Management of Atmospheric Storage Tank Fires

API RECOMMENDED PRACTICE 2021
FOURTH EDITION, MAY 2001

American Petroleum Institute

Helping You Get The Job Done Right.SM

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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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CONTENTS

CONTENTS

Page

Tables

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

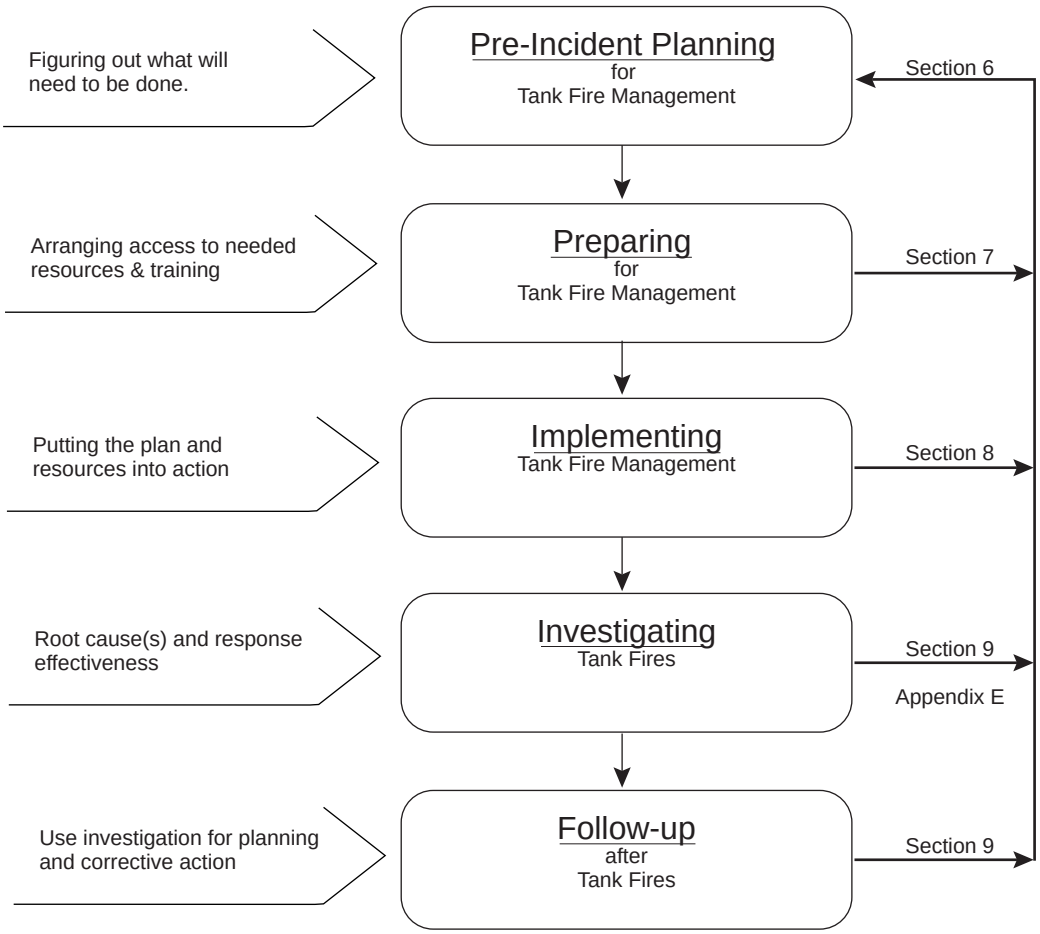

Figure 1—Overview of Management of Atmospheric Storage Tank Fires

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*
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

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

Guidelines for Technical Planning for On-Site Emergencies
Guidelines for Investigating Chemical Process Incidents

ANSI[2]
B31.3 *Chemical Plant and Petroleum Refinery Piping*

ASTM[3]
D 323 *Standard Method of Test for Vapor Pressure of Petroleum Products (Reid Method)*

Bureau of Mines[4]
Bull. 503 *Limits of Flammability of Gases and Vapors*
Bull. 627 *Flammability Characteristics of Combustible Gases and Vapors*

NFPA[5]
Fire Protection Handbook
Flammable and Combustible Liquids Code Handbook
10 *Portable Fire Extinguishers*
11 *Low-Expansion Foam*
11A *Medium and High-Expansion Foam Systems*
11C *Mobile Foam Apparatus*
12A *Halon 1301Fire Extinguishing Systems*
15 *Water Spray Fixed Systems for Fire Protection*
17 *Dry Chemical Extinguishing Systems*
20 *Installation of Centrifugal Fire Pumps*
22 *Water Tanks for Private Fire Protection*
24 *Installation of Private Fire Service Mains and Their Appurtenances*
25 *Inspection, Testing and Maintenance of Water-Based Fire Protection Systems*
30 *Flammable and Combustible Liquids Code*
58 *LP-Gas Code*
77 *Static Electricity*
291 *Fire Flow Testing and Marking of Hydrants*
325 *Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*
600 *Industrial Fire Brigades*
704 *Identification of Hazards of Materials for Emergency Response*
780 *Installation of Lightning Protection Systems*
1081 *Industrial Fire Brigade Member Professional Qualifications*
1561 *Fire Department Incident Management System*
1962 *Care, Use and Service Testing of Fire Hose, Including Couplings and Nozzles*
1971 *Standard on Protective Ensemble for Structural Fire Fighting*
2001 *Clean Agent Fire Extinguishing Systems*

OSHA[6]
1910.38 *Employee Emergency Plans and Fire Prevention Plans*
1910.119 *Process Safety Management of Highly Hazardous Chemicals*
1910.120 *Hazardous Waste Operations and Emergency Response*
1910.132 *Personal Protective Equipment*
1910.156 *Subpart L—Fire Brigades*

[2]American National Standards Institute, 1430 Broadway, New York, New York 10018. www.ansi.org
[3]American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103. www.astm.org
[4]U.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
[5]National Fire Protection Association, Batterymarch Park, Quincy, Massachusetts 02269. www.nfpa.org
[6]Occupational Safety and Health Administration, US Department of Labor, Washington D.C. 20402. www.osha.gov

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.

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 potential 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.

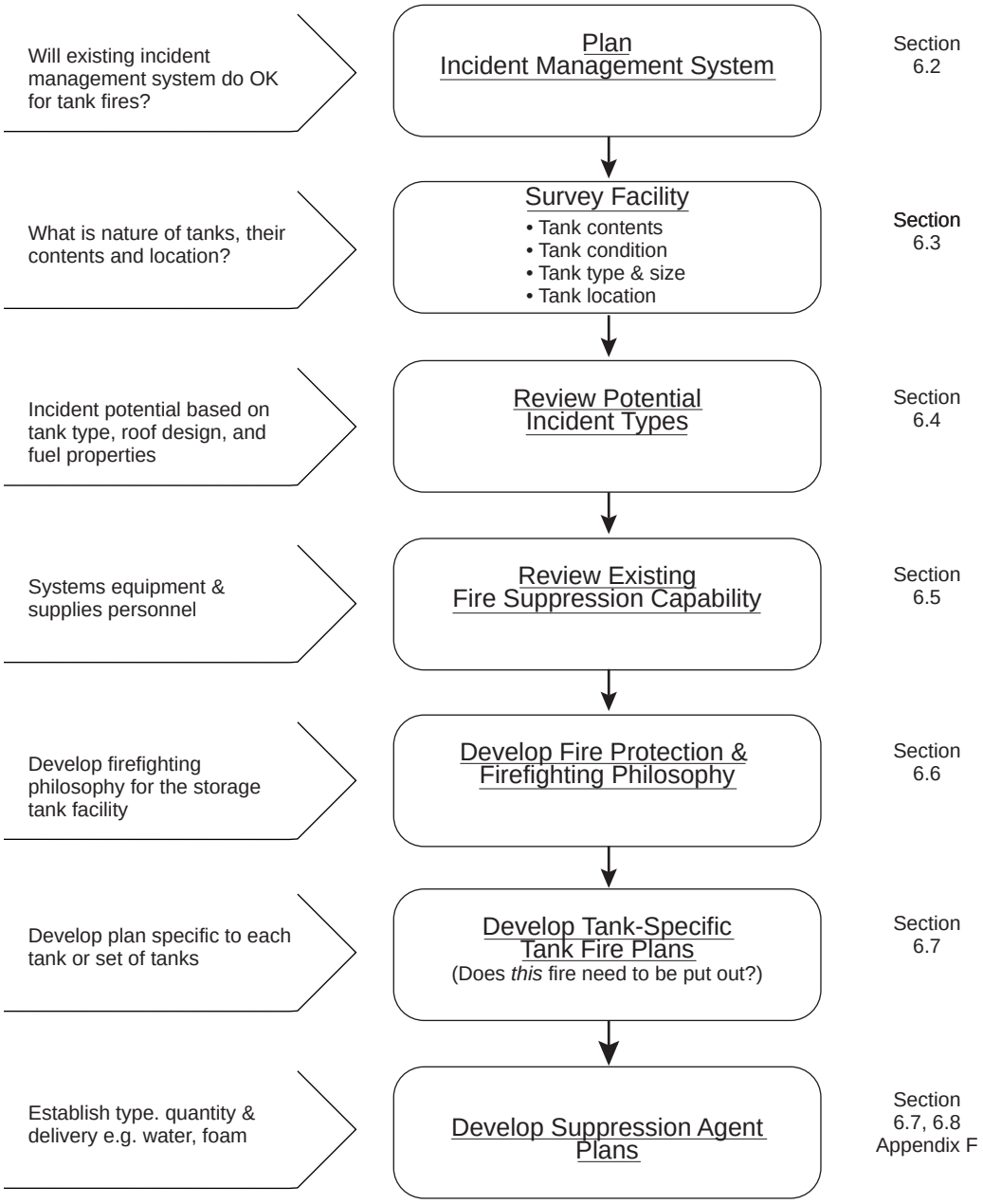

Figure 2—Planning for Storage Tank Fire Management

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) Ethanol (ethyl alcohol)	FP =52°F; 11°C BP =147°F;64°C FP = 54°F;12°C BP =174 °F; 79°C	Low flash point, High volatility, Wide flammable range	Water solubility, Low luminescence flames
Refining chemicals eg. “spent” acid (H_2SO_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: topside 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/cm^2). 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. Figures 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 G.2.1).

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-

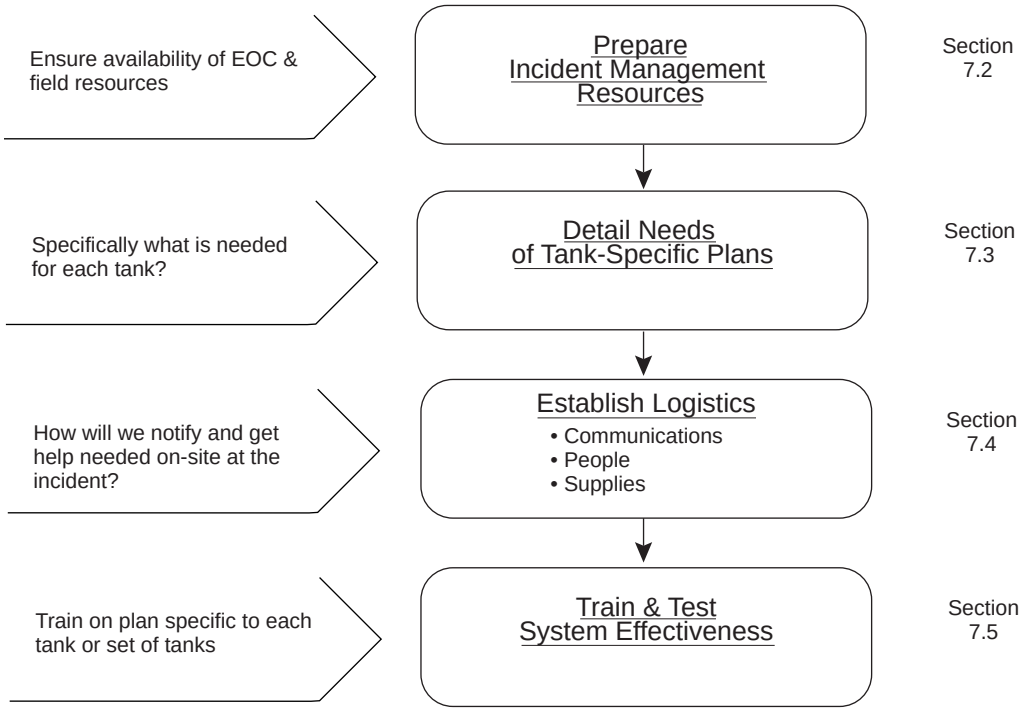

Figure 4—Preparation for Tank Fire Suppression

sonnel training, communication systems and (if necessary) upgrading systems to improve the ability to deliver firewater in the needed quantities.

7.2 PREPARATION OF INCIDENT MANAGEMENT RESOURCES

Most modern emergency management systems utilize an Emergency Operations Center (EOC) with facilities for communication and management oversight of all issues related to an incident. Normally the Incident Commander carries the delegated responsibility for developing an operational plan to mitigate the problem and to execute that plan. (The guidance and resources in this RP can help a facility prepare plans for tank fire incidents.) The emergency operation center's principle focus is on issues external to the emergency scene. These extend beyond fire fighting to include interface with the community, regulatory authorities, media and company management, as well as addressing facility operations or personnel issues impacted by the incident response while providing logistical services. In some cases the EOC is located in conjunction with the incident command post, but in many systems the EOC is deliberately located separately to reduce the potential for diversion of attention from the fire. A media center is often utilized and located apart from both the EOC and the incident command post.

Facilities for a field incident command or fire suppression operations post should be identified and availability confirmed. This may be a mobile center using resources from the facility, mutual aid or public fire department or may utilize dedicated facilities. Command staff should have access to local and wide area communications. Telephone and power outages should be anticipated, especially if the incident is weather related.

As part of their incident management resources, personnel working in the various elements of the incident management system should have access to information such as tank-specific contingency planning sheets (6.3), an incident command data sheet (Appendix C), an incident documentation data sheet (Appendix D) along with maps, standard operating procedures and relevant material safety data sheets.

7.3 TANK-SPECIFIC PREPARATION

The preparation phase can use tank-specific planning sheets (Figures 3a and 3b), and plans based on information in Section 6, to ensure that a plan is in place for each tank or group of similar tanks, and that the resources needed to implement the plan will be available. Where tanks are similar in design, location and stored contents they can be grouped for certain elements of the suppression preparation purposes. The key element of the tank-specific preparation stage is availability of resources at the time needed.

These include:

- Sufficient water for the most demanding tank fire scenarios.

- Confirmed access to sufficient supplies of the proper foam concentrate.
- Identified sources for foam delivery appliances.
- Identification of primary and alternate personnel with the knowledge and ability to implement the plan.

In many cases, not all of these resources will be on-site. The preparation phase should determine how much time it will take to access whatever resources will be used, including alternate sources and inconvenient timing (such as holidays, weekends or storms). For most facilities, an emergency response plan that considers the most demanding fire incident in a single tank is appropriate; however, at some facilities, multiple fire scenarios should be included based on facility design or as the result of a risk analysis. The resources and infrastructure needed to meet these demands should be considered as separate scenarios.

Time sensitive cases are cone-roof tanks with boilover potential (such as crude oil), heat sensitive materials and ground or diked pool fires (if they could lead to escalation involving multiple tanks or threaten vital facilities).

Advanced preparation can include mock incident drills as part of ongoing operations personnel "red tag" drills, emergency crew drills, mutual aid training or dialogue with public fire departments.

7.4 LOGISTICS PREPARATION FOR FIRE SUPPRESSION

7.4.1 General Logistics Needs

Logistics related to major tank fires are described in the following sections. Issues not specifically addressed relate to the potential for the involvement of many people and much equipment. Human needs for food, drinking water, rest, hygiene, communication and potential medical attention can be significant. If many resources (like fire trucks and foam tenders) respond there may be concerns with parking space and timely access to the fire site. Major prolonged incidents establish staging areas to assist with some of these needs. The Incident Command System includes logistics as a key function.

7.4.2 Communications Support

Command and incident response staff should have access to local and wide area communications using radios and wired or wireless telephones. Contingency plans should recognize the potential for power outage concurrent with an emergency incident interrupting telephone service (see Appendix N.3.3). Response personnel may have valid business or personal need to communicate with off-site personnel not associated with the incident and facilities should be considered to meet these needs.

7.4.3 Water (Including Pumping Capacity and Delivery to Tank Fire Site)

Since water is the primary resource required for generation of foam, key questions are, "How will water be brought to the tank fire at the required rate and duration?", and "Where will the water drain and accumulate?".

7.4.3.1 Water Supply to the Site

Options for getting water to a potential fire site include permanent piping through a facility firewater system and hydrants, or supplemental hose systems from a variety of temporary sources. Since tank storage areas often are remote from main facilities and system firewater pumps the preparation phase should evaluate the actual flow capacity and pressure available. The goal is to quantify the total water flow available, in gallons per minute (or liters per minute) and at what pressure. Both stationary and portable pumps (if available) should be considered. The source of power for the pumps should be identified and recorded, and whether they are automatic or manual start. For electric pumps, a review of power reliability should be considered along with the presence or absence of a backup pump or system. Similar review of steam pumps should be conducted. Supplies of diesel fuel and back-up starting batteries should be available.

Many facilities use computer modeling of firewater systems supported by flow testing to confirm the computer results. If use of hose lines is envisioned then review of hydraulics, pumping sources and access to sufficient quantities of large diameter hose (with compatible hose connections) should be established. The water source should be determined along with sufficient reserve to provide the proper flow rate for the required duration of foam application.

Finally, consideration should be given to the issue of "What happens to runoff of firewater?". Environmental, operational and regulatory aspects should be reviewed and integrated into the emergency response plan.

7.4.3.2 Water supply to application appliances

Once the water reaches the fire site, it needs to be distributed to the application devices. If these are not hard-piped then hoses are used. Large quantities of water may be required (such as for high-flow ground monitors). The preparation phase should not only consider access to sufficient quantities of hose but also evaluate the number of personnel needed to lay hoses, the time required for each hose lay, and the geographic constraints. Careful planning and execution may be required to lay multiple large diameter hoses along a road while maintaining the usability of the road. The time needed for each subsequent hose lay typically rises due to increased congestion.

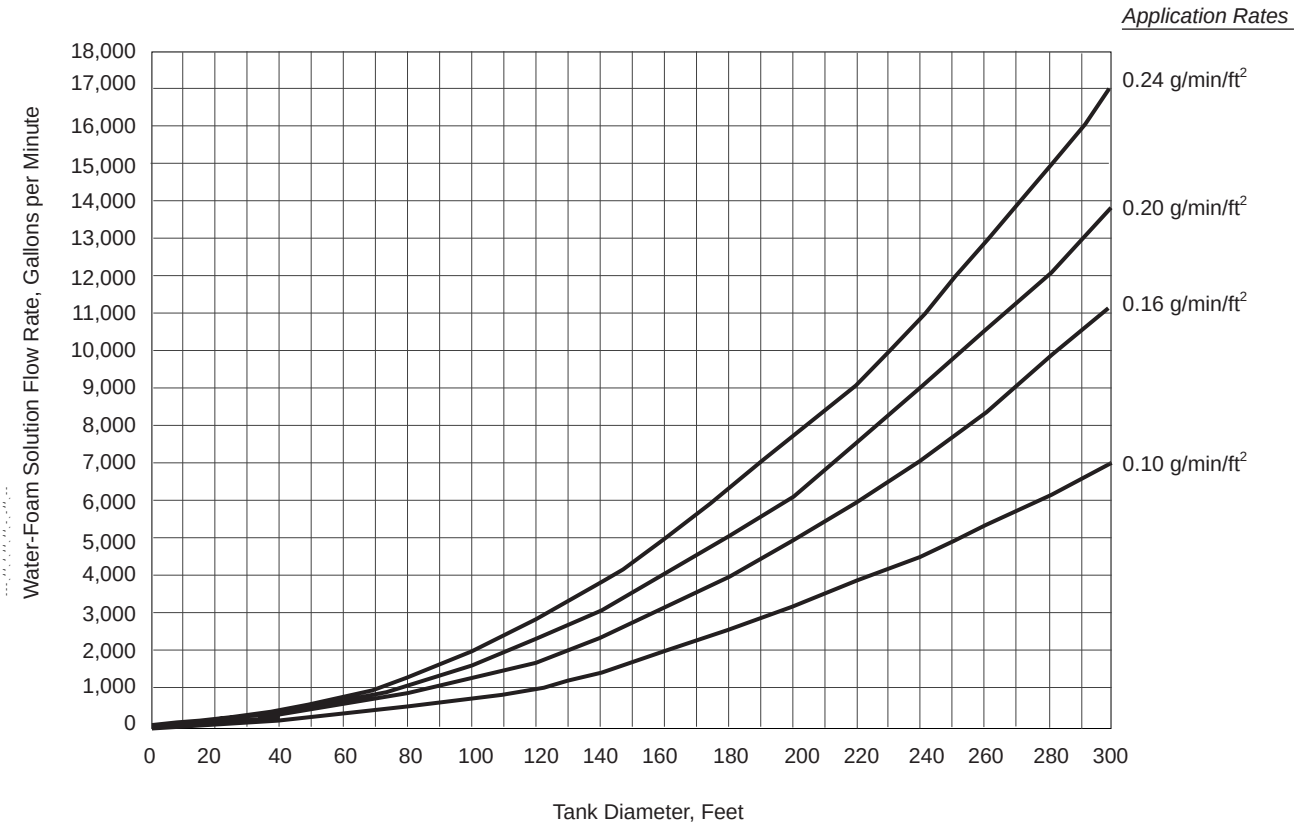

Figure 5—Water-Foam Solution Flow Requirement for Full Surface Fire, gallons/minute at Varied Application Rates (in g/min/ft^2)

7.4.4 Foam Concentrate

Each tank-specific plan should identify how much of what type of foam will be required for the appropriate application rate and time. Actual (not theoretical) application rates should be used. The amount of foam solution being applied as determined from calculation or from Figure 5 can be used with Figure 6 to see how much foam concentrate will be required for each ten minutes of foam.

Based on NFPA 11 the application time will range from 10 minutes for certain permanently attached systems for seal fires to 65 minutes for monitors or handlines. Pre-incident preparation should establish where the foam concentrate will come from (on-site, mutual aid, manufacturers storage). If material is in on-site long-term storage then there should be an established system for periodic evaluation of foam quality.

7.4.5 Foam Delivery Proportioning and Application

The tank-specific planning phase determined the preferred method of addressing the tank fire; this included the question "How will the fire suppression agent (water/foam or other) get onto the fire?". Figures 7 through 10 illustrate a variety of permanently attached and portable equipment used for foam delivery. The preparation phase reviews the ability of the facility to implement that plan. The preparation phase should determine that the necessary equipment and personnel are, or can be, available within the time span required to put each plan in action. This holds for permanently attached systems (top-side delivery via foam chambers, or subsurface), application by fire suppression personnel for seal fires, or monitors over-the-top for full surface fires. This preparation step is particularly important where very large fixed roof crude oil tanks are involved, especially if planning includes aggressive suppression for full surface fires where boilover-potential material is on fire. In this case, time is a factor and the scale of both hardware and consumable resources (and the people to staff the action) is large.

If the preparation phase indicates a shortfall in available resources to fit the tank-specific plan then management should review either the plan or the mechanism for obtaining resources and make appropriate adjustments.

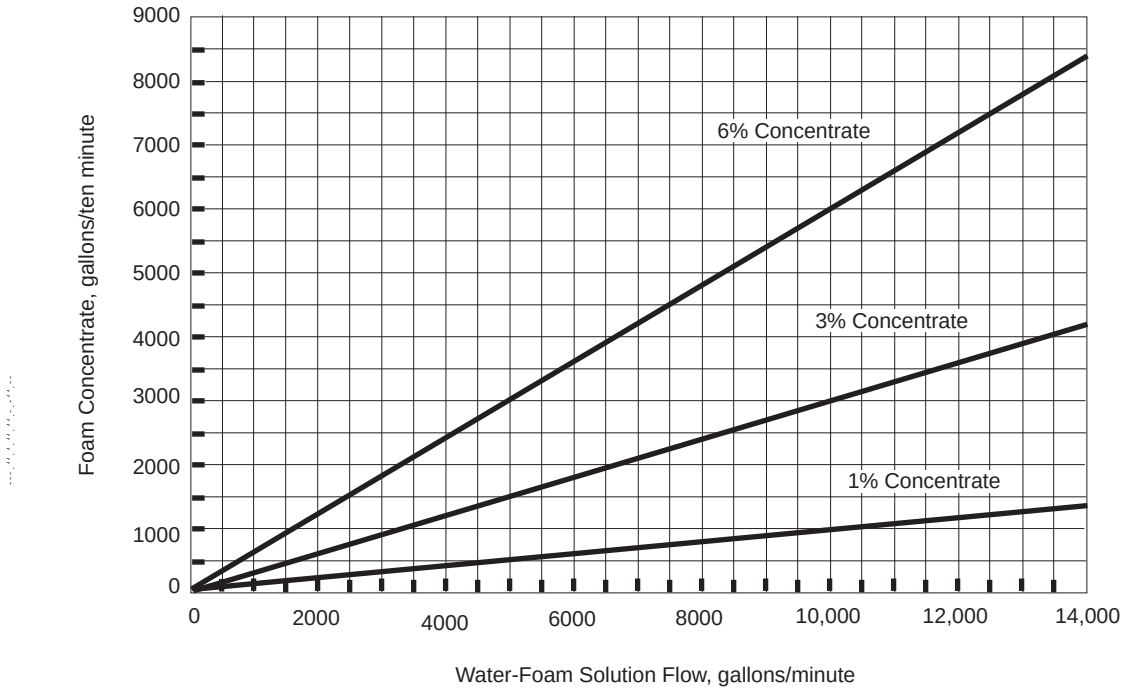

Figure 6—Gallons of Foam Concentrate Needed for Each Ten Minutes of Foam Application at 1%, 3% and 6% Concentrations.

7.4.6 Tank Access Preparation

A key review question in preparing access to tanks for fire fighting is "Is it possible to get fire suppression equipment to the site where it will be needed?". Access to tank areas should be assured by roads wide enough to permit passage of emergency vehicles. Both primary and alternate routes should be planned because it may be necessary to block certain roads in emergencies. Review of turning radii should ensure that the routes chosen have adequate space for mobile equipment to clear pipe supports and equipment. Roads through tank fields should be well drained and provided with sufficient turnouts so traffic can go both ways. Slightly elevated roads are preferred (and may be necessary) in areas subject to flooding.

Designated areas should be identified to position fire trucks, high capacity foam monitors, foam pumpers and foam tenders. Review should consider potential for wind shifting (and the unlikely effect of multiple tank incidents) on emergency operations. Management may choose to make physical modifications as part of a phased preparation program or preparation may involve identification of heavy equipment and operators for use in emergencies. Another option is stockpiling dirt so it is available to move with front-end loaders to build work areas at top-of-dike-level for large portable monitors or when access is required from multiple directions. Whenever possible, monitors should be situated so that they can deliver foam to the tank surface without the monitor being located within the diked area.

7.4.7 Personnel

Major tank fire incidents require many people. Staffing of logistics activities may involve many more personnel than actual on-site active fire fighters, especially if water supply to the tank will be by hose and mobile pumps or pumper relay. If foam is not available in bulk, the laborious handling of foam containers can require significant additional numbers of people. The support personnel required may outnumber the actual people involved in fire suppression by a factor of three to five. Skills needed may include pipefitters, electricians, heavy equipment operators and others as needed by the specific incident conditions.

The incident response plan should estimate how many people will be needed for the suppression strategy chosen, which specific skills or training are required, and from where they will come (on-site, call-out or mutual aid). Plans should include sufficient staffing to rotate people (tank fires can last a long time) and consider fire fighter "rehab" and medical care needs.

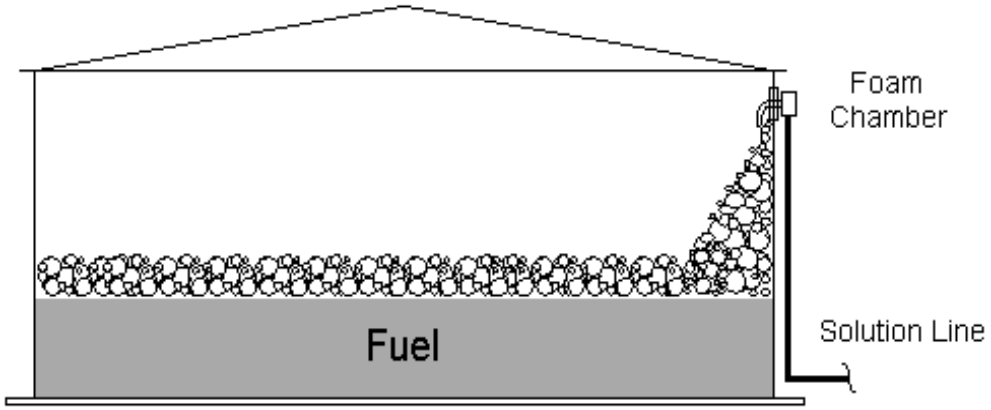

Figure 7—Permanently Attached Foam Chambers

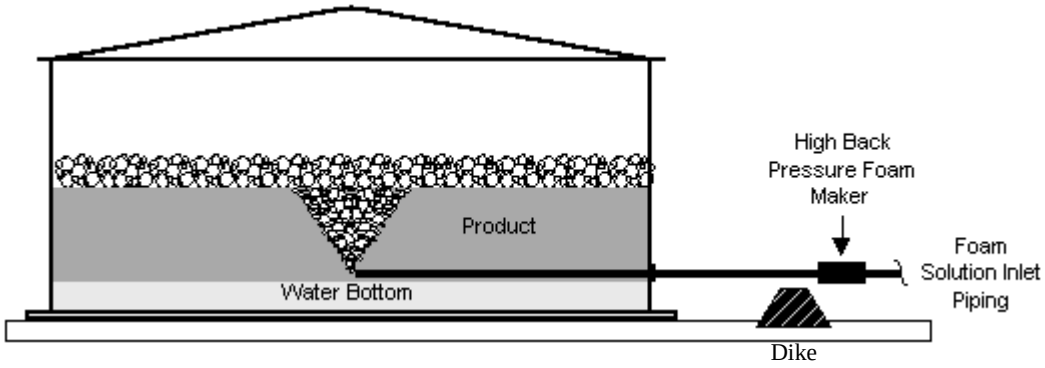

Figure 8—Subsurface Foam Injection

Key people may have to respond from off-site (including members of the fire-fighting squads, IC, EOC and support personnel). Issuance of special company identification is desirable in order to assist passage through roadblocks when proceeding to the facility during an emergency.

7.4.8 Notification Procedures

A notification system should be in place to contact personnel with emergency response duties. This includes those with incident command or emergency operations center roles. When a fire is reported, the procedure should include prompt notification of

- The facility fire fighting and emergency team personnel.
- Outside community or regulatory authorities requiring notification.
- Any outside mutual aid groups who may be called upon to provide equipment, supplies or personnel.

Consideration should be given to call-out of purchasing and warehouse personnel. Written procedures should be in place to establish sequence and priorities for notification depending upon incident needs.

In some facilities, arrangements are made for the fire or emergency calls to be received at constantly-attended locations, such as a laboratory, powerhouse, or main gate or remote coordination center. Special telephones are reserved for incoming emergency calls. A dedicated phone number is selected, and decals showing this number are attached to all facility phones.

The attendant receiving the emergency call initiates the alarm procedure. The attendant should be trained for the duty and be supplied in advance with the following:

- An emergency call-out list for key personnel, local public fire departments, ambulance services, and doctors. In some instances, an independent agency is used for handling this emergency call-out.
- A set of written notification scripts specific to incident type and personnel or agency being notified.
- An emergency communication system between the main office, the main gate, and other key locations. The location and nature of the emergency will be announced over this system.
- A method for recording all calls (e.g., logbook, tape recorder, etc.) and time of notification.

Figure 9—Three Monitors with Large to Very Large Flow Capacity

- Checklists to ensure that all notifications appropriate to the type of incident have been completed.

7.4.9 Traffic Control

Coordination with law enforcement agencies to establish procedures for emergency response incidents is beneficial. High visibility incidents can draw large numbers of spectators. Cooperation from the responsible police departments helps plan 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 if they become necessary, or provide a helicopter for an aerial view of the fire ground. Agreement on proper identification to enable quick passage through traffic control by emergency response personnel and key staff can help avoid delays in implementing on-site actions.

7.4.10 Mutual Aid

When working with supplemental fire-fighting groups, it is important to establish which personnel will be in charge of each aspect of the fire-fighting activity. If all mutual aid participants use the same or a compatible incident management system (ICS or IMS), then excellent functional tools will be available for this coordination. Where outside personnel have some jurisdiction, it is beneficial to arrange for a unified command approach before the occurrence of an incident.f

Participation in a mutual aid organization can be beneficial and cost effective for facilities with tank storage of flammable and combustible materials. Key questions during the preparation phase are: “What capability is available from mutual aid in terms of people, equipment (e.g. pumpers, large diameter

Figure 10—High Capacity Monitor

hose) and consumable resources (e.g. foam concentrate)?” and: “Is there capability to access other mutual aid organizations for very large incidents?”. For both questions a key consideration is: “How will this be accomplished?”. In reviewing mutual aid and outside assistance the facility management should determine what arrangements need to be made in advance of an incident, and enter into agreements as needed and appropriate. Dialogue within the mutual aid organization should review the compatibility of equipment from various participants and determine whether adapters will be needed to fully utilize available equipment. A compatibility review should place special emphasis on hose types and connections (sizes, threads and coupling types) in a review of the water delivery system from the source to each appliance to be used.

7.4.11 Third Party Arrangements

Some facilities do not have accessible resources on-site or through public fire departments or mutual aid groups sufficient to address a major (full surface) tank fire. In this situation, it may be appropriate or necessary to make advance arrangements with third party firms who specialize in tank fire suppression. If so, consideration should be given to facility surveys as part of the contract arrangement. Most major foam manufacturers can provide reference to firms in the business of contract tank fire suppression.

7.4.12 Resource Utilization, Tracking and Documentation

While incident command staff should monitor resources for incident management purposes, personnel representing the interests of the tank owner should also track and record the resources brought to the site and used. This applies especially to consumable materials such as foam concentrate. Materials may arrive from suppliers, mutual aid participants, or third party firms. At the end of the incident this information will be useful for critique and essential for cost accounting.

7.5 TRAINING

When reviewing emergency response training requirements in the context of tank fire suppression the key question is, "Do the people who are designated as responders have the training needed to satisfy both functional and regulatory compliance needs?". Training should be structured to develop an effective emergency response capability while also providing regulatory compliance. Personnel staffing the EOC should have ICS overview training as well as specific training relevant to their EOC assignments. Training should include testing the emergency plan.

Industrial firefighter selection and training are addressed in API RP 2001, NFPA 600 and NFPA 1081 with regulatory issues addressed in OSHA 1910.156 and 1910.120(q). Those personnel who will respond as firefighters to tank fire incidents should receive training specific to tank fires as well as their normal fire training; several foam concentrate suppliers offer tank fire training in conjunction with fire training schools. Responder training should include ICS training or education appropriate to their emergency response role (see Appendix C).

As noted before, suppression of a major tank fire is a resource intensive endeavor. Where possible, emergency plans should arrange to have supplemental assistance available from outside fire departments or mutual-aid groups. Hydrocarbon fire fighting, and especially tank fire fighting, is a specialized activity requiring experience and knowledge outside the scope normally found in public fire departments. Training of key personnel from those organizations should be made accessible where public department participation is part of the plan. Understanding of facility emergency management procedures is helpful. NFPA 1561 describes incident management in terms which are satisfied by ICS.

8 Implementing the Fire Suppression Process

8.1 GENERAL PROCESS FOR IMPLEMENTING FIRE SUPPRESSION

Tank fires are complex events. Fighting them requires implementation of plans (as described in Section 6 and Appendix D), preparation (Section 7) and proper utilization of resources coordinated by an effective emergency management organization (such as ICS). The following overview of the tank fire suppression process shown in Figure 11 presumes that the planning and preparation stages have been done. Experience shows that safe and successful fighting of tank fires can be achieved when based on this planning and preparation. In simplistic terms, when the plan is in place the suppression phase only requires implementing the plan. In the real world, workable and safe strategy and tactics are developed and implemented at the time of an incident, based on the plan, conditions encountered and implementation progress as monitored. If the plan is not achieving the desired results, the strategy and tactics should be changed accordingly.

The basic planning premise is that there will not be more than one concurrent tank fire. While infrequent, multiple tank fires do occur and pose more challenging logistical and coordination problems. Issues to be addressed include:

- Which tank fire should be attacked first?
- Are adequate resources available to extinguish all tanks?
- Are planned apparatus positions accessible and tenable?

Fires in tanks of large diameter (more than 100 ft) also pose significant challenges. Section 6.7.9 and API 2021A provide insights into these challenges. Because of the amount of foam concentrate and the high water flow rates required for full surface suppression efforts, large fires may require many hours to obtain and assemble the needed resources before aggressive emergency operations begin with actual application of foam. The resource demand includes the need for a large number of support personnel to manage, coordinate and deploy resources.

8.2 NOTIFYING AND ACTIVATING AN INCIDENT RESPONSE ORGANIZATION

The first step in activating an incident response organization is notification, using systems as described in 7.4.8. This is followed by establishment of an emergency operations center and then the Incident Command based on established written protocols as described in 6.2 and 7.2. Many facilities use these systems as normal practice to address even "minor" emergency situations. This provides practice and an opportu-

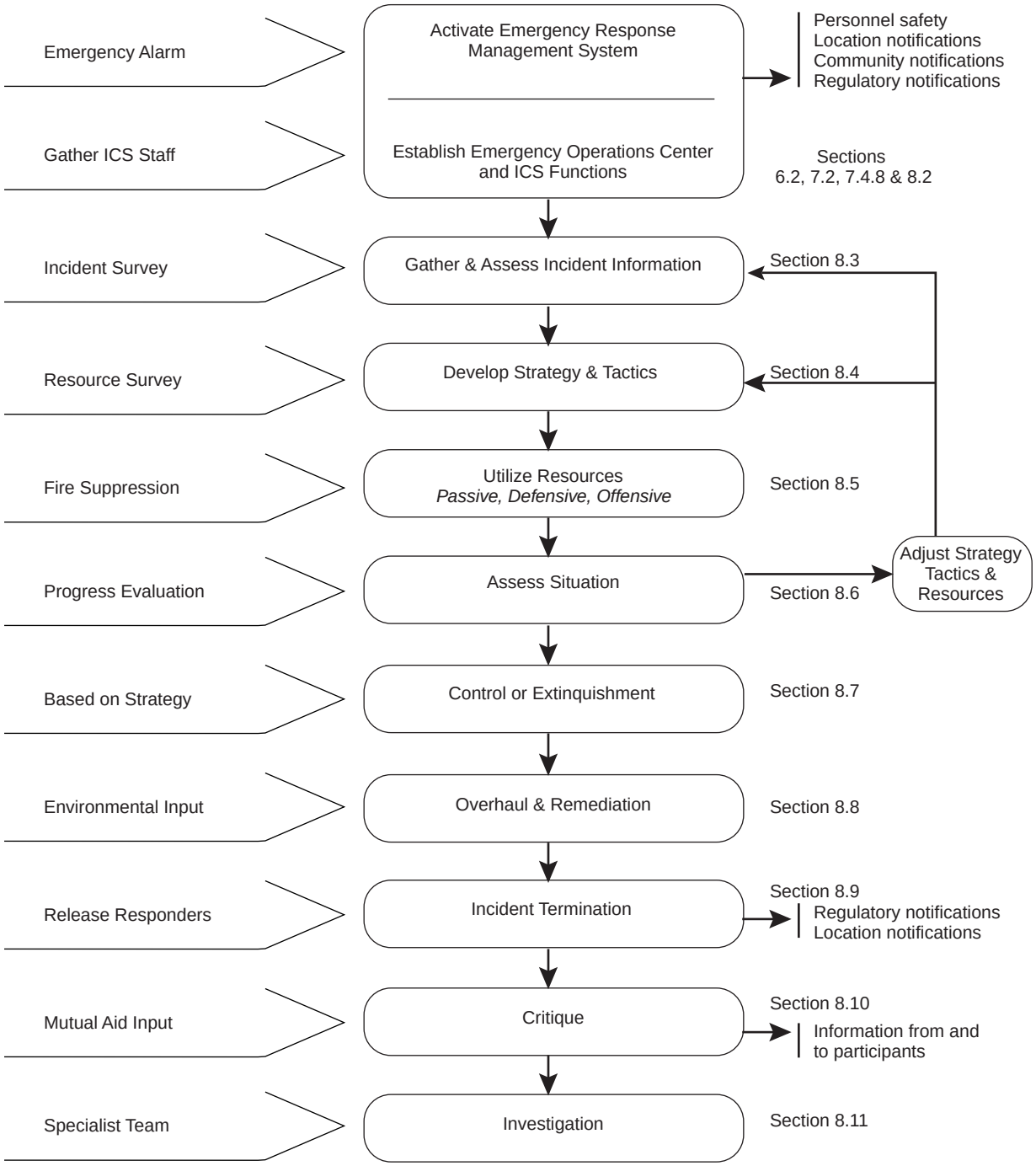

Figure 11—Implementing the Fire Suppression Management Process

nity to ensure that they will function as intended if need arises for a major incident response.

8.3 GATHERING AND ASSESSING INCIDENT INFORMATION

8.3.1 General

Incident-specific information gathered and analyzed during the course of a tank fire should be compared to existing plans for that tank or to generic tank fire suppression guidance. Assessment is a survey process gathering "real time" information related to the situation as an incident evolves. This ongoing assessment compares the status of fire suppression needs with resource availability to determine whether it is necessary to assemble and utilize more or different resources. The example incident command data sheet for petroleum storage tank facilities in Appendix C along with the tank-specific pre-incident contingency planning sheets (Figures 3a & 3b) provide examples of work aids which may be useful during size-up and situation assessment.

8.3.2 Assessing the Tank Fire Situation

An initial response action for an incident commander is to assess the situation. Information should be gathered quickly to develop an effective safe strategy to fight the fire. Some elements to consider are:

a. Social-economic factors
   - Rescue—the need for rescue of any trapped or injured people.
   - Life hazard—the potential need for on-site or off-site evacuation.
   - Environmental impact.
   - Impact on surrounding area.
   - Corporate impacts.

b. Situation assessment (size-up)
   Type of fire:
   - Vent fire.
   - Seal fire.
   - Piping-connection fire.
   - Seam fire.
   - Full involvement.
   - Overfill (spill) fire.
   - Combination (tank and dike) fire.
   - Multiple-tank fire.
   - Exposures—the probability or possibility of extension
   - Need for cooling water for metals exposed to flame.
   - Status of tank and dike valves.
   - Surface drainage.

c. Situation-types of tanks involved and their characteristics (tank-specific contingency planning sheets can help):
   - Pertinent data from the facility plan.
   - Whether the tanks have floating roofs (either open-top or internal).
   - Floating roof material, type, and inherent buoyancy.
   - Whether fixed roof tanks (with or without internal floating roofs) have weak roof seams.
   - Tank size and diameter.
   - Number and type of roof seals.

d. Situation—variable tank information
   - Position and condition of roof drain valves.
   - Volume of product in the tank.
   - Depth of water bottoms in tanks.
   - Condition of tank roof, shell, piping, and permanently attached fire suppression systems (intact, functional or damaged).
   - Product stored in the tank.
   - Boiling point of the contents.
   - Toxicity of the contents.
   - Possibility of boilover.

e. Situation— operational options or needs
   - Is it possible to pump out contents of tanks (for example, if extinguishment will be difficult)?
   - Can tank be pumped out without increasing hazards (if a crude oil tank with water bottoms)?

f. Need for coordinating emergency efforts with on-site operating personnel for efforts such as:
   - Shut fuel off (stop pumping into the tank).
   - Product transfer.
   - Pumping water into tank to displace fuel with water if there is leaking near the bottom of the tank.
   - Stopping product mixers because of their detrimental effect on the foam blanket (unless tank circulation can delay potential for boilover).

g. Response options and resources
   Fire-fighting resource availability, including the following:
   - Trained personnel.
   - Foam concentrate.
   - Water availability at the tank, including amount and pressure.
   - Foam proportioning and delivery equipment.
   - Vehicle access.

h. Weather conditions
   - Wind (can make foam application difficult and flame impingement more likely, affecting initial and subsequent placement of ground monitors and affecting smoke impact).
   - Rain (can interfere with foam blanket and create potential lightning hazards).
   - Temperature (Freezing complicates water supply, higher temperature generates more vapor; both stress personnel).

i. Evaluating pre-boilover phenomena
   - The time to reach boilover depends on the amount of material in the tank. Tanks holding wide boiling range materials (such as crude oil) should not be pumped out since pumping removes the buffer between the water

layer and hot heavy ends. While the rate of descent of the hot layer varies, as a first approximation it can be estimated to travel down from the burning fuel surface at the same rate at which fuel burns. Thus, the hot layer will be as far below the surface as the burning surface is below the original liquid level in the tank. From the original tank level, the descent of the heat wave is twice the rate of burning.

- In general, if foam cannot be applied successfully within 4 hours of the fire starting in a relatively full crude oil tank, then the incident commander should begin clearing the area within 10–15 tank diameters. All personnel not part of the fire fighting efforts should be removed.
- Appendix G.2.1 provides further guidance for evaluating the potential boilover status of the tank.

8.4 DEVELOPING INCIDENT-SPECIFIC STRATEGY AND TACTICS

Selection and implementation of strategy and tactics should be accomplished by the incident commander and the incident operations chief based on the facility tank fire suppression philosophy, pre-incident tank-specific plans and the assessment information from 8.3. Strategy relates to planning; tactics are the physical acts that accomplish the goals.

The three strategies discussed in 6.6 were:

A *passive* strategy involves no fire fighting activities; the fire will be allowed to burn out and the area evacuated if necessary for personnel safety.

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

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

The strategy for fighting tank fires should be developed in advance, as part of the facility emergency action plans (6.6 and 6.7). The tactics used at a tank fire should implement the strategic plan, including the site philosophy regarding pumping out tanks. In some cases, conditions present at the time of the fire (adverse weather, multiple tank involvement, extensive ground fires) will not be anticipated in the tank-specific plan. The incident operations chief can use the plan as the basis for developing a strategy and tactics applicable to the situation encountered.

8.5 RESOURCE ASSEMBLY AND UTILIZATION—FIGHTING THE FIRE

8.5.1 General

Resource assembly and utilization consists of staging, organizing, locating and using available fire fighting resources to achieve the strategic objectives set by the incident operations chief.

Adoption of the tank fire suppression guidelines presented should be based on applicable data from the facility to which they will be applied as well as information presented in this publication. No guideline can replace good fire-fighting judgment. Many variables are present in every emergency and sound on-the-spot judgment should be exercised in choosing a proper course of action.

Irrespective of the response approach taken the appropriate regulatory, community and corporate emergency notifications should be made.

8.5.2 Passive Tactics

The tactics associated with the passive strategy (6.6) consist of:

- Evacuating all personnel from the impact area of the fire (or a boilover or explosion if a boilover or unstable liquid is involved).
- Taking any loss reduction efforts, such as pumping down the involved tank, that can be executed without risking personnel. The temperature of the fuel that is considered for “pumping down” should be measured. Care should be exercised to ensure that hot oil is not put into a tank in which it will cause a hazard. Using tank mixers in tanks not on fire can help avoid localized hot spots.

Passive tactics should be considered if fighting a fire would jeopardize personnel unjustifiably. The following are examples of situations that dictate a passive strategy:

- Not enough personnel and materials are available for a safe and complete extinguishment attempt.
- Pumping out the tank is a viable option to reduce the time the tank will burn.
- There is imminent danger of a boilover, tank failure, or other life-threatening occurrence, dictating immediate evacuation of the area.

Without fire suppression mitigation, a boilover should be expected for full surface fires in crude oil tanks. For seal fires, neither boilover nor escalation would be expected.

8.5.3 Defensive Tactics

Defensive tactics might be chosen when there is little chance of extinguishing a tank fire but the area will not have to be evacuated. The fire fighters remain and take action to confine the fire within the tank and minimize exposure damage. Defensive strategy is appropriate when intervention cannot immediately and safely influence the outcome of the incident. If additional resources become available, the strategy could shift to an offensive one. Priorities for defensive action are protection of personnel, protection of exposed equipment and avoidance of excessive water runoff along with other measures to protect the environment.

Factors to be considered when using defensive tactics include:

- Whether the incident can be contained with available resources without jeopardy to life or further jeopardy to property. Can a controlled burn be maintained while minimizing losses by actions such as pumping down the tank.

  Pumping down the level in a crude oil tank may be inadvisable; it shortens the time for a hot layer to reach water bottoms, but reduces the amount of material which might be expelled from the tank. The same temperature precautions noted in 8.5.2 should be observed if transferring product.
- Flame impingement on adjacent tanks. This situation may require immediate action to prevent the involvement of additional tanks. Protective cooling streams and transfer of products to safe tanks should be considered.
- Product characteristics, product levels, and levels of water bottoms. These data should be readily available.
- Times until the potential occurrence of adverse events should be estimated if boilover or vessel rupture are potential hazards. In these cases a phased evacuation to a safe area, according to the emergency plans, should be considered. (Large-diameter tanks with boilover potential may require pulling back 2000 ft or more from the incident.)
- The status of all tank-roof drain valves. In most situations these valves should be kept open to allow firewater to drain and minimize the potential for sinking a floating roof.
- The status of all dike valves. In most situations these valves should be closed to localize the incident.
- The status of product-transfer or isolation valves should be determined.
- Heat load on nearby tankage, equipment or structures should be evaluated. Heating by radiant heat is slower than the combined radiant and convective heat from impingement, but can lead to vapor release from adjacent tanks which might ignite and cause escalation. Tankage downwind can receive convective heating at a less severe level than impingement.
- Whether the scope of the incident justifies the risk associated with an aggressive attack.
- Whether the facility uses a loss control philosophy which accepts a controlled burn, in which exposures are protected and losses are minimized.
- Mutual aid availability. Requesting mutual aid should be considered if there is potential to access additional resources and shift the strategy to an offensive one.

Examples of defensive tactics include the following:

- Preserve the integrity of permanently attached fire-fighting systems by cooling the tank's foam lines and chambers, sprinkler or water spray systems, and fire isolation valves until attempts can be made to extinguish or control the fire.
- Test exposures with a "hose stream heat test". If water from a hose stream does not "steam" no further cooling is normally needed (but the area should be checked periodically to verify the heat load on the vessel or structure while concerns persist). Since liquid acts as a heat sink the greatest concerns involve flame impingement above the liquid level on any tanks. Consideration should be given to the nature of the tank contents: volatile materials can generate significant quantities of vapor at tank shell temperatures below 212°F and some sensitive materials may experience heat-initiated reactions.
- Cool flame impingement areas 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. Use portable water streams or permanently installed cooling water systems where available. Apply supplemental water application from hose streams or monitors directly to the point of flame impingement (at ca 250 to 500 g/min) to cool the area and prevent localized failure. Vessel failure resulting in a BLEVE has been documented to occur in as little as 10 minutes. Cool areas of direct flame impingement on vessels that may be caused by flames from pressure-relieving devices. Cooling of the vessel may reduce the pressure enough to permit the PRV to close.

  2. If pressure fires are not impinging, they normally should be *extinguished by blocking in the fuel at the source*. Extinguishment of the fire while the leak is still releasing fuel under pressure can lead to the formation of a vapor cloud and subsequent ignition.

  3. *Exposed atmospheric tanks*. Protect by cooling the roof and the tank shell above the liquid level if a "hose stream heat test" indicates the metal temperature is above the boiling point of water. Roof valves on floating roof tanks should remain open to avoid sinking the roof with firewater. High priority should include cooling the area of flame impingement above the liquid level on horizontal tanks (which do not have frangible seams).

  4. *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 can fail, resulting in the release of more fuel to the fire. Cooling of these areas should be coordinated with extinguishment efforts. Product pipeline valves have high priority for protection 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.

5. *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.

- Use appropriate tactics for radiant heat. Evaluate non-impinging radiant heat exposure using the "hose stream heat test". Experience shows that water walls and water curtains should not be used for radiant heat exposure 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 generally is not a high priority. Periodic application of cooling water from hand lines to the exposed area is usually sufficient to supply protection.

8.5.4 Offensive Tactics

Offensive tactics (attack techniques) are generally used when adequate resources (personnel and materials) are available. They include attacking the fire, removing the fuel source (e.g. pumping out), and other actions intended to put out the fire completely. Fire-fighting personnel should be familiar with the equipment, agents, and procedures. Successful suppression of the fire requires effective delivery of the proper extinguishing agent (foam type) at recognized application rates for the required duration.

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

- Sufficient supplies and equipment should be available to apply foam at the recommended rates for the specified time duration. (If foam is applied at rates below those recommended the potential for fire extinguishment is low with a high probability of simply wasting the foam.)
- Weather conditions should permit extinguishment. (Wind and rain can destroy foam blankets and limit the reach of fire streams.)
- When foam is applied to a hot burning viscous liquid (for example, an asphalt fire), a slopover should be expected and contingency plans made (see appendix G).
- If a wide boiling range liquid has experienced prolonged burning and if a heat wave has established then significantly higher (twice or more) foam application rates may be necessary (see Figure K-1 and NFPA 11).

When there is a dike fire as well as a tank fire, typically the dike fire should be extinguished before extinguishment of the tank fire is attempted.

CAUTION: Personnel should avoid walking in a foam blanket covering fuel. If the foam blanket is disrupted, reignition can occur and result in injury.

- When there are multiple tank fires, the first priority should be to extinguish fires that pose the greatest hazards to life or property (for example, one creating impingement which could cause a potential BLEVE) or those that can most easily be extinguished (for example, the smallest).
- During the application of fire-fighting agents, the effectiveness of the attack should be monitored so that it may be altered, if needed.
- 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 specified in NFPA 11, this change should occur within 20 to 30 min.
- When fighting seal fires, extreme care should be exercised not to overload and sink the roof with the weight of foam and water. Hand lines are preferred over ground monitors as the method of foam application for rim seal fires.

For most incidents there are several offensive tactical approaches that can lead to a safe, effective extinguishment as discussed in the following sections.

8.5.5 Tank Vent Fires

Fires at the vents of fixed roof tanks can be extinguished with low risk to personnel and minimal resultant damage if addressed properly. The general design principle for pressure and vacuum vents is to fail open in case of failure of any component (but that is not mandatory for low pressure vessels). Assuming that the majority of vents will fail in the "open" mode in case of fire, this means that if a Teflon seat or other heat-sensitive part fails due to exposure to fire, the valve can continue to vent products and therefore remain a fuel source.

The following provides guidance for evaluation and suppression:

8.5.5.1 Vent Fire with Yellow-Orange Flame and 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 "fuel rich" (e.g. above its flammable or explosive limits). This type of fire may be extinguished with dry chemical fire extinguishers.

8.5.5.2 Vent Fire with 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.

This type of fire can be handled in one of the two following ways if other methods prove to be ineffective:

- In many cases a pressure reduction in the tank (caused by cooling) can 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 is pressurizing the tank, a pressure reduction can be obtained by stopping movement into the tank or pumping material out of the tank. As there is no guarantee the vent will close "bubble tight" there may be vapor leakage and a need to follow-up with a hose or dry chemical.
- A positive pressure is maintained in the tank by introducing fuel gas. When a fuel-rich condition is indicated by change of flame character (see 8.5.5.1), extinguishment may be accomplished with dry chemical.

Following any vent fire, vents should be inspected, refurbished or replaced as needed. Personnel reviewing the situation should recognize that if the vent has been damaged that there may be continued release of flammable vapors resulting in continuing fire or environmental concerns.

8.5.6 Rim Seal Fires

8.5.6.1 Rim Seal Fires in External Floating Roof Tanks

Success in extinguishing rim seal fires approaches 100% if there is no other associated damage (such as a pontoon explosion) and the if suppression efforts don't sink the roof through excessive use of water. Experience shows that rim seal fires can burn for extended periods (in some cases as long as several days) with no progression to involve the full tank surface. The use of ground monitors is considered inadvisable for seal fire suppression because of the difficulty of directing foam to the seal and risk of excess water sinking the roof. It is important to achieve complete extinguishment and cooling of the seal components as smoldering of Class A materials (fabric, rubber) can lead to reignition.

Two general types of permanently installed foam suppression are intended to extinguish fires in the seal area. One type, used in conjunction with a foam dam (Figure 12), supplies foam above the seal assembly (mechanical shoe seal, weather shield or secondary seal). The other type discharges foam below the topmost assembly (below the mechanical seal onto the liquid fuel, behind the

Figure 12—Foam for Seals Flowing into Foam Dam from Permanently Installed Foam Chamber

weather shield onto the tube seal envelope or below the secondary seal onto the primary seal). NFPA 11 covers the implementation of these design options in detail.

If permanently installed foam protection for the seal is not provided, it will be necessary to fight the fire with portable equipment. Foam hose streams (sometimes in conjunction with hand-held dry chemical extinguishers) may be directed into the seal area from the wind girder or the roof. If it is the practice to use the wind girder as access for fighting seal fires, hen handrails (Figure 15) and/or appropriate fall protection should be provided for emergency response personnel to protect against falling hazards.

Many rim seal fires have been extinguished with $1^1/_2$ in. foam handlines. 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. A new class of portable foam monitor is available which can be attached to the rim of the tank at the platform (see Figure 14). This can direct a foam stream from the platform against the inner wall of the tank to flow down to the seal.

Before emergency response personnel walk on a roof to attack a rim seal fire a situation size-up should be conducted. Preferably, these personnel will have a small diameter (such as $1^1/_2$ in.) foam handline for both protection and fire sup-

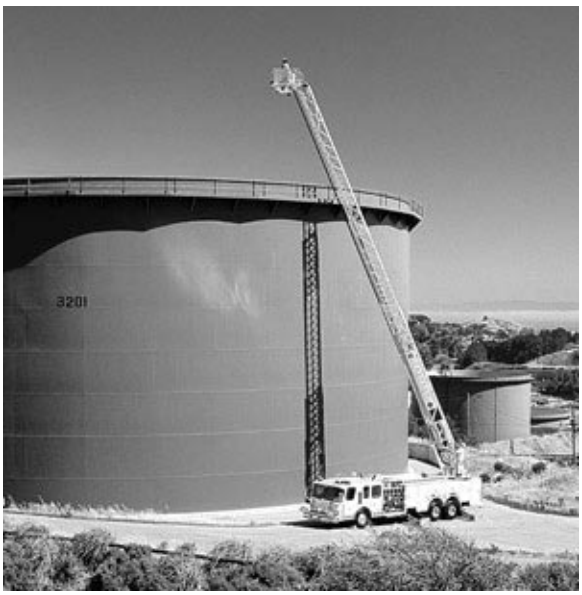

Figure 13—Elevating Platform Showing Access from Above Tank Rim

pression. The size-up should consider the variety of hazards that may be involved. It is important to establish that the compartments near the rim area are gas free so that heat in proximity to a flammable compartment does not result in a compartment fire or explosion.

Note: Under certain conditions the space above a floating roof up to the rim may be a "permit-required confined space" under the employer's safety rules or the OSHA 1910.146 confined space standard.

An evaluation should be made for the facility. Some locations include generic evaluation in their emergency response procedures based on the action required and the tank configuration. Appropriate personal protective equipment can then be specified. If the roof is not floating there may be a flammable mixture in the tank and personnel should not be allowed to walk on the roof.

If burning in the seal area beneath the stairway platform prevents access, foam can be applied to the area by elevated platform devices fitted with foam nozzles (Figure 13) or with foam wands brought up the stairs. In another approach, hand lines can be used to dissipate heat while foam is directed onto the seal area so that fire-fighting personnel can gain access to the platform. Caution should be exercised, however, to prevent excessive amounts of foam from flowing onto the roof and sinking it. If the roof is equipped with a foam dam the probability of this problem is reduced. The roof drains should be open. 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 to inhibit reignition and

Figure 14—Special Portable Monitor Attached to Edge of Floating Tank Roof to Fight Rim Seal Fires

reduce personnel hazards from the hot metal. Foam may have difficulty sealing against hot steel walls if there has been free-burning flame impingement for a significant period of time. Blistering or discoloring of the shell paint will indicate the need for supplementary cooling water, as will a "hose stream test" (Appendix N.4.1.a).

Directing large straight streams of foam or water into the flammable product at the damaged roof seal should be avoided. This can create personnel hazards or splash product onto the roof and increase the fire's intensity. Also, regardless of the type of foam concentrate being used, good foam-making nozzles should be used. Hand line water nozzles generally will not produce optimum results, even with AFFF. When dry chemical fire extinguishers have been used to put out a rim seal fire there should be follow-up application of foam to secure the potentially damaged seal area and inhibit vapor release.

8.5.6.2 Rim Seal Fires in Internal Floating Roof Tanks

Because tank design and construction limits access to the tank interior, rim seal fires in internal floating roof tanks are very difficult to extinguish. Permanently installed foam systems provide means for foam application and are installed on some tanks. Without such systems, essentially the only access to apply a suppression agent is through small vent openings at

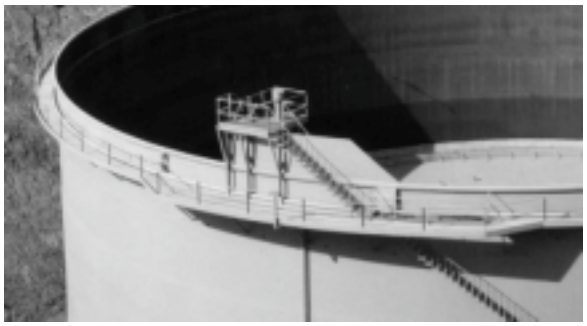

Figure 15—Wind Girder with Handrail Provides Safe Fire Personnel Access

the top of the tank or through the roof hatch. Some firefighters have used small diameter piping placed through the vents with the intent to direct foam down the internal wall of the tank to the seal, however, since internal floating roofs are built without foam dams there is no built-in mechanism to direct foam to the seal area; application from multiple locations may be needed. In addition, most vents have screens to protect the openings, impeding access; typically, these fires are addressed on a case-by-case basis. Covered external floating roof tanks may have foam dams.

8.5.7 Unobstructed Full Liquid Surface Fires Without Sunken Roofs

Full liquid surface fires where there is not a sunken roof are challenging but less complicated than when there is a sunken roof. These fires typically occur in fixed roof tanks where the roof has separated at a frangible (weak) seam and no longer obstructs the tank. A floating roof flooded with fuel on fire (but where the roof has not sunk) is really a special case to be addressed in a manner similar to the "sunken roof" case, with special care being taken not to sink the roof.

When the product involved in a full surface fire is a conventional hydrocarbon, there are two options for extinguishing the fire: topside application or subsurface injection of foam. Topside application provides the option to use protein foam, FFFP foam, FP foam, and alcohol-resistant foams or AFFFs approved for the purpose. Subsurface injection is limited to FP foam, FFFP foam, AFFF, and alcohol-resistant AFFFs specifically approved for subsurface injection use. For fires involving a strong polar solvent requiring an alcohol-type foam, NFPA 11 states that the extinguishing technique is limited to topside application. Before foam is applied to a tank, the minimum quantities recommended in NFPA 11 for the method and duration of application should be available on-site (or enroute with reliable delivery by time needed). Some experienced emergency response personnel recommend that sources be identified for twice the quantity calculated for one extinguishment, and that quantity be on-site before foam application begins. Foam concentrate availability should be integrated into the planning phase.

8.5.7.1 Topside Application

When topside application is appropriate, several application methods are open to consideration. These include permanently installed foam systems, high-capacity foam monitors, telesquirts (boom mounted monitors) and elevated platform devices fitted with foam nozzles. Primary protection for many tanks in service depends on traditional semi-fixed foam chamber systems with high-flow-rate portable foam monitors as a backup. Others consider large monitors a viable first-line approach, especially for very large tanks. An alternative, which has been installed on some tanks, uses multiple foam monitors permanently attached to the periphery of the tank.

Where the fuel is gasoline, containing alcohol or other oxygenates at 10% or less, the foam application rate does not normally need to be increased from that appropriate for gasoline itself. NFPA 11 specifies application rates of 0.10 gal/ft^2 (4 l/min-m^2) for permanently attached foam chamber installations and 0.16 gal/ft^2 (6.5 l/min-m^2) for over-the-top application using monitors. Some tank fire experts advocate significantly higher application rates in the range of 0.2 to 0.3 gal/ft^2 (8 to 12 l/min-m^2) using high flow-capacity ground monitors. NFPA 11 permits higher application rates for shorter times, but planning for not less than 70% of the recommended time.

8.5.7.2 Topside Application for Polar Solvents

Topside Type II foam chamber application to full-surface fires in cone-roof tanks containing polar solvents is effective only with foams that are approved or tested for such use. These include approved alcohol-resistant AFFFs or FFFP. The older protein-based, alcohol-resistant foams 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 foam concentrate used. Where fuels with special needs (such as methanol or ethanol) are involved the application rate is generally increased to 0.20 gal/ft^2 (8 l/min-m^2) or more. The foam manufacturer should be consulted regarding the recommended application rates, and expansion ratios, for specific polar solvents because these rates are generally much higher than those required for hydrocarbon products.

8.5.7.3 Subsurface Injection

Subsurface injection into hydrocarbon storage tanks has proven successful on numerous occasions. Tanks may be equipped with engineered foam injection and distribution systems, use fittings added to existing product lines to the tank, or have adapters added to tank appurtenances such as manway covers. Foam injection must be above any water bot-

tom in the tank. Even in initially dry tanks a water bottom will be created during subsurface injection. Subsurface injection may require special procedures for water withdrawal both before and during subsurface injection. Special high-back pressure foam makers are required for subsurface injection, and hydraulic calculations are necessary. Depending on its design, the foam maker will generally tolerate back pressure at the discharge of the foam maker equal to 20 to 40% of the inlet pressure. The back pressure generally consists of the head pressure in the tank and the friction loss of finished foam in the piping between the foam maker and the tank injection point (see NFPA 11).

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 ft (3 m) per second, based on the expanded volumetric rate. Combustible liquids will tolerate a velocity of up to 20ft (6 m) per second. NFPA 11 provides detailed guidance with charts to determine foam velocity.

Subsurface injection may require multiple injection points depending on the product involved and the diameter of the tank. NFPA 11 provides application information. These factors should be examined and calculated before any commitment is made to using subsurface injection. This information should be integrated into tank-specific planning.

Subsurface injection usually extinguishes the center of a tank fire first and the rim last. Observation from grade level may show a great deal of flame, which is the fire in the shell area. Elevated platforms or helicopters can sometimes provide a view into the tank to better evaluate progress.

Subsurface injection is not recommended for strong polar solvents requiring alcohol-type foam. MTBE, ETBE and similar weak polar solvent materials should be reviewed with the foam supplier as special cases based on their water solubility, volatility and physical characteristics.

8.5.8 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. If the tank is equipped with a roof that has “inherent buoyancy”, one that is a double deck or annular pontoon roof then the likelihood of causing a full surface fire by fire fighting operations and flooding of the roof is reduced.

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.

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 typical result is 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 various 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 avoided when the probability of a lightning storm is imminent.

External floating roofs can sink due to flotation failure caused by pontoon or double deck malfunction, mechanical failure or by excessive weight from rainwater or firewater.

Irrespective of the sinking cause, the roof becomes a barrier between the bottom of the tank and the surface of the burning fuel. This impedes or prevents foam from reaching the burning fuel surface if subsurface injection is attempted. Otherwise, the suppression efforts used for top-side foam application described in 6.5.4 are applicable. 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 reignition. This may require much more foam concentrate use than calculated in accordance with the ideal NFPA 11 minimum.

8.5.9 Fighting Ground Fires Around Tanks

When fighting ground fires around tanks the initial concerns are for containment of hydrocarbon, cooling impingement of pressurized and heat-sensitive storage and preventing ignition of tanks which are not on fire. This becomes more significant when multiple tanks share one diked area. Personnel should confirm that all dike water drain valves are closed to prevent spread of fuel and the fire. Cooling water should be applied to flame-impinged metal as soon as possible. Emphasis should be placed on impingement above the tank liquid level, especially for pressurized tanks. If material stored in an affected tank is especially heat sensitive it should also receive priority. The “hose stream heat test” can be used to determine the need for cooling of tanks subject to radiant heating without direct impingement. Some infrared remote temperature-measurement instruments may be useful.

When the immediate concerns have been evaluated and addressed, eliminating the replenishment of fuel for the

ground fire should be attempted by isolating the source of fuel in one of the following ways:

- Closing pertinent valves under the cover of water spray streams where needed for personnel protection.
- Displacing enough product with water to produce a water leak rather than a product leak (if the leak is from a tank or its piping). If this method is used, the water pressure must be greater than the product pressure in the line or tank. Care should be exercised to avoid overfilling the tank.

Various valves (dike valves, roof drain valves, and water bottom drain valves) are important means of isolating fuel. It is a high priority to control these valves. Although it is possible to extinguish some pressure fires involving a leak of fuel gas or liquefied petroleum gas, this should be done only by shutting off the fuel source. All hydrocarbon vapors (other than methane) are heavier than air. Extinguishing a gas fire without fuel shutoff may result in the formation of a hazardous vapor cloud. Sufficient wind may dissipate a leak while a gentle breeze may move a vapor cloud toward an ignition source. For detailed information concerning fighting fires in and around pressure vessels see API Publs 2510 and 2510A.

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

Small ground fires involving liquid products may be extinguished with dry-chemical extinguishers, provided the product is not exposed to reignition by hot metal and the fire fighters can address the problem without walking in pooled hydrocarbon. 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.

The typical strategy for extinguishing a large ground fire is to apply a foam blanket; however, with materials (such as diesel fuel) having flash points well above 100°F (38°C) or, more specifically, above the temperature of the water used, extinguishment can be achieved with water spray alone. Proper application of water cools the hot product surface below its flash point while steam evolved from vaporization of the firewater helps to exclude air. When vaporization of the product stops, the fire goes out.

Three-dimensional fires such as flange leaks or mixer fires generally have to be extinguished with an agent such as dry chemical unless sufficient foam or water can overwhelm the fire and cool the metal, preventing reignition. Simultaneous application of dry chemical and foam may be effective for these cases. 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 hand lines 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. For personnel safety reasons it is not advisable for firefighters to enter the pool area, even when the fuel surface is blanketed with foam.

8.5.10 Protecting Adjacent Tanks

Cooling water should be used with discretion. Fire fighters are trained to use cooling water on exposures; confronted with a tank fire, they may respond by cooling all adjoining tanks. This is usually not needed and may adversely affect attempts to extinguish the fire. Depending on the size of the fire, 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. The “hose stream heat test” can be used to determine the need for cooling, as discussed in 8.5.3. When this test shows that tanks do 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 where excess water should be avoided to minimize the potential for sinking the roof.

Although radiant heat does not seriously damage tank shells below the liquid level, several concerns may dictate the need for cooling adjacent tanks:

- Heat on shells of cone-roof tanks (with or without internal floating roofs) that contain combustible liquids may bring the vapor space of the tank within the flammable range.
- Heat on shells of tanks that contain low-flash-point liquids may generate enough vapor to cause the tank pressure to rise beyond the vent capacity and cause tank failure. Tanks constructed in accordance with API Std 650 have a weak roof-to-shell seam that allows the roof to separate from the tank shell to serve as an emergency vent. If caused by fire exposure this can be expected to result in a full-surface fire.
- Floating-roof tanks when heated may leak vapor which could ignite in the seal area.

8.5.11 Cooling Water

As discussed in the previous section, water used for cooling exposures should be used with discretion. Excessive water use reduces the available fire-fighting volume and pressure. It also can overtax sewers and drainage ditches and flood the fireground, making fighting the fire more difficult. Also, if diked areas are flooded, empty or

near-empty tanks may float from their foundations. These factors should be considered in fire planning and training so that water is used judiciously. Care should 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 instances in which concurrent use of water has disrupted or washed away foam blankets and hindered extinguishing efforts. This prolongs the extinguishing efforts and wastes foam.

8.6 ONGOING SITUATION ASSESSMENT AND ADJUSTMENTS

Evaluation of the ongoing situation should provide frequent information to the operations chief and incident commander who can use this information to evaluate the effectiveness of the response and modify the strategy, tactics and resources if needed (see Figure 11). This assessment step allows the observations of field personnel to be integrated into the overall action plan. This information will be provided to the emergency operations center for their use concurrent with fire suppression field activities. This should include observations regarding tank temperatures, movement of heat layers and observed phenomena as discussed in 8.3.2.i, 8.5.5 and Appendix G.

8.7 CONTROL OR EXTINGUISHMENT

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

- All dike and ground fires near a burning tank should be extinguished before attempting to fight the tank fire; otherwise, reignition of the tank may occur.
- 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 should be maintained.
- When there are simultaneous atmospheric tank fires, foam should be applied only to the tanks for which there is sufficient foam concentrate on hand for an attack at the recommended foam rates for 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.
- If the burning tank is fitted with permanently attached foam connections, they should be protected with cooling streams to keep them intact until foam can be applied.
- 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 pumping-out probably should not be undertaken.
- In some situations it is not feasible to fight a tank fire because of insufficient water, foam, personnel or foam-producing equipment. Accepting a burnout while protecting adjacent exposures may be the only available option in these instances. Under these conditions, pumping out the tank to recover the contents is recommended.
- "Control" of a fire is considered a reduction in fire intensity of approximately 90%. For "extinguishment" the fire should be completely out. With tank fires in which a portion of the roof is in the tank this may take as much as several days of periodic foam blanket renewal to put out pockets of fire behind portions of the distorted top.
- When 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 during the "overhaul" process.
- If the fire involved a tank holding boilover-potential liquids the temperature should continue to be monitored after the fire is extinguished. As discussed in Appendix G.2.1, theory suggests the heat wave generated while burning might continue downward after the surface fire is extinguished.

8.8 OVERHAUL AND REMEDIATION

The final stage in any fire is "overhaul". Overhaul ascertains that the fire has been completely extinguished and that the area is safe from reignition. Overhaul of a tank fire includes disposing of the remaining product and preventing its reignition. Care should be exercised to avoid all possibilities of ignition sources in the vicinity of an extinguished tank. Volatile product may remain in the tank, and until full cooling is achieved the hot metal can cause a foam blanket to deteriorate rapidly, exposing volatile vapors to potential sources of ignition. A foam blanket should be maintained on the surface until the product has been safely removed. Fire watch crews should be on standby with the proper foam equipment in position until this exercise has been completed. Since salvage can take many days there should be provision for continuing foam supply availability. Conditions should be supervised and controlled to prevent reignition. Incident Commanders should be aware of the possible reignition of vapors due to the static-generating potential of fire streams.

8.9 INCIDENT TERMINATION

When the tank and its contents are cooled to ambient temperature and the hydrocarbons removed or contained to eliminate an opportunity for reignition, the last of the fire

suppression resources can be released. Before release, incident operations personnel should ensure that they know the names of the participating groups and individuals. Mutual aid leaders should be provided a critique sheet and asked to provide input for their areas of involvement. A log should be made of the specific equipment and apparatus responding and which was put into service. To the extent possible an accounting tabulation of consumable materials provided by mutual aid should be made. While this may be maintained elsewhere, records from the incident site are valuable for verification.

Hazardous material concerns need to be addressed as the site moves into the scope of an environmental conservation concern. The incident command structure may continue to function with different individuals taking the modular roles of incident commander and operations chief to deal with the HazMat issue instead of fire suppression. At this time the environmental reporting and community relations interfaces may move to their normal contacts from the EOC if it is demobilized.

8.10 CRITIQUE

Ideally, soon after the incident termination (no more than a few days) representatives of all response participants should be invited to a critique session. The goal of this session should be to determine how well the facility emergency response organization(s) functioned with the mutual aid or other outside responders. How effective was the fire suppression, and how could it be improved in the future? The tank-specific contingency plan, plus the ICS incident data sheet and info from the EOC can be useful aids in the critique. This session can "fill in the blanks" and clarify time-line sequence of events which may be helpful in understanding "why things happened the way they did" during the response as well as for investigating team use.

The critique session is for reviewing activities relating to the fire suppression response and emergency management only. Events relating to the cause should be reserved for a different forum since the investigation typically is not complete and reported at this point.

9 Investigation, Reporting and Follow-Up

9.1 INVESTIGATION

Incident investigation is both an art and a science. Typically, emergency responders do not do this. A team with the proper skills should seek causes close enough to "root causes" so that effective prevention changes to systems can be implemented. Information from the tank specific planning sheets (Figures 3a & 3b), the incident command data sheet (Appendix C) and the incident documentation data sheet and summaries from the critique are valuable resources.

9.2 REPORTING

Feedback of results to management, operations and engineering functions should provide the level of information needed to accomplish their functions. Where findings have value to industry or society a mechanism for sharing should be done. The API (and other industry associations) can often provide an appropriate forum. Sharing general investigation results with the groups that provided emergency assistance nurtures mutual aid and community relations.

9.3 FOLLOW-UP

Follow-up based on results of an investigation is a management function. Follow-up could include changes in facility operations, emergency response equipment and procedures or facility configuration. Typical goals are providing safety for personnel, the community and the environment while protecting assets. For some incidents these goals will have been met and no follow-up action will be deemed necessary.

APPENDIX A—DEFINITION OF TERMS USED IN THIS STANDARD WHICH ARE IN GENERAL USE IN THE PETROLEUM INDUSTRY

A.1 autoignition temperature: Minimum temperature to which a fuel in air must be heated to start self-sustained combustion without a separate ignition source. This means that, should a leak occur on a line containing a petroleum product above its ignition temperature, ignition can occur independent of an ignition source.

A.2 boiling point: The temperature at which the vapor pressure of a liquid equals the surrounding atmospheric pressure. For purposes of defining the boiling point, atmospheric pressure shall be considered to be 14.7 psia (760 mm Hg). For mixtures that do not have a constant boiling point, the 20% evaporated point of a distillation performed in accordance with ASTM D86 shall be considered to be the boiling point.

A.3 classes of fire: NFPA 10 classifies fires based on the fuel involved–either type A, B, C, or D. Fire extinguishing agents are often identified by this system based on the type of fire for which they are effective (i.e., a dry chemical fire extinguisher may carry a Class ABC rating where a pressurized water extinguisher carries only a Class A rating).

- Class A fires are those involving ordinary combustible solid materials such as wood, coal, paper, rubber, and many plastics.
- Class B fires are those involving flammable and combustible liquids and gases such as gasoline, crude oil, asphalt, alcohols, LPG, and hydrogen.
- Class C fires are those involving energized electrical equipment. While electricity is not a fuel, it represents a significant hazard to firefighters if improper (electrically conductive) extinguishing agents or methods are used. Once the electrical circuit is de-energized, the fire is then treated as a Class A or B, depending upon the fuel involved.
- Class D fires are those involving combustible metals such as sodium, potassium, aluminum, magnesium, lithium or zirconium.

A.4 fire point: The temperature (usually a few degrees above the flash point) at which a liquid produces enough vapors to sustain combustion.

A.5 flammable range: A range of vapor-to-air ratios within which ignition can occur. The lower flammable limit (LFL) is the minimum vapor-to-air concentration below which ignition cannot occur. Atmospheres below the LFL are referred to as too lean to burn. The upper flammable limit (UFL) is the maximum vapor-to-air concentration above which ignition cannot occur. Atmospheres above the UFL are referred to as too rich to burn. Flammable ranges can vary widely, as illustrated by flammable vapor-to-air ranges for gasoline (1.4–7.6%) and acetylene (2.5–100%).

A.6 flash point: The lowest temperature at which a liquid gives off enough vapor to produce a flammable mixture with air immediately above the surface. A source of ignition is needed for flash to occur. When this temperature is above ambient, vapors will ignite but will not continue to burn until heated to the "fire point". The flash point temperature can be very low for volatile petroleum products; for instance, the flash point for gasoline is typically quoted as about –45°F (–43°C).

A.7 flammable liquids: Have closed cup flash points below 100°F (37.8°C) and vapor pressures not exceeding 40 psia (2068 mm Hg) at 100°F (37.8°C). Liquids with vapor pressures above 40 psia (276 kPa) at 100 °F (37.8°C) are considered gases by NFPA.

1. Class IA–flash point below 73°F (22.8°C) and boiling point below 100 °F (37.8°C)
2. Class IB–flash point below 73°F (22.8°C) and boiling point at or above 100°F (37.8°C)
3. Class IC–flash point at or above 73°F (22.8°C) and below 100°F (37.8°C)

A.8 combustible liquids: Have closed cup flash points at or above 100°F (37.8°C)

1. Class II–flash point at or above 100°F (37.8°C) and below 140°F (60°C)
2. Class IIIA–flash point at or above 140°F (60°C) and below 200°F (93.4°C)
3. Class IIIB–flash point at or above 200°F (93.4°C)

OSHA uses NFPA definitions for flammable and combustible in most general industry standards. Alternate systems using 140°F (60°C) as the dividing point between flammable and combustible appear in ANSI/CMA Z129.1–1994 and the regulations of the U.S. Department of Transportation and the United Nations. The NFPA classification system is used in this document and is widely used for facility-based fire protection purposes in the USA. For regulatory compliance purposes (including labeling for off-site transportation) reference should be made to the specific regulations or codes governing the activity of concern.

A.9 jet fire: A leak from a pressurized system which ignites and forms a burning jet which might impinge on other equipment causing damage. [Ref CCPS Guidelines for Safe Automation of Chemical Processes. In 7.2.4 for vinyl chloride monomer, the jet length in rough terms is about 150 times the jet orifice diameter—a jet from a 2 in. hole could produce a burning jet about 30 ft long.]

A.10 pool fire: Fuel from a release which forms a pool which when ignited can burn with a flame height two or three times the diameter of the pool. [Ref CCPS Guidelines for Safe Automation of Chemical Processes, 7.2.4]

APPENDIX B—UNITS OF MEASUREMENT

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

Table B-1—English to Metric (SI) Units of Measure Relevant to Tank Fire Suppression

English Unit	Metric Unit	Conversion Factor
Fluid Volume		
Gallon, g (US gallon)	liter, l cubic decimeter, d m^3 (e.g. 1 liter) cubic meters, m^3	1 g = 3.785 l 1 g = 3.785 d m^3 1 m^3 = 264.2g
Barrel (bbl) 1 bbl = 42 g	Cubic meter, m^3	1 bbl = 0.16 m^3 1 m^3 = 6.3 bbl
Density of Foam Application		
Gallons/ minute/square foot, g/min/ft^2	liters per minute per square meter, l/min-m^2	1 g/min/ft^2 = 40.746 l/min-m^2 4.075 l/min-m = 0.1g/min/ft
Volumetric Flow Rate		
Gallons per minute	cubic meters per hour Liters/minute = l/min	1000 g/min = 227 m^3/hr 1000 g/min = 3785 l/min
Pressure		
pounds per square inch, psi	mm Hg	1 psi = 51.7 mm Hg
pounds per square inch, psi	pascal, Pa	1 psi = 6894.757 Pa
pounds per square inch, psi	bar	1 psi = 0.0689 bar
	bar	1 bar = 10^2 Pa
pounds per square inch, psi	kilopascal, kPa	1 psi = 6.895 kPa
Length		
Foot, ft	Meter, m	1 foot = 0.3048 m
Inch, in.	Meter	39.37 in = 1 m
Area		
Square feet, ft^2	Square meters, m^2	1 ft^2 = 0.0929 m^2 1 m^2 = 10.76 ft^2
Temperature		
Degrees Fahrenheit, °F	Degrees Celsius, °C (e.g. Centigrade)	(°F–32)/1.8 = °C
Heat		
BTU/hr	Watts, W	1 BTU/hr = 0.293 W
BTU/hr/ft^2	kW/m^2	1 BTU/hr/ft^2 = 3.155 W/m^2 1.00 kW/m^2 = 317 BTU/hr/ft^2

APPENDIX C—INCIDENT COMMAND SYSTEM (ICS)

C.1 ICS Overview

Experience shows that the incident command system it is an effective tool for situations ranging from minor on-site incidents to major emergency events requiring outside help It is especially appropriate for resource intensive incidents such as major tank fires. The Incident Command System (ICS) is an integrated management system for emergencies such as fires, hazardous material spills, multi-casualty incidents, earthquakes, floods, etc. ICS provides a management structure with defined modular roles for coordination of facility personnel and operations, local fire departments, mutual aid organizations, and equipment responding to an emergency.

Many locations designate facilities and staff to function as an Emergency Operations Center (EOC). The EOC (see 6.2 and 7.2) addresses incident-related management needs not specific to the incident mitigation strategy or tactics. These include internal interface with non-involved operational units and external relations with the community, regulatory agencies and the media. Incident Command may operate from the same location as the EOC but frequently is situated in close proximity to the incident site while maintaining close communication with the EOC. This provides functional advantages for communication with emergency response and process operations personnel as well as providing useful isolation from distraction.

Fire suppression is only one aspect of handling fire incidents. An incident command system incorporating an emergency operations center can be used to manage a wide range of related emergency activities which are coordinated with emergency response personnel, which can include:

- Implementing emergency action and evacuation plans.
- Accounting for personnel from the area affected by the incident.
- Providing rescue and first aid for the injured.
- Shutting down equipment and rerouting fuel from the fire area.
- Performing special emergency maintenance work.
- Controlling utilities.
- Providing auxiliary traffic control and security.
- Managing firewater usage during emergency operations.
- Transporting and staging reserve personnel and fire-fighting equipment.
- Maintaining a system to account for personnel working in the “hot zone”.
- Providing rehabilitation areas for response personnel.
- Ensuring liaison among all the emergency activities.
- Providing for media communications and public relations.
- Providing for backup operating personnel.
- Making timely mandatory notifications of federal, state or local agencies.

Normally the person responsible for operations in the area where the fire has occurred takes the lead role for any needed emergency shutdown operations. An alternate should be identified in case the responsible person is not available. Supervision of the actual fire fighting is the responsibility of the Incident Commander or a designated alternate as incident Operations Chief. Coordination between the persons in these two roles facilitates safe and effective fire control.

A “Notional Incident Command Data Sheet For Petroleum Storage Tank Facilities” is included in this appendix. Each facility will need to determine and develop the appropriate tools for implementing their own incident management system. This sheet provides examples of the type of information required. Typically there would be more comprehensive aids for the logistics of managing staging areas, tracking personnel assignments, and managing the many varied incident needs.

ICS satisfies OSHA and EPA regulatory requirements as well as conforming to NFPA 1561.

Written policy, procedures, and training requirements for industrial fire brigades are specified in OSHA Subpart L, *Fire Brigades* (1910.156) and *Hazardous Waste Operations and Emergency Response* (HazWoPer,1910.120q). Specifically, use of ICS is mandated by OSHA for industry in HazWoPer. On March 6, 1990 the EPA extended mandatory use of ICS to include paid and volunteer fire departments (40 CFR Part 311). ICS also satisfies the requirements of NFPA 1561, *Fire Department Incident Management System.*

A study by the National Fire Service Incident Management Consortium resulted in the introduction of the term Incident Management System (IMS). This work was based on revisions to the widely used Incident Command system (ICS) system to accommodate a combination of various emergency management systems including the NFPA/Phoenix Fire Department Fire Command system.

C.2 Incident Command Data Sheet

Incident command data sheets help organize data acquired in the initial stages of an incident and from the tank-specific plans. They serve not only as “things-to-consider” checklists but also as a convenient, organized place to record important data. They provide a means of keeping track of assignments given to specific units on the fire ground. The sample chart illustrates the kind of information an incident commander may need as an incident develops. The data sheet provided is not currently in use by any specific organization. Each facility or organization should develop forms that fit their operations. Mutual aid organizations may choose to develop an incident data sheet used for all mutual aid responses. The sample chart

Incident
1. Location _____
2. Date and Time _____
3. Other Information/Medical/environmental needs _____
Exposures: 1)_____ 2)_____ 3)_____ 4)_____

Staging Area
5. Resources in staging area: Apparatus_____
Personnel: _____
Location of staging area: _____

Fire Brigades
7. Equipment _____
8. Personnel: Available: _____ Required: _____
9. Radio frequencies and mobile telephone numbers: _____
10. Officer(s) in charge _____

Storage Tank Involved
11. Type _____
12. Diameter, ft (M) _____ 13. Liquid surface area, ft^2 (m^2)_____
14. Attached equipment _____
15. Drains (and status) _____
16. Time to pump out _____

Product
18. Name _____
19. Flash point _____°F (°C) 20. Specific Gravity _____ (H_2O = 1) 21. Vapor Density _____

Fire Protection
22. Semi-fixed Systems _____ g/min (l/min) Flow Required _____
23. Access for subsurface injection? _____ g/min (l/min) Flow Required_____
24. Portable Systems _____ g/min (l/min) Flow Required _____
25. Other Devices _____

Water Supply
26. g/min (l/min) and pressure available at tank, PSIG (Bar, kPa) _____
27. Auxiliary sources of water _____
28. Water needed, g/min (l/min) for: Tank _____ Exposures _____ Ground Fires _____

Foam Concentrate:
29. Type Required _____ 30. Source _____
31. Amount required, G (L): Tank _____ Ground Fires _____
32 Amount available, G (L): on-site _____ Mutual Aid or Supplier _____
33. Time when sufficient supply in hand to start offensive attack on tank: _____
34. Special apparatus required & source _____

Other Information
35. Unit Assignments _____
36. Specialized Equipment _____
37. Police _____ 38. Other _____
39. Attach notes, drawings & Survey/Planning Sheets (and MSDS as required)

Figure C-1—Example Incident Command Data Sheet for Petroleum Storage Tank Facilities

has been reduced in overall size to fit on one page. Often the information needs may require much more space evolving into a set of sheets. Figures 3a and 3b can serve as a useful companion to this sheet. Data gathered during the incident can be helpful during the critique and investigation phases.

Exposures of adjacent facilities or the community to radiant or convective heat or combustion products should be identified early for consideration in developing strategy and tactics. Management of resources is the key to successful ICS implementation. Radio frequencies, mobile telephone numbers and the name(s) of the officer(s) in charge of responding fire brigades are key to incident management. Documenting and managing the staging area (listing personnel and apparatus in the staging area, the location of the area, and related data) will typically require expanded listings. The logistics function will need to know details of resources arriving or accessible to responding units. Unit assignment tracking will require more space than shown. Information regarding personnel in rehabilitation and units out of service is equally important. Information on pump-out time for a storage tank may be useful in determining attack, salvage, or burnout strategy.

Incident command data sheets differ from the incident documentation data sheet discussed in Appendix D. The command sheet is suitable for use during an incident. The incident data sheet is provided to recommend data that should be collected before, during, and after an incident. It provides information of value for incident investigation and documentation. Access to Incident Management Information

Once planning activities have been completed, the information should be maintained in a system from which it can be readily accessed. The urgent time demands of emergency response require quick reference to data during the course of an operation. Reference should be independent of electrical power and personnel staffing.

Current facility maps should be maintained with incident response information. 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,. If this is done, however, both sets of maps should be available 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 emergency response and off-site mutual aid or fire department personnel to maintain familiarity with the installation and promote good relations with the local fire brigade and management.

Design of the system for managing this information should recognize the need to ensure that the information is current. Information related to equipment and geography tends to change infrequently. Data relating to personnel may change frequently. Electronic storage for general access with a limited number of hard copies along with separation of specific personnel data may prove to be most easily managed.

C.3 Incident Command Training

For ICS to function effectively, training and education of all personnel (including management) who will assume ICS roles is important. Training information on ICS is available in publications from the Federal Emergency Management Administration (FEMA), the National Fire Academy, Oklahoma State University's Fire Protection Publications and in NFPA 1561. In 1999 the FEMA–IS-195, Basic Incident Command System–Independent Study course was available on the FEMA internet web site as a free download at http://www.fema.gov/EMI/is195lst.htm.

APPENDIX D—INCIDENT DOCUMENTATION DATA SHEET

D.1 Introduction

The incident documentation 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. The data will 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.

D.2 Tank Fire Incident Documentation

Despite the turmoil of excitement at a major tank fire, recording facts at the scene is important:

- Dependable data are needed for a critique after the fire. Such a review is necessary to appraise the effectiveness of the emergency response efforts and the strategy and tactics used.
- 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.

The sample incident documentation data sheet (Figure D–1) is provided as a guide. Copies of this sheet (or a similar one) should be used in conjunction with the tank-specific planning sheets (Figures 3a and 3b) as planning and simulated tank fire drills are conducted. Data sheets should be readily available for emergency use.

Location:

1. Company name _____
2. Street Address _____
3. City _____ State ___ Zip _____

Time:

4. Fire first detected: _____
5. Fire reported: _____
6. Fire personnel arrived on scene: _____
7. Fire suppression started: _____
8. Fire "under control" _____
9. Fire out: _____
10. Emergency personnel released: _____

Weather

11. Temperature _____
12. Humidity _____
13. Wind strength & direction _____
14. Sky conditions _____
15. Precipitation _____
16. Lightning? _____

Tank

17. Type of Tank _____
18. Diameter, ft (m) _____
19. Roof type: Cone _____ Open floating roof _____
    Covered floating roof _____
20. Dike: _____
21. Type of Seals: _____
22. Foam dam? _____
23. Automatic Detection? _____
24. Automatic Actuation? _____

Material in Tank - Fuel:

25. Type of Fuel _____
26. Reid Vapor Pressure (RVP) _____
    (Attach fuel-specific detail/information)
27. Initial Tank Temperature, °F, (°C) _____
28. Level in tank at start of fire, ft (m) _____
29. Water bottom in tank, ft (m) _____
30. Level in tank at end of fire, ft (m) _____
31. Heatwave settling rate, in./hr (cm/hr) _____
32. Boilover or frothover? _____
33. If "Yes", Time & extent _____
    (Attach detail)

Fire Suppression Available

34. Foam Chambers on tank shell _____
35. Subsurface system _____
36. Catenary system _____
37. Other Permanently attached foam - Type? _____
38. Portable ground monitors
    Monitor type _____ Capacity _____

Fire Exposure Protection

39. Was Cooling water used on exposures? _____
40. Estimated cooling water rate _____
41. What was cooled? _____
42. Total amount of cooling water used _____
43. Did cooling water prevent damage? _____

Fire Sizeup

44. Was roof in place throughout fire? _____
45. Did roof sink? _____
46. Was there a ground fire in dike? _____
    If "Yes", area, sq ft (m^2) _____
47. Did fuel leak from piping? _____
48. Was fire contained within tank? _____
49. Probable ignition source? _____

Foam Application

50. Foam Available: (Fluoroprotein
51. Polar/Alcohol Resistant, AFFF, FFFP, Synthetic
Other _____
52. How was foam applied? _____
53. How was foam proportioned? _____
54. What foam was used? _____
55. What percentage of concentrate? _____
56. What was foam application rate? _____
57. When was foam started? _____
58. When was foam stopped? _____
59. Total amount of foam concentrate used? _____
60. Source of water? _____
61. Water pressure: _____psig (Bar) at _____

Salvage & Overhaul

68. Time Pump-out started _____
69. Time Pump-out stopped _____
70. Pumpout rate _____
71. Quantity of fuel recovered _____

Other Information

72. Brief Description of Fire: Vent___ Seal___ Internal Seal___ Full Surface Unobstructed___ Full Surface Partially Obstructed___ Piping___ Ground Fire in Dike___ Other___
73. Lessons Learned. _____
74. Diagram of Fire Area: (attach) _____
75. Narrative of incident sequence (attach) _____
76. Person completing report: _____
    Name _____
    Role at Incident _____
    Phone _____
    e-mail _____
77. Date summary prepared _____

Figure D-1—Example Incident Documentation Data Sheet

APPENDIX E—TYPES OF STORAGE TANKS

E.1 General

Design and management of storage tank facilities is addressed in API standards. API Stds 620 *Design and Construction of Large, Welded, Low Pressure Storage Tanks* and 650 *Welded Steel Tanks for Oil Storage* are important references for refinery tank design. API Spec 12B *Bolted Tanks for Storage of Production Liquids* covers bolted steel tanks used in oil production. Management of tank facilities to reduce fire risk is addressed by other publications referenced in Section 2. While this publication specifically addresses atmospheric tanks, typical storage areas may also contain pressurized tankage. Other API and NFPA standards address this more specialized storage.

E.2 Fixed Roof Tanks

Fixed roof tanks are vertical steel cylinders with a permanently attached roof. In the petroleum industry these are typically cone shaped but can be flat or domed.These tanks have a vapor space between the liquid surface and the underside of the roof. On larger tanks, 35 ft (10 m) and greater in diameter, the roof is constructed with a weak roof-to-shell joint (see API Std 650 for the design of frangible roofs) so that in event of an overpressure (such as from an internal explosion) the roof will separate from the vertical shell to prevent failure at the bottom seam which would release the entire tank contents. Fixed roof tanks are typically used for storage of combustible liquids with flash points greater than 100°F (38°C). However, this is not always the case, and on occasion they are used for liquids with lower flash points, including crude oils, polar solvents, and contaminated combustible liquids. A particular hazard associated with fixed roofs occurs if a normally non-volatile stock such as diesel becomes heated by radiant or convective heat from a source such as a nearby ground fire or tank fire, causing the vapor space to pass into the explosive range. This phenomenon should be considered when prefire planning various scenarios. Fixed-roof storage tanks may be heated when used for storage of heavy residual products such as asphalt or bunker fuel (but heated tanks are not within the scope of this document). See RP 2023.

Fixed roof tanks may have open vents or be equipped with a pressure-vacuum vent to prevent the release of vapors during small changes in pressure resulting from changes in liquid level or temperature. Vents may be equipped with environmental controls for capture of fugitive emissions. Fixed roof tanks also may be equipped with emergency vents, or a frangible roof seam may be used intentionally for emergency venting

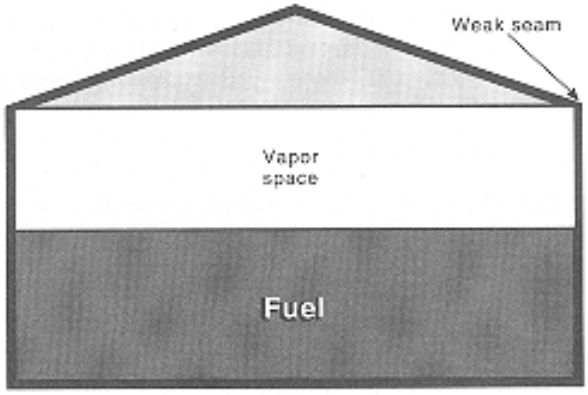

Figure E–1—Fixed Cone Roof Tank

Figure E-2—Low-Pressure Tanks without Weak Seam

E.3 Vertical, Low-Pressure Fixed Roof Tanks without Frangible Roof Seams

Tanks without weak seams should be designed and constructed in accordance with API Std 620 and be operated with metal temperatures not exceeding 200°F (93°C) and with pressures not exceeding 15 psig (1 kg/cm^2). Tanks without weak seams tend to be smaller tanks used in process areas or specialty storage areas.

E.4 Horizontal Fixed Roof Tanks

Above ground horizontal atmospheric tanks are normally small capacity [40,000 gal (150,000 l)] or less. They are constructed in a manner comparable to small vertical tanks with a fixed roof. NFPA 11 recommends against use of fixed foam chambers on these tanks.

Figure E-3—Horizontal Tanks

Figure E-4—Close-up View of Bolted Tank Seams

E.5 Bolted Seam Tanks

Fixed roof, bolted-seam tanks are used in oil production applications for storage of crude oil and oil field liquids. API Spec 12B covers material, design and erection requirements for these vertical, above-ground tanks. The nominal capacity range in which these tanks are used is from 100 to 10,000 barrels (16 to 1,600 m^3). Because of their construction, bolted tanks have a potential for three-dimensional fires. The sealing between shell plates is dependent on rubber or elastomeric material which can melt. Fuel leaking from the seams may burn and run down the tank shell. These fires may require suppression using an extinguishing agent such as dry chemical.

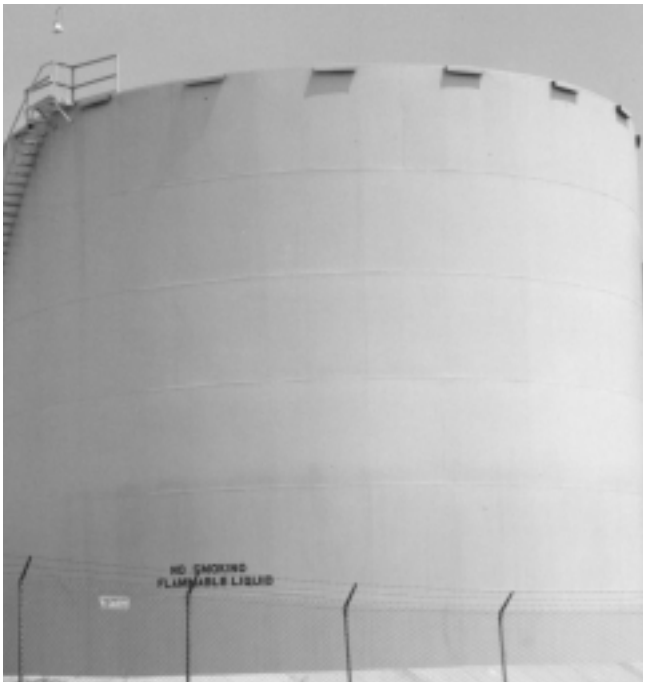

Figure E-5a—Internal (Covered) Floating Roof Tank

Figure E-6a—Open Top (External) Floating Roof Tank

E.6 Internal Floating-Roof Tanks

An internal or covered floating-roof tank has a permanent fixed roof with a floating roof inside the tank as shown in Figure E-5.

Internal floating roof tanks may have vertical supports within the tank for the fixed roof or have a self-supporting fixed roof. The internal floating roof rises and falls with changes in liquid level, just as does the roof in an external floating roof tank. Internal floating roofs can be constructed to API 650 Appendix C or H. They can be plastic, aluminum or steel. The deck of the internal roof may be supported by pontoons or float directly on the liquid (a contact roof). Con-

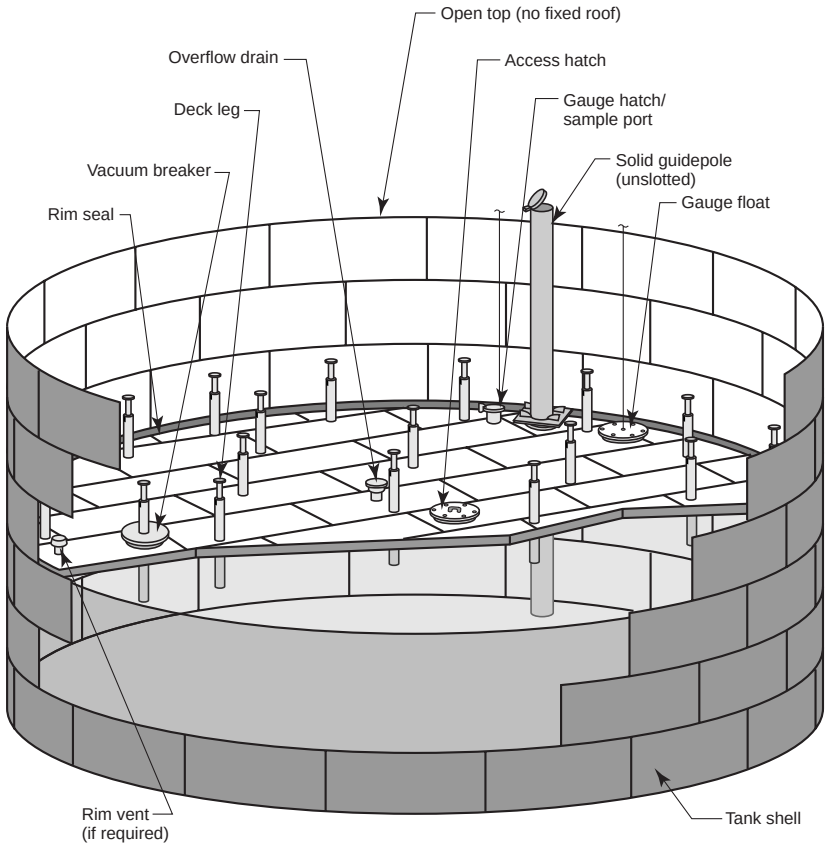

Figure E-6b—Open Top (External) Floating Roof Tank Diagram

tact decks can be constructed of aluminum sandwich panels, pan steel (either with or without pontoons) or fiberglass reinforced plastic. Non-contact decks are the most common type in service. They typically are constructed of aluminum. The fixed roofs of these tanks are freely vented with the expectation that the vapor space will be below the flammable limit. Only the steel annular pontoon or double deck type roof has "inherent buoyancy" when used in an internal floating roof application. Double seals are not required on internal floating roof tanks and most do not have double seals.

E.7 Open Floating–Roof Tanks

Open top floating roof tanks, as the name implies, are vertical steel cylinders with a roof which floats on the surface of the liquid in the tank which is open to the atmosphere above the roof.The roof may float on pontoons or have a double deck for flotation. The floating roof rises and falls with the liquid. A sealing system for the annular space at the roof's periphery edge is used to restrict evaporative losses of the product. Modern external floating roof tanks have double seals to minimize vapor releases of potential environmental concern. The floating deck is penetrated by fittings that serve operational purposes. The construction of many open top floating roof tanks includes a foam dam (conforming to NFPA 11) which is provided to hold foam at the periphery to extinguish fires in the seal area. Large crude oil storage tanks are typically of open floating-roof design.

E.8 Domed External Floating–Roof Tanks

Domed external (or covered) floating roof tanks are functionally similar to internal floating roof tanks created by retrofitting an external floating roof with a dome. This usually results in a heavy steel annular pontoon or double deck floating roof which has "inherent buoyancy" and is built to Appendix C of API 650. Consequently, sinking of these roofs is much less likely than for a conventional covered floating roof tank.

Domed external (or covered) floating roof tanks are very similar to an internal floating roof tank with a much more sturdy floating roof. They have the heavier type of roof used in open floating roof tanks, and a fixed dome-shaped roof. Typically, these tanks result from retrofitting an open floating roof tank with a fixed roof. The rim seal structure and roof fittings remain the same as an open tank. The function of the

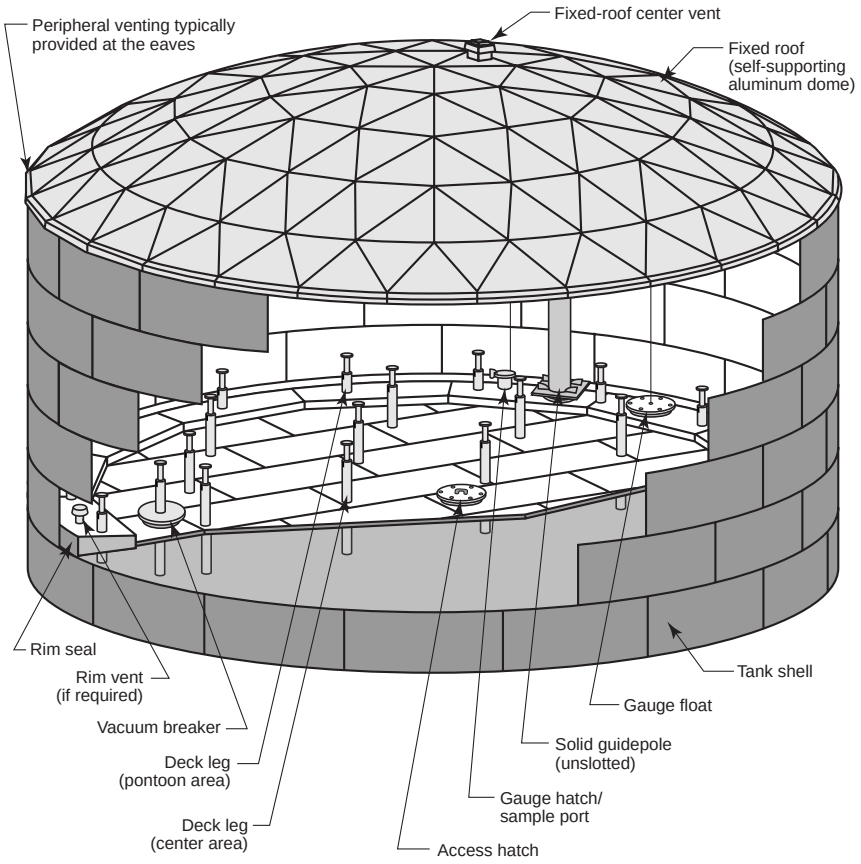

Figure E-7—External Floating Roof Tank with Dome

Figure E-8—Spheres Adjacent to Tanks

fixed roof is to serve as a wind and rain barrier (not typically for evaporative emission control) and like other internal floating roof tanks they are freely vented to the atmosphere.

E.9 Spheres

Pressure spheres, typically used for flammable liquefied gases, fall outside the scope of this publication. However, during the planning process they should be addressed as potential exposure concerns. They are often located in areas adjacent to atmospheric tanks, as shown in Figure E-8. Appropriate LPG references from API are in Std 2510, Publ 2510A and Publ 2030. Relevant NFPA publications are, NFPA 30, NFPA 58 and NFPA 15.

APPENDIX F—FIRE PROTECTION CONSIDERATIONS RELATED TO FLOATING ROOF TYPE AND DESIGN

F.1 The Role of Floating Roofs in Fire Prevention

Tank designers consider the floating roof to be the single most important design variable affecting the potential for, and severity of, a tank fire. A "perfect" floating roof, one that has what is often called "inherent buoyancy", cannot easily sink. The following describes why an inherently buoyant roof is important both for fire protection and during suppression.

The floating roof substantially reduces evaporation by reducing the liquid surface exposed to the atmosphere (in open floating roof tanks) and in the vapor space of internal floating roof tanks. Because the design limits the exposed area a fire is limited to the seal gap between the floating roof and the tank shell, as long as the floating roof is buoyant. This gap normally represents less than 2% of the total tank area. If a seal fire progresses to the full circumference, the floating roof keeps the fire contained in the rim area which averages only 8 in. wide. While a rim seal fire is serious, it is a far less serious event compared to a fire which escalates into a full surface fire. Nearly all rim fires are extinguished safely if the floating roof doesn't sink (i.e., remains buoyant).

The importance of inherent buoyancy cannot be overemphasized. There are many different floating roof materials and designs established both by the market and by the design standards. Floating roofs conforming to API 650 may be constructed of aluminum or steel; however, not all roofs are equivalent for the purpose of fire prevention. The design standards do not guide the user as to the type of roof that is best suited for fire prevention and protection.

In response to a rim seal fire, emergency response personnel may put excessive amounts of foam and water on the tank's floating roof. This concern increases when there are no foam dams to contain foam in the seal area. Excessive foam-water solution can overload and sink the floating roof. If this happens, the resulting full surface fire becomes more difficult (and expensive) to extinguish. Concerns with roof flooding are especially relevant when municipal firefighters without tank fire fighting experience or training are in command.

In order to have inherent buoyancy the roof must satisfy these requirements:

- be constructed of steel.
- have bulkheads.
- have liquid tight sealed compartments.
- have sufficient numbers of compartments to meet the requirements of API 650.

Lightweight aluminum and plastic roofs cannot meet these requirements since they cannot withstand the weight of the foam-water solution. API 650 requires the buoyancy of a floating roof be equal to a fixed percentage of its dead weight. Therefore, the lighter the roof, the less weight it can withstand before sinking. In addition, certain types of aluminum roof components can melt. Even an aluminum contact-type roof which does not melt will sink below the fuel surface if even small amounts of firewater are discharged on it. In addition to the problem of the weight of fire water on the roof, some forms of aluminum and plastic roofs will melt wherever they are not cooled by being in direct contact with (or beneath) the liquid surface. These become full surface fires. Since the support structure impedes free flow of foam agent, the difficulty of suppression increases.

Another advantage of a inherently buoyant floating roof (API 650 Appendix C or H steel double deck or annular pontoon) is apparent if the roof can be assumed to be resistant to sinking. Then the sizing of the foam and/or fire fighting systems, if any, can be based only on the surface area of the rim space and not on the full area of the tank surface. This applies if a semi-fixed foam system will be installed. These roofs can withstand some foam solution flooding before being in jeopardy of sinking.

Although steel annular pontoon and double deck roofs meeting API 650 requirements are highly resistant to sinking during fire fighting events if they have tight access covers, they can have problems too. Experience shows that about the time floating roofs are 10 years old there is increased possibility that one or more of the compartments may have a corrosion hole or fatigue crack. In this case an explosive mixture can form in the compartments. In a few rare instances external floating roof tanks with double deck steel roofs have had full surface fires when struck by lightning because one of the compartments exploded. Another problem with leaking compartments is that if a rim seal fire develops a compartment could explode, potentially endangering fire fighters and jeopardizing the buoyancy of the floating roof. This problem is more serious in external floating roofs because of the prevalence of lightning as an ignition source. For internal floating roofs the problem is partial loss of buoyancy. Then if a rim fire develops the roof can buckle due to excessive loads from both the fire water-foam solution and the presence of breached compartments. The potential for problems of this type can be reduced through focused inspection and maintenance.

There are inherent buoyancy–vulnerability issues with other types of steel floating roofs. There are pan designs and open topped compartmented designs. The open topped design is similar to an annular pontoon but without a cover on top of the compartments. Neither of these designs has inherent buoyancy because liquid can fill the roof and sink it; on covered floating roofs the source of liquid would be water/foam applied during fire suppression. For the pan, a single small hole can allow product to flood and submerge the entire roof. The open top design is designed to withstand 2 flooded com-

partments; while this is more buoyant it does not have inherent buoyancy. Without the cover it is weak under stress and can buckle. It can also be sunk, if while attempting to fight a rim fire, there is flooding of the compartments which are open to the firewater-foam stream.

For the purpose of pre-incident planning, the tank should be treated as a fixed roof tank with potential for a full surface fire, unless the roof is a steel annular pontoon or double deck roof meeting Appendix C or H of API 650.

APPENDIX G—SPECIAL HAZARDS ASSOCIATED WITH TANK FIRES

G.1 General

The inherent properties of hydrocarbon materials processed and produced in refineries present several unique hazards related to hydrocarbon storage. Some of these phenomena have the potential to cause substantial damage. These should be addressed while designing fire prevention programs and planning for emergency response.

G.2 Boilover

Boilovers are serious, potentially 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 G-1). In extreme cases, substantial amounts of flammable liquids can be expelled creating a serious hazard for hundreds of feet surrounding the tank. The height of the burning column of expelled material may be as much as ten times the diameter of the tank.

Boilover is defined in NFPA 30 as "an event in the burning of certain oils in an open-top tank when, after a long period of quiescent burning, there is a sudden increase in fire intensity associated with expulsion of burning oil from the tank. Boilover occurs when the residues from surface burning become more dense than the unburned oil and sink below the surface to form a hot layer, which progresses downward faster than the regression of the liquid surface. When this hot layer, called a 'heat wave', reaches water or water-in-oil emulsion in the bottom of the tank, the water is first superheated and then boils, almost explosively, overflowing the tank. Oils subject to boilover consist of components having a wide range of boiling points, including both light ends and viscous residues. These characteristics are present in most crude oils and can be produced in synthetic mixtures."

An example of a synthetic mixture, which might have boilover potential, would be a heavy fuel oil that was diluted with lighter hydrocarbons to reduce the oil's viscosity. At least one major boilover incident appears to have involved such a material.

Note: A boilover is different from (and much more hazardous than) the slopover and frothover phenomena described in G.3 and G. 4. And, a fire in a floating-roof tank will not produce a boilover as long as the roof is floating, even though the material in the tank may have boilover characteristics.

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

- The full-surface fire must involve all or most of the surface of the liquid.
- 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 is not uncommon in tanks used to store crude oil. It can occur in other ambient temperature heavy oil storage.
- The oil must contain components with a wide range of boiling points including both a heavy, high molecular weight, viscous fraction and light ends (e.g., like crude oil, but not like gasoline). When the lighter components have been "distilled off" by burning at the surface, the viscous oil remaining on top [even at a temperature of 300°F (149°C) or higher] is more dense than the oil immediately underneath. This residue sinks below the surface and forms the layer of gradually increasing depth (the heat wave) that advances downward at a rate of 1–4 ft (0.3–1.3 m) per hour. The heat wave is the result of the physical settling of a part of the hot surface oil. It is more complex than heat conduction from the burning surface downward.
- Water or oil-in-water (wet) emulsion bottoms are normally present in crude oil tanks. Water may also be inadvertently introduced into the tank from the firefighting efforts, or there may be layers 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 times the water volume.
- A high enough content of residue is needed 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 firefighting tactics. Foam application has the best result if it is begun within about 30 min of the fire starting. The proper agent may be applied either subsurface or topside.

G.2.1 EVALUATING BOILOVER POTENTIAL

If, for any reason, it is not possible to extinguish a burning cone-roof crude oil tank, a change in strategy is needed . 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. Because of heat transfer from the tank shell to the atmosphere the actual level of the heat wave near the center of the tank can be lower than that indicated by a water "hose stream test" or pyrometer measurements on the tank wall. Similarly, the downwind side of the tank can have a slightly lower heat wave than the cooler upwind side.

Experience suggests that for tanks more than half full the following may help evaluate boilover potential:

- 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 a pronounced "frying" sound.
- Large "blobs" of burning froth may be projected up a few feet and may be visible from some distance.
- Temperature can be measured with optical pyrometers.
- A hose stream can be used on the side of the tank to determine whether the temperature at that surface is hot enough for rapid evaporation of water.

The temperature should also be monitored after the fire is extinguished. The heat layer is heavier (i.e. higher molecular weight) than the full range material below because the light fraction has burned away. Because of this specific weight differential it can continue moving toward the bottom of the tank after extinguishment if the top layers are hot enough. So, the heat layer generated while the material was burning may continue transferring heat downward potentially raising the temperature sufficiently to cause a boilover when it reaches a water bottom. A boilover at this time would still be a personnel hazard and, if an ignition source exists, can be a fire hazard. Whenever a boilover is anticipated, personnel should be evacuated to a safe area.

Large-diameter tanks may require pulling back 2000 ft (600 m) or more from the incident. Some planners have suggested that it may also be appropriate to install additional earthen berms at elevations lower than existing diked areas (or perhaps built at the time of an incident). The total volume of burning hydrocarbon-steam froth can significantly exceed the volume of the tank, raising the possibility that the secondary containment could be exceeded by the burning froth. The elevation and grade should be considered when establishing placement of personnel and equipment to prevent exposure to burning boilover liquids running downhill. Finally, history shows that tanks can experience more than one boilover.

G.3 Slopover

A *slopover* is the minor frothing that occurs when water is sprayed on the hot surface of a burning oil. The oil must be viscous and its fluid temperature must exceed the boiling point of water. Since only the surface oil is involved, a slopover is a relatively mild occurrence.

Figure G—1—Boilover of a cone-roof tank

G.4 Frothover

A *frothover* is the overflowing of a tank that is not on fire when water (or volatile hydrocarbon) boils under the surface of 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. When the water becomes hot enough to boil, the expanding steam generated can cause the asphalt to overflow the tank car.

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

G.5 Material Specific Hazards

G.5.1 METAL ALKYL CATALYSTS AND OTHER REACTIVE MATERIALS

A variety of reactive materials may be stored in tanks. Usually these are relatively small tanks. Lead alkyls discussed in the third section were the most common in refineries. In chemical plants, materials such as aluminum alkyls may be used— such as in polymer production. Many of these materials react violently with water. Materials in this category

should be identified in the planning phases and appropriate response determined. Typically, the material supplier can provide technical advice for emergency response.

Phenol, which may be found at refineries as well as chemical plants, can be subject to heat-initiated progressive "runaway" reactions. And, even sulfuric acid used in alkylation will generate heat when water is added into concentrated acid. This has led to overpressure in small tanks designed without frangible roofs. Since "spent acid" tanks typically have a layer of hydrocarbon, this can result in releases of flammable materials with the potential for fires.

G.5.2 LEAD-CONTAINING ANTIKNOCK ADDITIVES

From a firefighting standpoint, it is essential to understand the physical and toxic nature of lead alkyl antiknock materials. Tetraethyl lead (TEL), tetramethyl lead (TML) and related antiknocks are toxic, and above a critical temperature "pure" or "neat" alkyls can decompose violently. If these materials are present in a gasoline blending plant the safety of personnel fighting fires depends on keeping the antiknock compound below its critical temperature. If an antiknock tank has ruptured (or otherwise released its contents) skin contact and fume inhalation must be avoided. Organic lead alkyls can be rapidly absorbed through the skin. Use of self-contained breathing apparatus (SCBA) is necessary if there is probability of inhalation of lead alkyl vapors or products of their combustion.

Tanks of lead alkyl antiknocks should be uncommon in the USA. Official statements said "Leaded gasoline will no longer be available in the United States after December 31, 1995. The Clean Air Act Amendments of 1990 mandate the elimination of lead from all U.S. motor fuel by January 1, 1996." This represents the final step in a gradual reduction of lead in gasoline since the early 1970s. "Regular" gasoline typically contained approximately 2 to 4 grams of lead per gallon; average lead content was reduced to 0.5 gram/gallon in 1985, and still further to 0.1 gram/gallon in 1986. The phase-out of alkyl-lead in automotive gasoline became final on December 31, 1995, when 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].

However, if lead alkyl tanks are encountered in a fire situation, special considerations are necessary for personnel protection. The following is included because information has become difficult to get with phasing out of lead and the scarcity of suppliers with technical support.

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 should be exercised in deciding the course of action to be taken. The following are recommended in the event of fire in the area:

- Stop transfer and blending operations.
- Use proper personal protective equipment.
- 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.
- 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.
- Extinguish hydrocarbon fires in the area.
- Use dry chemical to extinguish vent fires or fires involving flowing hydrocarbons.
- 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.

Water has been found effective for extinguishing burning antiknock compounds. 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.

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 (supplied by antiknock manufacturers 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 total of 4500 kg (10,000 lbs) 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 min in which to set up portable monitor nozzles to cool the tank or, if that fails, to evacuate personnel from the area.
- A total of 11,000 kg (24,250 lbs) 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 min in which to set up portable monitor nozzles to cool the tank or, if that fails, to evacuate personnel from the area.
- A total of 45,000 kg (100,000 lbs) 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.

The "classic" reference on lead alkyl antiknock emergency response from which much of the above information was drawn can be difficult to obtain. It is: *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 in 1970.

G.5.3 SPECIAL SITUATIONS INVOLVING PRESSURIZED GAS STORAGE

If pressurized gas storage spheres or "bullets" are in a tank fire area then special recognition should be given to the potential for a BLEVE (Boiling Liquid Expanding Vapor Explosion). A BLEVE is the catastrophic failure of a container into two or more major pieces at a temperature well above the atmospheric pressure boiling point of the contents. Classic cases of BLEVE have involved liquefied petroleum gas containers such as LPG rail cars where violent fire and explosion has been caused by rupture of the vessel wall. This rupture can be caused by localized overheating (such as by jet impingement) which reduces the strength of the container while increasing the internal pressure beyond the venting capability of the vessel being exposed to fire.

Recommended practice is to evacuate non-critical personnel and to establish cooling at the point of jet impingement using cooling water at the rate of 250 to 500 g/min (1000 to 2000 l/min).

The BLEVE phenomenon is applicable to other volatile liquids as well as to LPG. (See API Std 2510, Pub 2510A and the NFPA *Flammable and Combustible Liquids Code Handbook* for further information.)

APPENDIX H—FIRE SUPPRESSION AGENTS

H.1 General

Fire suppression is achieved by cooling, inhibiting vapor formation, eliminating oxygen or interfering with the free-radical chemistry of combustion. This section describes fire-fighting agents useful in fighting fires in storage tanks that contain flammable and combustible liquids and ground fires that could involve storage tanks. The effectiveness and usefulness of various fire suppression agents is a function of the type of fire and the fuel involved. Only agents and equipment designed specifically for fighting liquid fires should be used.

H.2 Water

Water is an ideal fire suppression agent. Water serves as a cooling, quenching, smothering, emulsifying, diluting, and displacing agent. It is used to cool equipment, structures, and tank shells that are exposed to the heat from a fire, thus preventing or reducing both heat damage to equipment and overpressure that could result from overheating vessel contents. 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 of foam.

When properly applied in spray form, water may be suitable for extinguishing small fires in combustible liquid hydrocarbon fuels (such as diesel fuel) with flash points above 100°F (38°C). Extinguishment will result if the fuel surface can be cooled below the temperature at which the fuel gives off enough vapor to support combustion. Water used effectively can control, but not extinguish, fires in low-flash-point flammable fuels such as gasoline.

Water spray applied lightly to burning viscous liquids with flash points above 200°F (93°C) can produce a layer of froth on the liquid surface that can act like foam and smother 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 and its bulk temperature. For example, a solution of 75% water and 25% ethyl alcohol will barely support combustion. In case of tank fires, it usually will be impractical to achieve sufficient dilution.

Water can be used to displace hydrocarbon in leaking lines. It can also be pumped into a tank to float liquid hydrocarbons above a leak and thus replace product leakage with water leakage. Care should be taken to avoid flow of a higher pressure product into a lower pressure water system and to avoid overpressure of the vessel and piping. Water cannot be used to displace product when the temperature is below freezing—32°F (0°C), or for liquids above water's boiling point of 212°F (100°C). Check valves should be used to prevent hydrocarbon backflow into the fire-protection system.

Experienced firefighting personnel can use a "full fog" water spray as very effective personal protection from radiant heat and flame contact to gain access to equipment so that valves can be closed, shutting off the fuel source for fire suppression. And, in some conditions, firefighters can disperse moderate quantities of escaping gas or vapor using water spray.

Excessive or improper water usage can cause problems as noted in 8.5.6.

H.3 Foams

H.3.1 GENERAL

Foam is the primary fire suppression agent used to put out hydrocarbon fires by cooling, exclusion of oxygen and vapor inhibition. Foam delivers water to a hydrocarbon fire and makes it buoyant on the hydrocarbon surface. Foam Concentrate is a liquid foaming agent as received from the manufacturer. When a small portion (from 1% to 6%, but typically 3%) of foam concentrate is added to water it becomes a Foam Solution. The foam solution becomes firefighting foam when air is entrained. This stable aggregate of air bubbles entrained in foam solution is lighter than oil and will float on the surface of a flammable liquid. Foam flows over a liquid surface and forms a cohesive air-excluding continuous blanket that smothers and cools the fuel, inhibits the release of flammable vapors and thus extinguishes the fire. Foam also prevents reignition by inhibiting vapor release which prevents the formation of combustible mixtures of vapor and air above the fuel surface.

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 for specific fuel and delivery service. Concentrates for use at 3% have logistics advantages compared to those for use at 6% because of their efficiency in use, storage, and handling. Some manufacturers provide concentrates for use at 1%. The equipment used to proportion and distribute the foam must be compatible. Technical consultation with the foam concentrate supplier is recommended to review the specific use. Mutual aid partners may find it beneficial to establish stocks of compatible foam concentrate.

The expanded foam can be delivered to the burning surface by a variety of methods. In sub-surface injection fuel-resistant foam is injected at the base of fixed roof hydrocarbon fuel storage tanks and rises through the fuel to the surface to effect extinguishment. Foam chambers or specially designed monitors permanently fastened to the tank at the top

perimeter deliver expanded foam directly to the fuel surface. Portable ground monitors deliver streams of foam "over the top" of the tank wall onto the burning surface. Current technology allows portable monitors to be built with the capacity to deliver expanded foam to a fire surface in volumes essentially limited only by the amount of water and foam concentrate available. Large monitors commercially available from several sources have very large capacities, some over 10,000 g/min (40,000 l/min). They are considered a viable option for large tank fires.

Applying a foam blanket to fuel spills before ignition may prevent a spill from becoming a fire; however, there can be concerns regarding static charge formation as a source of ignition when applying foam to unignited fuel on a tank as discussed in Appendix I. This concern is greatest when monitor streams lead to "plunging" of the foam and lowest with more gentle Type I or Type II application.

Foams are particularly suited for extinguishing two-dimensional (flat) flammable liquid fires that result from spills or involve pool fires such as in storage tanks. The foam forms a vapor-sealing blanket that extinguishes the fire and secures the area after extinguishment. In fires involving jetting or falling fuel, such as an overflowing tank or line flange leak, foam is effective only on the fire from fuel spills and pools that form flat surfaces. Foam is not suitable for extinguishing fires which involve flammable gases or liquids containing large amounts of liquefied petroleum gas or liquids with vapor pressure above atmospheric pressure. 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.

Three-dimensional fires can be extinguished by securing the pool fire with foam and then extinguishing the falling fuel by shutting off the source of fuel that is feeding the fire and extinguishing any residual fire with dry chemical. Three-dimensional or falling-fuel fires involving combustible liquids with flash points above 140°F (60°C) can usually be extinguished by using water or foam spray after the pool fire is extinguished and secured. Combined or sequential application of foam and dry chemical is also an option. The source of fuel should be blocked in to avoid reignition.

To extinguish tank fires or liquid fires in depth, continuous foam application at the required rate is essential. The fire will not be extinguished until a complete foam blanket covers the fuel surface. The rate established for continuous foam application for a specified minimum time is based on tests and experience to establish a foam blanket. Once the foam blanket is established it is important to replenish it by continued application to the liquid surface to maintain a sealing, cohesive foam blanket. The integrity of the blanket should be monitored and maintained for the safety of personnel and to prevent reignition.

When foam is applied by hand lines or monitors over the rim of a tank, wind and thermal updrafts can carry a portion of it away. Foam flow is increased to a higher application rate to replace this loss; the 60% higher rate for "over the top" application specified in NFPA 11 is intended to compensate for these losses.

To produce a good-quality foam blanket, the water quality should be appropriate for the foam concentrate being used. In general, 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 should not be used without prior consultation with the foam concentrate supplier. Recycled water from skim ponds or separators is of potential concern, because trace amounts of oil may affect the quality of the foam blanket.

H.3.2 FOAM APPROVALS

There are a large number of "approval" types available from various organizations around the world. In the USA the primary referenced approvals are Underwriters Laboratories Standard UL 162, and US Military Specification MIL-F-24385-F for AFFF listing on the US Military QPL (Qualified Product List). When comparing foam approval performance it is important to know specifically for what specification the approval has been granted, and the specifics of the approval conditions. Variables to consider are percentage of foam concentrate in the solution tested, application rates (which may vary depending upon the fuel) and any restrictions that accompany the approval. For instance, foam approvals for use at 1% may be restricted to portable aspirating nozzles on spills of not greater than 1 in. (25 mm) depth. See UL Fire Protection Equipment Directory for details on compatible equipment listings when UL approvals are involved.

H.3.3 STOCKING AND STORING FOAM CONCENTRATES

Storage of foam concentrates can be done in buckets, drums, large containers, in tankage on fire trucks or foam tenders, or in bulk. When preparing for tank fire suppression, large container or bulk storage is preferable as back-up to on-board supplies because of the large quantities of foam required. The manufacturer of the foam should be consulted to determine the necessary conditions for storage without deterioration. The manufacturer can also advise regarding the storage temperature constraints. A representative recommended storage environment is within the UL-listed temperature range of 20°F to 120°F (–7°C to 49°C). Where foam concentrate is stored in bulk on board foam pumper fire engines, the equipment manufacturer should be consulted to ensure that there are no corrosion concerns. (Similar advice should be obtained regarding proper flushing of lines and pumps following foam use.) Some foam concentrates are subject to evaporation that accelerates when the product is exposed to air. Storage tanks should be protected against free

exchange of air (such as by sealing and fitting with a pressure/vacuum vent). Periodic (such as yearly) sampling and testing is generally advised to ensure that the foam concentrate will perform as designed when removed from storage. Most foam suppliers offer a testing service if none is available locally.

H.3.4 TRANSPORTING FOAM CONCENTRATES

Foam is available in bulk containers that can be used both for storage and transporting foam concentrate to an incident scene. These hold quantities equal to about 5+ drums. In the United States 275 gal (1041 l) to 305 gal (1155 l) reusable "tote tanks" are available, and outside the US 1,000 l containers are offered. A method should be determined for moving these containers to potential incident scenes, as should a route accessible while an emergency response is in process.

Some facilities dedicate a flatbed trailer to foam transport; foam drums or bulk containers are stored on the trailer enabling quick attachment of a motive source to move the foam supply to the incident scene. Bulk storage is used at some locations with the ability to rapidly refill foam tenders which are used as shuttles to move foam concentrate to an incident scene.

Personnel required to operate any needed specialized heavy equipment should be identified and included in emergency response call-out lists.

H.3.5 MIXING FOAM CONCENTRATES

Different types and brands of foam concentrates 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. NFPA 11, 16, and 16A all specifically prohibit mixing different manufacturer's foam concentrates in long term storage.

The military system is designed to depend on compatible mixed storage of AFFF products qualified by the Naval Research Laboratory (NRL) under MIL-F-24385; products on the Qualified Products List (QPL) are tested for mixed storage compatibility. Some foam suppliers appear comfortable with this. However, other manufacturers recommend against considering this practice in industrial situations. They emphasize that the Military compatibility requirement applies only to products on the QPL. The MIL testing is based on ten days storage in glass, and some foam manufacturer's experience is that the material of the storage tank can have an effect on concentrate stability. Before planning mixed storage the assurance of each supplier should be obtained that the foam concentrate is on the MIL-F-24385 F QPL and that the supplier agrees that mixed storage is OK. Mixed storage generally is avoided in industry as introducing unnecessary potential problems with concentrate stability, usability and performance.

H.3.6 FOAM PERFORMANCE CRITERIA

Foam quality is a combination of measures of an expanded foam's physical and performance characteristics. This includes the foam's 25% drain time, expansion ratio, viscosity and burn-back resistance. The 25% drain time is the time required for 25% of the liquid contained in the foam to drain; this is an indication of the water retention ability of the foam, and thus the stability of the foam blanket. The expansion ratio is an indication of the amount of air entrained; in general, when more air is entrained (higher expansion) the drain time increases. Viscosity of the expanded foam is an indication of how rapidly it will flow on the burning fuel surface; generally viscosity (resistance to flow) increases as more air is entrained to produce higher expansion ratios. Burnback resistance in standardized tests (in UL 162 or MIL-F-24385) measure the ability of a foam blanket to resist destruction when subjected to radiant heat from an open flame; in general, foam burnback performance is better at higher expansion ratios.

At low flow rates, such as used in hand lines, non-aspirated foam produces expansion ratios in the range of 2:1 to 4:1; at high flow rates, such as in high flow monitors, non-aspirated foam may reach 6:1. Typical aspirated low-expansion delivery for AFFF would be in the 6:1 to 12:1 range. During delivery a foam stream should travel farther and be less affected by the wind at low expansion rates, irrespective of whether the stream is aspirated or non-aspirated. NFPA 11 recommends expansion ratios of 2:1 to 4:1 for subsurface injection.

H.3.7 PROTEIN FOAM CONCENTRATES

Protein foam concentrates, introduced in the mid 1930's, have been used widely for petroleum-spill and tank fires. They consist primarily of products from hydrolyzed proteins plus stabilizing additives and inhibitors to lower the freezing point, prevent corrosion of equipment and containers, resist bacterial decomposition and control viscosity. Primary use is to extinguish fires in hydrocarbon fuels where they can be expected to provide a stable long-lasting foam blanket with excellent burnback resistance. Normal dilution rates are 3–6%. For best performance protein foam concentrates should be used with aspirating nozzles and foam making equipment, and applied gently. Protein foams are not suitable for sub-surface injection.

Protein foam concentrates are incompatible with dry chemicals extinguishing agents either separately or as twin agent systems unless used with a dry chemical agent specifically recommended for that application.

H.3.8 FLUOROPROTEIN FOAM CONCENTRATES

Fluoroprotein foam (FP) concentrates are similar to protein foam concentrates but have synthetic, fluorinated surfactant additives. These increase fluidity of the foam enabling it to seal around obstructions and form an air-excluding foam blanket which may also deposit a film on the surface of a liquid fuel to inhibit evaporation. They were introduced in the mid-1960's to improve the performance of protein foam. FP foam has a much better resistance to fuel entrainment when compared with protein foam when submerged in the liquid fuel. This characteristic makes FP foam suitable for subsurface injection into tanks containing non-polar liquid hydrocarbons or for monitor or hose stream application over the rim of a tank where "plunging" of the foam stream into the fuel can be expected. Like protein, FP foams generally have greater stability and resistance to burn-back than other types of foams when used on petroleum fuels. FP foams possess excellent sealing action on hot metal surfaces and the foam blanket tends to reseal when disturbed by personnel or equipment. Concentrates are diluted with water to a 3 or 6% solution by volume, in accordance with the manufacturer's specifications. Like protein foams, fluoroprotein foam concentrates are incompatible with dry chemical extinguishing agents either separately or as twin agent systems unless used with a dry chemical agent specifically recommended for that application. Some specific FP foams have approvals for use on oxygenated gasoline blends (at higher specific application rates) and slightly polar oxygen blending additives such as MTBE, ETBE, and TAME, but not highly polar solvents such as methanol, ethanol or isopropyl alcohol.

H.3.9 AQUEOUS-FILM-FORMING FOAMS

Aqueous-film-forming foams (AFFFs) consist of synthetic fluorinated surfactants, hydrocarbon surfactants, detergents, solvents, and water. AFFF foam acts as a barrier to exclude air and also develops an aqueous film on the fuel surface capable of suppressing the evolution of fuel vapors from most petroleum fuels.

AFFF foams are designed for rapid fire knockdown by producing a thin aqueous film which spreads across the surface of the fuel, separating the fuel from oxygen. This is accomplished by allowing the foam solution to quickly drain from the foam bubble which in turn, affects long term sealability and burnback resistance. The aqueous film is produced by the fluorocarbon surfactant reducing the surface tension of the foam solution to a point where the solution can be supported by the surface tension of the fuel. The effectiveness of the aqueous film is directly influenced by the surface tension of the fuel. The film tends to be more effective on fuels with higher surface tension such as diesel and jet fuels, and less effective on fuels with lower surface tension such as hexane and gasoline. The vapor seal film may reseal and inhibit reflash if the foam blanket is ruptured and helps AFFF foam secure non-ignited spills. The same characteristics which provides rapid flame knockdown on short preburn, shallow spill fires (eg. aircraft crash fires), can make conventional AFFFs less suited for use on hot, deep-seated fires with extended preburn (eg. storage tank fires).

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. 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 applying protein foams. However, it is advisable to consult with the manufacturer before converting protein foam-proportioning for use with AFFF concentrates. Additionally, a thorough flushing of the complete system, including the foam tank, is required.

When used on tank fires, topside application by permanently attached foam systems or portable methods is a typical strategy. Some AFFFs are also suitable for subsurface injection into tanks containing ordinary hydrocarbons. AFFF is not suitable for use on polar solvents or water miscible fuels such as alcohols, ketones, esters, and ethers.

AFFFs are available for use at from 1–6% concentration. 1% applications are typically for special fixed systems (such as airport hanger sprinklers) where the foam percentage can be closely controlled.

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 using these concentrates are compatible and can be applied to a fire in sequence or simultaneously.

H.3.10 FILM-FORMING FLUOROPROTEIN FOAMS

Film-forming fluoroprotein (FFFP) foam uses fluorochemical surfactants in a protein base with stabilizing additives and inhibitors (to protect against freezing, corrosion and bacterial decomposition). FFFP combines characteristics of AFFF and FP foam. The foam 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 and with both protein and fluoroprotein foam.

Alcohol Resistant 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 plastic-like film on the surface of the fuel. They can be used in conventional foam-making devices. Higher concentrations or higher application rates may be required for water-miscible products.

H.3.11 ALCOHOL-RESISTANT FOAM CONCENTRATES

Alcohol Resistant (AR) foam concentrates are designed to be effective on fires involving liquid polar solvents which can cause conventional foams to be ineffective. Special foam concentrates are available that form an insoluble polymeric 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. Originally available only as concentrates for use at 6% on polar solvents and 3% on petroleum products, concentrates are now available for use at 3% on both types of fire. Some AR concentrates function as AFFFs on petroleum products.

Several different approaches to alcohol resistant foam are available. All-synthetic alcohol-resistant film-forming foam (AR-AFFF) concentrates and alcohol resistant FFFP foam are marketed as multi-purpose foams suitable for use on hydrocarbons or oxygenated solvents in permanently installed foam equipment or ground monitors and for subsurface injection on hydrocarbons. Systems that use these agents may require special design considerations.

Different alcohol-resistant foam concentrates should not be mixed together, nor should they be mixed with other categories 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 highly polar water-miscible liquids. For requirements and limitations see NFPA 11.

Certain oxygenated fuels, such as MTBE are low polarity and are not very water miscibile. Some fluoroprotein and FFFP foams not categorized as AR may be effective for use on gasoline/ MTBE blends or 100% MTBE.

H.3.12 CHEMICAL FOAMS

Chemical foams, introduced in the late 1920's, are outdated, obsolete and no longer recommended for use. They form foam by a chemical reaction between two powders that contain alkaline and acidic salts.

H.4 Dry Chemicals

H.4.1 DRY CHEMICAL FIRE SUPPRESSANTS–GENERAL

Dry chemicals are highly efficient in extinguishing fires involving flammable liquids. The finely divided chemical particles are free-radical interceptors break the combustion chain reaction oxidation process within the flame. Because they do not cool, dry chemicals do not secure the fuel against reignition if it is exposed to ignition sources such as metal heated by the fire which has been extinguished. Dry chemicals have been used, either alone or in combination with foam, to extinguish fires in the seal areas of floating-roof tanks, even when a large area of the seal is burning. They are effective on small spill fires involving jetting or falling fuel, although these fires are preferentially extinguished by shutting off the fuel. If the fire has a continued pressurized fuel source there is risk of reignition. Potential ignition sources should be quenched or cooled with water and secured with foam if dry chemical is used before the source of fuel is secured.

Several types of dry chemical 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. Foams based on AFFF or FFFP chemistry generally are recommended for use in dual agent dry chemical applications. For additional information concerning dry chemicals, consult NFPA 17 or the dry chemical agent supplier.

H.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.

H.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.

H.4.4 POTASSIUM BICARBONATE

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

H.4.5 POTASSIUM CHLORIDE

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

H.4.6 MONOAMMONIUM PHOSPHATE

Monoammonium phosphate (or a mixture of monoammonium and diammonium phosphates), a multipurpose "ABC" 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.

H.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.

H.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.

H.4.9 DRY CHEMICAL AGENT COMPATIBILITY

Monoammonium phosphate (Type ABC) is chemically incompatible with the sodium and potassium bicarbonate dry chemical agents. The reaction products are ammonia and carbon dioxide. If mixed in an extinguisher the evolution of these gases in a closed container can result in undesirable high pressure and loss of agent fluidity (caking). Care should be exercised to avoid mixing of agents.

H.5 Foam Applied Simultaneously with Dry Chemicals

Hose reels equipped with twinned hoses and twinned nozzles, turrets equipped with twinned nozzles, stand-alone twin-agent systems and integrated foam nozzles designed for coaxial dry chemical application have been developed for simultaneous or alternating application of foam and dry chemical. AFFF, FFFP or Alcohol Resistant Foam and potassium bicarbonate are usually the two agents. For integrated stand-alone installations the foam concentrate may be 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 50–200 ga (189–757 l) of premixed AFFF solution and from 500 to 3000 lbs (227–1361 kg) 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. The larger integrated nozzle systems are available in monitor sizes with flows of 2000 g/min (7500 l/min) foam and a nominal 40 lb/sec (18 kg/sec) dry chemical. The benefits quoted are the ability to cool and provide initial suppression with the foam (thus reducing potential for reignition) followed by suppression of the more difficult fire areas with the dual foam/dry chemical which can be projected with the foam stream up to 100 ft (30 m).

H.6 Halogenated Hydrocarbon Extinguishing Agents and Clean Agent Alternatives

Halon 1211 is an extremely effective fire fighting agent used in portable fire extinguishers for many years. Unfortunately, Halon 1211 has been judged to be an ozone depletion agent, and its manufacture in the United States has been suspended since 1994. Under US federal law it is still legal to posses, use, or recharge a Halon 1211 fire extinguisher. No federal phase out date has been set. Recharge supplies of agent manufactured before 1994 are available through specialists to recharge extinguishers.

Halon extinguishing agents such as 1211, 1301 and 2402 are no longer recommended for use in new installations in accordance with the Montreal Protocol, due to concerns regarding effects on the earth's ozone layer. For maintenance of existing Halon 1301 systems, refer to NFPA 12A Halon. A variety of Halon replacement agents are currently available. See NFPA 2001 Standard on *Clean Agent Fire Extinguishing Systems* for total flooding systems.

APPENDIX I—THE POTENTIAL DANGERS OF POURING FOAM ONTO PETROLEUM

From CONCAWE Review Volume 6, Number 2, October 1997[7]:

I.1 Attempts to prevent the outbreak of fires by using fire-fighting foam in tanks where the floating roofs had sunk are believed to have occasionally ignited the oil and led to serious fires.

Over the years, there have been a number of incidents, mostly involving a failed floating roof of a petroleum storage tank, where the oil caught fire unexpectedly. A common factor of these fires was that a foam blanket was being applied to the exposed surface of the fuel to prevent ignition or to minimize evaporation of the fuel.

It is well known that the generation of static electricity when pumping refined products is greatly increased by small quantities of water and that discharges of static can ignite oil. It was realized, therefore, that in these situations, electrostatic charging mechanisms might have led to the ignitions. These could be caused either by an electrochemical interaction between the foam and the fuel, or by charge generation in the foam branch-pipe.

A limited programme* of laboratory and medium-scale experiments was carried out to test a number of theoretical possibilities. The presence of an electrochemical charging mechanism was confirmed in experiments on both scales. Although the charge generated by the small hand-held branch-pipes used in these experiments was demonstrated to be a contributory factor to the hazard, the 3.4 m diameter tank used in the medium-scale work was not large enough to simulate realistically the application of foam to a large tank. The charging mechanism was considered too complex to use the data to predict the behaviour of larger foam monitors in a practical case.

However, the work clearly demonstrated that a potential hazard exists, and provides sufficient information to give general guidelines for minimizing the hazard. The use of these guidelines should be considered in the event of an incident involving pools of refined products above the floating roofs of open topped storage tanks or other situations where there are deep pools of exposed refined petroleum products.

In order to give these guidelines a wider circulation, they are reproduced in the next section. It must be stressed that this is only guidance and each incident must be assessed taking the particular situation into account. There are circumstances in which foaming is the correct action and the guidelines also offer information on the safest way to do this.

Copies of the page can be obtained from CONCAWE on request.

[7]CONCAWE Madouplein 1, B-1210 Brussels Belgium Telephone: 32-2-220 3111 Telefax: 32-2-219 4646. http://www.concawe.be/

* This programme was sponsored by BP Oil Ltd. and was undertaken by staff at their UK Research Centre.

CONCAWE is the oil companies' European organization for environment, health and safety. The emphasis of its work lies on technical and economic studies relevant to oil refining, distribution and marketing in Europe. CONCAWE was established in 1963 in The Hague, and in 1990 its Secretariat was moved to Brussels.

I.2 CONCAWE RECOMMENDATIONS on how to deal with an exposed unignited pool of flammable refined petroleum product.

This situation is most likely to occur when the roof of an open topped floating roof tank has sunk. It may also arise in the event of a deeply flooded bund area.

- The recommendations do NOT apply to shallow pools (E.G. ground spills).
- Flammable refined products include naphtha, gasoline, kerosene and similar fuels.
- The recommendations do NOT apply to crude oil which is not a static accumulator.

RECOMMENDATIONS:

STOP ALL TRANSFER OPERATIONS until it has been shown that it is safe to continue.

- Determine the extent of the hazardous environment using gas detectors. Remove/prevent any sources of ignition in this area and prohibit personnel access.
- Set up the resources as stipulated in the pre-fire plan in readiness for a fully involved surface fire.

DO NOT FOAM UNLESS:

- It is necessary to protect personnel from fire or flash burns if ignition were to occur during restoration of the floating roof or removal of product.
- There is an uncontrollable ignition source in the vicinity such as an approaching electrical storm, fired heaters, road traffic etc.
- It is necessary to apply a foam blanket to control vapour emissions which would pose a greater hazard than a fire.

IF FOAM IS APPLIED:

Never apply foam or water directly to the fuel surface.

- Apply the foam gently down the inside walls of the tank using permanently installed foam pourers (chambers) wherever possible.
- Foam generated by handlines or monitors should be applied onto the inside surface of the tank and allowed to slide down the tank wall onto the fuel surface.
- Wherever possible the use of portable foam inductors which induce foam into the delivery hose should be avoided. Foam production should be by means of fire

pumps having built-in inductors or round-the-pump proportioners.

- If portable inductors are the only type available, ensure full foam output is established with the jet directed away from the tank before applying the foam to the tank walls.
- After applying foam, maintain a total surface covering at all times. This will require adequate stocks of foam to be on hand.
- Even in the event that a tank fire has been successfully extinguished, vigilance should be maintained until most of the product has been removed. The natural degradation of the foam blanket could promote a build-up of electrostatic charge and, hence, ignition is a concern as the foam drains through the remaining fuel.

APPENDIX J—FOAM FRICTION LOSS & BACK-PRESSURE

Foam friction loss and back-pressure are especially significant when using subsurface injection. Typically the foam is aerated at some distance from the tank in a high back-pressure foam maker at an expansion ration of between 2:1 and 4:1. The foam delivery system must overcome the static head of the liquid in the tank and the friction loss in the piping. The allowable back-pressure is in the range of 25% to 40% of the inlet pressure to the high-pressure foam maker (depending on the specific equipment's rating). At the point the foam reaches the tank the velocity should not exceed 10 ft/sec (3 m/sec) for light Class 1B liquids (like gasoline) or 20 ft/sec (6 m/sec) for heavier classes of liquid. NFPA provides detailed guidance for determining liquid head, friction and velocity for a variety of piping size and tank configurations.

APPENDIX K—DETERMINING FOAM CONCENTRATE REQUIREMENTS FOR FULL SURFACE FIRES

K.1 General

Fire-fighting operations at petroleum storage facilities require an understanding of the amount of water and foam concentrate required for successful suppression. NFPA 11 provides the accepted guidelines for the minimum application rates and the duration for which application at this rate should be continued. Factors affecting the application rate and time are:

- Method of foam application.
- Type of material on fire (physical properties and soluility in water).
- Duration of preburn (for hydrocarbons with a wide range of boiling points).

Table K-1 summarizes minimum application rates, while Table K-2 addresses time that foam should be applied at that rate. These are based on NFPA-11.

When in accordance with NFPA 11, protection for tanks over 60 ft (18 m) in diameter consists of primary protection through permanently attached systems with supplemental protection generally being provided by portable or mobile application devices.

K.2 Primary protection

Foam concentrate requirements are determined by the following equation:

$$C = RSTF$$

Where:

C = concentrate required, in gallons.

R = rate of foam solution application, in gallons per minute per square foot.

S = liquid surface area, in square feet.

T = application time, in minutes (see NFPA 11).

F = foam concentrate, as a percent of foam solution.

Table K-2 provides information consistent with NFPA 11 for application rates and time of application which can be used for calculating foam concentrate requirements.

K.3 Supplemental protection

For protection in addition to the requirements listed in K2, the following equation is used:

$$C = NLTF$$

Where:

C = foam concentrate required, in gallons (liters).

N = nozzle application rate of foam solution, in gal lons per minute (liters per minute).

L = number of lines needed at 50 g/min (190 l/min) per hose line (see NFPA 11).

T = application time, in minutes (see NFPA 11 requirements shown in Table K-3).

F = foam conentrate, as a percent of foam solution.

Supplemental protection is in addition to permanently installed foam chamber protection. Per NFPA 11, it is not added to foam requirements when handlines or monitors are used in lieu of permanently installed protection. Table K-3 shows the number of supplemental hose streams of 50 g/min (190 l/min) each called for in NFPA 11. These are intended for “first aid” firefighting, not suppression of major spill fires. The minimum operating time allows calculation of the total amount of foam concentrate required for supplemental hose streams.

K.4 Examples

K.4.1 EXAMPLE 1

K.4.1.1 Problem statement

A cone-roof tank 48 ft (14.5 m) high and 60 ft (18 m) in diameter contains kerosene with a flash point of 120°F (49°C). The tank is protected by semi-fixed foam chambers permanently attached to the shell. In accordance with NFPA 11 (as shown in Table K-1) for tanks with semi-fixed fire protection the application rate is 0.1 g/min/ft^2 (4 l/min-m^2) and the duration of discharge is 30 minutes.

K.4.1.2 Primary Protection Calculation

The primary protection requirement is calculated as follows:

Foam solution flow rate

= area × application rate = 2828 ft^2 × 0.1 g/min/ft^2 = 283 g/min foam solution

= 254 m^2 × 4 l/min-m^2 = 1016 l/min foam solution

Foam concentrate flow rate

= 283 gallons per minute at 3% (0.03) = 283 × 0.03 = 8.5 g/min foam concentrate

= 1016 l/min foam solution at 3% (0.03) = 1016 × .03 = 30.5 l/min foam concentrate

Concentrate supply

= 8.5 g/min × 30 minutes = 255 gallons

Table K-1—NFPA Full Surface Fire Minimum Application Rate Based on Fuel and Application Method

Fuel Type	Type II Foam Chambers	Subsurface Injection	Handlines or Monitors
Hydrocarbon	0.10 g/min/ft^2 (4 l/min–m^2)	0.10 g/min/ft^2 (4 l/min-m^2)	0.16 g/min/ft^2 (6.5 l/min-m^2)
Alcohols & Oxygenates[a]	0.10– 0.16 g/min/ft^2 (4–6.5 l/min-m^2)	Not Applicable[b]	0.16 - 0.20 g/min/ft^2 (6.5 - 8 l/min-m^2)
Wide Boiling Range (Crude) Initial	0.10 g/min/ft^2 (4 l/min-m^2)	0.10 g/min/ft^2 (4 l/min-m^2)	0.16 g/min/ft^2 (6.5 l/min-m^2)
After prolonged burning -- if heat wave established	0.20 or more g/min/ft^2 (8 l/min-m^2)	0.20 or more g/min/ft^2 (8 l/min-m^2)	0.20 or more g/min/ft^2 (8 l/min-m^2)

[a] Application rates and foam concentrate percentage for specific oxygenates can vary widely and should be determined in consultation with the foam concentrate supplier.
[b] Subsurface injection is not recommended by NFPA 11 for strong polar solvents requiring alcohol-type foam. MTBE, ETBE and similar weak polar solvent materials should be reviewed with the foam supplier as special cases based on their water solubility, volatility and physical characteristics.

Table K-2—NFPA Full Surface Fire Minimum Application Time in Minutes Based on Application Method

Hydrocarbon Type	Type II Foam Chambers 0.10 g/min/ft^2 (4 l/min-m^2)	Subsurface Injection 0.10 g/min/ft^2 (4 l/min-m^2)	Handlines or Monitors 0.16 g/min/ft^2 (6.5 l/min-m^2)
Flash Point between 100°F and 140°F (38°C and 60°C)	30	30	50
Flash Point below 100°F (38°C) or liquids heated above their flashpoints	55	55	65
Crude Petroleum	55	55	65
Products requiring alcohol resistant foam	55	not recommended	65

Table K-3—Supplemental Hose Streams Recommended by NFPA 11

Largest Tank Diameter	Supplemental Hose Streams 50 g/min (190 l/min) each	Minimum Operating Time Minutes
Up to 35 ft (10 m)	1	10
35 to 65 ft (10– 20 m)	1	20
65 to 95 ft (20–29 m)	2	20
95 to 120 ft (29–36 m)	2	30
Over 120 ft (36 m)	3	30

= 30.5 l/min × 30 min = 915 l

K.4.1.3 Supplemental Protection Calculation

The supplemental protection requirement as outlined by NFPA 11 (and shown in Table K-2) is calculated as follows: for a 60 ft (18 m) diameter tank containing material with a 120°F (49°C) flash point one hose stream should be available that can furnish water at a rate of 50 g/min (190 l/min) for 20 minutes.

Foam concentrate flow rate

= 50 g/min at 3% = 1.5 g/min of foam concentrate, or

= 190 l/min at 3% = 5.7 l/min of foam concentrate

Concentrate supply required

= 1.5 g/min × 20 minutes = 30 gal, or

= 5.7 l/min × 20 min = 114 l of foam concentrate

K.4.1.4 Total System Supply

The total minimum foam concentrate supply required for the incident, based on NFPA 11, is

255 gal + 30 gal = 285 gal, or

915 l + 114 l = 1029 l

K.4.2 EXAMPLE 2

K.4.2.1 Problem Statement

A cone-roof tank 48 ft (14.5 m) high and 60 ft (18 m) in diameter contains kerosene with a flash point of 120°F (49°C). The tank is protected by a monitor nozzle. In accordance with NFPA 11 (as shown in Table K-1) the application rate is 0.16 g/ming/min/ft^2 (6.5 l/min-m^2) and the duration of discharge (Table K–2) is 50 minutes.

K.4.2.2 Primary protection

The primary protection requirement is calculated as follows:

Foam solution flow rate

= area × application rate = 2828 ft^2 × 0.16 g/min/ft^2 (6.5 l/min-m^2) = 453 g/min

= 254 m^2 × 6.5 l/min-m^2 = 1651 l/min foam solution

Foam concentrate flow rate

= foam solution rate x % concentrate = 453 g/min × 0.03 = 13.6 g/min, or

= 1651 l/min at 3% = 49.5 l/min of foam concentrate

Concentrate supply required

= concentrate flow rate x time = 13.6 g/min × 50 min = 680 gal

= 49.5 l/min × 50 min = 2475 l of foam concentrate

K.4.2.3 Supplemental protection

According to NFPA 11 no supplemental protection is required when using a monitor (or hose lines) for primary tank fire suppression.

K.4.2.4 Total system supply

The total minimum foam concentrate supply required for the incident based on NFPA 11 is 680 gal for a 60 ft diameter tank (2475 l for a 14.5 m diameter tank).

K.4.3 EXAMPLE 3

K.4.3.1 Problem statement

A floating-roof tank 56 ft (17 m) high and 150ft (45.5 m) in diameter contains gasoline with a flash point of 45°F (7°C). The tank is not protected by a permanently installed foam system. Suppression will be accomplished using portable monitors. In accordance with NFPA 11, the application rate is 0.16 g/min/ft^2 (6.5 l/min-m^2) and the duration of application is 65 minutes.

K.4.3.2 Primary protection

The primary protection requirement is calculated as follows:

Foam solution flow rate

= area × application rate = 17,671 ft^2 × 0.16 g/min/ft^2 (6.5 l/min-m^2) = 2827 g/min foam solution

= 1626 m^2 × 6.5 l/min-m^2 = 10,569 l/min foam solution

Foam concentrate flow

= 2827 g/min of foam solution at 3% = 2827 × 0.03 = 85 g/min of foam concentrate

= 10,569 l/min of foam solution at 3% = 317 l/min of foam concentrate

Concentrate supply required for primary protection

= concentrate flow rate x time = 85 g/min × 65 min = 5525 gal of foam concentrate

= 317 l/min × 65 min = 20,605 liters of foam concentrate

K.4.3.3 Supplemental Protection

According to NFPA 11 no supplemental protection is required when using a monitor (or hose lines) for primary tank fire suppression.

K.4.3.4 Total System Supply

The total minimum foam concentrate supply required for the incident, based on NFPA 11, is 5525 gal (20,605 l).

APPENDIX L—DETERMINING FOAM CONCENTRATE REQUIREMENTS FOR SEAL FIRES

When foam is applied to seal fires the application rate is higher than for pool fires, but because the areas are small the required flow is modest. Two types of foam discharge outlets for seals on open-top floating roof tanks are recognized by NFPA 11. One uses Type II devices to direct foam into the top-of-the-seal area and is intended to be used with a foam dam. The other directs foam into the space below the seal or weathershield.

The application rates and times of application are shown in Table L-1. For determining the area to which the foam will be applied the following rationale can be used. For above the seal application, the area to be foamed equals the circumference of the tank times the distance from the tank wall to the foam dam not less than one nor more than two feet (0.3–0.6 m). If portable equipment (such as handlines) will be used, it is reasonable to multiply the permanently installed foam chamber flow by the same 1.6 factor used to accommodate foam losses for full surface fires when "over the top" application is used versus foam chambers. This rationale is the basis for the "portable equipment" values in Table L-1.

For foam injection into the area below the weathershield or seal, the area should be the circumference of the tank times the distance from the tank wall to the floating roof pan, typically about 8 in. (0.2 m). Engineered systems should be based on the actual measurements of the specific tank. In determining and controlling foam application rates, it is important to achieve the suppression goal with the minimum amount of water to avoid overloading the roof. Roof drains should be open unless there is hydrocarbon on the roof.

Table L-1—Foam Application and Time for Seal Fire Suppression Consistent with NFPA 11 Recommendations.

Foam Application Location	Application Density	Application Time, Minutes
Above the Seal - foam chambers	0.30 g/min/ft^2 (12 l/min-m^2)	20
Above the Seal - portable equipment	0.50 g/min/ft^2 (20 l/min-m^2)	20
Below the Weather Shield or Seal	0.50 g/min/ft^2 (20 l/min-m^2)	10

APPENDIX M—WATER FLOW THROUGH FIRE HOSES AND PIPES

For fire suppression, a basic concern is how much water can be pumped with available systems, and what the pressures will be at the point of need. The general principles for pipes are the same for hoses (which can be considered "just flexible pipes").

The amount of water which will flow from a given centrifugal fire pump depends on the pump flow capacity (g/min or l/min) at the pressure which results from the resistance of the pipe and hose system into which it is pumping. As the pressure goes up (more resistance) the flow goes down.

At a given flow rate (g/min or l/min), the resistance of pipes or hoses is a function of the pipe or hose length, diameter and "roughness" (friction factor).

Resistance increases in direct proportion to the length (of pipe or hose) and decreases when the pipe or hose is larger.

Resistance increases with roughness (which increases with age because pipes accumulate scale, and hose linings fray). This is a constant for a given piping or hose condition. Resistance data can be found in the NFPA Fire Protection Handbook and from hose manufacturer's specifications.

For a given flow, resistance decreases when hose or pipe diameter gets larger for the following three reasons.

- The velocity (v) of the water increases for a given g/min flow as an inverse function of the pipe or hose diameter (d) to the second power ($v \sim d^{-2}$).
- The resistance (R) increases as the square of the increase in flow velocity and is independent of pressure in the hose ($R \sim v^2$); substituting ($v \sim d^{-2}$) means ($Rv \sim d^{-4}$) which is the cumulative effect of velocity on resistance as related to a change in diameter.
- And, since the ratio of hose or pipe friction surface area (fsv) to water volume increases in inverse proportion to diameter ($fsv \sim d^{-1}$) the overall effect of diameter on friction loss is proportional to the velocity effects related to diameter times the surface-to-volume effect -- then the total resistance $Rt = (Rv \sim d^{-4})(f\,sv \sim d^{-1}) = (Rt \sim d^{-5})$.

As a result of these three factors, for constant g/min flow rate the friction loss varies inversely with the fifth power of hose diameter ($f \sim d^{-5}$).

Thus a small increase in pipe or hose diameter results in a large reduction in friction loss and thus significantly increases discharge pressure at a given flow or flow at a given outlet pressure. In practice it takes about six hoses of one size to equal the flow through a hose of twice the diameter; an example is shown in Figure M-1. Some hose manufacturers cite a ratio of eight to one because of the designed differential in the intentional swelling of their hoses at working pressure results in larger effective diameters.

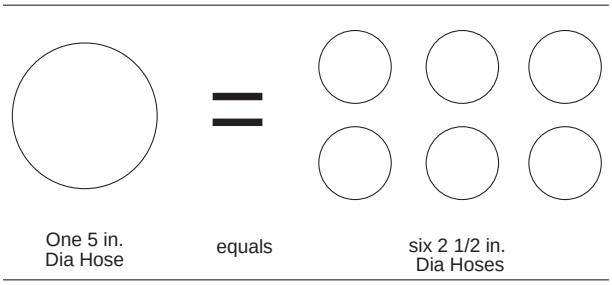

Figure M-1—Effect of Size on Flow Capability with Same Pressure Loss

M.1 Basic flow facts

For a given system velocity increases in direct proportion to the flow rate in g/min or l/min.

The pressure at the hose nozzle equals the pressure at the pump outlet minus the friction loss in the hoses and piping.

Because water is not compressible, the combined flow from the hose outlets (nozzles, chambers or monitors) is the same as the flow from the pump outlet (minus any leakage from pipes or hoses before the water reaches the nozzles).

M.2 Characteristics of water (in English system units)

One gallon of fresh water weighs 8.3 pounds (8.3453)

One cubic foot of fresh water weighs 62.4 pounds

One cubic foot of salt water weighs 64 pounds

One gallon = 231 cubic inches

One cubic foot = 7.48 gallons = 1728 cubic inches

One cubic foot per minute (cfm) = 449 gallons per minute

Pressure at the bottom of a water column is 0.43 psi per ft of height

M.3 Miscellaneous

Fire truck pumps are rated at 10 ft (3m) vertical draft and 150 psig (10 bar) discharge pressure.

Typical monitor baseline performance results are quoted for 100 psig (7 bar) nozzle inlet pressure.

APPENDIX N—OBSERVATIONS, LESSONS LEARNED AND "TRICKS OF THE TRADE"

N.1 Prevention

N.1.1 CULTIVATING A "MANAGEMENT OF CHANGE" APPRECIATION

If operations and maintenance personnel have an understanding and appreciation of basic "management of change" concepts they can assist in reducing incidents involving tanks. One key is recognizing what constitutes a "change" from an operations standpoint. An example of an MOC incident is:

A spent acid tank at a refinery alkylation plant was temporarily changed to fresh acid service without cleaning. During a delivery of fresh acid hydrocarbon vapors from the residual spent acid layer in the tank were displaced through an open vent and ignited, resulting in a tank explosion. Operations personnel did not recognize that the delivery constituted a "change" and that welding in the area under permit should be suspended before the delivery began.

N.2 Planning

N.2.1 USE OF GROUND MONITORS

During the process of tank-specific pre-incident planning, locations for placing ground monitors may be considered as one suppression option. It will be necessary to determine how high the foam stream must travel to get over the tank and how far the stream must travel to this apex point. Table N-1 shows data for water and foam streams.

From review of manufacturers flow charts for monitors we can also see that:

- Distance (range) increases with increase in pressure.
- Larger monitors (with higher flow) in the same series have more range at the same pressure as the smaller nozzle. Of course the water supply system must be able to supply the increased flow rate at the same pressure. Larger flow at the same pressure requires less friction (e.g. a larger hole or bore); with less friction loss a higher percentage of the energy is converted into velocity–allowing the stream to travel further.
- The maximum height for any angle is typically reached at about $^{2}/_{3}$ of the range.
- Maximum height and maximum distance are achieved at two significantly different monitor discharge angles.
- Foam stream height and reach are less than for water streams.
- In general, the greater the expansion ratio of the foam at the monitor the less the reach.
- Foam stream reach and height are dependent on monitor design as well as the factors above.

In planning for placement of monitors the specific capability of the equipment to be used should be determined based on the manufacturer's data, along with pressure and flow available at the proposed site. This should be supplemented by flow testing of the monitors with the actual system to be used to confirm actual performance conformance to specifications. Consideration of the planned monitor placement should be included to ensure the reach is sufficient to reach the tank without over-shooting it. Planning should recognize the probable need to reposition equipment during an incident because of wind shifts. Hoses lays supplying ground monitors should be along or parallel to roads and not across roads. The necessary multiple hoses required can inhibit logistics access and may block escape routes if conditions change.

N.2.2 USE OF FIREBOATS

Where the facility has access to waterfront and there is also availability of a fireboat then it may be possible to arrange piping connections at the waterfront or dock area. Properly arranged, a fireboat can connect to the facility firewater system and pump water into the firewater system providing additional firewater pumping capacity to supplement the on-site firewater system.

Table N-1—Reported Angle for Monitor to Achieve Maximum Height or Distance

Type of Equipment (from different suppliers)	Angle for Height	Angle for Distance (Range)	Optimum
Solid Fire Streams (Historical[a])	60 to 75 degrees	30 to 35 degrees	
High Capacity Water Monitor[b]	80 degrees	35 degrees	50 degrees 60% of ht, 95+% distance
Foam Cannon[b]	60 degrees	35 degrees	
Foam Nozzle on Monitor[b]		25 to 30 degrees	
High Volume Foam Monitor[b]		Data reported at 35 degrees	
[a] From *Hydraulics for Fire Protection*, Harry E. Hickey, NFPA 1980.			
[b] From various manufacturer's performance data.			

N.2.3 USE OF DRY-LIFT PIPING

If the facility has access to water, and if the draft to the water is not in excess of 10 ft, there may be another option to supplement flow through the firewater mains. It may be possible to install onshore piping that will allow a "pumper truck" or a portable pump to take suction from the body of water and pump into the FW system. This approach can be used where there is not a firewater mains system but access to the water would be difficult for a pumper truck. The permanently installed dry lift piping can speed putting response equipment into service.

N.2.4 FIREWATER CONNECTIONS WITH ADJACENT PLANTS.

Two adjacent facilities may share a fenceline. It may be possible to arrange valved piping between the independent firewater systems to provide supplemental "mutual aid" firewater. If the firewater systems are not adjacent, but within a few hundred feet, it may be feasible to provide large diameter hose fittings on each system to allow temporarily connecting one facility's firewater supply with that of the neighbor.

N.2.5 REGULATORY REPORTING

N.2.5.1 Federal Environmental Reporting

While this recommended practice does not specifically address environmental issues, in the event of a tank fire and release there may be a need to make an environmental report to a Federal Agency. The National Response Center serves as the sole national point of contact for reporting all oil, chemical, radiological, biological, and etiological discharges into the environment anywhere in the United States and its territories. The NRC is staffed by Coast Guard personnel 24 hours per day, 365 days per year. For the Environmental Protection Agency, the NRC receives incident reports for the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), Clean Water Act, Clean Air Act, SARA Title III, and the Oil Pollution Act of 1990. At the time of this publication the NRC "on-line" internet reporting site was:

http://www.nrc.uscg.mil/report.htm

If a release requires filing an NRC report the following information will be required:

- Who you are: Your name, address and phone number. The name, address and phone number of the responsible party, if known.
- What happened: What material was released? How much was released?
- Where it happened: City, County, State Location, nearest street corner or landmark.
- When it happened: When did you discover it?
- Why it happened: How did it happen? What caused the discharge?

The National Response Center reporting number is 1-800-424-8802.

There are state (and possibly local) reporting requirements potentially relating to tank fire incidents which should be reviewed for inclusion in planning and response resources.

N.2.5.2 OSHA 8–Hour Reporting—Fatalities and Multiple–Hospitalization Incidents (29 CFR 1904.8)

The Occupational Safety and Health Administration has a final rule requiring employers to report any occupational fatality or catastrophe involving in-patient hospitalization of three or more workers within eight hours [59 FR 15594]. This requirement which revised Title 29 of the *Code of Federal Regulations* Part 1904.8, became effective May 31, 1994.

The requirement applies to each fatality or hospitalization of three or more employees that occurs within 30 days of a work-related incident. The report must include the name of the establishment, location and time of the incident, the number of fatalities or hospitalized employees, contact person, phone number, and a brief description of the incident. Employers are instructed to make their report by telephone or in person to the OSHA Area Office nearest the site of the incident, or to utilize the OSHA toll-free number, 1-800-321-6742 (1-800-321-OSHA). Do not use e-mail.

N.3 Preparing

N.3.1 REVIEWING MUTUAL AID

In reviewing mutual aid response arrangements several issues should be addressed:

- Assure that each organization that says that they use "ICS" or "IMS" is consistent with other mutual aid participants. Review specific command structures and how "Unified Command" will work (if needed).
- Review compatibility of facility system emergency response equipment firewater pipe connection threads with threads used by potential mutual aid participants, including public fire service participants. Obtain adapters as needed.
- Review compatibility of radio frequencies among all participants and determine how to resolve issues of non-compatibility. (CB radios are generally unsatisfactory and are subject to public monitoring and conflicting use of frequencies. Ham radio clubs using short wave equipment may be able to help.)
- Review of prospective mutual aid participants should include airport and military fire departments. They may be able to provide specialized apparatus and equipment to assist in extinguishing of flammable liquid fires.
- Entry into the facility should be possible, day or night, for both the initially assigned emergency response unit and followup personnel. In large complexes responders

unfamiliar with the facility may need guidance to get to their assigned positions.

- The location and identification of staging areas should be considered during planning, established during the preparation phase and used during mutual aid drills.
- Large-scale, long-duration incident operations require sufficient numbers of personnel to provide relief periods. Staffing expectations should be adjusted to accommodate the changing needs dictated by extreme heat or cold weather conditions.
- Necessary rehab facilities should accommodate resting firefighters (including food, hygiene and family communication).
- Transportation of foam concentrate supplies to the site of a potential large-scale incident should be addressed during the planning and preparation phases.
- Refueling plans should be developed to recognize the needs of fire apparatus during long-term pumping operations.
- While use of SCBA at petroleum tank fires is uncommon, it may be an appropriate precaution for some portion of the responders to certain chemical tank fires. This should be addressed in the planning phase. If the operation may require the use of self-contained breathing apparatus, a plan should be formulated for the supply of breathing air; for example, provision of spare bottles, a cascade system, or an air supply unit.

N.3.2 REVIEWING CAPABILITY OF FIREWATER SYSTEMS

- Flow test water supply to ensure that available flow and pressure are as expected.
- Test public water supply where this is a significant facility resource (history has shown that municipal utility system "advertised" flow capability may not represent actual capability).
- Where public water supply is from a single supply, review the supply system to see if a second public source (different water main) may be available in proximity to the plant.

N.3.3 COMMUNICATIONS

- Many communication systems rely on power-dependent computers somewhere in the system; non-digital analog telephones (such as may be used with Fax machines or pay phones) may function when digital systems are out of service.
- Where mutual aid responders are participating the Logistics review should consider the various radio frequencies which may be used, and whether these are compatible. Shared radios, paired personnel or cellular telephones help resolve identified concerns.
- Cellular phone systems can become overloaded during emergency situations. Access to cellular phones operating on different exchanges or from different towers or nodes may be helpful.
- Where normal communications fail, a system of "runners" carrying written instructions can be used as a "last resort"; or for transmitting information of a sensitive nature.
- In many areas "ham radio" clubs have sophisticated communications capability and are willing to provide personnel equipped and prepared to assist in emergencies using portable equipment transmitting on reliable short wave frequencies.

N.3.4 EXPLOITING FACILITY MAINTENANCE "WINDOWS OF OPPORTUNITY"

As facility maintenance becomes due several types of revision are potentially cost effective:

- Handrails can be installed on wind girders of floating roof tanks to permit safe access for seal fire suppression.
- Where firewater system maintenance includes pipe replacement, consider the installation of larger piping. Frequently the differential cost for increasing the size of pipe is small relative to the cost of the overall repair, but flow improvements can be substantial (see Appendix M for flow benefits of increased size).
- When tanks become available for maintenance consider installing access for subsurface injection of foam through one of three possible routes - a dedicated piping system, "piggyback" on existing tank product lines (with appropriate safeguard valving) or through connection fittings added to manways.
- If regrading and repair of firewalls and dikes is required, consider enlarging portions of the dike for use as equipment location spots for fire trucks or large ground monitors.

N.3.5 ON-SITE LABELING OR SIGNS

One approach to aid emergency response for tank fire incidents uses on-site posting of basic information needed for fire suppression at the tank. This information may include tank dimensions (diameter, height and surface area); type of material in tank, application method, appropriate type of foam, application rate and flow rate. While this information can be found on the tank-specific planning sheet, having it posted provides immediate access. This approach works best for tanks that are in dedicated service. A sample is shown in Figure N-1.

Some facilities use markings on dedicated tanks using the NFPA 704 diamond along with the name of the material. This can aid compliance with hazard communication requirements as well as supply information for emergency responders.

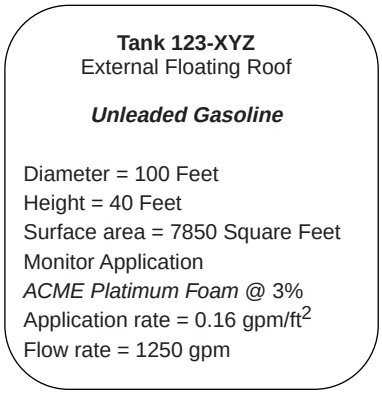

Figure N–1—Example of On-Site Tank Emergency Response Information Sign

N.4 Implementing fire suppression

Several important principles hold throughout a tank fire incident as discussed in the following sections.

N.4.1 SIGNIFICANT TANK FIRE SUPPRESSION "DO'S"

N.4.1.1 Maintain a focus on personnel safety

Do evaluate conditions using direct observation. The hose stream test (spraying water on side of the tank to determine whether the temperature at that point on the surface is hot enough for rapid evaporation of water) is an example where tank or equipment temperature is evaluated from a distance. A variation of this is described by one expert firefighter as the "Wet Glove Test"; a dripping wet glove is worn while going up the stairs of a tank (for instance with a seal fire). The water from the wet glove provides the same semi-quantitative (above or below 212°F) information regarding tank temperature and helps to identify location of a heat wave, if any.

Do consider use of infrared meters which may be available in engineering or inspection departments for measuring surface temperatures of operating equipment such as furnaces. Their use may be applicable to determine the impact of radiant and convection heating on adjacent heat sensitive storage vessels, tanks, equipment and structures, and possibly to track heat waves in boilover-potential tanks.

Do consider use of metal shielding which may provide possible stationary or mobile barriers where radiant heat loads impact emergency response personnel. These can be constructed of corrugated steel roofing. Before this approach was used in Kuwait it was implemented to protect firefighters blocking valves at a "world class" LPG pressure fire in the USA Gulf Coast. In both cases it was successful in providing personnel protection.

Do conduct a hazard evaluation if inert blanketing is needed, especially if steam is being considered as an agent. For example, steam can generate static electricity and should not be used as a substitute for inert gas to "blanket" an internal floating roof tank with a sunken roof. Any rapidly flowing fluid carries static charge generation concerns and should be carefully evaluated before implementation. Static charges from attempted inerting have become the source of ignition in the area they were intended to protect.

Do use check valves whenever there is a possibility of backflow of hydrocarbon into the firewater system. This especially holds for equipment field-installed during an incident. Examples are temporary connections for subsurface injection or appliances (wand-like) supplying foam over-the-top of tanks if there is a potential to establish a siphon.

Do shut off the fuel source to extinguish pressure fires involving a leak of fuel gas or liquefied petroleum gas. Extinguishing a pressure fire without fuel shutoff may result in the formation of a hazardous vapor cloud.

N.4.1.2 Exploit available resources

Do consider use of helicopters for video surveillance where visibility makes it difficult to evaluate the extent of the incident or progress in suppression. It may be possible to observe and/or videotape the situation using a police or media helicopter. Video brought back to the Incident Command Center can be used to evaluate progress and plan strategy and tactics. Some "hi-rise" extension ladder trucks or aerial booms may provide similar potential, as can locations on top of adjacent tanks.

Do consider recycling water from firewall diked area using fire trucks to draft if significant quantities of water are collecting in a firewall or diked area. It may be possible to use a pumper truck to take suction and recycle this water (with appropriate precautions to avoid using water contaminated with hydrocarbons) into the system. This may be more feasible with protein-based foam than with synthetics. Groundwater from lagoons used for storm water runoff may be another resource for drafting.

Do consider use of optical or laser distance measuring equipment that may be available from a facility engineering group for evaluating distances foam may have to travel if ground monitors are used.

Do consider converted foam towers as have been developed by some facilities for use with cherry pickers to drop over a tank rim to apply foam directly inside the tank. This requires a crane or cherry picker that can reach the tank and is tall enough to achieve the objective.

Do use news media as appropriate to keep local residents informed of the situation and any associated community needs.

N.4.2 SIGNIFICANT TANK FIRE SUPPRESSION "DON'TS"

Don't start foam application until enough is in sight to finish the job. Foam used before sufficient quantity is available will probably be used in vain and not contribute to the eventual extinguishment. Foam promised for delivery may not arrive in time for continuity of application.

Don't try to fight a major tank fire taking draft from 5-gallon buckets of foam. As shown from the earlier discussions of quantities needed the logistics could be tremendous and very labor intensive. If the required quantities are available in buckets then these should be transferred into a bulk container before foam application starts. This will avoid interruption of suppression efforts caused by inability to transfer foam.

Don't sink the roof fighting a seal fire in a floating roof tank. If the roof is floating in its proper location it is important to address the fire suppression efforts in a manner that does not sink the roof. Historical experience shows that seal fires in external floating roof tanks can burn for many hours (or days) without progressing to full surface fires. Appendix E discusses benefits of floating roofs and some of the concerns that may lead to their sinking.

Don't burn up your fire truck. Position equipment for removal if conditions (such as wind direction or intensity) change. Considering the route for repositioning equipment should be part of the initial placement decision.

Don't extinguish a pressure fire without blocking-in the fuel source. Although it is possible to extinguish some pressure fires involving a leak of fuel gas or liquefied petroleum gas, this should be done only by shutting off the fuel. All hydrocarbon vapors (other than methane) are heavier than air. Extinguishing a pressure fire without fuel shutoff may result in the formation of a hazardous vapor cloud.

N.4.3 FOAM APPLICATION OBSERVATIONS

Foam applied at low expansion rates (3:1 to 6:1) travels further on the surface of the burning liquid, but drains rapidly. As a result, the foam blanket needs higher application rates and more frequent replenishment. When using monitor application, some practitioners apply foam at a higher expansion ratio (6:1 to 8:1) after "knockdown".

Some experts believe that foam which has "lost its water" through draining or boiling can form a crust which impedes the flow of subsequently applied foam.

Consider discontinuing use of cooling water when foam application begins. This can ensure that water streams do not interfere with, or dilute, foam delivery.

N.5 Investigating fires

As discussed in Section 9, investigation of fires is typically done by persons other than the emergency responders. However, information gathered during the emergency response activity is very valuable.

Data summaries which can be collected include:

- Information from the Tank Specific Planning Sheets (Figure 3a and 3b).
- Incident Command Data Sheet (Appendix C).
- Incident Documentation Data Sheet (Appendix D).
- Summaries from the Critique .
- Photos & "raw" video from news and media broadcasts (these may be available from the media if requested soon after the incident before their files are purged).
- Emergency Operations Center and Incident Command logs.
- Operations logs.
- Location TV security or environmental surveillance video.
- Interview information from employees, contractors and neighbors.
- Engineering and maintenance records.
- Work permits.

APPENDIX O—PPE FOR PERSONNEL FIGHTING TANK FIRES

Each person working at a tank fire incident should use PPE (personal protective equipment) appropriate to his or her duties and potential exposures. The specific PPE needs may be included in generic emergency response operating procedures.

Alternatively, PPE requirements may be determined by command staff as part of an on-site hazard assessment. Most individuals at the incident site will function in support (not fire suppression roles). Most of these persons will need no special PPE.

For those persons with fire suppression duties, the level of protection should be determined by exposure potential. The principal concern is heat exposure. For personnel situated upwind of the fire, the heat exposure will be from radiation.

Like all radiation, heat follows the 'law of squares'. Thus, the heat flux is reduced by a 'factor of four' for each doubling of the distance from the heat source.

The actual suppression activities related to tank fire fighting in exposed areas should be categorized as "Advanced Exterior Fire Fighting". As defined in NFPA 600 *Industrial Fire Brigades*, this is "offensive fire fighting performed outside an enclosed structure when the fire is beyond the incipient stage". NFPA 600 states that clothing shall be available in sufficient quantity and sizes to fit each brigade member expected to fight advanced exterior and/or interior structure fires.

NFPA 600 states that all firefighters protective clothing (frequently called bunker gear or turnouts) must meet the requirements of the appropriate NFPA standard. Thermal protective clothing is required and the uses of self-contained breathing apparatus (SCBA) could be required.

NFPA 600 4-3.1 specifies that thermal protective clothing to be used by personnel entering hot and warm zones 'shall be in accordance with NFPA 1971 *Standard on Protective Ensemble for Structural Fire Fighting*. Non-fire brigade personnel working in areas with comparable exposure should be similarly protected.

The insulating effect of firefighters bunker gear (turnouts) should be considered when deciding proper and appropriate PPE. It is beneficial to define zones in which bunker gear is not required for protection; this can reduce heat stress caused by "keeping heat in" when there is no special need to "keep heat out". Heat shielding can be provided by barriers ranging from metal shields to hose line "full fog" water spray.

The decision on what constitutes appropriate PPE rests with the Incident Commander. The OSHA standard on Personal Protective Equipment 1910.132 uses such performance language. It states that "(d)(1) The employer shall assess the workplace to determine if hazards are present, or are likely to be present, which necessitate the use of personal protective equipment (PPE). If such hazards are present, or likely to be present, the employer shall: (d)(1)(i) Select, and have each affected employee use, the types of PPE that will protect the affected employee from hazards identified in the hazard assessment".

Proper protective clothing is required for fire brigade members and emergency responders is based on their anticipated exposure and duties. Federal regulatory requirements are outlined in OSHA *Subpart L* (1910.156) and *Hazardous Waste Operations and Emergency Response* (1910.120(q).

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