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BP Process Safety Series

Liquid Hydrocarbon Storage Tank Fires: Prevention and Response

A collection of booklets describing hazards and how to manage them

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This booklet is intended as a safety supplement to operator training courses, operating manuals, and operating procedures. It is provided to help the reader better understand the 'why' of safe operating practices and procedures in our plants. Important engineering design features are included. However, technical advances and other changes made after its publication, while generally not affecting principles, could affect some suggestions made herein. The reader is encouraged to examine such advances and changes when selecting and implementing practices and procedures at his/her facility.

While the information in this booklet is intended to increase the store-house of knowledge in safe operations, it is important for the reader to recognize that this material is generic in nature, that it is not unit specific, and, accordingly, that its contents may not be subject to literal application. Instead, as noted above, it is supplemental information for use in already established training programmes; and it should not be treated as a substitute for otherwise applicable operator training courses, operating manuals or operating procedures. The advice in this booklet is a matter of opinion only and should not be construed as a representation or statement of any kind as to the effect of following such advice and no responsibility for the use of it can be assumed by BP.

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Contents

Note: *all units in this booklet are metric and US (a US gallon equals 0.83 UK gallon).*

1

Introduction

Fires in petroleum product storage tanks are, fortunately, rare occurrences. However, when they do occur they require considerable resources both in manpower and equipment in order to extinguish successfully. Some of the causes of tank fires are outlined in chapter 3. In view of the low number of tank fires on record, relatively few people have had direct experience with fighting tank fires. This document has been prepared to help remedy this deficiency.

This booklet should be used as a training document only. For more in-depth guidance, the API 2021 fourth edition of May 2001, current NFPA Standard 11, BP Guidance Note n°17 on 'Oil tank fires' and other documents listed in the bibliography should be consulted.

It is also important to remember that once started, even if they look impressive, tank fires are not usually a life threatening hazard, as long as good practice is applied.

A major study, known as the LASTFIRE Project, has been carried out by 16 oil companies to review the risks associated with fires in open top floating roof storage tanks. This has now become the definitive study into this subject and many of its findings have been incorporated into this document. This booklet wholly endorses the findings of the LASTFIRE study and the subsequent work carried out on foam testing.

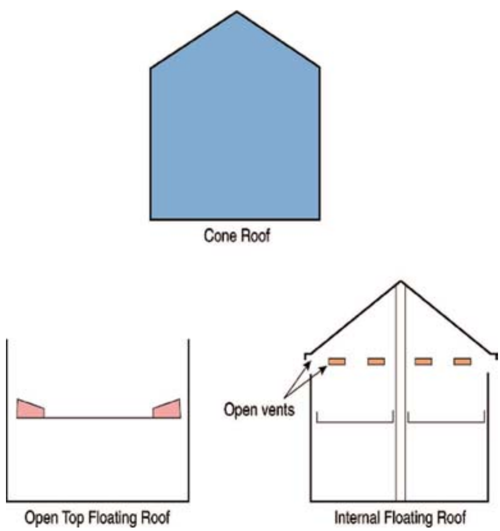
Rimseal fire at an early stage

Note: To complement this book, BP Refining Fire Community of Practice produced two double slide rules to use for training purposes. See Section 7.5 for more details.

2
Tank design

There are three main different types of tank for storing liquid hydrocarbons in large quantities:

- fixed (also called ‘cone’) roof tanks;
- fixed roof tanks with internal floating roof (also called ‘floating screen’);
- open top floating roof tanks (simple pontoon or double deck).



As a general rule, fixed roof tanks are used for ‘black’, heavy products (heavier than jet/kerosene/gasoil/diesel/naphtha) such as fuel-oils, atmospheric or vacuum residue and asphalt (bitumen). Therefore, they are often fitted with accessories such as steam or oil coil heating and insulation.

Open top and internal floating roof tanks are mainly dedicated to products capable of emitting large quantities of vapours at ambient conditions such as:

- crude oil;
- ‘white’ light products like jet, diesel, gasoline.

As their roof is floating directly on top of liquid, this design prevents the formation of a flammable mixture of air/hydrocarbon vapours which would occur in a fixed roof tank.

Internal floaters increase protection from fire exposure (therefore fitting a geodesic dome over a floating roof tank significantly decreases the probability of ignition).

More details are given in Chapter 5 and in the BP Process Safety Booklet *Safe Tank Farms and (Un)loading Operations*.

For fire prevention and firefighting purposes, it is important to note that tanks may be fitted with a very wide range of accessories (mixers equipments, inerting systems, instrumentation monitoring (level, temperature. . .), controllers, fire proofed valves. . .) and that each site should maintain an up-to-date database of its tanks, their specifications and the product they routinely contain. Also, it is important to know where the product comes from and how process upsets/deviations can modify it. The next two accidents are illustrations of why this is essential:

ACCIDENT The figure below shows an incident which occurred when a 15 bar steam heating system was mistakenly left on for several days, on an atmospheric residue tank containing water (as is often the case with product received from ships). When the temperature was enough to vaporize the trapped water, this happened instantly and damaged the tank beyond repair. Hot product was also projected over a large area. This could have resulted in a serious fire, had an ignition source been found.

ACCIDENT

An explosion and a fire occurred when lightning struck this fuel-oil tank. The investigation showed that the fuel-oil contained enough propane to create a flammable atmosphere below the roof (fuel-oil stream from propane deasphalting unit).

3

Initiating events

The LASTFIRE study listed the most common initiating events for large tank fires.

For fixed/cone roof tanks:

1. unexpected flammable/explosive mixture in the tank;
2. flammable/explosive mixture in normal operation;
3. overpressure;
4. high temperatures/autoignition;
5. holes in roof;
6. overfilling;
7. leakage from tank bottom or shell;
8. leakage/spillage in bund during preparation for maintenance;
9. external event (terrorism, earthquake, flare, escalation from another tank . . .).

For floating roof tanks:

1. failure of pontoon or double deck roof;
2. accumulation of liquid on the roof;
3. tank overfilled;
4. ignition by lightning of flammable vapour in rim seal area;
5. leakage from tank bottom or shell;
6. leakage from side-entry mixers;
7. backflow of liquid onto the roof from the emergency drain on pontoon roofs;
8. leakage/spillage in bund during preparation for maintenance;
9. external event (terrorism, earthquake, flare, escalation from another tank . . .).

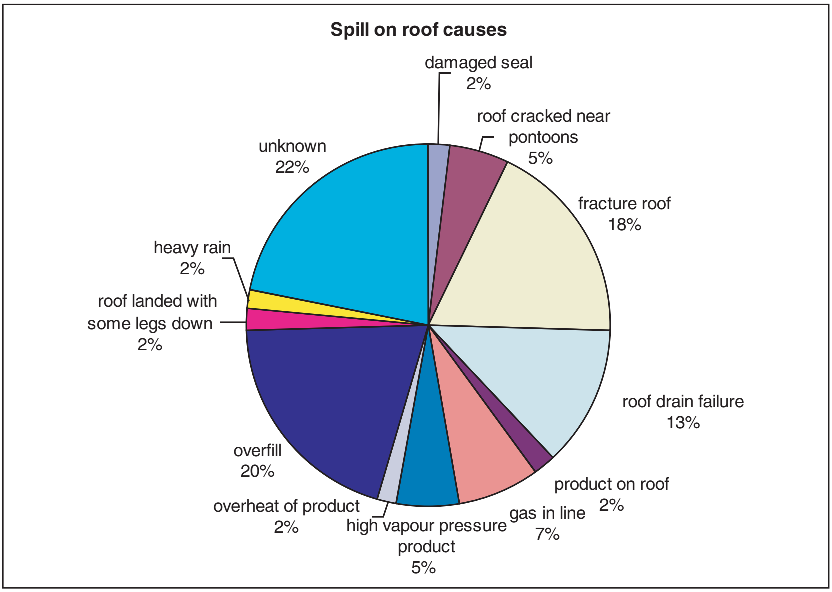
We can also add:

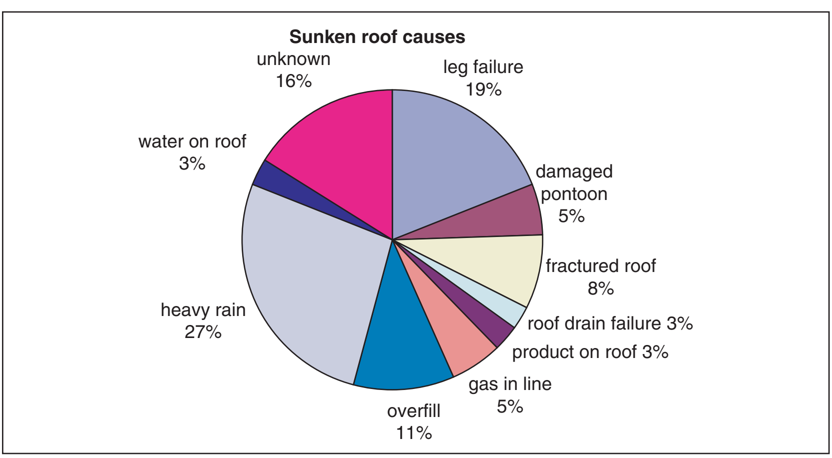
- misapplication of foam generating static spark (see end of this chapter);
- ignition by pyrophoric scale deposits;
- ignition by non explosion-proof electric equipment;
- hot work;

- introduction of a product with too high True Vapour Pressure (TVP) (such as injecting too much butane in a gasoline tank).

See examples in this booklet and in the BP Process Safety Booklet *Safe Tank Farm and (Un)loading Operations* (ISBN 978 0 85295 509 3).

The following two graphs are extracted from the LASTFIRE study for large floating roof tanks:

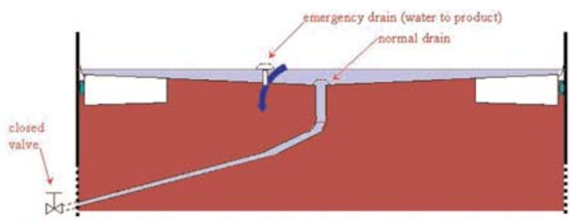




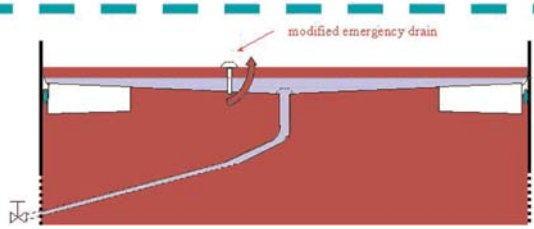
ACCIDENT An accident occurred when the roof of a Jet A1 tank began to be covered with product after heavy rain. The tank had just been put back in service after routine inspection and repairs.

These repairs included changing some metal sheets of the simple deck roof. The investigation revealed that during that job, the contractor replaced the emergency drain pipe (which is supposed to send rain water into the tank in case the normal drain is closed or plugged, to prevent overloading of the roof) by a longer pipe than the original one. Therefore, more rain was allowed to stay on the roof, and the weight from the roof and rain forced Jet A1 to flow back through the emergency drain and flooded the roof.

Normal design of the emergency drain—in case of heavy rain, water is allowed into the tank to prevent the roof from sinking.



Emergency drain modified—weight of water pushes the roof down, forcing product on top of the roof.



Note that emergency drains on single deck floating roofs are not recommended because of the risk of product backflow onto the roof. These tanks should be equipped with a sufficient number and size of normal rainwater drains with outlet valves kept opened, and should be regularly inspected to ensure their continued integrity.

However small and cheap a modification appears to be, it must still be subjected to your site's 'Management of Change' procedure to ensure all potential hazards have been adequately addressed.

3.1 Tank fire scenarios

The method of dealing with a tank fire will depend upon the type of construction of the tank roof.

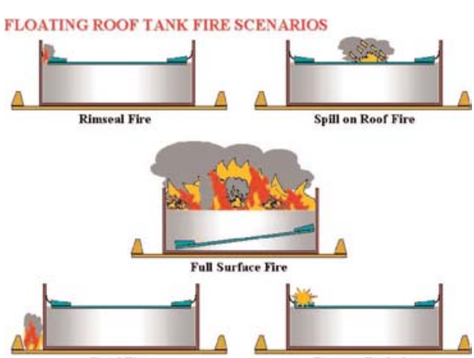
An explosion ***in a fixed roof tank*** will generally result in the weak tank shell to roof joint opening for only part of the tank circumference. In tanks of small or medium diameter the complete roof may be lost (see Appendix 5). The effect of only being able to apply foam through this 'fishmouth' (as illustrated by the picture below) can mean that it may be necessary to attempt to tackle the fire from inside the bunded (diked) area with its inherent risks to firefighting personnel.

Internal floating roof tanks should be tackled in the same manner as fixed roof tanks, as the internal roof is of light construction and will rapidly break up under the effects of the fire.

Fires in ***floating roof tanks*** can either be:

- in the seal area;
- on the roof itself due to the presence of product;
- full surface because a seal fire or fire on the roof was not dealt with promptly, or because the roof has sunk, either prior to the fire or as a result of poor firefighting techniques. Particularly difficult to extinguish are those fires where the roof is partially submerged as it will be difficult for the foam to flow under the overhanging angled roof.

The LASTFIRE study showed that rimseal fires are the most common scenario. They are unlikely to escalate to full surface fires in well maintained tanks (some rimseal fires have been known to last for weeks without escalation).



3.2 Ignition sources

Lightning is the most common ignition source. Correlations between rimseal fire frequency and thunderstorm frequency have been developed in the LASTFIRE study. Typical frequency for Northern Europe sites is 1×10^{-3}/tank year; 2×10^{-3}/tank year for Southern Europe, North America and Singapore; and up to 13×10^{-3}/tank year in Venezuela or Thailand; and 21×10^{-3}/tank year in Nigeria.

Therefore, a refinery having 50 large floating roof tanks in the US or Southern Europe statistically has one rimseal fire every 10 years (with possible escalation) ($50 \times 2 \times 10^{-3} = 0.1$ fire/year => 1 fire/10 years).

Picture of a floating roof to shell shunt test (submitted to a 830 A current to simulate lightning) showing the sparks generation (note that wax and rust deposits increase sparking).

It is very likely that such sparking will ignite any vapour present near the seal area, emphasizing the importance of seal integrity.

Picture from tests by Culham Electromagnetics and Lightning Limited for the Energy Institute (UK) and API.

However, other sources are not uncommon, such as:

- operators investigating a suspected leak with an engine driven vehicle;
- hot work;
- pyrophoric deposits;
- static electricity;
- plant flare;
- outside activity (for example, waste disposal field sending burning cardboard on top of floating roof tanks . . .), etc.

ACCIDENT

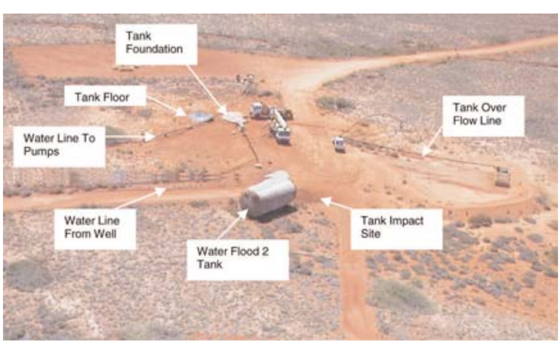
This is what is left of the car of operators rushing to investigate a suspected gasoline leak.

Operators were killed and the fire lasted for days, destroying numerous tanks.

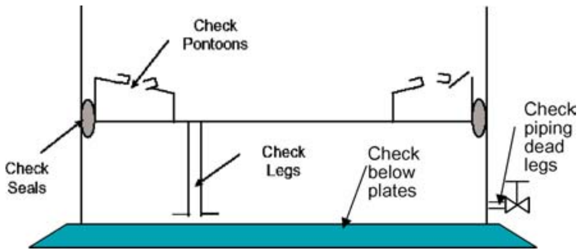
ACCIDENT A vacuum bottoms tank's shell to roof weld joint failed spilling hot oil in the surrounding dike/bund. This resulted in a dike/bund fire which was eventually extinguished after approximately two hours. Investigators considered that the most probable cause of the weld failure was a minor internal explosion/overpressure due to the ignition of flammable vapour by pyrophoric deposits.

ACCIDENT Another accident occurred when a Fluid Catalytic Cracker Unit was started after a turnaround. Liquid was sent to the flare and ignited a water treatment tank (without roof) 140 m (460 ft) away. The tank contained water contaminated with the crude from the crude unit desalter. Are water treatment tanks included in your emergency response prefire plans? Do you have enough hydrants nearby?

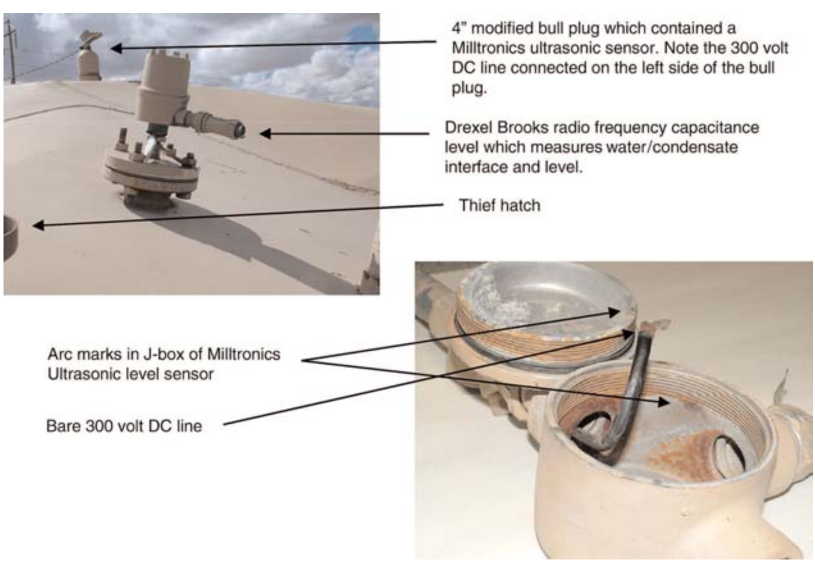
ACCIDENT An explosion occurred in a waterflood header tank. It was ignited by welding repairs to an inlet nozzle. Unknown to the three contractors working on the tank, there was an explosive gas mixture inside the tank. All three employees received bruising and abrasions from the incident.



For hot work, it is important to note that product can be trapped in many places, as the figure below illustrates.



ACCIDENT A 5000 barrel crude tank was being cleaned when an explosion lifted it several feet off the ground, splitting the roof open 1/3 to 1/2 the circumference at the roof seam and shooting a yellow flame horizontally 20 to 30 feet (6–9 m) out of the roof opening. The vapours coming from an open hatch ignited on the 300 v DC line that was left seven years before when an ultrasonic level sensor was dismantled.



ACCIDENT Batch blending was going on in a 7,000 m^3 unleaded gasoline tank when a fire occurred. During more than 30 hours, 56 fire trucks tried to tackle the fire, successfully protecting adjacent tanks. The investigation team found that the blending calculations were wrong: three times too much butane was being sent to the tank. A bubble of light ends probably lifted and tilted the roof, creating enough static or metal to metal friction to ignite the vapours.

Bad control of blending operations has caused multiple floating roof sinkings (see the Booklet *Safe Handling of Light Ends* (ISBN 978 0 85295 478 2) in this series).

Refer to the booklet *Safe Tank Farm and (Un)loading Operations* (ISBN 978 0 85295 509 3) in this series for more information on different tank incidents.

3.3 Static from foam and sunken roof management

It has become apparent that a number of tank fires which hitherto have been recorded as 'cause unknown' have been caused by static electricity generated during the application of foam from firemen's nozzles or remote monitors. Indeed, the re-ignition of fires may be related to foam application.

Refer to appendix A9.4 for an example of such an incident.

ACCIDENT An accident was caused by foam application on exposed naphtha after the floating roof of a storage tank sank. Static created by foam application ignited the fire that it was supposed to prevent. As a result of escalation, three naphtha tanks were destroyed as the figures below illustrate.

a. Roof sunk

b. Tank ignited by foam application

c. Adjacent tank beginning to burn

d. Two tanks fully involved

e. Three tanks fully involved

Sunken roof management

In the case of a large exposed surface of refined product (such as a sunken roof on a jet tank):

1. *Stop all transfer of product on or out of the tank:*
   - Assess the situation and determine the hazardous area using gas testers.
   - Make sure that there is no close ignition source and evacuate personnel.
2. *DO NOT USE FOAM*, except:
   - if there is a higher probability of ignition by a non-removable ignition source (such as a lightning storm);
   - if personnel must be protected against fire during the subsequent operations (for example, removal of product, roof repairs);
   - if the product involved has a high conductivity (such as crude oil).
3. *IF A DECISION IS MADE TO APPLY FOAM*:
   - If possible, use fixed pourers so as to apply foam as gently as possible down the tank shell.
   - Foam generated by monitors or hand held nozzles should be applied on the internal shell of the tank before going on the product.
   - Fire appliances with integrated foam proportionners are preferred to portable foam proportionners.
   - If portable foam proportionners are used, the maximum foam flow must first be generated outside the tank and then applied as gently as possible on the internal shell of the tank before going on the product.
   - Never apply foam or water directly to the surface of the hydrocarbon product.
4. *If a foam cover was established on a refined product (after a fire or after conditions of the above chapter):*
   - Once the foam cover is created, maintain it regularly and gently.
   - Keep a close watch on the tank until all product is removed.
   - The natural degradation of the foam cover may lead to an electrostatic ignition by the foam and water sinking through the hydrocarbon product.

ACCIDENT

The roof of this tank was damaged during an earthquake. Foam was applied as a preventive measure using foam pourers but the foam blanket was not maintained. Ignition occurred because of static build-up where a foam pourer maintained a continuous dripping of water and foam onto the naphtha surface.

4

Fire prevention

The LASTFIRE study showed that many tank major incidents were due to simple practices being forgotten or overlooked. *The most efficient technique to prevent tank fires or major leaks is to adhere to the good practices briefly mentioned below (refer to the BP Process Safety Booklet Safe Tank Farms and (Un)loading Operations for more details).*

Operations

- monitor tank fill/discharge levels as a routine;
- respond to high level or low level alarms;
- react to any level alarms (even if trips are provided);
- if high-high alarm: visual check of tank (overfilling into bund);
- prevent roof «landing» => air entry or damage;
- hazop routine and non-routine operations;
- safeguard against product transfer errors (high RVP, hot product . . .);
- have clear and up-to-date emergency operation procedures and train operators.

Monthly formal checks by operator

- cleanliness of roof;
- leakage signs;
- roof drains (including emergency one);
- pressure valve vent mesh;
- weather shields/seals;
- pontoon compartments (water, oil, LEL test, covers tight . . .);
- earthing cables;
- guide poles;
- rolling ladder;
- roof drain valves;
- bottom of shell.

Example of a roof with waxy deposits

Examples of roofs showing leaks of product

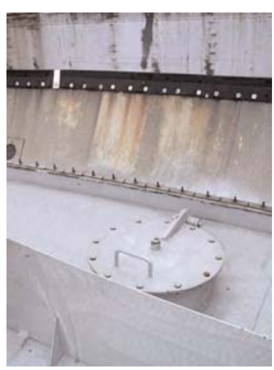
ACCIDENT This rimseal fire escalated quickly to a full surface fire when vapours contained in leaking pontoons exploded. While the rimseal fire might have been dealt with, the full surface fire proved difficult to extinguish because of a lack of water resources. The site had no routine practice of gas-testing pontoons regularly and therefore, escalation was inevitable.

Early stage of the rimseal fire as captured by security camera. Note flying pontoon plate in yellow circle

Fire once the roof lost buoyancy

Example of poor design of a pontoon manhole cover. There is no gas-testing hatch. (Also note that the foam dam is lower than the secondary seal, which was fitted later to the tank for environmental reasons—this denotes poor Management of Change and poor understanding of foam systems).

Manhole covers should be secured as loose covers can float away when the roof starts to sink, or they can be blown away by wind or fire water streams. A gas-testing hatch should be provided for each compartment.



5

Maximum feasible extinguishment

According to evidence from actual incidents that have occurred throughout the world over the past few years, extinguishing a full surface fire in a large tank (over 46 m (150 ft) in diameter) using mobile equipment is feasible (tanks up to 83 m (272 ft) in diameter have been successfully extinguished using only mobile equipment) but needs careful planning, large delivery devices and support equipment and well trained teams of operators. In accordance with the LASTFIRE study, a risk analysis should be carried out to assess the feasibility and justification of attempting to extinguish full surface fires. In the event that it is thought feasible then mobile monitors or fixed systems can be considered according to local circumstances.

Reputation and media attention issues should be included in any assessment.

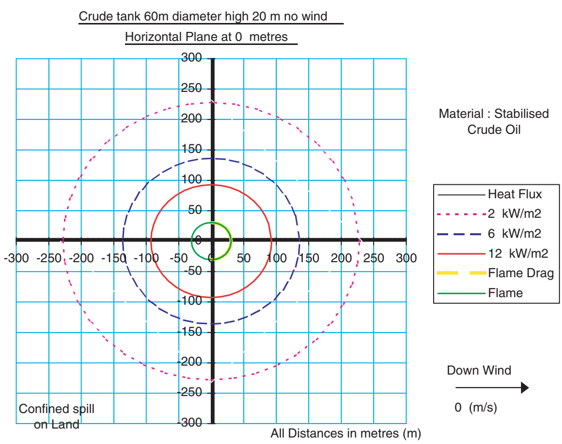
This full surface 83 m (270 ft) diameter tank fire was successfully extinguished using mobile equipment (application rate roughly 8.8 l/m^2/min (0.21 gpm/ft^2), no wind or rain)

Typical scenarios that must be included in these formal risk assessments are, considering a tank farm only (other issues such as pump rooms fire, loading gantries fire should also be considered as part of the emergency planning but are outside the scope of this booklet):

- three dimensional fire at tank bottom;
- rimseal fire for floating roof tanks;
- vent fire for fixed roof tanks;

- full surface tank fire;
- bund spill fire;
- full bunded area fire.

Modelling of a crude tank fire



These formal risk assessments should use models such as BP CIRRUS to evaluate the consequences of each scenario (for example, thermal radiation). A fire is very unlikely to escalate to adjacent tanks if the radiation levels on the exposed tank are kept below a level of 8 kW/m^2. Fire modelling can be used to assess, under typical site environmental conditions, how far apart tanks need to be to achieve this.

Typical outcome of the QRA is a choice between:

- fight this scenario with fixed or semi-fixed equipment;
- fight this scenario with mobile equipment;
- pump the product out, let the tank burn and cool exposed adjacent tanks.

This last option is perfectly acceptable in some situations, for example, remote storage in desert with limited water supply (see appendix 5). The following plans therefore need to be prepared for such a contingency:

- how and to where the product in the affected tank will be pumped;
- the necessity for protecting adjacent tanks;
- the effect of boilover or slopover (overfill).

It is important to include a fire specialist to consider life threatening hazards while studying the possible strategies:

- Except in very rare occasions, products susceptible to boilover should not be left to burn out (see Appendix 5).
- Generally speaking, the policy is that *no person should have to go onto the roof of a floating roof tank to extinguish a rimseal fire*. However, in some cases, it might be (and has been) the only option, particularly if there is no safe walkway around the wind girder and there is no fixed foam system. In this case, it should be done to a preplanned response which includes completion of a Job Safety Analysis included in the emergency plan (further information on safety aspects of this can be found in the LASTFIRE video and documents). Firefighters are warned not to get onto floating roofs during a rimseal fire unless there is a good floating roof pontoon inspection program in place and the chance of pontoon explosions due to heat are limited to a very low probability.
- Firefighting strategies should not normally require firefighters to enter a bund to install monitors when a tank is on fire in that bund (see monitor range considerations in appendix 7), although sometimes this might be the only option.

Example of a damaged pontoon after an internal explosion. This is why every means of fighting rimseal fires from the wind girder with portable equipment or from the ground, via fixed or semi-fixed systems, should be in place. Firefighting from the ground level using monitors should not be used due to the possibility of tilting the roof.

Portable equipment has been specifically designed to be manually attached to the shell of a tank on fire (see the following pictures and refer to Section 7.2) and has been used successfully in June 2003 on a rimseal fire on a BP site.

6

Foam firefighting

6.1 Foam application

With few exceptions, extinguishing a fire in a petroleum storage tank will require the application of a foam concentrate/water solution at a rate sufficient to be able to cause a blanket of aerated foam to cover the surface of the burning liquid, thus eliminating the air.

Failure to achieve this 'critical application rate' (Appendix 2) will see the foam blanket destroyed at a faster rate than it can be produced and therefore the fire will not be extinguished.

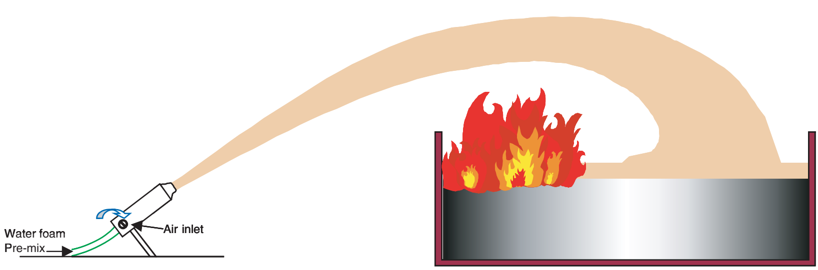
Manufacturers of foam concentrates and the NFPA National Fire Codes give recommended application rates for use with particular products which depend upon the method of application. *These recommended rates are based upon the assumption that all the foam will reach the surface of the burning liquid.* The foam concentrate must be of good quality and maintained in good condition by proper storage and testing. The use of the LASTFIRE fire test is recommended for evaluating foam for storage tank application.

Using portable equipment

Liquid hydrocarbons (with no more than 15% alcohol by volume*):

It is recommended that when using portable foam monitors to apply foam, *the rate that foam is produced at grade level should be increased by up to 60% over recommended minimum NFPA rates* to allow for the loss of foam which

Foam application through a portable monitor.



** This includes gasoils and motor spirits containing no more than 15% alcohol (MTBE or ETBE) by volume. Once this percentage is exceeded, the product should be considered as a water soluble fuel and the concentrate should be used as is recommended by the manufacturer for such a fuel (3 to 6%).*

fails to reach the tank interior and breaks down due to heat and thermal currents (the latter have been recorded upwards of 80 km/hr (50 mph)), inexpert operation of monitors and variations in wind speed/direction.

Foam losses can be caused by a number of combined causes such as insufficient range, high wind, foam/monitor quality, tank deformed. . .

The guidance given in NFPA, strictly speaking for tanks up to 18m (60 ft) diameter, is that if monitor attack is to be used for a full surface fire in crude oil and light product tanks, the foam solution should be applied at a rate sufficient to ensure an applied rate at the surface of the liquid of 6.5 l/min/m^2 (0.16 gpm/ft^2). In order to ensure this, it will be necessary to generate 10.4 l/min/m^2 (0.26 gpm/ft^2) i.e. 6.5 l/min/m^2 (0.16 gpm/ft^2) plus 60%.

Flammable liquids having a boiling point of less than 100°F (37.8°C) may require higher rates of application. Flammable liquids with a wide boiling range may develop a heat layer after prolonged burning and can require application rates of 8.1 l/min/m^2 (0.2 gpm/ft^2) or more (therefore recommended rate 12.9 l/min/m^2 (0.32 gpm/ft^2)). (See also Appendix 5)

Other flammable/combustible liquids

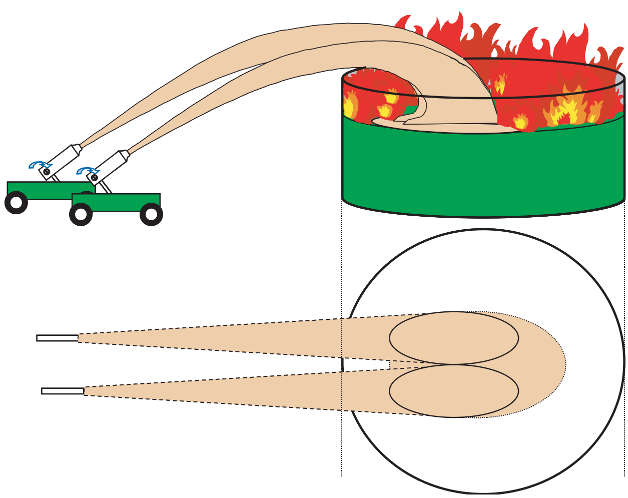
Water soluble, certain flammable and combustible liquids and polar solvents are destructive to regular foams and require the use of alcohol resistant foams. In most instances a 6% foam solution will be necessary, however some suppliers now provide 3% alcohol resistant foams.

Liquid	*NFPA application rate*	*Recommended application rate (NFPA +60%)*
Methyl alcohol–Ethyl alcohol–Acrylonitrile–Ethyl acetate–Methyl ethyl ketone	6.5 l/min/m^2 (0.16 gpm/ft^2)	10.4 l/m^2/min (0.26 gpm/ft^2)
Acetone–Butyl alcohol–Isopropyl ether	9.8 l/min/m^2 (0.25 gpm/ft^2)	15.7 l/m^2/min (0.4 gpm/ft^2)

Discharge duration

Products with a flash point between 100°F (38°C) and 200°F (90°C) (kerosene)	50 min.
Products with a flash point below 100°F (38°C) (gasoline)	65 min.
Crude oil	65 min.

Foam monitors should all be sited at the one location with the foam streams entering the tank at the same point (see figure below) and impinging on the surface in the same area. This will help establish a stable foam blanket quicker and more effectively than applying the foam on the surface at three or four separate locations. It is application density that establishes a *bridge head*.



Siting of monitors

The sooner a large pool of foam is established (or a foot print as it is sometimes called), the sooner the fire will be put out.

Externally cooling the tank shell in the region of the liquid level may assist the foam in sealing against the hot tank walls, but cooling water streams should only be played onto the shell once the foam blanket has achieved good control of the fire. Care has to be exercised when using any water streams during foam application since they may dilute the foam blanket being formed if the streams break up and water 'drifts' into the foam. Also, application of water cooling may distort the tank shell.

Water applied to the shell of a burning tank is normally ineffective and a waste of resource. However, such cooling may assist in the late stages of extinguishment of a full surface fire or rimseal fire, as the cooling of the area of the liquid level allows the foam to seal against the hot tank wall. Water should be reserved for the immediate protection of exposures being subjected to radiated heat.

Using fixed equipment

The best protection for storage tanks containing flammable liquid is the provision of fixed firefighting equipment. The use of portable foam equipment to extinguish a full surface fire is difficult and fraught with danger. There are numerous documented cases where failure to extinguish a fire can be directly linked to the absence of a fixed protection system.

Lower application rates than with mobile equipment are permissible when using fixed fire equipment such as subsurface (base injection) systems or fixed foam pourers (see figures on pages 22 and 23).

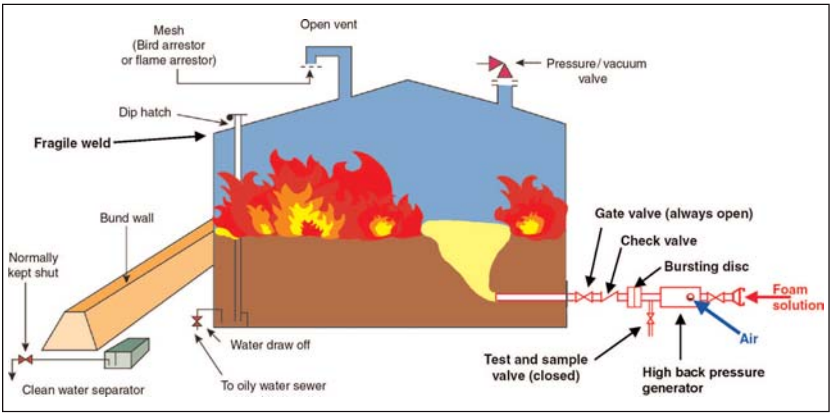
Types of systems

There are three main types of systems currently in use designed to enable the aerated foam concentrate/water mixture to reach the surface of the burning liquid:

1. **Subsurface foam injection system**. Designed to discharge foam into the base of a tank either through product lines or separate specific pipework. The foam floats to the surface of the liquid and is not affected by the flames or thermal updraft. Not suitable for floating roof tanks, for cone tanks with internal floating roofs or water soluble fuels. There are also semi–subsurface* injection systems that are designed to protect the foam from the hydrocarbons, but these are strongly not recommended due to the difficulty of testing them.
2. **Rimseal foam pourer system**. Designed to place foam in the area of the rimseal of a floating roof tank. A foam/water solution is injected into a pipework system from outside the bund area, and it is aerated and allowed to fall into a dam constructed around the seal. There are a number of variations of this system.
3. **Top foam pourer system**. Designed to place foam on the surface of a liquid through pipework accessed from outside the bund. Can be used on fixed (cone) roof, floating roof and internal floating roof tanks.

** The equipment used for the semi-subsurface technique consists of a container, either mounted in the fuel itself or just outside the tank shell near its base, with a hose having a length greater than the height of the tank. The non-porous foam discharge hose is made from a synthetic elastomer coated nylon fabric and is lightweight, flexible and oil resistant. It is packed into the container in such a way that it can easily be pushed out by foam entering it from a foam generator. The container is provided with a cap or bursting disc to exclude products from the hose container and foam supply piping.*

Subsurface injection (roof is shown intact for demonstration purposes)



Application rates for subsurface injection

Flash point of contained product*	**Solution rate NFPA**	**Minimum duration** (minutes)
flash point > 100°F (38°C)	4.1 l/min/m^2	30
flash point < 100°F (38°C), including crude oil	(0.1 gpm/ft^2)	55

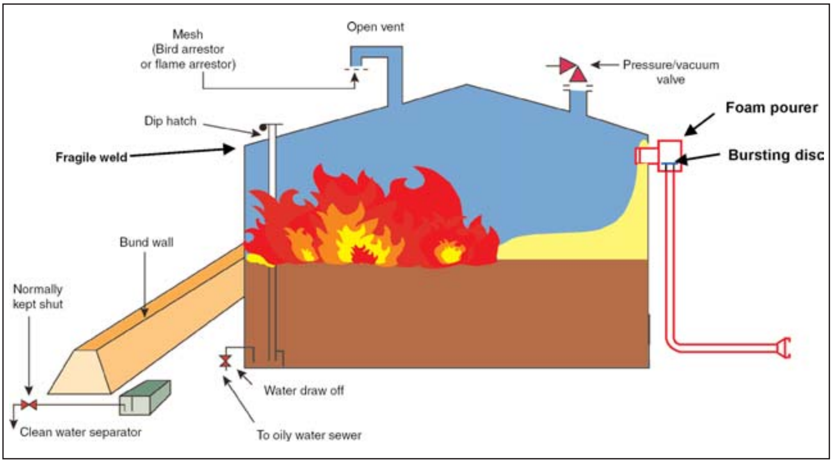
** This includes gasoils and motor spirits containing no more than 15% alcohol (MTBE or ETBE) by volume. Flammable liquids having a boiling point of less than 100°F (37.8°C) may require higher rates of application. Water soluble and certain flammable and combustible liquids and polar solvents are destructive to regular foams and require the use of alcohol resistant foams.*

Preference is for top pourers rather than subsurface system as the latter are more difficult to maintain and cannot be easily tested unless special test points are incorporated into the design (see also Appendix 6). They do not allow change of product in the tank (from non-foam-destructive to foam destructive) or upgrading of the tank (from simple fixed roof to fixed roof with internal cover float). These systems also represent a potential liquid leak source. However, it must also be recognized that top pourers are more vulnerable to damage from an internal explosion or the subsequent fire.

Subsurface application is ineffective on polar solvents because the foam dissolves and topside application is required.

Top pourer foam application (roof is shown intact for demonstration purposes)

Note: Some bursting discs are vertical along the shell tank, which is a better option than the one shown below (gas free atmosphere when opening foam pourer).

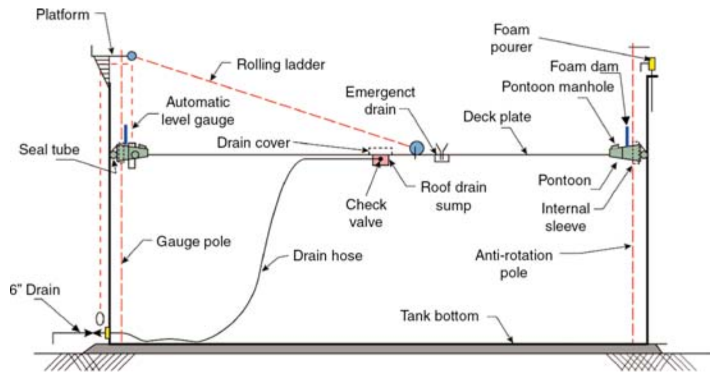


Application rates for top pourers for fixed roof tanks

Flash point of contained product*	**Solution rate**	**Minimum duration** (minutes)
Tanks below 45 m (150 ft) diameter (NFPA)		
flash point > 100°F (38°C)	4.1 l/min/m^2 (0.1 gpm/ft^2)	20** 30***
flash point < 100°F (38°C), including crude oil		30** 55***
Tanks above 45 m (150 ft) diameter (BP)		
All products	6 l/min/m^2 (0.15 gpm/ft^2)	30** 55***

** is as * on page 22 for subsurface systems.*
*** a discharge outlet that will conduct and deliver foam gently onto the liquid surface without submergence of the foam or agitation of the surface.*
**** a discharge outlet that does not deliver foam gently onto the liquid surface but is designed to lessen submergence of the foam or agitation of the surface.*

Floating roof tank

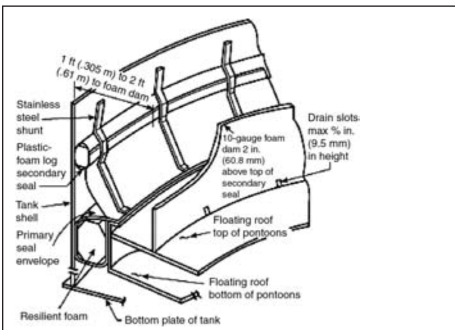


Application rates for top pourers for floating roof tanks

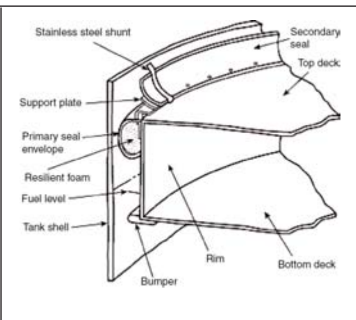
Type of system*	Solution rate NFPA	Minimum duration (minutes)
Rimseal pourer (with foam dam)	12.2 l/min/m^2 (0.3 gpm/ft^2)	20
Rimseal pourer (without foam dam)	20.4 l/min/m^2 (0.5 gpm/ft^2)	10
Full surface fire pourers	See table for fixed roof tanks	

** is as * on page 22 for subsurface systems.*

For a fire in the roof seal of a floating roof tank, foam solution should be applied at the rate of 12.2 l/min/m^2 (0.3 gpm/ft^2) when a foam dam is fitted, or at the rate of 24.2 l/min/m^2 (0.6 gpm/ft^2) in the absence of a foam dam, based upon a nominal dam width of 600 mm as specified in the NFPA Codes (Appendix 5).



Double seal system for floating roofs using a plastic-foam log (secondary seal).

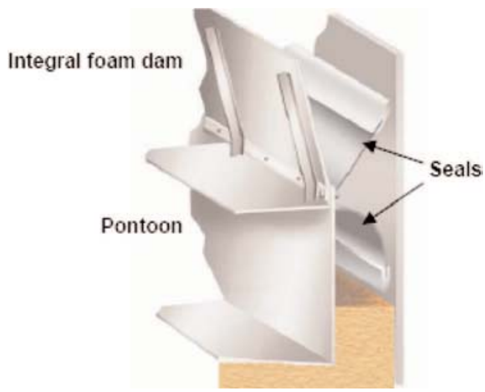


Double seal system for floating roofs.

Floating roof seals (extract of NFPA 11)

Integral foam dams (dam located directly above edge of the pontoon, closer to the shell than traditional NFPA11 dams see picture below) should be preferred as they prevent water and oil accumulation on the pontoons and allow fast accumulation of foam while reducing the amount of foam necessary.

However, dams designed in accordance with NFPA11 are acceptable. For NFPA11 dams, drain slots are mandatory and shall be big enough to allow rain water/foam water to flow, including an allowance for debris accumulation; but they should not be too big to prevent foam build-up (see right hand side picture above).



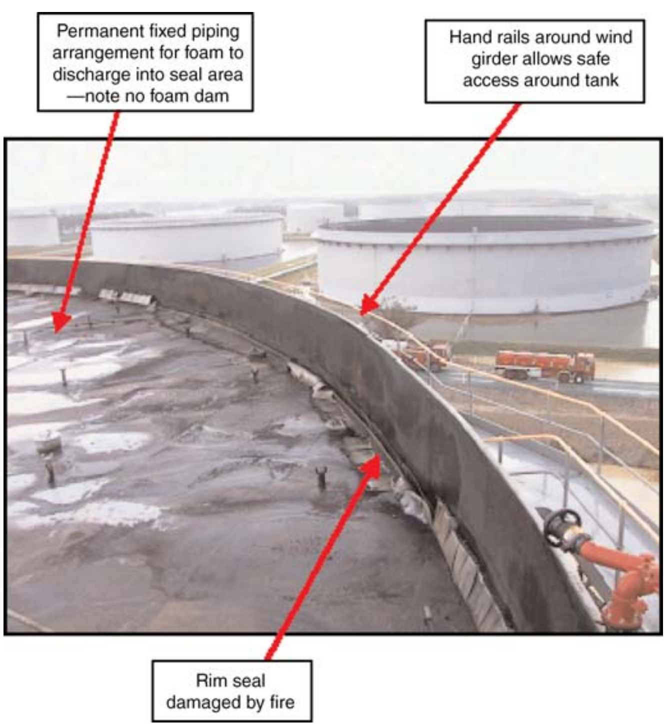
Rim seal fires

ACCIDENT A 500,000 bbls (80,000 m^3) open top floating roof tank 91% full with crude oil was struck by lightning. The resulting rimseal fire (60% of the circumference) and small roof spot fires were completely extinguished within 90 minutes of ignition.

The tank was used for high pour point crudes which left a wax residue on the inside of the shell because of ineffective seal scrapers. When the wax melted in the sun, it ran onto the roof and plugged the internal drain. The wax also acted as insulation preventing a good contact for the metallic shunts and an increased potential gap for sparks. The tank was equipped with primary and secondary seals.

The tank was 75 m (246 ft) in diameter and fitted with a rim foam distributor system (central foam distribution manifold located on the roof—see Appendix 7) and had no foam dam.

Application of foam with the fixed system only pushed the fire onto the roof. A team had to climb on the wind girder to tackle the fire using hand-held nozzles and some of the tools shown at the end of Chapter 5. The wind girder was equipped with hand rails which permitted safe access around the tank to fight the spot roof fires using a hand line.



Foam concentrate

The preferred type of foam for application on a petroleum storage tank fire should be a concentrate that provides good burnback resistance and also rapid knockdown characteristics—foam should have been selected as part of the LASTFIRE tests. The correct expansion ratio and flowability of foam concentrate are two further critical factors to be considered. Appendix 7 gives guidance on these matters.

Many types of foam concentrate are available for use as 1, 3 or 6 percent solutions by volume. Concentrates for use at 3 percent are normally preferred to those for use at 6 percent because of their greater efficiency in use, storage and handling. The equipment used to proportion and distribute the foam must be compatible with the concentrate being used. It is therefore recommended to use 3 or 1 percent concentrations. 1% solution is now available and is considered as efficient as 3% foams (as demonstrated during LASTFIRE tests) but proportioning equipment must be sufficiently accurate at this setting. Also, as 1% foams are less fluid, attention should be given to pumping capabilities, especially in cold weather conditions.

Foam concentrates of different types or from different manufacturers should not be mixed unless it has been established that they are completely compatible.

LASTFIRE fire test of a foam (see Appendix 6 for more details)

6.2 Firefighting equipment

Appendix 7 gives examples and advice on equipment.

The preferred configuration is:

- **Fixed roof <18 m (60 ft) diameter without internal floating deck:** Top pourers for an application rate of 4.1 l/m^2/min (0.1 gpm/ft^2) over the full surface area of the tank (pourers should be fitted to the shell of the tank not the roof). However use of mobile or portable monitors is acceptable if manpower is available.
- **Fixed roof >18 m (60 ft) diameter**: Top pourers over the full surface area of the tank for an application rate of:
  a. 4.1 litres/m^2/minute (0.1gpm/ft^2) below 45m (150ft) diameter
  b. 6 l/m^2/min (0.15 gpm/ft^2) above 45m (150ft) diameter

Pourers should be fitted to the shell of the tank not the roof as the roof is more sensitive to damage from an internal explosion.

- **Fixed roof with internal floating deck**: Top pourers to cover the full surface area.
- **Open top floating roof <35 metres (115ft) diameter**: Top pourers for an application rate of 4.1 l/m^2/min (0.1 gpm/ft^2) over the full surface area of the tank. (However use of mobile or portable monitors is acceptable if manpower is available). Pourers should be fitted to the shell of the tank not the roof (as they are designed to fight a full surface fire, in which case the roof is sunk).
- **Open top floating roof >35 metres (115ft) diameter**: Fixed or semi-fixed foam system pourers are recommended to fight rimseal fires, the application rate to be achieved with foam dams is 12.2 l/m^2/min (0.3 gpm/ft^2); without foam dams 20.4 l/m^2/min (0.5 gpm/ft^2). Where pourers are designed to cover the whole of the tank roof area (if justified by a risk analysis—see Chapter 5), the application rate should be 4.1 l/m^2/min (0.1 gpm/ft^2). For very large tanks multiple foam supply lines to alternate pourers are recommended to prevent the whole system being disabled through a single system failure. Pourers should be fitted to the shell of the tank not the roof as the roof is not always accessible for maintenance and test operations and the flexible hose needed may be a reliability concern. In addition, should the roof become flooded with either water or product, the roof could sink, taking the foam system with it.

  Open top floating roof tank installations can benefit from a foam dry riser terminating at the gauger's platform, together with hand rails installed round the wind girder, to facilitate an attack using portable equipment to extinguish any remaining pockets of fire in a rimseal if fixed/semi-fixed pourers are not totally effective in extinguishing the fire.

An alternative, preferred option is to have foam solution hydrant outlets at the wind girder level connected to the foam system pipework. For large tanks it may be necessary to have several outlets to reach all parts of the circumference with manageable lengths of hose. It is important to ensure that the foam proportioning system can accommodate changes in flow rate when using the hydrants (and also to allow for some blocked pourers).

- **Shell cooling water deluges**: Water cooling of a tank shell is often over-used. Fire modelling should be used to determine the needs for water cooling. Guidance on this subject can be found in documents listed in the bibliography in Appendix 1. If required, water deluges should be sized for a minimum of 2.1 l/m^2/min (0.05 gpm/ft^2) to protect against radiant heat (not direct flame impingement).

Tank shell and roof waterspray tests

It should be noted that localized cooling of a tank on fire (for example, with a single water monitor) will distort the shell—which is why this is not recommended if there is no fixed water deluge.

Typical example of cooling water effect when applied only to one side. The non cooled side is folding and the shell is subjected to extreme stress.

7

Firefighting techniques

7.1 Full surface fires

Satisfactory extinguishment of a petroleum storage tank fire begins with pre-fire planning and therefore much of the following information should have been considered. The person in charge of the fire will have to consider the following points:

Rescue: the need for rescue of injured people.

Life hazard: the potential need for evacuation of personnel (evacuation distances may exceed 600 m (2,000 ft) (see Appendix 5)), based on:

- type of product burning;
- number of tanks burning;
- protection of exposed structures;
- construction of tanks;
- status of tank and tank valves;
- dike/bund fires;
- vent fire;
- seam fire;
- foam supplies;
- water supplies/location;
- siting of foam monitors;
- water drainage.

For more pre-planning guidelines, see bibliography in Appendix 1 and Appendix 4.

Manpower requirements to tackle a major tank fire will, of course, vary depending upon the type, location and nature of the fire, the method of extinguishment required and the availability of trained personnel. The general requirements for any particular tank will need to be determined during the production of the pre-fire plans.

In general it is recommended that firefighting personnel should be given a rest break after approximately three hours of work. This time may need to be reduced depending upon fatigue levels brought about by environmental stress (including heat/cold, breathing apparatus, dehydration . . .). Manpower planning should take account of this aspect.

Early alerting of emergency response teams is essential to afford them the maximum opportunity to extinguish the fire in its incipient stages. To this end it is recommended that consideration be given to the installation of an automatic linear heat detector (LHD) around the rim of a floating roof tank (see the bibliography in Appendix 1 and Appendix 7 for more details).

It is absolutely essential that all personnel involved in frontline firefighting wear full firefighters turnout gear (see bibliography for more details).

Type of product on fire

The product involved will dictate the required foam application rate. This has an immediate impact upon the control of the fire as it determines the logistical support required.

Crude oil and certain heavier oils are prone to the effects of 'boilover' (see Appendix 5). Due consideration will have to be given to the consequences of this for equipment layout, personnel safety and the anticipated time of extinguishment.

Are the quantities of combustion products given off such as to warrant additional safety features? If so what is the need for evacuation? What are the likely requirements for firefighters to use breathing apparatus? What are the hazards after extinguishment (for example, reignition, explosion, toxic vapours if liquid is toxic e.g. benzene).

A methanol fire such as this one will require alcohol resistant (AR) foam.

Note that this type of fire produces very little smoke and sometimes, even the flames are invisible, except with IR imagery.

Note the helicopter dropping water—use of helicopters or aircraft has been tried on multiple storage tank fires and has never added any technical benefit. It can also prove dangerous on a rimseal fire by sinking the roof.

Number of tanks burning

The number of tanks burning will determine the requirements for manpower, equipment, water and the level of exposure protection necessary.

An immediate assessment will be required of the additional support necessary. This should be ordered without delay.

Tanks are too close—escalation likely

Refer to BP Process Safety Booklet *Safe Tank Farms and (Un)loading Operations* for more details on tank farm design and see Appendix 3 of this booklet.

Status of tanks and tank valves

The ullage space in a tank that is on fire can influence the quantity of foam that may be applied. If the tank is at maximum dip there is a possibility of causing an overfill (slopover) due to the amount of water being released by the breakdown of the foam increasing the level in the tank. There is, however, a positive side to tank depth. A full tank means that there is less heat and flame for the foam to travel through and therefore less breakdown due to these factors. In some instances extinguishment has been aided by pumping water into the bottom of a tank to raise the level and enhance the possibility of more foam reaching the surface of the burning liquid. Such a technique should only be used with great care—if water is pumped into a tank on fire there is probably no indication of liquid level height in the tank. Level indicators will almost certainly have been damaged or destroyed, and guessing where the liquid level is could be dangerous and lead to large quantities of burning fuel being spilled into the bund. *This technique should not be attempted in liquids where the risk of a boilover or slopover exists*. A full tank will also assist in dissipating heat away from the tank shell, whereas if the ullage space is considerable there is far more chance of the tank sides folding in. A tank fire in the UK resulted in the sides folding within eight minutes of the occurrence of a full surface fire.

Example of partial fold-in of a tank shell. The liquid level is well visible as the product kept the paint cool and intact.

Final stage complete fold-in

The effect of radiant heat on export transfer pumps situated nearby must also be considered as they may be required for pump out operations. The fire referred to above also required substantial cooling sprays on transfer pumps situated 25 m (80 ft) away.

It will often be necessary for firefighters to operate or cause to be operated a number of the valves found on a tank. The reasons for requiring valve operation will be varied but the following should be taken as a guide:

- Roof drains on floating roofs are normally left in the open position. In the event of a roof sinking it is then possible for product to leak into the bund (dike) area via this valve. It will normally be prudent to close it and, to do so, it will often be the case that firemen have to enter the bund as the valve will be located on the tank shell. Emergency response plans will normally state that the valve shall be closed at the earliest possible opportunity.
- Water drains for draining water from the tank floor of most tanks are located on the tank shell, and it may be decided that, in order to reduce the effects of a boilover, water should be drained from this point. (Draining water from the bottom of a crude oil tank may not necessarily stop a boilover as water

can be layered in the crude or caught in a sunken roof). In reality, it is virtually impossible to drain all the water from the bottom of a tank and only a few centimetres are needed to create a big boilover! If a decision is made to open a water drain valve, consideration should be given to the problems associated with closing it at a later point. Also, the outlet could become covered by slow draining water in the bund (dike) and it will not be possible to determine whether water or product is being released.

- Product suction and fill lines which may or may not be fitted for remote actuation are normally close to the tank shell. It may be necessary to use these valves either for removing or putting product into the tank.

Protection of exposed equipment

An immediate assessment should be made of the risk to both the site workforce and the surrounding population. Immediate evacuation, provided it is safe to do so, is often the safest method of protection. Factors to consider are the nature of the product, wind direction, boilover potential and probable time to extinguishment.

All tanks and vessels closer than one tank diameter upwind and two tank diameters downwind may require cooling water applied to their exposed surfaces. Tanks at 90° to the wind direction within one tank diameter may also require cooling. If resources are limited the water should be applied first to tanks containing lighter products; very small tanks and nearly empty tanks. The water should be applied to the side of the tank facing the involved tank and to the roof area of fixed roof tanks. Other exposures, such as pumps and pipelines, should have water applied according to the prevailing circumstances.

Example of cooling adjacent tanks with mobile equipment

Protection of adjoining tanks with water spray should seek to maximize the water contacting the tank shell thus minimizing water run off. The use of excess water on exposures can reduce supply and pressure and overtax drainage facilities. In order to minimize water use, firefighters should aim to supply just enough water to generate steam from hot surfaces. Excessive water run off will flood drainage systems and allow oil spillage to spread, thus increasing the risk of a flash fire from remote ignition sources.

A combination of both the extensive modelling and experiments suggests that a reasonable application rate is 2 l/min/m^2 (0.05 gpm/ft^2) of surface exposed to radiated heat. Older tanks with rough surfaces will need considerably more cooling water than new smooth-skinned tanks.

Perhaps the best practical application of water spray protection, for either fixed systems or mobile systems, is that recommended by NFPA, which suggests that if steam is generated when cooling water is applied, then its application should be continued. If it is not, then the cooling water should be shut off but the test should be repeated at regular intervals.

Despite the application of water spray, ***adjacent floating roof tanks*** may still be affected by radiated heat causing surface boil-off especially with low boiling point fuels, thus creating a flammable atmosphere at roof level.

Exposed floating roof tanks should receive immediate application of foam to the rimseal area. An early decision is required as to the possibility and advantages of completely covering the roof with foam. This will depend upon the availability of equipment, the proximity of the fire and wind conditions. At the recommended rate of 6.5 l/min/m^2 (0.16 gpm/ft^2) it will take approximately 8 minutes to cover to a depth of 1/2 metre (1.5 ft) and the load on the roof will be around 50 kg per square metre (10.2 pounds/ft^2). It should be ensured that roof drains are open and the tank roof is not overloaded. Gentle application techniques should be used to be sure not to tilt the roof.

On a pontoon roof it will only be necessary to cover the area inside the pontoon, i.e. the area of single plate in the centre of the tank. It is not necessary to apply a foam cover to the total roof area if the roof is of the double-skinned type. In all cases advice should be sought from the local engineering department at the pre-fire planning stage. It is preferable to try to cover the roof by using a rimseal foam system (if fitted), whereby foam application continues beyond 20 minutes and foam overflows the foam dam and flows into the roof centre.

Radiant heat may prevent fire crews accessing the wind girder to try foaming the roof via foam handlines. Alternatively, fire crews may need water curtain protection to gain access to the wind girder.

Applying foam from ground-based portable foam monitors in an attempt to foam the roof is not the best option and should only ever be considered as a last resort. Regardless of whichever tactics are reviewed, each should be risk assessed for consequences.

Careful evaluation will be required before the product in adjacent exposed tanks is pumped out, as this could increase the risk i.e. full tanks assist in preventing the temperature of the shell increasing unduly.

Factors influencing escalation are shown in Appendix 3, as are the estimated typical times for hazardous conditions to be generated at an adjacent tank when exposed to a full surface fire in a 50 m (165 ft) diameter tank containing naphtha.

This crude tank fire could not be extinguished due to lack of resources. Despite boilovers occurring, adjacent tanks were unharmed, due to a sound design that included large tank spacing.

Care must be taken to ensure that ***nearby LPG and LNG storage vessels*** are kept cool at all times. As a general guide they should, if exposed, be kept covered with a film of water either through the fixed spray system or using portable equipment. Any protective water film should be applied to such vessels (if uninsulated/fireproofed) at a rate of 10.2 l/min/m^2 (0.25 gpm/ft^2). As well as the vessel itself, particular attention shall be given to cooling exposed steelwork such as stairways, top bridles and valve platforms, even where LPG and LNG storage vessels are provided with Passive Fire Protection (PFP).

Example of a LPG sphere that required heavy cooling during a nearby tank fire.

Refer to booklets *Safe Handling of Light Ends* (ISBN 978 0 85295 478 2) and *LNG Fire Protection and Emergency Response* (ISBN 978 0 85295 515 4) in this series.

Successfully achieving the last stages of extinguishment can sometimes be very difficult due to folded shell, roof pieces, etc, that prevent foam from reaching in the last pockets of fire (see picture below). Multiple techniques can be used but they must be planned in advance to prevent the foam attack from running out of supplies.

Use of medium expansion foam can give good results in this type of situation as shown in picture below.

7.2 Rimseal fires

On external floating roof tanks

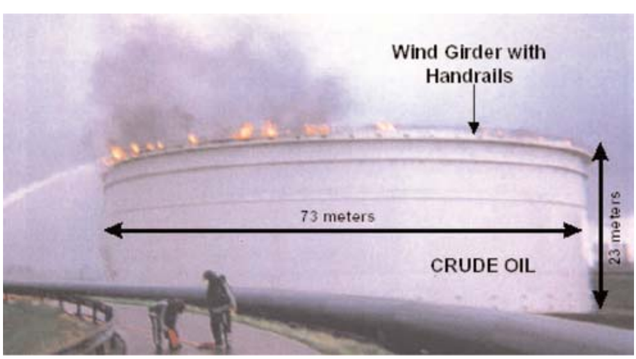
A fire in the seal area can be tackled in a number of ways, the best and most obvious being by utilizing fixed rimseal pourers. However, if these are not available and a manual attack is the only recourse then the following options are available.

- Use water spray protection to enable a crew to ascend to the gaugers platform with hand-held foam equipment. From this point, and from the wind girder if it is safe to do so, an attack can be made on the seal. It may prove necessary to bring larger equipment to the platform if it is not possible to use the wind girder and the tank diameter is such that hand-held equipment will not reach all the way across the roof (see also pictures at the end of Chapter 5).

Example of a seal fire being attacked from the gaugers platform with a hand-held foam monitor.

Attack of a rimseal fire from stairway—see how much manpower is needed to deploy flexible hoses when there is no fixed dry risers.

- Attack the fire using large foam monitors. Monitors should not be considered as the primary method of attacking rimseal fires (although it is recognized that use of monitors from elevated hydraulic platforms has been successful in some cases). With monitors, there is always the risk of tilting the roof. Preplanning for rimseal fires should consider the provision of alternative response equipment.



On tanks fitted with internal floating roof

Internal fires in these tanks are rare. However, when they occur, they are very difficult to tackle if the tank is not fitted with adequate fixed systems. Foam pourers combined with foam dams are the most effective and the design of these systems should be based on full surface fire.

Aluminium, pan type roofs, and open-top bulkhead pontoons should be assumed to sink and obstruct foam flow.

Ignition usually occurs during first filling with or without switch loading (refer to BP Process Safety Booklet *Safe Tank Farms and (Un)loading Operations*), exposure to radiant heat from a close-by fire or hot work.

Signs of an internal rimseal fire that ignited after this tank was exposed to radiant heat from another tank fire.

Fires at the vents are very difficult to tackle. This 95 ft (29 m) gasoline tank fire was extinguished by using foam and three of the vents were 'shot out' utilizing dry chemical (Hydro-Chem™ type).

7.3 Bund (dike) fires

The general rules for full surface fires are applicable here. The technique for fighting fires in bunded (diked) areas is to extinguish and secure one area then to move on to and extinguish the next section of the bund. This procedure is continued until the complete bunded (diked) area is extinguished.

Before extinguishing fires in a bund (dike) it is important to ensure that the flammable liquid remaining does not pose a greater hazard than if it had been allowed to continue burning (such as if the burning liquid is benzene). It will be necessary to keep this liquid covered with a blanket of foam.

Equipment requirements

NFPA 11 recommends fixed foam pourers for common bunds surrounding multiple tanks with poor access or less than 0.5 tank diameter spacings.

Minimum application rates for bund pourers are (from BS 5306):

- 4 l/min/m^2 (0.1 gpm/ft^2) for hydrocarbons;
- 6.5 l/min/m^2 (0.16 gpm/ft^2) for foam destructive liquids.

However, BS 5306 specifies that there should be one 2,600 l/min (690 gpm) discharge device (low or medium expansion) for each 450 m^2 (4,800 ft^2). Discharge time is calculated for 60 minutes.

This foam equipment should be capable of being operated simultaneously with tank-surface foaming operations. However, the bund fire must be extinguished prior to *attacking* the tank fires (if not, it will reignite the tanks).

There should be sufficient monitors and hand-held foam nozzles (or fixed systems depending on the manpower available) to deal with any bund fire that may occur. When applying foam on a bund fire with monitors, the tanks should be used as a deflector plate. This keeps the flame from the tank shell and starts the foam blanket where it is most urgently needed. The use of water monitors in tandem with foam monitors creates foam application dilution problems—only minimum cooling water should be applied when foaming.

There is value in keeping the water level above any product lines in the bund as this will protect them from the effects of radiated heat and flame impingement, and will help prevent the ‘spreading’ of flanges.

Use of medium expansion can be a very effective tool in quickly suppressing bund fires, as demonstrated by the following pictures:

Never commit firefighters into a bund contaminated with product, even if the spill is covered with foam. In a situation such as the ones illustrated in pictures below, wind or a water stream can open the foam blanket and fuel can reignite in seconds (see St. Ouen incident described in Appendix 9 of this booklet).

7.4 Foam supplies

The quantity required varies according to the tank size and the use of fixed or portable equipment.

A foam attack must be capable of being sustained for a minimum period. Therefore the quantity available before commencing the foam attack should reflect this requirement.

If the foam supplies are in drum storage then the logistics of supply will need to be considered. There will also be a need for additional manpower and equipment such as forklift trucks and vehicles to transport the drums to the area where they are to be used. Mechanical or manual transfer pumps may also be required.

Foam stored in bulk will require access. Mobile tanks may require towing vehicles. Care must be taken to ensure free access by foam vehicles for the duration of the incident.

It is recommended that bulk storage is provided in mobile tankers, elevated bulk storage tanks or 1,000 litre (265 gallons) Schutz containers on mobile platforms. In each case pre-fire plans should ensure that immediate access to foam storage units is available 24 hours a day and appropriate valves, pipework or foam pumps are provided to decant the foam compound. The use of 25 or 200 litre (6.5 or 53 gallons) drums is not acceptable due to the intense use of manpower needed to mobilize and decant them.

6% foam concentrates shall not be used anymore for new installations. 1% foam concentrates are strongly recommended for all mobile equipment options for tanks of 70 m (230 ft) diameter or bigger as this concentration helps to reduce significantly the foam logistics. If seawater is used, application rates should be increased by 20% to take into account significant degradation of finished foam quality, unless detailed tests can give a more accurate value.

7.5 Water supplies

As water constitutes 97% at 3% concentration of finished foam solution, considerable quantities of water will be required for the production of foam for mounting an attack on tank fires, dike/bund fires and for the cooling of exposed equipment.

The following table *(given here as illustration for the specific case of a full surface tank fire supposed to be containing gasoline and using mobile equipment only, with 3% foam)* gives an indication of water required for foam production at the recommended rate of application in tanks of varying diameter—water and foam are mixed and applied at the NFPA +60% rate which equals 10.4 l/min/m^2 (0.26 gpm/ft^2).

Tank diameter		Approximate rate of foam solution application rate		Water needed for foam production only (add cooling if needed)		3% Foam concentrate		Total foam concentrate required for 65 min application	
m	ft	lpm	gpm	m^3/h	gph	lpm	gpm	litres	gallons
8	26	523	138	30	8 284	16	4	1 019	269
10	33	817	216	48	12 941	25	7	1 593	421
12	39	1 176	310	68	18 628	35	9	2 294	606
14	46	1 601	423	93	25 360	48	13	3 122	824
16	52	2 091	552	122	33 121	63	17	4 078	1 077
18	59	2 646	699	154	41 913	79	21	5 161	1 363
20	66	3 267	862	190	51 749	98	26	6 371	1 682
22	72	3 953	1 044	230	62 616	119	31	7 709	2 035
24	79	4 705	1 242	274	74 527	141	37	9 174	2 422
26	85	5 522	1 458	321	87 468	166	44	10 767	2 842
28	92	6 404	1 691	373	101 439	192	51	12 487	3 297
30	98	7 351	1 941	428	116 440	221	58	14 335	3 784
40	131	13 069	3 450	761	207 013	392	103	25 485	6 728
50	164	20 420	5 391	1 188	323 453	613	162	39 820	10 512
60	197	29 405	7 763	1 711	465 775	882	233	57 340	15 138
80	262	52 276	13 801	3 042	828 052	1 568	414	101 939	26 912
100	328	81 682	21 564	4 754	1 293 843	2 450	647	159 279	42 050
120	394	117 622	31 052	6 846	1 863 132	3 529	932	229 362	60 552

An example of foam/water requirements (NFPA +60%)

Note: To complement this book, BP Refining Fire Community of Practice produced two double slide rules to use for training purposes. These study plastic slide rules enable users to estimate the application flow, and foam and water quantities required for:

- *Slide 1 side 1: a full surface tank fire using mobile firefighting equipment.*
- *Slide 1 side 2: a full surface tank fire using fixed firefighting equipment.*
- *Slide 2 side 1: a rim seal fire using fixed firefighting equipment.*

- *Slide 2 side 2: a bund (dike) fire, based on the spill surface or bund surface on fire.*

The first three sides calculations are based on inputting the tank diameter.

These handy slide rules are valuable training tools for tank designers, industrial firefighters and fire brigade officers. Detailing 1%, 3% and 6% foam concentrates, they cover both Metric (SI) and Imperial units (US) and are available from IChemE Booksales (sales@icheme.org).

The water for foam production will need to be supplied to the one location so it will be necessary to evaluate hose requirements, along with intermediate pumps for water relays if the supplies at the chosen location are inadequate. Consideration should be given to the use of a large diameter hose for feeding foam monitors i.e. 152 mm (6 in) diameter or greater. A hydraulic study and/or practical exercise should be carried out at the pre-fire planning stage to ensure that adequate supplies at the appropriate pressure are available.

Pre-fire plans should consider ***total*** water consumption from both direct foam attack on the tank involved in the fire and adjacent risks from radiated heat needing water spray protection.

8

Conclusions

Factors that will increase the probability of successful extinguishment of a storage tank fire are:

- The use of low expansion-ratio aspirated foam.
- Adequate application rate.
- Large capacity water/foam monitors in sufficient numbers.
- Efficient handling of foam concentrates.
- Sufficient water supply to monitors (volume and pressure).
- Adequate time and manpower.
- No attempt should be made to apply foam unless sufficient resources are available to mount an extended attack for the recommended duration of application. However, the GESIP tests (see bibliography on page 45) show that, if there are sufficient foam stocks, an early continuous foam application at half the extinguishment rate is efficient in reducing the thermal flux, and therefore, in reducing the strain on firefighters and the probability of escalation. This, of course, relies on the concentrate being in good condition.

If it is planned to let a tank fire burn out then it is important for firefighters to know that tank shells exposed to fire normally fail by folding inwards above the liquid. Therefore the available water supplies should be directed to protecting exposures and not on the shell of the tank on fire. External roof drains on floating roof tanks which are normally left open should be closed to prevent the loss of flammable material into the bund.

Storage tank fires are often spectacular in nature, generating much heat accompanied by a highly visible column of smoke. However the application of the correct techniques has resulted in many such fires being successfully extinguished. If the foam is being applied correctly then visible evidence of fire reduction should be seen in less than thirty minutes after commencement. If no signs are seen then further checks need to be carried out to ensure that the correct rates are being applied.

Appendix 1: Short bibliography

- NFPA Codes, Standards and Journal
- GESIP foam tests reports
- LASTFIRE study, risk workbook and foam tests
- API 2021 last edition
- Fire Service Manual Volume 2 Petrochemical (The Stationary Office 2001 edition)
- Technica Report on the Singapore Tank Fire 1988
- BP fire school manual
- Resource Protection international ‘foam seminar’ documents
- BP booklet ‘Alternatives to halon 1211 and 1301 fire fighting suppressants’, May 2004 edition
- BP fire response workbook, 1994 edition
- BP booklet ‘Fire Protective Clothing’, May 2004 edition
- BP Engineering Technical Practices 44-10 and 24-40
- Model Code of Safe Practice in the Petroleum Industry: Part 19. Fire Precautions at Petroleum Refineries and Bulk Storage Installations, Institute of Petroleum, ISBN 04719 43282
- Face au Risque
- Industrial Fire Journal
- Industrial Fire World Magazine
- Fire International
- See also all references in BP Process Safety Booklet *Safe Tank Farms and (Un)loading Operations*
- INERIS report 13 on Boilover, March 2003
- ‘Control of Major Accident Hazard (COMAH) Competent Authority Policy on Containment of Bulk Hazardous Liquids at COMAH establishments’, UK HSE and EA, February 2008
- ‘Storage of flammable liquids in containers, HSG 51’, HSE Books, ISBN 07176 14719
- ‘Storage of flammable liquids in tanks, HSG 176’, HSE Books, ISBN 07176 14700

- ‘Pollution prevention guidelines: Controlled burn; PPG 28’, UK EA, July 2007
- ‘Pollution prevention guidelines: Managing firewater and major spillages; PPG 18’, UK EA
- ‘Fire Systems Integrity Assurance’ available from www.ogp.org.uk.

Most relevant videos

- SRC (Singapore) tank fire;
- Total St Ouen depot fire;
- Denver airport tank farm fire;
- Jacksonville fire;
- Neste Panva Finland fire;
- Sunoco Sarnia Canada tank fire.