BRANDVEILIGHEID OPSLAGTANKS

THE ATMOSPHERIC STORAGE TANK TECHNICAL FRAME OF REFERENCE (CIV02)

PART ONE

BACKGROUND AND TECHNICAL INFORMATION (CIV 02)

VOORWOORD

Het document Atmospheric Storage Tank- Technical Frame of Reference is de eerste uit een reeks van drie publicaties van het Centrum Industriële Veiligheid over opslagtanks. Doel van deze documenten is een handreiking te bieden voor het verbeteren van de brandveiligheid bij atmosferische opslagtanks. Na recente grote en kleinere incidenten is de aandacht hiervoor verscherpt. Aangezien verhoging van de kwaliteit van brandveiligheid niet zozeer gebaat is bij meer en strengere normering maar met vergroten van het inzicht in de mechanismen van brandveiligheid bij tankopslagbedrijven, adviesbureaus en overheden, zijn hiervoor deze specifieke documenten ontwikkeld. Deze documenten vormen een complete set incidentscenario's (CIV 04), een auditmethode voor de volledige analyse van brandveiligheid bij een opslagtank (CIV 03) en dit ondersteunende document met achtergrondkennis en verbeteropties (CIV02). De documenten vertegenwoordigen niet per definitie de actuele mening van de Regionale Brandweer Rotterdam Rijnmond van de Veiligheidsregio Rotterdam Rijnmond en vervangen niet bestaande normeringen.
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Meer informatie is tevens te vinden op www.centrum-iv.nl

COLOFON

Deze publicatie is gemaakt in opdracht van: Veiligheidsregio Rotterdam Rijnmond (www.vr-rr.nl)
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CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION

This document, the Atmospheric Storage Tank Technical Frame of Reference, has been prepared as guidance to assist personnel responsible for reviewing and approving fire safety measures at storage tank facilities.

It gives guidance on all aspects of risk reduction from prevention through to firefighting strategies. It is intended to assist in the overall assessment of the adequacy and appropriateness of measures at a particular facility and thus provides background material for the Storage Tank Fire Hazard Management (FHM)Audit Methodology (CIV03).

It is emphasised that the document is intended to give sufficient information for the auditor to understand the basic purpose and concepts behind each of the subjects. It is not intended to provide in-depth knowledge or to replace specialist audit tools such as EEMUA 159 (Engineering Equipment and Materials Users Association Document 159 – Users Guide to the Maintenance and Inspection of Above Ground Vertical Cylindrical Steel Storage Tanks) which gives comprehensive details of the inspection of mechanical aspects of storage tanks.

As well as facilitating understanding and implementation of the FHM Audit Methodology, this document can provide useful guidance and information to tank operating companies that are developing or reviewing policies. While the document is aimed primarily at the unique situation in Rotterdam Rijnmond area (See Section 2), the information provided has universal application.

It has been assumed in the preparation of this publication that the user will ensure that the contents and information are directly relevant to the application selected and are correctly applied by appropriately qualified and experienced people for whose guidance it has been prepared. The Rotterdam-Rijnmond Fire Brigade, and the writers, Resource Protection International, expressly disclaim any liability or responsibility for damage or loss resulting from the use of the document. Any information contained herein is based on the most authoritative sources available at the time of writing and on good engineering practice, but it is essential to take account of appropriate subsequent developments and/or local legislative requirements relevant to any particular facility.

Scope

This document concentrates on Fire Hazard Management issues relevant to Atmospheric Storage Tanks containing flammable or combustible liquids. However, much of the information provided is also relevant to other types of tank and to tanks containing toxic materials.

1.2 BACKGROUND

1.2.1 Rotterdam Harbour District

Rotterdam Harbour District is a unique area. It is Europe's most concentrated region of oil and chemical storage and processing facilities.

Facilities include crude oil import terminals, refineries, petrochemical processing plants, chemical storage depots and plastics manufacturing facilities. Consequently, it contains a massive number of storage tanks containing a wide variety of materials.

As the Harbour District lies on the estuary of Europe's main waterway, much of the storage facility is used on an "entrepot" basis where chemicals are delivered in bulk, stored temporarily and then transferred to smaller vessels, rail transport or road vehicles for onward distribution throughout Europe. Exports of products are sent throughout the world.

Thus, the ongoing safe operation is not only important to the economy and environment of the immediate locality, but also vital to that of Europe as a whole.

1.2.2 Rotterdam Fire Brigade and the Unified Fire Brigade

Recognising the special needs of the area, a specialist Fire Brigade – the Unified Fire Brigade (UFB)- has been formed in the Europoort area.

This is under the management of the Rotterdam Port Authorities (RPA) and the Rotterdam Fire Brigade (RFB). The UFB is part funded by RFB to meet its legal obligations to provide fire cover for the area, including residential facilities and part by local industry in recognition of the special resources (including training) required for the hazards in the area. The Rotterdam Fire Brigade is mandated to inspect, audit and approve facilities processing and storing flammable liquids. Over 25 specialist industrial fire officers are working in the harbour district. When accidents do occur, the fire officers of the RFB are in charge and give leadership to the fire-fighters of the UFB. They are the ones who have to work with the audit tool and the technical frame of reference.

1.2.3 Current Legislative Position

Federal Disaster Prevention Committee (PGS) guidelines have previously been used in the Netherlands as an aid when drawing up requirements for facility licensing in the Europoort area. The PGS29 national guideline sets out general rules including fire protection for the storage of flammable liquids. No recognition of the levels of incident prevention are incorporated into the rules.

The demands on tank storage are taken in the environmental licence with is put out by the environmental protection agency (DCMR) and renewed every 10 to 20 years. The demands are based on codes like the PGS29 and the advise of the Fire Brigade.
Some of the tank operating companies are under the scope of the SEVESO II directive (BRZO) which means that the company should apply to best technical means.

The Rotterdam-Rijnmond Fire Brigade is authorised to demand companies to have and to audit company fire brigades. Aim is to formalise the last line of defence in fire hazard management: fire fighting. The major tank storage operators do have a company fire brigade or joined up in the unified fire brigade. In the past there have been frequent deviations from guidelines, as a result of which different requirements have been imposed on similar storage facilities.

There is a great variety in safety features and fire hazard policy on tanks at the different companies.

Consequently, Rotterdam-Rijnmond Fire Brigade set up a project to develop a standardised approach to assessing and licensing flammable liquid storage facilities, taking into account the levels of incident (loss of containment and fire) prevention measures, at the specific facility.

This document, which describes the concepts and principles of relevant fire risk reduction measures, was developed as part of this project.

1.2.4 Fire Hazard Management

Due to the recognition by many legislators and storage facility operators of the benefits of risk based fire safety measures (see section 3.2), the concept of Fire Hazard Management (FHM) has been introduced.

Fire Hazard Management is one very important part of a Safety Management System. The term is used to mean an integrated facility approach to reducing risk from fires and explosion by the most appropriate means for a particular facility. The “integrated” approach means considering design, plant layout, prevention measures, incident detection, protection systems, mobile equipment, training, etc. etc.

The basic steps of FHM are:

STEP 1	Review fire scenarios that can occur
STEP 2	Review different policies to reduce fire and explosion risk
STEP 3	Decide which policy is the most appropriate
STEP 4	Implement and maintain policy

It is this approach that is being adopted by the Fire Brigade.

Definition of Risk

The term risk refers to the combination of frequency and consequences.

Risk = Frequency x Consequences

Risk can therefore be reduced by either reducing the frequency of an incident or by reducing its consequences. Normally legislators are only interested in risk to persons (on and off site) and the environment. In this particular case the Fire Brigade is also, obviously, concerned regarding the safety of their own personnel when responding to storage tank incidents.

More information about the FHM methodology can be found in the UKOOA publication.

CHAPTER 2

GENERAL INFORMATION - TANK STORAGE

2.1 GENERAL LEGISLATION/ CODES OF PRACTICE

The latest fire safety legislation (e.g. Seveso II) in Europe has, in general, tended to move away from prescriptive requirements that precisely detail exactly what fire safety measures are required. A more risk-based approach has been adopted where incident frequency and recognition that there may be several different ways of achieving appropriate risk reduction are taken into account. (Indeed, it is this trend that has led Rotterdam-Rijnmond Fire Brigade to develop these guidance notes and associated Storage Tank Fire Hazard Management Concepts).

The final choice of safety system measures to be put in place is therefore the decision of the facility operator provided they can demonstrate to the authority that the measures are adequate and appropriate and that they are implemented and maintained correctly.

This approach follows the introduction of the Seveso II Directive from the European Parliament and its consequent risk-based legislation.

Thus, the trend in legislation has led to the production of "Guidance" rather than "Prescriptive" Demands.

One such example is the guidance document The Storage of Flammable Liquids in Tanks produced by the United Kingdom's Health and Safety Executive. (The organisation responsible in the U.K. for overseeing implementation of the Seveso Directive). This gives guidance on Risk Assessment using the following steps:

STEP 1	Look for the hazards
STEP 2	Decide who might be harmed and how seriously
STEP 3	Evaluate the risks from the hazards and decide whether existing precautions are adequate or more should be done
STEP 4	Record your findings
STEP 5	Review your assessment from time to time

In terms of Storage Tanks, the stated aims of the Risk Assessment are:

- Minimise the risk of Loss of Containment (i.e. product or vapour release)
- Minimise the risk of a fire or explosion occurring on or in the tank itself
- Mitigate the consequences of such an incident, particularly with regard to people and the environment
- Protect the tank from fires occurring elsewhere

This document Note then goes on to discuss various risk reduction options. It must be emphasised that the vast majority of guidance is given in the form "should" rather than "shall", i.e. it is not mandatory, although of course, good, reputable operators will implement most of the advice provided. However, it is very much up to the operator to develop their own practices to reduce risk to acceptable levels and then demonstrate to the regulator that they are implemented and maintained. It is the regulator's responsibility to approve and monitor the operator's chosen policies.
Generally speaking, in terms of the provision of risk reduction measures, once it is decided to implement a certain measure, a great deal of assistance/guidance is available (see 3.2 below) and the regulator will recognise Codes of Practice and design guidance from recognised organisations such as the USA based National Fire Protection Association.
Most of such guidance has been developed by specialist organisations such as the NFPA, American Petroleum Institute, the Institute of Petroleum or the Oil and Gas Producers Association, or national/international standards committees such as EN, ISO, etc.

Codes of Practice

Probably the most relevant, internationally recognised Codes of Practice and Design Guidance are published by the following organisations:

- American Petroleum Institute (API)
- Institute of Petroleum (IP)
- National Fire Protection Association (NFPA)
- Oil and Gas Producers Association (OGP)
- Engineering Equipment and Materials Users Association (EEMUA)

In addition many National Standards organisations issue their own guidance, but most of

theses generally follow the information given by the above.
Each of these organisations publish many Guidance Notes and Design Standards, some of which are general in nature, others specifically aimed at storage tank FHM.

In particular, the following documents are available:

American Petroleum Institute (API)

API 500	Classification of Locations for Electrical Installation at Petroleum Facilities Classified as Class 1, Division 1 and Division 2.
API 505	Recommended Practice for Classification of Locations for Electrical Installation at Petroleum Facilities Classified as Class 1, Zone 0, Zone 1 and Zone 2.
API 575	Recommended Practice for Inspection of Atmospheric and Low Pressure Storage Tanks
API 650	Tank Construction.
API 653	Tank Inspection Repair Alteration and Reconstruction.
API 2001	Fire Protection at Refineries.
API 2003	Static/Lighting Protection.
API 2004	Inspection of Fire Protection.
API 2015	Safe Entry/Cleaning of Tanks.
API 2021	Fighting Tank Fires.
API 2025	Emergency Planning.
API 2026	Safe Descent onto Floating Roofs.
API 2030	Waterspray Systems.
API 2610	Design, Construction, Operation, Maintenance and Inspection of Terminal and Tank Facilities.

Institute of Petroleum (IP)

Model Code of Practice;

Part 14	Protective Instrumentations Testing.
Part 15	Area Classification.
Part 16	Tank Cleaning Safety Code.
Part 19	Fire Precautions – Refineries/Storage.

National Fire Protection Association

NFPA 11	Foam Systems.
NFPA 15	Waterspray Systems.
NFPA 20	Installation of Stationary Pumps.
NFPA 24	Private Fire Service Mains.
NFPA 30	Flammable and Combustible Liquid Code.
NFPA 497	Classification of Flammable Liquids, Gases or Vapours and of Hazardous (Classified) Locations for Electrical Installation in Chemical Process Aras.

Oil and Gas Producers Association

Fire Systems Integrity Assurance - (available from www.ogp.org.uk)

Engineering Equipment and Material Users Association

EEMUA 159

Users Guide to the Maintenance and Inspection of Above Ground Vertical Cylindrical Steel Storage Tanks.

Centrum Industriële Veiligheid

- Borging Integrale Brandveiligheidsproces - CIV01
- Audit Methodologie Brandveiligheid Opslagtanks - CIV03
- Atmospheric Storage Tank Bow Tie Diagrams - CIV04

2.2 OPERATING COMPANY CONSIDERATIONS

There can be great differences between different oil companies in their approach to fire safety. Some companies will do the minimum required to meet legislation, others will recognise long term benefits to business continuity and asset protection from imposing a more rigorous Fire Hazard Management regime.
One issue that should be borne in mind with all companies is that, in general, over recent years there has been a tendency to reduce manning levels. This, in some cases, has led to reduced equipment inspection, reduced maintenance and reduced process/operation training, all of which can affect Fire Hazard Management.
Generally speaking large multi-national companies will have in-house standards that specify minimum standard to be met in all aspects of FHM. Often they will have access to corporate expertise if they need assistance or guidance. Smaller companies are less likely to have such facilities and may rely heavily on external expertise, including from the Fire Brigade, in developing and implementing FHM policies. This

Table 2.1: Summary of materials with characteristics and potential hazards

TANK CONTENT	CHARACTERISTICS	POTENTIAL HAZARDS
Petroleum	Broad boiling range	
Middle distillates (Kerosene, Jet fuel, Diesel)	Volatile, low flash point	Potential flammable vapour space if tank temperature above flash point. Potential electrostatic ignition when foaming
Crude Oil	Volatile, viscous	Boilover, frothover, slopover
Heavy Residual Fuels	Heavy Residual Fuels temperature. May be blended with lighter hydrocarbons	Frothover, slopover, boilover. Potentially pyrophoric ignition with "sour" crude
Chemicals	Single Boiling Point	High vapour pressure and vapour evolution if boiling point is approached
MTBE (Methyl Tertiary Butyl Ether)	Volatile, low flash point	High volatility Low surface tension
Methanol Ethanol	Low flash point, volatile, wide flammable range	Water soluble (requires special foam considerations), low luminescence flames
Refining Chemicals Spent Acid Phenol	hydrocarbons	
Process Chemicals Benzene Styrene	Varied	Long term health effects (Benzene)
Methyl Methacrylate		
Lead Alkyl Antiknock TEL	Toxic, reactive, combustible	Potential detonation at elevated temperatures (100-150°C) Toxic
Metal alkyl catalysts	Highly reactive	compound, toxic combustion products Violent reactivity with water, pyrophoric in air
"Slops" Waste water/sour water	Flammable due to potential contamination by light hydrocarbons.	Potentially pyrophoric ignition with "sour" or sulphur containing materials

Note: This table is not exhaustive. MSDS sheets should be consulted wherever possible for physical property data, potential hazards etc.

is not to say that they will have lower standards or are less committed to fire risk reduction than well known multi-national companies - indeed, sometimes they can be more aware of the potential for asset or business loss from fires especially if they only have one facility - but it can mean they need more guidance and assistance. Obviously, manning levels at a facility can also influence FHM policies. Even though Europoort is in the unique situation that they have the Unified Fire Brigade with industrial incident response equipment, initial response from site personnel in carrying out shutdown or fuel isolation as well as, possibly, some preparation for fire attack can play a vital role in minimising escalation and reducing fire loss. Many companies, especially with reducing manning levels may not be able to provide this capability, others may go as far as having a number of personnel dedicated to initial response.

Thus the initial fire control and response preparedness capability can vary considerably from company to company.

Thus, the size and structure of a company can have a significant impact that should be taken into account when assessing or developing FHM strategies, especially when preparing Emergency Plans, and liaison between the site and the incoming fire responders.

2.3 FUEL TYPES AND CHARACTERISTICS

Up is a summary of materials commonly encountered at storage facilities with characteristics and potential hazards.

2.4 TANK TYPES AND SAFETY FEATURES

2.4.1 Introduction

The following is a brief description of the main systems used in the storage of bulk liquids in the petroleum and petrochemicals fields. Only tanks operating at, or near, atmospheric pressure are included, including horizontal vessels.

The types of tanks (Fig 2.1) are:

1. Fixed roof tanks
2. Fixed roof tanks with internal floating roofs
3. Open top floating roof tanks

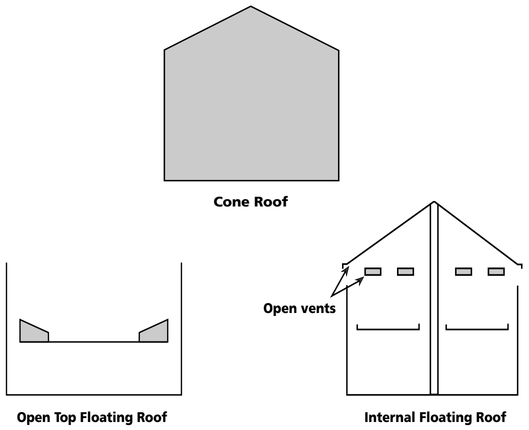

Fig 2.1 - Tank Types

2.4.2 Fixed Roof Tanks

Tanks with fixed roofs include cone roof tanks, dome roof tanks and column supported roof tanks, all of which are of either welded, riveted (older types), or bolted (older types) construction.

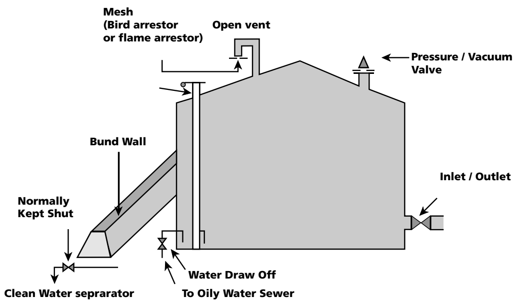

Fig 2.2 - Typical basic design of a fixed roof tank

These are simple containers and their shells, bottoms and roofs will have been built with steel plate conforming to nationally recognised-standards for quality and strength. Components such as roof trusses and attachment nozzles can also be taken as conforming to the minimum requirements of the design codes.

Irrespective of design calculations, the minimum plate thickness that is acceptable for shell, roof and bottom are stated in the codes. This guarantees a certain reserve margin of strength in the completed structure.
Fixed roof tanks are typically used to store a range of refined products, from volatile materials to heavy fuel oils. When used for petrol (gasoline) storage, the requirements of EU Directive 94/63/EC apply and reflective paint has to be used plus an internal floating cover to limit evaporation.

“Petrol” is any petroleum derivative, with or without additives, having a Reid vapour pressure of 27.6 KPa, or more, which is intended for use as a fuel for motor vehicles.

Fixed roof tanks comprise a tank bottom/base, a cylindrical shell constructed in a number of plated levels (tiers) with the number of tiers depending on the tank capacity required. On the top tier of the shell a structural section is fitted to maintain circularity and to allow for attachment of the roof. One or more structural sections, known as wind girders, may be attached to the shell, generally though not exclusively for the purpose of resisting buckling and wind loads.

The roof is fixed welded to the curb at the top of the shell and is formed in a shape that resists downward forces. Generally this shape will be a conical shape although domed roofs are also used. Depending on the thickness of plate used, the roof plating will not be self-supporting in the tank sizes normally found in refinery and storage terminal use.

The minimum thickness for the roof plating is 5 mm on a new tank. (API 650) To support the roof plating in tanks up to about 30 metres diameter, some form of rafters or trusses are employed. The roof plating is not attached to these structures in tanks over 12.5 metres diameter. Roof trusses often extend downwards below the curb and therefore may lead to a reduction in storage capacity if, at a later stage, the fixed roof tank is modified to hold an internal floating roof cover. The roof plating is attached to the curb, by welding, and if specified the weld may be minimal to make the joint frangible as a protection against accidental overpressure.

All fixed roofs need to be vented, (Fig 2.3 / 2.4) either by open vents or via pressure/vacuum valves (Fig 2.5). For liquid to get in, air and vapour must be pushed out. The pressure in the tank must be slightly above atmospheric.

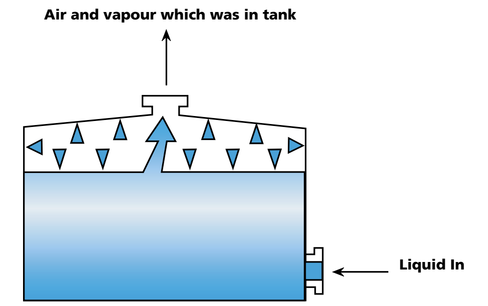

Fig 2.3 - Venting (Emptying)

For liquid to get out, air and vapour must be sucked in. The pressure in the tank must be slightly below atmospheric. (fig. 2.4)

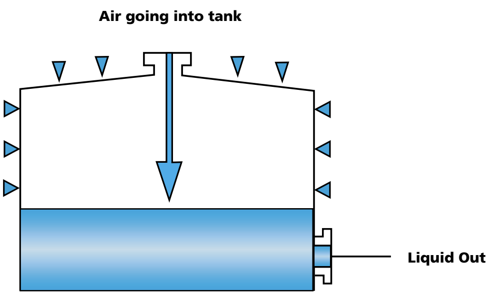

Fig 2.4 - Typical example of a Pressure/ Vacuum

Right is an example of what can happen when the PV valve is blocked, in this incident, by heavy gauge plastic sheeting that was used to protect the valve during painting. (Fig. 2.6 / 2.7) The tank operators activated the tank pump out in error, resulting in a vacuum in the tank. The results are obvious.
Tank diameters greater than 30 m may require

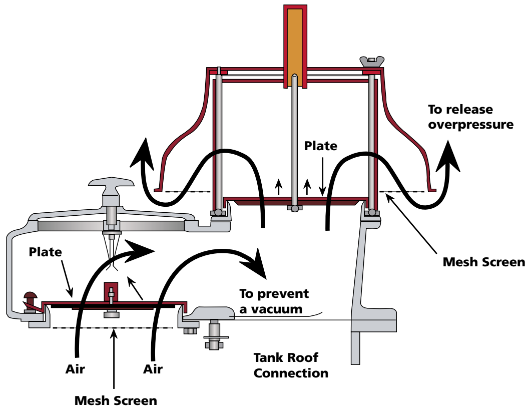

Fig 2.5 -Typical example of a Pressure/Vacuum Valve on fixed roof tanks

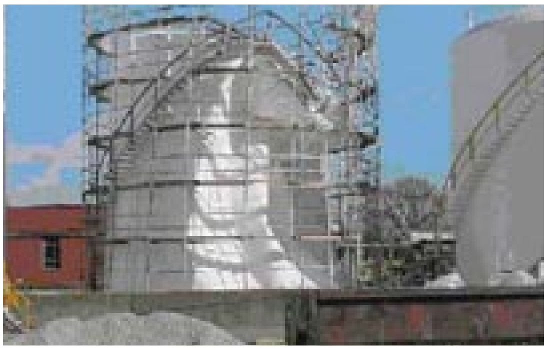

Fig 2.6 - Tank damage on PV being blocked

Fig 2.7 - Plastic sheeting used to cover the PV on the roof

such massive roof trusses that the design is uneconomic. For larger diameter fixed roof tanks, column supported roof structures may be used. In these tanks vertical columns carry the self-weight and other roof loads directly to the foundations. A single column at the roof centre acts as a “king post”. Multiple columns are frequently used; but there must be a high degree of confidence in the foundation provisions for column-supported designs.

Domed roof designs, where the roof is in the form of a partial dome (generally 0,8 to 1,5 times the diameter of the tank) can be made in steel or aluminium alloys. When retrofitted to an existing tank, the steel dome may impose unacceptable loads on the tank shell and on the foundation. The aluminium alloy option is ideal in such circumstances since it is generally designed on geodesic principles that combine great strength with lightness.

2.4.3 Internal Floating Roof Tanks

Such tanks are the same as ordinary fixed roof cone tanks but with internal floating roofs (fig 2.8). These covers may be of aluminium, stainless steel or polymer construction. Those of polymer construction have exhibited a tendency to absorb vapour and are not now in common use. By far the most common type currently is the pontoon type, in aluminium alloy where a skin of aluminium is carried on a structure and an array of cylindrical pontoons.

with double deck internal roof

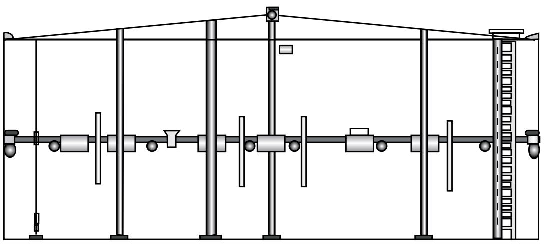

Fig 2.8 - Example of internal floating roof tank

These tanks will generally be found in service conditions where high volatility (Low Flash Point) or toxic liquids are stored.
In a fixed roof tank without a floating cover the liquid surface is in direct contact with the air space above it.

Without an internal roof, vapour passes into the air until it is saturated. As the tank is refilled after emptying, the complete air space vents to atmosphere to make way for liquid, taking with it its load of vapour. Depending on the physical characteristics of the stored liquid, these losses can be very large indeed and represent a significant financial loss as well as causing atmospheric pollution and presenting a fire or explosion hazard. Heavy gases can collect at low-level points outside the tank, presenting a hidden hazard.

The reason for having an internal floating roof is to conserve vapour and protect the environment from Volatile Organic Compounds (VOCs).

The presence of an internal floating cover reduces these vapour losses by at least 95%, a very important feature where high cost, toxic or flammable materials are concerned. The tank will normally be fitted with open vents around the fixed roof (as Specified in BS 2654 and API 650); but PV vents are often used in practice.

Internal floating roofs are fitted with most of the accessories found on external floating roof tanks; although these are modified due to their lighter construction. Supporting legs are normally not adjustable in height.

A suitable checklist should be available for staff to use in the periodic inspection of the floating roof. Checks on internal floating roof tanks should include:

- Gaskets and anti-static protection
- General condition of the deck skin, observations of serious deviations in shape, punctures etc.
- Loss of contact of legs with the floor or deck distortion (may indicate tank settlement)
- For product change of use, check with vendor for materials suitability, particularly for the seal.
- Check all fittings gaskets and replace as required
- Check deck drain tubes are clear

2.4.4 Open Top Floating Roof Tanks

An open top floating roof tank is a vertical cylindrical tank that has a roof, which floats on the liquid product surface. It significantly reduces evaporative losses and the hazards associated with having a large, possibly flammable vapour space, as is the case with a standard fixed (cone) roof tank. The floating open top roof, however, is exposed to snow, ice and rain.

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These tanks are the workhorses of the industry and in the large diameters common in the industry are more economical than fixed roof tanks. Of major importance however is their ability to reduce vapour losses by around 95% when compared with similar operations in a fixed roof tank.

Typically, such tanks are used for the storage of crude oil and all volatile (low flashpoint) products. Crude oil tends to be self-protective where the open tank shell is concerned, while white oils lack this property and the exposed shells become roughened by exposure to the weather.

The basic design concept of floating roof tanks - that of floating a circular roof on the product surface within a tank shell and sealing the gap between the shell and roof with a flexible device - has not changed since the first tanks of this type were built in the 1920s. However, there have, of course, been detailed design and material specification improvements as operating experience has developed. Generally speaking these design enhancements have been aimed at reducing emissions. Although this is generally done for economic or environmental reasons, there is also usually a Fire Hazard Management benefit, as reduced probability of losses of containment should lead to reduced probability of fire incidents.

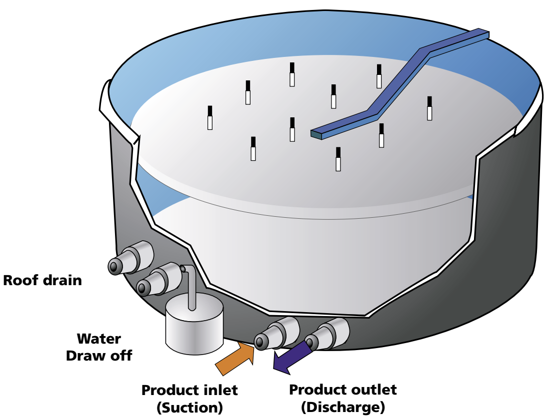

Fig 2.9 - Example of Open Top Floating Roof Tank

There are 4 basic roof design options:

Pontoon or Single Deck Roofs

Pontoon Floating Roofs, first introduced in the early 1950's, have a compartmented annular ring of pontoons and a centre single deck. If designed in accordance with recognised standards such as API, the design of the floating roof provides sufficient strength and buoyancy to keep the roof floating when the centre deck and any two adjacent pontoon compartments are punctured or when the centre deck is loaded with the design rainfall with the primary drain inoperative. (The typical design rainfall is 250mm in a 24-hour period. However, the roof can be designed for greater rainfall when required.) Thus, most roofs are designed to remain buoyant with 250mm (10ins) of water on them. (API 650)

The roof is designed to float directly on the product. The underside of the pontoon usually slopes upward toward the centre of the roof to hold temperature-generated condensable vapour under the single deck. The top deck of the pontoon slopes downward toward the centre to direct rainwater onto the centre single deck.

Double-Deck Roofs

Double-deck floating roofs have two complete decks joined by a series of concentric rims. The outer annular bay is compartmented by radial bulkheads.

The design of the roof provides sufficient buoyancy to keep the roof floating with any two compartments punctured. Emergency overflow drains are provided to prevent storm water accumulation from exceeding the capacity of the roof.

The roof is designed to float directly on the product. The air space between the upper and lower decks reduces the amount of surface product heating from ambient air temperatures and solar radiation. This significantly reduces the formation of temperature generated condensable vapour under the floating roof. For heated tanks, the insulating effect of the double deck-floating roof reduces heat loss and helps to maintain the desired product temperature.

Centre draining roofs have the top deck sloped downward from the outer rim to the centre of the floating roof. The centre draining roof profile is typically used on roofs up to about 60m in diameter. A reverse slope profile is used on tanks larger that 60m is diameter.

This profile has the top deck sloped downward from both the floating-roof rim and centre to a low point located about mid-way between the rim and centre of the floating roof. A minimum of three equally-spaced drains are provided at the low point of the top deck.

Buoydeck or Multiple Pontoon Roofs

The Multiple Pontoon roof is essentially a combination of the Pontoon and Double Deck roof types. It is similar to a single deck pontoon roof but with additional pontoons positioned strategically over the entire roof area to increase buoyancy. There are also variations on this where rather than additional pontoons, there are stiffening members on the roof.

In practice it has been found that this type of roof construction has led to considerable integrity problems because of the additional and non-uniform stresses caused by the extra pontoons or struts. (The extra pontoons cause localised rigid areas over the more flexible roof.)

Geodesic Roofs

In recent years, as weather protection, it has become popular to install geodesic dome type roofs. These are lightweight structures over the complete floating roof tank, thus making, effectively, an internal floating roof tank. In general, it is thought that this should be a good fire hazard management measure because the tank roof is not subject to environmental extremes such as heavy rainfall, but there are certain considerations that should be taken into account:

There has been a case where a lightning strike on such a roof damaged the roof to such an extent that it collapsed and fell onto the floating roof, causing a major incident.
The dome may make it more difficult to access rimseal fires or spills on the roof or give problems due to its collapse in a full surface fire.
Under the dome should be treated as confined space entry with the consequent procedural constraints.
Until more operational experience is obtained, it may be necessary to increase the frequency of gas "sniff" tests under the dome under different environmental and operational conditions in order to check for build up of flammable atmospheres.

Floating Roof Tank Rim Seals

The vapour conserving devices on a floating roof tank may include some of the following types of rim seal:

There are two basic primary seal types:

- Mechanical seals
- Tube seals

Mechanical Primary Seals

A mechanical primary seal consists of a fabric reinforced elastomeric seal mounted between the edge of the roof and the tank wall. The seal is securely fixed to the roof and pushed against the tank wall by means of a pantograph arrangement and/or compressed spring type mechanism.

After construction a tank can, due to settlement, deform from being truly circular. Rim seal support mechanisms are designed to centralise the roof and keep the width of the gap constant around the entire tank circumference.

The tank shape may continue to change over a long period due to differential settlement, flat-spots and bulges. This tends to be worst in the upper shell tiers and rim gaps of up to 22 inches (558 mm) have been found in some cases.

Typically the design of the mechanical mechanism is such that movements of + 100 mm from

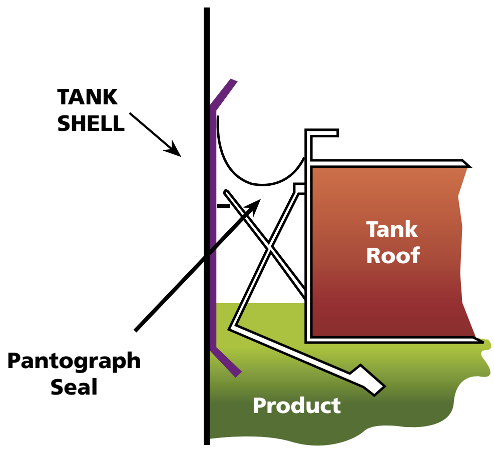

Fig 2.10 - Pantagraph (mechanical) seal

a nominal 200 mm gap between the roof edge and the tank wall can be accommodated

Tube Seals

Tube seals consist of a fabric reinforced elastomeric tube fitted with a resilient material. The tube distorts according to the movement of the roof such that a seal is maintained between the roof and shell. Again, the dimensions of the seal are such, typically, to allow for a + 100 mm movement of a nominal 200 mm gap.

The tube may be fitted with resilient foam or a liquid.

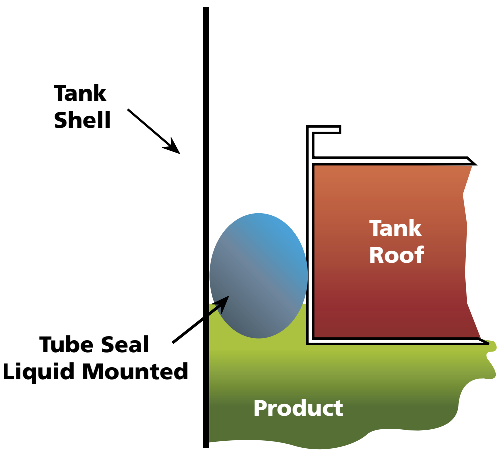

Fig 2.11 - Flexible resilient tube type seal

Secondary Seals

As environmental restrictions have become more stringent and to reduce losses from emissions, most operators have supplemented the primary seal with a secondary seal mounted above the primary seal. In many countries it is an environmentally driven legislative requirement to have secondary seals for the more volatile organic liquids.

Secondary seals give protection of the primary seal to the elements, but are themselves exposed. Therefore secondary seals should be fabricated in stainless steel and the primary seal in galvanised steel or stainless steel. Fastenings should be in stainless steel.

Secondary seals often consist of bent compression plates with an elastomer tip, which maintains constant contact with the tank wall. Alternatively they may consist of elastomer coated fabric.

Other Tank Fittings

On a floating roof tank there are a number of different fittings such as guide poles, vents and roof legs. These may include:

- Stairway/Rolling ladder to allow access to the roof.
- Windgirder with walkway
- Roof legs/ drain lines
- Emergency drains
- Rim vents
- Gauging facilities
- Level alarms
- Guide pole
- Shunts to dissipate static charge between roof and shell
- Scrapers to remove wax deposits on tank walls
- Fire fighting equipment
- Roof Access Ladder/Walkway

Several recognised fire fighting strategies for rim seal fires and roof spill fires (see Section 5) require manual intervention. Preferably this is initially carried out from the walkway at the top of the tank rather than having to go onto the roof itself.

When no safe full circumference walkway can be provided at the top of the tank, an access ladder should be available wherever possible and this should be kept in good working order by adequate maintenance. (ref: LASTFIRE)

Roof Drains

The purpose of the roof drain is to drain rainwater from the roof. In theory, the drain should have 100% integrity and so it should be possible to leave the drain valve at the bottom of the tank open without the risk of discharging product into the bund. This would be the preferred situation. In practice the roof drain does often leak and, consequently, the drain is kept closed and only opened after rainfall. This practice has led to tank roofs sinking from excessive weight in areas having very heavy rainfall. In Holland it is common to keep roof drains closed (general demand in the environmental licence.) A few companies already use detection in the roof drain.

Guide Poles (Antirotation Devices)

Floating roofs must be prevented from rotating within the tank shell while being free to move vertically. This is mainly achieved by passing a guide pole down through the roof, close to the shell. Alternatively, some tanks have a guide rail fitted to the tank shell for the same purpose.

Guide Pole Seal

Vapour losses do occur through slotted guide poles and there is a current fashion to enclose these in a folding envelope to further reduce vapour losses. More volatile and more toxic materials may be considered for this treatment. An additional refinement to the guide pole seal may also be observed, where a sleeve is fitted into the guide pole well.

Roof Leg Socks

Losses of vapour from adjustable floating roof legs have been assessed. Obviously, the stored product and wind conditions have a large bearing on the likely losses; but they may typically be around 10 kg/annum/leg on the centre deck and about 12 kg/annum/leg around the roof perimeter. If fitted, they should be of the sealed sock type, typically made of polyurethane sheet.

Shunts

Storage tanks must be suitably earthed to ground. The Design codes specify the number of earthing bosses to be provided for tanks of various diameters. This measure is necessary for the safe disposal of lightning strikes and lesser static electrical charges to earth.
Since the floating roof is a large, steel, surface without direct contact to the tank shell, it must be adequately provided with anti-static conducting means to complete the circuit roof/shell/earth. Traditionally, roof peripheral seals have incorporated such anti-static components. The rule-of-thumb guideline was always to place sliding anti-static shunts at intervals of 10 feet (3 metres) around the seal. The shunts are normally thin stainless steel strips, approximately 30mm wide, connected to the steel roof at one end and in sliding contact with the tank shell. More recently, evidence has suggested that intervals of 2m for the shunts is preferable. Some seals, with flexible foam or liquid fillings incorporate carbon in the formulation of their outer envelope to provide an anti-static connection. With these seals, there could however be a loss of contact with the shell over considerable lengths of the perimeter.

Obviously, anti-static components will be correctly positioned when the seal system is installed; however there needs to be an awareness of their purpose and a commitment to check and adjust them at regular intervals. The presence of such a programme is recommended. It is generally accepted that the best position for shunts is in the open air, above the secondary seal tip.

Some operators use a cable attachment from roof to shell to provide a backup conductor for seal types with anti-static polymers in their make-up. In practice it is difficult to maintain this cable in working order since the roof constantly rises and falls and the slack cable becomes damaged. It is possible that elaborate cable controls may be dependable but they must be viewed with caution.

2.4.5 Horizontal Cylindrical Tanks

These tanks will be relatively small with capacities up to about 25,000 litres and are typically used for the storage of motor spirit at filling stations etc. operating at, or near, atmospheric pressure. “Type A” Horizontal tanks for static storage of flammable liquids are generally simple cylindrical shapes with flat or slightly dished ends. Average diameters are in the range 2 to 3 metres. There are normally two supporting saddles, generally of brick or concrete. There will also be open vents to the atmosphere. Provided that the operator has in place reasonable procedures for inspection and maintenance, there is little to comment upon. The two saddle positions need care to ensure that corrosion does not take hold at the obscured parts of the shell, and vapour expelled when filling must be controlled (usually this is exchanged to a delivering tanker in the case of motor spirit). Good bunding is essential to prevent spread of spillage.

Fig 2.12 - Example of Horizontal Storage Tanks

GENERAL INFORMATION - TANK STORAGE

2.4.6 Tank Design and General Safety Features

The design of atmospheric pressure bulk liquid storage tanks has been addressed in many Codes of Practice over many years. In Europe, tanks will have been designed and constructed to one of the major codes of practice such as API650, BS2654 or similar. The objective of such codes is to give reassurance to a tank purchaser or operator that any tank designed and built to the code will embody the benefits of good engineering practice, overlaid by the guidance of many years of practical operational experience. However, tank safety systems, operator training and awareness of the facility operations are just as important as the available hardware.

Corrosion Factors

Plate thickness at the design stage is often further boosted by the purchaser requesting a corrosion allowance, which is a surplus thickness of steel in excess of the design code requirements. This is seldom applied over the entire tank and is used more on vulnerable corrosion areas such as the bottom shell plated tier and the tank bottom in tanks containing crude oil and some of its derivatives.

This is necessary because salt water in crude oil can gather at the bottom of the tank and affect the steel by chemical or microbial action. Alternatively, many operators may coat these vulnerable areas with a resistant coating of epoxy or similar. Tank bottom leakage is not an infrequent occurrence and is almost always the result of corrosion. (See Bow Tie Diagrams, Section 5.6) Cathodic protection is another method of guarding against corrosion and can be very effective if properly applied and maintained.

Over the years they are in service, tanks will deteriorate due to atmospheric corrosion, wind damage, attack by stored liquids, maloperation and ground settlement.

Tank Foundations

In the Netherlands, tank foundations can be unreliable since they are usually built on the banks of river estuaries and sometimes on reclaimed ground. The industry standard foundation for atmospheric pressure tanks is a simple mound of compacted sand/gravel, up to one metre high and finished with a 50 mm coating of sand/bitumen across the top and sloping sides. As simple as this is, this is usually adequate for most situations, but experience dictates that the Netherlands requires particular care in this respect. Careful design will limit the operating height of the tank, commensurate with the ground load bearing capacity. This results in a tank of larger diameter for a given capacity but this is not always popular with operators.

A more reliable foundation is where the tank foundation is made of a concrete ringwall on which the tank shell rests and the centre of the ringwall consists of compacted gravel to support the tank floor.

The best foundation is a concrete pad of the full tank size, possibly supported on piles although this is very expensive. This would normally only be justified for refrigerated LPG or LNG tanks.

Foundation settlement can have several effects on a tank. If the settlement is uniform, the tank sinks into the ground with little effect apart from additional stresses where the external piping systems are connected to the shell. These stresses can become dangerous unless action is taken to relieve the condition. Relief measures could involve re-alignment of piping or fitting adjustable pipe supports to cater for changes in level.

Non-uniform settlement, where the rate of settling varies at different locations beneath the tank, often results in the tank shell tilting. This can be tolerated to a certain extent, after which the matter must be resolved. The tank can sometimes be jacked up at the low points and gravel/aggregate rammed into the space before lowering the shell. It is also possible to jack the entire tank off the ground and re-lay the entire foundation.

Apart from the visible effects on the tank shell, settlement can have a major effect on the tank bottom. To facilitate drainage and to cater for a certain amount of ground settlement, the foundation is generally shaped so that the floor plating is in the form of a cone, upwards at the centre. As settlement occurs, the cone gradually flattens and the plate material takes up new positions. This can lead to severe wrinkling of the bottom plate that may result in a cracked weld. Loss of product through bottom leakage is a frequent outcome of settlement.

Tanks, or even the entire bund, may be underlaid with an impermeable membrane to guard against contamination of ground water in the event of leakage. This is a major undertaking and is unlikely to be done unless the tanks are new-build.

Steel bunded tanks have found favour with some companies, although they have disadvantages in the longer term as they may be impossible to jack up. Here the storage tank is surrounded by an open top shell capable of holding the entire tank contents in event of a rupture. This is an expensive approach and is therefore not widely used.

The outside of the tank can often suffer the effects of settlement where the shell-to-floor connection settles below the water level of the enclosing tank bund. This thinning of the shell at a critical position could lead to catastrophic failure if neglected.

The threats associated with tank settlement are covered in separate 'Bow Tie Diagrams' (CIV04).

Reference documents: API 650, BS2654 and PGS29

Vents

Vents are features of all tanks. As stated, this treatment covers tanks of approximately atmospheric rating and mainly the vents will be simple openings in the roof at a level above the maximum liquid level. Some of these tanks may be fitted with pressure/vacuum valves that are designed to open if the pressure increases beyond the set pressure dictated by the tank design. Some stored hydrocarbon/petrochemical products are sensitive to air, or the moisture it contains, and have to be stored under a blanket of nitrogen to maintain an inert atmosphere and these tanks will certainly be fitted with PV valves.

All vents, whether open or valved have a finite capacity to pass air or gas and there should be good operational controls in place to ensure that, for example, the filling and emptying rates used for the tank never exceed the safe rating of the

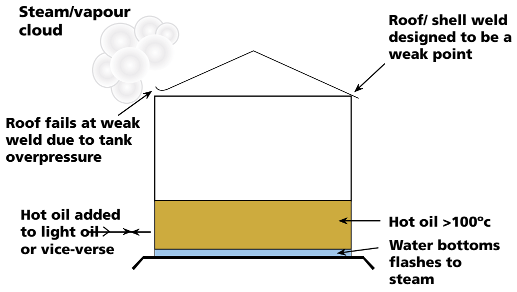

Fig 2.13 Tank roof separating due to internal pressure rise

valve system. This factor can be forgotten when new pumping systems are brought into operation, hence the need for good operator training and awareness. Additionally, PV valves should be checked at regular intervals for correct operation in accordance with a maintenance plan. . Overpressure in the tank can result in rupture, usually at the shell to roof connection. The following illustrates a tank roof separating due to internal pressure rise due to steam build up.

Tank Repairs and Maintenance

Product loss (Loss of Containment) from a tank should never be ignored. Usually the first sign may be the presence of oily traces in the bund. In spite of recent advances, in-service repairs are not generally successful. The tank has to be taken out of service and a detailed examination made to decide the extent of repairs.Tanks are generally prepared for a targeted period of service before routine inspection and repairs are carried out. This involves taking the tank out of service after say 10 to 15 years, cleaning and inspecting it before repairs. Operators should have safe working procedures with work-permit systems but there may be exceptions. Despite the planned maintenance schedule, much benefit can be derived from a trained observer simply looking at the tanks once or twice per year. (ref. EMUUA 159)

Tank Bunds

Tank bunds are important, as their function is to contain any spillage and prevent general contamination of the environment. Earth bunds are the norm although some companies use concrete bunds or concrete lined bunds. Earth bunds offer an inexpensive means of containment but they are often infested with rabbits and other wildlife. Additionally, poorly constructed or poorly maintained earth bunds can be subject to

”washout”, where heavy rain or in a worst case, oil or product filling the bund can wash away sections of the bund. There are a number of such incidents.

2.5 POMPPLAATSEN (NL)

Om veilig te kunnen werken aan pompplaatsen moeten de onderstaande punten in acht worden genomen.

Vluchtwegen

Grondslag: Arbeidsomstandighedenbesluit en Beleidsregels Arbeidsomstandighedenwet Arbeidsplaatsen zijn veilig toegankelijk en kunnen veilig worden verlaten. Ze worden zodanig ontworpen, gebouwd, uitgerust, in bedrijf gesteld, gebruikt en onderhouden, dat gevaar voor de veiligheid en de gezondheid van de werknemers zoveel mogelijk is voorkomen. Voorts worden zij zindelijk, zoveel mogelijk vrij van stof en voor zover de veiligheid van de arbeidsplaats dat vereist, ordelijk gehouden.

Verlichting / noodverlichting

Grondslag: Arbeidsomstandighedenbesluit en Beleidsregels Arbeidsomstandighedenwet Arbeidsplaatsen en de directe toegangen daartoe moeten gedurende de aanwezigheid van werknemers voldoende verlicht door daglicht dan wel kunstlicht indien is voldaan aan de NEN 3087:1997. Bij het uitvallen van de kunstverlichting moet deze arbeidsplaats zijn voorzien van adequate noodverlichting. Deze noodverlichting moet minimaal aan de volgende voorwaarden voldoen. Minimaal 1 lux op vloerhoogte vanaf 15 seconde na het uitvallen van de normale electriciteit.

V&G-signalering

De V&G-signalering van werknemers is terug te vinden onder §5.5

Aarding

De aarding van pompen is terug te vinden onder §6.6

CHAPTER 3

OPERATION OF STORAGE TANKS

Typical Practice

Most operators specify, operate and inspect tanks in accordance with API 650 standard and its associated codes or equivalent. NFPA 30 or IP Model Code of Safe Practice Part 19 are generally used to determine minimum tank spacing.

There is a wide range of approaches to the provision of electrical shunts and lightning protection such that it is not possible to say that there is any “typical” practice. Some operators have accepted that the concept of lightning strike prevention or mitigation is sufficiently proven and have, accordingly, adopted it.

In general, operators do not formally require personnel responsible for fire response to carry out inspections of the type described in Section 5.7 leaving it to the electrical and mechanical maintenance department. It is thought that this situation is one that should be rectified.

Most operators are now installing secondary seals for higher vapour pressure fuels due to environmental restrictions.

The practice of specifying fire retardant rimseal materials is becoming more popular but is not yet widespread.

Most tanks are fitted with independent high and high-high alarms.

Different companies have different practices regarding status of roof drain valves. It is generally recognised that they should be left open but in practice many are closed due to drain line leakage and procedural requirements to open them after rainstorms are in place. Although drain line leakage is relatively common, it is not possible to repair such leaks without taking tanks out of service. Therefore in such cases the drain valve status and procedures are adopted as described.

PART TWO

PREVENTION OF LOSS CONTAINMENT AND IGNITION

CHAPTER 4

LOSS OF CONTAINMENT SCENARIOS

4.1 MODES FOR LOSS OF CONTAINMENT

For a tank fire to occur flammable material must be exposed to an ignition source. Each case of release of flammable material or introduction of an ignition source occurs as the result of the presence of a threat and the failure of a line of defence (barrier). For example, the threat of tank overfill is normally prevented by the barrier of process controls such as independent high and high-high level alarms and action to shut down on alarm, the threat of ignition from hot work is prevented by procedural controls such as permit to work systems. Thus, at least two barriers have to fail to produce a fire. In general, many barriers have to fail before a large fire event occurs.

This section details Loss of Containment modes (i.e ways in which flammable or toxic materials can be released) for the following types of tank:

- All tank types (generic)
- Fixed roof tanks
- Floating roof tanks

As well as lists of the most common failures that may result in product releases, there is an in-depth analysis of the most common failure modes for floating roof tanks, as there is currently good information on these from the LASTFIRE project and it is possible to provide a high level of detail for floating roof tanks. (See section 11) Whilst these apply in the main to large diameter floating roof tanks, the loss of containment modes reviewed may well occur in smaller diameter floating roof tanks and other types of storage tank. Section 5.2 outlines the most common barriers against loss of containment given in this section.

4.1.1 Causes for loss Of Containment (LOC)

For All Tanks

There are common causes for Loss Of Containment (LOC). These are as follows and appear in the "Bow Tie Diagrams" included in Section 5.8 as initiating events (left hand side):

Overfilling

- Failure of high level and high-high level alarms;
- Operator error;
- Maloperation.

Corrosion

- Poor drainage caused by water filling bund with valves remaining closed or tank piping in bund not raised above bund floor and rainwater rising above piping;
- Mill scale (tank bottom) ;
- Water migration under tank which can becaused by tank floor buckling or where earth/grass grows up around the tank and acts as a wick to transfer moisture unde rthe edges of the tank;
- Significant tank settlement where tank floor forms spaces to allow water to gather;
- High natural water table/springs affecting the tank base and lower shell tiers;
- Poor quality foundations;
- Failure of cathodic protection;
- Topside/roof corrosion
- Pitting or weld corrosion
- Product or crude and water corrosion
- General metal wastage
- Removal of protective scale

Other

- Operator error, through inadequate training or poor judgement
- Incorrect materials or component specifications;
- Tank or bund piping impact;
- Tank weld failure;
- Tank isolation valves failure;
- PV valve blockage or failure
- Tank sample valve failure
- Introduction or transfer of hot oil into cold oil tank and visa versa
- Bund washout or partial failure
- Bund drain left open
- Boilover if crude oil burning

For Fixed Roof Tanks

- Vapour expulsion via daily cycling or refilling operations;
- Loss of inert nitrogen or fuel gas blanket;
- Failure of or corrosion holes in steam coils;
- Failure of mixer seals or mixer;
- Blocked flame arrestors or bird mesh screens

For Floating Roof Tanks

- Roof drain failure (jamming of drain)
- Roof tilt/jam
- Failure of primary seal
- Failure of or corrosion holes in steam coils;
- Failure of mixer seals or mixer;
- Leg failure

For floating roof tanks, depending on construction, some or all of the examples may apply.

4.1.2 Losses of Containment for Floating Roof Tanks - Detail

The following types of product release have all been observed to occur in the past on floating roof storage tanks. Many of the modes outlined here may be applicable for other types of storage tank.

Releases into rim seal area

The primary seal can fail from excessive tank movement or rubbing against tank walls corroded by salt air or from foreign objects falling into the rim seal gap.

Some early designs of certain types of seal have also failed by rolling under the rim of the roof as the roof was moved or by losing the tension force holding the seal in place against the tank shell.

Failure of process monitoring can allow hot product or high vapour pressure product or gas (including nitrogen or air) into a tank causing an eruption of vapour and product out of the rim seal area. Failure of heating controls can also produce such a vapour eruption.

Failure of process monitoring can lead to overfill of a tank. Gauges can give incorrect readings if there is a sudden change in the specific gravity of the product. Failure of high and or high-high level alarms may not be reported to operators on subsequent shifts.

Tank settling can cause a tank to go out of round, leading to rim seal gaps. When a tank is out of round, there is also the possibility that the roof could stick or jam.

Subsequent sudden movement of the roof could cause product and flammable vapour to escape into the rim seal area.

Product in pontoons or between decks of roof

Corrosion or bad construction of pontoons has lead to product inside pontoons.

The same problems can occur in the spaces between double deck roofs.

If pontoon inspection hatches are not closed tightly, overflow of product onto the roof from vents, drains or from the rim seal area can lead to product in pontoons.

Product on roof

Escalation of releases in the rim-seal area or into pontoons or roof spaces can lead to product on the roof if large amounts of product are involved.

Leaks directly onto roofs can occur in single skin roofs which have cracked from wind induced stressing or corrosion.

Leaks onto roofs have also been known to occur from the fracture of double deck roofs.

Wind can blow rainwater to one side of a roof tilting the roof.

Rolling ladders on roofs can come off their rails and puncture single skin roofs or cause the roof to jam.

If pontoon inspection hatches are not secured in place, they can be blown off by the wind, allowing rainwater in and causing the roof to lose buoyancy.

Failure of non-return valves on drain sumps of single skin roofs can lead to product on the roof. Product will flow up onto the roof because the weight of the roof causes it to form a shallow saucer shape such that the product level at the edge of the roof is higher than the upper side of the roof in the centre.

Product can leak from leg sleeves or the hole for the gauging pole.

It has been known for a roof to be landed with some of its legs in the normal operating position and the others in the lower, maintenance position. The roof can then tilt and jam as it comes to rest on its legs at different heights. If the jamming of the roof is not noticed by operators, subsequent filling of the tank pushes product on top of the roof. The same problem can also occur if corrosion of legs leads to some of them failing when the roof is landed.

Product can appear on the roof from operational or instrumentation failures leading to overfill or the introduction of gas or high vapour pressure product into the tank. Overheat of product can also lead to product on the roof.

Product in bund

Escalation of releases in the roof area can lead to product or flammable vapour escaping into the bund.

The shell-to-bottom joint can fail from corrosion, brittle fracture of the weld, tank settlement or erosion of the tank foundations.

The tank bottom plate can fail from corrosion, can buckle and fail due to settlement or erosion of the tank foundations or can puncture due to failure of the roof leg pads.

Roof drains, steam coils and mixers can fail, allowing product into the bund.

Pipework within the bund can leak at flanges, valves or measurement tappings.

Sumps for water or product take off are sometimes installed at the base of tanks. Excessive settlement of the tank can collapse the pipe connections leading to a release into the bund.

Failure to monitor an open water draw has lead to product spillage into the bund.

Product can collect in bund drains.

Leaks from shell fittings

Connections through the tank shell can leak at flanges or valves. Such incidents usually begin as a small seepage and should be detected by routine inspection. If there is a significant hydrostatic head of product, the leak can form a jet or spray of liquid.

Air under roof

When a roof is landed on its legs and emptying continues air is sucked into the vapour space under the roof and can form a flammable atmosphere. Landing the roof during operation is not a recommended procedure, however, it is happening more frequently as tanks are cycled more often, and especially since the stored product is being changed more and more frequently. When there is a vapour space under the roof, there is an increased risk of an explosion under the roof and an increased risk of fire when the flammable vapour is pushed out of the tank as the tank is refilled.

Sinking roofs

Roofs can sink from larger spills of hydrocarbons on the roof, torrential rainfall that either exceeds the capacity of open roof drains or which overloads the roof before the roof drain can be opened, damage to pontoons or fracture of the roof. A roof can also sink if it jams and sticks and product continues to be pumped into the tank.

Dominant failure modes - results from LASTFIRE incident survey

The LASTFIRE Analysis of Incident Survey document gives an indication as to the dominant failures modes for spills of hydrocarbons onto the roof, the sinking of roofs, or spills into the bund from incidents on 2420 tanks with 33909 tank years of operation in the 15-year period 1981-1995. There were 37 recorded roof sinkings, 55 recorded liquid hydrocarbon release incidents in the roof area that did not lead to sinking of the roof and 96 recorded liquid spills outside the tank.

In addition, one site, with 30 tanks and an operational history of 450 tank years within the scope of the survey, recorded 14 instances of seal damage and 20 instances of product in pontoons found during inspections and 9 instances of holes in tank bottoms found during maintenance work on out-of-service empty tanks. These incidents suggest that a significant proportion of tanks may have lost some integrity during a fifteen-year period and they highlight the importance and value of regular inspection and preventative maintenance.

LOSS OF CONTAINMENT SCENARIOS

The failure modes can be grouped into three categories:
Mechanical failure or corrosion (seal or pontoon damage, leg failure or failure of the roof leg pads, cracking or fracture or the roof, roof drain failure, tank bottom or bottom ring corrosion, steam coil failure, and leaks from mixers, pipework, flanges or valves).

Process or procedural failures (overfilling, gas or high vapour pressure product in the line, over heating of product or landing the roof with some of the legs in the maintenance position).

Failures arising from environmental overload (e.g. heavy rainfall).

Mechanical failure was the dominant mode of failure leading to spills in the roof area.

The most frequent cause of roof sinking was from overload due to excessive rainfall. Torrential rainfall is approximately ten times more likely to lead to the sinking of a roof than just a spill on the roof. Operational failures are the least likely cause for sinking roofs. The most frequent cause of mechanical failure leading to sinking roofs was due to failure of legs from corrosion of their lower ends. All 7 cases of this type of failure occurred in one company. Seal damage alone is unlikely to lead to sinking the roof. However, it appears that about one in four cases of roof cracking or fracture are severe enough to sink the roof. Roof sinking from roof drain failure is less likely (one in seven cases). Process or procedural failures such as allowing gas or high vapour pressure product into a tank, or overfilling leads to sinking of the roof in about one in four cases.

An analysis of the data of the effect of roof type on roof spill and sunken roof failure modes has produced the following conclusions.
Double deck roofs appear to suffer just as much from fractured roofs as single deck roofs.
Buoydeck type roofs seem to suffer disproportionately from damaged pontoons and roof cracks near pontoons.

Roof drain failures can lead to product on the roofs of double deck roofs.

Single deck roofs may be slightly more susceptible to sinking from torrential downpours than double deck roofs.
Corrosion and mechanical failure was the most common cause of major bund spills. The most common mechanical failure leading to product spillage was roof drain failure. The most common process or procedural failure was from overfill.

4.2 BOW TIE DIAGRAMS

For a large tank fire to occur flammable material must be exposed to an ignition source. Each case of release of flammable material or introduction of an ignition source occurs as the result of the presence of a threat and the failure of a barrier. For example, the threat of tank overfill is normally prevented by the barrier of process controls such as independent high and high-high level alarms and action to shut down on alarm, the threat of ignition from hot work is prevented by procedural controls such as permit to work systems. Thus, at least two barriers have to fail to produce a fire. In general, many barriers have to fail before a large fire event occurs.

In this document, losses of containment and ignition sources are represented diagrammatically within simplified forms of “Bow-Tie Diagrams”. Each mode of loss of containment or ignition is shown on the left-hand side of the bow tie with corresponding threats and barriers.

‘Bow-Tie Diagrams’ are provided for tank fire scenarios listed below and are based on Loss of Containment / ignition source scenarios as detailed in the document “Bow Tie Diagrams” (CIV04) to develop the fire scenario concerned.

Scenarios for which bow ties are provided include the following:
- Fixed (Cone Roof) Tanks
- Vent Fire
- Bund Fire
- Full Surface Fire (partial/full roof removal)
- Internal (Covered) Floating Roof Tanks
- Vent Fire
- Bund Fire
- Full Surface Fire
- Open-Top Floating Roof Tanks

• Spill on Roof Fire
• Bund Fire
• Rim seal Fire
• Full/Partial Surface Fire

The left hand side of the "bow tie" may be made up of a number of initiating fire events, loss of containment modes and ignition sources depending upon the tank type, scenario and expected threats.

The right hand side will comprise one or more intermediate events (e.g fire response options, threats or escalation events) leading to one or more eventual outcomes. An outcome may be extinguishment of the tank fire, or a new fire scenario resulting from the previous escalation event(s).

The fire scenario (shown as the "knot" of the bow tie) will generally arise due to a combination of one or more loss of containment and ignition source modes or events, and will be "tied" together by means of an AND gate (i.e. both must occur for the tank fire to manifest itself).
The preceding modes may occur independently of one another and will generally be "tied" together using an OR gate. (i.e. Overfill OR mechanical damage can result in a loss of containment, whilst lightning OR electrical equipment can result in an ignition source).
In all cases, modes and events are grouped together, denoted by a 'box', under which examples are given. Those that appear in red type are generally failures or actions that could result in loss of containment, ignition or escalation (i.e. threats). Examples appearing in green type are generally "barriers" or Lines of Defense that may prevent loss of containment and ignition, or mitigate the effects of the tank fire scenario. On the right hand side of the bow tie, the eventual outcomes will be dependent upon the effectiveness of the barriers or lines of defense, and for more guidance on this reference should be made to Sections 6 and 9, which detail Lines of Defense and Fire Systems Integrity Assurance (CIV01).

Significant initiating events on the left hand side of the bow tie have their 'own' left hand sides.

These are as follows:

• **Corrosion of Tanks**
  Underside - External
• **Corrosion of Tanks**
  Annular Plates - Internal
• **Corrosion of Tanks**
  Shell Plates - Internal/External
• **Tank Settlement**
  Bottom Settlement
• **Ignition Sources**
  Lightning and Floating Roof Tanks
• **Vapour Expulsion**
  Fixed Roof Tanks
• **Pontoon Leakage**
  Open Top Floating Roof Tanks
• **Double Deck Leakage**
  Open Top Floating Roof Tanks
• **Roof Drain Failure**
  Open Top Floating Roof Tanks

They can be used in the same way as the main 'fire scenario' Bow Tie Diagrams in order to view threats and barriers associated with the events concerned.

The bow ties allow rapid assessment of the potential threats for each fire scenario and list the barriers that may be in place to prevent initial loss of containment and ignition giving rise to a tank fire. For example, the significant initiating events listed above are common failure modes such as tank corrosion and tank settlement that can result in loss of containment.

CHAPTER 5

PREVENTION OF LOSS OF CONTAINMENT

Barriers may be in place to prevent the following:

1 Loss of Containment
2 Ignition

Once a fire has happened, there may be further barriers in place to control and prevent escalation or to mitigate the consequences.

Each initiating event occurs as the result of the failure of some barriers, as shown in the left-hand side of the “Bow-tie” diagram (Fig 5.1)
The function of “Bow Tie Diagrams” is explained in more detail in Section 4.2
At least two barriers have to fail to produce a fire. For example, the failure of process controls such as level monitoring and high-high level alarms combined with the failure of ignition source controls has the potential to start a fire. In general, many barriers have to fail before a large fire event occurs.

Without ignition, a loss of containment can be a problem. The evaporating of large quantities of H2S from crude oil or the prevention of fires when spills have occurred may require actions, such as the application of foam.

Once a fire starts, there may be several escalation events that can make the fire more severe, and the failure of barriers on the ‘Right Hand Side’ of the “Bow Tie” can result in any one of a number of outcomes ranging from an isolated incident such as a rim seal fire, to a multi tank/bund fire.

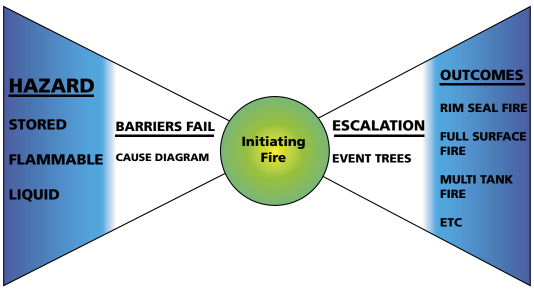

Fig 5.1 – ‘Bow Tie Diagram’ Showing Failure of Barriers

The function of ‘Bow Tie Diagrams’ is explained in more detail in Section 4.2

The barriers covered in Chapter 5 are as follows:

- Barriers to Prevent Loss of Containment
- Loss of Containment Detection Options
- Tank Operating Procedures / Safe Practices
- Tank Operational Instrumentation and Alarms
- Tank Inspection and Maintenance
- Tank and Bund Drainage

Barriers to prevent ignition are covered in Chapter 6 (Section 6.2).

Most of the barriers described in this section are generally preventative measures and are present on the ‘Left Hand Side’ of the Bow Tie. Barriers such as water-cooling, foam systems and barriers to prevent escalation may appear on the ‘Right Hand Side’, as fire control and mitigation measures (Corrective Lines of Defence).

Corrective Lines of Defence are covered in detail in Chapter 8.

CHAPTER 5

PREVENTION OF LOSS OF CONTAINMENT

5.1 BARRIERS TO PREVENT LOSS OF CONTAINMENT

This section lists some general barriers against 'Loss of Containment' (i.e. product releases). Notes are also provided for those barriers not considered elsewhere in this Technical Frame of Reference. Clearly, the avoidance of loss of containment is the first step in prevention of storage tank fires. However, there will be circumstances when this is not entirely possible (as when a fixed roof tank expels vapour through vents during the daily breathing cycle, or during filling operations). However, there are many barriers to prevent serious product losses that an operator can implement to minimise the risk of a tank fire.

5.1.1 General

- Tank foundation constructed to standards codes;
- Tank constructed to standards/codes;
- Tank level alarms;
- Tank level trips (valve closures or pumps shut down);
- Tank temperature indicators;
- Corrosion inspection programme;
- Corrosion protection;
- Hazop study;
- Tank operations and maintenance procedures and instructions;
- Tank operator training/competence;
- Permit-to-work system;
- Tank and piping maintenance programme;
- Bund vehicle entry barriers;
- Corrosion allowance on tank base and lower shell tiers;
- Tank overhaul/refurbishment programme;
- Good specification and quality control of tank/ piping and associated materials;
- Regular roof drains inspection;
- Provision and inspection of secondary seal;
- Regular inspection for debris or corrosion scale in seal area;
- Bund wall constructed to recommended practices;
- Bund wall piping transit pieces sealing;
- Bund drains normally closed;
- Tank welding inspection;
- Floating roof inspections after heavy rainfall.

5.1.2 Inspection and Maintenance

Tank builders, operators and fire fighting personnel generally agree that the most cost effective fire risk reduction measure is implementation of appropriate inspection and maintenance procedures within a formal well managed inspection regime. The main intention is to spot any leaks before they become a significant fire hazard coupled with inspection of potential ignition sources to check their integrity.

5.1.3 Corrosion Protection

Corrosion protection is one method of reducing losses of containment. It is not possible to state which type of protection, coatings, linings or cathodic protection, is the best or most appropriate for any particular tank because it depends very much on local site conditions and tank design. The operator must therefore satisfy himself that he has reviewed all corrosion protection possibilities and selected the most appropriate. In practice it is not only corrosion protection itself that contributes significantly to reduction in fire risk but regular inspection to ensure that any product leakage whether caused by corrosion or some other factor such as "springing" of flanges is detected early and appropriate actions are carried out to stop it.

5.2 LOSS OF CONTAINMENT DETECTION OPTIONS

Various systems are available for detecting releases of product (liquid or vapour) on tank roofs, at vents or in bunds.

5.2.1 Gas Detection

Point type gas detectors can be positioned adjacent to a rim seal to detect vapour loss from the seal. However, it is generally felt that they cannot reliably be calibrated to differentiate between abnormal losses of containment from the seal and those levels of vapours that can be present and accepted during normal operations, such as tank emptying, especially with product clinging to the tank wall.

For similar reasons, gas detectors at tank vents are considered impracticable.

Point type gas detectors at the top of a tank or beam type gas detectors positioned across the tank diameter at the top of shell level can be used to detect a large abnormal release of vapour such as that caused by either major product spill on roof or a sinking roof. The beam type has been used successfully in at least one facility.

The release of vapours from volatile products in a bund from, for example, a flange leak or spill from an overfill incident can be detected by gas detectors. These may be of a point type strategically positioned to pinpoint leak sources and/or beam type being used for general area coverage.

Although flammable vapour detection systems of the type described above are available and could contribute to risk reduction, they are not normally provided, except possibly in the following cases:

In the inter-shell area of double-shell type tanks.

In any bund associated with tankage for toxic materials. (e.g. H_2S in crude). In such cases specific toxic material detectors are used adjacent to potential leak points.

“Live” crude oil tankage where the product has high gas content.
If fixed systems are not provided for such applications, it would be normal practice for personnel operating in the areas to carry portable detection devices and have gas testing as part of the Permit to Work procedures.

5.2.2 Liquid Detection

There are various systems available for detection of liquid spills on tank roofs and in drain lines. The basic principles of detection used can also be applied to spills in the bund area.

A fibre optic based system is available to detect a major build up of liquid (either water or product) on the roof.

A hydrocarbon monitor can be fitted at the roof drain ground level outlet for detection of product in the drain system, and automatically close the drain valve.

Automatic sensors, based on conductivity measurements, are available to determine if liquid is in the drain line and to differentiate between product and water.
There are no internationally recognised fire related standards requiring continuous liquid leak detection equipment on the roof or from tank fittings. However, for environmental purposes as emission controls become more stringent, there have been pressures on operators to provide greater levels of leak detection. In some countries, this has resulted in local authorities requiring automatic product detection in the roof drain with automatic closure of the valve.

Normally inspection schedules and procedures are considered sufficient to provide detection of liquid build up on tank roofs. Similarly, it is normally considered that operating and inspection procedures will detect the presence of product in the drain line, water draw off or bund. It is therefore not normal practice to have any automatic detection system for these applications unless required by local legislation.

5.2.3 Visual Detection

Visual detection due inspection rounds of a operator, or due video detection which will visualize it in the control room.

5.3 TANK OPERATING PROCEDURES/ SAFE PRACTICES

The following is a list of guidelines outlining the most common safety precautions and examples of good industry practice with respect to safe tank operations. The list is not exhaustive, however, as site conditions (e.g. environmental) may require further precautions to be taken. Included are precautions to be taken whilst sampling from tanks, as well as general safety measures. Ideally, an operator should possess written procedures, documentation and training schemes to ensure that such steps are taken.

- Tank operations specific to the facility, tank type(s), products stored and blending operations etc. should be covered in appropriate tank operating manuals. These should state in full detail the practices and procedures required, including fill rates, liquid stream velocities, sampling / gauging duties etc.

- In older tanks or black oil tanks there may be a need to use portable temperature measurement tapes, which are battery-powered instruments. When using these, they must be connected to an earth before switching on.

- Ropes to be used for dipping for samples or for water finding rods must be of natural fibre and not synthetic fibre to prevent static accumulation/discharge.

- Oil soaked rags, used for cleaning dipping tapes or ropes, must not be left on top of tank roofs.

- All dipping/sampling equipment must be constructed of brass or other spark resistant materials.

- Broken or repaired dipping tapes must be discarded since they may fall off and block up drains or damage mixers etc.

- All equipment used for manual dipping, including water finding, must conform to IP specification IP PMM Part II, Section 1 and 2, or equivalent specification.

- Tanks containing black oils must be operated and maintained below 95 °C so that any water bottoms will not flash to steam and cause roof separation or tank rupture.

- Streams entering a hot tank should have no free water or excessive amounts of light hydrocarbon liquid.

- Any black oils tank temperature moving above 95 °C must be investigated immediately.

- Fixed roof tank failures can occur because of vents blocked by:

coke waxy deposits/scale / rust/bird's nests/ice Screen replaced by finer mesh (eg. flame arrestor mesh used to replace bird screen).

- Tank operating instructions must be kept up to date - especially where duty has changed.

- Tanks must be clearly labelled as to contents.

- Inlets and outlets must be clearly labelled.

- Avoid dip / sampling tanks with flammable atmosphere / mist above oil level. For low conductivity product not dosed with anti-static, do not dip/ sample within 30 minutes of stopping filling pumps.

- Do not dip / sample during electrical storms / heavy rain / hail.

- Use the commen personal protection equipment due working. Working in tanks is simular to working in closed spaces. For safe working on closed spaces, the Labor Law of the Netherlands has AI 5 (Veilig werken in besloten ruimten) as issuing of rules.

5.3.1 Hydrogensulfide Policy (H_2S) (NL)

De opslag van stoffen die H_2S bevatten vereist de implementatie van een H_2S policy.
Een dergelijke policy bevat voorschriften met betrekking tot:

Engineering Design, bijvoorbeeld het toepassen van gesloten drains, minimising hold-ups, veilige ontluchting.

H_2S detectie systemen, zowel vaste detectie systemen (bijvoorbeeld in pompputten) als personal monitoring systemen.

Procedures, bijvoorbeeld de identificatie van H_2S houden apparatuur, opening van H_2S houden apparatuur, monstername, pyrophoric FeS, veilig drainen.

Emergency instruction met betrekking tot het vrijkomen van een H_2S wolk.

Persoonlijke beschermingmiddelen, de toepassing, de instructie, training en het onderhoud.

EHBO met betrekking tot blootstelling aan H_2S.

5.4 WERKEN AAN OPSLAGTANKS (NL)

In oktober 1989 en december 1991 zijn in het Botlek/Europoort gebied twee opslagtanks geëxplodeerd, waarbij in totaal 10 mensen zijn omgekomen.

Naar aanleiding van deze tankexplosies geeft de Arbeidsinspectie een aantal adviezen die er op gericht zijn dergelijke rampen te voorkomen.

Ten eerste dat er een gemeenschappelijke factor is bij beide explosies, nl.:

HET VERRICHTEN VAN LAS-, BOOR- OF SLIJP-WERKZAAMHEDEN (zgn. heet werk) AAN, OP OF MET OPSLAGTANKS MET BRANDBARE STOFFEN DIE NIET LEEG, SCHOON EN DROOG ZIJN.

Het uitgangspunt voor het verrichten van werkzaamheden aan tanks moet zijn leeg, schoon en droog. Met andere woorden er mogen geen vloeibare of gasvormige restanten van brandbare vloeistoffen aanwezig zijn. Dit uitgangspunt moet reeds vastliggen in de 'veilig werk-' en 'heet werk' procedure.

De verantwoordelijkheid voor het leeg, schoon en droog opleveren ligt altijd bij de productie- cq. operationele afdeling. Hier mag alleen van afgeweken worden bij hoge uitzondering en gebleken noodzaak. Er dienen dan maatregelen genomen te worden die de extra risico's compenseren.

Het resultaat van deze maatregelen moet zijn dat het risico is teruggebracht naar het niveau van leeg, schoon en droog. Hierbij valt te denken aan inertiseren, vullen met water, ontluchting verplaatsen, en combinaties van diverse maatregelen. Deze maatregelen dienen te zijn uitgewerkt in een veiligheidsplan of draaiboek. Dit veiligheidsplan dient bekend te zijn bij alle betrokkenen en moet onderdeel uitmaken van de 'heet werk' vergunning.

Ten tweede dat bij het verrichten van 'heet werk' aan opslagtanks altijd door middel van metingen moet zijn aangetoond dat zich, noch in noch buiten de tank, een explosief gasmengsel bevindt. De metingen moeten worden verricht door personen die voldoende zijn opgeleid en met apparatuur die in goede staat verkeert en waarvan vaststaat dat zij geschikt is voor de desbetreffende situatie en stof. Dit laatste vereist bijvoorbeeld extra aandacht bij mengsels die kunnen condenseren of kristalliseren en in situaties met een verlaagd of verhoogd zuurstofgehalte.

Ten derde dat in toenemende mate 'heet werk' uitgevoerd wordt in area's waar zone 1 of 2 met betrekking tot gasexplosiegevaar geldt. Vergunningverleners worden geconfronteerd met 'heet werk' aanvragen in deze area's, waar de productie niet, zonder dat dit verstrekkende gevolgen heeft, stil gelegd kan worden. De contractorfirma's staan te wachten en zien elke vertraging als kostenverhogend. Dit spanningsveld kan aangepakt worden door de arbeid op een goede manier te organiseren. Bijvoorbeeld door een goede planning en voorbereiding van de uit te voeren karweien, waarbij tevens rekening gehouden wordt met de werkbelasting van de vergunningverlener. Wij wijzen u er op dat het organiseren van arbeid op een zodanige wijze dient te geschieden dat er geen nadelige invloed van uitgaat op de veiligheid. Dit is een *verplichting die de Arbeidsomstandighedenwet aan werkgevers oplegt.*

Het voorgaande is tevens van belang om gevaar, schade of hinder buiten het bedrijf en eventuele luchtverontreiniging te voorkomen. De werkwijze dient in overeenstemming te zijn met het gestelde in de Arbeidsomstandig-hedenwet, de voorschriften welke zijn opgelegd in de verleende vergunning ingevolge de Wet milieubeheer en het gestelde in deze paragraaf.

5.5 V&G-SIGNALERING (NL)

Grondslag: Arbeidsomstandighedenbesluit en Arbeidsomstandighedenregeling

Ter voorkoming of beperking van gevaren voor de veiligheid en de gezondheid van werknemers moet doeltreffende veiligheids- en gezondheidssignalering aanwezig zijn op de Arbeidsplaats. Hierbij wordt verwezen naar artikel 8.12 van de Arbeidsomstandighedenregeling

5.6 TANK OPERATIONAL INSTRUMENTATION AND ALARMS

Due normal operation certain indicators and alarm are required for safe operation, some of these are described underneath.

5.6.1 Level Indicators

Tanks will normally be provided with level instrumentation to indicate to tank operators the progress of loading or unloading operations. The number and location of these will depend on the type of instruments in use and the size of the tank.

5.6.2 Level Alarms

All tanks should have a means of alarm that will alert tank operators to a high level filling condition that requires tank filling to halt. This is simply known as a “High-Level Alarm” usually termed as Hi-Hi Alarm, and is normally actuated by the tank liquid as it rises in the tank. For increased safety, an additional, independent High-High Level Alarm can be provided and connected to the tank filling valve to enable closure. This creates double assurance since it is possible that the High-Level Alarm may be defective or the alarm sound may be missed by tank operators. Where such High-High Level Alarms are provided, they will almost always be termed Hi-Hi Level Trip, denoting the additional function of closing (tripping) the tank fill valve after taking account of potential surge problems or the affect on other plant/process.

High-High level alarms should be totally independent of other alarms. i.e. It should not rely on the same sensing device, control equipment or power sources as the High level alarm. The High-High level alarm should be set at a level such that an operator can respond to a High level alarm in sufficient time to prevent actuation of the High-High alarm. The High-High level alarm should be set at such a level that when actuated any residual flow prior to full shutdown is not sufficient to overflow the tank.

Equally necessary for tank safe operations is a Low Level alarm, to prevent overdrawing/suction of the tank. This is provided even where a vacuum valve is fitted, which should prevent a tank vacuum event. The Low Level Alarm becomes very important when fitted to a floating roof tank, as it will warn operators to halt discharge before the roof is "landed" on it's legs, thereby allowing air to enter below the roof and crate a flammable atmosphere. In some cases, a Low-Low Level Trip will be provided, which can be connected to the discharge valve to close on alarm.

5.6.3 Temperature Alarms

Tanks may have temperature indicators or in some cases, temperature alarms. This is especially so, if the tank contents are heavy oils or bitumastic oils or crude oils and more so where a tank heating element, usually with steam as the heating medium, is provided.

Temperature instrumentation is necessary for means of indication that may cause tank product instability. For instance, water ingress into a tank, caused by rainfall through open dip hatches etc, will eventually result in water layers near the tank bottom. If the temperature of the oil or product stored exceeds 100 °C "water boiling point " then the water will vaporise. This vaporisation causes a steam cloud to erupt within the tank. The expansion of water to steam/vapour is in the order of 1:1600. Such an expansion can violently eject the tank contents up and out of tank vents or in some cases, result in pressures that separate the weak tank-to-roof seam and eject oil out in this way.

One reason for use of temperature indicators is in case there is the possibility of transferring, by accident, hot oils (> 100 °C) into low flash point product tanks. The reason for this is to prevent a sudden increase in the vapour pressure of such tanks, which may lead to roof separation due to high internal pressure.

Slops tanks, used for off-spec or drain slops of oil or product can contain a wide variety of flash point liquids. Ballast tanks, used for oil tanker/ship bunkering and ballast functions may also contain a wide range of oil product. It is therefore important to monitor the temperature of such tanks.

5.7 TANK INSPECTION AND MAINTENANCE

Undoubtedly the most cost-effective risk redution is good maintenance and operation. In fact, the LASTFIRE project concluded that it should be regarded as mandatory. This demands rigorous inspection followed by rapid remedial action being taken on any problems found. Very often, tank inspection is carried out by operators who, understandably, generally concentrate on issues that are likely to affect efficient tank operation and may not be fully aware of fire related issues. Such inspections will usually be carried out using a specialist tank inspection guide such as EEMUA 159. It is therefore important that a site-specific inspection procedure aimed at fire issues is carried out by personnel responsible for fire response. Ideally, walk-round checks should be carried out weekly and, typically, should include:

- Mechanical failures or damage leading to product loss.
- Integrity of Electrical Fittings.
- Fire Detection systems.
- Fire Protection systems.
- Firefighting equipment.

Such walk round checks do not, of course, replace more comprehensive inspections or tests required from specialists in different aspects of tank design and operation.

This section is intended to outline a typical tank inspection and maintenance programme that, ideally, should be adopted by an operator. The outline takes the form of a checklist, with examples of typical deficiencies an operator ought to note and correct.

Routine Safety and Fire Inspection

Following is a typical safety inspection list for tankage, to be carried out on a routine basis. (Note – site specific inspection schedules should be developed)

- Is the tank bund drain valve closed?
- Is there water pooled around the perimeter of the tank?
- Is the bottom and side wall joint visible?
- Are there any visible signs of leakage around the base of the tank?

PREVENTION OF LOSS OF CONTAINMENT

- Are side manways leaking?
- Are pipe joints at the shell secure?
- Is there any indication of stress or leaks on lap joint flanges?
- Are tank ground wires intact and in good condition?
- Are mixers noisy - indicating wear and tear ?
- Are mixers leaking or mixer oil seals leaking?
- Is mixer oil level correct?
- Is mixer oil discoloured?
- Are all shunts between roof and wall in good condition and making conduct
- Is floating roof water drain valve at the tank shell open?
- Is the floating roof water drain line outlet unobstructed?
- Are there any visible holes or cave-ins in the surrounding tank bund?
- Are there any indications of the tank bund drain valve leaking?
- Is there any debris or vegetation build up in the bund?
- Is the tank bottom water drain valve leaking?
- Are any sample taps double blocked?
- Are all sample taps leaking?
- Is the deadman valve leaking?
- Is the sample valve and deadman valve operable and piped into oily sewer system?
- Is the stairway and handrail in good condition
- Is the gauge hatch cable operable and in good condition?
- Is the rolling stairway on it's track and in good condition?
- Is the rolling stairway ground wire intact and in good condition?
- Is there any water pooled on top of the floating roof or on the top of the internal floating roof? If so, indicate location and amount.
- Is there any trash, grass, debris on top of the floating roof?
- Is the floating roof drain on top of the floating roof unobstructed?
- Is there any visible signs of leakage through the floating roof?
- Are all leg sleeves in good condition?
- Are all legs in the same position?
- Are the secondary seals rolled under or pulled away from the wall?
- Are all pontoon covers and inspection manholes securely in position?
- Are all pontoons clean and dry?
- If not, indicate which pontoon(s) are not.
- Is the floating roof anti-rotational guide in place and in good condition?
- Is gauging cable in place and in good condition?
- Is the side gauge operable?
- Is gauge service cover sealed?
- Floating roof explosibility reading:_______ % LEL.
- Are linear heat detection and associated fittings in good condition?
- Are support clips for linear heat detection in place and undamaged?
- Are all lighting fittings in good condition?
- Are all foam pourers free from debris and unobstructed? Is the air inlet on foam generators free from obstruction?
- Are foam dam and seal area clear of any debris or product?
- Do all foam ports appear unobstructed?

Note: Asterisk indicates tank must be static, a first entry permit issued and a safety standby person is required.

The following examples show deficiencies that regular tank inspection should note and correct.

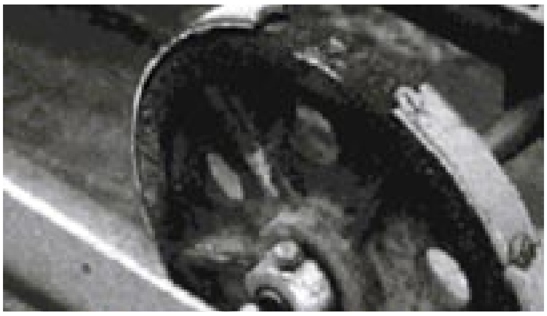

Fig 5.2 – Floating roof ladder wheel damaged – eventually the ladder will "jump" off the track and may tear the roof open.

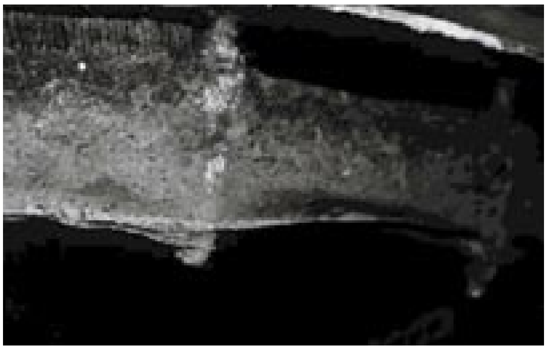

Fig 5.3 – Blocked filter on a floating roof drain cover.

Fig 5.4 – Corrosion, waxy crude deposits and waste on a floating roof will lead to blocked roof drain, which in turn will load the roof and lead to roof sinking.

Fig 5.5 – Guide poles and the rollers can jam, causing roof jam and tilt

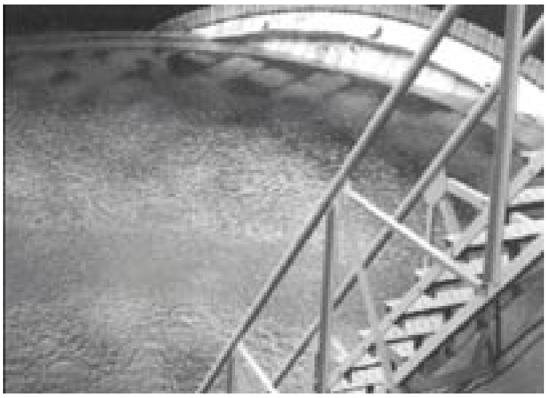

Fig 5.6 – Example of a sunken floating roof – caused by roof overloading

Fig 5.7 – Example of a tank collapse due to internal corrosion which was not detected properly.

5.8 TANK AND BUND DRAINAGE

5.8.1 Floating Roof Drain

Floating roof drains have been described previously in this document as have the potential blockages or defects that may occur with such drains. Tank operating practices vary for such drains. Most will ensure that the roof drain valve at the tank base is closed, to prevent any leakage of oil or product into the drain line pouring out into the bund. However, other operators may use a practice of normally open roof drains so that rainwater will always be removed from the floating roof.

Regardless of the practice used, frequent inspection of such tanks is required to a) check if rainwater needs to be drained of from the roof when the drain is kept closed, or, b) to check that oil or product is not leaking into the drain line when it is kept open.

In the Rotterdam Rijnmond area the environmental permits all state that drains e.g. bund or roof drains must be closed, except when is proven that the safety procedures used on operation are simualar as closing the drains.

5.8.2 Tank Water Drain

Over the years that a tank is in service, there may be water settling at the base. Rainwater can enter a tank through tank vents, open dip hatches, small corrosion holes in the roof, etc, etc. This water has to be drained off to prevent internal corrosion and also to reduce product contamination.

Where tanks have such drain facilities fitted, sometimes known as BWS (Bottom Water Settling/Sediment) drains, they should not be left in an open position for obvious reasons, since product or oil will eventually displace the water and leak from the drain into the bund. Some tanks will have such drains linked into the facility oily/water drainage system, whereby the drain valve outlet is fixed above a tun dish (collecting dish) connected to the enclosed oily/water system. This allows tank operators to observe the draining liquids and close the valve when any product begins to come through.

5.8.3 Bund Drains

Tank bunds, of necessity, must have high integrity to hold any spill release or catastrophic release from a single tank. Therefore, there should be no bund leakage paths or open drains in bund walls. During heavy rainfall weather, especially over the autumn, winter and spring months, it will be necessary to release rainwater from bunds via the drains to prevent the tank pad becoming undermined and to prevent corrosion at tank bases and tank floor to shell curbs.

Typically, bund drains will consist of a sump/pit at the lowest corner of the bund so that spills will flow to this sump and from here a simple piping and valve system, with the valve on the outside of the bund, carries the spill to either the facility oily/water treatment plant or to an oily/water separator.

Bund drains should not normally be interconnected, which would then enable spilled oil or product migration from one bund to another.

Bund drains should have clear signage and valve indications to enable easy observation of the valve status – open or close. Doubts over the status can lead to drain valves being left permanently open, which must be avoided in case of an oil or product spill or major release from a tank.

CHAPTER 6
IGNITION SOURCES

6.1 MODES OF IGNITION SOURCES

This section outlines the ways in which threats of ignition can arise. When combined with the failure of barriers resulting in loss of containment (see Chapter 5), a tank fire may occur.

Ignition may occur as a result of the failure of one or more barriers intended as prevention. These barriers are outlined in Section 6.2

The main potential causes of ignition are as follows and appear in the "Bow Tie Diagrams" (See Section 4.2) :

- Hot Work
- Welding
- Arc
- Sparks
- Induced currents
- Inadequate grounding
- Grinding
- Inadequate shielding
- Gas torch burning
- Sparks beyond considered distance
- Unpermitted work
- Lightning;
- Direct Strike
- Induced (nearby strike)
- Unclassified Electrical Equipment;
- Poorly specified equipment
- Inadequate maintenance
- Floating roof jamming – friction generating heat or sparks;
- Electrostatic discharge;
- Fluid flowing too fast
- Inadequate grounding during (un)loading
- Vehicles in bunds;
- Lighting;
- Tank stairways
- Gaugers platform
- Wind girder
- Flares;
- Incandescent drift
- Liquid carry over
- Pyrophoric substances
- Pyrophoric materials (e.g. FeS)
- Pyrophoric combination (e.g. fine metal mesh and flammable contamination)

NB: Not every product release may be ignited, leading to a fire. The number of ignited spills compared with actual unignited spills has been observed to be in the order of 1 in 100, depending on fuel type.

The following notes expand on the ignition source modes listed above. The information has been compiled from an analysis of escalation mechanisms as part of the LASTFIRE project (See next sections) and applies to floating roof tanks, although the ignition source modes are equally as valid for other types of tank. Section 6.1 gives guidance on the prevention of ignition sources by implementing suitable barriers or 'lines of defence'.

Hot Work

Two rim seal fires recorded in the LASTFIRE survey were from hot work on live tanks. Sparks were carried from gas free areas into regions where flammable mixtures existed. 7 fires occurred during hot work on empty tanks. There were cases of fire even when gas checks had been carried out before the work started. In these cases heat from welding caused flammable vapours to be given off from hydrocarbon deposits. The exposure of personnel is higher on tanks under maintenance than on tanks in normal operation. Therefore, it is important that to ensure that correct permit to work procedures are carried out, with an assessment of all potential consequences of the work actions as part of the planning of the work, in order to minimise the risk of fire on tanks under maintenance.

Lightning

Lightning is by far the most frequent source of ignition of fires on floating roof storage tanks. In the LASTFIRE incident survey, 52 of the 62 initial fire events within the scope of the survey were lightning ignited rim seal fires. It is not necessary for lightning to strike a tank directly for an ignition to occur. A strike in the immediate neighbourhood can generate a discharge of static electricity between the floating roof and the tank shell. A separate 'Bow Tie Diagram' is provided for ignition by lightning on floating roof tanks. (See Section 5.6)

CHAPTER 6
IGNITION SOURCES

Ignition outside tank (including vehicles, lightning etc.)

Some of the worst recorded fire incidents started with ignition outside the tank.

Overfilling of tanks has lead to the formation of a flammable cloud which then found an ignition source outside the bund area (e.g. in a boiler house, or at process heaters or at a generator being used for maintenance work on another tank). The severity of the ensuing fires was partly as a result of the large volumes of product released into the bund area and partly because of damage to tanks from the explosion produced by ignition of the flammable vapour cloud in the neighbourhood of the tank and its pipe work.

Hot work during maintenance in the bund was responsible for ignition of hydrocarbon in the bund drains in one severe fire incident.

Other ignitions outside the tank have been caused by friction and over-heating in mixer pumps.

Electrostatic Discharge

Electrostatic discharge has been postulated as the source of ignition in several fires that have occurred when foam has been put onto tanks after the roof has been discovered to have sunk or to be partially sunk. However, in other cases, the surface of tanks with sunken roofs has been foamed without leading to electrostatic discharges. Whilst the build-up of electrostatic charge is known to be possible when water drains through low conductivity (typically refined) products, it is thought that the method of foam application affects the probability of an electrostatic discharge. Foam should be run gently over the liquid surface after flowing down the sides of the tank. Particular problems appear to occur when a foam blanket is applied, foaming is stopped, and then restarted sometime later because it is perceived that the foam blanket is degrading.

Electrostatic discharge may occur if the electrical bonding between roof and shell or the earthing of the tank is inadequate. The Institute of Petroleum Electrical Safety Code Part 1 states that the maximum resistance to earth of a storage tank should be 10 ohms for lightning and electrostatic protection or even less for earthing of electrical equipment. However, lightning strikes generate peak currents of between about 2000 and 200,000 amperes. In addition to the enormous heating effect of such currents, the high rate of rise of current, in combination with the resistance can create voltage differentials of over one million volts with respect to ground and hence a risk of flashover to adjacent metal.
Storage tank linings may affect the electrical bonding between roof and tank shell. API 652 gives guidance on selection of suitable linings.
For single isolated tanks a minimum number of 2 earth electrodes should be fitted for tanks up to 30 m in diameter and 3 for a tank greater than 30 m in diameter. There should be an independent connection to the tank.

Cathodic protection is sometimes used to inhibit corrosion in storage tanks. Standards such as API 651 give guidance on system design but do not give suitable guidance on the safe operation of tank farm cathodic protection systems. The main method of cathodic protection is impressed current cathodic protection, which involves the application of d.c. current to the storage tank, to lower its potential with respect to earth and make corrosion thermodynamically impossible. This current may be tens of amps. The current is at a relatively low voltage, but because the current is so large, there is the potential for a spark if any section of current carrying pipework or cable is disconnected. Operators should be aware of this potential source of ignition and audit cathodic protection systems to ensure their safety.

API 2003, which provides guidance on electrostatic hazards is being revised to take account of the most recent knowledge. However, it must be recognised that the understanding of the mechanisms remains incomplete.

Several serious fires have been ignited through electrostatic discharge by operators performing gauging duties after a process upset has occurred. Such actions should be covered by operational procedures.

Flares

Two fire incidents are known to have been caused by incandescent particles from flare stacks. Ideally, flare stacks should not be positioned upwind in the prevailing wind direction from storage tanks.

Pyrophoric Reaction

Pyrophoric iron or scale is iron or its compounds in a form capable of such rapid oxidation on exposure to air that heating to incandescence can occur. It may consist of the metal in finely divided state, but it is usually finely divided ferrous sulphide formed in the presence of mercaptans or hydrogen sulphide. It can form in tanks containing products rich in sulphur compounds (usually sour crudes and various hydrotreater feedstocks). When exposed to air, pyrophoric scale can rapidly reach temperatures above the auto ignition temperature of most hydrocarbons.

6.2 BARRIERS TO REMOVE IGNITION SOURCES

The first part of the section outlines some general barriers against ignition and includes a discussion on the avoidance of 'Loss of Containment' from storage tanks as the primary barrier against ignition of tank contents (specific barriers against product releases are given in Section 6.2).

A section detailing barriers against individual ignition source modes outlined in Section 4.6 follows some general guidance.

6.2.1 General

There are various barriers for ignition source control as follows:

- Controlling vehicle access into tank bunds;
- Prohibiting matches and lighters for any personnel working or visiting the area;
- Prohibiting mobile telephones, pagers or radios (except for intrinsically safe or other approved hardware);
- Use of only correct rating of hazardous area electrical equipment and lighting for the tanks and bunds;
- Clean shunts between floating roof and tank shell;
- Lightning rods or array systems;
- Grounding cable from tank to earth;
- Grounding cable from floating roof to tank shell/gaugers platform;
- Permit-to-work system;
- Tank gauging operations grounding;
- Flare location downwind (prevailing wind) and at distance;
- Wearing of anti-static clothing and safety boots; Following anti-static procedures.

Obviously, such measures are only strictly necessary in hazardous areas, but it has often been found advantageous to apply them across a facility, as part of a Safety Management System or dedicated 'Safety Culture'. It is often recommended that these practices and procedures be reinforced regularly, and for visitors incorporated within the site induction process.

Avoidance of Loss of Containment

Preventing ignition of tank contents should, in the first instance, rely on the avoidance of loss of containment since fires generally occur if product is released to atmosphere, and an ignition source with sufficient energy is present Where small quantities of vapour exist in the atmosphere during normal operations, then adequate ventilation is one way of achieving dispersion of vapours such that an explosive concentration cannot be reached. When combined, these measures provide one of the most effective ways of ensuring that the risk of ignition is reduced.

However, situations will always arise when flammable liquids or vapours are present (such as around the vents of fixed roof tanks) and so the two measures described above cannot be relied on in isolation. Such situations may be as a result of accidental spillage, failure of vessels or pipework, operator error, or simply because flammable concentrations of liquefied gas occur in certain areas from time to time.

In addition situations may arise when an explosive mixture is formed within an empty tank, due to minute quantities of product adhering to the tank walls, releasing vapours and presenting an explosion risk, particularly during filling or tank cleaning operations. Well documented cases of accidents resulting from failures to adhere to strict ignition source controls, as well as other measures such as gas-freeing are sometimes all too common.

It follows therefore, that all personnel and visitors to a facility storing petroleum products should be made aware of the risks of ignition and suitable steps should be carried out to ensure that items of equipment or procedures do not allow the ignition of vapours that may be present. Such steps should form an integral part of the Fire and Explosion Hazard Management (FEHM) strategy for the storage facility. Full risk assessments should be carried out to determine the nature and location of potentially hazardous areas or atmospheres and to identify both fixed and portable ignition sources, (as well as procedures constituting an ignition hazard) so that steps can be taken to avoid them.

General Guidance

As a first line of defence, steps can be taken to ensure that the systems associated with tanks at storage facilities are engineered appropriately so that they are 'inherently' able to contribute to ignition source control.

Standards such as NFPA 70, "National Electrical Code", and IP "Model Code of Safe Practice, Part 15 – Hazardous Area Classification" provide guidance relating specifically to ignition source control at petroleum installations, amongst which general guidelines are as follows:

a) Open flames or other sources of ignition should not be permitted in pump houses, or other similar locations.

b) Open flames, cutting or welding, portable electric tools, and extension lights capable of ignition should not be permitted within classified areas unless tanks and associated facilities have been freed of all liquid and vapour or special precautions have been taken under carefully controlled conditions.

c) General precautions against static electricity should be taken, with specific information on grounding and bonding for protection found in NFPA 77, 'Recommended Practice on Static Electricity').

d) Fixed electrical equipment and wiring installed within classified areas should be specified and installed in accordance with a recognised standard such as NFPA 70, ' National Electrical Code', or in Europe, ATEX 137 (section 6.5), both of which provide guidance on selecting, installing and maintaining 'explosion-proof' equipment. In addition, such systems should be maintained effectively so that the protection afforded by them is not compromised over the lifetime of the equipment.

e) From 2003, all electrical equipment fulfilling the latter specification above, should be selected such that it meets the requirements CE marking and ATEX compliance (see 6.5).

6.2.2 Barriers Against Specific Ignition Sources

Information outlining the ignition source modes in this section is given in Section 6.1. The following are common barriers against these.

Barriers against ignition by lightning

Floating Roof Tanks - Shunts

Many floating roofs have shunts between the roof and tank shell. They are designed to equalise the electrical potential of the roof and the tank shell but they are not designed to take the current that can be generated by a nearby lightning strike. Different companies appear to have different recommendations about the best spacing of shunts around the rim seal. The minimum spacing of shunts is 3m apart around the rim, and they should be constructed so that metallic contact is maintained between the floating roof and the tank shell in all operational positions of the floating roof.

These recommendations originate from findings by Chicago Bridge and Iron Co. Some companies place the shunts more frequently. There has been no definitive study to determine the spacing or types of shunt required to provide adequate electrical bonding for different types of roof design. As described in the LASTFIRE Risk Reduction Options document, shunts should, however, be placed above the rim seal and any secondary seals or weather shields so that they can be inspected easily and so that they are away from areas where flammable vapours may be present.

Lightning can cause ignition on tanks with rim seals in perfect condition.

Lightning Protection Systems

Lightning protection systems have been installed in some locations worldwide. Such systems claim to reduce the possibility of ignition by direct and indirect lightning strikes. When considering such a system, the question should be asked whether it is justified, taking into account the frequency of lightning strikes in a given location, criticality of tank contents, and other FEHM factors.
It must be emphasised that there are currently no internationally recognised standards or codes of practice clearly defining the design parameters and efficiency of lightning protection systems for tanks. NFPA 780, which deals with the installation of lightning protection systems, makes no specific attempt to outline the applicability of such systems, other than recognising that tanks should be suitably grounded.

These precautions may be necessary to conduct away the current of direct lightning strokes, and to avoid the build-up and potential that can cause sparks to ground.

Barriers against ignition outside tank

Reduction of the number of fires started by ignition outside tanks can be achieved through use of measures to prevent hydrocarbon spills outside the tank and incident pre-planning to remove potential sources of ignition should a major spill occur.

Barriers against ignition by electrostatic discharge

Specific barriers against this type of ignition source concentrate mainly on effective tank grounding and the safe operation of tank farm cathodic protection systems.

The prevention of ignition whilst operators are present on tanks should be covered by operational procedures, such as a Permit to Work system. These systems are described in more detail in Section 6.4.

Barriers against ignition by flares

As mentioned previously, flare stacks should not be positioned upwind in the prevailing wind direction from storage tanks.

Barriers against ignition by pyrophoric reaction

If the presence of pyrophoric scale is suspected, walls and internals should be kept wet during ventilation and cleaning to inhibit the reaction.

Landing the roof during normal operation of tanks suspected of containing pyrophoric scale is not recommended, since air can then be introduced.

6.3 PERMIT TO WORK (PTW) SYSTEMS

6.3.1 General

Control of work in hazardous areas is obviously necessary to prevent accidental release of hydrocarbon liquids or vapours which then create a threat to personnel and if ignited, cause injury and/or damage to tanks or equipment.

Work permits in the oil and gas industry have been developed over many years and have been improved and enhanced after near miss incidents or serious events in the industry. Nevertheless, permit systems are no substitute for training, experience care and conscientious attention because safe tank and related operations can only be achieved by diligent and competent work.

Oil and gas companies will employ different formats and forms for their work permit system but most will follow the same basic procedures to ensure safe working conditions for non-routine jobs. The basis for most work permit systems in the industry is API 2009 Publication – Safe Welding, Cutting and Other Hot Work Practices in Refineries, Gas Plants and Petrochemical Plants. The Rotterdam Rijnmond Area can use Deltalink (Appendix B) as basic procedure for several operations.

Essentially, a work permit is a statement by an authorised person that a non-routine job may be carried out under listed precautions. Typically, the Work Permit will state that specified/required checks, inspections or tests have been carried out by an authorised person and that conditions are acceptable for the work to progress.

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A Permit-To-Work system can be defined as a formal safety system to control the risk of injury, fire, explosion or damage to tankage or plant when foreseeable hazardous work is undertaken.

The basic Permit-To-Work will be used to assess requirements to make the work area acceptable but "Certificates" are then issued for specific aspects of work in hazardous areas as follows:

Excavation Work
Where digging or excavation work is to be carried out in, say a bunded area or in an area where tank pipelines may be buried or are in close proximity to the location.

Electrical Work
Where work is required on electrical apparatus, switches, connections or fittings on or around tankage or within bunded areas. This will include the use of electrical isolation tags and lock-out hardware to ensure there is no accidental power restoration during the electrical work.

Cold Work
Cold work may include valve or flange removal, bund wall repairs, painting, etc, etc.

Vessel Entry
Where personnel are to enter a tank for inspection or cleaning work and where hazardous atmospheres may exist within the tank. This may also include entry on to a floating roof tank where the roof is below a certain height, thereby allowing the build up of hazardous gases.

Gas Testing
May be used for either vessel entry, to establish there are no hazardous gases, or for hot work to establish no gases in the work area. Gas testing has to be ongoing to ensure that no hazardous gases are entering or migrating into the work area.

Hot Work
Where any naked flame, heat generating equipment or heat source or spark producing hardware is to be used for work tasks on, in or around tankage. The ignition potential of such items is obvious and requires to be controlled.
For "live" tank age (containing products) there will not normally be any hot work permits issued, due to the continuing presence of the oil or product and their vapours. There is seldom any such work done on a live tank due to the risks involved.

Examples of tools and equipment that would require a Hot Work Certificate include:

- Abrasive wheels;
- Ferrous tools – spanners, hammers etc;
- "Reduced Sparking" Tools (tools that although being of soft metal can have steel particle embedded in them, causing sparks);
- Electrical welding generators
- Welding torches;
- Gas cutting torches;
- Air compressor engines;
- Pneumatic tool engines;
- Vehicles.

The above list is not exhaustive and serves only as an indication of the type of tools and equipment where Hot Work Permits are concerned.

There are many and various forms of work permit in use although they will all contain similar sections and requirements and the signatories will differ according to the company using them.

The following is therefore an overview only, which does not confined itself to one particular type of work permit system.

6.3.2 Permit Work Stages

The stages of preparing a work permit can be broadly categorised into three groups as follows:

Job Preparation
The permit applicant fills in a work permit form with the details of the job or task(s) to be done, specifying the exact location, the equipment or tools to be used, the estimated time to complete the job and the number of personnel who will be present to carry out the job. The completed form is then handed to the Responsible Operations Supervisor.

The Responsible Operations Supervisor then details the precautions required before and during the job and may include a time limit for which the permit is valid. When these precautions have been detailed the work permit is returned to the permit applicant who will retain this until the preparations (including the precautions required before the job starts), are complete. The permit applicant will confirm this by signing the permit.

The Responsible Operations Supervisor will ensure that the plant or equipment or area to be worked on is in a safe condition and will certify this by signing the Clearance Certificate section of the work permit. The Supervisor will also check the need for Other Certificates and take appropriate action for these. If the nature of the job requires, the Supervisor will organise gas testing to be carried out by an Authorised Gas Tester and will issue the relevant Certificate stating the required gas testing frequency during the job. When all such actions are completed, the Supervisor signs the work permit and the job can be started.

Job Execution

One copy of the work permit and any attached certificates are retained in the office or control room of the facility. A second copy is held at the worksite by the permit holder, ready for inspection at any time.

Throughout the work, the personnel performing the job must ensure that any change in working conditions is noted and if necessary the work halted and the Supervisor informed. Likewise, if there is an operational change that may cause hazards to the permit workers, the Supervisor must halt the work.
The Supervisor must regularly check the worksite and ongoing work to ensure that any gas tests listed are carried out and that conditions have not changed to affect the work.

The handover from one facility operations shift to the next shift should include a review of all outstanding permits issued. If a job is to continue until after a shift change of the permit workforce, the permit should be signed by both the outgoing and incoming permit holder. The permit form should have space for several such transfers.

If the job is stopped whilst incomplete, the permit should be signed off by the permit holder and returned to the Supervisor. The permit should then be filed as temporarily closed and re-issued at a later time, providing conditions allow by initialising the Validity and Renewal Section of the permit.

Job Completion

When the job is complete, the permit holder signs off the work permit and returns it to the Supervisor who inspects the worksite and the job and if satisfied with both, will sign off both permit copies to show that the permit is now withdrawn.

Typically, the first copy of a permit will be filed by the Facility Operations in a Completed Work file and another copy is filed by the work execution department if there is one. The permits are evidence which may be required if latter day claims for injury or damage or compensation are made against the company involved and should therefore be kept for as long as may be needed under local laws.
An example of a work permit is the DeltaLinqs work permit. It must be noted that this is only one kind of permit and the move to Risk Assessed Permits by several companies now means that this type may be obsolete in some companies.

6.4 FIRE PREVENTION / PROTECTION MEASURES FOR TANK AGE

The main issues of fire prevention for tank age focus on a combination of preventing loss of containment and preventing ignition if such loss occurs. This section is intended to outline other fire prevention measures that may be applicable.

Electrical Hardware

Any electrical, connections, fittings, switches, lights or other equipment to be used on or around tanks or in the bunds should be rated for the appropriate Hazardous Area Classification. This also applies to any electrical equipment used on a temporary basis.

Earth Wiring

Bonding wiring and connections from the tank to ground should be clean and in good order. Floating roof tank roof shunts should be firmly in place, clean and in good order. Bond wiring connecting the floating roof to tank shell should be clean and in good condition.

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Level and Temperature Alarms/Trips

Level and temperature indicators and relays and trips to close valves etc need to be tested on a regular basis to ensure reliability.

Vehicular Access

Vehicles should not be permitted into tank bunds unless as part of permitted hot work and the area have been checked for flammable gas presence. Only diesel engine vehicles or driver units having spark arrestors and engine overspeed protection should be allowed entry into bunded areas under work permit checks. Drivers of vehicles must be informed about the common safety procedures.

Personnel Access

Personnel, other than tank operators, should not be allowed entry into bunds or on to tanks unless it is part of permitted work. The use of work permits will reduce the potential for personnel to be carrying ignition sources.

Tank Dipping/Sampling/Gauging

The following precautions, as described earlier, should be taken during dipping or sampling:

- Avoid dipping or sampling tanks with flammable atmosphere / mist above oil level;
- Do not dip or sample within 30 minutes of stopping pump (low conductivity product not dosed with anti-static;
- Carry sample cans / bottles in baskets or carriers;
- Sample containers / dip tape plummets to be non-sparking (brass);
- Natural fibre ropes to be used for sampling;
- Make sure steel dip tape is in contact with metal edge of dip hole;
- Keep dip hole, sampling hatch covers closed;
- Do not dip during electrical storms / heavy rain / hail.

6.5 MAATREGELEN BIJ EXPLOSIEVE ATMOSFEREN (ATEX 137) (NL)

Via paragraaf 2a van het Arbeidsomstandigheden-besluit is de Europese Atex 137 richtlijn in het Nederlandse recht ingebed. Deze Europese richtlijn stelt regels voor de inrichting van arbeidsplaatsen waar mogelijk een explosieve atmosfeer kan voorkomen.

De definitie van explosieve atmosfeer luidt: een mengsel van lucht en brandbare stoffen in de vorm van gassen, dampen, nevels of stof, onder atmosfe-rische omstandigheden waarin de verbranding zich na ontsteking uitbreidt tot het gehele niet verbrande mengsel.

Paragraaf 2a verplicht werkgevers om de gevaren in verband met explosieve atmosferen en de bijzondere risico's die daaruit kunnen voortvloeien, in het kader van de risico-inventarisatie en -evaluatie, voor de aanvang van de arbeid en bij iedere belangrijke wijziging, uitbreiding of verbouwing van de arbeidsplaats, de arbeidsmid-delen of het arbeidsproces, in hun geheel te beoordelen en schriftelijk vast te leggen in een explosieveiligheidsdocument.

Indien uit de beoordeling is gebleken dat er explosieve atmosferen kunnen voorkomen, worden gebieden waar deze atmosferen kunnen heersen ingedeeld in gevarenzones als bedoelt in bijlage I van de Atex 137.
Voorts verplicht het werkgevers tot het treffen van algemene, specifieke en bijzondere maatregelen, die verband houdend met explosieve atmosferen of de kans daarop.

6.6 AARDING POMPPLAATSEN (NL)

Grondslag: Arbeidsomstandighedenbesluit en Beleidsregels Arbeidsomstandighedenwet

Aarding moet in ieder geval aanwezig zijn indien:

- *Er arbeid wordt verricht met of in de aanwezigheid van gevaarlijke stoffen die statische lading kunnen veroorzaken;*
- *Er arbeid wordt verricht aan leidingen, slangen of reservoirs waarin zich restanten van gevaarlijke stoffen kunnen bevinden die statische lading kunnen veroorzaken.*

Met de aarding moet een ongewilde gebeurtenis worden voorkomen of anders zoveel mogelijk worden beperkt.

PART THREE
FIRE SCENARIOS

CHAPTER 7

TANK FIRE SCENARIOS

This section describes fire scenarios and the ways in which releases of product (losses of containment) can occur for the following tank types:

- Fixed Roof Tanks
- Internal Floating Roof Tanks
- Floating Roof Tanks
- Bund Fires
- Multiple Tank/Bund Incidents

In addition, there is a section on the risks associated with tanks containing toxic materials.

Reference can also be made to the following sections for more detailed information:
The Bow Tie Diagrams can be used to view the most common threats and barriers for each type of tank fire scenario, as well as potential escalation routes. A full explanation of the function of the Bow Ties is given in Section 4.2.

7.1 FIXED ROOF TANKS

The types of fire scenario for this type of tank are:

1. Vent Fire
2. Full Surface Fire
3. Bund Fire

7.1.1 Fixed Roof Vent Fire

A vent fire is a fire in which one or more of the vents in a fixed roof tank has ignited. Flammable vapours will always be present in the vicinity of vents, either because of the tank's daily breathing cycle or during tank filling operations. Most vent fires are attributed to lightning, although instances have occurred when ignition sources outside the tank have started vent fires.
When addressed properly, vent fires can usually be extinguished with minimal damage and low risk to personnel.

Losses of containment associated with vent fires will typically occur as a result of overfilling due to operator error, or in normal operation of the tank. Ignition may be by any one of a number of modes outlined in Section 6.1.

The general design principle of pressure and vacuum vents is to fail open in the event of a component failure, and so during a vent fire the vent will continue to vent products and remain a fuel source. Fire fighting tactics are sometimes centred around assessment of the flame and smoke emitted by a vent fire, and the approach in Bow Tie Diagrams (Section 4.2) is based on the following:

Vent fires with predominantly orange and yellow flames with black smoke will tend to indicate that the vapour/air mixture in the tank is "fuel rich". Flashback into the tank may not result in a vapour space explosion, and it may be possible to extinguish the fires using a dry chemical extinguish ant or foam.

Vent fires with a predominantly blue-red 'snapping' flame that is nearly smokeless will tend to indicate that the vapour/air mixture in the tank is flammable or explosive. As long as product is vented through an open PV valve, flashback may not occur, and a vapour space explosion may be avoided. However, a defective PV valve or flame arrestor may result in flashback and subsequent explosion. Therefore it is imperative that these components are maintained well and function correctly.

In some cases these fires have been extinguished by bringing about a pressure reduction in the tank, either by cooling the tank roof and shell with water, or by halting tank operations or pumping out of the tank. These actions may result in the flames being snuffed out either by the vent flame arrestor (if fitted) or once the PV valve closes. In all cases, the valve may not close fully, however, and supplementary extinguishment may be needed.

One other method that has been used to extinguish this type of vent fire is to introduce fuel gas into the tank to maintain a positive pressure, and bring about a fuel rich vapour space so that a change in flame character to a yellow-orange state means that extinguishment can be attempted.

7.1.2 Fixed Roof Full Surface Fire

A full surface fire in a fixed roof tank can be brought about by vent fire escalation. A vapour space explosion may occur if the vapour space is within a flammable range at the time of flame flashback, especially if PV valves and/or flame arrestors are defective. If the tank is constructed to a recognised code such as API 650 then the roof should separate from the tank shell along a weak seam. Depending on the force of the vapour space explosion, the roof may either be partially removed (creating a "fish mouth" opening) or fully removed. (Fig 7.1) Also, there have been instances when the roof has not separated at all, and the tank has been lifted into the air by the force of the explosion. If the roof is only partially removed, then there may be difficulties in applying foam to the tank surface and an insufficient foam application rate may prolong the fire. Extinguishment of these fires has been attempted by either 'topside' foam application, using monitors and/or foam pourers or by subsurface foam injection. In the case of foam pourers, it must be recognised that damage can have occurred as a result of the initial explosion, and so foam application may need to be increased.

Unlike conventional hydrocarbons, fuels with high water miscibility may require special considerations when applying foam, such as topside application only, increased application rates or use of semi-subsurface injection.

Fig 7.1 - Fixed Roof Tank Full Surface Fire (Full Roof Removal).

Fig 7.2 – Loss of containment, fixed roof tank

7.2 TANKS CONTAINING TOXIC MATERIALS

Tanks containing toxic materials present their own special risks. As well as a fire risk if the material is flammable, loss of containment may result in hazards to personnel, as well as further reactive hazards which may ultimately lead to fire (fig 7.2).

Some materials may also be pyrophoric, such that impurities in tanks or off-spec products will spontaneously combust. Certain products may react violently with water, necessitating special fire response tactics. The majority of toxic products at atmospheric pressure are stored in fixed roof tanks and horizontal tanks. Loss of containment modes are as for conventional hydrocarbons stored within fixed roof tanks, and if the material can ignite so are the ignition source modes.

Typical products may include:

- Acrylonitrile
- Refining chemicals e.g. "spent acid (H_2SO_4) and phenol
- Process chemicals e.g. benzene, styrene, methyl methacrylate
- Metal alkyl catalysts

Potential losses of containment should be addressed within an operating company's Safety Case documentation, practices and procedures and appropriate Emergency Response Plans should be drawn up to cater for these risks. MSDS sheets should be used as a basis for providing appropriate information on the special hazards that may be encountered.

CHAPTER 7

TANK FIRE SCENARIOS

As well as threats to personnel and fire responders, environmental issues should be dealt with including the safe application and disposal of firewater. Also it should be recognised that tanks containing toxic materials may just as easily become involved in an incident through escalation, as well as directly and Emergency response measures should take this into account.

7.3 FLOATING ROOF TANKS

The types of fire scenario for this type of tank are:

- Vent Fire
- Full Surface Fire (Fig 7.3)
- Bund Fire

Losses of containment and ignition source modes are largely a combination of those for fixed and floating roof tanks.

Fig 7.3 – Full surface fire

One type of tank that can be considered as an internal floating roof tank is a floating roof tank upon which a geodesic dome has been fitted. The purpose of the dome is to further restrict evaporative losses of product and also to prevent product contamination by rainwater. Currently there is some debate over whether the dome acts as a risk reduction measure by acting as a "Faraday cage", or whether the presence of a dome may allow a flammable vapour space to be formed. At present, there is no evidence from gas testing within these structures to indicate the latter and this type of tank construction is generally regarded as a risk reduction measure. To all intents and purposes, the fire scenarios for this type of tank are the same as for conventional fixed roof tanks, and similar threats and barriers are listed in the Bow Tie diagrams. (In the case of geodesic domes, these have been listed as a barrier against ignition by lightning in the floating roof tank rim seal fire Bow Tie).

7.4 OPEN TOP FLOATING ROOF TANKS

The types of fire scenario for this type of tank are:

1. Rim seal fire
2. Spill on Roof Fire
3. Full Surface Fire
4. Bund Fire

7.4.1 Open Top Floating Roof Tank Rimseal Fires

A rim seal fire is one where the seal between the tank shell and roof has lost integrity and there is ignited vapour in the seal area. The amount of seal involved in the fire can vary from a small-localised area up to the full circumference of the tank (Fig 7.4). The flammable vapour can occur in various parts of the seal depending on the seal design.

Fig 7.4 – Full Circumference Rimseal Fire

Loss of Containment Modes – Rimseal Area

Product releases into the rim seal area may occur for the following reasons:The primary seal can fail from excessive tank movement or rubbing against tank walls corroded by salt air or from foreign objects falling into the rim seal gap. Some early designs of certain types of seal have also failed by rolling under the rim of the roof as the roof was moved or by losing the tension force holding the seal in place against the tank shell. Failure of process monitoring can allow hot product or high vapour pressure product or gas (including nitrogen or air) into a tank causing an eruption of vapour and product out of the rim seal area. Failure of heating controls can also produce such a vapour eruption.

Failure of process monitoring can lead to overfill of a tank. Gauges can give incorrect readings if there is a sudden change in the specific gravity of the product. Failure of high and or high-high level alarms may not be reported to operators on subsequent shifts. Tank settling can cause a tank to go out of round, leading to rim seal gaps. When a tank is out of round, there is also the possibility that the roof could stick or jam. Subsequent sudden movement of the roof could cause product and flammable vapour to escape into the rim seal area.

Ignition Source Modes – Rim seal Area

Lightning is by far the most frequent source of ignition of fires on floating roof storage tanks. In the LASTFIRE incident survey, 52 of the 62 initial fire events within the scope of the survey were lightning ignited rim seal fires. Those regions of the world with a significantly higher than average frequency of electrical storms have a higher frequency of lightning ignited rim seal fires. It appears that some tanks are located in lightning "black-spots" and have suffered lightning ignitions more than once.

The LASTFIRE incident survey recorded two sites where the same tank had been struck twice and one instance where a tank had been struck three times in succession. The incidence of multiple tanks being ignited by a single lightning strike or a single storm is also high. Three tanks were ignited simultaneously at a site in Italy (one of these tanks was struck again 7 years later). Two tanks were ignited simultaneously at a site in the UK. A single storm caused all three recorded rim seal fire incidents at two sites in Belgium. Finally, in four cases of lightning related rim seal fires, it appears that lightning was attracted towards lightning rods that had been installed with the intention of preventing such fires.

Prevention/Mitigation of Rimseal Fires

Rim seals are designed to prevent the exposure to air of product in the gap between the floating roof and the tank shell. The main purpose of their design is to reduce unwanted hydrocarbon emissions to the atmosphere, but at the same time they reduce the risk of fire since there is a smaller chance of a flammable mixture being formed. Rim seal properties can greatly affect the extent of a fire, and whether or not a rim seal fire can result from escalation from a nearby tank. The main rim seal properties governing fire risk are discussed in Section 6.13, Barriers to Prevent Escalation.

7.4.2 Open Top Floating Roof Tank Full Surface Fires

A full surface fire is one where the tank roof has lost its buoyancy and some or the entire surface of liquid in the tank is exposed and involved in the fire. (Fig 7.5) If a roof is well maintained and the tank is correctly operated, the risk of a rim seal fire escalating to a full surface fire is very low.

Escalation from rim seal fire to full surface fire occurred in only one of the 55 rim seal fires on operational tanks, recorded as the initial fire event in the LASTFIRE incident survey. Furthermore, escalation from a rim seal fire to full surface did not occur in one of the two major impinging bund fires recorded in the LASTFIRE survey.
In the rim seal fire that escalated, a pontoon containing flammable vapour exploded at the same time lightning ignited the rim seal. It was also known that high vapour pressure product had been introduced into the tank at the same time. The roof lost its buoyancy one and a half hours later, leading to a full surface fire.

Fig 7.5 – Full Surface Fire

TANK FIRE SCENARIOS

Open Top Floating Roof Tank Spill-On Roof Fires

A spill-on-roof fire is one where a hydrocarbon spill on the tank roof is ignited but the roof maintains its buoyancy. In addition, flammable vapours escaping through a tank vent or roof fitting may be ignited. It is very difficult to prevent a spill on roof fire from escalating to a full surface fire because most fire fighting systems are designed for fires in the rim seal area. Unless a fixed system designed for a full surface fire is installed, it is difficult to apply foam to a burning roof from ground level without causing it to lose its buoyancy.

A single spill on roof fire recorded in the LASTFIRE survey occurred at Milford Haven in 1983 on a single skin roof. The fire covered 50% of the roof within 10-15 minutes. Within one hour, the fire had escalated to a full surface fire.

Loss of Containment Modes – Spill on Roof

Mechanical failure or corrosion is the dominant mode of failure leading to spills in the roof area. The causes can thus be summarised as:

- Seal or pontoon damage
- Leg failure or failure of the roof leg pads
- Cracking or fracture or the roof
- Roof drain failure
- Tank bottom or bottom ring corrosion
- Steam coil failure
- Leaks from mixers, pipework, flanges or valves

7.5 BUND FIRES

A fire in the bund (Fig 7.6) is any type of fire that occurs within the containment area outside the tank shell. These types of fire can range from a small spill incident up to a fire covering the whole bund area. In some cases (such as a fire on a mixer) the resulting fire could incorporate some jet or spray fire characteristics due to the hydrostatic head.

Fig 7.6 – Bund Fire

An analysis of loss of containment modes (i.e. releases into the bund area) is given in Section 7.6.

Bund Fire – Escalation from Full Surface Fire
Full surface fires on the top of a burning tank have been known to escalate to produce a fire in the bund. The various mechanisms by which such escalations can occur are as follows.

- When the roof sinks to produce a full surface fire, product can escape into the bund through the roof drain.
- Part of the shell of the tank on fire can collapse. Normally, the tank shell is designed to collapse inwards when it loses its mechanical strength at high temperatures. However, if cooling water is applied to only part of the shell of the burning tank the tank shell may collapse in an unpredictable manner releasing product into the bund.
- The tank shell to bottom seam may fail because of erosion of the tank foundations by firewater in the bund.
- Fires on pipework or mixers may cause flanges or valves to fail, allowing product into the bund.
- Boilover or slopover may occur.

However, only one full surface fire involving a non-boilover fuel in a large diameter floating roof tank has known to have escalated to a severe bund fire.

Impinging Bund Fires

The type of fire that is most likely to produce ignition of a nearby tank is a bund fire impinging on the tank shell. Local boiling of the product can occur along the wall of the flame-impinged tank and the impinging flame easily provides an ignition source for the vapour driven off. Both the major bund fires reported in the LASTFIRE Analysis of Incident Survey document impinged on nearby tanks and lead to escalation; one to a rim seal fire and the other to a full surface fire.

7.6 MULTIPLE TANK/ BUND INCIDENTS

A multiple tank/bund incident is a major fire that occurs as a consequence of escalation from one or more initial fire events, and results in one or more tank and/or bund fires. Another type of 'multiple tank incident' is when a number of tanks are ignited simultaneously, although the former is the more frequent occurrence.
There are four main escalation routes which may result in a multiple tank/bund incident:

1. Radiant heating from a full surface fire, causing ignition of nearby tank
2. Direct flame impingement
3. Boilover / slopover
4. Explosive ignition (fixed roof tanks)

Radiant Heating

Radiant heating from a full surface fire is one possible cause of ignition of a fire on a nearby tank. The heat loading from the fire is conducted through the steel shell and roof of the neighbouring tank and into a layer of fluid next to the wall. The heat transfer is not high enough to boil the heated layer next to the wall, it merely becomes buoyant and sets up convection currents up the wall of the tank and across the roof. These convection currents produce a stratification of the product in the tank, with a hot layer next to the wall and under the roof. Eventually, the fluid at the top of the shell under the roof reaches it initial boiling point and vapour is driven past the seal to be ignited as a rim seal fire. Furthermore, with large quantities of vapour being generated, there is potential for the roof to be destabilised. However, large amounts of heat and a significant amount of time are required to before some part of the product reaches its initial boiling point. Furthermore, fire fighting measures such as cooling exposed tanks are usually put in place. Thus the potential for escalation to downwind tanks by radiant heating alone is only restricted to those products with an initial boiling point close to the temperature at which the product is stored.

Direct Flame Impingement

This mechanism is as described previously in Section 7.5 – Bund Fires, since the type of fire that is most likely to produce ignition of a nearby tank is a bund fire impinging on the tank shell.

Boilover, Slopover and Frothing

Boilover is a phenomenon that can occur when a fire on an open top tank containing crude or certain types of heavy fuel oils has been burning for some time. It can result in large quantities of oil being violently ejected even beyond the containment bund. Boilover is a potential escalation route to multiple tank/bund incidents and a major hazard to fire fighters. The LASTFIRE review of major fires recorded 16 fire incidents on tanks containing boilover fuels (including fixed roof tanks), of which 7 boiled over, 2 slopped over and 7 spilled oil into the bund when the tank failed without boiling over. It is not known how many of these 7 fires would have boiled over if the tank shell had not failed.

There are three key elements that must be present for boilover to occur in its most violent form:
1. An open top tank fire
2. A water layer in the tank
3. Development of a high temperature, relatively dense hot zone, which is determined by the nature of the stored product.

In full surface fires involving crude or certain specifications of heavy fuel oils there is the possibility of a boilover. This occurs when a hot zone of product falls through the fuel and hits the water base at the bottom of or elsewhere in the tank.
The water boils, turns to steam and pushes up through the fuel above. The result is a massive eruption of tank contents that can spread to several tank diameters away from the tank.

Other fuels that can produce boilovers include petroleum intermediates such as "tops" or crude distillates, residual oils, heavy fuel oils and refined products contaminated with another product with a different boiling point. High boiling point fuels with narrow boiling ranges such as fuel oil or hexadecane produce shallow, high temperature, hot zones that result in a boilover type event when the hot zone comes into contact with a water layer.
Slopover can occur when firewater or foam is introduced into hot oil. The water boils and causes the hot oil to froth up and slop out of the top of the tank. This type of event may lead to a bund fire, as well as the initial tank fire.

Product may also boil within a tank. This can occur when a tank is engulfed and heated by a bund fire. If the product has a low boiling point, it is possible to raise its temperature above it boiling point, leading to the generation of large amounts of fuel vapour, which may cause frothing of product out of the tank.
(See also: NFC 30)

Explosive Ignition (Fixed Roof Tanks)

Explosive ignition of some tanks (particularly fixed roof tanks) has lead to fragments flying off, hitting other tanks and causing a fire.
Multiple Tank/Bund Incidents – Preventing Escalation

Preventing escalation to multiple tank/bund incidents is achieved in the following ways:
Tank spacing to prevent escalation by radiant heating/direct flame impingement
Effective bund and tank layout
Controls on condition of tanks and tank fittings
Rimseal properties to prevent escalation
Use of waterspray / water curtains
Cooling of tank shells
Tank pumpout
Boilover mitigation

These barriers are discussed further in Section 8.11.4 – Barriers to Prevent Escalation.

CHAPTER 8
CORRECTIVE LINES OF DEFENCE

8.1 GENERAL

This chapter describes the accepted strategies which could be used to tackle rim seal fires, roof spill fires, bund fires and full surface fires in large floating roof tanks.

Note: Some of the strategies outlined in this section may not be those adopted by the Rotterdam-Rijnmond Fire Brigade in accordance with the Tank Policy. The options are listed for information purposes only.

The strategies in this chapter utilise combinations of fixed firefighting systems and portable firefighting equipment referred to elsewhere in this chapter. In all strategies the affected tank operations should be suspended prior to any fire attack although pump out and/or use of mixers may subsequently become part of the response strategy.

Most tank related incidents are such that there is sufficient time to assess the situation visually and start strategy implementation before major escalation occurs (such as roof spill fire escalation to full surface fire). As it is impossible to predict exactly the conditions that will pertain at a fire, this assessment is vital to ensure that the chosen strategy is relevant and appropriate even, as should be the case, the basic response strategy has been agreed and preplanned beforehand.

The fire assessment or "size up" demands an understanding of tank construction and potential escalation mechanisms as well as flammable liquid fire fighting. This emphasises the need for the person responsible for initiating fire attack to be thoroughly trained and have authority to make and implement the final decision on the strategy to be adopted.

For some of the scenarios (rimseal events and smaller spill fires on the roof), the visual assessment may mean having to ascend the tank access ladder and view the incident from wind girder level. This can only be done safely if the responder is fully trained and aware of the hazards.

Breathing apparatus and protective clothing must always be worn and water handlines be available to provide protective water spray when firefighting or investigating/evaluating rimseal or roof spill incidents. In cases where it is not possible, due to fire location or intensity, a "cherry picker" unit may be of value to gain a line of direct vision to the fire from an elevated point. This should be done from outside the bund.

Some of the following strategies such as those for rimseal fires require personnel to go onto the roof to complete extinguishment. It must be recognised that such practice, although accepted by many operators, is not ideal and should generally be regarded as a "last resort". Where manual firefighting is required either as the primary means of extinguishment or as back up to a system, it should preferably be by the use of foam handlines from a walkway at the top of the tank. However, if going onto the roof is essential because final extinguishment cannot be gained in this way, then the decision to do so should be the responsibility of the Fire Chief. The factors that need to be considered prior to going onto the roof are:

- Have all measures to extinguish the fire without
- going onto the roof been tried?
- Have all tank operations ceased?

- Extent of the fire.
- Possibility of incident escalation by, for example, pontoon explosions. (If flammable vapours or liquids are present in pontoons, then pontoons adjacent to the fire could explode. Alternatively, if liquid product is on the roof, the fire could escalate to a spill on the roof.)
- Position of fire - is it immediately below the access ladder and consequently jeopardising means of approach or escape.
- Availability of fixed system for initial attack.
- Amounts of smoke and consequent impairment of visibility.
- Integrity of the tank and roof access ladders.
- Availability and need of safety harness and lines.
- Availability of protective clothing.
- Availability of Breathing Apparatus.
- Wind speed and direction affecting smoke movement or build up.
- Availability of handlines for foam application, water cooling or spray protection for firefighters.
- Reliability of water supply and foam supply to maintain attack.
- Availability of manpower for fire attack and back-up to protect front-line firefighters.

- Availability of sufficient extinguishers to complete extinguishment.
- It should be recognised that some operators expressly forbid going onto the roof under fire conditions. Where a decision is made to sendmen onto a roof, their numbers should be kept to the minimum required but at all times there should be back up to the front line firefighting effort.

8.2 LEUNINGEN RONDOM OPSLAGTANKS (NL)

Algemeen principe

Grondslag: Arbeidsomstandighedenbesluit.

Arbeidsplaatsen zijn veilig toegankelijk en kunnen veilig worden verlaten. Ze worden zodanig ontworpen, gebouwd, uitgerust, in bedrijf gesteld, gebruikt en onderhouden, dat gevaar voor de veiligheid en de gezondheid van de werknemers zoveel mogelijk is voorkomen. Voorts worden zij zindelijk, zoveel mogelijk vrij van stof en voor zover de veiligheid van de arbeidsplaats dat vereist, ordelijk gehouden.

Voorzieningen bij valgevaar

Grondslag: Beleidsregels Arbeidsomstandigheden-wetgeving.

Het tegengaan van valgevaar bij het verrichten van arbeid door het aanbrengen van doelmatige hekwerken, leuningen e.d. (de zgn. randbeveiliging) is in ieder geval noodzakelijk:

- *indien het valgevaar 2,5 m of meer is;*
- *indien de arbeid wordt verricht op statische arbeidsplaatsen;*
- *bij ieder valgevaar indien arbeid wordt verricht op arbeidsplaatsen, die daarbij in beweging zijn of kunnen komen.*

Randbeveiligingen worden als doelmatig aangemerkt indien:

- *zij aan de bovenzijde zijn voorzien van een stevige leuning op tenminste 1,0 m boven het werkvlak;*
- *zij bij open constructies aan de onderzijde aansluitend op het werkvlak zijn voorzien van een kantplank van 15 cm hoog;*
- *in open constructies de openingen zodanig beperkt blijven, dat een kubus met zijden van 47 cm de openingen niet kan passeren;*
- *zij niet bezwijken bij een op de meest ongunstige plaats aangebrachte neerwaartse belasting van 1,25 kN danwel de vervorming ten gevolge van die belasting van dien aard is dat de functionaliteit van het hekwerk c.q. de randbeveiliging gewaarborgd blijft;*
- *zij zijdelings niet meer dan 3,5 cm doorbuigen en niet worden verplaatst bij een horizontale belasting van 0,3 kN;*
- *zij in functie blijven (niet uit een aanwezige bevestiging worden getild) bij een opwaarts gerichte belasting van 0,3 kN.*

Kooiladders

Onder "het verrichten van arbeid waarbij valgevaar bestaat" wordt ook verstaan het zich begeven naar de arbeidsplaats. Doelmatige voorzieningen hiervoor kunnen ladders zijn, mits deze bij klimhoogten van 10 m of meer op maximale afstanden van 7,50 m zijn onderbroken door rustbordessen. Ladders steken tenminste 1 meter uit boven de gewenste sta- of overstaphoogte. Op het te betreden vlak is aan weerszijden van de toegang randbeveiliging aangebracht over een lengte van 4,0 m of sluit de toegang aan op de aanwezige randbeveiliging.

Een ladder die toegang geeft tot een hoogte van meer dan 5 m boven de begane grond moet zijn voorzien van een klimkooi te beginnen op maximaal 2,5 m hoogte, gerekend vanaf het uitgangspunt. (NEN 2023)

8.3 RIM SEAL FIREFIGHTING STRATEGIES

The strategy for rim seal firefighting will use one or more of the following:

(I) Portable/mobile, manually deployed fire protection equipment.
(II) Fixed, automatically actuated fire protection systems (See 6.2.2).
(III) Fixed, manually actuated fire protection systems (See 6.2.3).
(IV) Semi-fixed, manually actuated fire protection systems (See 6.2.3).

CORRECTIVE LINES OF DEFENCE

Portable equipment - Rimseal firefighting strategies - general strategy notes

Even if fixed or semi-fixed fire protection systems are provided, it is essential that back-up portable attack capability is provided. The objective of the portable equipment response is to be able to complete extinguishment safely if this has not been achieved by the system itself. In cases where no fixed or semi-fixed system is available, the portable equipment response becomes the primary response. The notes in this section relate in general to portable equipment response strategies whether they are intended as primary attack or back-up.

Notes specific to individual overall strategies are given in the appropriate section.

The overall strategy using portable equipment can be summarised as follows. (It is based on there being no foam solution riser at walkway level and consequently it is necessary to pump foam solution from ground level via hoselines. If, as is preferable, a foam solution riser was available, it would be used for solution supply.)

- Shut down involved tank operations.
- Deployment of foam handlines for taking to tank top.
- Ensure roof drain open.
- Personnel don breathing apparatus and ascend tank to confirm system discharge if system available.
- Evaluation of fire area and system effectiveness.
- Verification of water/foam solution flow/ pressure availability.
- Take uncharged foam handline to tank stairway top. (If no foam solution riser available.)
- Foam handline actuation.
- Foam application over the seal area to ensure cooling and extinguishment. If a walkway is provided, initial attack should be from this and foam discharged against the tank shell to flow down the wall to the seal area. However, if no foam dam is provided, extinguishment may be very difficult resulting in a requirement to go onto the roof. Also, entry onto the roof will be required if no walkway is available.

This strategy would utilise either:

- foam pumper or fixed system with water and foam pump and proportioning system;
- foam trailer with water and foam pump and proportioning system; or,
- water pumper and either an inline inductor at tank top or foam nozzle induction with 25 litre foam concentrate drums. (This is the least preferred option due to manoeuverability and manhandling problems with foam concentrate drums.)

Strategy Notes

Breathing apparatus should always be worn when firefighting or investigating/evaluating rim seal fire extent. This safety point considers not only potential toxic fumes from the product but also toxic smoke from burning rim seal material, however minor that fire may be.

It is possible to use other means of foam supply such as a basic foam tank and suitable proportioners sited near a hydrant outside the bund wall of a tank.

Provision of a foam dam even when a fixed pourer system is not installed can facilitate blanketing of the rimseal area.

Where no foam dam is provided, excessive use of foam may overload or tilt the roof. It is important that the roof drain is open but equally important that foam application is used as sparingly as possible.

The use of foam or dry chemical extinguishers (see additional notes below) in place of foam handlines may be considered for back-up where there is no foam dam. However, this strategy would assume a relatively small rim seal fire length and a large number of extinguishers may be required. Foam handlines should be the preferred strategy with some dry chemical extinguishers on hand for fast knockdown of residual flames if foam cannot be applied to some areas.

Personnel may have to create access to the fire base by physically separating the weather shield or secondary seal from the tank shell so that total extinguishment is achieved. This can obviously only be done from the roof itself.

Having foam handlines as back-up also means having cooling capability on hand. Some rim seal fires may burn for several hours with resultant tank shell distortion and so there is potential for rim seal fire spread as tank shell distortion releases additional vapour from the seal area.

The minimum quantity of foam concentrate for the required application time should be on hand before foam handline deployment. A minimum of 10 minutes supply should be available.

The fire hydrant and, by association, the ring mains, must have the required capacity to provide the minimum water rate for the foam solution for the rim seal area.

Any foam proportioning system should have the flowrate capability for the minimum required rim seal foam application rate. It should be variable flow so differences in flow and pressure can be accommodated easily. Standard venturi inductors are not normally appropriate.

Personnel may have to create access to the fire base by physically separating the weather shield or secondary seal and the rim area so that total extinguishment is achieved.

Use of extinguishers for rimseal fires

The types of extinguishers to be considered are foam and/or dry chemical.

Any extinguishers to be used in an attack strategy should be stored in a "Firebox" at the top of the external tank access ladder.

The use of extinguishers only for rimseal fire attack would normally only be applied where small fire lengths are anticipated. Attempting to deal with large length rim seal fires using extinguishers requires a large number of extinguishers being carried to the roof and highly effective continuous application which needs several fire personnel "following-on" in teams to ensure continuous agent application.

The number of men to be on the roof at one time is a consideration. If a high ratio of extinguishers to firefighters is required the weight of men on the roof may cause a stability problem apart from the obvious exposure to risk of more people.

It would be unrealistic, and wholly impractical, to expect to use foam extinguishers to fill a rim seal foam dam. This would require an extremely large number of foam extinguishers and manpower to carry them up to the roof.

Dry chemical extinguishers should always be available in case they are required to achieve final flame knockdown and extinguishment. The dry chemical and foam should be compatible.

When dry chemical extinguishers are used, two teams of firefighters should start application from different ends of the fire "strip" and work their way towards each other, crossing their dry powder streams as they meet and continuing forward past each other to the other end of the fire and then move backward and repeat the application. As one extinguisher is nearing complete discharge, the next team member commences using his extinguisher to maintain application.

Dry chemical may extinguish a rim seal fire but re-ignition may well occur and so foam handlines should always be available. It may be that foam handlines need not be immediately deployed and that foam handlines are only considered once repeated unsuccessful attempts are made using dry chemical.

If it is obvious that the rim seal fire has been burning for some time, immediate deployment and use of foam handlines will offer a more realistic extinguishment strategy than using dry chemical extinguishers since re-ignition potential from hot metal will very probably mean unsuccessful firefighting actions with dry chemical.

Use of foam nozzles

The strategy of using only foam nozzles for rim seal firefighting recognises that it may take some time to set up the foam handlines but that once foam is applied, early fire control and extinguishment should follow.

Foam nozzles can be used, preferably, from the wind girder around the tank or from the tank roof.

Smaller foam nozzle capacities, in the range of 200-400 lpm, offer greater handline control

which is very important when working around the wind girder or on the roof. Such flowrates should not jeopardise the stability of the tank roof, provided the roof drain is open.
Most foam nozzles and water nozzles require an inlet pressure of approximately 5-7 bars to work effectively.

High wind conditions may mean that personnel are safer applying foam from the tank roof rather than the wind girder. Alternatively, safety harnesses may have to form part of the protective equipment for personnel on the wind girder.

Use of Mobile Crane and Foam Nozzle

This portable equipment strategy envisages a nozzle or piping being fixed to a crane top and fire hose supplying foam solution to the nozzle which can then be moved over the tank shell and the nozzle stream directed into the rim seal area. Although this technique has been used in some incidents it is not advised because nozzle directional control is extremely difficult. It should be noted that such application techniques to rimseal fires may result in roof tilt, thus escalating the fire.

Crane access must be assured all round the tank if this is to be an accepted strategy.

Directing the foam stream will require good expertise between fire personnel and crane driver.
Method of supplying nozzle or monitor with foam would have to be decided and must consider operating height and consequent pressure losses where portable foam induction is considered an option.
Effective communications will be required.

The flow rate of the application must be sufficiently small (400-500 lpm) so as not to jeopardise the stability of the tank roof.

Use of Hydraulic Platform and Foam Nozzle

This strategy would be similar to the mobile crane strategy but does have the advantage that the nozzle can be directly controlled by someone on the hydraulic platform with a direct line of sight to the fire area.

Hydraulic platform availability and access to the tank would need to be assured to make this an acceptable response.

Use of platform monitor may cause considerable overflow of foam from any rim seal dam into roof centre. Care must be exercised to avoid this potential.

The throughput of the nozzle must be sufficiently small so as not to jeopardise the stability of the roof.

Nozzle operator, even though not in the immediate vicinity of the fire, must be wearing protective clothing and have Breathing Apparatus.

The following sections describe the strategies adopted when fixed or semi-fixed fire protection systems are available. As mentioned above, portable equipment should always be available and deployed/used as described even when systems are also available.

In such cases, the portable equipment acts as a back-up to the system and may not, in practice, be actually used if the system has worked correctly.

Fixed Automatic Fire Protection Systems

These systems are assumed to be fire detector actuated and include:

Foam extinguishing system (“one-shot” or extended discharge type)
Fully automatic actuation of a rimseal foam pourer system is not normally required because, except in very critical circumstances, there is usually time for incident assessment prior to system discharge followed by manual actuation, thus reducing risk of spurious discharge.

Gaseous extinguishing system

Dry chemical extinguishing system
(**N.B**. Chapter there are potential disadvantages of using dry chemical systems. However, they are included here for completeness, recognising that some facilities may be provided with them.)

None of these should be regarded as a replacement for an extended discharge foam system.

This strategy, following actuation of an automatic system, would be to shut down tank operations if not already done by executive actions on fire detection and then deploy portable equipment and assess the situation to check the effectiveness of the automatic system.

Specific system strategy notes

Dry chemical in any system should be compatible with the foam being used as there may be occasions where both are used simultaneously.

With both dry chemical and gaseous agent systems it must be recognised when approaching the fire area that there is always a greater chance of reignition than with a foam system. With a foam system there is greater cooling of hot surfaces and a vapour suppressing blanket should be formed.

Fixed or semi-fixed, manually operated fire protection systems

This refers to fixed or semi-fixed extended discharge systems (i.e. pourers, catenary systems or "Coflexip" systems), which require manual intervention for actuation.
The strategies described here assume that a foam dam is provided as part of the system of sufficient height to contain the foam applied to the rimseal area from the system.

Fully Fixed, Manually Actuated Firefighting Systems

The strategy adopted with fixed manually actuated systems will be the same as that with automatic systems. The only difference in strategy will be to actuate the system after incident assessment, from either the top of the tank, tank base, outside the bund wall or at a strategic location such as control room or fire pumphouse. At least one actuation station should be outside the bund area. If remote operation of motor operated valves is used, then all system valves must have manual-only operation also.

Semi-Fixed, Manually Actuated Firefighting Systems

This describes a foam system which requires connection from one of the following:

- foam pumper using a hydrant and on-board foam tank, water pump, foam pump and proportioning system;
- water pumper using a hydrant and on-board water pump, foam concentrate drums/containers and portable or mobile foam proportioning system;
- direct from a hydrant using foam containers and portable or mobile foam proportioningsystem.

The following notes describe the strategy to be used if a foam pumper (i.e. a vehicle with on-board foam proportioning capability) is available. The basic strategy when using one of the other options is exactly the same except that the foam concentrate proportioning mechanism is separate to the pumper vehicle if only water pumpers are available. If hydrant supply only is to be used there is no need to start on-board water pumps. The "direct from hydrant" option can only be used if sufficient water flow and pressure is available in the firewater main to operate the systems (including proportioning concentrate) and back-up equipment without the need for supplementary pumping.

Strategy Using A Foam Pumper

This can be summarised as:

- Connection from hydrant to pumper.
- Deployment of delivery hose to foam system inlet.
- Ensure roof drain open.
- Commence foam solution application from pumper into foam system inlet.
- Verification of achieving system operating pressures.
- Maintain foam application for minimum 10 minutes or until foam dam filled.
- Hold foam pumper and equipment in position and in readiness until fire hazard is over.
- Re-apply to maintain foam blanket if necessary.

The calculated minimum quantity of foam concentrate to meet the system and back-up equipment application time should either be available in the foam pumper on-board tank or be on hand in tankers, trailers or "polytanks" before foam application commences.
The water pump and foam pump on-board the foam pumper should have the required capacity to provide the minimum foam solution for the system and back-up equipment operating simultaneously.

The foam proportioning system should have the flowrate capability to meet the total foam application rate. The proportioning system should be of a variable flow type so that the system (possibly with some outlets partially blocked) and the back-up equipment can be operated either separately or simultaneously.

All system operating controls should be clearly identified with operating instructions clearly shown at operating station.

8.4 ROOF SPILL FIREFIGHTING STRATEGIES

The strategies for fighting a spill fire on the roof will be very similar to rim seal firefighting using foam handlines, crane or hydraulic platform as mentioned in 8.3. One alternative is to provide a fixed system with sufficient application rate to cover the whole roof area. Such a system would still require back up with manual equipment but, if correctly designed, would very much reduce risk to firefighter life safety and the number of personnel required to control the incident.

Strategy Notes

Since foam may have to be applied directly on to the roof, the roof drain must be fully open to prevent roof overload. However, as product is on the roof, this may drain through the line also (and be at raised temperature due to the fire) so the drain outlet should be constantly monitored with stand by foam handlines deployed and actuated to blanket any spillages. This will help prevent ignition and facilitate safe access to drain line valves if the decision is made by the Fire Chief that they should be closed because the risk of fire in the bund becomes greater than the risk of tilting the roof.

Foam application from a crane or hydraulic platform must be carefully controlled. Excessive foam stream on one side of the roof may cause tilt and lead to a full surface fire.

For "minor" spill fires on the roof, such as might be at a vent, portable foam or dry powder extinguishers may be used. However, if the spill is increasing in area and is caused by a leaking roof, personnel should not move onto the roof in case the roof sinks. Where this may be the case, foam handlines from the wind girder or foam application from a crane or hydraulic platform is considered the best strategy.

If the spill fire is such that the roof is totally covered by product and the roof is still in position, it will be very difficult to avoid a full surface fire. Fire personnel would not be able to access the wind girder or remain on the stairway top due to radiant heat/flame contact. Although it may be possible to extinguish such a fire, the resources required will be greater than that used for a rim seal or a small spill on the roof.

8.5 BUND FIREFIGHTING STRATEGIES

In all cases of bund fire, the strategy must be to prevent the tank, if not already ignited, becoming involved in the fire. This assumes greater importance where there is more than one tank in a common bund.

If the bund fire is not threatening a tank and a foam attack can be quickly organised, then foam application by fixed system, monitors or handlines, without cooling may be carried out.

If a foam attack will take some time to organise, cooling water streams should be directed onto exposed piping, valves or any tank shell which is above the tank product liquid level. (Particular attention should also be paid to maintaining the integrity of any tank access ladder in case it is necessary, after the bund fire has been extinguished, to inspect the tank or attack fires on the tank.)

For large area bund fires, or where a tank has totally released all its contents into the bund and fire occurs, the strategy should be to "split" the fire into manageable areas or segments.

This can apply to both fixed systems and portable equipment. It is often necessary because of the large fire area making it impracticable to tackle the complete bund at one time, radiated heat factors and the limitations of foam to flow over a large surface area. Portable foam monitors or portable foam bund pourers may be used for firefighting under these conditions and moved as control is gained in one area.

Rim seal protection systems should always be supported by foam handlines. For bund firefighting using fixed bund foam systems, it is also the case that back-up with foam handlines should be available.

Unlike a rim seal fire, which can be defined at a maximum size/area, bund fires may be relatively small or, in the event of tank failure, full bund sized and may also involve more than one tank in a common bund.

The strategies for bund fires are as follows based on the normal practice of not having remote containment basins to which the product can be directed so that the tanks are not in the fire area. Where remote containment basins are available, the basic strategies would be the same but tank cooling would not be required, unless the leak was such that the tank was still engulfed in flame.

(I) Fixed, automatic foam bund pourer system.
(II) Fixed, manually operated foam bund pourer system.
(III) Semi-fixed, manually operated foam bund pourer system (fed from foam pumper or other devices as described under rimseal strategies).
(IV) Portable, manually operated foam bund pourers.
(V) Portable, fixed or semi-fixed foam monitors.
(VI) Portable foam nozzles.

The strategy for fire attack would be:

- Shut down tank operations if not already done by automatic executive actions;
- Isolate release source if possible;
- Actuate any fixed or semi-fixed system foam application devices;
- Actuate any rimseal foam system on exposed tanks;
- Deploy portable foam monitors and/or nozzles/ pourers to support foam system application;
- Maintain foam application until fire is extinguished and a secure foam blanket has been developed.

Strategy Notes

It should be noted that currently a maximum flow range of 30-40m should be used in design calculations for bund pourers. Thus the maximum bund width that can be protected is 60-80m unless additional discharge devices are placed in the bund or monitors are used to supplement the pourers. It is recognised that some bund pourers may give better flow range but the end-user should satisfy himself that sufficient test work has been done to validate the claimed ranges. In any case, monitors and/or handlines should always be available to supplement pourer systems.

Bund drains should be closed during firefighting operations unless there is a remote containment basin into which the bund contents are drained. However, constant monitoring of the situation should be done to ensure that the addition of firewater and/or foam solution does not cause the bund to overflow or threaten to cause flotation of the tank. Keeping the bund drain closed will prevent fire spread and reduce potential environmental damage.

If product release is from the tank shell it may be possible to pump water into the tank to raise product level above release source, thereby isolating fuel. This action should be weighed against the potential continuous release of water creating movement and spread of the remaining bund fire.
If a bund pourer system is defective and fire area is considered large, foam monitors may need to be used instead of foam handlines. Delays in deployment of foam monitors and required resources may result in damage to tank shell tops and any rim seal foam systems. Foam monitor deployment may need to be delayed until water monitors are set-up and directed onto affected tank tops.

Rimseal foam systems should be actuated on any exposed tank.

In the case of semi-fixed systems, system connection points must be sufficiently distant from the potentially affected area that personnel are not put at risk when approaching them.

In the case of portable bund pourers, protective waterspray handlines will be necessary to protect personnel deploying the equipment.

The total calculated minimum quantity of foam concentrate for the particular application devices, bund fire area and application time should be available before foam application commences.

The portable bund pourers strategy can be used for small to moderate bund fires where personnel can access the bund wall without risk to life safety. Although it is theoretically possible to extinguish a large surface area bund fire using portable bund pourers, the number required and the supporting resources would take some time to deploy. The strategy for using portable foam bund pourers is similar to the use of foam handlines.

For large pool fires in bunds, efforts should concentrate on creating manageable sections of fire. This is done by creating secure foam blankets through the fire area which will "split-up" the fire area and allow each separate area to be extinguished before moving onto the next area. Obviously, a secure foam blanket has to be achieved on each area before moving onto the next.

When monitors are used and the fire area is large, the strategy adopted would be similar to using portable foam pourers whereby the foam streams should be directed toward a single point in the fire, near the edge of the pool fire area, and moved such that a footprint or strip is developed from the edge of the fire to the tank. This footprint forms the control area and from here the foam streams are directed to one side of the footprint until a clear section of the fire is controlled. The foam streams are then moved to a new location to form a new dividing footprint or strip and control is achieved of this section. This process is repeated until the fire is extinguished and a thick foam blanket developed to ensure vapour suppression.

Use of medium expansion foam of the correct characteristics may offer a more rapid fire control time than low expansion foam when used through portable bund pourer nozzles designed specifically for this purpose.

At all times, product/firewater levels in the bund should be monitored and drain off used to prevent overfilling.

8.6 STRATEGY FOR FULL SURFACE FIREFIGHTING

General

(i) Fixed pourer systems

Note: If a full surface fire protection system is installed it is vital that it is actuated quickly to prevent damage to it occurring from the fire effects. Realistically, this strategy should be such that system actuation and consequent extinguishment occur so quickly that cooling of adjacent tanks should not be required. However, it is considered that back-up monitors should be available to supplement foam attack if required. The strategy is then:

- Stop affected tank operations.
- Ensure that sufficient tank capacity (freeboard) is available to accept foam application by product pump out if required.
- Actuate foam system.
- Continue system discharge until extinguishment is achieved.
- Standby with monitors for supplementary foam application until situation stabilised.
- Pump out to reduce inventory and minimise product involved in any subsequent boilover.

(ii) Monitor application

It should be noted that use of foam monitors requires considerable resources and manpower and, from previous experience, does not have great chance of success unless all equipment can be deployed within a short period. This can only be achieved when preplans are in place and exercised thoroughly on a regular basis.

For ground level foam attack on a tank full surface fire there will be a substantial quantity of resources required and almost all of these resources will need to be on-hand before a foam attack is attempted.

CORRECTIVE LINES OF DEFENCE

Considerations regarding the use of cooling water.

The need for cooling the affected tank shell above the product level has been much debated over the past few years. There is no known incidence of tank shell failure leading to product release under full surface fire conditions where cooling water was not applied to the shell. However, there have been some cases where it is thought that uneven application of water to the tank shell has caused distortion in some areas and consequent loss of product.

The tank shell is intended to fold inward under full surface fire conditions instead of folding outward with potential loss of burning product. Another factor is that cooling the involved tank shell with uneven or erratic water streams will lead to hot and cool zones on the shell surface area which may lead to distortion and possible product spillage or overflow.

However, it must be remembered that if extinguishment is to be attempted, tank shell folds may trap pockets of burning product which foam streams or more correctly, the foam blanket cannot flow over.

This may cause some difficulty in achieving complete extinguishment. In addition it is recognised that cooling may be required to gain full extinguishment by giving the foam a better chance to seal against the tank wall. (The hotter the wall, the more difficult it is to seal against it.) Therefore, cooling water, applied evenly around the complete tank shell may be required and calculations to determine maximum water requirements should make allowance for it. In practice it may only be required at the latter stages of the fire in which case cooling water on adjacent facilities may no longer be required, thus reducing total water flow demand.

Various codes give guidance on water cooling requirements for exposed tankage but a practical fireground method of checking whether an adjacent tank or other plant/equipment is affected by radiant heat is to sweep a water stream across the exposed structure or tank shell above the liquid level. If it steams off, it needs cooling. If not, heat input is minimal or non-existent and therefore is not a hazard at that time. Regular checks should obviously be made if in doubt about prolonged exposure to radiant heat.
Overall it should be recognised that the final decision as to whether or not cooling water should be applied should be the responsibility of the individual in charge of fire attack based on the conditions prevailing at the time.

Foaming Rim Seals and Roofs Affected by Radiant Heat

Where radiant heat is affecting adjacent tanks, there may be a need for foaming the rim seals to provide vapour suppression and cooling of rim seal area and to prevent potential vapour ignition. This is a precautionary measure which should always be considered part of any strategy for fighting full surface fires. Once foamed, the rim seal foam blanket will need to be monitored regularly and topped-up if necessary.

There may also be circumstances where the roof of an adjacent tank is adversely affected by radiant heat and cooling needs to be considered. The obvious hazards in using water streams to achieve this cooling is that the roof may tilt or sink. Therefore, a foam blanket, carefully applied, will provide both cooling and some insulation from the radiant heat. The roof drain needs to be opened during either rim seal or roof foaming. The roof foaming requirement will be more pronounced for a single skin roof rather than for a double deck roof.

Water Monitor Stream Ranges

It is worthwhile repeating that care must be exercised when selecting water monitors for cooling large storage tanks. Factors such as prevailing winds and wind speeds, bund wall distance from tank and height of tanks play a major role in selection. The stream range (straight stream or jet) and height (trajectory) of a water monitor as advertised by manufacturers will always give best possible figures obtained and will always be under still air conditions. This is the only way to standardise the range figures. Therefore, end-users must consider their own particular typical weather conditions and winds to select appropriate monitors. The best method is to request or conduct tests of monitor stream ranges under different wind speeds against the stream.

CORRECTIVE LINES OF DEFENCE

Although it is possible to commit fire personnel into the bunds of adjacent heat affected tanks to set up water monitors for cooling and to briefly re-enter to redirect streams, this practice is definitely not recommended when the tank contents are crude, heavy oils or bitumen/asphalt products since there may be burning or frothing product carryover into the bunds. Worst-case example of this is a severe boilover.
This being the case, the water monitors may need to be set-up on the bunds/walls of the tanks. For large storage tanks, the distance from the bund walls to the tank shells may be considerable. This is why the stream range is important to the end-user.

Foam Monitor Capacities

If fire extinguishment is attempted, the importance of foam monitor capacities and stream range becomes obvious. Foam streams have to be such that the bulk of the stream's output reaches the tank liquid surface. Again, the manufacturer's performance figures will be under still air conditions and this range will be greatly affected by any appreciable wind.

It may be that a desktop calculation shows that the range and trajectory of a foam monitor placed on a bund reaches the liquid surface easily only to discover in practice that the stream falls short due to a facing breeze or greater wind speed.

It is stressed that the range of any water or foam monitors should be checked regardless of any manufacturer's test figures. Tests should always be conducted to ensure monitors will perform under the end-user's site layout and environment.

Practical Calculations of Monitor Requirements

The method of calculating the foam concentrate requirements for a full surface tank fire when using portable foam monitors for "over the top" application are generally well known and are based on a typical recommended 6.5 lpm/m² of foam solution.

However, what must be remembered is that this is based on the 6.5 litres per minute being applied on every square metre of the liquid surface. It does not account for foam stream drift loss, foam stream drop-out/fall out due to stream turbulence, tank fire thermal updraft currents or rapid evaporation losses as the stream enters the heat zone of the fire.
These losses can be large and need to be compensated by a higher application rate. The rate currently in use by several major oil company fire departments is 10.4 lpm/m² for hydrocarbon fires. (more for water soluble fuels.). This is 60% more than the minimum rate to be applied to the fuel surface to ensure that the minimum rate of 6.5 litres settles on the liquid surface.

The 60% figure is not based on any actual validated test programme but is estimated from viewing foam trajectories in incidents and in exercises. It is suggested that under high wind conditions that more than the 60% may be required. However, the higher the application rate, the greater quantity of foam concentrate and number of foam monitors required with corresponding cost increases as well as deployment problems.

Once the surface area of the tank is known and the total foam solution application rate calculated accounting for foam losses, the most important factor is then to select the foam monitors which will meet the total minimum application rate.

For example,

80m diameter tank	= 5028m²
Foam application rate	= 10.4 lpm/m²
Total foam application rate	= 52291 lpm (foam solution)
Typical monitors to be used	= 4500 lpm each
Number of monitors required	= 12

The calculated flowrate was 52291 lpm but translating this into number of monitors gives a final actual flowrate of 54000 lpm (12 x 4500 lpm). The use of 11 x 4500 lpm monitors would not meet the minimum calculated requirement of 52291 lpm.

The final number of foam monitors to be used will have an impact on the total foam concentrate requirements since the actual flowrate is higher than the calculated flowrate.

Foam Concentrate Supply Considerations

Bulk movement and foam monitor supply of foam concentrate represents a major logistical problem which, if not carefully considered, planned and rehearsed, will greatly delay foaming operations and, in some instances, will prevent effective and continuous foam application. It must be remembered that once foam application commences onto a fire, it must be maintained uninterrupted for the duration required.

The use of 25 litre foam concentrate drums is not a viable option for supply of foam concentrate during a large storage tank fire. The capacities of foam monitors for large tank fires would typically begin at 4500 lpm, which at a 3% induction would use 135 lpm or more than 5 drums each minute.

Although many industrial fire brigades favour 200 litre drums for supply, these will obviously last for less than 1.5 minutes assuming a 4500 lpm monitor is in use. With monitor flowrates above 4500 lpm, the 200 litre drums are consumed rapidly. These drums are therefore of no benefit when foam monitors of 30,000 - 60,000 lpm are to be used.

The best options are either to use large capacity “polytank” containers of 1000 litres or more, which can be transported to each fire vehicle or monitor and dropped off on the spot within foam suction hose reach. Dropping two or more within suction hose reach will obviously increase the duration before changeover and therefore give more time for transport crews to keep re-supply moving. If the containers have a side-top mounted funnel point the containers can be stacked at the vehicles or monitors.

Using foam tankers in the range of 10000 - 15000 litre capacity is the other method of supply but this needs large assets/procurement in the form of foam tankers dedicated only to a full surface large tank fire and these would have to be on-site within a very short period of the incident start.

Mutual aid schemes may help justify this approach. If this is to be pursued, hose connections from tanker to pumper or monitor must be compatible. The pumping vehicles must also have efficient foam pumps to draft/lift the foam or have easy access to pumper tank tops. It should be remembered that if the foam tankers are pumping foam to the pumper’s tank top that some agitation and therefore aeration is bound to occur.

Foam Compatibility

Foam compatibility is also an important factor. If mutual aid is to be used, a single foam concentrate at a uniform induction rate is preferred. Although it is possible to use, for example, AFFF based foam on a hydrocarbon fire and then use fluoroprotein based foam on top of the AFFF blanket without any serious adverse effect, this is not recommended for large tanks. Mixing foam concentrates of different types is not recommended as this may destroy foam making properties completely. The intention is to have a uniform foam type suitable for the burning fuel type at a uniform induction rate so that the chance of pump operator errors in proportioning are minimised.

Considering that for some of the large diameter tanks (80-100m) there could, in theory, be 18 x 4,500 lpm aspirated foam monitors in use and therefore more than 24 fire pumper vehicles, the monitoring of foam supply becomes very difficult.

Foam concentrate selection

It is currently considered that a good quality fluoroprotein foam or multi-purpose foam is most suitable for tank fire fighting of a hydrocarbon liquid. Multi-purpose foams must be used for any fuel that is water soluble (e.g. alcohols, ketones, etc.) However, none of the current multi-purpose foams are particularly effective on water-soluble fuels when using monitor attack that plunges the foam into the fuel. Application rates, depending on the fuel type, may have to be increased considerably (to 2 or more the normal rate for hydrocarbons) to be effective. Carrying out trials on the particular fuels on site to make some assessment of what application rate is appropriate is the only way to find out if monitors can be used at all and, if so what application rates might be effective. Overall though, it must be accepted that monitor attack is even less efficient in terms of application rate on water-soluble fuels than it is on hydrocarbon fuels.

Water Supply Considerations

The water supply for firefighting large storage tank fires is the key to any fire response decisions. There is no point in scaling up to tackle a large tank fire only to be let down by the water supply. The cooling of exposures plus the foam attack water requirements will add up to a very large rate and quantity of water.

For example, if a hydrocarbon storage tank is in the order of 80 m diameter, and total foam monitors provide a flowrate of 54000 foam solution on a 3% induction the water demand for foam production will be will be 50670 lpm. This figure does not include water for cooling any exposed tanks or plant or for any cooling, if required, of the ignited tank.

Pressures and flows of firewater systems are the cornerstone of any successful firefighting operation. Typically water pressures of at least 8 bars under full flow conditions are required for efficient foam monitor application. If reliance is placed on using pumpers to draft/lift from an open water source, the number of pumpers required to supply the water demand for the foam application and water cooling must be guaranteed available throughout the incident. If not, there is no point in pursuing this strategy further. This particular water supply method also presents heavy maintenance demands for all required fire vehicles or indeed for trailer pumps if they are to be used instead of fire vehicles.

Manpower Considerations

Manpower requirements for fighting large storage tank fires are often overlooked until the event. The issue of manpower for such fire incidents has assumed greater importance over the last few years as on-site reductions have been made in the numbers of petrochemical company employees.

There is no "rule of thumb" for calculating exactly how many people will be required. However, by reviewing the areas of work to be done, and the mobile and portable equipment to be used, it is possible to have a minimum total manpower requirement identified. This would not include relief crews, which would be needed after 4 or 6 hours to prevent fatigue.

Rest areas for personnel need to be provided and catering for the total manpower requirements is also considered a very important part of the strategy in extended incidents.

Boilover Considerations

One of the major escalation risks of a full surface fire is that of a boilover. Boilovers can occur in fuels which have fractions with differing boiling points. A full description is given in the LASTFIRE project Escalation Review.

When a boilover occurs it can lead to burning product spreading over an area of several tank diameters away from the tank. Although no definitive work has been carried out to validate figures, there is a "rule of thumb" that a boilover fall out can extend 5-10 diameters in each direction from a tank. Actual distance will depend on the quantity of fuel involved, the amount of vapourised liquid and wind direction.

The results of a boilover can be catastrophic and obviously will expose anyone in the vicinity to a high level of risk. Therefore if it is realised that extinguishment is not going to be achieved and the fuel has the potential for boilover, it is vital that all personnel retreat to a safe distance.

Unfortunately although here are some opinions regarding signs of an imminent boilover, there is currently no definitive method of determining when a boilover will occur. It must be recognised that the fall of hot product through the fuel is not necessarily uniform over the whole surface of the tank. Therefore, measuring fall of the hot zone at the tank shell by thermal imaging cameras or heat sensitive paint cannot be relied upon. A generally accepted "rule of thumb" is that the hot zone will travel downwards at a speed of approximately 1-2m every hour. This can only be used as a very rough estimate as actual speed will depend on fuel type and constituents. Also, it is possible that the hot zone does not have to reach the bottom of a tank to create a boilover - pockets of water or fuel constituents that will boil can be stratified within the tank at different levels, especially in crude oils.

In order to minimise fuel inventory in the boilover it is recommended that pump out is commenced as soon as possible. It is considered that this can be done even when the firefighting operation is going on because the turbulence and product movement caused is usually sufficiently small as to not have any significant effect on foam effectiveness.

Slopover/Frothover

Slopovers or frothovers occur when water applied to the fire as foam solution boils and turns to steam. They can also occur when product fractions within the fuel boil. This has a similar effect to a boilover but to a lesser degree because the water is near to the fuel surface so the steam does not eject so much fuel. However, there can be serious escalation events as burning product can enter the bund.

Concerns have been expressed that large quantities of foam applied, particularly when unaspirated, can cause significant frothover events.

Firewater Containment

It is probable that during an attack on a full surface fire that significant quantities of foam and water, often contaminated by product, will accumulate in the bund. Any overall strategy must consider disposal of this fluid. Large quantities of foam solution, even when uncontaminated, cannot be handled by most water treatment plants.

Strategy for sunken roofs with no ignition

The generation of foam and its subsequent discharge from a nozzle can produce an electrostatic charge which can cause fuel ignition. In addition, the breakdown of foam applied to a fuel surface into foam solution which then falls through the fuel as droplets of, effectively, water is thought to have the potential to generate a charge sufficient to cause ignition.
These phenomena are thought only to be a problem with non-conductive fuels such as refined spirits and then only when there is fuel spillage of an appreciable depth (more than 0.5m).

In order to minimise the risk of ignition in this way, it is considered that the most appropriate strategy for a sunken roof in a tank containing non-conductive fuel is to not put on a foam blanket unless there is an immediate risk to safety due to vapour spread or there is a definite potential ignition source (e.g. a lightning storm or generation of such a large vapour cloud that it could reach an ignition source such as vehicles on public roads, heaters, flares, etc.).

However, it is recommended that the resources required to foam the surface are deployed and put on standby so that application can be carried out immediately if required.

If foam application is required in an unignited surface then foam should not be applied directly into the fuel but should be allowed to run down the tank wall onto the fuel surface.

Pump out of fuel from a tank with a jammed roof should not be carried out until the roof is secured in some way or refloated.

Full Surface Firefighting Strategies

The following strategy assumes that all required resources will be on-hand before any extinguishment attempt:

- Shutdown tank operations.
- Pump out / transfer sufficient product to tank at safe location or allow burn off to allow application of foam.
- Deploy and actuate cooling water monitors as required.
- Deploy foam monitors in a close group using any wind direction to carry foam onto tank surface.
- Ensure foam concentrate stocks on-hand are at least the minimum required. Typical standards require at least 65 minutes operating time. If the fire has been burning for some time, this should be increased to at least 120 minutes.
- Ensure foam distribution operations are ready and understood.
- Commence foam application and maintain application uninterrupted for the required time.
- Do not halt foam application until required time has expired even if fire is extinguished.
- Cool tank walls (if required) to assist final extinguishment.
- If fire not extinguished, remove all personnel to safe location and continue to pump out product until burn out occurs.

Strategy Notes

Pump out operation should be carried out during firefighting efforts. This will at least salvage product and, over time, reduce boilover consequences even though it may reduce the time to boilover. (In some cases it may be necessary to over-ride automatic pump cut-out such as in the case where the product reaches a higher temperature than normal acceptable for product transfer.)

Any water bottoms in product that can boilover should be drawn off. However, in practice it is probably impossible to draw off the water completely due to tank bottom distortion, position of emergency water draw off or water suspension. Once a decision is made to attempt extinguishment of a full surface fire, all resources required for this must be on site before the attempt is made. To commence foam application on the basis that full resources are being mobilised and can be expected soon on site will be to potentially waste a fire control opportunity. Once foam application has commenced, it must not be interrupted until extinguishment is achieved and a foam blanket established.

Foam streams need to be constantly checked to ensure they are still reaching the tank surface. Variable wind speeds, change of wind direction and water pressure drop are only a few reasons why foam stream may "drop-off" and miss the tank surface.
If the fire is obviously extinguished foam application should be continued to ensure complete extinguishment and secure foam blanket development on the tank liquid surface.

If the product level in the tank is high, there may not be adequate freeboard for foam application and any attempt at foaming the tank surface may result in slopover. Where the tank level is high, it may be necessary to delay the foam attack until the tank level drops by pumpout or burn-off as mentioned in the above strategy sequence.

Regardless of the capacity of monitors to be used, the method of attack will be the same; that of concentrating foam monitor streams onto a single point of the burning liquid surface. Generally, though not always, this method of attack will be from an upwind position and will be aimed at just above the tank shell with the objective of establishing a footprint or foam patch from which foam can flow over the burning liquid.

Use of monitors inside bunds is not normally considered good practice. However, for light refined products such as gasolines, naphtha, condensate etc., there is not normally a product release hazard from the tank provided that water streams are not being directed into the tank to cause slopover or burning product flooding over the tank top shell.

Unrefined and heavy product tanks (such as fuel oils Nos 4-6) are a more hazardous fire event and it is not recommended that personnel enter the bund at any time. If a boilover does occur, equipment in the bund will be destroyed along with a significant risk to any remaining personnel.

Full surface firefighting requires safety officers to monitor personnel as they carry out actions in the fireground area. These safety officers become vitally important if a crude oil or heavy oil tank full surface fire is to be fought. The hazard of boilover cannot be over-emphasised. A boilover can occur after only a few hours of full surface burning. It should not be assumed that it will not occur until the fire has been burning for some considerable time and that the water bottom is the only water in the tank. Crude oil in a large tank will virtually always boilover if left to burn.

Some bund floors may be porous and overuse of water for cooling tanks may lead to tank pad "floating" with potential stresses on the tank. Close monitoring of water cooling and tank pads will be necessary. Also, tank bund drains may need to be open where tank cooling is being carried out and there is no risk of product being carried out through the drain system. However, if there is contaminated water or the possibility of a boilover spreading fuel into the bund, the bund drain valves should be closed to minimise risk of fuel spread out of the bund.

It is probable that foam tankers and other vehicles will have difficulty moving around the tank farm roads due to the number of vehicles and hose distribution blocking roads. Careful planning is needed to avoid blocking roads with vehicles and hose runs.

8.7 TANK FIRE DETECTION OPTIONS

General

The rapid detection of tank or bund fires and vapour releases from tanks is essential if a rapid response is to be mounted. At one end of the scale, detection may be via regular patrols and this method may be appropriate if manning levels are high, or a facility has only a small number of tanks. Alternatively, the operator may consider and employ fully automatic detection. This section is intended to outline the most common detection options for tank application:

1. Floating Roof Tanks – Detection Options
2. Fixed / Internal Floating Roof Tanks – Detection Options
3. Bund Fire Detection
4. Detection of Vapour Releases – Gas Detection

8.7.1 Floating Roof Tanks – Detection Options

Rimseal fires are the most common types of incident. They can burn for some time, especially at sites with low manning levels, before being detected manually. Although such fires, in well-maintained tanks, are unlikely to escalate to full surface fires, they can, if allowed to escalate to full circumference incidents and burn for some time, still cause significant tank damage and consequential losses.

It is, therefore, important to detect incidents as quickly as possible and extinguish the fire while it is limited to small sections of the rimseal area.

Although newer types of fire detection including thermal imaging and “smoke tracking” systems are considered to show great promise for the future as rimseal and spill on roof fire detection systems, they are currently unproven for this application.

Flame detectors can be used in an application where the fire will quickly give rise to flames. This, of course, is normally the case with hydrocarbon fires. Therefore, in theory, flame detectors can be used to monitor for all types of fire incident scenarios associated with floating roof tanks.

However, in practice, they have disadvantages that often preclude them. For example, they tend to be more expensive that other detectors that are more suited to the application, each type of flame detector is prone to some form of spurious alarm source, and it is often necessary to have a large number of detectors for a rim seal fire if the roof diameter exceeds 60m.

Thermal Imaging detection systems can, potentially be used for detection of all types of fire associated with floating roof tanks. With careful location (including elevation) a relatively small number of units could be used to monitor several tanks and the associated bunds. However, it must be recognised that no directly relevant field experience has been gained to date.

There has been a trend towards provision of detection systems for rimseal fires to the extent that several companies now fit them on all open top floating roof tanks.

The type of detector chosen normally for rimseal fire detection is Linear Heat Detection. Previously these were normally of the pneumatic tube type but as technology has developed, experience grown and reliability improved there has been a move to the electrical cable types due to their simpler installation and maintenance and their less complex control and monitoring requirements.

Normally a single detector is provided without any automatic executive action being carried out as preplanned response procedures are usually to make a visual confirmation of the incident.

Specification Considerations

In order for such detectors to be effective it is important to consider certain points:

As the detector is fully and continuously exposed to the weather, it must, for example, be resistant to long term sunlight effects as well as product vapours. Ancillary fittings such as junction boxes must be fully waterproof and appropriate to the area classification.

Generally speaking, the fire response actions will not be dependent on the precise location of the fire. Therefore, it is not normally necessary for operators to require “zoned” detectors or have a type that detects the precise location of the fire. In the case of electrical cable types, a straightforward “digital” type is normally adequate.

As automatic discharge of a rimseal foam system is not normally necessary, only one detector covering the whole tank circumference is usually sufficient..

(i.e. A back up detector is not normally required to confirm the fire as executive actions such as shut down or foam system discharge would normally only occur after visual confirmation of the fire.)

Electrical cable detectors should be of the type that can be monitored for integrity right up to the end of the detector itself. (i.e. The complete system is monitored for integrity.)

The operator must take great care in selecting and installing the method by which the detector passes over the tank shell down to the roof to ensure that it cannot be snagged.

It is a good idea for operators to possess extra length(s) of detector for the installation to allow easier repair of damaged sections.

The detector assembly should always include a test mechanism that allows testing of the complete detector. This, in the case of electrical detectors, can usually be achieved by including a test switch assembly at the end of the detector.

Detector Location

The detector should be positioned to minimise the probability of mechanical damage. The detector must be installed as close as possible, preferably within 50mm, to the top of the rimseal assembly.

This will normally require special clips or supports. If there are other critical parts on the roof that are considered to require monitoring for fires, such as vents or potential spill areas, the detector can always be diverted to them, although this is not normally considered necessary for most applications.
Too often, for convenience, the detector is positioned away from the rimseal. For example, it is often mounted on the structure designed to hold firefighting foam over the rimseal area. This can lead to a considerable delay in incident detection.

Point or Linear heat detection systems are used extensively to monitor for rimseal fires on floating roof tanks, but they can also be used to detect fires on fixed roof tank vents or fittings attached to the tank shell such as valves, mixers etc.

Wherever possible, the detector(s) must be located close to the expected origin of fire. Once again, flame detectors are not often applied due to cost considerations etc.

8.7.2 Bunds – Detection Options

Flame detectors have been used to monitor bunds at some facilities. Typically, they can detect a fire of 0.1m² area at a distance of 20m within a few seconds. Again, it must be stressed that there are no internationally recognised Codes of Practice or Standards requiring provision of automatic fire detection specifically for bund areas.

However, local legislation varies considerably and there is a definite trend in some countries and regions towards local authorities demanding detection systems.

8.7.3 Detection of Vapour Releases – Gas Detection

The use of gas detection to detect vapour releases is covered in Section 5.3 – Loss of Containment Detection Options.

8.8 WATER COOLING SYSTEMS FOR TANKS

The primary purpose of water cooling systems will be to provide the following elements:
• Cooling fire engulfed tanks
• Cooling from radiant heat

This can be achieved by a ring of nozzles mounted on the tank at the top of the shell to allow water to drain down the sides of the tank. Additional nozzles may be required to compensate for discharge disruptions due to fittings on the tank and so ensure all exposed surfaces are wetted.

Critical components such as mixers or shut-off valves/actuators attached to the tank can also be protected by waterspray systems either from dedicated systems or with supplementary nozzles from the tank protection system.

The purpose of a water deluge/spray system should be clearly defined before a design is attempted. Whatever the configuration, it is imperative that good coverage is achieved by laying nozzles out over the whole surface of the tank.

Applicability

The first consideration will always be to decide whether a water deluge/spray system is needed, taking into account the legislative position and appraising fully the risk Requirements should always be determined through scenario based evaluation of credible fire scenarios.

A single small tank, where options exist for rapid deployment of portable fire fighting equipment may not necessitate use of such a fixed system.

With respect to the specification of a water deluge or spray system, typical application rates should be in the order of 10 lpm/m², adequate for spill fires and surface cooling of heat affected vessels, although it is worth noting that a higher application rate may be necessary for jet fire impingement (perhaps from a mixer leak). For cooling adjacent tanks, the minimum application rate should be in the order of 2 lpm/m².

Other important concerns will include:

- Pipework specification and ability to withstand radiant/direct heat and jet fire erosion
- Potential for and effects of nozzle blockage
- Containment and drainage of firewater / carry over of fuel (should take into account water from portable equipment used, also)
- Actuation points – should be remote from fire area
- Testing facilities and ease of testing
- Position of inlets remote from potential fire area, if semi-fixed system
- Need to cool adjacent tanks (only needed where tanks are close together and is often provided unnecessarily).

Requirements for cooling heat affected vessels may be determined by techniques such as fire modelling, in which case the recommendations outlined by guidance such as in the Institute of Petroleum (IP) Model Codes of Safe Practice should be followed.
Most companies do not provide fixed waterspray systems on storage tanks unless the spacing is below the minimum recommended in recognised standards such as NFPA 30 or IP Model Code of Practice Part 19.

It is more usual practice to provide cooling by monitors at ground level. In some cases where access is difficult or the facility has insufficient manpower to deploy mobile monitors, fixed units can be provided. However, in most cases reliance is placed on mobile units.More information regarding the use of tank water spray systems as a barrier for preventing fire escalation is given in Section 8.11.4 – Barriers to Prevent Escalation.

8.9 FIRE FIGHTING FOAM SYSTEMS FOR TANKS

Many tanks around the world containing flammable liquids do not have any form of fixed foam protection systems. In these cases it has been assumed that a fire fighting attack can be mounted from portable or mobile equipment. Major incidents have shown that this cannot always be relied upon. However, large diameter tanks have actually been extinguished successfully with large throughput monitors and several manufacturers market this type of equipment. Monitor application should therefore only really be considered for supplementary protection in the case of damage to a fixed system. The answer may be to have a fixed system designed in accordance with an internationally recognised standard. The standard most commonly used is National Fire Protection Association (NFPA) Code 11 – Standard for Low Expansion Foam
In particular, NFPA 11 (and more recently, the LASTFIRE study – see Section 10.6) clearly state that foam handlines should not be considered for primary protection of tanks greater than 9m diameter or 6m high and that monitors should not be used for this purpose on tanks over 18m diameter. (This does not mean that this equipment should not be used as supplementary protection for such risks.)

The type of protection system specified depends on the construction of the tank and the properties of the fuel stored.
As well as providing protection for the storage tank itself, it is important to remember that there

should be an associated bund (dike) area designed to contain the fuel in the event of tank rupture.

The various methods of protecting both tanks and bunds are described in Section 7. Each method includes a description of the equipment used and its' limitations, as well as offering an example calculation sheet outlining a typical design example. In all cases, a recognised standard has been applied (NFPA 11)

For auditing purposes, to fully demonstrate that a foam system or application method is suitable for a given risk, an operator ought to be able to provide design and operability data in line with one or more of the approaches given. The design examples and descriptions given will also allow the auditor to more fully understand the criteria applied in designing such systems, and to fully appreciate whether a foam application method or system is suitable for a given risk.

Systems may be "fixed" or "semi-fixed", i.e. the discharge equipment mounted on a storage tank may be permanently fixed to the supply of foam solution or the connection may only be made at the time of an incident in which case the term semi-fixed applies. (Usually in such cases the foam solution will be supplied from a specialist fire fighting vehicle.)

It must also be remembered that all fixed systems must have supplementary foam back up. The requirements for this are discussed later.

An alternative method of protecting storage tanks to those described below is the use of portable foam towers. These are not included because they are gradually becoming obsolete due to the manpower requirements and safety problems associated with them.

All fire-fighting equipment, including foam systems, is only used in anger when a problem has occurred. Therefore, it is vitally important to ensure that the equipment is designed and manufactured to the best possible standards so that when it is needed it can be brought rapidly into effective operation. (Of course, in order to ensure that the equipment is in a constant state of readiness, a comprehensive maintenance programme must be rigorously applied.) The best method of doing this is to design in accordance with a recognised code of practice and use materials that have been approved by a reputable testing authority.

The relevant material that is available to the foam system design engineer can be split into two categories. The first is Design Guides that outline the recommendations for overall system and component design. The second is Component Approvals that includes both equipment and foam concentrates. In both categories there are many sources of information available. Only the most widely recognised will be mentioned here. In addition to the information available from "nationalised" concerns, many of the major end users such as oil companies have their own in-house design standards.

Design Guides

The standard for foam-extinguishing systems most recognised internationally is the National Fire Protection Association (NFPA) Code 11. The history of this document started in 1921 when the NFPA Committee on Manufacturing Risks and Special Hazards prepared standards on foam as a section of the general Standard on Protection of Fire Hazards Incident to the use of Volatiles in Manufacturing Processes. Nowadays a new edition is issued every 2-3 years.

NFPA 11 is a comprehensive code of practice dealing with all aspects of designing foam systems for oil and petrochemical handling plants including guidelines for maintenance and test procedures. It is part of a set of codes of practice which includes many other relevant standards such as NFPA 11A (Medium and High Expansion Foam Systems), NFPA 16 (Standard for the Installation of Foam-Water Sprinkler Systems and Foam-Water Spray Systems) and NFPA 1901 (Automotive Fire Apparatus). In the text of NFPA 11 other standards are mentioned. For example, suitable mechanical standards for pipework in systems are provided. The American Petroleum Institute (API) provides several publications including information on foam usage. These include API 2021, "Management of Atmospheric Storage Tank Fires".

8.9.1 Fixed Systems

Fixed Foam Pourer Installations for Bunds

Fixed foam pourers have been used for many years for protection of bunded areas. Some manufacturers produce an integral foam-maker and discharge device, others use separate items. In both cases the discharge devices are fixed to the bund wall at equally spaced intervals so that the foam discharges into the bund itself.

Application Rates and Discharge Device Spacing

NFPA Code 11 states that fixed foam protection may be desirable for common diked areas surrounding multiple tanks with poor access for fire fighting or less than the spacing specified in NFPA 30, Flammable and Combustible Liquids Code. Suggested application rates are:

4.1 LPM/M^2 FOR HYDROCARBON LIQUIDS

For foam destructive fuels, the foam liquid manufacturers' recommendations must be sought. The following tables gives application rates for bund pourers.

Typical industry practice and incident experience has shown that discharge device spacing may be specified by giving the maximum bund area to be protected by a given number of devices as follows:

NO. OF DEVICES	MAXIMUM BUND AREA (M^2)
1	450
2	1020
3	1380
4	1810
5	2290
6	2820

Table 8.1: Number of devices

For larger bund areas, an additional device should be added for each 450m^2 above 2820m^2.

Discharge Times

NFPA

20 minutes for hydrocarbon liquids having flash point above 37.8˚C.
30 minutes for all other liquids.

EXAMPLE CALCULATIONS SHEET FIXED POURER PROTECTION OF BUND AREA.

Risk
A bund area 40m x 30m containing a methanol (methyl alcohol) storage tank.

Design Standard

NFPA 11 / Manufacturer's recommended application rate (typical – alternative application rate may apply)

Objective

Calculate total amount of foam concentrate required and the number of discharge devices required for the above risk.
N.B. This does not include any allowance for reserve supplies.*) AR means alcohol resistance

Fixed Foam Pourer Installations for Cone Roof Tanks

Fixed foam pourers are often used as the primary protection method for cone roof tanks.
In this case they are located immediately below the weak seam joining the roof to the tank shell.
A vapour seal to prevent fuel vapours from the tank escaping into the foam solution lines is incorporated into the units. This normally takes the form of a frangible glass diaphragm that breaks under pressure from foam entering the device.

Essentially, there are therefore 3 components to a foam pourer assembly used for storage tank protection:

(I) The Foam Generator - This may be mounted very close to the discharge device or remotely from it.
(II) The Vapour Seal Box containing the glass diaphragm.
(III) The Discharge Device inside the tank. Normally this is of a type that forces foam back against the tank wall so that it flows down relatively gently onto the fuel surface.

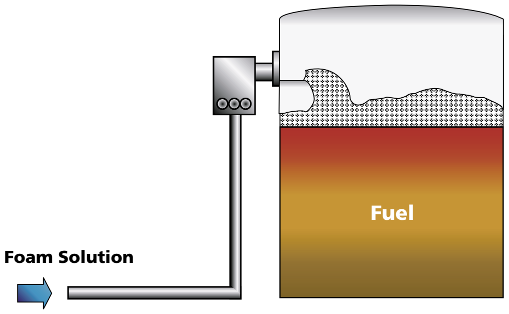

Fig 8.1 – Top Pourer Foam Application to Storage Tank

Top Pourer Foam Application to Storage Tank

The major disadvantages of foam pourers for tank protection is the relative difficulty of maintaining them because they are sited at the top of the tank and the fairly strong possibility that they will be damaged by an explosion or fire prior to foam discharge being started.

However, in some circumstances they may be the only practicable solution particularly where water pressure is low as they tend to require less pressure for operation than the alternative protection methods for cone roof tanks.

Where an internal floating roof is present with a cone roof tank, they are the preferred and recommended protection method. In such cases, foam solution application rates are the same as for standard cone roof tanks and are based on the entire surface area of the tank.
Exactly the same rules for the number of outlets and discharge times also apply.

Prior to discussion of application rates etc., it is worth mentioning some definitions contained in NFPA regarding foam pourer devices. NFPA classifies these according to how gently they deliver foam to the fuel surface:

Type I A device that will conduct and deliver foam gently onto the liquid surface without submergence of the foam or agitation of the surface.

Type II A device that does not deliver foam gently onto the liquid surface but is designed to lessen submergence of the foam and agitation of the surface.

Most foam pourers commercially available fall into Type II classification. To qualify for Type I classification it is necessary to have foam chutes or large diameter hoses directing the foam to the liquid surface. These are expensive and can cause maintenance problems, so they are effectively becoming obsolete. Therefore, all the subsequent notes on pourer application to storage tanks are relevant to Type II discharge outlets.

Application rate and spacing of devices

N.F.P.A. gives a minimum application rate of 4.1 lpm/m² for hydrocarbon liquids and 6.5 lpm/m² for foam destructive liquids (with the proviso that foam liquid manufacturers' recommendations should also be sought on foam destructive fuels). Spacing and number of application points is quoted as given in the table below:

TANK DIAMETER (M)	MINIMUM NUMBER OF POURERS
Up to 24	1
Over 24 to 36	2
Over 36 to 42	3
Over 42 to 48	4
Over 48 to 54	5
Over 54 to 60	6
Above 60	1 additional pourer for every 465m² fuel surface area.

Discharge Times

NFPA - For type II outlets, the following discharge times apply:

Hydrocarbon liquids with flash point between 37.8°C and 93.3°C	30 min.
Hydrocarbon liquids with flash point below 37.8°C, liquids heated above their flash point or crude petroleum	55 min.
Foam destructive liquids	55 min.

In the NFPA standard, and from industry experience it may be allowable to reduce the system running time if discharge rates are actually above the minimum values specified. A reduction in proportion to the increase in application rate is allowed provided that the time does not go below 70% of the minimum discharge time at the minimum application rate.

EXAMPLE CALCULATIONS SHEET FOAM POURER PROTECTION OF CONE ROOF TANK

Risk
A storage tank, diameter 30m, containing hydrocarbon fuel with a flash point of 29°C.

Design Standard: **NFPA 11**

Objective: Determine the total amount of foam concentrate and the number of foam pourers required for the above risk.

CALCULATION	
(i)	Fuel area = $\frac{\pi \times d^2}{4} = \frac{3.14 \times 302}{4} = 707m^2$
(ii)	Foam concentrate chosen 3% FP
(iii)	Application rate: 4.1 lpm/m²
(iv)	Total application rate 707 x 4.1 = 2899 lpm:
(v)	No of injection points required: 1
(vi)	Running time: 55 minutes
(vii)	Amount of foam concentrate required:
3899 X 55 X 0.03 = 4783 LITRES	

N.B. This figure does not include the requirement for supplementary protection or reserve supplies.

Semi-Subsurface Protection of Cone Roof Storage Tanks

In an attempt to overcome the disadvantages of a standard pourer system for cone roof storage tanks not having an internal floating roof, some companies have developed a semi-subsurface system in which the discharge equipment moving parts are at ground level but the actual foam is applied gently to the fuel surface.

To some extend this equipment was made obsolete by the use of foams which can be used in a true subsurface system (see later). However, true subsurface systems cannot be used on water-soluble fuels, so semi-surface techniques might be the best solution in such cases. (This is a point to be borne in mind now that more and more foam destructive additives are being added to standard hydrocarbon liquids such as in the case of lead free gasolines.)

The equipment used for 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 equal to 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.
When foam is generated, a pressure wave in the container causes the bursting disc to burst allowing the unattached end of the hose to float to the surface. Foam flowing through the hose gives the hose added buoyancy and is delivered gently to the fuel surface.
The disadvantages of the system are that it is relatively complicated compared to other types. It is also relatively difficult to maintain and check and the unattached end of the hose can cause disruption of the foam blanket as it moves around due to the reaction force of the discharging foam.

However, it does have the advantages that all equipment is at ground level and it can be used with foam destructive liquids.

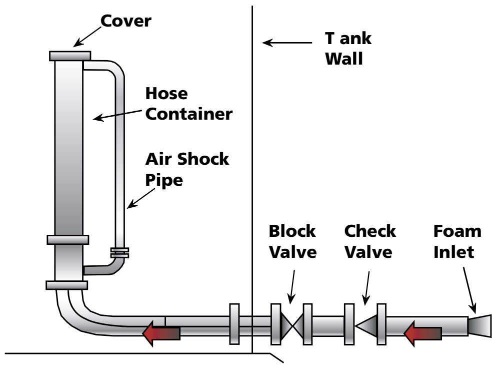

Fig 8.2 – (a) Before discharge

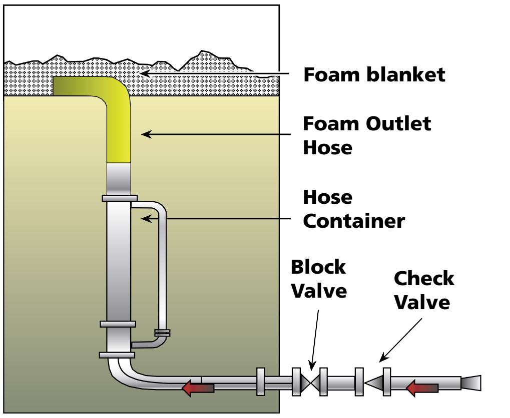

Fig 8.3 – (b) Semi-subsurface protection system. During discharge

Design Parameters

NFPA 11 does not give any very helpful guidance as to application rates, number of discharge points or running time.

During discharge

However, typical industry practice is to treat this application technique exactly the same as pourer systems for cone roof tanks, so the same design parameters may be applied. (See notes above.)

Subsurface Protection of Cone Roof Storage Tanks

With sub-surface application or "base injection" the foam is forced directly into the fuel either via a product line or at a point near the bottom of the tank (but above any water base that may be present). The foam then travels through the fuel to form a vapour tight blanket over the entire surface. Circulation of the fuel caused by the travel of foam through it helps to cool the fuel surface. The system equipment used is relatively simple to operate and maintain compared to semi-subsurface and there is the advantage over top pourers that there is less chance of damage to it during an incident. Therefore, subsurface injection systems have become very popular as the primary protection method for hydrocarbon storage tanks. Standard protein foams cannot be used for subsurface systems, and, at present, there is no foam suitable for use in such systems with water-soluble risks.

Special consideration should be given to high viscosity fuels as subsurface injection may not be suitable.
With some fuels where there has been a long preburn prior to the application of foam, a hot zone may exist near the burning surface at temperatures in excess of 1000°C. In order to avoid frothing and slop-over, continuous application of foam should be avoided in the initial stages. Intermittent application of foam can induce circulation of the fuel in the tank, thereby bringing the cooler layers of fuel to the surface. The foam injected intermittently will disperse without sufficient steam formation to produce frothing.

Special foam generators are needed which are designed to produce suitable quality foam against the back pressure caused by the fuel head in the tank and any friction losses between the foam generator and foam discharge point inside the tank. Such generators are called "High Back Pressure Generators" and typically, they can produce foam against 25-40% backpressure. Normally a minimum inlet pressure at the generator of 7 bars is required.
In order to minimise fuel pick-up and foam break-down it is important in subsurface systems to limit the foam discharge velocity into the tank. This factor, along with the need to calculate and minimise back pressure, means that the pipework sizing and routing can be more critical than with other systems. In order to provide a positive seal against the fuel leaking back down the foam system pipework, it is advisable to position abursting disc in the line as well as a non-return valve.
Testing of subsurface systems can be relatively easy provided test discharge outlets and the corresponding valving has been incorporated into the system layout.

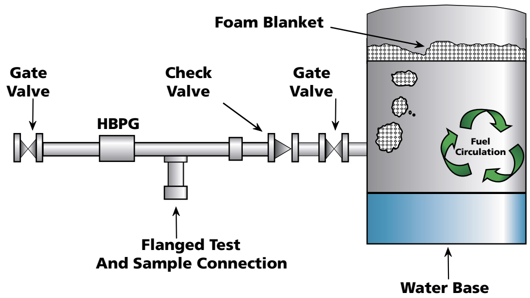

Fig 8.4 – Subsurface Protection of Cone Roof Storage Tanks

Subsurface Injection System Schematic

An application rate of 4.1 lpm/m² is specified in NFPA 11. The spacing of discharge outlets specified in NFPA 11 is given in the table below:

TANK DIAMETER [M]	HYDROCARBONS WITH FLASH POINT NOT ABOVE 37.8 °C	HYDROCARBONS WITH FLASHPOINT ABOVE 37.8 °C
Up to 24	1	1
Over 24 up to and including 36	2	1
Over 36 up to and including 42	3	2
Over 42 up to and including 48	4	2
Over 48 up to and including 54	5	2
Over 54 up to and including 60	6	3
Above 60	6 plus one inlet for each 465m² of tank area above 2820m²	3, plus one for each 465m² of tank area above 2820m²

Discharge Times

NFPA:

Flash point between 37.80 °C and 93.30 °C - 30 minutes

Flash point below 37.80 °C, crude petroleum and liquids heated above their flash points - 55 minutes

In the NFPA standard, and from industry experience it may be allowable to reduce the system running time to 70% of the values given provided there is a proportional increase in the application rate over the minimum required.

EXAMPLE CALCULATIONS SHEET SUB-SURFACE PROTECTION OF CONE ROOF TANK

Risk

A storage tank, diameter 30m, containing hydrocarbon fuel with a flash point of 29°C.

Design Standard

NFPA 11.

Objective

Determine the total amount of foam concentrate and the number of subsurface injection points required for the above risk.

CALCULATION	
(I)	Fuel Area = $\frac{\pi \times d^2}{4} = \frac{3.14 \times 302}{4}$ = 707m²
(II)	Foam concentrate chosen: 3%
(III)	Application rate 4.1 lpm/m²
(IV)	Total application rate: 707 x 4.1= 2899 lpm
(V)	No. of pourers required: 2
(VI)	Running time 55 minutes
(VII)	Amount of foam concentrate required: **2899 x 55 x 0.03 = 4783 litres**

N.B. The amount of foam concentrate required and the total application rate are the same as that for the pourer protection system example given before. However, only one discharge point is required with subsurface application rather than two in the case of pourer protection.
The foam concentrate requirement above does not include that for supplementary protection or reserve supplies.

Foam Pourer Protection of Open Top Floating Roof Tanks

The main fire risk for open top floating roof tanks is the seal area between the tank shell and the floating roof. There are several different types of seal in common use.
In fact this type of tank has a relatively good safety record and some companies choose not to install any fixed protection system at all but rely on a fire fighter, at the time of an incident, going on to the roof with a suitable extinguisher.

In some cases a foam riser is installed at the top of the rolling ladder so that a handline can be connected here and by walking around the walkway, a fire fighter can direct foam into the seal area.

Such methods are not really safe and therefore not acceptable. The alternative is to provide a fixed system. There are 3 basic methods of doing this on the market - pourers, catenary systems and “Coflexip” systems. The pourer system comprises a number of pourers positioned strategically around the top of the tank discharging foam into the seal area. In most cases a foam dam is fixed on the tank roof to contain the foam in the seal area. (The other types of system are described later.)

Pourer systems have the following advantages:

- **(A)** Relatively simple installation.
- **(B)** No moving parts on tank roof.
- **(C)** Maintenance of pourers is straightforward and safe to carry out provided the tank has a walkway.
- **(D)** Only fairly low solution pressures are necessary at the foam generators.

The main disadvantage is that, particularly when the tank is nearly empty and the roof is some way below the top of the tank shell, a large proportion of the foam may miss the seal area due to disruption of the foam stream by turbulent wind effects.

With foam pourers it is only possible to apply foam over any secondary seal or water shield. With other types of system described below it is possible to inject the foam directly into the space under these.

Foam Dams

As mentioned above a foam dam is often used to contain the foam over the seal area. NFPA and industry practice allows for such a device where:

- **(I)** Foam is discharged above a mechanical shoe seal, weather shield or secondary seal.
- **(II)** Foam is discharged below a weather shield or a secondary seal of a tube seal type roof and the distance between the top of the tube and the top of the floating roof is less than 150mm.

The design of the foam dam is also covered in standards. Essentially there are three important parameters to consider:

- **(I)** The dam must be high enough to contain the foam. A minimum height of 0.3m is specified when there is no secondary seal or weather shield. If there is such a device, then the dam must be at least 50mm above it according to NFPA standards. Other standards state that in this situation, the dam should extend at least 50mm above any non-combustible secondary seal, and should be at least 0.6m high if the secondary seal consists of fabric sections between metal plates.

Dam height affects the allowable distance between foam discharge outlets (See fig. 8.5 Foam Pourer System). To maximise this it is normal practice to install a 0.6m high dam on new tanks.

- **(II)** There must be sufficient drainage to allow foam solution to drain from the dam, but not so much that
foam is lost from it. Guidelines on this are given in the standards.

The foam dam should be in the area 0.3 - 0.6m away from the tank shell. When a foam dam is installed the area for foam application is the annular surface between the foam dam and the tank shell. If there is no dam, the area of application for calculation purposes is the annular surface between the floating roof and the tank shell.

Detection

Floating roof tank fires should be detected and protection systems actuated as quickly as possible. Therefore, it is common practice to install an automatic detection system and link it to an alarm and system actuation panel. The best type of detector for this application is a linear device positioned around the seal area such as an Electrical type. This type has the added advantage that no electrical components or air systems (to “top-up” pneumatic detectors) are required on the tank roof.Application Rates and Spacing of Discharge Devices

It should be remembered that with pourer systems for floating roof tanks, it is only possible to provide "top of seal" application, so a foam dam must be used. Therefore, the application rates mentioned here must be applied over the annular area between the foam dam and the tank shell.

NFPA

An application rate of 12.2 lpm/m² shall be used over the risk area. Maximum spacing between discharge points shall be 12.2m of tank circumference with a 0.3m high dam and 24.4m of tank circumference using a 0.6m high dam.

Discharge Times

NFPA 11 specifies a minimum duration of discharge of 20 minutes. No reduction in this is allowed if the application rates are higher than the minimum specified.

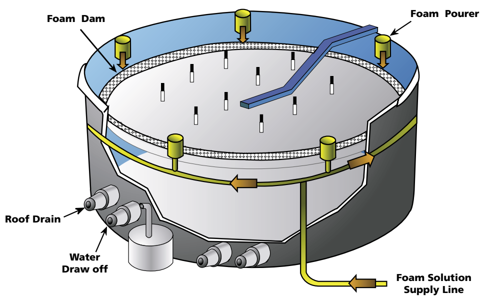

Fig 8.5 – Foam Pourer System

EXAMPLE CALCULATIONS SHEET FOAM POURER PROTECTION OF OPEN TOP FLOATING ROOF TANK

Risk

An open top floating roof storage tank, diameter 30m, containing hydrocarbon fuel with a flash point of 29 °C.
A foam dam, 0.6m high is fitted at 0.45m distance from the tank wall.

Design Standard

NFPA 11

Objective

Determine the total amount of foam concentrate and the number of discharge devices required for a pourer system for the above risk.

A very close approximation to this area is given by multiplying the circumference of the tank by the distance between the foam dam and the tank shell. (δ).

N.B. This figure does not include the requirement for supplementary protection or reserve supplies.

Catenary System Protection of Open Top Floating Roof Tanks

In over to overcome the disadvantages of the top pourer system for open top floating roof tanks, some manufacturers developed a system known as the Catenary System. In this, a foam solution riser goes to the top of the tank. This is connected to a flexible hose that is attached to the rolling ladder and feeds the foam solution to a ring of pipework on the floating roof.

At equal intervals around this ring there are foam makers discharging foam into the seal area. Depending on the type of seal there may or not be a foam dam and discharge may be above or below a secondary seal. (For information on when a foam dam is required see "Foam Pourer Protection of Open Top Floating Roof Tanks" above.)

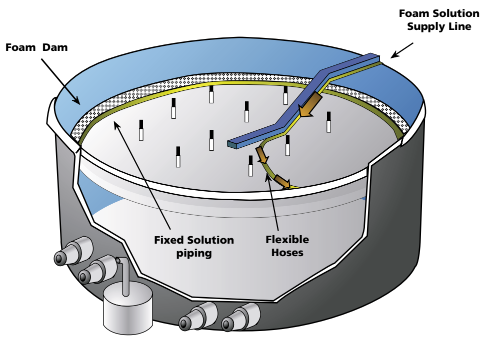

Fig 8.6 – Catenary System Protection of Open Top Floating Roof Tanks

Catenary System

Catenary systems therefore overcome the problem of losing foam as it travels down the tank walls, but unfortunately experience has shown that they do suffer from other disadvantages:

(I) Routine maintenance has to be carried out on the floating roof.
(II) Air inlets to the foam maker are on the roof and so may draw in fumes or combustion products.
(III) The flexible hose is very prone to damage from the environment on the rolling ladder Trapping it.

For the above reasons, catenary systems have not found wide acceptance.

Design Parameters

When application "above the seal" is used with catenary systems, exactly the same design parameters are to be used as for the pourer systems describes earlier.

The following notes apply when foam is injected below a secondary seal and no foam dam is required. It is important to remember that this technique should not be used if the seal under which foam is applied is made of combustible material.
Application rates and spacing of discharge devices. (Below seal application, no foam dam)

NFPA specifies an application rate for these situations. This is 20.4 lpm/m² of protected area. The protected area is the annular area between the tank shell and the floating roof.

The spacing allowed between foam outlets is as follows:

Mechanical shoe (Pantograph) Seal	- 39m (NFPA)
Tube shield with - weather shield or non-combustible secondary seal	18m (NFPA)

Discharge Times

NFPA specify a minimum duration of discharge of 10 minutes. No reduction in this is allowed if the application rates are higher than the minimum specified.

EXAMPLE CALCULATIONS SHEET CATENARY SYSTEM PROTECTION OF OPEN TOP FLOATING ROOF TANK

Risk

An open top floating roof tank, diameter 30m, containing hydrocarbon fuel with a flash point of 29 °C. Seal is a tube type with a metal weather shield. The top of the tube is 200mm below the top of the floating roof. The distance between the floating roof edge and the tank shell is 0.2m.

Design Standard

NFPA 11

Objective

Determine the total amount of foam concentrate and the number of discharge devices required for a catenary type foam system for the above risk.

CALCULATION	
The conditions are met where no foam dam is required and the application area is that annular space between the tank shell and the floating roof. (0.2m in this case).	
(I)	Application are = π x d x (See pourer example) = 3.14 x 30 x 0.2 = 18.9m²
(II)	Foam concentrate chosen: 3% FP
(III)	Application rate: 20.4 lpm/m²
(IV)	Total application rate: 18.9 x 20.4 =386 lpm
(V)	Number of discharge devices is given by tank circumference divided by maximum permissible spacing (18m in this case). Number of discharge devices = $\frac{\pi \times d}{18} = \frac{3.14 \times 30}{18} = 5.24$ Therefore, number of devices used = 6
(VI)	Flow required/device = 65 lpm
(VII)	Running time: 10 minutes
(VIII)	Amount of foam concentrate required:
386 x 10 x 0.03 = 116 litres	

N.B. This figure does not include the requirement for supplementary protection or reserve supplies.

"Coflexip" System Protection of Open Top Floating Roof Tanks

In recent years an alternative system to top pourers and catenary systems has been introduced. In this, a special flexible pipe of the type used for storm water drains on a floating roof tank is installed inside the tank.
Depending upon the total flow rates required either foam solution or finished foam is pumped from outside the bund wall up through this pipe to the tank roof. From there it is distributed through a "spider" network of metal pipe to the seal area (via foam makers if foam solution only has been pumped into the system). (If foam bubbles are pumped in, it is necessary to use a foam generator of the type normally used for subsurface application to overcome back pressure in the system.)

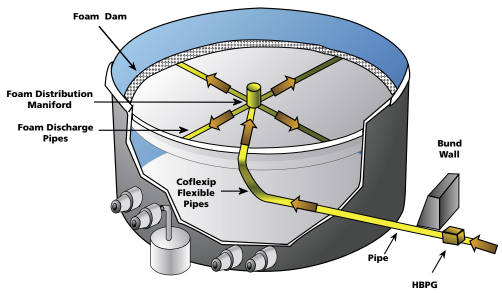

Fig 8.7 – "Coflexip" System Protection of Open Top Floating Roof Tanks

Coflexip System

This system therefore overcomes the disadvantages of top pourer and catenary systems, but does mean that a critical part of the system is actually inside the tank and therefore cannot easily be maintained, repaired and inspected.

Acceptance of this type of system therefore depends on the reliability of the flexible pipe and the joints connecting it to the distribution pipework. The company COFLEXIP produce such a flexible pipe (hence the system's name) and can point to many years trouble-free usage of it in drain lines.

Design Parameters

Discharge from this type of system can be either "top of seal" or "under the seal" according to the seal construction and type. The relevant design information to these application methods is given in the notes above on top pourer and catenary systems descriptions for open top floating roof tanks.

Covered Floating Roof Tanks

The fire fighting problem posed by covered or internal floating roof tanks is that they are vented so that if there is an explosion or fire, the roof tends to stay intact.
It is then very difficult to apply sufficient foam through the vents with monitors to extinguish the fire. (Floating roof tends to be made from light gauge material and is usually quickly destroyed in a fire giving rise to a fully involved tank surface.)
The recommended practice is therefore to install a fixed system. The preferred type is the top pourer system as there is a risk of the floating roof blocking the outlets of a semi-subsurface or subsurface system. However, some oil companies recommend that both top pourer and subsurface systems be fitted and there have been cases where, under emergency circumstances, a fire in such a tank has been extinguished by subsurface methods.

Design rules are then the same as those for standard cone roof tanks except that separately valved laterals for each foam discharge device are not required.

In situations where a double deck or pontoon type-floating roof is used, consideration may be given to protecting only the seal area in accordance with the standards for open top floating roof tanks.

Supplementary Protection for Storage Tanks

In all cases, particularly for large diameter tanks, a fixed system should be supplemented with portable foam nozzles and hydrant outlets for dealing with small spill fires from valves, meters etc. in or around a bund area.

The standards specify how many nozzles of a given throughput should be available according to the size of tank.

The amount of foam concentrate required for them, in addition to that required for the fixed systems, can then be calculated from the running times that are also specified.

It should also be noted that, in addition to the handlines, it is desirable that at least one portable or mobile monitor be available in the event that a fixed discharge outlet is damaged.

NFPA

The minimum number of foam handlines may be as stated below. Each may have a solution flow rate of at least 189 lpm (50 USgpm) and sufficient foam concentrate shall be available to allow the minimum number of handlines to be run simultaneously for the minimum operating times stated.

DIAMETER [M] OF LARGEST TANK [MIN]	NUMBER OF HOSE STREAMS	OPERATING TIME
Up to 10.5	1	10
Over 10.5 and up to 19.5	1	20
Over 19.5 and up to 28.5	2	20
Over 28.5 and up to 36.0	2	30
Over 36.0	3	30

EXAMPLE CALCULATIONS SHEET SUPPLEMENTARY FOAM HANDLINES FOR STORAGE TANKS

Risk
A storage tank, diameter 30m, containing hydrocarbon fuel.

Design Standard

NFPA

Objective

Determine the number of foam handlines required and the amount of foam concentrate necessary.
N. B. This figure does not include any reserve supplies.

CALCULATION	
The conditions are met where no foam dam is required and the application area is that annular space between the tank shell and the floating roof. (0.2m in this case.	
(i)	From above tables, number of hose streams is 2 x 189 lpm with an operating time of 30 minutes.
(ii)	Foam Concentrate chosen: 3% FP
(iii)	Foam concentrate quantity required:
2 x 189 x 30 x 0.03 = 340 litres	

8.9.2 Semi Fixed Systems

In a “semi-fixed” system the application devices are permanently fixed to the protected hazard but the extinguishing agent is not. Thus, some manual intervention is required for complete system actuation. For example, in the case of a rim seal foam system, the rim seal pourers might be permanently fixed to the tank and foam solution fed to them from a foam truck, connected at the time of the incident, between the water supply system and the rim seal pourer pipework system.
The decision as to which option (Systems, fixed or semi-fixed; portable/mobile equipment) to use will depend on site specific conditions taking into account the following: (Mobile response is covered in the next section)

Number of hazards protected

Fire Protection Systems require application equipment to be mounted on every tank, thus increasing cost whereas the Portable/Mobile equipment can be deployed at different locations according to need. (However, it should also be noted that mobile equipment usually requires greater flow rates and quantities of water and extinguishing agents - see below - thus offsetting the cost savings.)

Manpower available

Fire Protection Systems, if correctly designed, can be operated by less personnel than required for portable/mobile equipment.

Manpower Capabilities

Fire Protection Systems do not require the same high levels of fire fighting expertise as Portable/

Mobile Equipment for operation. Obviously, training in and preplanning for system operation is still required.

Speed of Deployment

It is generally recognised that the faster that the design application rate of foam solution can be applied, the more likely it is to be effective. Properly designed fixed systems can be actuated within minutes (or even less), whereas portable/ mobile attack can take several hours to deploy.

Access/Egress

The deployment of Portable/Mobile Equipment needs good access, often requiring hard standing and roadways, to locations close enough to the fire for effective agent application. During major incidents it may be necessary to deploy Portable/ Mobile Equipment in areas where there is a significant risk to personnel in order for the equipment application to be effective.

Availability of water/foam concentrate

Application of agents through systems is generally more efficient in terms of the application rates required to be effective. For example, one standard for foam systems requires an application rate of 4 lpm/m² of foam solution for a particular type of fixed system application whereas, for the same type of incident, 6.5 lpm/ m² onto the fire is required when using mobile monitor equipment. When additional losses are allowed due to wind, thermal updraughts, etc., the actual rate required can reach 10.5 lpm/m² - more than 2.5 times that required for the system.

In addition, accepted standards normally require longer running times for mobile equipment than systems. Thus, overall, the required amounts of water and foam concentrate for mobile monitor attack on an incident can be much greater than that required by systems.
Also, the additional water quantities applied may cause drainage/disposal problems.

System vulnerability

The fact that the application equipment is permanently attached on or close to the protected hazard in the case of systems, means that it is more vulnerable to damage from the incident. Speed of system actuation can, therefore, be critical to minimise potential for system damage.

Requirements for back-up equipment

Back-up mobile/portable equipment is usually required to supplement systems in case of damage or failure. Equally, of course, the levels of mobile equipment provided for an incident should not be based on minimum requirements but should recognise the possibility of failure of some items during the incident.

Performance Criteria

For any system it is important to understand the required performance objectives. Hence it is useful if a performance based specification is prepared against which the actual performance achieved can be measured.

Mobile Response Options

As mentioned above, monitors should not normally be considered as the primary protection method for storage tanks of greater than approximately 20m diameter. (This is due to the difficulty in ensuring sufficient foam solution application by such equipment on large tanks because of convection current effects caused by a fire and wind disturbance of the foam jet as it travels through the air from the monitor nozzle. In addition, there is a strong possibility that free access to the fuel surface will not be possible because of the tank roof collapsing into the tank.)
In the case of open top floating roof tanks it should also be borne in mind that use of high output monitors can cause the floating roof to sink and so increase the fire area if the tank drainage system is not of sufficient size to cope with the amount of solution being applied. Monitors should not normally be used for fighting tank fires with water-soluble fuels such as alcohols. In fact, the British Standard goes as far as saying that monitors and hand-held nozzles are not recommended for any storage tank containing these risks. This is because the foams available for such risks tend to need more gentle application than on hydrocarbons. When plunging of foam into these fuels occurs, application rates of foam solution required increase very dramatically. (When using any type of foam on any fuel, it is good practice to apply the foam as gently as possible, but this is especially true for alcohol-resistant foams although the modern types can tolerate somewhat more forceful application than previous types.)

Application Rates

The following application rates should be achieved on the fuel surface. Due allowance must be made for losses due to drop-out, wind effects and convection currents. These may mean having to allow up to an additional 100% foam solution throughput.

NFPA - The foam solution application rate for liquid hydrocarbon storage tanks shall be at least 6.5 lpm/m² of the liquid area. Included in this are gasohols and unleaded gasolines containing no more than 10% alcohol by volume.

For alcohols and other water soluble risks, it is stated that the manufacturers recommendations shall be sought, but some minimum application rates are suggested for some of the more common fuels of this type. For example, 6.5 lpm/m² is given for methyl alcohol and 9.8 lpm/m² for acetone.

For bund protection the relevant application rates are specified as 6.5 lpm/m² when protein or fluoroprotein concentrate is used and 4.1 lpm/m² with AFFF or FFFP.

It is pointed out that the procedure for fighting bund area fires is to adopt a tactic whereby roughly one quarter of the flow rate is used in a "quadrant" foaming tactic, applying foam to one of the pool fire quarter areas and then relocating the foam monitors to the adjacent quadrant and re-commencing foam application, and so on until the total pool fire area has been covered. This differs from "normal" foam application in that each quadrant foam application should be for 15 minutes (rather than the pool fire area total application time of 15 minutes), giving a total of 60 minutes foam application. Like all pool fire foam calculations, in practice, when using foam monitors or foam branches for foam application it will be the number and capacity of these monitors or branches which will determine the flow rate since it is not possible to adjust to obtain precise, incident specific flow rates.

In order to obtain maximum flexibility it is suggested that portable or trailer mounted monitors are more practical than fixed units for bund protection unless several monitors are positioned around the entire risk, thus increasing cost.

Due some research by WF&HC for application rates for 'over the top' mobile monitoring they recommend for a 65 minute application the following application rates:

TANK DIAMETER APPLICATION RATE	RECOMMENDED
1 - 45 Metre	6.5 Lpm per sq. m
46 - 61 Metre	7.3 Lpm per sq. m
61- 76 Metre	8.1 Lpm per sq. m
77 - 91 Metre	9.0 Lpm per sq. m
92 + Metre	10.16 Lpm per sq. m

The above WF&HC application rates have been developed from their experience as to be minimum effective when dealing with such tank fires, currently NFPA are looking to consider revising their recommendations more in line with the application rates above that WF&HC have found effective on the numerous tank fires they have been called upon to extinguish

Discharge Times

NFPA - The equipment shall be capable of operation to provide primary protection of storage tanks at the delivery rates specified above for the following minimum periods of time:

CALCULATION	
Fire area	935 m². (34.5 m dia.)
Foam Concentrate	3% FP foam
Minimum Application Rate	6.5 lpm/m²
Recommended Rate	10.4 lpm/m²
Total Application Rate	935 x 10.4 = 9724 lpm
Total Cocentrate Required	9724 x 0.03x 50mins= 14,586 litres
TOTAL WATER REQUIRED	
9724 – 291.72(3%) X 50 MINS = 472 M³.	

Flash point between 37.8 and 93.3 °C	-	50 minutes
Flash point below 37.8 °C or liquids heated above their flash point	-	65 minutes
Crude petroleum	-	65 minutes
Fuels requiring special	-	65 minutes

AR foams (unless fire tests establish shorter times are permissible)

No specific times are given for major incidents in bunds being fought with monitor application. However, figures are given for spill fires - 10 minutes for fixed equipment, 15 minutes for portable.

These discharge times are clearly insufficient for a major incident and it is recommended that 60 minutes is used instead

EXAMPLE CALCULATIONS SHEET 34.5m DIAMETER STORAGE TANK FOAM APPLICATION USING PORTABLE FOAM MONITORS

For calculation purposes, the foam/water application rates applied through monitors are assumed to be those specified in NFPA 11:

Foam monitors – 6.5 lpm/m² x 1.6 for losses = 10.4 lpm/m²

In practice, when using foam monitors for foam application it will be the number and capacity of foam monitors that will determine the flow rate since it is not possible to adjust to obtain precise flow rates. In this example, resource requirements for foam monitors have been calculated on the assumption that equipment providing 3600lpm – 4500lpm flow are utilised
Monitor application rates should also be based on incident experience and the availability of application equipment on site.

Flowrate desired	9724 lpm
Best Foam Monitors	4500 lpm
Total Number Required	3 x 4500 lpm
Total Application rate	13,500 lpm
Total Concentrate Required	13,500 x 0.03 x 50mins = 20,250 litres
Total Water Required	13,500 – 405 (3%) x 50 mins = 654.75 m³.

8.10 IN-HOUSE TESTING PROCEDURES FOR FOAM SYSTEMS AND FOAM CONCENTRATE

There are, of course, many variations possible in system design and equipment selection for foam systems. It is, therefore, impossible to provide exact and detailed testing requirements unless full details of every component are available. For example, in systems where a pump is used in foam concentrate service, it is vital to take into account the pump manufacturers precise testing recommendations. However, it is possible to recommend some general guidelines.

To demonstrate that a foam system can be expected to function effectively when called upon, an operator ought to be able to show that a system of foam system and foam concentrate testing is in place within a framework of FSIA (Fire Systems Integrity Assurance). The following are notes which should enable the auditor to appreciate fully the main requirements in terms of the most common tests.

The most obvious requirements in the development of a comprehensive in-house routine testing procedure are:

(i) Defined test intervals.
(ii) Precisely defined and documented testing methods.
(iii) Specific acceptable values of test parameters.
(iv) Documentation to record results.
(v) Review procedure.

Stage 1 - Test Intervals

The standards may recommend a suitable test and inspection schedule as follows:

Weekly - Visual check that there are no leaks or obvious damage to pipework, all operating controls and components are properly set and undamaged, the water supply is available and at the right pressure.

Monthly - Check of all personnel who may have to operate the equipment or system are properly trained and authorised to do so, and in particular that new employees have instruction in its use.

3 Months - Testing and servicing of all related electrical detection and alarm systems. (More detailed test requirements are provided in standards relating to fire detection)

6 Months - Foam producing equipment

Inspection of proportioning devices, their accessory equipment and foam makers for mechanical damage, corrosion, blockage of air inlets and correct manual function of all valves.

Pipework

Examination of external above ground pipework to determine its condition and that proper drainage pitch is maintained. Hydraulic pressure testing of normally dry pipework when visual inspection indicates questionable strength due to corrosion or mechanical damage.

Strainers

Inspection and cleaning of strainers. (This is essential after use of the system and after any flow test.)

Valves

Check of all control valves for correct manual function and automatic valves additionally for correct automatic operation.

Tanks

Visual inspection of all foam concentrate and foam solution tanks, without draining; checks of shipping containers of concentrate for evidence of deterioration.

12 Months - Test of foam concentrate or solution for changes in constitution or characteristics and the formation of sediment or precipitate.

As required by statutory regulations - Inspect internally all tanks

It must be emphasised that these are only general recommendations and should be developed to suit a particular system but they do provide some helpful guidance for most systems.

Stage 2 - Defining and documenting test methods

Any foam equipment, either portable or fixed, should include descriptions of detailed testing methods. In practice the documentation provided to operators is often very poor and consists of a few data sheets on system components put together as a “manual”. At the very minimum, the documentation should include step-by-step instructions of how to measure the system parameters described in standards such as NFPA 11 (i.e. Systems flow, time to achieve effective discharge, proportioning rate, expansion and drainage time.)

Foam System Tests

The ultimate test for the system hardware is to carry out tests on the proportioning accuracy and finished foam properties. It is recognised that this may be difficult in some circumstances, especially in foam spray systems where it is usually impossible to discharge a complete system. However, good initial system design will include test points where foam solution can be collected or utilise foam equipment allowing testing without foam discharge onto the risk itself. (e.g. In the case of storage tanks with foam pourer protection, good equipment design will allow discharge of finished foam outside the tank during routine testing.)

The tests that can be carried out in the field at commissioning stage and at subsequent routine intervals are:

(i) Foam expansion
(ii) Drainage time
(iii) Application rate
(iv) Solution strength (Proportioning Accuracy)

The parameters (i) and (ii) are sometimes referred to jointly as “foam quality”.

It is advisable for operators to make two tests for each of these properties in order to minimise the risk of any spurious results. Comprehensive records should be kept of the test results recorded during regular maintenance procedures. If any changes occur from test to test, then it is important that the foam liquid and the system is investigated further to determine the cause.

It must be remembered that some of the parameters such as drainage time and expansion depend on the test method used to measure them as well as the foam equipment. Therefore, it is important to ensure that all tests are carried out in a standard way using the same techniques on every occasion.

While there are certain measurable criteria for evaluating the quality of foam as described above, interpretation of the results may require experience. Because of the number of types of foam available, the physical characteristics of the foams produced are subject to considerable variations.
It is vital to ensure that a standard test method and standard test conditions are used to monitor and assess the changes in foam produced from a particular system over a period of time. Any change in characteristics suggests degradation or contamination of the foam liquid or some change occurring in the system itself. The possible causes of such changes are numerous, so an investigation is required in order to find the exact reason and rectify the problem.

It is important to remember that, depending on the risk, other tests such as foam shear stress may also be required to provide a full assessment of foam quality.

When evaluating foam for use on water-soluble fuels, a test of the foam's stability on a control fuel such as isopropyl alcohol may be required. With film forming foams, surface tension and film forming capability should be measured and with the new polymeric membrane forming foams, viscosity evaluation may be relevant.

As an example of a more specific series of tests, the following are guidelines for testing of foam systems. Documentation provided by the installer/supplier, and hence by the operator should include test methods specific to the actual equipment concerned

Examination and Testing of Foam System and Equipment

1. It should be verified that all cylinders containing gaseous media or tanks containing foam concentrate or premix have been correctly charged (evidence to this effect should be obtained from a responsible party).

2. The surveyor should be satisfied that the quality of the stored foam concentrate is within manufacturer's specifications (test records should be made available).

3. The foam system should be tested during realistic wind conditions where appropriate.

4. The foam throw in metres of monitors (with no other applicator operating) under maxi mum flow condition should be established. The throw can be considered to be the range beyond which at least 50% of the foam output is projected in still air conditions.

5. It should be verified that under the prevailing wind conditions the foam cascade from the system, when discharging the minimum quantity of foam required by the standards can be brought to bear on any part of the application area (e.g. rimseal area). The wind speed and direction should be recorded during the tests. As a guide, the maximum throw required from an applicator projecting into the wind should not be more than 60% of the throw in still air conditions.

6. The quantity of concentrate in litres per minute taken by each applicator and the water pressure in bars available at the applicator should be measured. On deluge type systems with an array of nozzles, the output pressure should be measured at the hydraulically most remote nozzle.

7. It should be ensured that the quality of foam formed is satisfactory when testing in accordance with the requirements of NFPA 11 or similar standard.

8. It should be ensured that all associated controls and instrumentation function as intended.

9. It should be ensured that satisfactory and suitable means of access are provided to the operating stations for each applicator.

10. It should be ensured that the applicators (including associated services) can be rapidly deployed and manipulated. Applicators arranged for remote control should also be tested under local control.

11. Suitable provision should be made to enable the foam system and foam concentrate to be tested without detracting from the operational efficiency of the system or disruption to the normal routine operations of the installation.

Foam Concentrate Testing

As far as the foam concentrate is concerned, the situation is slightly more complicated.

It is important that an operator develops his own test methods that are truly relevant to his special needs.

Test methods to determine changes in physical properties of foam concentrate are relatively easy to specify - pH, specific gravity, surface tension, viscosity, etc. All are simple laboratory tests which can be carried out by the operator at purchasing, batch acceptance and at regular intervals throughout the lifetime of the concentrate. In this way, test results can be compared against previous results or those of a retained sample, highlighting changes in the concentrate from time to time. It is important to realise that the physical properties of a foam concentrate will not determine the fire fighting performance, but significant changes in physical properties may indicate a problem such as degradation or contamination that may ultimately compromise the effectiveness of the foam.

Fire Testing

What is more difficult is the precise specification of the fire test to be carried out. A regular fire test is essential to find out the true capability of any foam concentrate - after all its ultimate purpose is to prevent or extinguish a fire.
There are several fire tests that have been developed around the world. Some are good and selective, others very poor allowing low quality foam to pass. All have been designed with a particular risk or foam concentrate in mind. It is quite possible none of them test the precise properties for a particular application. In addition, most of them are only of the pass/fail type, so they do not usually differentiate between several foams that meet a minimum requirement.

It is, therefore, advisable to develop an in-house company fire test specific to the particular conditions of the risk in question. Often this may be a standard recognised test adapted only slightly to ensure that the best available foam is selected and that it retains its properties over a period of time. In the case of evaluating fire performance of foam for storage tank application, then a suitable fire test such as the 'LASTFIRE' Foam Test For Storage Tank Fires should be specified.

Ideally the foam concentrate tests including the fire test should be carried out in-house by the end-user. Suppliers or manufacturers should not, unless there is absolutely no alternative, carry them out. If this is the case, the end-user should insist upon witnessing the tests and demand a certificate that clearly states test results, the test carried out and the exact results rather than just "pass" or "fail".

Stage 3 - Specification of Acceptable Test Results

It is not possible to provide precise values for acceptable test results unless full details of the risk are known, but it is possible to provide certain guidelines. The operator should ideally consider the following as measures of foam system integrity:

Expansion, drainage time, flow rates and solution strength should be in accordance with an independent standard such as NFPA 11.
Foam concentrate physical properties are obviously dependent on the foam concentrate chosen. The manufacturer's quality control values must be sought by the operator. In general, a supplier with good quality control and consistent product will be happy to provide these figures. Acceptable variations in physical properties' values from good suppliers would not be expected to be greater than + 5% of their nominal value.
Fire test acceptable results must be based on the in-house specification suggested previously.

Again, it must be emphasised that the operator should carry out the tests or otherwise a recognised independent testing station witnessed by the operator. Results provided by suppliers should not necessarily be relied upon.

Stage 4 - Documentation

Standards in-house company test documentation policy should obviously be followed when developing paperwork to record foam system test results.
It is a relatively easy matter for operators to build up standard sheets specifically for foam systems. Most of the information required is a straightforward record of the test figures. (i.e. Specific gravity, pH, etc.) Some test parameters, such as expansion and drainage time, require calculations as well as the record of results. It is suggested that the calculations should be recorded on the same documentation as the test measurements. A typical record sheet for foam concentrate is attached.

It is strongly recommended that space is also allowed to record acceptable values of the measured properties so that an immediate comparison can be made with the field or laboratory results.

Stage 5 - Review of Results

Any result found to be outside acceptable values must demand immediate action by the operator. In the case of the foam concentrate this means that consideration should be given to replacement. If a system test result is outside acceptable values then the cause must be investigated.

Equally important, however, is a review of the test results compared to those previously recorded. A tendency for the results to vary from test to test even though they may still be within acceptable limits suggests that some changes have occurred in the foam concentrate or system that might ultimately cause failure unless rectified. It is therefore important to compare the results with those obtained from at least the previous two tests.

8.11 RESOURCE REQUIREMENTS FOR LARGER (>40M) DIAMETER TANKS

8.11.1 Full Surface Fire Portable Equipment Options

For ground level foam attack on a tank full surface fire, typical portable equipment includes the following:

- water monitors
- water pumping appliances
- large capacity foam monitors
- foam pumping appliances
- foam concentrate tankers or containers
- fire hose including large diameter/capacity hose
- water supplies

All of the above points are discussed below as a practical review of the issues involved in a full surface tank fire and are included as a useful guide for equipment selection. It must be remembered that fire attack on large diameter tanks in the way described here have not, generally, been successful. In addition, they require relatively high manpower levels and put the firefighters at higher risk than the use of systems.

Water Monitors

Water monitors may be necessary for cooling adjacent tanks affected by radiant heat, or in some cases where tank spacing is inadequate, from flame impingement.
It is generally accepted that water cooling of the tank on fire is not normally necessary except, possibly, to assist foam blanket sealing against a hot tank wall. In some cases, cooling of the ignited tanks by monitors is thought to have led to distortion and consequent tank failure due to the creation of some cool sections of metal and some hot sections. Manufacturers claim that tanks are designed to fold inwards and not rupture in the event of a full surface fire. The individual in charge of the fire attack must therefore be responsible for deciding if and when cooling of the tank on fire should be carried out based on an assessment of the potential damage to the tank, the need for cooling to help the foam blanket/tank wall sealing, availability of cooling evenly around the tank circumference and any potential water drainage problems.

An important point to remember when using water or foam monitors is that water misting or drift will occur if there is any appreciable wind. If there are nearby power lines, this water may conduct electricity. Care needs to be exercised if there are any power lines in the vicinity of the tanks, or plant, to be cooled.

Water Pumping Appliances

The capacity of any water pumping appliances to be used for water monitor supply must be as large as possible. Typical "standard" water tender/ pumpers may have only a 2500 lpm pump on-board. This will obviously be enough for only 1 water typical monitor and if larger water monitors are to be used, then it may require 2 or more water pumping appliances for every monitor.

This can lead to major logistical and deployment difficulties.

Fixed Water Monitors On Fire Vehicles

It is generally accepted that fixed water monitors on fire vehicle roofs or on hydraulic platforms or aerial ladders will be of limited use during a full surface fire. The restricting factors in their use will be road access around the tank and distance to the tank from the safe parking area. It is also accepted that there is limited flexible use of the vehicle once it is parked and connected to hydrants. In other words, it may become a very expensive fixed monitor instead of a flexible response which can be moved around to suit circumstances.

Foam Monitors

It is important to note that most recognised standards (such as NFPA 11) state that monitors should not be used as the primary attack method for tanks greater than approximately 20m diameter. However, in practice they have been used for larger tanks although experience on tanks greater than 40m is limited.

If fire extinguishment is attempted, the importance of foam monitor capacities and stream range becomes obvious. Foam streams have to be such that the bulk of the streams output reaches the tank liquid surface.

It is recognised that the best method of application is to project foam with the wind behind the stream and not against. However, there have been, and will be situations where cross winds or a variable breeze causes reductions in stream ranges and these need to be considered.

It may be that a desktop calculation shows the range and trajectory of a foam monitor placed on a bund reaches the liquid surface easily only to discover in practice that the stream falls short due to a breeze or greater wind speed.

It is possible to supply foam to foam monitors by either using foam pumpers or foam pumps to create the water/foam solution or to use water tenders or large capacity water pumps to pump water to the foam monitors where foam concentrate is picked-up via the monitor package induction. Both present foam concentrate re-supply logistical problems with the monitor induction method creating the greatest problems in terms of access to and around them.

A very important point to note is that when using foam monitors for full surface fires there will be losses from the foam stream due to thermal updrafts from the fire preventing some of the foam reaching the liquid surface. There will also be some loss due to stream feathering or fall out. With this in mind, a much higher total application rate is necessary to ensure that 6.5 lpm/m² reaches the fuel surface. It is now generally accepted that a rate in the order of 10 lpm/m² or more should be used for foam monitor application on a full surface fire.

This high application rate often makes such application methods impracticable from an existing facility ring main.

8.11.2 Foam Pumping Appliances

Foam pumpers for use at full surface tank fires would typically be used for supplying foam monitor flowrates of a minimum 5000 lpm. Foam tank capacity on-board the foam pumper should be a minimum 5000 litres. This would give over 30 minutes supply time to a 5000 lpm foam monitor, allowing time to replenish the on-board foam tank by either tankers or other method. Note that this is based on a 3% ratio. Obviously, if 6% is used, the time would be reduced to 15 minutes only.
If foam pumpers are to supply foam monitors

with both foam and water then the on-board water pumps and foam proportioning systems should be capable of a minimum 5000 lpm supply.

Fixed Foam Monitors on Fire Vehicles
It is generally agreed that fixed foam monitors on fire vehicle roofs or on hydraulic platforms or aerial ladders will be of limited use during a full surface fire in tanks >40m diameter, due to stream ranges being reduced by vehicles parking distant from the bund walls.

Foam Concentrate Containers and Supply Considerations

Bulk movement and foam monitor supply of foam concentrate represents a major logistical problem which, if not carefully considered, will greatly delay foaming operations and, in some instances, will prevent effective and continuous foam application. It must be remembered that once foam application commences onto a tank surface fire, it must be maintained, uninterrupted, at the required rate for the duration required.
The typical methods of foam concentrate re-supply are:

(i) 25 Litre Drums

The use of 25 litre foam concentrate drums is theoretically possible during a large storage tank fire but very difficult. Using the example of the 5000 lpm foam monitor and a 3% induction rate, this monitor would use 135 lpm foam concentrate, or more than 5 drums each minute which will probably result in interrupted supply and is also labour intensive. This is not considered a practicable option.

(ii) 200 Litre Drums

One 200 litre drum of 3% foam concentrate supplying a 5000 lpm foam monitor would last for just under 1.5 minutes. With monitor flowrates above 5000 lpm, the 200 litre drums will be used up in similar fashion to that of the 25 litre drums. For example, a 7,500 lpm monitor would need 225 lpm foam concentrate, less than 1 minute supply using a 200 litre drum. Again, this would create massive logistical problems.

(iii) 1000 + litre Containers

Large capacity “polytank” containers of 1000 litres or more are an option for supplying large capacity monitors. They can be transported to each fire vehicle or monitor and dropped off on the spot within reach of the foam suction hose of the vehicles or monitors.

Dropping several within suction hose reach will obviously increase the duration before change-over is necessary and therefore give more time to transport crews to keep foam concentrate re-supply moving but may cause congestion in an already restricted area.

If the containers have a side-top mounted funnel point each container could be stacked two high or more at the vehicles or monitors.

(iv) Foam Tankers

Using foam tankers in the range of 10,000 - 15,000 litre capacity is the preferred method of supply and re-supply for large capacity foam monitors, especially those of >15000 lpm. Tankers can be also be used for refilling foam pumper on-board foam tanks, foam monitor trailer tanks or other foam containers at the monitor locations.

Foam Compatibility

Foam compatibility is an important factor. If mutual aid is to be used, a single foam concentrate at a uniform induction rate is preferred. Although it is possible, given suitable foams to use, for example, AFFF produced foam on a fire and then use fluoroprotein produced foam on top of the AFFF blanket without any serious adverse effect, this is not recommended for large tank fires.

Mixing foam concentrates of different types is also not recommended and can completely destroy foam making capability. The intention should be to have a standardised foam type suitable for the fuel at a uniform induction rate so that there are no pump operator errors in proportioning.

Fire Hose/Water Delivery Hose

The typical size of delivery hose for water monitors and foam monitors will be 70mm diameter. Usually these will be in 20 - 25m lengths.

Although there will be a need for the 70mm size, especially for water monitors, the use of large diameter or large flow hoses offers a less labour intensive option for deployment. Typically, the large diameter hose will be used from either hydrants or direct from large capacity fixed or mobile pumps. Sizes will vary depending on the capacity of the foam monitor or monitors.
The sizes of large capacity hoses will typically be:

- 100 mm
- 120 mm
- 150 mm
- 250 mm
- 300 mm

Whilst recognising the advantages of large diameter hose it should be borne in mind that they may require special mechanical handling facilities due to their weight. Also, if only large hose is used, there may be no flexibility for combating other types of fires in a facility where smaller monitors are to be used which only require 70mm hose.

If hydrants are located very remote from the incident, it may be necessary to use hose trailers or hose layers rather than having a totally manual deployment.

8.11.3 Water Supplies

The water supply for firefighting large storage tank fires is the key to any fire response decision. Opting to combat a full surface fire must fully consider the existing water supplies beforehand. On at least two occasions it was discovered that the cooling of exposures plus the foam attack water requirements greatly exceeded normally available water supplies in terms of flow and pressure.

For example, if the tank is in the order of 80 metre diameter, the total foam solution application rate for aspirated foam on a 3% induction based on approximately 10 lpm/m² will be approximately 52,500 lpm of which more than 50,000 lpm will be water.

Add to this possible exposed tanks cooling based on 6 x 2500 lpm water monitors and the water rate required will exceed 65000 lpm.
Pressures and flows of firewater systems are the cornerstone of any successful firefighting operation. In some cases reliance is placed on using pumpers or trailer pumps to draft from an open water source. Although this method may be successful, the logistics, in terms of vehicles, hose and manpower are will need very careful coordination and supervision.

This particular water supply method also presents heavy maintenance demands for all required fire vehicles or trailer pumps.

An additional factor to consider is that any contaminated cooling water, or water/foam mixtures may need to be contained and treated prior to being “released” into water streams or rivers etc..

Full Surface Fire Portable Equipment Selection Considerations

Water monitor stream ranges are very important. The stream range (straight stream or jet) length and height (trajectory) of a water monitor as advertised by manufacturers will always give best possible figures obtained and it will always be under still air conditions. This is the only way to standardise the range figures. Therefore, end-users must consider their own particular typical weather conditions and winds to select appropriate monitors. The best method is to request or conduct tests of monitor stream ranges from anticipated positions to the tanks or plant in question under different wind speeds against the stream.

The capacities of portable water monitors for cooling large diameter tanks should be considered from 2500 lpm upward. It is usually the case that the smaller flowrates will not provide the desired range but it should also be noted that if higher capacity water monitors are to be used they will require higher capacity water pumping appliances.

Water pumping appliances may be needed for supplying water monitors to cool exposures during tank firefighting. If the pumpers have limited capacity, say of only 2250 lpm and the minimum size of water monitor to be used is 3600 or more then obviously more than one pumper will be required for supplying one monitor. Pumpers should have a minimum 4500 lpm pumping capacity. Obviously, if the site firewater ring main has adequate flow and pressure, then water tenders may not be required for monitor supply.

In selecting foam monitors there are several important factors to bear in mind.

- There is no recognised international standard for monitors, or foam application rates, to be applied when using them for firefighting full surface tank fires with diameters over 20 metres. In fact, most standards suggest that monitors should not be used as the primary extinguishment method for such tank fires.
- Calculations of the application rate and thereby, the number of foam monitors required, must account for foam losses due to foam stream drift, stream break-up, evaporation due to thermal effects etc.
- Foam stream ranges will always be listed in still air conditions but, in reality will be affected by even a slight breeze.
- Selecting low capacity monitors (5000 lpm), if they are able to reach the tank roof, will have an impact on the quantities of fire hose, foam pumpers, manpower and means of distributing foam concentrate.
- Foam monitors selection should consider foam stream range, stability under working pressure and on rough terrain, portability/manpower required for deployment versus flowrate desired, remote and local foam concentrate pick-up capability and time taken to set-up for use.

Foam pumpers should have either a balanced pressure proportioning system as described in NFPA 11, or similar method of foam pumping proportioning if they are to be used for foam supply to monitors. Pumpers which have round-the-pump-proportioning (RTPP) systems will not always be able to produce foam when working from a hydrant or other pressurised supply.

Use of 200 litre or 1000+ litre containers as re-supply for foam pumpers must ensure that the pumpers have a means of picking-up (drafting) the concentrate from the containers as it will obviously be impossible to place these on vehicle roofs to drain into on-board tanks. The most efficient method of re-supplying foam pumper on-board tanks is to have the foam pump suction inlet valved to enable rapid changeover of foam containers as one is emptying. The best item of equipment for this is a collecting breeching (siamese) with 2 x valved inlets which connects onto the foam suction inlet and has connections compatible with the foam suction hose. Using this method and with large capacity containers of concentrate, only one pump operator per vehicle is required since he can easily changeover containers by suction hose movement rather than having several personnel at each pumper.

If hydraulic platforms, aerial ladders, fire vehicle roof mounted monitors or a combination of these are to be considered then the use of large capacity foam monitors (5000 lpm +) on top of the ladders or platforms or fire vehicle roofs should be carefully examined to ensure the range will be suitable from the parking area. In addition, the number of such vehicles needed to create the required foam flowrate should be examined to ensure that they will normally be available and can access and park on tank area roads without blocking traffic for concentrate re-supply.

The selection of 25 litre foam drums must consider that when foam application time is 65 minutes as specified in NFPA 11, personnel would have to manhandle 325 drums, each one weighing some 25 kgs. Firefighter fatigue would soon set in and reduce efficient foam supply operations. For these reasons, this size of drum is not considered practicable.

The selection of 200 litre foam drums for foam re-supply must consider the weight, movement and rotation of full and empty drums which will be labour intensive and will also create movement odifficulties around the fire pumper/vehicle area. With very large capacity foam monitors of up to 15,000 lpm (450 lpm foam concentrate) for aspirated foam and 60,000 lpm (1800 lpm foam concentrate) for unaspirated foam it is very obvious that the 200 litre drum supply method will not be adequate.

Where foam tankers are to pump foam to the pumpers on-board foam tanks from topside, it should be noted that some agitation and therefore aeration is bound to occur and this may have an adverse effect on the foam concentrate supply.

The knock-on effect regarding manning levels, hose requirements and overall water requirement of selecting portable/mobile equipment for full surface firefighting should be remembered and can be best illustrated by using an 80m diameter tank as the example of a full surface fire to be tackled.

Total Surface Area (rounded up)	5028m^2
Application Rate (Considered rate accounting for foam stream losses)	10.4 lpm/m^2
Total Application Rate (rounded up)	52230 lpm
Foam Concentrate	3%
Duration of Foam Application(For 80m tank full surface, 2 hours application would be considered although some standards state 65 minutes)	120 mins
TOTAL FOAM CONCENTRATE	**52230 X 0.03 X 120 = 188,028 LITRES**

For this example, and recalling that this application rate is considered the minimum, selecting 5000 lpm foam monitors would require 11 monitors and so would need slightly more foam concentrate since 11 x 5000 lpm = 55000 lpm. Concentrate requirement would then be 55000 lpm x 0.03 x 120 mins = 198,000 litres. Also, 11 foam pumpers of at least 5000 lpm foam/water pump capacity would be needed, assuming each foam pumper had 5000 litre foam tank on-board (55000 litres total) then several foam tankers or flatbed vehicles would be needed to distribute foam containers or foam concentrate direct to pumpers, possibly 132 x 70mm delivery hose for monitors, based on 12 for each monitor, 88 x 70mm soft suction hose from hydrants, based on 11 pumpers, and the manpower to deploy, monitor and reposition this equipment.

For the same example, selecting 15000 lpm foam monitors would require 4 and so would need more foam concentrate since 4 x 15000 = 60000 lpm. Consequently concentrate requirement would be 60000 lpm x 0.03 x 120 mins = 216,000 litres. Also, 12 foam pumpers or water pumpers of at least 5000 lpm water pump capacity would be needed, several foam tankers or flatbed vehicles to distribute foam containers or supply monitors directly, possibly 96 x 70mm soft suction delivery hose from hydrants, possibly 144 x 70mm delivery hose and 32 x 150mm delivery hose for monitors and the manpower to deploy, monitor and reposition this equipment.

If 30000 lpm foam monitors are selected, then 2 would obviously be required, or 1 at 60000 lpm capacity. The resources required for these would be similar to the 15000 lpm foam monitor example.
A point to note is that if reliance is placed on a single very large diameter foam monitor and this malfunctions during the fire, the firefighting efforts up to the point of failure will have been wasted.

Obviously, combinations of monitor capacity could possibly be used, depending on the effectiveness of the smaller capacity monitors when used alongside the larger monitors but the same logistics problems would exist and would need to be resolved before final selection of monitors.

Fire hose sizes selection needs to consider the physical capabilities of firefighters to deploy them. The number of hoses required to be laid out may exceed one hundred and so weight of hose becomes an important factor. Alloy couplings and a maximum diameter of 70mm and 20 metres length are typically used. Large diameter hose is increasingly used with very large capacity foam monitors. Again, alloy couplings will reduce weight but the length of these hoses should be limited to 3 or 4 metres for weight considerations unless mechanical deployment methods are possible. The maximum hydrant and pump working pressures should be checked to ensure that delivery hose will withstand the anticipated operating pressures. Particular attention should be paid to the strength and reliability of the large hose coupling attachment.

Water supplies are a critical consideration for manual firefighting of a full surface tank fire. Using the previous example tank size of 80 metres, for the foam monitors water supply there may be water demands of up to 58,200 lpm in the order of 10 bar. Add to this possible water monitor cooling of radiant heat affected tankage or plant and it is obvious that total water demand could exceed 75,000 lpm. Water supply flowrate, pressure and availability must be carefully reviewed before considering manual firefighting, not only as a paper exercise but also as an actual test.

8.11.4 Barriers to Prevent Escalation

This section is intended to outline the most common barriers to prevent escalation of fires to involve adjacent tanks and bund areas.

The escalation of initial fire events to multiple tank/bund incidents is discussed in detail in Chapter 7.

Preventing escalation to multiple tank/bund incidents is achieved in the following ways:

- Tank spacing to prevent escalation by radiant heating/direct flame impingement
- Effective bund and tank layout
- Controls on condition of tanks and tank fittings
- Rimseal properties to prevent escalation
- Use of waterspray / water curtains
- Cooling of tank shells
- Tank pumpout
- Boilover mitigation
- Tank Spacing
- Tank spacing requirements have two objectives:

To prevent flames from a full surface fire on a tank from impinging on a nearby tank (heat loading is significantly increased by convective heat transfer from the flames when impingement occurs)

Enabling access for fire fighters to get close enough to cool exposures on nearby tanks Various company, national and international standards give definitions of required spacing between tanks and between tanks and bund walls to prevent escalation by radiant heating. Each standard gives different definitions. However, as as a general rule escalation is unlikely if separation distances of at least 0.5 tank diameters (0.5D) are maintained. However, Institute of Petroleum guidance suggests that some form of cooling (could be mobile) may be required at distances up to 2D separation downwind.

8.11.5 Tank and Bund Layout

Putting several tanks in a common bund increases the risk of escalation of a fire on one tank to others. Tanks containing boilover products ideally should be placed in separate bunds. However, it is recognised that for many sites it is not feasible to put each tank in a separate bund. One solution may be to place lower, intermediate bund walls between tanks and grade bund floors to contain and direct the flow of product leaking from a burning tank away from the other tanks. Similarly, it may be possible to raise tanks on plinths to mitigate flame impingement slightly. Tank drainage patterns can be arranged so that burning liquids will be directed away from exposures such as piperacks or other tanks. Low berms can be constructed beneath piping, valves, meters to reduce the potential for pool fires directly beneath. All these measures to keep spilled product away from tanks or other equipment can be given further benefit if a remote impounding area with flame traps is constructed, to contain spilled product once it has flowed away from any tanks.
High leak potential equipment such as pumps, strainers and manifolds should be located outside bunds. If fire-fighting equipment is located on the bund wall, controls should be outside the bund where they are protected from fire exposure.

International standards allow tanks to be placed close to bund walls (typically within 1.5 m). Tank nozzles near bund edges should be below the level of the bund wall to avoid jetting of product outside the bund.
Finally, the arrangement of tanks within a bund should be planned with a view to access for fire fighting. Tanks for the storage of Class I, II(2) and III(2) should be arranged so that each tank is adjacent to a (fire) road or place accessible to mobile fire fighting equipment. For large diameter storage tanks, consideration should be given to the construction of landings that extend into the bund, allowing access for fire fighting equipment to within 15-20m.

8.11.6 Condition of Tanks and Tank Fittings

The condition of a tank and it fittings greatly affects the risk of escalation.

One rimseal fire recorded in the LASTFIRE Study occurred on a tank on which there existed 2-5 inch gaps between rim seal shoe plates. The tank contained product with a high vapour pressure, and flammable vapours were present in the rim seal area in explosive proportions. The lightning strike that caused the initial explosion and ignition of a fire in the rim seal area where the gaps existed also caused an explosion in a pontoon, which contained flammable vapours. The fire subsequently escalated to become a full surface fire. Other cases involving faulty valves made from the wrong metal have been known to have produced large gasoline leaks. Ignition of the subsequent flammable cloud has in some cases lead to an explosion and major fire that destroyed tanks.

Thus a major barrier against escalation is the effective specification, inspection and maintenance of tanks and tank fittings

Rimseal Properties

It is now common policy in many countries to fit secondary seals which further reduce hydrocarbon emissions. Secondary seals are thus likely to reduce the chance of flammable mixtures forming above the rim seal area. However, fire fighters have sometimes experienced difficulties extinguishing the last remains of a number of rim seal fires. It has sometimes been necessary to pull back the secondary seal by hand to enable the foam to flow into the rim gap because the foam dam was of insufficient height to cover the secondary seal effectively. When a secondary seal is fitted, the foam dam must be increased in height at the same time, to ensure that foam poured into the rim seal area will reach a sufficient depth to cover the top of the secondary seal. Different companies have different specifications of the minimum height of foam dam above the top of the secondary seal ranging from 51 mm (as Recommended in NFPA 11 [10]) up to 200 mm. Secondary seals can also be fitted with small panels which burn out in the event of a rim seal fire, allowing foam to flow into the rim seal area. These are not recommended since the foam dam should be of sufficient height to ensure a layer of foam above the secondary seal.

Rim seals constructed from fire retardant materials have been shown in tests to limit the rate of progression of fire significantly and hence to improve the management and extinguishment of rim seal fires

Finally, a tank can, due to settlement, deform from being truly circular. Rim seal support mechanisms are designed to centralise the roof and keep the width of the gap constant around the entire tank circumference. In practice, this is not always the case. Ideally the seal mechanism should be able to accommodate movements in the range 100%-300% of the minimum gap (i.e. 100%-300% of the length of the bumpers provided to prevent the roof hitting the tank wall)

Use of Waterspray / Water Curtains

The function of water sprays in mitigating the effects of fire is primarily to cool exposed surfaces. Application of water to the roofs of floating roof storage tanks can lead to problems from overloading the roof with water. Water sprays can be applied either by means of fixed systems of pipework and nozzles attached to the tank shell, or by means of portable monitors. Fixed systems can be designed to supply the amount of water required to cool a given exposed area much more efficiently than mobile monitors. The water throughput for mobile monitors is often dictated more by the requirement to achieve a certain jet range than by the amount of water needed to cool an area of exposed surface.

Water curtains consist of a water “wall” between the fire and the exposed tank, which is intended to block radiant heat from the fire reaching the exposed tank. Water curtains can be created using an array of fixed fan shaped nozzles. However, it is difficult to achieve a sufficient spray height to be effective. A limited, less even curtain can be achieved using monitors. The curtain is easily blown away by the wind, therefore a more usual application of monitors is to spray water directly onto exposed surfaces. Water curtains are more often and more successfully used to protect fire fighters working in exposed positions.

Fixed water spray systems can be used to provide protection to critical systems such as shut-off valves or mixers.

Excessive use of water can cause problems. Used firewater collecting in bunds takes up volume designed to contain a spill from a tank. Thus if a tank fails, it may not be possible to contain the product within the bund. Drainage systems should be designed so that firewater can be removed to a safe location where is can be stored or reused if necessary. It has been known for small tanks and near-empty tanks to float off their foundations because of the collection of firewater in a bund. Furthermore, used firewater requires treatment and disposal. The wastewater containment and treatment plant should have a large enough capacity to cope with the planned emergency response to a fire. When only limited water supplies are available, the use of water for cooling exposures should be kept to the minimum required to prevent escalation.

Further comments on the use of waterspray systems are given in Section 8.8.

Cooling of Tank Shells

Cooling the shell of a tank exposed to heat from a nearby fire has the effect of reducing heat transfer into the product contained within the tank.

The Institute of Petroleum Model Code Safe Practice recommends that any tank or similar nearby structure should be considered to require cooling if it is within one tank diameter distance from the burning tank, or two diameters downwind, or 30m which ever is the greater. This guidance indicates that more than one tank downwind of the fire may require water cooling, if the IP minimum spacing of tanks is used, as described earlier.
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.

Tank Pumpout

All operations on a tank should be stopped whilst fire extinguishment is attempted. This can also help to prevent a floating roof from losing its buoyancy if it is still in place and it assists foam to seal. However, if a full surface fire ensues and extinguishment is not practical, pumping out the tank acontents is one of the best methods of mitigating the potential for further fire escalation. It saves some of the tank assets and reduces the inventory that potentially could be involved in further escalation. Pre-fire plans should take into account the fact that pumping out a tank on fire that contains a boilover fuel may bring forward the time when a boilover would occur. However, the amount of fuel involved in the boilover would be reduced by pumping out.

Boilover Mitigation

Methods of mitigating boilover have met with mixed success. In small tanks it has proved possible to break-up the hot zone or to prevent it forming by sub-surface injection of foam or aerated water. (The use of this tactic is not generally recommended) Sub-surface injection is difficult if the hot zone has achieved an appreciable depth because of the potential for slopover. Some success in preventing slop-over has been obtained by performing intermittent sub-surface foam injection; stopping foaming when steam is observed on the surface of the tank. However, there is insufficient data and incident experience to give definitive advice on this subject.

Use of tank mixers should not be relied upon as a means of preventing a water bottom forming since localised pockets of water may form even though the mixers are running. Water may also accumulate in the event that power to the mixers is lost.

Most fire fighters recommend pumping out the fuel when extinguishment is not considered possible or practical, because it reduces the inventory that can take part in a boilover, even though it may make the boilover occur sooner. Some companies have installed storage tanks with bottoms sloping towards an emergency water draw point, which can be opened when the hot zone reaches 3m above tank bottom, in an attempt to drain as much of the water bottom out of the tank as possible.

CHAPTER 9

FIRE SYSTEMS INTEGRETY ASSURANCE (FSIA)

9.1 INTRODUCTION

The term 'Fire Systems Integrity Assurance' can be defined as a comprehensive scheme including, but not limited to, maintenance of fire detection and protection systems. FSIA is a structured approach that enables the implementation of test, inspection and maintenance procedures taking into account performance based criteria defined at the design and implementation stages of a project.

In order to demonstrate that a Risk Reduction Option or 'Line of Defence' is fully satisfactory, both in design and in terms of continued operability, the Operator should ideally establish a framework of Fire Systems Integrity Assurance. This system will allow both the Operator and the Fire Brigade to fully assess the continued effectiveness of the fire systems in place, and to monitor their role in overall fire risk reduction.

The information here is intended to be an outline of the FSIA process and is for general guidance only. More comprehensive guidance is given in the International Oil and Gas Producers (OGP) document, "Fire System Integrity Assurance". For auditing purposes, it is important that the Fire Brigade ascertains whether the Operator has implemented such a scheme, hence the FSIA philosophy is outlined within this Technical Frame of Reference. The dutch version of the FSIA document is published in the "Borging intergrale Brandveiligheidsproces - BIB" (CIV01).

9.2 FSIA PROCESS AND LINK TO "BOW-TIE DIAGRAMS"

The overall effectiveness of Lines of Defence, or 'barriers' (shown in green on the Bow Ties) in reducing fire risk will depend on whether a system of FSIA is in place. To evaluate whether a fire system (fixed or otherwise) is likely to contribute to overall risk reduction, it will be necessary for the Fire Brigade to find out if this is the case. Experience has often shown that fire detection and protection systems are not always detail to ensure that they meet the performance criteria necessary to reliably achieve their intended role. In some areas this role is not even clearly defined. The problem is sometimes compounded because the system designer/specifier has little or no operational experience or the feedback necessary to ensure system practicability. Also, as fire systems do not provide a direct contribution to production and revenue, they are sometimes not given the inspection or maintenance priorities that they deserve. Consequently, problems may go undetected for some time. Commissioning of systems to demonstrate that they meet their performance requirements when initially installed, and subsequent routine testing to check that they meet it on an ongoing basis, are essential, especially when the system is intended as a risk management measure for personnel safety.

In any event it is impracticable to give them a full performance test on site that truly reproduces the design fire event. This situation often results in fire systems not providing the performance required, when called upon to do so.
To overcome this problem, a structured approach from design phase through to implementation is required for fire systems to ensure that they have a clearly defined role with respect to fire hazards, and consequent levels of risk reduction.
In keeping with a hazard based approach to the provision of fire systems, it will be necessary to define a structured approach to Fire Systems Integrity Assurance (FSIA) by implementing a number of steps:

- Review potential fire incidents as part of Risk Assessment
- Set performance standards to clearly define exactly what measurable criteria the system must meet.
- Develop component specifications suitable to meet the performance criteria.
- Develop relevant test, inspection and maintenance procedures through which ongoing performance can be assured.
- Implement and keep records of the test, inspection and maintenance programme

This process will be iterative, since it is often found that a system cannot practicably meet the required performance criteria that are developed. In these situations, alternative methods of achieving the required levels of Fire Hazard Management may have to be sought, and the iteration loop detailed in Fig 9.1 (§ 9.3.2) will have to be revisited.

It is worth noting that the loop should also consider all relevant aspects of Fire Hazard Management that feed into the FSIA process. These may include inputs ranging from fire systems and process engineering, incident and equipment experience through to maintenance programmes and competency standards.

Assuming relevant performance criteria have been defined, and fire systems incorporate suitably specified components able to meet these it will be necessary to develop testing regimes and maintenance procedures using a performance-based approach.

9.3 INSPECTION AND TESTING OF FIRE SYSTEMS

Test procedures should be based on ensuring that critical performance criteria defined at the design stage are met, and maintenance schedules on ensuring that any system problems will be quickly identified. When defining schedules and procedures, it will be necessary to consider the reliability of system components and the levels of risk reduction that the system is designed to provide. For example, a system that is critical to life safety may require a more rigorous testing regime than a similar system designed purely for asset protection.
Any system testing should be relevant to the role of the system and either a direct measure of functional performance criteria or a measurement of a parameter that will demonstrate that the functional performance can be achieved.

If appropriate schedules and procedures are unable to be drawn up, then guidance should be taken from manufacturer's recommendations and recognised codes of practice, such as the NFPA publication 'Fire Protection Systems – Inspection, Testing and Maintenance Manual'

It is, of course, impracticable to replicate exact fire conditions to test the operation of a fire system under its' intended design intent. However, to test functionality against performance criteria it is possible to undertake system tests in one of two ways:

1. Directly
2. Indirectly

9.3.1 Direct System Tests

Direct system tests are effectively tests of the complete system, including the discharge of extinguishing agent where applicable. Such tests may require specialist equipment or skills not commonly found within in-house maintenance personnel. A typical direct test on a floating roof tank might be a complete discharge of a rimseal foam system to determine overall application rate and foam quality, which would then be assessed against the required performance criteria for that system. Other direct tests might include a 'hot wire' test (as detailed in BS6266) for incipient fire smoke detection systems in control room or computer suite areas. Tests of single, or groups of nozzles or detector heads would not, however, be considered as a direct test because this would not allow measurement of the whole systems' ability to meet performance criteria.

Direct testing is most often carried out at the commissioning stage, but it is unfortunate that insufficient direct tests are carried out at most facilities during the lifetime of fire systems. Often, this is as a result of excuses and concerns regarding clean up, corrosion problems and operational upsets. These problems ought, however, to be addressed in performance criteria and could be overcome by modifying system design, utilising components that minimize the problem. Should a modification be necessary, then it is important to develop appropriate maintenance schedules and procedures to suit.

The results of direct testing may be compared comparatively easily against relevant performance criteria, although in some cases, specialist advice may be required to pinpoint the cause of any problems. (This is often the case with foam systems, since a variety of faults may cause insufficient foam quality)

9.3.2 Indirect System Tests

In indirect testing, as much of the system as possible is tested. A deluge system protecting liquefied gas storage fitted with a full flow test line should be tested by actuation of the relevant detectors, thus testing detectors, control logic, firewater pump start, ringmain integrity, pump capacity and deluge valve operation. With careful thought going into individual component testing and ensuring that all components are subjected to the testing regime, it may be possible to demonstrate system availability meets the relevant performance criteria with relatively large intervals between direct testing exercises. However, it is unlikely to do away completely with the need for direct testing.

Indirect test results will often generate more records and require more in-depth analysis, since they will only demonstrate whether discrete parts of the system or individual components are functioning correctly. Therefore, overall system integrity assurance is harder to ascertain.

Testing Passive Fire Protection

The long term testing (and therefore assurance) of Passive Fire Protection (PFP) used to protect liquefied gas vessels and piperacks, valves etc. is particularly difficult, and manufacturers and specialist fire engineers should be consulted to provide indicators of system deterioration.

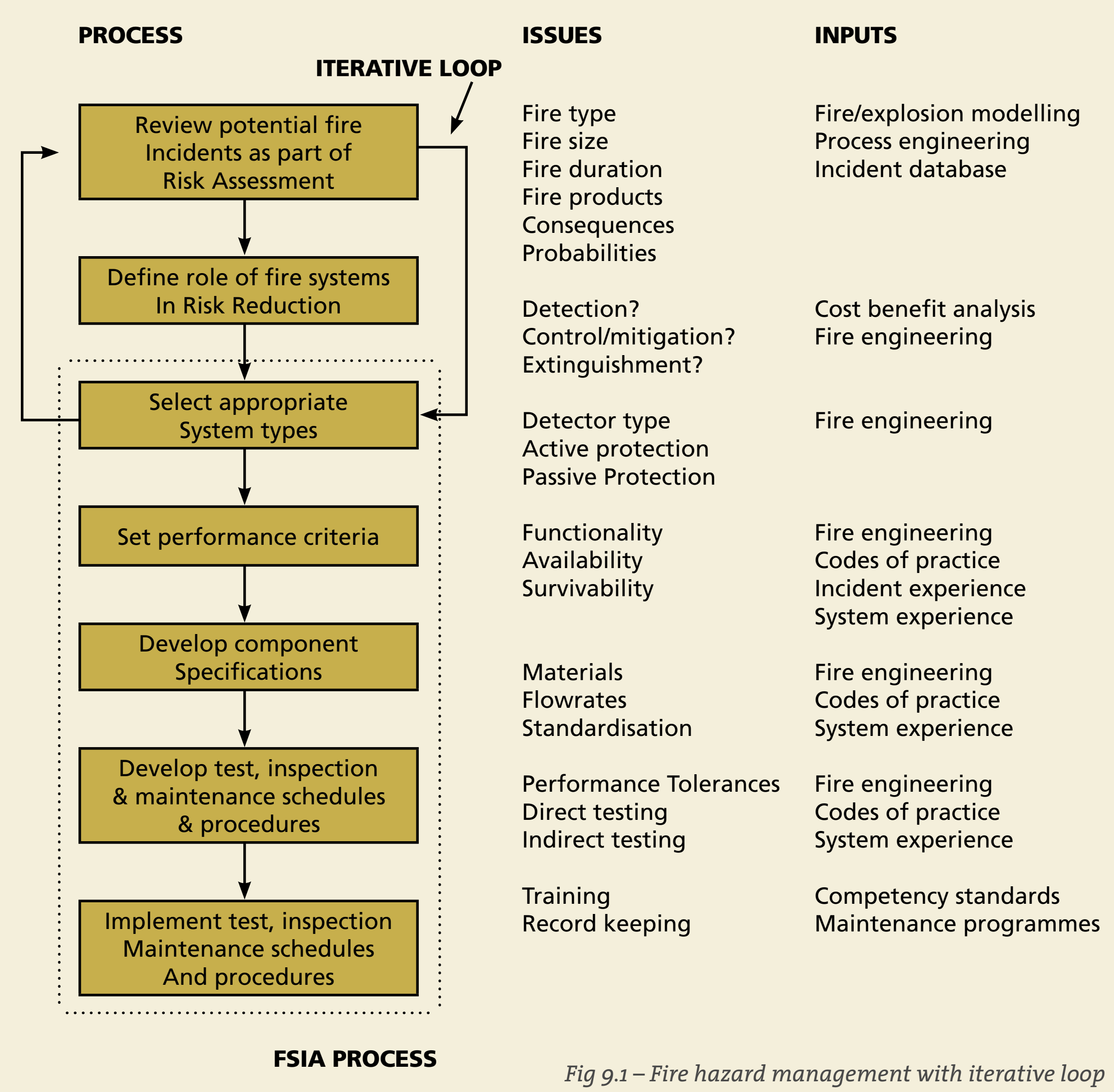

Fig 9.1 – Fire hazard management with iterative loop

CHAPTER 10

EMERGENCY RESPONSE PLANNING

10.1 THE NEED FOR PRE-FIRE PLANNING

A major conclusion that came from the LASTFIRE study (See Section 10.6) was that it is vital to preplan the response to any incident. Even if the accepted policy is "burn down" a preplan (Emergency Response Plan or 'ERP') is needed to formalise it. A good preplan will cover both operator and fire responder actions. In other words it will list all the actions to be carried out, including those by operators, who may be involved in pump out and shutdown actions, as well as fire fighters.

Of course preplanning is only of value if the equipment that is going to be used in the fire response is well maintained and the preplans are exercised regularly to check that they are workable and that everyone is aware of their role in a real incident. After any exercise it is important that a full critique should be carried out and any identified deficiencies corrected with the preplans being modified accordingly.

Overall, the only way that tank fire incidents can be handled safely and effectively is by having a formalised and justified strategy that everybody involved understands, preplans are available to remind personnel of their role and exercises are carried out to test the preplans and ensure that they are workable and relevant.

It is also worth noting that the implementation of risk-based legislation under the Seveso Directive specifically requires operators to demonstrate emergency preparedness and to develop, maintain and exercise pre-plans for major incidents. In addition, major incident pre-plans should act as training aids for responders, enabling desktop and practical exercise response performance to be measured.

10.2 EMERGENCY RESPONSE PLAN PURPOSE

The purpose of an Emergency Response Plan (ERP) should be to provide instant written instructions, guidance and helpful information for operators and fire fighters to assist them at the critical early stage of a serious or major incident. In addition, it should provide sufficient potential hazard information to enable informed decisions to be taken regarding the safety of personnel responding to the incident.

Typical plans are intended to provide guidance for the first 20 to 30 minutes of the incident and indicate the actions and resources required to deal with the incident during this time. Once this period of time elapses, a stable response should have been established and if the incident duration is prolonged, the responding fire brigade will develop an ongoing strategy for dealing with this and will have early knowledge, reference and access to other relevant emergency plans. In some cases, where relevant, the resources required for ongoing incident control should also be listed to assist responders.

10.3 TYPICAL EMERGENCY RESPONSE PLAN

Depending on the size and complexity of a facility, manning levels and the availability of an on-site fire brigade, a good preplan will offer a two, or in some cases three-tiered response outlining the key response actions to be taken by operators and fire responders. The example ERP shown in Fig 10.1 and explained below is typical of a format currently used by major oil companies, and has gained acceptance by the United Kingdom's Health and Safety Executive. (The organisation responsible in the U.K. for overseeing implementation of the Seveso Directive).
In cases where an on-site fire team can be mobilised, the Emergency Response Plan may feature three distinct 'panels' giving actions as follows:

The "1st Responders" heading covering the immediate process control, personnel alerting, evacuation and assessment related tasks to be carried out by plant/installation operators, together with the equipment and resources required unless these are obvious.

The "2nd Responders" heading, intended primarily for the Lead Operator (acting as On-Scene-Commander) and/or on-site fire team, although

further plant operator actions may be listed in some ERP's. The text here will usually be the recommended tactics/actions for minimising escalation potential or controlling or extinguishing the incident, together with the minimum equipment and resources identified as necessary to do so. The "3rd Responders" heading, intended primarily for the fire brigade. (e.g. Unified Fire Brigade) The text here will usually be the recommended tactics/actions for continuing the control or extinguishment, or in some cases, the evacuation of personnel at an incident. A good preplan should also recognise that it will not always be possible nor desirable to list every single action necessary for successful control or extinguishment of any incident. Therefore, the On-Scene Commander and/or the fire officers, using dynamic risk assessment, may decide at any time that a change in strategy or tactics is required due to changing conditions or circumstances.
As well as the tiered response, the ERP may include a "Strategy" heading and a broad series of statements intended as guidance on what actions should be taken during the first 20 to 30 minutes to either minimise or control the consequences from a given incident. Typically, the strategy should be taken from incident scenario 'worksheets', used in the initial assessment of fire response at a facility and in determining firewater flows, monitors, hose, foam concentrate, fire vehicles and manpower resources etc for the incident. The ERP should also feature specific information relating to ongoing potential hazards encountered throughout the incident. In the example given, two headings are provided for this purpose:

The "Incident Potential Hazards" heading is used for any known hazards or hazardous events that may occur as a result of the incident. Information under this heading may include personnel exposure hazards, boilover potential, escalation hazards etc, etc.The "Other Concerns" heading will normally highlight any other identified concerns including off-site considerations, incident control cautions, resources related concerns or other incident specific concern which has been noted during the course of the incident scenario evaluation work. This assists the responders in that it prompts early consideration or an early decision without having to wait for, or physically seek, sources of information.

10.4 FIREMAP

A good preplan will also offer guidance in the form of a "firemap" or plot-plan showing the location and potential extent of the fire scenario. It is a good idea to provide this on the reverse of the text page for ease of reading. The firemap may be indicative of the potential fire area that may be, or may become, involved during a major incident. To show this pictorially, the results of fire modelling calculations are often used to give a series of "effects contours" indicating the levels of radiant heat that may be experienced in the vicinity of a tank fire.

The principal effects contours used in the firemaps are:

Pool fire (i.e. tank fire) extent, whereby the radiant heat would be in the order of 200-300 kW/m². Radiant heat contour emanating from the pool area down to 12.5 kW/m². Radiant heat contour of 6.3 kW/m² lessening from the edge of the 12.5 contour down to 6.3.

Radiant Heat Examples (see also PGS 1)

To put these into context, example heat radiation levels are given below: (as typically given in Institute of Petroleum guidance)

1 to 1.5 kW/m²	=	Sunburn
6.3kW/m²	=	Personnel injury (burns) if normal clothing worn and fast escape not possible.
12.5 kW/m²	=	For example, escalation through ignition of other fuell surfaces is long exposure times without protection. Cooling of tank shell necessary (e.g using portable or fixed monitors)
32 kW/m²	=	Level at which IP guidance suggests that fixed cooling may be required
200-300 kW/m²	=	Within the flame of a pool or jet fire. Steel structures can fail within several minutes if there is no cooling or other protection.

A firemap may also give locations of available hydrants and fixed or semi-fixed fire protection systems and actuation points, as well as other useful information such as prevailing wind direction and other plant specific hazards.

It should be stressed that firemaps be used as guidance only, since it is impossible to predict exactly what the effects for a given fire will be with any certainty. The heat contour for a tank fire is often shown as a circle since a tank fire may form a circle, although in practice it may well be an irregular shape or even a rectangle or square if burning product is contained in bunds or retention walls. Environmental effects such as prevailing wind and precipitation, as well as fire size will all have a bearing on the levels and extent of heat radiation encountered. Nevertheless, a good firemap will enable fire responders to make informed decisions on approach angles, hydrant availability and safe distances.

For a rim seal fire Emergency Response Plan, it may be sufficient to show the location of the tank concerned and a representation of the fire without any contours as detailed in Fig 10.2

10.5 TRAINING / RESPONSE PERFORMANCE MEASUREMENT

In addition to their use during an incident, ERPs provide an effective means of measuring emergency response performance, in terms of the logical and sequenced actions needed, time to carry out these actions, status of systems or equipment used for control actions and so on. The provision of effects maps enhances responder collective vision of the fire area, which better focuses the exercise when compared to “imaginary” areas.

Simulated incidents (exercises) can be carried out at a facility. The actions performed by installation operators at a plant control room, as well as the facility outside general area, can checked by exercise observers using the ERP.
The actions by fire responders at the simulated incident scene can also be checked against the ERP instructions and guidance.

In this way, the ERPs offer an objective and beneficial means of ensuring that operators and responders act in accordance with a structured and logical response plan and that they train together for tank fire incidents at the particular facility

10.6 LASTFIRE STUDY OVERVIEW

Storage tank fires are rare events, but when they do happen they can create high levels of media and public interest and, if not handled correctly, can pose safety and environmental problems. With this background, 16 oil companies joined together to review the fire related issues of one of the more common types of tank construction in order to better understand the associated risks. This project was known as LASTFIRE - Large Atmospheric Storage Tank Fires.

The project sponsors included companies with facilities throughout the world, thus giving a wide range of operating experience and environmental conditions. The project itself was co-ordinated by an independent consultancy (Resource Protection International) specialising in Fire Hazard Management of oil and petrochemical facilities. Each sponsoring company had one place on the Project Steering Group. Some of the companies formed the Working Group responsible, under the direction of the Project Co-ordinator, for carrying out the work.

The specific project objectives were :

- To determine current levels of risk associated with fires.
- To establish recommended design and operation practice and to make this knowledge available throughout the industry.

- To provide techniques to enable individual operators to determine their level of fire related risk and identify appropriate and cost effective risk reduction measures.

A true Fire Hazard Management approach was used. The stages of this approach were as follows:

- Analysis of credible scenarios.
- Review and comparison of potential risk reduction options.
- Definition of the site-specific Fire and Explosion Hazard Management policy to be used.
- Implementation of the policy.

ERP- 1 EMERGENCY RESPONSE PLAN FOR: FLOATING ROOF TANK 21 - FULL SURFACE FIRE

STRATEGY CR closes tank valves – alerted – sirens actuated and evacuation – Technicians assess fire extent if safe to do so – Pipeline operations alerted to incident – Technicians move to safe access gate to direct units – Spare tank line up for crude transfer – On site fire team deploys cooling water monitors on adjacent tanks – Crude transfer and tank burn-out strategy or foam attack strategy adopted – Foam handlines deployed to wind girder walkway to support foam system – Foam application until the foam dam is completely filled – CFS stand-by until tank is declared safe.

1ST RESPONDERS	ACTIONS	EQUIPMENT / RESOURCES	INFO / COMMENTS
[ ] CR Technicians [ ] CR Technicians [ ] CR Technicians [ ] CR Technicians [ ] OSC [ ] OSC [ ] OSC [ ] OSC [ ] OSC [ ] OSC	Isolate affected tank and halt affected tank operations. Confirm Fire Station response and alert Shift Manager. Activate sirens and alert Gate House. Alert Pipeline operations to incident and ESD actions. Delegate 2 available personnel to act as MPC's. Send field tech to safe gate to meet. Request tank levels and ullage status for crude transfer. Establish site muster status via MPC's. Alert Refinery to crude supply impact from fire. Ensure section actions checked & advise fire officer of completion.	Via process control in control room. Tele. 999 for fire station. Siren controls in CR - Gatehouse telephone 3333. Techs in CR to advise of conditions and level alert. Both to act as Muster Point Coordinators (MPC) Radio contact with KCR technicians. Radio or MP telephones. CR techs to relay message. Radio or Fire Station Tele. No. 9999.	If engaged – Telephone 4444 – same location. MPC's coordinate Muster Point assembly/checks. Ensure will be met at safe gate for directions. Gatehouse access control read out used. . Handover this ERP, marked-up.

2nd RESPONDERS	ACTIONS	EQUIPMENT / RESOURCES	INFO / COMMENTS
[ ] Onsite Fire Officer [ ] Fire Crew [ ] Field/CR Techs [ ] Fire Crew [ ] Fire Officer [ ] Fire Officer	Contact OSC & confirm incident level and advise where units are to report. Deploy cooling monitors on immediately adjacent tanks. Line up available tanks and commence crude oil pump out. Connect to adjacent heat affected tanks rim seal foam systems and pump foam solution to foam dam Post a safety officer to monitor crude burning in tank Check all actions in this section are marked and hand ERP to Officer on arrival.	Radio incident level and holding/location/reporting through to Control. Minimum 3 x foam tenders, 5 responders, 2 x 4500 lpm portable water monitors, 16 x 70mm fire hose. Minimum 1000 litres foam concentrate for each tank rim seal, 8 x 70m fire hose for connecting to rim seal foam systems. This ERP and ensure radio handset for fire officer in charge.	Safety officer to alert on any change in burning intensity, burning noise or smoke colour change which may indicate a slopover or boilover.

ERP- 1 EMERGENCY RESPONSE PLAN FOR: FLOATING ROOF TANK 21 - FULL SURFACE FIRE

3rd RESPONDERS	ACTIONS	EQUIPMENT / RESOURCES	INFO / COMMENTS
[ ] Fire Officer [ ] Fire Officer [ ] Fire Officer [ ] Fire Officer [ ] Fire Officer	Contact OSC and Onsite F.O. on arrival for assessments. Deploy further water monitors for cooling heat affected tanks If decision taken to attempt extinguishment, deploy foam monitors for foam attack. On foam attack, continue application until extinguishment and thereafter until a secure foam blanket is achieved. Shut down any water monitor streams, which may affect the foam monitor streams.	Minimum 12 x water tenders, 48 UFB responders, 6 x 4500 lpm portable water monitors. 9 x 4500 lpm foam monitors or equivalent monitors to give 39,600 lpm foam solution Flowrate, plus all fire hose and 77,200 litres 3% foam concentrate.	Based on a foam application rate of 10.4 lpm/m2 for a duration of 65 minutes.

INCIDENT POTENTIAL HAZARDS The resources listed would be required as a minimum before any attempt is made. Hazard of crude oil boilover will need to be given careful consideration. Therefore, if 'pump and burnout' strategy is chosen all personnel must evacuate to a safe distance from the tank in anticipation of boilover event. Crude oil full surface fires in tanks, if left to burn freely, create a heatwave, which descends into the tank. On contacting a water layer the heat causes a "boilover" with sometimes violent ejection of burning crude. This event, in worst cases, may lead to burning crude flowing over an area of 300 metres diameter. Personnel should not work inside the tank bund after the initial stages of the fire due to boilover hazard. A boilover may occur at any time after the first few hours of the incident and no reliance should be placed on anticipating heatwave reaching base of tank before boilover will occur. It is prudent to expect boilover anytime after the first 2/3 hours of the incident.

OTHER CONCERNS Foam should not be applied to tank fire until there is sufficient freeboard in tank. Foam application without freeboard to accommodate foam volume will lead to slopovers. This is most important where tank overfill has caused incident and where crude oil is at or very near to the tank shell height. It may be that the fire has to burn for 1 hour or so before applying foam. A check on visual heat indications on the tank shell top will indicate where the level is at any time. If decision made to attempt tank fire extinguishment then careful monitoring of water streams will be necessary to prevent water drift affecting foam streams. Care must be taken to prevent foam slopping over the tank, which may happen if there is inadequate capacity (freeboard) in the tank. Additionally, if water streams are played or drift into the tank, the burning crude may slopover.

ERP- 2 EMERGENCY RESPONSE PLAN FOR: FLOATING ROOF TANK 21 - FLOATING ROOF RIM SEAL FIRE

STRATEGY CR closes tank valves – alerted – sirens actuated and evacuation – Technicians assess fire extent if safe to do so – Pipeline operations alerted to incident – Technicians move to safe access gate to direct units – On Site Fire Team connects to rim seal foam system inlet manifold – Foam application via system – Foam handlines deployed to wind girder walkway to support foam system – Foam application until the foam dam is completely filled – stand-by until tank is declared safe.

1ST RESPONDERS	ACTIONS	EQUIPMENT / RESOURCES	INFO / COMMENTS
[ ] CR Technicians [ ] CR Technicians [ ] CR Technicians [ ] CR Technicians [ ] OSC [ ] OSC [ ] OSC [ ] OSC	Isolate affected tank and halt affected tank operations. Confirm Fire Station response and alert Shift Manager. Activate plant sirens and alert Gatehouse. Alert Pipeline operations to incident and ESD actions. Delegate 2 available personnel to act as MPC's. Request tank levels and ullage status in case of crude transfer requirements and check tank roof drain is open. Establish site muster status via MPC's. Ensure section actions checked & advise fire officer of completion.	Via process control in control room. Tele. 999 for fire station. Siren controls in CR - Gatehouse telephone 3333. Techs in CR to advise of conditions and level alert. Both to act as Muster Point Coordinators (MPC) Affected tank roof drain. Radio contact with CR technicians. Radio or Fire Station Tele. No. 9999.	If engaged – Telephone 4444 – same location. MPC's coordinate Muster Point assembly/checks. Available techs as Local Evacuation Officer (LEO) direct evacuees cross wind to safe muster point. Handover this ERP, marked-up.
2nd RESPONDERS	**ACTIONS**	**EQUIPMENT / RESOURCES**	**INFO / COMMENTS**
[ ] Onsite Fire Officer [ ] Fire Officer [ ] Fire Crew [ ] Fire Crew [ ] Fire Officer	Contact OSC & confirm incident level and advise where units are to report. Check fire extent in the rim seal area. Connect 1 or more foam tenders to rim seal foam inlet manifold and pump foam solution to foam pourers. Deploy a foam handline at the tank top using the tank top foam outlets at the wind girder walkway Check all actions in this section are marked and hand to Officer on arrival.	Radio incident level and holding/location/ reporting through to Control. Minimum 3 x foam tenders, 5 responders, 16 x 70mm fire hose for foam system connect and minimum 1000 litres 3% foam plus 1 x 450 lpm foam branch, 6 x 70mm fire hose and 300 litres 3% FP foam for foam handlines This ERP and ensure radio handset for fire officer in charge.	Initial foam application should commence form foam inlet at ground level before foam handline teams ascend the tank to support rim seal foam application.

ERP- 2 EMERGENCY RESPONSE PLAN FOR: FLOATING ROOF TANK 21 - FLOATING ROOF RIM SEAL FIRE

<table>
<tr><th>3rd RESPONDERS</th><th colspan="2">ACTIONS</th><th>EQUIPMENT / RESOURCES</th><th>INFO / COMMENTS</th></tr>
<tr><td>[ ] Fire Officer
[ ] Fire Officer

[ ] Fire Officer
[ ] Fire Officer

[ ] Fire Office</td><td colspan="2">Contact OSC and on-site F.O. and assess foam application status.
Deploy 2 foam handlines at the tank top using the tank top foam outlets at the wind girder walkway.
Maintain OSC liaison for process status.
Once rim seal fire is extinguished, intermittent foam application into the foam dam may be necessary to maintain vapour suppression. Stand-by until tank is declared safe.</td><td>Minimum 2 x water tenders, 8 responders.

2 x 450 lpm foam branches, 8 x 70mm fire hose and use foam pourer auxiliary foam outlets on tank top.</td><td>The foam handlines may not be used to apply foam but should be deployed in readiness, in any case.</td></tr>
<tr><td colspan="5">INCIDENT POTENTIAL HAZARDS Foam handline teams can use the foam outlets on top of the tank at the wind girder walkway or they may use foam tender for foam supply. Early checking that all foam pourers are working is necessary to ensure full foam application. Rim seal fires will not normally escalate to a full surface fire. If the foam application from the rim seal system is not successful or the foam handline teams cannot use the tank top foam outlets, it may be necessary to carry/haul 25 litre foam concentrate drums up the tank stairway and use in-line foam inductors with the foam branches. Where this is the case, a minimum of 600 litres of foam concentrate should be made available, based on foam application for 20 minutes. It should be noted that the use of dry powder extinguishers on a rim seal fire will often result in re-ignition due to hot metalwork and therefore foam handlines are best for this type of fire event.</td></tr>
<tr><td colspan="3">OTHER CONCERNS It should not normally be necessary for firefighters to access the tank roof to fight the rim seal fire, but if a decision is made that they should, they must wear SCBA and a lifeline in case of roof tilt emergency.</td><td colspan="2">RADIOACTIVE (RA) HAZARDS / ASBESTOS HAZARDS / TOXIC HAZARDS
H_2S present in crude upstream of and within gas sweetening units</td></tr>
<tr><td>OSC - On Scene Commander</td><td colspan="2">CR – Control Room (facility)</td><td colspan="2">MPC – Muster Point Co-ordinators</td></tr>
</table>

The FHM approach recognises that risk can be reduced by either reducing incident probability or incident consequences. All potential contributors to risk reduction were reviewed during the project including both prevention and damage mitigation measures.

Through the project deliverables, the LASTFIRE project provides data and a methodology to enable an operator to analyse risk and decide which detailed policy is relevant for his facility. It also provides information to assist in the detailed practical implementation of the chosen policy. The information presented in the LASTFIRE project was gained from a worldwide data collection involving not only detailed experience from the sponsoring companies, but also international brainstorming meetings with all relevant industry groups including tank builders, operators, insurers and fire response personnel.

The project deliverables comprised inter-related reports on:

- Incident frequencies - based on a detailed survey within the Steering Group members
- Incident escalation mechanisms
- Risk reduction options including a review of fire fighting foams
- The methodology, described in the Risk Workbook, to develop site specific, cost-effective fire hazard
- management policies relevant to a particular facility.

The information in these documents has a direct input to the Fire Hazard Management Process.

Thus, the LASTFIRE project was a comprehensive study resulting in a better understanding of the fire risk related to open-top floating roof tanks and a tool allowing persons responsible for developing Fire Hazard Management Strategies to make risk based decisions on the policies to be adopted and the resources required to carry them out.

10.6.1 Project conclusions

The main project conclusions were:

Fires in open top floating roof storage tanks should not represent a major risk to life safety or the environment if response is to a well-managed, preplanned strategy. Therefore, risk reduction policies should usually be determined on the basis of reduction in risk to continued production, asset value or other concerns such as public image.

The most cost-effective risk reduction contributor is good fire-related inspection and maintenance.

Prescriptive approaches to risk reduction should not be applied because of varied operating conditions and the different combinations of risk reduction measures that can be applied to achieve acceptable risk levels according to these different operating conditions.

It is important that site specific, cost-effective, risk based policies are developed. The LASTFIRE Risk Workbook describes a methodology that, in combination with the information in the other project deliverables, can be used to do this.

The Statistical Analysis has shown that fire incident probability and the associated risk is relatively low.

Rim seal fires are the most common scenario. These are unlikely to escalate to full surface fires in well maintained tanks.

Lightning is the most common ignition cause. In the LASTFIRE incident survey at least 52 out of the 55 rimseal incidents reviewed were ignited by lightning.

The overall frequency of rimseal fires was found to be 1.6 x 10^{-3}/tank year but major differences according to geographical location were noted. It was recognised that this was mainly due to local frequency of lightning storms. Correlations between rimseal fire frequency and thunderstorm frequency have been developed to assist site specific risk evaluation. As an example, rimseal fire frequency in Northern Europe was found to be in the order of 1 x 10^{-3}/tank year. In other words, if you have 100 tanks in this part of the world, statistically on average you would expect a rimseal fire every 10 years.

Generic worldwide event frequencies for fires other than rimseal fires are:
3 x 10^{-5}/tank year for "Spill on Roof" fires
9 x 10^{-5}/tank year for small bund fires
6 x 10^{-5}/tank year for large bund fires
and 3 x 10^{-5}/tank year for full surface fires

The detailed design of detection and protection systems is often incorrect or impractical due to the lack of operational experience in design engineering houses. It is important to receive design input from site experienced personnel including fire responders to ensure that systems are workable and perform in accordance with the design intent.

It is vital that incident response strategies are pre-planned and that regular exercises and training are carried out to ensure that the strategies are workable, and that everyone is aware of and fully trained in their response role.

It is emphasised that site specific Fire Hazard Management policies should be developed by using the project Risk Workbook methodology. The risk reduction options which, in general, are most likely to be cost effective when this analysis is carried out are:

- Provision of secondary seals.
- Use of fire-retardant elastomers and fabric for the seal material.
- Provision of linear heat detection in the rimseal area.
- Installation of an extended (10 minutes + i.e. not "one shot") rimseal area foam application system. (For example a rimseal system is full compliance with NFPA 11.)
- Provision of high-high level alarms independent of any other level sensors.
- Provision of full circumference top-of-shell walkways and handrails to allow safe access for foam application to the rimseal area by use of hand-lines to back up any system application.

Over all, the LASTFIRE project has made a major contribution to the understanding of the risks associated with fires in large open roof storage tanks and provided operators and fire responders with the tools and knowledge to develop appropriate site specific and cost-effective risk reduction policies.

10.6.2 Follow up work

Risk Workbook

The LASTFIRE project has clearly demonstrated that a prescriptive requirement for risk reduction options cannot be universally applicable as there are so many different operating conditions and environments. Instead, an operator should carry out a risk assessment, review potential risk reduction measures and decide which are practicable and justified for the specific facility in question.

As part of the fire hazard management philosophy adopted by the LASTFIRE Project, a methodology has been developed which enables a site-specific quantification and comparison to be made of the potential reduction in fire risk that can be achieved with different risk mitigation options.

The methodology is based on a cost-benefit analysis framework that involves an assessment of a site's existing level of risk and the potential levels of risk reduction that can be achieved by implementing particular risk reduction measures. It utilises information reported in the main LASTFIRE Report, and based on the document, guidance is given on appropriate values to use for a first pass cost benefit analysis.

The Workbook itself takes the form of an MS Excel spreadsheet that is simple to use – guidance is included in the form of drop down boxes and pop-up notes. Default values form a worked example to facilitate analyses.

It is intended that this document provides a tool to help identify the most appropriate and cost effective risk mitigation options, which in itself should be one component of a co-ordinated fire hazard management process.

10.6.3 Foam Test For Storage Tank Fires

In the event of a fire in a large diameter storage tank, it is imperative that firefighting foam with suitable physical properties is applied so that the best fire extinguishing performance is achieved.

Current fire tests used to evaluate fire-fighting foams have invariably been designed for either specific foam types, or specific applications. The LASTFIRE project sought to examine existing fire test methods and suggest possible improvements.

It was concluded that no single test had been developed specifically for large tank fires. Many standards express their foam performance criteria upon the time to extinguishment, and in terms of re-involvement following burnback. Whilst these are indeed relevant parameters, it was considered that in the case of a large tank fire, thermal resistance, spreading ability and the influence of the application method would also be pertinent measures of foam's performance.

The development of a test protocol to address these issues was undertaken in September 1998 and following an initial test series a test specification was issued by Resource Protection International. Following further development work the following year, the specification gained acceptance within the LASTFIRE consortium and was refined, allowing LASTFIRE Group members and other interested parties to build further test facilities.

Practically, the test protocol has several advantages, and is entirely relevant to tank fire foam application. This is achieved in three ways:

Critical Application Rates

Application rates amounting to roughly one-half of prescribed NFPA 11 rates are used, since in a real incident foam losses due to 'dropout' and thermal updraft from the fire would mean that these application rates would be largely unachievable. The application rates of 3.2 lpm/m² for 'monitor' application, and 2.5 lpm/m² for 'system' application were carefully selected to ensure that only those foams achieving optimum foam properties would be able to perform to a high level at such critical application rates.

Realistic Application Methods

The LASTFIRE test incorporates application methods that are as realistic as possible, and uses specially designed nozzles for foam application.

The characteristics of these nozzles are such that they emulate the foam properties typical of commercially available monitors and fixed systems. A wide variety of foam properties can be attained, ranging from non-aspirated to slow draining and low expansion.

Aspirating nozzles are intended to simulate monitor application, and the foam is thrown directly onto the fuel surface. In this way, the foam blanket is continually disturbed and tests for post-fire security address a poorer quality foam blanket. This invariably results in a much sterner test and one that is more akin to real incident conditions

In order to simulate a more gentle foam application, foam discharge is from a 'system nozzle' arrangement. The 'gooseneck' nozzle is positioned so that it overhangs the test pan rim. Upon application, the foam runs down into the pan, simulating that from a foam pourer.

Realistic Foam Properties

The LASTFIRE test nozzles enable foam to be produced which is similar to that generated at real incidents, whether by monitors or other fixed equipment. Consequently, the foam that is applied to the fuel surface reproduces faithfully the qualities expected under tank fire conditions.

Fighting Floating Roof Tank Rimseal Fires Video

As part of the LASTFIRE follow-up work, a video was produced which offers guidance on fighting the most common fire scenario associated with floating roof tanks – rimseal fires.

This 25 minute video, made by fire-fighters for fire-fighters, draws extensively on the knowledge gained from the LASTFIRE Project and provides an invaluable guide to fighting rimseal fires under different operating conditions. A variety of training exercises and fire-fighting strategies are shown along with guidance on creating pre-fire plans, making this the definitive training aid for rimseal fire scenarios.

APPENDIX A
EMERGENCY RESPONSE PLANNING

LIST OF STANDARDS AND WEBPAGES

There are many national and in-house company standards regarding tank design, layout and inspection. Most of these are heavily based on the American Petroleum Institute standard, API 650 - Welded steel tanks for oil storage, which in turn then refers to many other relevant standards on specific issues such as lightning protection.

One issue that is receiving more attention is that of bund design where there is a definite environmental legislation trend towards more stringent bund design requirements. In particular, in some European countries local legislation requires concreted bund floors and sizing to be able to contain the contents of all tanks within the bund plus any firewater requirements.

In addition, there is an increasing trend for environmentally driver legislation to require secondary seals for tanks used for more volatile products.

The following is a list of what are considered to be the most relevant and useful standards:

API 650	Welded Steel Tanks for Oil Storage.
API 653	Tank Inspection, Repair, Alteration and Reconstruction
API 2517	Evaporation Losses from External Floating Roof Tanks
API 2003	Protection against Ignition Arising out of Static, Lightning and Stray Currents.
API 2021	Management of Atmospheric Storage Tank Fires

www.api.org

EEMUA Publication No. 159	Users Guide to the Maintenance and Inspection of Above Ground Vertical Cylindrical Steel Storage Tanks (EEMUA - Engineering Equipment and Materials Users Association)

www.eemua.co.uk

Institute of Petroleum, Model Code of Safe Practice:

Part 15	Area Classification Code for Petroleum Installations
Part 19	Fire Precautions at petroleum Refineries and Bulk Storage Installations

www.petroleum.co.uk

NFPA 30	Flammable and Combustible Liquids Code.

www.nfpa.org

www.centrum-iv.nl

CIV01	Borging Integrale Brandbeveiligheids-proces
CIV03	Audit methodologie Brandveiligheid Opslagtanks
CIV04	Atmospheric Storage Tank Bow Tie Diagram