

Management of Atmospheric Storage Tank Fires

API RECOMMENDED PRACTICE 2021
FOURTH EDITION, MAY 2001

REAFFIRMED, MARCH 2020



AMERICAN PETROLEUM INSTITUTE

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Safety & Fire Protection

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FOREWORD

Although there are more than one hundred thousand petroleum storage tanks in service in all phases of petroleum operations, only a very small percentage of tanks ever experience a fire. Consequently, relatively few people have had direct experience with fighting tank fires. This guide was prepared to help provide a basic understanding of tank fire suppression. The information presented is based primarily upon experience in the petroleum industry over a number of years. It is not intended to exclude or limit the use of other approaches of comparable merit.

API strongly supports the principles of fire prevention as the most effective means of ensuring personnel and property protection. Many API publications such as Std. 2610 *Design, Construction, Operation, Maintenance and Inspection of Terminal and Tank Facilities* provide guidance for reducing the probability of fire. The information provided in this document emphasizes planning and preparation as additional steps to protect people and property in those infrequent situations where fires occur.

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Management of Atmospheric Storage Tank Fires

1 General

1.1 PURPOSE

This recommended practice provides experience-based information to enhance the understanding of fires in atmospheric storage tanks containing flammable and combustible materials. It presents a systematic management approach which can assist tank fire prevention. If fires do occur, this information can help responders optimize fire suppression techniques to reduce the severity of an incident and reduce the potential for escalation.

1.1.1 Retroactivity

Any provisions in this recommended practice related to design are intended for reference use when designing new facilities or when considering major revisions or expansions. It is not intended that the recommendations in this publication be applied retroactively to existing facilities. This publication should provide useful guidance when there is a need or desire to review programs or facilities.

1.2 SCOPE

This recommended practice provides information to assist management and fire suppression personnel to manage the needs associated with safely fighting fires in above ground atmospheric storage tanks. The discussion includes planning, preparation, suppression, investigation and follow-up activities as shown in Figure 1.

If a liquid at a petroleum facility can burn and is stored in an unheated tank at atmospheric pressure, it fits the scope of this publication. Fires can be fueled by flammable or combustible liquids ranging from gasoline to lube oil, asphalt or crude oil. Some chemicals used in the petroleum industry fit this scope. Heated tanks are not addressed in this publication, but are the subject of API 2023.

This publication is based on industry experience. It emphasizes planning and preparation along with practical tank fire suppression strategy and tactical guidelines. Guidance and precautions address developing and implementing fire suppression plans for fighting fires in and around flammable and combustible liquid atmospheric storage tanks. A review of fire suppression agents is provided; emphasis is on firefighting foam, with dry chemical agents discussed for seal fires and vents. It should be understood that this document provides basic guidelines. Its application must remain flexible to relate to changing technology, philosophy and regulations. Appendix N provides “Lessons Learned” information organized in the same general categories shown in Figure 1.

This publication specifically excludes fighting fires in tanks containing pressurized gases (see API Pubs 2510 and

2510A) and nonmetallic tanks. Detailed discussion of types of fire protection equipment and maintenance are also outside the scope of this publication. They are covered in publications such as API Publ 2001, NFPA 11, NFPA 30 and the NFPA *Fire Protection Handbook*; further references are noted in Section 2.

There may be situations in which it may not be possible, or appropriate, to mount an aggressive attack to extinguish a fire (as noted in 6.6). In most cases, if sufficient resources are available, extinguishing tank fires is conceptually simple. When enough of an appropriate extinguishing agent (fire-fighting foam) is properly applied to the burning fuel surface, the fire goes out. If the foam blanket is maintained until the fuel and tank metal are sufficiently cooled, the fire stays out. Accomplishing these conceptual goals involves both art and science—and provides a significant logistical challenge in addition to the fire suppression challenge. This publication provides guidance to assist understanding and systematically addressing these challenges.

While this publication provides guidance for fighting tank fires, in considering tank fire issues it is prudent to review prevention of such fires. Preventing tank fires is preferable to fighting them. Section 5 and Appendix I provide brief discussions of fire prevention issues. Appendix O briefly reviews personal protective equipment for firefighters in the tank fire environment.

2 Referenced Publications

The most recent editions of each of the following standards, codes, and publications are referenced in this publication as useful sources of information. Additional information also may be available from the cited Internet World Wide Web sites.

API	
Spec 12B	<i>Bolted Tanks for Storage of Production Liquids</i>
Publ 327	<i>Aboveground Storage Tank Standards: A Tutorial</i>
Publ 340	<i>Liquid Release Prevention and Detection Measures for Aboveground Storage Facilities</i>
API 570	<i>Piping Inspection Code: Inspection, Repair, Alteration, and Rerating of In-Service Piping Systems</i>
RP 574	<i>Inspection Practices for Piping System Components</i>
RP 575	<i>Inspection of Atmospheric and Low-Pressure Storage Tanks</i>
RP 576	<i>Inspection of Pressure-Relieving Devices</i>

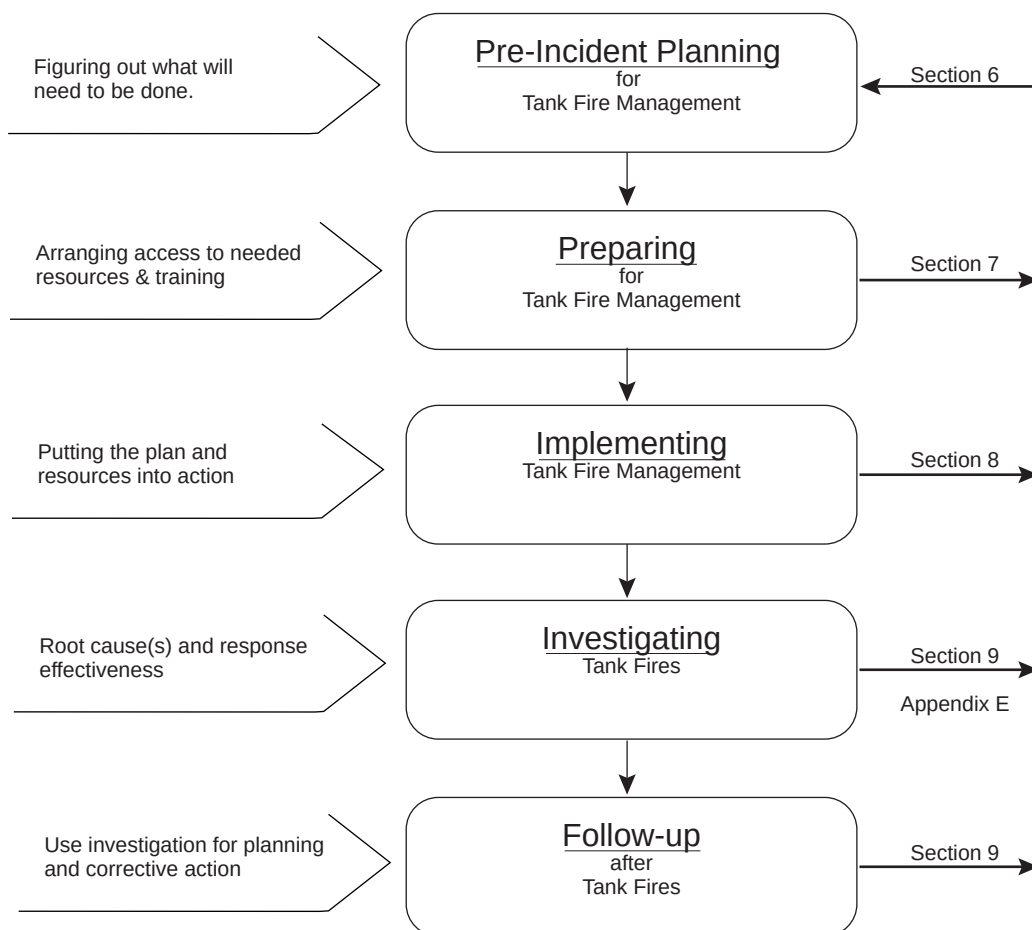


Figure 1—Overview of Management of Atmospheric Storage Tank Fires

Std 620 *Design and Construction of Large, Welded, Low Pressure Storage Tanks*

Std 650 *Welded Steel Tanks for Oil Storage*

Std 653 *Tank Inspection, Repair, Alteration and Reconstruction*

RP 750 *Management of Process Hazards*

RP 760 *Model Risk Management Plan Guidance for Petroleum Refineries—Guidance for Complying with EPA’s RMP Rule (40 Code of Federal Regulations 68)*

Std 2000 *Venting Atmospheric and Low-Pressure Storage Tanks: Nonrefrigerated and Refrigerated*

RP 2001 *Fire Protection in Refineries*

RP 2003 *Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents*

Publ 2021A *Interim Study—Prevention and Suppression of Fires in Large Aboveground Atmospheric Storage Tanks*

RP 2023 *Guide for Safe Storage and Handling of Heated Petroleum-Derived Asphalt Products and Crude Oil Residue*

Publ 2210 *Flame Arresters for Vents of Tanks Storing Petroleum Products*

RP *RP*

Std 2350 *Overfill Protection for Petroleum Storage Tanks*

Std 2510 *Design and Construction of Liquefied Petroleum Gas Installations (LPG)*

Publ 2510 A *Fire Protection Considerations for the Design and Operation of Liquefied Petroleum Gas (LPG) Storage Facilities*

Std 2610 *Design, Construction, Operation, Maintenance and Inspection of Terminal and Tank Facilities*

AICHE (CCPS)¹ *Guidelines for Engineering Design for Process Safety*

Guidelines for Hazard Evaluation Procedures

¹Center for Chemical Process Safety, 345 East 47th Street, New York, New York 10017 www.aische.org/docs/ccps

<i>Guidelines for Technical Planning for On-Site Emergencies</i>	780	<i>Installation of Lightning Protection Systems</i>
<i>Guidelines for Investigating Chemical Process Incidents</i>	1081	<i>Industrial Fire Brigade Member Professional Qualifications</i>
ANSI ²	1561	<i>Fire Department Incident Management System</i>
B31.3 <i>Chemical Plant and Petroleum Refinery Piping</i>	1962	<i>Care, Use and Service Testing of Fire Hose, Including Couplings and Nozzles</i>
ASTM ³	1971	<i>Standard on Protective Ensemble for Structural Fire Fighting</i>
D 323 <i>Standard Method of Test for Vapor Pressure of Petroleum Products (Reid Method)</i>	2001	<i>Clean Agent Fire Extinguishing Systems</i>
Bureau of Mines ⁴	OSHA ⁶	
Bull. 503 <i>Limits of Flammability of Gases and Vapors</i>	1910.38	<i>Employee Emergency Plans and Fire Prevention Plans</i>
Bull. 627 <i>Flammability Characteristics of Combustible Gases and Vapors</i>	1910.119	<i>Process Safety Management of Highly Hazardous Chemicals</i>
NFPA ⁵	1910.120	<i>Hazardous Waste Operations and Emergency Response</i>
<i>Fire Protection Handbook</i>	1910.132	<i>Personal Protective Equipment</i>
<i>Flammable and Combustible Liquids Code Handbook</i>	1910.156	<i>Subpart L—Fire Brigades</i>
10 <i>Portable Fire Extinguishers</i>		
11 <i>Low-Expansion Foam</i>		
11A <i>Medium and High-Expansion Foam Systems</i>		
11C <i>Mobile Foam Apparatus</i>		
12A <i>Halon 1301 Fire Extinguishing Systems</i>		
15 <i>Water Spray Fixed Systems for Fire Protection</i>		
17 <i>Dry Chemical Extinguishing Systems</i>		
20 <i>Installation of Centrifugal Fire Pumps</i>		
22 <i>Water Tanks for Private Fire Protection</i>		
24 <i>Installation of Private Fire Service Mains and Their Appurtenances</i>		
25 <i>Inspection, Testing and Maintenance of Water-Based Fire Protection Systems</i>		
30 <i>Flammable and Combustible Liquids Code</i>		
58 <i>LP-Gas Code</i>		
77 <i>Static Electricity</i>		
291 <i>Fire Flow Testing and Marking of Hydrants</i>		
325 <i>Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids</i>		
600 <i>Industrial Fire Brigades</i>		
704 <i>Identification of Hazards of Materials for Emergency Response</i>		

²American National Standards Institute, 1430 Broadway, New York, New York 10018. www.ansi.org

³American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103. www.astm.org

⁴U.S. Bureau of Mines [part of NIOSH/CDC], Pittsburgh Research Laboratory, P.O. Box 18070, Pittsburgh, Pennsylvania 15236. www.cdc.gov/niosh/pit/welcome.html

⁵National Fire Protection Association, Batterymarch Park, Quincy, Massachusetts 02269. www.nfpa.org

3 Definitions

Terms especially relevant to tank fire suppression are defined in 3.1 through 3.42. Definition of terms which are in general use in the petroleum industry are found in Appendix A.

3.1 advanced exterior fire fighting: As defined in NFPA 600 is “offensive fire fighting performed outside an enclosed structure when the fire is beyond the incipient stage” which “often requires fire brigade members to contain, control, and extinguish exterior fires involving site-specific hazards such as flammable and combustible liquid spills”.

3.2 aqueous-film-forming foam (AFFF) concentrates: Based on fluorinated surfactants plus foam stabilizers. 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 (see Appendix H).

3.3 alcohol resistant foam concentrates: Specifically designed to be effective on fires involving liquid fuels, such as polar solvents, which can cause some foams to be ineffective.

3.4 base injection: An alternate term for sub-surface injection.

3.5 class of a fire: 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.

⁶Occupational Safety and Health Administration, US Department of Labor, Washington D.C. 20402. www.osha.gov

3.6 control: Considered a reduction in fire intensity of approximately 90%.

3.7 extinguishment: The elimination of all flames from the fuel surface and adjacent areas.

3.8 film-forming fluoroprotein (FFFP) foam concentrate: A foam concentrate 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 (see Appendix H).

3.9 fixed systems: Complete permanent installations (typically not used on tanks in the USA) in which the foam is piped from a central station to fixed delivery devices permanently installed to protect the hazard. These systems include all piping, pumps and foam concentrate storage. (More self contained than semi-fixed systems.)

3.10 floating roof: A cover that floats on the tank liquid surface and moves up and down with changes in tank inventory. It limits the exposed liquid surface to the small fraction in the seal area around the periphery. The safest floating roofs have “inherent buoyancy”.

3.11 fluoroprotein (FP) foam concentrate: 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 (see Appendix H).

3.12 foam: A stable aggregate of small bubbles of air in a water-based foam solution resulting in a lower density than either oil or water. It flows over a liquid surface and forms an air-excluding, continuous blanket that inhibits the release of flammable vapors.

3.13 foam application rate: 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.

3.14 foam chamber: A foam discharge outlet attached to the periphery of a tank shell to introduce foam.

3.15 foam concentrate: A liquid foaming agent as received from the manufacturer.

3.16 foam dam: A steel plate at least 12 in. high (and at least 2 in. higher than the seal) installed as a concentric wall attached to the floating roof at a distance 1 to 2 ft inside the tank wall. Along the bottom of the foam dam are drain slots of specified minimum (to drain rain water) and maximum (to retain foam) dimensions. Foam dams are intended to keep the foam where it is needed in the seal area while reducing poten-

tial for sinking the roof by avoiding unnecessary foam water solution on the roof (see NFPA 11).

3.17 foam expansion value: The ratio of final foam volume to the volume of the original foam solution before adding air. The reciprocal of the foam expansion value is the specific gravity of the foam.

3.18 foam quality: A measure of a foam’s physical characteristics, expressed as the foam’s 25% drain time, expansion ratio, and burn-back resistance.

3.19 foam solution: A mixture of foam concentrate in water at a concentration recommended by the concentrate supplier (typically from 1% to 6%) before being mixed with air.

3.20 frangible roof seam: On a fixed roof tank a frangible roof seam is a weak roof-to-shell attachment designed to fail preferentially to any other joint and thus vent excessive pressure without liquid loss if the tank becomes over-pressurized for any reason, including fire (see API 650). Studies show that tanks built to the applicable requirements of API 650 are frangible at diameters of 35 ft or greater; for tanks under 35 ft in diameter it is possible for the tank to fail in other modes.

3.21 full surface (or fully involved) fire: One in which all of the cross-sectional area of the tank is burning.

3.22 hazard: An inherent chemical or physical property with the potential to do harm (flammability, toxicity, corrosivity, stored chemical or mechanical energy).

3.23 hose stream heat test: As used by experienced firefighters, if water from a hose stream does not “steam” when sprayed on potentially heat-affected equipment no further cooling is needed.

3.24 Incident Command System (ICS): The combination of facilities equipment, personnel, procedures, and communications operating with a common organizational structure, with responsibility for the management of assigned resources to effectively accomplish stated objectives pertaining to an incident. Incident Management System (IMS) is an integrated system incorporating elements of ICS with other management systems, including Fire Command (NFPA/Phoenix FD).

3.25 inherent buoyancy: Based on a steel roof constructed to the applicable requirements of API 650 Appendix C or H with closed top annular pontoons or a double deck.

3.26 overhaul: The process of ascertaining that the fire is extinguished, securing the tank contents from reignition, and recovering or disposing of the unburned liquid, foam and combustion products.

3.27 minimum application rate for foam: The rate sufficient to cause extinguishment and demonstrate satisfactory stability and resistance to burn-back (see NFPA 11).

3.28 polar solvent: A flammable liquid partially or totally miscible with water. Alcohols, ethers, ketones and aldehydes are common organic polar solvents.

3.29 protein foam concentrates: Consist primarily of products from a hydrolyzed protein plus stabilizing additives and inhibitors (see Appendix H).

3.30 red tag drill: An emergency response exercise in which facility operating personnel respond to a hypothetical emergency in which a red tag indicates the site and nature of the problem.

3.31 rim fire: Burning occurs only at an annular surface around the periphery of an internal or external floating roof tank where the roof seals against the tank's vertical wall.

3.32 risk: A measure of the probability and severity of harm or adverse effects resulting from exposure to a hazard.

3.33 securing: The prevention of reignition of a liquid fuel by maintaining a covering of foam on the liquid surface until overhaul is complete.

3.34 semi-fixed systems: Similar to fixed systems but are not self-contained. Foam discharge devices are permanently attached to the tank and are connected to piping which terminates at a safe distance from the potential fire site. Necessary foam producing equipment and supplies are brought to the scene and connected after a fire starts.

3.35 subsurface injection: A method of fighting hydrocarbon tank fires in which fuel-resistant aspirated foam at expansion ratios typically between 2 and 4:1 is injected into the base of a burning tank above any water bottoms and below the surface of the burning fuel. The foam rises through the fuel to the surface to effect extinguishment by cooling and blanketing the fuel vapor at the surface; also called base injection.

3.36 thermal protective clothing (bunker gear): A special ensemble of protective clothing constructed in accordance with NFPA 1971 for used by personnel entering hot and warm zones as defined in NFPA 600.

3.37 topside application: A method of foam discharge in which the foam is applied to the surface of the burning fuel.

3.38 top pourer set: An alternate term for a foam chamber.

3.39 twenty-five-percent drain time: The time required for 25% of the liquid contained in the foam to drain; this is an indication of the water retention ability and fluidity of the foam.

3.40 type I discharge outlet: 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. These are generally considered obsolete because nearly all current foams are suitable for use with type II discharge outlets.

3.41 type II discharge outlet: 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.

3.42 type III discharge outlet: 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. Note: this term no longer appears in NFPA 11.

4 Units of Measurement

Values for measurements used in this document are generally provided in both U.S. customary and SI (metric) units. To avoid implying a level of precision greater than intended, the second cited value may be rounded to a more appropriate number. Where specific code or test criteria are involved, an exact mathematical conversion is used. Appendix B provides information on conversion factors. The unit "gallon" refers to the US gallon.

5 Tank Fire Prevention

While this publication provides guidance for fighting tank fires, in considering tank fire issues it is prudent to review prevention of such fires. Experience shows that a large proportion of tank fires can be attributed to design (including roof design), operation, maintenance and environmental factors. API and other industry bodies have addressed storage tank facilities in a number of standards. API Std 2610 discusses design and operation of tank facilities.

Fire risk reduction methods addressed in other publications include:

- control of spills and protecting against overfill (API RP 2350).
- environmental ignition factors such as lightning, especially relevant to open floating roof storage tank seal fires (API RP 2003 and NFPA 780).
- maintenance of tank integrity (API Publ 653).
- proper arrangement and spacing of tanks (NFPA 30).
- providing fire, control and extinguishment equipment and systems (API RP 2001 and NFPA 11) may help prevent small fires from escalating into large ones.
- mechanical design, fabrication, and nondestructive examination of storage tanks, and protective systems (API Stds 620 and 650).
- safe cleaning of storage tanks (API Std 2015 and RP 2016).

- proper operation of vacuum trucks (API Publ 2219).

It is not within the scope of this document to discuss all of the issues impacting fire prevention which are covered in detail by these referenced standards. However, some aspects of tank design are addressed which specifically impact fire protection, safety of fire protection personnel, and assessment of risk.

Both environmental protection and fire prevention share common goals. If the flammable or combustible material is kept in the tank and associated piping system, the probability of either an environmental or fire incident is greatly reduced. A number of documents oriented toward prevention of environmental releases (such as API 327 and API 340) may also be applicable background for fire prevention.

Process safety management concepts, such as Management of Change (MOC), can be applied to prevention of tank incidents. Changes with recognizable potential impact include:

- Operational revisions (changes in volatility or chemical composition of material stored, rate of filling, or tank storage or run-down temperatures).
- Changes in piping or valving arrangements.
- Conducting maintenance and hot work.
- Changes to venting or vapor recovery systems.
- Modifications to the tank itself.
- Weather.

Changes with impacts that are less evident in nature include:

- Soil subsidence.
- Installation of environmental controls (such as activated carbon drums used for vapor capture).
- Low level gauging of floating roof tanks.

Any activity containing the key word “temporary” should trigger at least an informal MOC review.

Conventional wisdom advocates applying a protective foam blanket on pools of hydrocarbon which have not ignited. This has been done successfully many times and continues to be a prudent choice for environmental emission control and fire prevention. There has been contrary experience in a very few situations with sunken-roof tanks. In these isolated cases ignition of the in-depth hydrocarbon pool has been attributed to static charges generated during the application of foam. The European oil companies’ organization for environment, health and safety “CONCAWE” detailed this experience and follow-up laboratory experiments in their October 1997 journal publication *CONCAWE Review*. The article and recommendations to prevent ignition, developed as a result of their experiments and experience, are reproduced in Appendix I.

6 Planning for Tank Fire Management

6.1 GENERAL PLANNING PROCESS

The planning phase starts with a scenario analysis for the specific facility to determine “what might happen” and “what would need to be done”. Based on the planning phase, subsequent activities involve advance preparation (Section 7, making sure that fire fighting resources will be available) and, if necessary, actual fire suppression (Section 8) which activates the incident management system to implement plans using resources identified during preparation.

The typical steps involved in planning for tank fire suppression are shown in Figure 2. These are: developing an incident management organization/system; surveying the facility to assess factors related to fire potential; identifying the types of fires that can occur at the facility; developing a fire protection/suppression philosophy for each type of fire; developing specific pre-fire plans for each tank with a fire risk and developing a plan to meet the logistics needs.

These steps are discussed in the following sections:

6.2 INCIDENT MANAGEMENT SYSTEM PLANNING

Every facility needs an Incident Management System (IMS) to cover the range of possible emergency events that could occur. Facility management, through existing knowledge or survey, should determine if there is a potential for a tank fire which should be addressed (see 6.3.1 for assistance in determining tank fire potential). If there is, then the first planning action should confirm that an appropriate IMS is in place and can accommodate tank fire emergencies. An IMS comes first because it will be needed in the event a tank fire occurs before planning and preparation are finished.

The logistics associated with major tank fire incidents can be complex. The Incident Command System (ICS) is well suited for managing such incidents. ICS planning for a resource intensive tank fire emphasizes logistics, effective manpower control and coordination, and communication of information both internally and externally. ICS provides a structure for coordinating facility personnel and operations, local fire departments, mutual aid organizations, and equipment responding to an emergency. Coordination of incident management concepts and procedures with potential industrial and public mutual aid responders’ plans is highly recommended.

Training and education is necessary for ICS to function effectively. This need includes all personnel (including management) who will assume ICS roles.

Firefighting is only one aspect of handling a major tank fire incident. An Emergency Operations Center is frequently used to provide a physical location for coordinating the wide range of related emergency activities associated with a highly visible, resource intensive tank fire incident.



Documents

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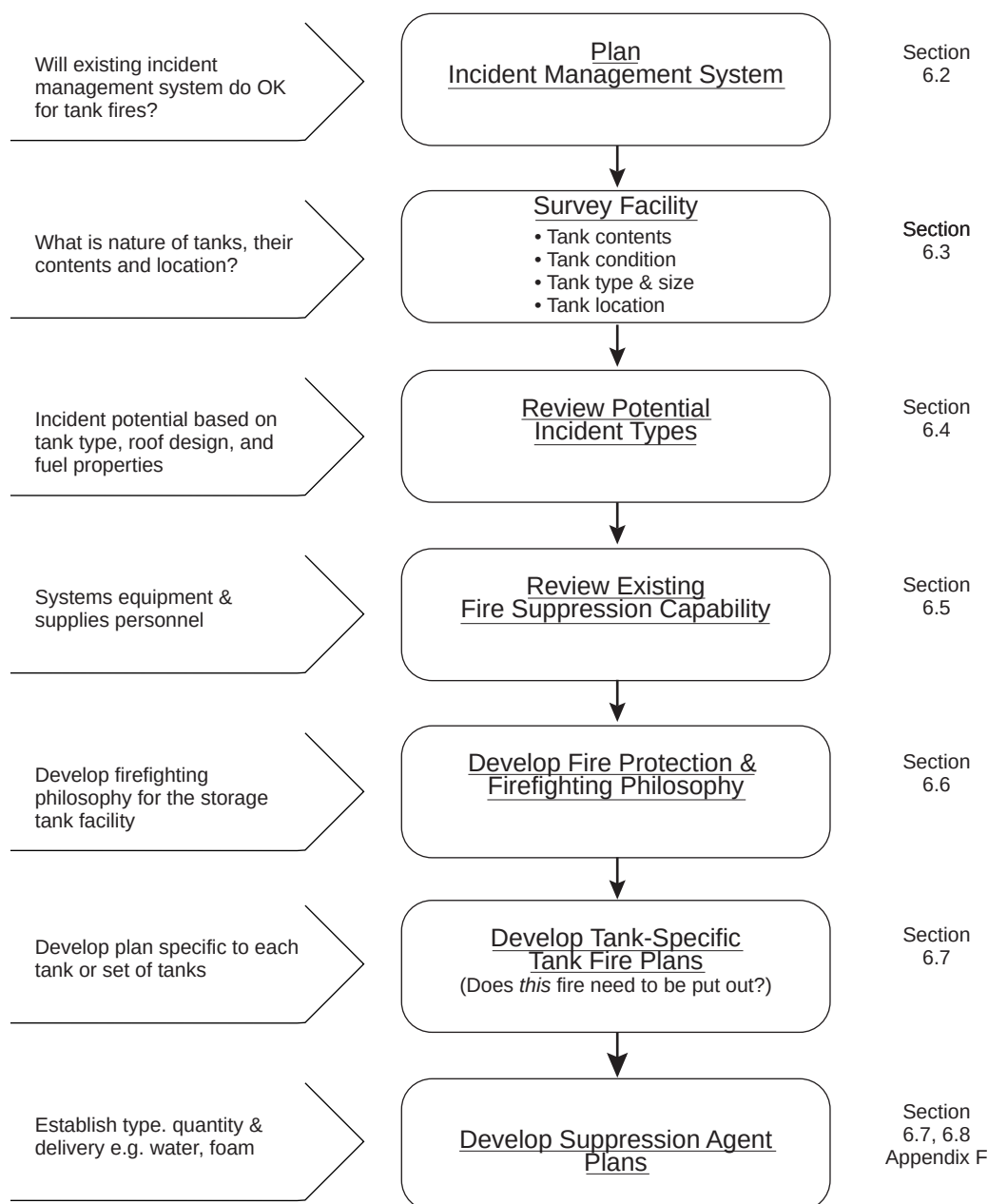


Figure 2—Planning for Storage Tank Fire Management

Appendix C presents more detailed information on incident management systems, including ICS and IMS. This RP is not an IMS tutorial; it provides guidance and suggestions for some elements particularly relevant to tank fire emergency management for consideration within whatever incident management system a facility may use.

6.3 FACILITY SURVEY AND HAZARD ASSESSMENT

6.3.1 Survey

An initial survey of the facility should determine whether atmospheric tanks at the facility contain flammable or combustible liquids. This review should document tank contents which are potential fuels, the tank types and sizes, and their location. Using this information the various types of potential fire which might involve these tanks can be postulated. Figure 3 provides a two-part “Tank-Specific Contingency Planning Sheet”. The first half (3a) can be used to document the initial survey information, and then the second part (3b) can be used as subsequent, more detailed, tank-specific planning devel-

Initial Tank Survey Information		
Tank Name, Number or Designation:	Tank Data	Reference
Tank Location or Area Designation		
Name of Material Stored in Tank		Section 6.3.2
Type of Tank	Vertical or Horizontal? _____ Fixed Roof? Frangible Roof Seam? Yes__ No __ Internal or External Floating Roof? Inherently buoyant? Yes__ No __	Section 6.3.3 Appendix E
Tank Diameter		
Tank Full Surface Area		
Tank Height		
Tank High Gauge	ft_____ Barrels_____ Capacity_____	
Type of Tank Vents	Normal?_____ Emergency?_____	
Type of Floating Roof (if any)	Steel? __Aluminum? __Plastic? __ Steel Pan? __ Open topped Steel? __	Appendix E Appendix F
Tank Siting relative to ignition sources or vulnerable occupancies		Section 6.3.4 API 2001 NFPA -30
Permanently Attached Fire Protection?	Yes_____ Type_____ No_____	Sections 8.5.6-8
Access for Subsurface Injection?	Yes_____ Where?_____ No_____	Section 8.5.7.3 NFPA-11

Figure 3a—Tank Specific Pre-Incident Contingency Planning Sheet

ops. Tanks in similar service might be grouped for “tank-specific” planning. This overview survey provides data which begins to quantify “what do we have” and “what might happen”. The later, more detailed tank-specific fire contingency planning (see 6.7) seeks to answer the question “how will we address a fire situation” and will document this information in the second half of the tank-specific contingency planning sheet.

At many facilities significant parts of the needed planning data already exists for environmental regulatory compliance or operations needs, thus providing a “head start” for fire contingency planning.

6.3.2 Storage Tank Contents Hazard Assessment

The characteristics of a tank’s contents directly affect the potential for a fire in that tank. Volatile materials generate more flammable vapor at a given temperature than less volatile materials. The volatility of concern is most easily characterized by flash point, but also can involve the overall distillation curve for the material.

Materials with flash points higher than their maximum storage, ambient and rundown temperatures are typically considered low fire risks. Table 1 provides a listing of materials frequently stored in tanks at petroleum facilities, their fire hazard based on flash point, and special hazards inherent with

these materials. If the storage temperature for the material typically exceeds its flash point then there can be the potential presence of an ignitable quantity of flammable vapors. If the expected temperatures for the material are typically lower than its flash point then an ignitable quantity of flammable vapors is less likely to be present.

6.3.3 Types and Size of Storage Tanks

The API has addressed design and management of storage tank facilities in a number of standards. API Standards 620, *Design and Construction of Large, Welded, Low Pressure Storage Tanks* and 650, *Welded Steel Tanks for Oil Storage*, are key references for refinery and terminal tank design. API Spec 12B, *Bolted Tanks for Storage of Production Liquids*, covers bolted steel tanks used in oil production. Other publications referenced in Section 5 address methods for management of tank facilities to reduce fire risk. While this publication specifically addresses atmospheric tanks, typical storage areas may also contain pressurized tankage. Other standards, such as API 2510, API 2510A and NFPA 58, address this more specialized storage.

Tank types which will be considered in this publication are:

- Fixed roof tanks.
- Vertical, low-pressure tanks without frangible roof seams.

Detailed Tank Planning Information		
Tank Name, Number or Designation:	Tank Data	Reference
Foam Type to be Used		Appendix H NFPA-11
Access for Rim Seal Fire	Platform, Wind Girder with Railings; Elevated Nozzles, Semi-Fixed or Other Systems	Section 8.5.6
Foam Application Rate for Seal Fire	g/min/ft ² (l/min-m ²)	Appendix L
Foam Application Rate for full surface Foam Chambers _____ Subsurface _____ Over-the-Top _____	g/min/ft ² (l/min-m ²)	Appendix K NFPA-11
Time duration for foam application	Minutes for: Seal _____ Full Surface _____	Appendix K, L NFPA 11
Minimum^a Total quantity of foam required and Type		Appendix K, L NFPA 11
Foam Supply Available • On-site • From mutual aid (time) • From Manufacturer (time)		Appendix K, L NFPA 11
Physical Properties of Material in Tank	Attach MSDS	
Special Hazard Considerations	Table 1 & Appendix G (e.g. Toxicity, Reactivity, Boilover)	Section 6.3.2; 6.7.10 Appendix G
Tank Accessibility for Suppression		Section 6.3.4; 6.7 API 2001, Appendix N
Water Supply • Needed, g/min • Permanent, piped to area • Available using temporary supply • Not Available from any source		Section 7.4.3 Appendix M
Personnel for Contingency Plan • Needed • Available from Facility • Available via Mutual Aid	Identify means of notification and response time	Section 7.4.7
Other Resources Required/Available	Mutual Aid or Contract Assistance	
^a In many incidents the final total amount of foam concentrate used has been greater than the NFPA minimum.		

Figure 3b—Tank-Specific Pre-Incident Contingency Planning Sheet

- Horizontal fixed roof tanks.
- Bolted tanks.
- Internal (or covered) floating-roof tanks.
- Open top floating-roof tanks.
- Domed (or covered) external floating-roof tanks.

Detailed discussion of tank type and construction appears in Appendix E.

Size is a significant factor for planning emergency response to tank fire incidents. Large diameter tank fires are challenging and resource intensive. Smaller tank roofs may not separate at a frangible seam and thus present hazards associated with rupture or separation at the shell-to-bottom seam.

6.3.4 Tank Location Relating to Hazard Assessment

The location of storage tanks is significant in several respects. Proximity to ignition sources such as flares or furnaces influences probability for ignition if there is a release of material from storage. Poor “housekeeping” provided a means for fire escalation in a “classic” incident in the UK when oil on floating roofs was ignited from wind-borne cinders, resulting in a multi-tank fire scenario.

Distance to fence lines is significant in respect to potential impact of a tank fire incident if there are relevant exposures of concern; proximity to the fence line also increases the potential for mischief originating from off-site. NFPA 30 provides

Table 1—Tank Content Characteristics and Potential Special Hazards

Tank Contents	Flash Point	Material Characteristics	Potential Special Hazards & Characteristics (See Appendix G)
Petroleum Materials		Broad Boiling Range	
Gasoline, Naphtha	ca -40°F; -40°C	Low flash point, volatile	
Middle distillates Kerosene, jet fuel Diesel fuel Home heating oil (#2 oil)	minimum 100°F; 38°C	Combustible	Low conductivity & static ignition. Potential flammable tank vapor space if tank temperature is above flash point.
Crude oil	Typically low, below ambient	Volatile to viscous containing a heavy, high molecular weight fraction	Boilover, frothover, slopover; Pyrophoric iron sulfide formation possible with sour crude
Heavy residual products (Asphalt, #6 oil, bunker fuel)	Typically high (Unless “cut back” or contaminated)	Frequently stored at elevated temperature; may be “cut back” (blended) with lighter hydrocarbons	Frothover, slopover boilover potential if blended with light product such as middle distillate
“Pure” chemicals	FP = Flash Point BP = Boiling Point	Have single boiling point	High vapor pressure and evolution possible as boiling point is approached
MTBE (Methyl Tertiary Butyl Ether)	FP = -22°F; -30°C BP = 131°F; 55°C	Low flash point, High volatility	High volatility, Low surface tension
Methanol (methyl alcohol)	FP = 52°F; 11°C BP = 147°F; 64°C	Low flash point, High volatility, Wide flammable range	Water solubility, Low luminescence flames
Ethanol (ethyl alcohol)	FP = 54°F; 12°C BP = 174 °F; 79°C		
Refining chemicals eg. “spent” acid (H ₂ SO ₄), phenol	FP = 175 °F; 79°C BP = 358 °F; 181°C	Flammable if contaminated by hydrocarbons	Corrosivity, reactivity and toxic hazards
Process chemicals Benzene, Styrene Methyl methacrylate	FP = 12°F; -11°C BP = 176°F; 80°C FP = 90°F; 32°C BP = 295°F; 146°C FP = 50°F; 10°C BP = 214°F; 101°C	Varied	Long Term Health Effects (Benzene) Exothermic Reactions (Including Heat-Induced Polymerization)
Lead alkyl antiknock Compounds TML TEL	FP = 89°F; 32°C FP = >245°F; >118°C	Toxic Flammable or combustible Reactive	Detonation Possible at Elevated Temperatures 212 to 300°F Toxicity of Compounds and Combustion Products
Metal alkyl catalysts	Below ambient	Highly reactive	Violent Reactivity with Water Pyrophoric due to Moisture in Air
“Slops” Waste water Sour water	Varied	Flammable (due to potential contamination by light hydrocarbons); low probability if no flammable materials are at the facility	Pyrophoric Iron Sulfide Formation Possible with Sour or Sulfur Containing Materials
Note: Appendix G contains additional information on hazards; the MSDS for the specific product can also be consulted.			

Table 2—Tank Types and Fire Potential

Tank Type ^a	Potential Type(s) of Fire	Comments
Fixed (Cone) Roof Tanks	Vent Fire Overfill Ground Fire Unobstructed Full Liquid Surface Area Obstructed Full Liquid Surface Fire if frangible roof remains partially in tank	For volatile liquids, the rich vapor space typically prevents ignition within the tank. Environmental regulations typically prevent storage of Class I flammable liquids in larger fixed roof tanks
Vertical, Low-Pressure Fixed Roof Tanks without Frangible Roof Seams	Vent Fire Overfill ground fire Tank Explosion and failure with subsequent ground fire	Rich vapor space inside of tank typically prevents ignition within tank. Lack of frangible roof seam can result in failure of tank at bottom or side, resulting in significant or total loss of tank integrity, and/or launching of tank.
Internal (or Covered) Floating-Roof Tanks	Vent Fire Overfill ground fire Obstructed Rim Seal Fire Obstructed Full Liquid Surface Fire	Many fires in this type of tank occur as a result of overfilling. Tank will be extremely difficult to extinguish if entire liquid surface becomes involved. Fires in tanks with pan type covers can be expected to develop into obstructed full liquid surface fires.
Domed (or covered) External Floating-Roof Tanks	Vent Fire Overfill ground fire Obstructed Rim Seal Fire Obstructed Full Liquid Surface Fire	Fires in this type of tank most often occur as a result of overfilling. Tank will be extremely difficult to extinguish if entire liquid surface becomes involved.
Open Floating-Roof Tanks	Rim Seal Fire Overfill ground fire Obstructed Full Liquid Surface Fire Unobstructed Full Surface Fire	Application of fire water to the roof area should be carefully controlled to prevent overloading and sinking the roof when fighting a rim seal fire.
Horizontal Tanks	Vent Fire Overfill ground fire Tank Explosion and failure with subsequent ground fire	Rich vapor space inside of tank typically prevents ignition within tank. Explosion of vapor/air mixture in tank can result in catastrophic failure, with tank ends travelling significant distances. Exposure of unwetted surface of tank to fire can result in a Boiling Liquid Expanding Vapor Explosion (BLEVE).
^a Appendix E provides pictures and information for various types of storage tank.		

guidance for some minimum distances which should be used with knowledge of the social environment surrounding the facility. In case of a fire, the distance to firewater supplies will affect flow and pressure.

Access to tank areas to bring in equipment and supplies is significant. Some facilities have dikes wide enough for equipment to reach a fire scene; others may provide raised staging pads alongside the dikes on two sides of tanks for setting up large ground monitors.

6.4 TYPES OF TANK FIRES AND GENERAL SUPPRESSION STRATEGIES

6.4.1 General

When the term “tank fire” appears in the media and statistical summaries, it can mean many different things. While the term evokes visions of a fully involved full surface fire requiring extensive resources, it also describes events which involve low risk, damage and resource use, such as rim seal fires or vent fires.

The planning process “scenario analysis” should address each potential type of fire (and the resources required) for the tanks and materials stored at the facility. Table 2 provides an overview of fire types associated with different types of tank. The following sections lists these types of fire in general order of increasing resource intensity.

Suppression methods vary as a function of roof construction, type of fire and product stored. Section 8 provides more extensive tank suppression information.

6.4.2 Tank Vent Fires

Vent fires on fixed roof tanks typically are attributed to lightning. If addressed properly they can usually be extinguished with minimal damage and low risk to personnel using dry chemical or by reducing the pressure in the tank as discussed in 8.5.5.

6.4.3 Rim Seal Fires

6.4.3.1 Rim Seal Fires in External Floating Roof Tanks

Rim seal fires comprise the majority of fires involving external floating roof tanks. Lightning provides the ignition source for most rim seal fires. In many cases this is attributed to an induced charge without a direct lightning hit. Success in extinguishing rim seal fires approaches 100% if there is no associated damage (such as a pontoon explosion) and if suppression efforts don't sink the roof through excessive use of water.

Semi-fixed equipment for seal fires is described generally in Section 8.5.6.1 and in detail in NFPA 11. If permanently attached foam protection for the seal is not provided, it will be necessary to fight the fire with equipment which can be brought to the scene. Pre-incident planning and preparation can reduce delays and address potential personnel hazards when manual extinguishment is required.

6.4.3.2 Rim Seal Fires in Internal Floating Roof Tanks

Extinguishment of rim seal fires in internal floating roof tanks provides a special challenge, especially if there is no permanently attached foam system. The only access to apply a suppression agent is through small vent openings at the top of the tank, which typically have protective screens.

6.4.4 Unobstructed Full Liquid Surface Fires Without Sunken Roofs

Extinguishment of full liquid surface fires where there is not a sunken roof is relatively simple in smaller tanks, but presents a major challenge in large tanks because of size and resources required. These usually involve fixed roof tanks where the roof has totally separated at a frangible (weak) seam leaving the total surface uncovered.

Fixed roof tanks have a vapor space between the liquid surface and the underside of the roof. If the vapor space is in the flammable range at the time an ignition source is introduced, an explosion will occur. If the tank is constructed in accordance with API Std 650, the roof should separate from the shell at the frangible seam joint. The roof usually separates in one piece. Depending on the severity of the internal pressurization or explosion the roof will vary from a "fishmouth" a few feet long to a fixed roof which is blown completely away

from the tank shell. 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 except where obstructed by the remaining roof. There may be fire "hiding" below roof segments (6.4.5).

When the tank contains a conventional hydrocarbon, extinguishing options include both topside application and subsurface injection of foam. The foam type must be compatible with both the fuel and the application technique. If a fire involves polar solvent with high water miscibility, the extinguishing technique is limited to topside application. For planning purposes the approach to be used should be determined based on the installed equipment on the tank, the material stored in the tank and the suppression philosophy. Then, the resources needed can be determined.

6.4.5 Obstructed Full Liquid Surface Fires with (Wholly or Partially) Sunken Roofs

Full surface fires with a full or partially sunken roof can occur where tanks have fixed roofs, internal floating roofs or external floating roofs. The roofs of internal and external floating roof tanks can sink for a variety of reasons. Where the roof is internal, gas or vapor can cock the roof causing it to buckle and sink or allowing liquid to overflow the rim. Since this introduces flammable material into the ventilated air space between the fixed and floating roofs, the result can be an explosive mixture in the vapor space below the fixed roof. If this is ignited the fixed roof may stay intact or it may separate in one of the scenarios described for fixed roof tanks without internal floating roofs. Also, if the tank seals are not vapor tight, during filling the vapor space in an internal floating roof can be in the flammable range. If lightning strikes during this time an explosion can result. Filling operations should be conducted with caution or avoided when a lightning storm is imminent in the vicinity. Vapor recovery systems may reduce the ignition hazards associated with lightning.

External floating roofs can sink due to flotation failure caused by pontoon or double deck leakage, malfunction, mechanical failure or by excessive weight from snow, rainwater or firewater. There is reduced likelihood of sinking the roof and escalating to a full surface fire should fire fighting operations flood the roof, if the tank is equipped with a roof that has "inherent buoyancy" (a double deck or annular pontoon roof).

Irrespective of the sinking cause, the roof forms a barrier between the bottom of the tank and the surface of the burning fuel. In such cases, subsurface foam injection should be considered a "last resort". The roof impedes or prevents foam from reaching the burning fuel surface. Fire suppression efforts using top-side foam application are most appropriate. Difficulty will be experienced if a portion of the roof

obstructs full access to the burning surface. Extended foam application may be required to seal the obstructed area and prevent burn-back and reignition. This may require much more foam concentrate use than the minimum amount calculated in accordance with NFPA 11.

6.4.6 Ground Fires Around Tanks

Ground fires in tank areas can result from tank or piping leakage or overflow. API 2350 outlines the principles for preventing tank overfills. If the tank area conforms to NFPA 30, and drain valves are closed, the fuel for a potential fire should be confined within dikes. If tanks are not on fire the primary objective should be to keep them from igniting. This becomes especially significant when more than one tank shares the diked area.

In case of a ground fire in a tank area, high emphasis should be placed on exposures which could raise temperatures of tanks not on fire. This can result in greater vapor release or heat-triggered reactions of some chemicals. Direct flame impingement normally receives highest priority with radiant heating concerns following. This priority might be reversed if the material stored in an affected tank is especially heat sensitive. Tanks containing heat sensitive products should be identified in the survey and planning process. Fire suppression should be addressed with vulnerable areas receiving the first attention.

6.5 REVIEW EXISTING FIRE SUPPRESSION CAPABILITY

The capability for suppressing a fire relates to understanding the resources required and then being able to apply them to problem resolution. Before a fire suppression philosophy can be developed for a storage tank facility, the firefighting resources and capabilities in place should be evaluated.

The basic fire-suppression resource needed for most non-pressurized hydrocarbon fires is firefighting foam. This in turn requires water, foam concentrate and the means of delivering an expanded foam solution to the right location, in the right quantity, for the required duration. In most cases, delivery capability involves equipment, consumables and personnel. Meaningful "delivery" must be to the burning fuel surface at the proper rate for sufficient time to achieve extinguishment.

NFPA 11 provides guidance on minimum foam flow to be applied to a burning tank. The facility capability review should determine the actual water flow rate and pressure which can be delivered to the specific tank. This value is then compared to the required flow. If there is not sufficient water available from on-site firewater systems, and fire suppression is planned, then alternate water sources should be evaluated. Some facilities or mutual aid groups can establish supplemental water supplies using large diameter hose with additional pumping from pumper

trucks or portable fire pumps. However, planning should note that this not only requires access to the hoses, but is also labor intensive and time consuming.

Along with the water, a source for supplies of an appropriate foam concentrate in sufficient quantity should be identified. This often includes both on-site storage as well as supplies from mutual aid participants and/or suppliers.

Finally, the expanded foam/water solution must reach the burning surface. The review should determine how the foam will be applied and whether the appropriate equipment will be available on-site or be brought to the incident scene.

An essential factor is time. If the fire can burn unabated (such as a seal fire) without creating further problems (such as boilover in crude oil tanks) or exposures to vulnerable equipment (such as LPG spheres), then more time is safely available. If it is inappropriate to delay before starting aggressive suppression efforts with foam application, then water, foam concentrate and the means to apply them need to be more readily available.

6.6 REVIEW, REVISE OR DEVELOP FIRE PROTECTION AND SUPPRESSION PHILOSOPHY

After the fire risks at the site have been identified, and the existing fire suppression capability has been evaluated, a decision can be made regarding the fire suppression strategy that will be used for each type of fire that may occur in each tank.

Basically, three general strategies may be used for a tank fire: *passive*, *defensive* or *offensive*.

A *passive* (or evacuation) strategy involves no fire fighting activities; the fire will be allowed to burn out and the area evacuated if necessary for personnel safety (such as concerns for potential boilover of a crude oil tank).

The following are examples of situations that suggest adoption of a passive strategy:

- Not enough personnel and materials (foam and water) are available for a safe and complete extinguishment attempt (such as in isolated areas).
- There is imminent danger of a boilover, tank failure, or other life-threatening occurrence, requiring immediate evacuation of the area.

Without fire suppression mitigation, a boilover should be considered a realistic probability for full surface fires in crude oil tanks. No one can predict with precision if, or when, a boilover will occur in these situations. Appropriate contingency plans should be developed. If a reliable means of monitoring the progress of the heat wave is available it may help (see Appendix G.2).

Locations where a passive fire protection philosophy might be adopted include remote storage facilities and facilities without an adequate firewater supply.



A *defensive* strategy protects personnel and exposed equipment and allows the fire to burn out.

A defensive strategy should be considered when tank conditions (such as a sunken roof obstructing large portions of the fuel surface) or lack of resources preclude a successful offensive strategy, and:

- The incident could be contained with available resources without jeopardy to life or further jeopardy to property. (A controlled burn can be maintained while minimizing losses by operations such as pumping fuel from the tank and protecting exposures to prevent escalation.)
- Potential flame impingement or radiation on adjacent tanks may require immediate action to prevent the involvement of additional tanks. Protective cooling streams and transfer of products to safe tanks should be considered.
- The scope of the incident does not justify the risk associated with an aggressive attack. (For some incidents [sometimes referred to as plot limit incidents] risk considerations dictate that fire-fighting efforts should center on preventing further losses and salvaging assets until additional resources become available.)
- Management has accepted a loss control philosophy that extinguishment will not be attempted but exposures will be protected and losses minimized. (For a full surface fire this means accepting as a minimum the likelihood of loss of the entire tank and whatever product is not pumped out versus the cost of fire suppression.)
- Mutual aid is not immediately available. A defensive strategy should be used as a “holding action” until planned mutual aid can provide additional resources. The strategy then shifts to an offensive mode.

Examples of situations where a defensive strategy may be adopted include large diameter obstructed full liquid surface fires with no boilover potential. For tanks containing fuels with boilover potential, plans should be developed recognizing that potential.

An *offensive* strategy is an aggressive attack to attempt to extinguish the tank fire.

An offensive strategy should be considered in the following situations:

- If life is in imminent jeopardy, then a focused aggressive fire suppression action should support rescue if the risks are consistent with the potential for a successful rescue and the offensive firefighting action is faster than rescue or evacuation.
- Probable exposure to non-involved facilities could significantly increase hazards if they became involved.
- When adequate resources (personnel, equipment and materials) are available within an acceptable time

frame to give a reasonable probability of safely extinguishing the fire.

An offensive strategy should be the first option considered whenever adequate resources are present and there is a reasonable chance of successful fire extinguishment. Examples of situations where an offensive strategy is typically employed are vent fires, ground fires, rim seal fires, and unobstructed full liquid surface fires in small to medium size tanks.

6.7 TANK-SPECIFIC PLANNING

6.7.1 Tank-Specific Planning—Overview

An initial survey such as described in 6.1.1 can identify tanks at the facility which may be most susceptible to fires. The type of information described in 6.4 can help identify the types of fire each tank potentially might experience. The tank-specific planning process uses this information to characterize fire suppression needs, based on the hazards associated with each tank (or group of similar tanks) and the facility fire suppression philosophy. Some facilities integrate this planning into emergency response training or assign an employee task force to perform this task.

A portion of the needed tank-specific planning information typically exists in environmental inventory databases. The “Tank-specific Pre-Incident Contingency Planning Sheet” (Figure 3b) provides an example of the types of information needed. It also serves as a guide to sections of this publication which may be helpful in completing the survey. The specific planning includes methods and fire suppression agents (foam type) needed to extinguish a tank fire. This in turn depends on the product involved (light or heavy hydrocarbon, polar or reactive liquid—see 6.3.2) the construction of the tank roof (see Appendices E and F) and any special hazards which may be involved (see Appendix G). Application methods in terms of roof construction and product types are covered in 6.7.2 through 6.7.8. Tank-specific planning should address whether more than one scenario needs to be considered. For each scenario, the planning sheet should indicate the type of foam to be used and should calculate and record the flow rate of water and total quantity of foam concentrate required for the application method chosen. This should be based on the minimum quantities recommended in NFPA 11 or alternate values chosen in the planning phase. This is a significant planning value since before foam is applied to a tank during suppression this minimum quantity should be available on-site. Assurance of delivery of off-site material is sometimes included, but increases the risk of running out of foam. Since the NFPA 11 values are “minimum” quantities, consideration should be given to a situation where more than the minimum may be required. Where necessary, the length of hose lays and access required for specific tanks should be reviewed.

6.7.2 Fixed Roof Tank Fire Suppression Planning

Fixed roof (cone roof) tanks may be subject to vent fires (6.4.2), unobstructed full surface fires where the roof has completely separated (6.4.4), or obstructed full surface fires with the roof partially intact or in the tank (6.4.5). Tank-specific planning should integrate the facility's generic fire fighting emergency response strategy into the needs for specific tanks, their contents, and the resources available.

Combustible liquids (for example, liquids with flash points greater than 100°F (38°C) such as diesel fuel) are materials typically stored in fixed roof tanks. However, liquids with lower flash points, including crude oils, polar solvents, and contaminated combustible liquids, may also be stored in fixed roof tanks.

If the vapor space between the liquid surface and the underside of the roof is in the explosive range when an ignition source is introduced, an explosion will occur. In a large tank, the roof normally separates from the tank shell resulting in a fire which involves the entire surface area of the tank. When the product involved is a light hydrocarbon (such as gasoline), there are two options for extinguishing the fire: top-side application or subsurface injection of foam. The roof may not separate completely resulting in partial obstruction of the tank surface.

Tank-specific planning for this type of tank should consider whether there is a boilover hazard (such as with crude oil).

6.7.3 Fire Suppression Planning for Vertical Fixed Roof Tanks without Frangible Roof Seams

Low pressure tanks such as those designed and constructed in accordance with API Std 620, are intended for operation with metal temperatures not exceeding 93°C (200°F) with pressures up to 15 psi (1 kg/cm²). Fires involving these tanks are often 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. Tank-specific planning should include consideration of this factor so that fire fighters can be alerted and injuries prevented. This becomes a particularly relevant consideration when tanks without frangible roof seams are impacted by another fire (especially if there is direct impingement such as from a ground fire).

Tanks with nonfrangible roofs or no emergency vents should be identified in the tank-specific prefire plan and on the tank in the field. In tank farms, vertical low-pressure fixed roof tanks without frangible roof seams are often close together. While this is in accordance with NFPA 30, it does make them especially vulnerable to pool fires. The fire-fighting principles and practices for such tanks are similar to those

in other sections of this publication, depending on the type of fire. However, access can be difficult because of proximity.

6.7.4 Horizontal Tank Fire Suppression Planning

Tank-specific planning for this type of tank should recognize that these tanks do not have a frangible seam. They require supplemental cooling if subject to flame impingement or high radiant heat loads. If venting is not sufficient to maintain low pressure, a vessel failure could forcibly propel the tank or pieces a considerable distance with inherent life-safety concerns for personnel in the area. If there is extended fire exposure of unwetted tank surface, and the tank does not vent sufficiently, there is potential for a BLEVE.

According to NFPA 11, "Fixed foam systems shall not be used to protect horizontal or pressure tanks". Tank-specific planning for horizontal fixed roof tanks should include fuel source isolation and cooling when necessary to maintain tank integrity. Cooling can be provided by directing hose streams at the point of flame impingement. Water spray from a fire hose "power cone" pattern can be used to cool areas affected by a heavy radiant heat load.

6.7.5 Bolted and Riveted Seam Tank Fire Suppression Planning

Bolted tanks can be a special fire hazard because they typically do not have frangible roofs and when a fire occurs the sealing between shell plates is dependent on rubber or elastomeric material which can melt (Figure E-4). Riveted tanks may or may not have a frangible roof depending on whether they were modified sometime in their lives. A retrofitted roof is often made frangible. Whether or not the roof is frangible should be documented in pre-fire plans. Information on how to evaluate roof frangibility can be found in API Std 650.

When a fire occurs in a bolted or riveted tank, fuel leaking from the seams may burn and run down the tank shell. If 3D fires involve light products, they can be extinguished with dry chemical; if leaking heavy material is involved in a 3D fire it may be quenched with water. It will be necessary to secure the area against reignition if leakage continues after extinguishment. Tanks initially built with no frangible roof seam have the potential to fail and leave their initial position with the same life-safety concerns as horizontal tanks. Protection for these tanks typically includes fuel source isolation. Tank-specific planning for bolted and riveted-seam tanks should include cooling when necessary to maintain tank integrity as well as identifying roof type (whether frangible or not).

6.7.6 Internal Floating-Roof Tank Fire Suppression Planning

Covered or internal floating-roof tanks are cone-roof tanks with a weak roof-to-shell joint and an internal floating roof or pan. Many are easily identified from the exterior by the vents

located around the tank shell, usually just beneath the roof joint. Some are vented on the roof, and others use both types of vent. Because of this venting, the space between the floating roof and the fixed roof normally should be free from an ignitable mixture. Ignitable mixtures can exist if there is a problem with the condition of the roof or seals, or during periods of initial fill and for 18–25 hours thereafter, depending on the volatility of the product. Although infrequent, there have been instances of fires in this type of tank, and such fires are extremely difficult to extinguish unless the tank is equipped with a semi-fixed or other permanently installed system. Seal or rim fires in a covered floating-roof tank are very difficult to fight with portable equipment. The side vents are too small to apply foam by using streams directed from ground level. It may be possible to direct foam through the side vents with special-purpose wand appliances if the vents can be reached safely; however, the vents may be covered with screens making access difficult. Some suppression experts suggest using plastic or fiberglass screening which will melt or burn away to provide access.

On some occasions, the fixed roofs have blown partially open or completely off. If a pan is still present, the entire liquid surface area will be involved when the pan sinks. In these instances, the fire should be treated as a full surface fire with a sunken roof section and extinguished by techniques discussed in 8.5.8 using foam chambers (if so equipped), monitor nozzles or other topside application. It should be noted that the sunken roofs will probably obstruct foam travel from subsurface systems; however, if other approaches fail, subsurface injection may be attempted and, in rare cases, has been successful. Some companies have installed Type II semi-fixed foam protection constructed in accordance with NFPA 11 to cover the total surface area of tanks which have internal roofs. At least one company has used projecting foam devices on large diameter internal floating roof tanks.

6.7.7 Open-Top Floating-Roof Tank Fire Suppression Planning

Most fires in open-top floating-roof tanks are confined to the annular rim seal area between the floating roof and the tank shell. Sections 6.4.3 and 8.5.6 discuss suppression of these fires, with further discussion in Appendix L. The success rate is very high for extinguishing seal fires on open-top floating roof tanks. Experience shows that these seal fires can burn for extended times (hours to days) with no escalation beyond the seals. Only modest resources are needed for tank seal suppression when compared to resources required for full surface fires. Tables 3 and 4 discussed in 6.7.9 compare two hypothetical cases illustrating the difference in minimum required resources for a seal fire and a full surface fire in a large tank.

For a fire where the roof is flooded with fuel or the roof has sunk, the fire suppression approach discussed in 6.4.4

and 6.4.5 for full surface fires with wholly or partially sunken roofs should be used. Large crude tanks are typically of floating-roof design.

Tank-specific planning for this type of tank should include review of techniques and equipment which will be used for extinguishing seal fires, and recognition that there is potential for a full surface fire. Should only a seal fire develop on a crude oil tank, no boilover will result. If excess firewater is used it could cause the roof to sink leading to a full surface fire, now entering the regime where a boilover is possible. By using a floating roof tank for boilover liquids the potential for a boilover is substantially reduced.

6.7.8 Domed External Floating-Roof Tank Fire Suppression Planning

Tank-specific planning for this type of tank should be the same as for other fixed or cone-roof internal floating roof tanks (6.4.3.2 and 6.7.6).

6.7.9 Large Tank Fire Suppression Planning

Table 3 shows the resources required for extinguishment of a hypothetical seal fire in a large open-top floating-roof tank containing hydrocarbon. Application density and duration are based on NFPA 11 minimum rates. Handline application requires 1.6 times the rate for a permanently attached system. The required foam concentrate supply for the seal fire case is within the range carried on many industrial foam pumpers.

Planning and preparation for a full surface fire in a large diameter tank should recognize the much greater resource demands. The example in Table 4 based on NFPA guidelines shows the minimum resources required for a fully involved fire in a 250 ft (75 m) diameter tank.

Extinguishment of full surface fires requires 50 to 100 times more foam concentrate than a seal fire. And, achieving suppression becomes more difficult as the diameter of the tank increases. The largest full surface tank fires known to have been extinguished have been in tanks of about 150 ft (45 m) in diameter. 100 ft is the generally accepted maximum distance that foam will flow on a burning surface under ideal conditions before water dropout is excessive and foam loses its fire-extinguishing ability. Many practitioners use 75 to 80 ft (23 to 25 m) as a maximum.

Therefore, conventional wisdom suggests that the largest cone-roof tank that should be protected with shell-mounted foam chambers is a maximum of 200 ft (60 m) in diameter. API Publ 2021A *Interim Study—Prevention and Suppression of Fires in Large Aboveground Atmospheric Storage Tanks* discusses three permanently installed system types for potential extinguishment of a fire in a tank over 200 ft in diameter.

The first is subsurface injection, which for full effectiveness requires appropriate piping to properly distribute the

Table 3—Example of Minimum Resources for Seal Fire Suppression in 250 ft Diameter Hydrocarbon Tank

Foam Application Location	Below the Seal or Weather Shield	Above the Seal
Width of annular area to be foamed	Assumes 8 in. (20 cm) from wall to edge of floating roof	Assumes 1.5 ft (0.5 m) from wall to foam dam
Application Density	0.50 g/min/ft ² (20 l/min-m ²)	0.30 g/min/ft ² (12 l/min-m ²)
Application Time, Minutes	10	20
Foam Solution Flow Rate	260 g/min (985 l/min)	355 g/min (1345 l/min)
Total Foam Concentrate Required at 3%	80 gal (300 l)	210 g (800 l)
Concentrate required for handline application	n.a.	335 g (1270 l)

foam. The second is semi-subsurface injection utilizing a buoyant hose at each “bottom of the tank” foam outlet to gently deliver the foam to the surface. The success of these subsurface approaches in tanks with floating roofs is problematic and these systems are not often installed. Subsurface injection for suppression of obstructed tank fires is not recommended except as a “last resort”. There have been a very few success stories reported where subsurface injection was used, and those were in smaller obstructed tanks. The third permanently attached system proposed (and installed on a few large tanks with internal floating roofs) uses “projecting foam applicators”. These tank shell mounted nozzles are intended to project foam onto the center of the burning fuel surface to spread to the edge, instead of foam chambers on the tank rim which are designed to spread toward the middle. However, there is no fire experience to document the effectiveness of the semi-subsurface or projecting nozzle approaches on large diameter tanks. One concern with any foam delivery apparatus attached to the rim of fixed roof tanks is the potential for damage during whatever incident leads to a full-surface fire.

Fire personnel have proposed that a combination approach for fires in tanks more than 200 ft in diameter could use shell-mounted foam chambers from the periphery and subsurface foam application for the center area. Expansion rate and inlet velocity are critical parameters for subsurface application to limit the amount of product entrained as foam rises through the fuel. Subsurface systems should be designed in accordance with NFPA 11.

Recent studies of successful tank fire extinguishments show that high-capacity foam monitors are effective on full surface fires either when several streams are concentrated in one area in the initial attack or when very large monitors are used. Both approaches allow the foam to quench the fire in a small area. This reduces the heat degradation and thermal updraft effect, and enables a foam blanket to establish itself on the surface and spread to cover and extinguish the rest of the burning surface. Several manufacturers offer very large foam monitors with flow capacity of 10,000g/min (40,000 l/min) or more. Fig-

ures 5 and 6 show the amount of water-foam solution and foam concentrate needed for full surface fires based on tank size, application rate and duration of the application. Appendix M addresses some basic hydraulics related to supplying water to tank fires and the benefits of large diameter hose. The preparation phase should determine the sources of foam and water and the personnel required to handle the physical movement of water and foam to the incident site.

6.7.10 Fire Suppression Planning for tanks with Special Considerations

6.7.10.1 Tanks Containing Materials with Boilover Potential

Special tactics and continuing surveillance are needed when fighting tank fires that involve crude oil (or other wide boiling range heavy petroleum oils) that can produce a boilover. It is important for the emergency response leaders to understand this behavior and be alert to this hazard not encountered with other fuels (see 8.3.2.i and Appendix G).

A *boilover* is the sudden overflow or ejection of the contents of a crude oil storage tank during a full surface fire. Boilover occurs only with tanks containing oils with a wide boiling range including both a heavy (high molecular weight) viscous fraction and light ends (e.g., like crude oil, but not like gasoline). It is caused by a heat wave (layer of very hot, heavy oil) reaching water or a water-oil emulsion such as normally found at the bottom of crude oil tanks. When the hot oil turns the water to steam the rapid expansion can send the tank contents a significant distance. In extreme cases, substantial amounts of burning liquids can be expelled creating a serious hazard for hundreds of feet surrounding the tank.

For boilover to occur a major full-surface fire must involve all or most of the surface of the liquid and the tank fire must burn for a long enough time for a hot layer to develop and then reach the water layer. The heat layer can continue moving toward the bottom of the tank after extinguishment if the top layers are hot enough (see Appendix D2.1).

Table 4—Example of Minimum Resources for Full Surface Fire Suppression in 250 ft diameter Hydrocarbon Tank

Resource Type (Minimum)	Method of Applying Foam to Tank	
	Subsurface Injection (with or without Foam Chambers)	Ground Monitors
Foam Application Rate	0.10 g/min/ft ² (4 l/min-m ²)	0.16 g/min/ft ² (6.5 l/min-m ²)
Foam Solution Flow Rate	4900 g/min (18,500 l/min)	7850 g/min (29,700 l/min)
Foam Concentrate Usage per minute at 3%	147 g/min (556 l/min)	235 g/min (890 l/min)
Minimum Number of 1000 ft (300 m) long 5" Hoses Required	5	8
Duration of Application Based on NFPA 11	55 min	65 min
Total Foam Concentrate Required at 3%	8085 gal (30,600l)	15,300 gal (57,910l)
Note: Values in Table 4 are based on foam concentrate proportioned at 3% and water brought 1000 ft to the incident site by hose. The flow rate of the method and equipment used will determine actual rates and water/foam flow facilities needed. This example does not include supplemental requirements for ground fires or exposure cooling.		

Boilovers are infrequent occurrences. When they do occur, it is usually in fixed roof or gas blanketed tanks storing crude oil. Other instances may involve internal floating roof tanks with aluminum or compartmented pans not meeting the requirements of API Std 650 Appendix C or H.

6.7.10.2 Oxygenates

Certain oxygenated materials have been widely used as gasoline additives for octane improvement and to satisfy environmental regulatory requirements. Although the two widely used oxygenate materials have been MTBE and ethanol, MTBE was being phased out of most gasoline in the USA starting in 1999. Other oxygenated materials have been used or proposed. Fire suppression concerns relate to physical properties, which vary widely among materials, including solubility of these oxygenates in water. Suppression efforts for fires in tanks containing these materials blended in gasoline are generally similar to approaches used for normal gasoline. Tanks holding only unblended oxygenates require special consideration. For instance, MTBE has low water solubility but high volatility while ethanol is less volatile but infinitely soluble in water. Where oxygenated materials are stored in high concentrations or as "neat" materials, the situation should be reviewed with the foam supplier. The proper foam concentrate and application rates should be confirmed and included in incident planning information.

6.7.10.3 Lead Alkyl Antiknocks

A historical concern at refining and gasoline blending locations had been the presence of lead alkyl antiknock compounds such as TEL in blending or storage tanks. In the USA, the phase-out of alkyl-lead in automotive gasoline became final on December 31, 1995. At that point it became unlawful for any person to sell, offer for sale, supply, offer for supply,

dispense, transport, or introduce into commerce, for use as fuel in on-road motor vehicles [40 CFR Part 80.22] fuel containing lead. Some active facilities may still exist for leading fuel off-road/aviation use. In other cases, out-of-service facilities may not have been removed. Lead antiknock use continues in some regions outside the USA. Appendix G provides information on hazards specific to these materials. Tank-specific planning for lead alkyl tanks should recognize the potential hazards for toxic products of combustion and the heat sensitivity of these compounds.

6.7.11 Drainage and Runoff

Consideration should be given to drainage and runoff of surface water resulting from fire suppression activities in an incident area. Controlling the amount of effluent flow and the direction of the flow are important considerations. This review should consider downstream vulnerability should hydrocarbon leave the site floating on effluent water. Both fire and environmental considerations are relevant.

The following information is helpful if obtained and documented before an incident:

- Availability of equipment to move dirt and other materials to build temporary diversion dams to direct effluent flow away from the incident area.
- Knowledge of the normal drainage, including direction of flow and collection points.
- A plan for controlling the flow of incident runoff. The plan should include holding areas and a means of treating and disposing of the collected runoff.
- A list of the appropriate authorities and organizations available to manage anticipated spills and cleanup.
- Knowledge of regulatory reporting requirements (see Appendix N.2.5.a).

6.8 FIRE SUPPRESSION AGENTS

6.8.1 General

Fire suppression is achieved by cooling, inhibiting vapor formation, eliminating oxygen or interfering with the free-radical chemistry of combustion (see Appendix H). The effectiveness and usefulness of various agents is a function of the type of fire and the fuel involved. The planning phase is the appropriate time to review the proper agents for each tank-specific scenario.

6.8.2 Water

Water is the ideal fire suppression agent as discussed in Appendix H.2 (although it cannot be used alone to extinguish flammable liquid pool fires); it absorbs heat very effectively thus inhibiting vapor formation. Steam generated by flame contact expands and tends to blanket and exclude air. Water is the primary ingredient in foam. The logistics of delivering sufficient quantities of water for a major tank fire can be challenging, as discussed in 7.4.3. Section 8.5.6 explains the need for using water carefully to avoid causing problems. Appendix M provides a brief review of hydraulics, explaining why there are significant benefits accompanying the use of large diameter hose (LDH).

6.8.3 Fire Fighting Foam

Fire fighting foam carries water to a burning fuel surface and makes it buoyant on a hydrocarbon surface, even with specific gravity less than 1. With good heat resistance, it keeps the water where it is needed and maximizes its effectiveness. Foam is the primary fire-suppression agent used to put out hydrocarbon fires by cooling, exclusion of oxygen and vapor inhibition. The expanded foam can be delivered to the burning surface by injection at the base of the tank from where it floats to the surface, by foam chambers permanently attached to the tank, by monitors permanently fixed to the periphery of the tank or by portable ground monitors. Current technology allows portable monitors to be built with the capacity to deliver volumes of expanded foam to a fire surface essentially limited only by the amount of water and foam concentrate available. Monitors commercially available from several sources have very large capacities, 4,000 g/min (15,000 l/min) to over 10,000 g/min (40,000 l/min) or more.

In choosing how to deliver expanded foam to a burning tank the potential impact of the method chosen and equipment available should be considered. Some portable systems have fixed delivery rates. If used for tanks smaller than intended this fixed rate will deliver foam at a rate significantly above the theoretical (calculated) amount for a specific density in that diameter tank. Using the higher foam application rate, NFPA 11 allows the specified time to be reduced proportionately, but not to less than 70% of the standard time. In such cases, the total amount of foam concentrate and water

flow required may increase and should be accommodated in the tank plan.

There are many types of foam concentrate. Choice of foam type depends on the fuel to which it will be applied and the application method used. Some varieties serve in multiple applications and others may only function effectively in specific fuel and delivery service. Technical consultation with the foam concentrate supplier is recommended to review the specific use.

Different types and brands of foam concentrates might not be compatible and should not be mixed in storage; however, most manufacturers agree with NFPA 11 that most different types of expanded foam generated separately can be put on the same fire in sequence or simultaneously. Some manufacturers suggest that in emergency situations similar foam concentrates from different manufacturers can be mixed together to provide an uninterrupted supply. Different opinions arise regarding the relative effectiveness of this mixed application versus maintaining only one type. In certain circumstances the simultaneous or sequential mixed option may be the only one available if application has begun and foam concentrate is in limited supply. Special consideration may be needed if one or more of the foam concentrates is specifically designated as an alcohol resistant type. Consultation with foam suppliers is recommended for their view on when they consider mixing foam acceptable.

6.8.4 Dry Chemical Fire Suppressants

Dry chemicals are highly efficient in extinguishing fires involving flammable liquids, but dry chemicals do not secure fuel against reignition if exposed to ignition sources such as metal heated by the fire. Dry chemicals have been used successfully, either alone or in combination with foam, to extinguish fires in the seal areas of floating-roof tanks.

Dry chemical suppressants are available that contain additives to produce free flow and water repellency. Certain varieties are compatible with concurrent foam application as dual extinguishing agents. Specialized dual-agent foam nozzles are available which are constructed so that dry chemical can be applied with (and carried by) the foam stream. The foam and dry chemical must be compatible.

7 Preparation for Tank Fire Suppression

7.1 GENERAL PREPARATION

The preparation stage for tank fire suppression is a more intensive form of planning. It involves reviewing the planning information and systematically identifying resource needs and whether they already exist on-site. If not, it determines how they will be obtained in time of need. This process should recognize that some resources require significant calendar time to put in place. Examples are development of an incident management system, per-