gravity ______
20. Vapor density ______
21. Level in tank, feet ______
22. Storage temperature ______

Fire Protection

23. System ______
24. Tank devices ______
25. Other devices ______

Foam Concentrate

26. Source ______
27. Supply ______
28. Utility control ______
29. Special apparatus ______

Other Information

30. Unit assignments ______
31. Specialized equipment ______
32. Police ______
33. Other ______
34. Notes and drawings:

APPENDIX C—INCIDENT DATA SHEET

C.1 Introduction

The incident data sheet is provided to recommend data that should be collected before, during, and after an incident involving a tank or the area around a tank. Additional data for the specific site may be desirable and should be added to the data sheet.

Gathering data before, during, and after a fire is important for many reasons. The data can be of use if there are legal proceedings as a result of the fire. The data can point to ways that lead to more effective fire fighting. The data can also be used after the fire to evaluate what happened and to prevent the same things from happening again.

C.2 Tank Fire-Fighting Records

In the turmoil of excitement at a major tank fire, recording facts at the scene is sometimes neglected. This is unfortunate for the following two reasons:

a. Dependable data are needed for a critique after the fire. Such a review is necessary to appraise the efficiency of the emergency organization and the strategy and tactics used.

b. When foam is used, data are needed at the start of the fire for calculating the required foam application rates and total amount of foam concentrate needed.

Special data are needed if a cone-roof crude oil tank is involved. The sample incident data sheet is provided as a suggested guide. Copies of this sheet (or a similar one) should be used when prefire planning and simulated tank fire drills are conducted. Data sheets should be readily available for emergency use.

When a tank fire involves petroleum products, the American Petroleum Institute invites the owner to share information pertaining to the incident to assist in developing further guidelines. Information should be sent to the following address:

Director, Safety and Fire Protection Department
American Petroleum Institute
1220 L Street, N.W.
Washington, D.C. 20005

INCIDENT DATA SHEET

Page 1 of 1

Incident Date ____________

Location
1. Company name ____________
2. Street address ____________
3. City ____________ State ______ Zip ______

Time
4. Time fire first observed ____________
5. Time fire reported ____________
6. Time fire suppression started ____________
7. Time fire under control ____________
8. Time fire out ____________

Weather
9. Temperature ____________
10. Humidity ____________
11. Wind strength & direction ____________
12. Sky conditions ____________
13. Precipitation ____________

Salvage
14. Time pumpout started ____________
15. Time pumpout stopped ____________
16. Pumpout rate ____________
17. Quantity of fuel pumped out ____________

Tank
18. Product ____________
19. Type ____________
20. Diameter ____________
21. Roof type: ☐ cone ☐ open floating roof ☐ covered floating roof
22. Dike ____________
23. Type of seal(s) ____________

Fixed Fire Protection
24. Foam chambers on tank shell ____________
25. Subsurface system ____________
26. Catenary system ____________
27. Fixed foam system ____________
28. Portable foam system ____________
29. Foam:
    Type: ☐ fluoroprotein ☐ AFFF ☐ polar ☐ other
    Supply: ☐ cans ☐ drums ☐ bulk ☐ other
30. Automatic detection ____________
31. Automatic actuation ____________

Fuel
32. Type of fuel ____________
33. Reid vapor pressure ____________
34. Initial temperature ____________
35. Boiling range ____________
36. Flash point ____________
37. Level in tank at start of fire ____________
38. Level in tank at end of fire ____________
39. Heatwave settling rate ____________
40. Time of first boilover ____________
41. Time duration & extent of boilovers ____________
42. Time of first frothover ____________
43. Time & extent of frothovers ____________

Fire-Fighting Phase
44. Was cooling water used? ____________
45. Estimated cooling water rate ____________
46. What was cooled? ____________
47. Total amount of cooling water used ____________
48. Did cooling water prevent damage? ____________

Fire
49. Is roof in place? ____________
50. Did the roof sink? ____________
51. Is fire in dike? ____________
52. Is fuel leaking from piping? ____________
53. Is fire contained within tank? ____________
54. Ignition source ____________

Foam
55. Type of water used ____________
56. Quantity of foam used ____________
57. Types of foam used ____________
58. How was foam applied? ____________
59. How was foam proportioned? ____________
60. When was foam started? ____________
61. When was foam stopped? ____________
62. What was foam application rate? ____________
63. Total quantity of foam concentrate used ____________

Other Information
64. Brief description of the fire: ☐ seal ☐ vent ☐ full surface ☐ dike ☐ piping ☐ other
65. Lessons learned ____________
66. Diagram of the fire area:

APPENDIX D—CRUDE OIL TANK BOILOVER, SLOPOVER, OR FROTHOVER

D.1 Boilover

Boilover occurs in the burning of certain products in open-top tanks. After a long period of quiescent burning, there is a sudden increase in fire intensity associated with the expulsion of burning product from the tank. Boilover occurs when the residues from surface burning become denser than the unburned product and sink below the surface to form a hot layer that progresses downward much more quickly than does the liquid surface. When this hot layer, called a *heat wave*, reaches freestanding water or water-in-oil emulsion in the bottom of the tank or on top of the sunken roof, the water is superheated and subsequently boils almost explosively, overflowing the tank. Products subject to boilover contain components with a wide range of boiling points, including both light ends and heavy residues. These characteristics are present in most crude oils and can be produced in synthetic mixtures.

A boilover is entirely different from a *slopover* or a *frothover*. Slopover is the minor frothing that occurs when water is sprayed on the hot surface of a burning oil. Frothover is not associated with a fire but results when water is present in or enters a tank containing hot viscous oil. Upon mixing, the sudden conversion of water to steam causes a portion of the tank contents to overflow.

For a boilover to occur, the following three conditions must be present:

a. The tank must contain free water or water-in-oil emulsion, typically at the tank bottom or on top of the sunken roof. This situation normally occurs in tanks used to store crude oil. It has also occurred in tanks containing heavy fuel oil that was intentionally diluted with a cutter stock to reduce the oil's viscosity.

b. The oil must contain components with a wide range of boiling points so that when the lighter components have been distilled off and burned at the surface, the residue [at a temperature of 149°C (300°F) or higher] is denser than the oil immediately underneath. This residue sinks below the surface and forms a layer of gradually increasing depth (the heat wave) that advances downward at a rate of 1–4 feet per hour. The heat wave is the result of settling of a part of the hot surface oil. It is not heat conduction from the burning surface downward.

c. Boilovers are serious, life-threatening events. Tanks may burn quietly and uniformly for many hours and then, suddenly and without warning, erupt and eject great volumes of burning oil above the rim of the tank. A burning froth wave may travel over the ground away from the tank at speeds up to 20 miles per hour (see Figure 2 and 4.4.2).

D.2 Slopover

A *slopover* can result when a water stream is applied to the hot surface of a burning oil, provided the oil is viscous and its temperature exceeds the boiling point of water. Since only the surface oil is involved, a slopover is a relatively mild occurrence.

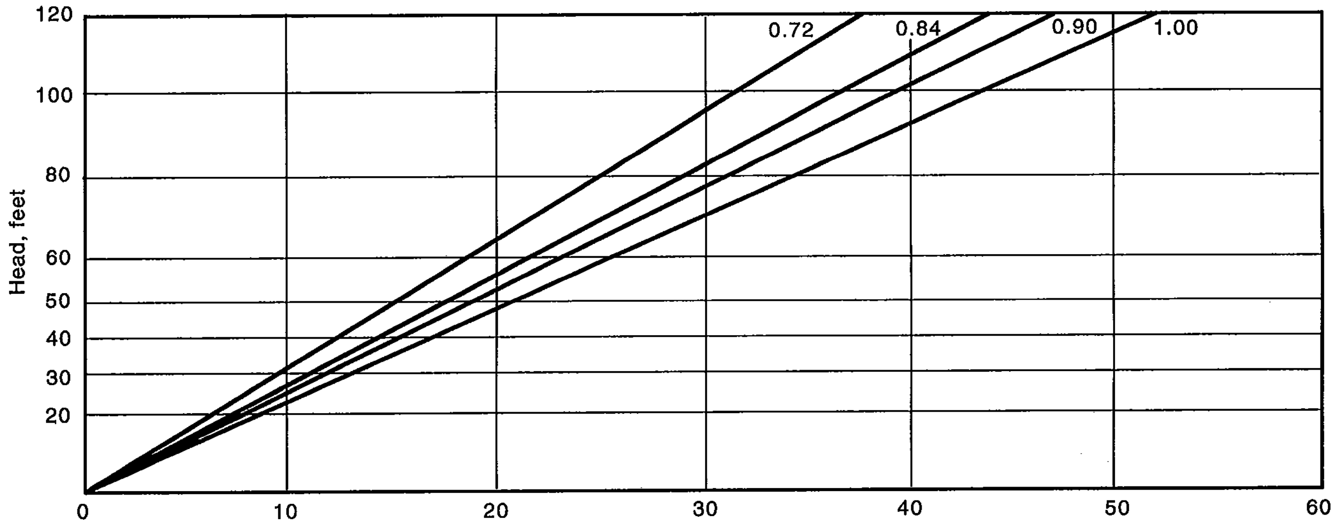
D.3 Frothover

A *frothover* is the overflowing of a tank that is not on fire when water or volatile hydrocarbons boil under the surface of a viscous hot oil. A typical example occurs when hot asphalt is loaded into a tank car that contains some water.

The asphalt is cooled initially by contact with the cold metal, and at first nothing may happen. Later, the water can become superheated. When it finally starts to boil, the asphalt may overflow the tank car.

A similar situation can arise when a tank that is used to store slops or residuum at temperatures below 93°C (200°F) and that contains a water bottom or oil-in-water (wet) emulsion receives a substantial addition of hot residuum at a temperature well above 100°C (212°F). After enough time has elapsed for the effect of the hot oil to reach the water in the tank, a prolonged boiling action can occur, which can rupture the tank roof and spread froth over a wide area.

APPENDIX E—FOAM FRICTION LOSS DATA



Note: Numbers on lines show specific gravity

Figure E-1—Static Head Conversion

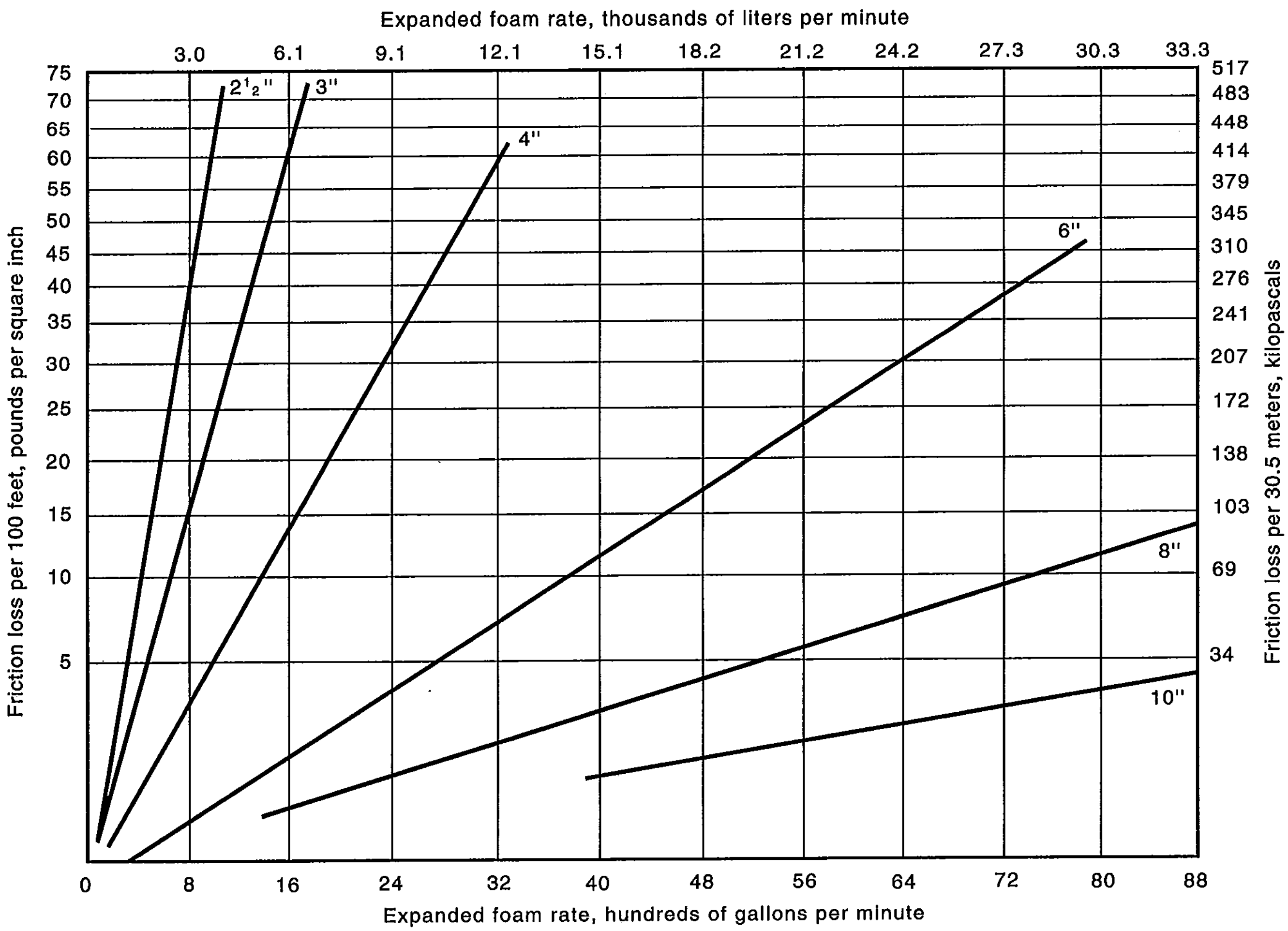


Figure E-2—Foam Friction Losses (2½-, 3-, 4-, 6-, 8-, and 10-Inch Pipe)

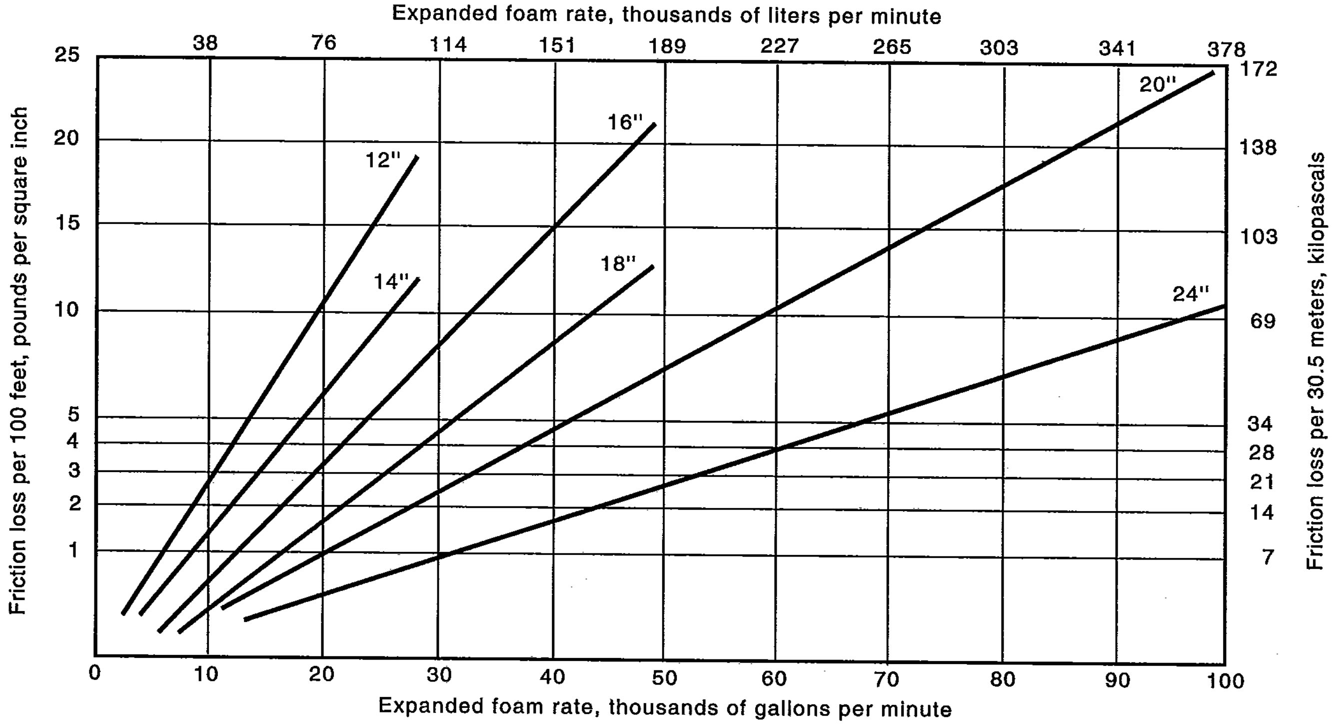


Figure E-3—Foam Friction Losses (12-, 14-, 16-, 18-, 20-, and 24-Inch Pipe)

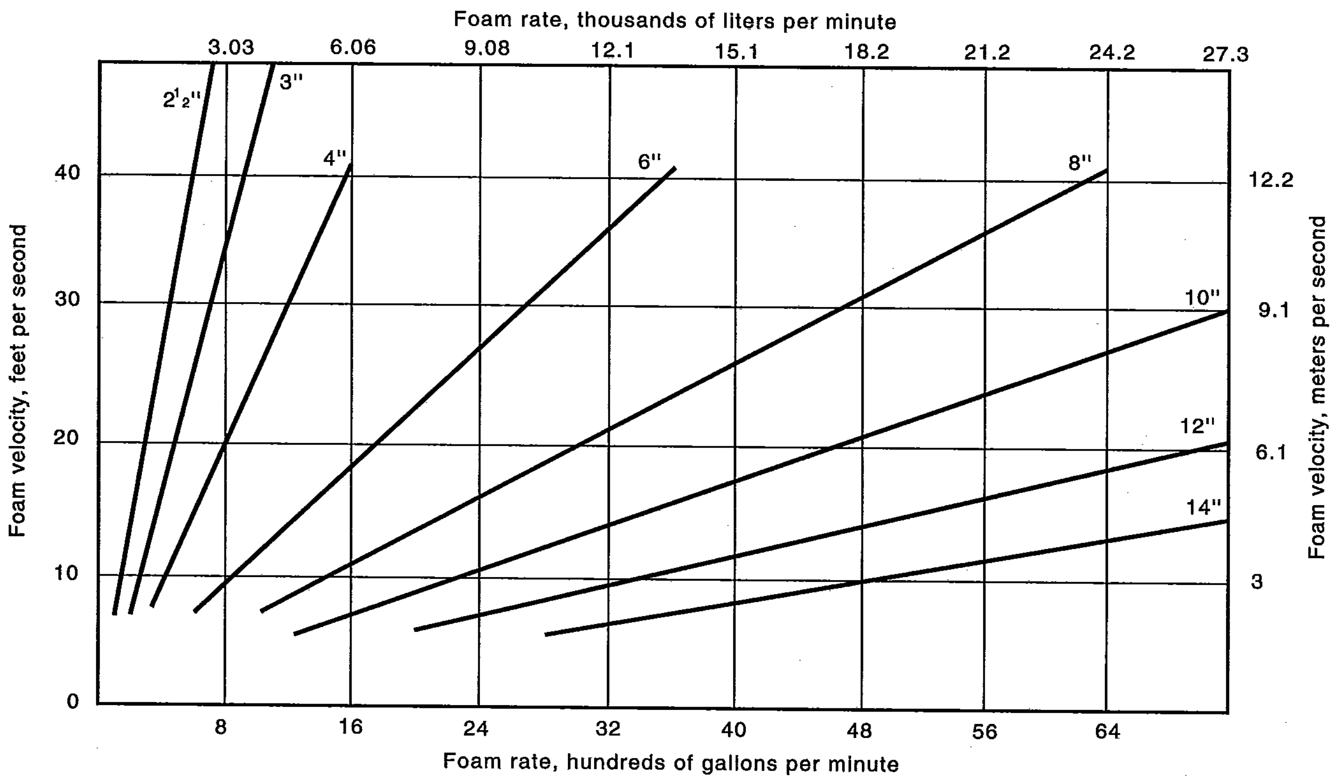


Figure E-4—Foam Velocity Versus Foam Rate: Schedule 40 (2½-, 3-, 4-, 6-, 8-, 10-, 12-, and 14-Inch Pipe)

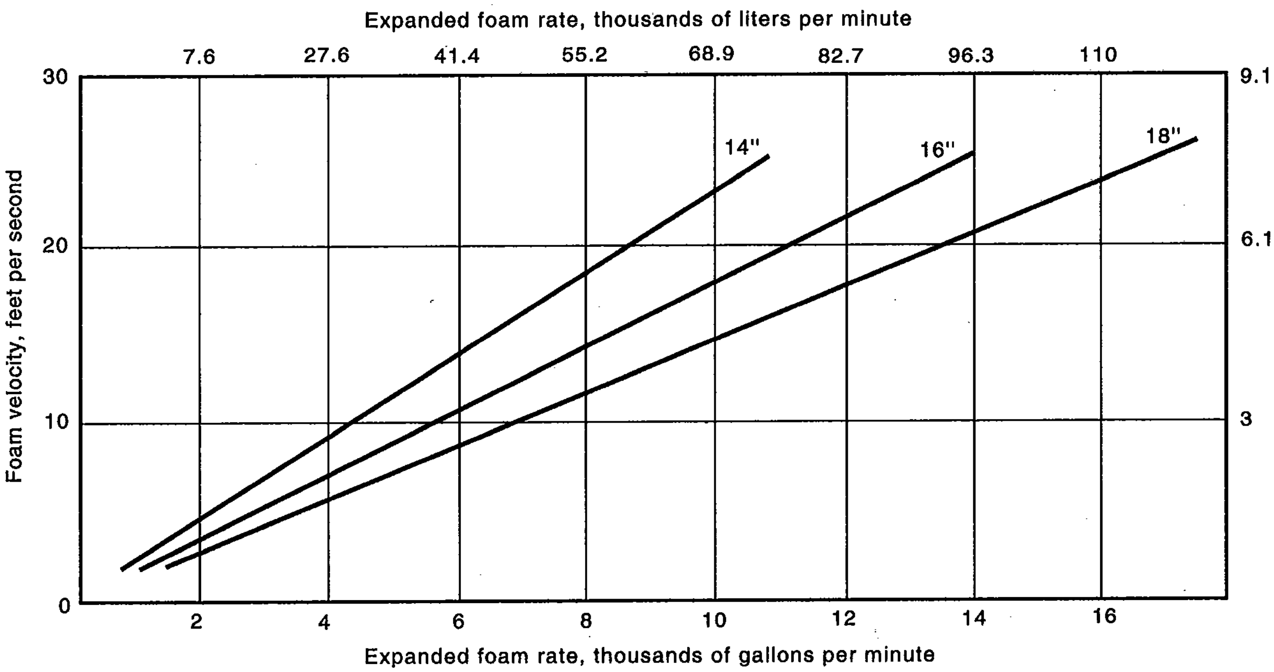


Figure E-5—Foam Velocity Versus Expanded Foam Rate: Schedule 40 (14-, 16-, and 18-Inch Pipe)

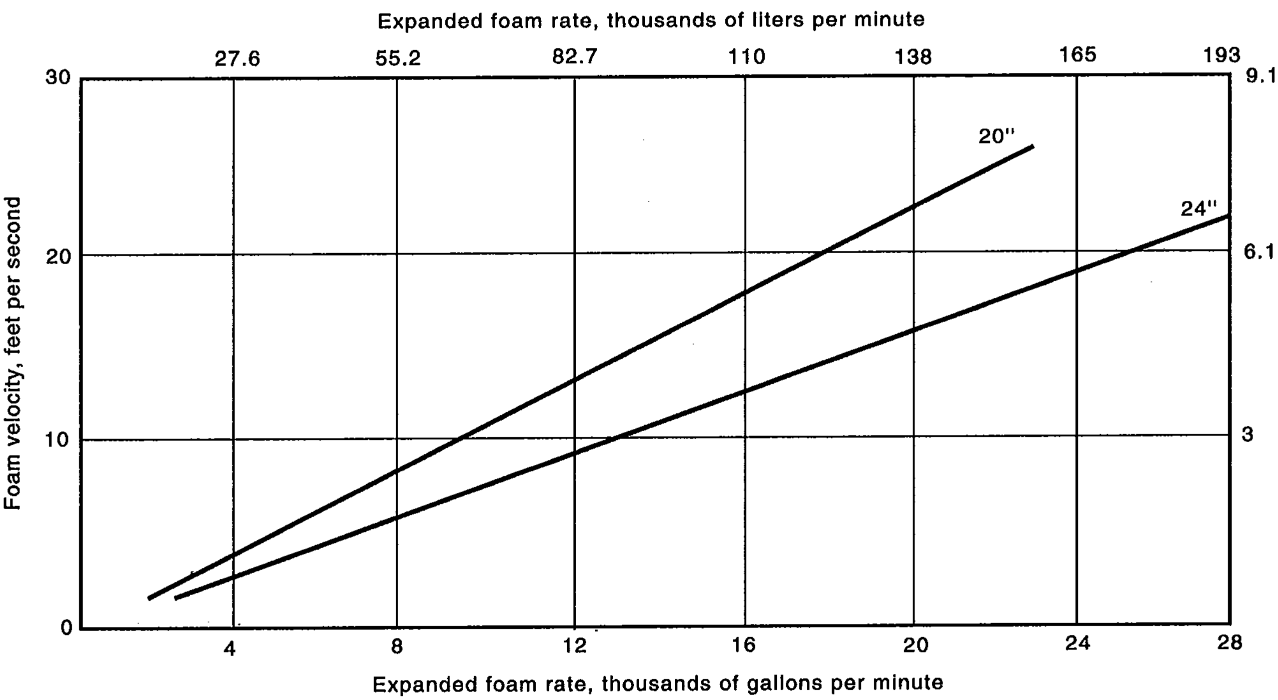


Figure E-6—Foam Velocity Versus Expanded Foam Rate: Schedule 40 (20- and 24-Inch Pipe)

Order No. 855-20210

1-1410—1/91—2M (9C)

American Petroleum Institute
1220 L Street, Northwest
Washington, D.C. 20005