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Model code of safe practice

Part 19

Fire precautions at petroleum refineries and bulk storage installations

2nd edition

An IP Publication

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IP MODEL CODE OF SAFE PRACTICE IN THE PETROLEUM INDUSTRY

PART 19: FIRE PRECAUTIONS AT PETROLEUM REFINERIES
AND BULK STORAGE INSTALLATIONS

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PART 19: FIRE PRECAUTIONS AT PETROLEUM REFINERIES AND BULK STORAGE INSTALLATIONS

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FOREWORD

IP *Fire precautions at petroleum refineries and bulk storage installations* ('IP 19') provides guidance on selecting, implementing and monitoring the continuing performance of site-specific justified risk reduction measures – from prevention through detection, protection systems to mitigation measures – to reduce the risk from design event fires at installations that process and store petroleum, intermediates and refined products.

In line with recent legislation in the UK, Europe and elsewhere in the world, IP 19 does not set out prescriptive practices for adoption. Instead, it provides good practice guidance on options that may be appropriate to implement in order to satisfy pertinent risk drivers such as legislation, safety, environmental protection, asset protection, reputation and business continuity. The publication is based upon a framework of risk-based fire and explosion hazard management (FEHM) to achieve this, although it recognises that other approaches can be used.

The guidance in this publication should assist process safety engineers, safety advisors, designers, emergency planners or others with responsibility for fire and explosion hazard management to meet the pertinent requirements of the European Seveso II Directive, whether sites are classified lower or upper tier.

This publication is based primarily on the UK and European legislative framework, publications and good practice. However, its guidance is internationally applicable provided it is read, interpreted and applied in conjunction with relevant national and local requirements. It can be used as a basis for establishing a consistent fire and explosion hazard management policy for companies with multi-site operations within a country or across several countries.

The second edition of IP 19 was commissioned by the Energy Institute's Distribution and Marketing Safety Committee, contracted to Resource Protection International and directed by a Steering Group. It supersedes the first edition, published in 1993. Whilst amendments have been made throughout, major changes have been made to:

— Clarify the scope and exclusions, and how users should apply the publication internationally, whether using the FEHM approach or another approach.
— Arrange sections in a logical, sequenced order of: fire-related hazards; the FEHM approach; fire prevention; fire and flammable gas detection; fire protection; response strategies and options; and maintaining an effective FEHM policy.
— Set out a portfolio of FEHM risk drivers.
— Enhance the guidance on fire and explosion scenarios, consequences and modelling.
— Capture improved knowledge of risks associated with fires in large storage tanks.
— Recognise that hazard identification and incident prevention are usually the primary concern.
— Capture the experience gained and developments in risk reduction techniques and equipment for use in various installations/areas.
— Provide guidance on maintaining FEHM policy through emergency planning and fire systems integrity assurance (FSIA) by outlining typical approaches.

— Revise guidance on typical fire-fighting media application rates and provide a commentary that recognises incident experience and recent good practice.

The technical content of this publication was being finalised at the time of the Buncefield bulk storage installation major accident in December 2005. Whilst only some findings of the investigation have been released, thus far the FEHM process described herein has not been technically compromised. However, this publication does not fully reflect the unprecedented consequences of the seemingly partially confined vapour cloud explosion. The decision to proceed with publication of the second edition of IP 19 was based on balancing this issue and other issues that may transpire from the Buncefield investigation against the value of the rest of the updated guidance, which replaces the first edition published over ten years ago. The integrity of this publication will be further reviewed on release of additional findings of the Buncefield investigation. Similarly, readers of this publication should keep abreast of technical issues contained in those findings.

This publication may be further reviewed from time to time. It would be of considerable assistance in any future revision if users would send comments or suggestions for improvement to:

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KEY TECHNICAL CHANGES

This section sets out in a generalised form, the key technical changes between the first and second editions of IP 19 (IP *Fire precautions at petroleum refineries and bulk storage installations*). Note that the second edition of the publication also contains numerous editorial amendments.

The key technical changes are to:

— Clarify the scope and exclusions, and describe how users should apply the publication internationally, whether using the FEHM approach or another approach.
— Arrange sections in a logical, sequenced order; thus, the fire-related hazards associated with petroleum and its products are discussed first and this is followed by general guidance relating to the FEHM approach. Thereafter, fire prevention, fire and flammable gas detection, and fire protection systems (both active and passive) are covered in separate sections. There are also sections on response strategies and options, and maintaining an effective FEHM policy.
— Set out a portfolio of FEHM risk drivers; in particular, legislation, life safety, environmental protection, etc.
— Enhance the guidance on fire and explosion scenarios, consequences and modelling.
— Capture improved knowledge of risks associated with fires in large storage tanks, e.g. from the large atmospheric storage tank fires (LASTFIRE) project.
— Recognise that hazard identification and incident prevention are usually the primary concern. Thus, risk reduction measures and methods of controlling residual risk are usually considered once fire prevention methods have been fully addressed.
— Provide guidance on fire scenario analysis, credible scenario identification and design event selection in support of hazard identification.
— Capture the experience gained and developments in risk reduction techniques and equipment, such as by providing more guidance to assist implementation of detection systems (e.g. flammable gas and fire detection and their application) and protection systems (e.g. fire-fighting media and its application using various fire response equipment) in typical installations/areas.
— Provide guidance on maintaining FEHM policy through emergency planning and FSIA by outlining typical approaches. This is supported by typical incident response strategies, an example site-specific emergency response plan (ERP) and an emergency response team (ERT) member competency profile.
— Set out the requirements of pertinent UK and European legislation, such as the COMAH Regulations and the Seveso II Directive respectively.
— Revise guidance on typical fire-fighting media application rates and provide a commentary that recognises incident experience and recent good practice.
— Update the glossary of terms and abbreviations.
— Illustrate technical issues with diagrams and photographs, as appropriate.
— Update the listing of references and bibliography (e.g. codes of practice, design standards, specifications, guidance, etc.) and provide a new listing of contact details for pertinent organisations.

ACKNOWLEDGEMENTS

The 2nd edition of IP *Fire precautions at petroleum refineries and bulk storage installations* was commissioned by the Energy Institute's Distribution and Marketing Safety Committee. The project was contracted to Resource Protection International, whose contributors were Paul Watkins, Niall Ramsden and John Frame. It was directed by a Steering Group that also comprised:

David Athersmith	Consultant (formerly MoD Defence Estates) (member, Distribution and Marketing Safety Committee)
Kevin Westwood	BP (Secretary, Joint Oil and Industry Fire Forum)
Ken Palmer	Consultant (member, Distribution and Marketing Safety Committee)
Gerry Johnson	Fulcrum Consultants (member, Joint Oil and Industry Fire Forum)
Paul Evans	Chevron (member, Major Hazards Working Group)
Mark Scanlon	Energy Institute (Secretary, Distribution and Marketing Safety Committee and Observer, Major Hazards Working Group)

The Institute wishes to record its appreciation of the work carried out by them in providing technical direction to the project.

Comments on the draft of this publication were received during its technical review from several organisations; significant contributions were made by:

Phil Chatfield	Environment Agency
David Hughes	Chevron
Mike Longman	ExxonMobil
Dave Carter	Health and Safety Executive
Dr John Sawyer	Health and Safety Executive

Such comments have been considered and, where appropriate, incorporated. The Institute wishes to record its appreciation of the work carried out by them and others who participated during the technical review.

Project co-ordination and technical editing was carried out by Mark Scanlon (Energy Institute).

OVERVIEW

Section 1 clarifies the scope and exclusions, and describes how the publication should be applied internationally. It introduces the concept of risk-based FEHM, which is the framework upon which the publication is based. It also notes the legislative trend towards a risk-based approach and sets out a portfolio of other risk drivers.

Section 2 outlines the fire-related hazards of petroleum and its products (including their IP classification) and common fire and explosion scenarios that should be considered as part of a risk-based FEHM approach.

Section 3 expands on the key steps in the FEHM procedure: fire scenario analysis – typical scenarios are outlined for various facilities/areas; review risk reduction options – a listing of options is provided; define FEHM policy between the limiting cases of burndown and total protection; and implement FEHM policy, by referring to a range of measures from FSIA through to staff personnel competency development and emergency planning.

Section 4 describes several means of hazard avoidance that aim to prevent unplanned releases and avoid their ignition. Fire prevention measures described include: control of flammable substances; control of sources of ignition; maintenance; site layout; and operations.

Section 5 describes the use of fire and flammable gas detection to give early warning of a fire event in critical installations or where there is a high emphasis on life safety. Their use should enable immediate investigation and/or fire response. The section describes the various types, their application to various facilities/areas and design issues.

Section 6 describes passive and active fire protection measures, which are intended to reduce the consequences of fire. Options, applications and design issues are reviewed for passive fire protection materials in limiting temperature rise and preventing excessive heat absorption. The capabilities of active fire protection media are reviewed for controlling a fire, extinguishing a fire, or preventing ignition during an emergency in typical installations/areas. In addition, media application is reviewed, whether using fixed or semi-fixed systems and portable/mobile fire response equipment.

Section 7 provides incident response strategies for various fire and explosion scenarios to maintain FEHM policy; it includes options for mobile and portable fire response, including the specification, use and maintenance of fire-fighting equipment ranging from fire monitors to responder personal protective equipment (PPE). The guidance on incident response strategies reflects experience and good practice in fire response; it can be used as a basis for developing site-specific fire response strategies accompanied by ERPs.

Section 8 sets out the requirements for maintaining an effective FEHM policy, in particular through emergency planning from high-level incident preplans through to scenario-specific ERPs. In addition, it covers personnel competency development, emergency plan testing and FSIA for fire and flammable gas detection and fire protection systems.

Annex A reviews the requirements of pertinent UK and European legislation, such as the COMAH Regulations and Seveso II Directive, respectively.

Annex B provides the IP classification and physical properties of petroleum and its products, which should be used when assessing their fire-related hazards.

Annex C provides typical applications of the most common fire and flammable gas detection and fire protection risk reduction measures for various installations/areas.

Annex D provides guidance on typical fire-fighting media application rates for various equipment types and fire scenarios, focusing mainly on applying water and foam to large petroleum fires for extinguishment and/or cooling. In addition, some guidance is provided on incident experience and recent good practice.

Annex E provides an ERT member competency profile based on four units: operations; maintenance; procedures; and skills.

Annex F details the European basis of classifying fires and reviews other classification systems.

Annex G provides an example site-specific ERP and an example scenario worksheet. In addition, some benchmark radiant heat levels and their effects are provided.

Annex H provides a glossary of terms and abbreviations.

Annex I provides details of publications referenced and a bibliography of additional ones (e.g. codes of practice, design standards, specifications, guidance, etc.). It also provides a listing of contact details for pertinent organisations.

1

INTRODUCTION

1.1 INTRODUCTION

This section clarifies the scope and exclusions, and describes how the publication should be applied internationally. It introduces the concept of risk-based fire and explosion hazard management (FEHM), which is the framework upon which the publication is based. It also notes the legislative trend towards a risk-based approach and sets out a portfolio of other risk drivers.

Generally, the petroleum industry is successful in minimising fire incidents and containing their effects. This should not lead to complacency, however, and this publication aims to help maintain and, indeed, improve fire and explosion hazard management.

1.2 SCOPE

IP 19 provides guidance on selecting, implementing and monitoring the continuing performance of site-specific justified risk reduction measures – from prevention through detection, protection systems to mitigation measures – to reduce the risk from design event fires at installations that process and store petroleum (e.g. crude oil), intermediates (e.g. naphtha) and refined products (e.g. gas oil). The publication provides a framework of good practice which should assist attainment of legal compliance, in particular with the pertinent requirements of European Seveso II Directive, and satisfying other risk drivers.

Its scope includes petroleum refineries and bulk storage installations (e.g. terminals, depots and larger customer storage installations). In addition, it can be applied to bitumen refineries and bulk storage installations, blending and storage at lubricants installations, and similar petroleum industry installations. Installations excluded from scope are:

- filling stations;
- smaller customer storage installations;
- natural gas storage installations (at ambient conditions);
- processing and storage on offshore installations.

Whilst the publication is built upon the principles of FEHM, the focus is on fire aspects; whereas, explosion hazards, prevention and protection are specialised topics and are outwith the scope.

1.3 APPLICATION

In line with recent legislation in the UK, Europe and internationally, this publication does not set out prescriptive practices for adoption. Instead, it provides good practice guidance on options that may be appropriate for users to implement in order to satisfy pertinent risk drivers; in particular, legislation, safety (e.g. to personnel and society), environmental protection, asset protection, reputation and business interruption.

Reducing the frequency or consequences of fires may assist in risk reduction for any risk driver; yet, when a measure is considered for risk reduction, it should be justified using cost benefit analysis (CBA) and as low as reasonably practicable (ALARP) principles. The reasons why any particular fire risk reduction measure is provided should therefore be understood, appropriate performance criteria for it should be developed, and it should be ensured that it meets those criteria on a continuing basis. Thus, site-specific risk reduction strategies should be adopted and this publication provides guidance on their selection, implementation and monitoring.

This publication is based on a framework of risk-based FEHM, hence its guidance is therefore provided in support of that approach; however, the publication can also be used independently by applying guidance of relevant sections, as summarised in Table 3.1.

IP 19 is based primarily on the UK and European legislative framework, publications (codes of practice, design standards, specifications, guidance, etc.) and good practice. However, its guidance is universally applicable provided it is read, interpreted and applied in conjunction with relevant national and local statutory legislation and publications. Where the requirements differ, the more stringent should be adopted.

This publication can be used as a basis for establishing a consistent FEHM policy for companies with multi-site operations within a country or across several countries. The FEHM approach can accommodate variations in risk drivers in determining the levels of risk reduction measures; for example, in justifying higher levels of risk reduction measures where an installation is critical to a country's economy or of major strategic importance.

This publication is based on the premise that the general design and construction of petroleum refineries and bulk storage installations are in accordance with all relevant legislation and publications (codes of practice, design standards, specifications, guidance, etc.).

The guidance in this publication should assist process safety engineers, safety advisors, designers, emergency planners or others with responsibility for fire and explosion hazard management to meet the pertinent requirements of the European Seveso II Directive, whether sites are classified lower or upper tier.

Whilst the publication provides guidance relating to fire prevention and protection measures to assist implementation, where appropriate, users should consult relevant publications (codes of practice, design standards, specifications, guidance, etc.) for further information. The legislation, publications, etc. referenced are correct at the time of writing; however, users should keep abreast of developments by contacting the pertinent organisations.

1.4 RISK-BASED FIRE AND EXPLOSION HAZARD MANAGEMENT (FEHM)

For the purposes of this publication risk is defined as the product of incident frequency (or probability) and consequences. Thus, it is possible to reduce risk by implementing frequency reduction (prevention) measure(s) or consequence reduction (mitigation) measure(s). In practice, both are applied.

The term risk-based FEHM is used to describe an auditable, integrated approach to risk reduction by the provision of prevention and consequence reduction measures appropriate to the levels of risk. It should be viewed as one method of addressing fire safety issues at an installation and may form an integral part of an installation's overall safety, health and environment management system (SHEMS). The key stages in the approach are:

— Fire scenario analysis.
— Review risk reduction options.
— Define FEHM policy.
— Implement FEHM policy.

This sequence is shown in Figure 1.1, which also includes details of typical input tools at each stage.

The basis of the decision on which risk reduction measures are to be put in place is based on the actual risk determined following a risk assessment which includes an evaluation of typical fire scenarios. Once it has been decided that a particular measure is to be provided then, and only then, are publications (codes of practice, design standards, specifications, guidance, etc.) on fire protection system design used to give guidance on its implementation. In addition, it should be noted that implementation does not just mean the installation of fire systems; it includes system maintenance, preplanning, competency development and assessment of system operation and fire response, exercises and training. Site management should thus be involved on a continuous basis to ensure implementation is continually effective.

The final decision on the most appropriate fire risk reduction options should depend on site-specific conditions. In theory the options can range from no provisions to a totally integrated package of automatic process shut down, depressurisation, fixed automatic fire detection systems and fixed automatic protection systems, backed-up by a full-time occupational fire brigade with mobile equipment. In practice, most installations typically adopt a combination of fixed systems for critical items and mobile response for other areas.

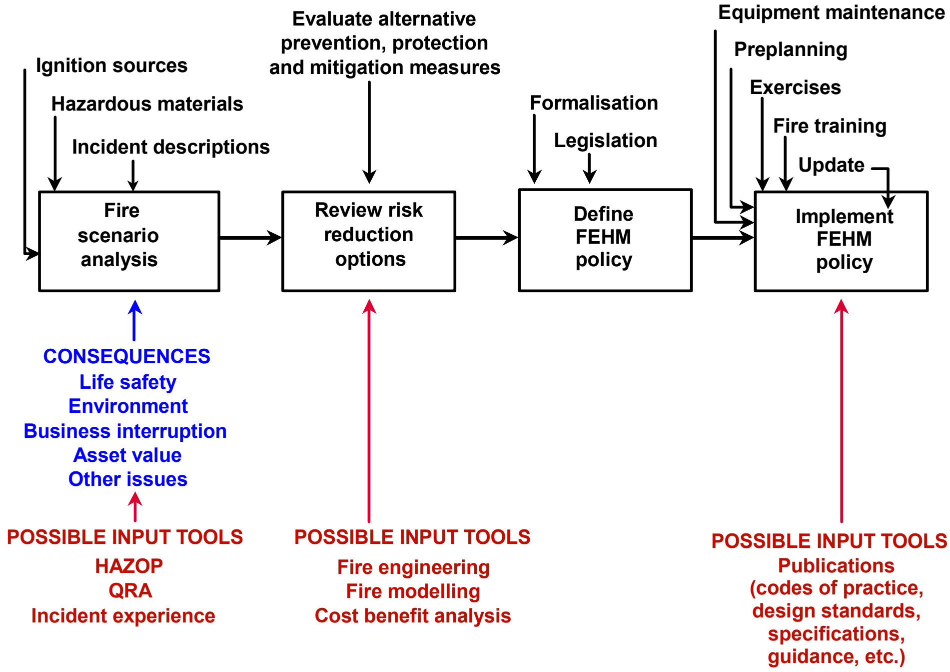

Figure 1.1: FEHM process

By demonstrating the link between potential scenarios and the risk reduction measures implemented, the FEHM process, if carried out properly by competent personnel, should result in a strategy that is consistent with both legislation and business risk reduction requirements.

1.5 LEGISLATIVE TRENDS IN FEHM ASSESSMENT AND PROVISION OF FIRE RISK REDUCTION MEASURES

Following experience from major incidents, UK and European legislation and that in many other parts of the world has moved away from prescriptive requirements. Instead, a risk-based approach has been taken putting the onus on duty holders to demonstrate to the competent authority (CA) that they are taking all necessary measures to reduce risk to life safety and the environment to acceptable levels. This may be achieved by a number of options including both prevention and mitigation measures.

The key European legislation is the European Communities Council Directive 96/82/EC on the Control of Major-Accident Hazards Involving Dangerous Substances (commonly called the Seveso II Directive, named after a major accident at Seveso, Italy), as amended by Directive 2003/105/EC of the European Parliament and of the Council of 16 December 2003 amending Council Directive 96/82/EC on the Control of Major-Accident Hazards involving Dangerous Substances. Each European Community country implements this Directive through national legislation. For example, in the UK it is implemented as the COMAH Regulations, except for land-use planning. See annex A.2 for more information regarding the requirements of the COMAH Regulations.

For enforcement in the UK, the CA comprises the Health and Safety Executive (HSE) and, for England and Wales the Environment Agency (EA), for Scotland the Scottish Environment Protection Agency (SEPA), and for Northern Ireland, the Northern Ireland Environment and Heritage Service (EHSNI).

In the UK, all petroleum refineries and most bulk storage installations are subject to the COMAH Regulations, although only lower tier duties apply for some smaller bulk storage installations. Smaller installations would, in any case, be subject to the Dangerous Substances and Explosive Atmospheres Regulations (DSEAR), which implement European Communities Explosive Atmospheres Directive 99/92/EC and the safety aspects of European Communities Chemical Agents Directive 98/24/EC. See annex A.3 for more information regarding the requirements of DSEAR.

A duty holder may, of course, decide to provide additional levels of fire risk reduction to reduce business and reputation losses. For example, a minor fire incident in a critical part of an installation may have minimal life safety or environmental effects but could cause considerable downtime; hence, additional fire detection or extinguishing systems may be included, not as a matter of safety, but to reduce business interruption.

Thus, there is no conflict between the approach required by regulators to demonstrate the reduction of risk to acceptable levels and that of duty holders to reduce business risk. However, the types of risk that are important to regulators and those additional ones important to duty holders should be defined.

1.6 INTERNATIONAL APPLICATION

Due to the nature of the petroleum industry, many users of this publication will have operations in several countries. This publication can be used to give the basis for fire risk reduction measures under different operating conditions, thus ensuring consistency in approach from location to location. It can therefore be used as a basis for establishing company FEHM policy.

On an international level, the FEHM approach is particularly appropriate where an installation is critical to a country's economy or of major strategic importance. In some areas, oil-related revenues represent the vast majority of national income. This should result in the justification of higher levels of risk reduction measures. Indeed, in some countries these are prescriptively applied. This does not conflict with the guidance in this publication but reflects the levels of risk for such installations.

In some cases, users should seek specialist expertise regarding requirements for, and design of fire precautions and protection systems; for example, where operations are situated in adverse environments.

1.7 RISK DRIVERS

The FEHM process and the consequent provision of cost-effective, justified, risk reduction measures requires a comprehensive review of actual risk, including downstream issues as well as immediate consequences.

Legislators/regulators are concerned about risk to personnel on the installation, to society living around it and to the environment. Whilst duty holders should also see these as their priorities, they should also consider other risk drivers, such as business interruption and reputation (especially for large multi-national companies).

A formal quantitative CBA may ultimately be required to determine whether or not a risk reduction measure is justified, particularly where the major risk is to business interruption and reputation. In other cases, a more straightforward experience-based decision may be used.

The main risk drivers that should be considered are set out in the following sections.

1.7.1 Legislation

Local relevant legislation should be considered as the ultimate risk reduction requirement; if it is not met, then the duty holder may face enforcement action.

As noted in 1.7, regulators should not request duty holders to put measures in place where there is no significant impact on life safety, property and environmental protection. Duty holders who have a robust risk assessment and consequent FEHM policy should be in an advantageous position in such circumstances. Another legislation-related risk to be considered is that of downstream cost repercussions in terms of investigations and the imposition of additional legislative requirements.

1.7.2 Life safety

Life safety is clearly the primary risk driver. This should not only consider the risk to individuals due to the incident itself but also to fire responders, given the chosen response strategy. In addition, life safety risk due to escalation should be taken into account. For example, in a full tank surface crude fire, escalation to a boilover (see section *2.5.5.7*) could lead to multiple injuries and/or fatalities if the response strategy did not include evacuation of personnel from the potentially affected area.

Life safety is often the subject of high levels of risk quantification.

Typically, results are expressed as risks either to personnel (individual risk) or to population groups as a whole (societal risk).

When evaluating the need for risk reduction measures to life safety, risk criteria should be set and agreed with local regulators; they may comprise criteria for personnel and societal risks. Criteria may be based on company standards or regulators' criteria such as those in HSE *Application of QRA in operational safety issues* or HSE *Reducing risks, protecting people*.

1.7.3 Environmental effects

Fires at petroleum installations can have environmental effects in terms of causing loss of product containment, or producing smoke and other toxic combustion products. However, inefficient or incorrect fire-fighting actions can also result in escalating environmental effects. For example, over-use of fire-fighting water can carry petroleum products outside bunded areas and overload wastewater treatment plants.

EA *Environmental impact of controlled burns* recognises that in some cases, subject to a risk assessment (which should be done, in any case, as part of the FEHM process and to satisfy legislation), and under certain conditions, the strategy with least environmental impact may be a controlled burn. The final decision on whether such a strategy is acceptable depends on such factors as potential escalation (e.g. boiling liquid expanding vapour explosion (BLEVE) (see section *2.3.3.3*) or boilover (see section *2.5.5.7*)), long-term smoke production and reputation.

One issue that is becoming an increasing concern is the potential environmental effects of the use of fire-fighting foam. This has mainly, but not solely, been associated with the use of fluorosurfactants which give foams resistance to petroleum product contamination. Some fluorosurfactants have been found to be particularly long lasting in the environment and have an effect on aquatic and other life.

At the time of writing of this publication, no definitive guidance has been issued on which fluorosurfactants (or other ingredients) can be used and under what circumstances. However, users should monitor developments as it might affect the decision on which response strategy should be adopted.

1.7.4 Asset loss

Every fire results in some damage to an installation and hence direct asset loss and subsequent repair or reinstatement costs. In practice, the direct asset loss is usually much lower than the consequential loss. In addition, asset loss is often covered by insurance but consequential loss may not be.

1.7.5 Business interruption

Fires usually lead to short or long term business interruption. This may only be limited to stoppage during the incident itself but, if the damaged installation is critical, then the down time may be prolonged. An example of this is a fire incident at a petroleum refinery jetty which could prevent import of crude and/or export of refined products, thus effectively closing down the refinery.

1.7.6 Reputation

The reputation (i.e. public image) of a company and its perceived capability of being in full control of its installation can be severely affected by a fire incident. This is particularly true for companies operating internationally and for long-duration incidents (such as the controlled burn of a full surface tank fire).

Television footage of incidents can be quickly transmitted around the world, often with ill-informed commentary, and to the detriment of reputation; this may be evidenced in a company's share price.

1.7.7 Insurance

An incident may have a significant effect on the ability of a duty holder to obtain insurance cover at competitive rates. However, insurance cover may also be used to limit the overall financial consequences of an event, particularly if environmental damage and business losses are covered. (In other words, insurance can be viewed as a risk reduction measure by limiting the financial consequences of an incident.)

2

HAZARDS

2.1 INTRODUCTION

Storing, handling and processing petroleum and its products invariably carries a risk of fire, or in certain cases explosion, with threats to life, the environment, assets, business interruption, etc. (see section 1.7).

Combustion and its potential consequences should be fully understood when developing appropriate, justified fire risk reduction measures and fire response strategies.

Petroleum and its products are stored, handled and processed in different ways and this can have a bearing on the type(s) of fire and explosion scenarios and their consequences. Their fire-related properties should also be understood because they influence the probability of combustion as well as fire (or explosion) characteristics.

For example, crude oil and certain petroleum products with a wide range of boiling points may undergo boilover (see *2.5.5.7*) during an incident giving a potential escalation route as well as posing a major hazard to fire-fighters. Other petroleum products might not pose a significant life safety hazard if allowed to burn in a controlled manner, but might require special mitigation measures if extinguishment is to be attempted (e.g. using alcohol resistant multi-purpose foams for polar solvents (see section *6.4.3.4*)).

This section outlines the fire-related hazards of petroleum and its products (including their IP classification) and presents key principles relating to their combustion, as well as common fire and explosion scenarios that should be considered as part of any risk-based FEHM approach.

2.2 FIRE-RELATED PROPERTIES OF PETROLEUM AND ITS PRODUCTS

Crude oil and its derivatives are hazardous substances. The degree of the hazard can be characterised by volatility (as indicated by boiling point/range), flash point, flammable limits, ignition temperature and IP classification.

The flash point of a flammable liquid is the lowest temperature, corrected to a barometric pressure of 101,3 kPa, at which the application of a source of ignition in a prescribed manner causes the vapour of a test portion to ignite and the flame propagates across the surface of the test sample under the specified test conditions.

Flash points are dependent on various factors, including the test method used; the latter should be specified when a value is quoted. For the purposes of this publication, when reference is made to flash point it will be to a closed cup non-equilibrium test method. For liquids having flash points below 40 °C the test method to be used to determine the flash point should be IP 170; whereas, for liquids having flash points above 40 °C the method used to determine the flash point should be IP 34.

The ignition temperature of a substance is the minimum temperature required to initiate or to cause self-sustained combustion independent of a spark or flame. The vapours of petroleum and most petroleum products have ignition temperatures in the range 250-500 °C. Combustible cellulosic materials (i.e. non-hydrocarbon materials such as paper and rags) have lower ignition temperatures. Oil that has soaked into insulation may ignite at a reduced ignition temperature. See Table B.1 for typical ignition temperatures.

The ignition temperature data in Table B.1 should be regarded as approximate only, since they depend on the characteristics of the test method used. Some of the variables known to affect the results are: percentage composition of the vapour-air or gas-air mixture; shape and size of the space where ignition occurs; rate and duration of heating; and catalytic or other effect of the material of the container.

The system of IP classification of petroleum and its products is based upon their flash points (see Table B.2). When handled above their flash point, there is a greater risk of ignition; accordingly, their IP classification will change.

Flammable substances are also characterised by upper and lower flammable limits, between which gases or vapours mixed with air are capable of sustaining combustion. These limits are referred to as the lower flammable limit (LFL) and the upper flammable limit (UFL), and are usually expressed as percentages of the substance mixed with air by volume. For flammable liquids and combustible solids, however, they may be expressed as a mass or volume (e.g. in g/m^3 for dusts). Flammable limits for commonly encountered petroleum products are provided in Table B.3.

2.3 COMBUSTION OF PETROLEUM AND ITS PRODUCTS

2.3.1 General

The three essential conditions that must co-exist before a fire can become established are a sufficient supply of flammable vapour, a source of ignition, and a supply of oxygen (e.g. from air).

The mechanisms of burning in fires and in explosions are different. In a fire the plume of vapour evolved by the fuel has been ignited and continues to burn at the interface with the surrounding air. The rate of burning, which affects the flame length, is controlled by the rate of diffusion of oxygen from the air to the burning vapour; the flames involved are termed diffusion flames. With petroleum and its products the flames are typically yellow or orange in colour, and are usually accompanied by the emission of black smoke. Damage to neighbouring structures is due almost entirely to heat transfer by convection and radiation. Damage by pressure effects is negligible.

In an explosion the fuel vapour becomes mixed with air before it is ignited. Flame then propagates through the mixture, burning the fuel, with the rate of burning governed by the chemistry of the oxidation. The flame is termed a pre-mixed flame. The rate of burning is relatively fast, and the rapid releases of energy can generate sufficient pressure to damage neighbouring structures. Associated heating effects are transient. For petroleum and its products, explosion flames are blue or pale yellow, depending on the stoichiometry of fuel and air. Smoke emission is much less than in fires.

The characteristics of fires and explosions are best considered separately.

2.3.2 Fires

Once a vapour has been ignited it will usually burn as a diffusion flame, which will stabilise in the vicinity of the fuel. The flame travels to all exposed surfaces of liquid above its flash point, providing there is sufficient air supply.

Nearly all the heat produced is distributed by convection and thermal radiation; the majority is convected away. The significance of the convection component is that it forms an upward moving fire plume that rises under the influence of buoyancy.

It has been estimated that up to one third of the heat from a fire is lost as thermal radiation from the flames and accompanying smoke and soot. Radiation from the flames can greatly hinder the approach to the fire by fire-fighters and cause the heating of neighbouring tanks and other installations, requiring cooling water to be applied to keep temperature low. See Section 6 for fire protection measures.

Anticipated wind velocities should be considered when designing risk reduction options. Wind velocity has contributed to transporting petroleum vapour from a neighbouring tank heated by radiation, to a burning tank, leading to flashback of flame to the neighbouring tank and to its ignition.

A consequence of the upward velocity within the fire plume is the effect on fire extinguishing agents applied to the surface of the petroleum fuel. When the agent is fire-fighting foam, it may be swept upwards by the plume instead of falling onto the petroleum liquid surface and so provides neither the desired covering nor cooling effects.

2.3.3 Explosions/boiling liquid expanding vapour explosions

2.3.3.1 General

Firstly, a air/vapour mixture must be within the flammable limits, e.g. in the case of liquefied natural gas (LNG) vapours, not less than about 5,0% or more than about 15,0% of vapour by volume in air. Data on flammable limits are widely available. Table B.3 gives typical flammable limits under ambient conditions of some petroleum products. Flammable limits are considerably wider if the vapour is oxygen-enriched or if substances are processed at elevated temperatures and pressures. The special case of hydrogen should be noted, it being flammable between the wide limits of 4,0% and 75,0% volume in air.

Secondly, a source of ignition must be present. Ignition can take place anywhere in the cloud where the fuel/air ratio is within the limits of flammability; the flame then travels through the vapour cloud, pushing unburnt gas ahead of it and generates a 'shock' wave. Also, a vapour cloud may ignite if any flammable portion encounters a hot surface and is locally heated to the ignition temperature. Alternatively, the whole flammable vapour may be brought up to its ignition temperature. Examples of typical ignition temperatures are given in Table B.2.

If explosion takes place in a confined space, the heat release may result in a pressure rise greater than the walls of the space can withstand. Examples of locations in storage installations where confined explosions have occurred include drainage systems and storage tanks. In addition, explosions have occurred at petroleum refineries in process areas, furnace combustion chambers and flare systems.

It is also possible for explosions to take place in the open air when a large volume of flammable vapour is ignited. Such volumes may accumulate, e.g. from a spill of highly volatile product, or release of high-energy product such as LPG. Where such volumes are confined or there is a degree of congestion (e.g. in a process area) the flammable vapour/air cloud can become very turbulent and explosion severity increases.

Confined and congested explosions are characterised by high flame speeds and overpressures; local personnel cannot escape. These contrast with spills leading to flash fires where flame speeds are generally much lower and escape may be possible.

Explosions may be classified into physical and chemical explosions:

(a) Examples of physical explosions, in which there is no chemical reaction, are over-pressurising a vessel and the explosive vaporisation of water due to very rapid heating. Although a flame may not be involved in the explosion, the result can give rise to a flammable atmosphere.

(b) Chemical explosions may be divided into uniform (or homogeneous) and propagating explosions:
- In a uniform or homogeneous explosion the chemical reaction occurs throughout the mixture simultaneously, e.g. uncontrolled exothermic reaction.
- In a propagating explosion, the chemical reaction occurs in a flame front, which involves only a thin layer of flammable mixture. The flame then propagates through the remainder of the mixture. If the velocity of the flame is subsonic, the propagation is termed deflagration. With a deflagration in a closed volume the pressure rise is effectively uniform throughout the volume. If the flame velocity is sonic or supersonic, propagation is termed detonation. The flame is accompanied by a shock wave that causes localised high pressure, and the pressure rise is not uniform throughout the volume. Detonations and deflagrations are very hazardous, and preventing their development is a main purpose of explosion protection.

2.3.3.2 Pressure effects

For the deflagration of petroleum vapour in air, in a closed vessel initially at 1 bar absolute pressure, the explosion pressure can typically rise to a maximum of 8 bar absolute pressure, unless containment is lost.

If the enclosure is vented, the maximum pressure is reduced. As pressure is equal to force per unit area, a modest pressure exerted over an extended area such as a door or wall can generate a high total force. The strength of the attachment of the door or wall to the remainder of the structure should be adequate.

If a deflagration can accelerate over a long distance, as in an extended pipelines system, it may undergo transition to detonation. In a detonation in air the maximum pressure at the shock front may be as high as 20 bar; the pressure is exerted over a smaller area and for a shorter time than in a deflagration. Detonations have a much greater shattering effect than deflagrations. Although the total amount of energy released is similar, it is concentrated at the shock front and venting does not give protection.

2.3.3.3 Boiling liquid expanding vapour explosion

A BLEVE is usually a consequence of prolonged heating of a pressurised (normally LPG) vessel by an external fire. The vessel may heat up rapidly and fail, spreading burning fuel as it ruptures. The initiating fire may be a pool or jet fire, which heats the vessel, increasing its internal pressure. During the fire, a relief valve may operate and result in an additional jet fire. Regardless of heating mechanism, as the liquid level in the vessel drops due to combustion, the vessel above the liquid level is weakened and can eventually fail due to a combination of continued flame impingement, high heat flux and overpressure. The sudden relaxation of pressure on the liquid inside causes massive instantaneous boiling and release of vapour, which is ignited by the fire. The resultant fireball can take the appearance of a large 'mushroom cloud' (sometimes called a 'ball on a stick') and fragments of the vessel may be projected over several kilometres.

2.4 SMOKE AND GASES FROM FIRE

2.4.1 General

Smoke consists of particulate matter suspended in the gaseous products of combustion, i.e. fire gases. Smoke is formed by the products of partial combustion of the fuel, as well as the products of thermal decomposition.

The composition and quantity of smoke generated by a fuel in a fire are not solely characteristic of that fuel but depend upon fire conditions. Amongst other factors, smoke emission depends upon the air supply, the temperature of the fire and the presence of other materials.

Moisture affects smoke emission in a complex manner. Dampness in solids slows down the rate of combustion and reduces its completeness, and can cause increased generation of smoke. The addition of steam to a flare burning gaseous fuels can reduce the burning rate in the flame, but may also reduce the smoke generation and change its appearance. Addition of water to a liquid petroleum fire either can reduce smoke emission if the fire is subdued, or can increase emission if splashing enhances the fire.

Smoke and fire gases present the following serious health hazards to life:

— Reduced visibility results from obscuration by the smoke and from irritation of the eyes; consequently escape from the fire and efficient fire-fighting is difficult.
— High temperatures of smoke and gases cause damage to the lungs and to exposed skin. They may inhibit attempts to escape from the fire.
— The inhalation of toxic or oxygen-deficient gases can cause death, collapse, or chronic damage, and smoke inhalation can severely damage the trachea and lungs.

Smoke also has the potential to damage the environment, especially if the fire is sizeable and volume production is large.

It is also worth noting that large smoke plumes can also damage company reputation if seen from afar (see section 1.7.6).

2.5 FIRE AND EXPLOSION SCENARIOS

2.5.1 General

The first step in the FEHM process involves fire scenario analysis. Credible fire and explosion scenarios should be identified at each installation on a site-specific basis.

As introduced in Section 1, one way to define and implement appropriate and justified fire and explosion hazard management policies is to adopt a risk-based FEHM approach. This process is increasingly being recognised worldwide as an alternative to prescriptive means of providing fire and explosion prevention and protection measures. NB: The term FEHM includes 'explosions' but it should be noted that explosion hazards, prevention and protection are specialised topics and are outwith the scope of this publication.

As part of this, fire and explosion scenarios should be evaluated for probability and consequences (i.e. risk) so that appropriate, justifiable risk reduction options can be selected.

Scenarios selected as posing appreciable risk, and meriting risk reduction measures may be included in a COMAH safety report used to demonstrate FEHM policy and its implementation. In most cases, documentation should be provided to show that credible scenarios have been identified, and risk reduction measures are in place and maintained as part of the installation's FEHM policy.

Fire scenario analysis can be achieved through a combination of various qualitative scenario analysis tools including hazard analysis (HAZAN)/hazard identification (HAZID)/hazard and operability (HAZOP) and quantitative methods such as event or fault tree analysis. Quantified risk assessment (QRA) can also be used. Industry databases giving incident probabilities can be employed to assist quantitative methodologies. These can be combined with fire and explosion consequence modelling tools to gain an overall assessment of risk.

Incident experience may also provide a useful tool for assessing incident probabilities and consequences. For example, it might be shown that certain types of incident have occurred or are more likely because of certain failure modes, initiating events or even human factors and inadequate practices and procedures (e.g. inappropriate maintenance). Similarly, consequences in terms of life safety, asset loss, environmental impact etc. can be estimated from documented incidents.

2.5.2 Scenarios

A range of fire and explosion scenarios should be considered. In most cases it will be impractical to consider every possible scenario and a balance should be struck between addressing larger, less frequent scenarios that would cause more damaging consequences to personnel, business and the environment, and smaller, potentially more frequent events that could lead to escalation or significant localised damage.

Scenarios should include:

- unignited product releases;
- pool fires;
- atmospheric storage tank fires:
  - vent fires;
  - full surface fires;
  - rim seal fires;
  - spill-on-roof fires;
  - bund fires;
  - boilover;
- jet fires:
  - gas jet fires;
  - liquid spray fires;
- BLEVEs;
- vapour cloud explosions (VCEs);
- flash fires.

As well as the above, potentially toxic product releases should be considered, and it is worth noting that these may have the potential to result in fires and/or explosions if ignited.

The probability and magnitude (i.e. consequences) of these events depend on a number of product factors:

- Release characteristics (e.g. whether the product is released as a gas, liquid or mixture; whether it is of short duration or prolonged).
- Whether the substance released is toxic, flammable or both.
- If flammable, whether ignition occurs, and if so where and when.
- For ignited gas releases, whether overpressures are generated on combustion (this depends on the degree of confinement or congestion, as well as fuel reactivity and strength of any source of ignition).

In addition, incident probability may be increased during activities such as maintenance and start-up operations.

2.5.3 Unignited product releases

Paradoxically, ignition source control measures routinely adopted at installations mean that releases of flammable liquids and vapours (whether pressurised or at atmospheric pressure) have the potential to accumulate and remain unignited. Consequently, the amount of flammable product may be large with potential to create damaging fires and explosion if ignited. For flammable liquid releases, the extent of any fire depends on containment measures, as well as any mitigation such as spill response carried out at the time of the release. For gaseous releases, atmospheric dispersion is of importance. As part of any fire scenario assessment, potential release rates should be determined with the help of a 'source' model. The results of these can be fed into pool fire, jet fire and VCE consequence models to determine fire extent and characteristics. Also, there are a number of gas dispersion models available that can be used to evaluate the magnitude of any vapour cloud.

Unignited product releases generally require careful mitigation and response actions to remove the hazard. These can include containing, neutralising and disposing of the product, or achieving gas dilution or assisted dispersion with the use of water sprays and/or curtains. Such measures are discussed in Section 7.

It is also worth noting that in addition to fire and explosion, unignited releases can pose environmental, toxic and asphyxia hazards and these should be included in any scenario analysis.

2.5.4 Pool fires

Pool fires can be contained (e.g. atmospheric storage tank or bund fires) or uncontained (e.g. unbunded or because of bund overtopping). The ignited fuel usually has very little or no momentum (i.e. it lies in a static pool) and combusts as heat is fed back to the product and it evaporates from the liquid surface. A pool fire can occur in areas such as in bunding below a vessel. If unconfined, the spread can depend on the surface characteristics (e.g. whether hard concrete or permeable), nearby drains and the presence of water surfaces. Pool fire flames are often 'tilted' due to wind effects and can 'drag' downwind for some considerable distance. In addition, they can be accompanied by large quantities of smoke.

Pool fires present a thermal hazard dangerous to personnel and installations. The potential heat flux in the flame of a pool fire may be in the order of 250 kW/m^2.

Fire escalation under pool fire conditions would normally involve direct flame impingement on adjacent tanks, vessels or pipework and valves or prolonged exposure to heat fluxes in excess of 8-12 kW/m^2 near to the fire if there is no protection. Escalation may be much more rapid if exposures are subjected to fluxes in excess of 32-37,5 kW/m^2 nearer the flame.

Pool fires may be preceded by a jet/spray fire as installations or process plants depressurise, and this should be taken into account during any fire scenario analysis.

Note, in many cases, the level of thermal flux from a pool fire determines personnel safety, levels of fire protection that should be provided and emergency response requirements. See later in this section, as well as Sections 7 and 8.

2.5.5 Atmospheric storage tank fires

Atmospheric storage tank fires are, essentially, contained pool fires and can vary from being relatively small rim seal fires (in the case of a floating roof tank) to spill-on-roof fires and full surface fires. The RPI *LASTFIRE* project (see annex I.3) – a joint petroleum industry initiative reviewing the risks associated with large diameter storage tank fires – provides a comprehensive review of tank fire scenarios, as well as typical incident probabilities and consequences based on incident experience and a comprehensive industry database.

The type of fire scenarios to be considered depends largely on the tank construction and to a lesser extent on the product:

— For fixed roof and internal floating roof tanks, vent fires and full surface fires (see *2.5.5.1-2.5.5.2*).
— For open top floating roof tanks, rim seal fires, spill-on-roof fires and full surface fires (see *2.5.5.3-2.5.5.5*).
— For all tank types, bund fires (see *2.5.5.6*).
— For tanks containing crude oil and wide boiling point products, boilover (see *2.5.5.7*).

2.5.5.1 Vent fires

A vent fire is a fire in which one or more of the vents in a tank has ignited. Flammable vapours are always 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 (see section 4.4.3), although instances have occurred when sources of ignition 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 typically occur as a result of overfilling due to operator error, failure of level instrumentation or in normal tank operation.

2.5.5.2 Full surface fires

A full surface fire in a fixed roof tank can be brought about by vent fire escalation. A vapour space explosion can occur if the vapour space is within the flammable range at the time of flame flashback, especially if vents and/or flame arrestors are defective. If the tank is constructed to a recognised publication such as API Std. 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 or fully removed.

2.5.5.3 Rim seal 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. The flammable vapour can occur in various parts of the seal depending on its design.

The most common source of ignition for a rim seal fire, as determined by the RPI *LASTFIRE* project (see annex I.3) is lightning (see section 4.4.3). Clearly, the probability of ignition is increased in areas of the world where 'lightning days' are more common but ignition probability may be further increased if tank maintenance is poor. Other notable sources of ignition for documented rim seal fires include hot work on a 'live' tank where permit-to-work (PTW) procedures (see section 4.5) have failed to identify fire risk.

2.5.5.4 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.

2.5.5.5 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. 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.

2.5.5.6 Bund fires

A bund fire is any type of fire that occurs within the secondary containment area outside the tank shell due to pipe fracture, corrosion, etc. 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.

2.5.5.7 Boilover

Boilover is a phenomenon that can occur when a fire on an open top floating roof tank containing crude or certain types of heavy fuel oils (which contain a range of fractions), has been burning for some time. It can result in large quantities of oil being violently ejected, even beyond the bund. Boilover is a potential escalation route to multiple tank/bund incidents and a major hazard to fire-fighters.

A boilover can occur in crude oil tank fires when the hot zone of dense, hot crude oil created by the burning of lighter ends descends through the bulk and reaches any water base, which may have been augmented by fire-fighting or cooling actions. The water turns to steam, expanding in the order of 1 500:1. This steam pushes up through the bulk, taking crude with it and creates a fireball above the tank. Boilovers have spread burning crude oil several tank diameters from the source, thus escalating the incident and endangering fire responders.

The phenomenon of boilover plays a key role in decision making on the most appropriate and cost effective strategy for crude oil tank fires. Although such events are very rare due to normal operating and design controls, when they occur they can cause major asset, business interruption and reputation damage. Boilovers have been known to cause multiple fatalities as well as fire escalation to adjacent installations.

2.5.6 Jet fires

A jet fire is a stable jet of flame produced when a high velocity discharge catches fire. The flame gives varying amounts of smoke depending on the product and degree of air entrainment during discharge. For example, gas/oil jet fires can produce more smoke than both gas or gas/condensate fires and may also feed pool fires.

Jet fires can result because of ignition of a high-pressure gaseous release, or otherwise because of the combustion of a liquid spray (e.g. a high-pressure crude release).

The proportion of the release burning as a jet or spray tends to increase with the pressure and the volatility of the liquid.

By their nature, jet fires are very hot and erosive and have the potential to rapidly weaken exposed plant and equipment (even if passive fire protection (PFP) is provided) as well as pose a serious thermal risk to personnel. The potential heat flux in the flame of a jet fire can be in the order of up to 350 kW/m^2. Escalation from jet fires would normally involve direct flame impingement or prolonged exposure to high heat fluxes in the region of the flame.

2.5.7 Boiling liquid expanding vapour explosions

See *2.3.3.3* for an explanation of BLEVE.

Pool and jet fire scenarios should be assessed for their capacity to create potential BLEVE situations; these are more likely where fires can burn directly under or close to pressurised vessels containing Class 0 products.

2.5.8 Vapour cloud explosions

A VCE involves the explosive combustion of flammable vapours released to the atmosphere. The consequences of a VCE depend on factors such as the reactivity of the vapour, degree of congestion and confinement and ignition characteristics. Also, characteristics such as vapour density can affect the travel, ease of dispersion and therefore extent of the cloud.

Potential release areas in petroleum refineries are typically very congested with pipework, process units, vessels and other equipment. Ignited releases there have the potential to be major, generating damaging overpressures because the vapour/air mixture becomes very turbulent and the combustion rate increases very rapidly.

Installations and structures within the blast zone may be demolished or severely damaged, depending on the extent of overpressure generated. Personnel may also be at risk from the overpressure, as well as flying debris and blast/heat effects.

For assessment purposes, the probability of vapour releases should be determined along with the likely extent of dispersion. As well as this, the potential for damaging overpressures should be ascertained. A number of explosion modelling techniques are available to carry this out, and some of these are configured to provide 'lethality' data to assist in assessing personnel or societal risk.

2.5.9 Flash fires

A flash fire can occur when the combustion of a flammable liquid and vapour results in a flame passing through the mixture at less than sonic velocity. Damaging overpressures are usually negligible, but severe injuries can result to personnel if caught up in the flame. Also, a flash fire may travel back to the source of any release and cause a jet or spray fire if the release is pressurised.

2.6 CONSEQUENCES

2.6.1 General

The consequences of the fire and explosion scenarios include:

- Thermal fluxes hazardous to plant, buildings and people.
- Potentially damaging overpressures affecting plant, buildings and people.
- Flammable and/or toxic vapour/air 'clouds' hazardous to people and the environment.
- Blast effects and missiles (e.g. because of BLEVE) hazardous to plant, buildings and people.

Depending on release size, and extent of fire or explosion, consequences may be restricted to site areas or the effects may be felt offsite, endangering the public and the environment. Fire and explosion consequence modelling can assist in the assessment of hazard distances. Most models give hazard contours representing the levels of heat flux, overpressure, vapour/air concentration, etc. as a function of distance from the fire or explosion centre. Such models are described in section 2.7.

As well as the above physical consequences, other impacts are possible, such as asset loss, business interruption, reputation etc. These can be very difficult to quantify and are best assessed on a site-specific basis. However, as a guide, some insurance industry estimates place typical consequential incident costs in the order of at least ten times the initial incident cost.

In terms of life safety, fire and explosion consequences have the potential to cause injury or even death; in most cases, additional risk reduction options to eliminate or reduce them should be taken.

2.6.2 Thermal flux – consequence assessment

Both pool and jet fires have the potential to create hazardous heat fluxes in the region of the flame and outside it, and damage or injury to plant and personnel can be a consequence.

For consequence assessment purposes, and to determine fire response resource requirements, times to failure of unprotected plant and potential fire escalation may be in the order of:

- 5 – 20 min. for reactors and vessels at 250 – 350 kW/m^2.
- 5 – 10 min. for pipework at 250 – 350 kW/m^2.

These data should be used for guidance only; times to failure and/or escalation may vary depending on the extent and duration of exposure, as well as the characteristics of plant and equipment. For practical fire response purposes, equipment/plant exposed to 8 – 12 kW/m^2 for a prolonged period will generally need cooling at some stage, possibly provided by mobile means. Fixed cooling equipment should be considered for equipment/plant likely to be exposed to 32 – 37,5 kW/m^2. Fire responders wearing appropriate personal protective equipment (PPE) would normally be able to carry out very brief (<1 min.) tasks if subjected to no more than 6,3 kW/m^2.

Table 2.1 categorises the potential consequences of damaging radiant heat flux and direct flame impingement. See also IP *Guidelines for the design and protection of pressure systems to withstand severe fires.*

2.6.3 Overpressures

VCEs can result in damaging overpressures, especially when flammable vapour/air mixtures are ignited in a congested area. Personnel may be killed or injured by blast effects, and buildings, plant and equipment could be damaged or demolished.

Assessing consequences for VCE scenarios involves considering the release size, and potential fireball and overpressure effects generated by the explosion. As a guide, the overpressures given in Table 2.2 are often used as a basis for damage assessment.

Table 2.1: Heat flux consequences

Thermal flux (kW/m^2)	Consequences
1 – 1,5	Sunburn
5 – 6	Personnel injured (burns) if they are wearing normal clothing and do not escape quickly
8 – 12	Fire escalation if long exposure and no protection
32 – 37,5	Fire escalation if no protection (consider flame impingement)
Up to 350	In flame. Steel structures can fail within several minutes if unprotected or not cooled

Table 2.2: Overpressure consequences

Static overpressure (barg)	Consequences
0,01	10% window breakage
0,03	Injuries from flying glass. 50% window breakage
0,15	Partial collapse of brickwork, roofs lifted. 100% window breakage
0,3	Destruction of steel-framed buildings, ear-drum rupture. Severe roof damage, people killed by falling masonry
0,5	People in the open picked-up and thrown. Severe masonry damage, rail tank wagons overturned, trees snapped in half
0,7	Severe structural damage to heavy steel and reinforced concrete buildings. Rail tank wagons ruptured and reactors overturned

2.6.4 Flammable/toxic vapour clouds

Accidental releases of flammable and/or toxic substances can have wide ranging consequences including:

— Incapacitation and/or death of onsite personnel and offsite populations.
— VCEs if ignited.

For example, a release of highly toxic substance such as acrylonitrile or hydrogen fluoride might require immediate evacuation of affected areas or sheltering in a temporary refuge to safeguard personnel. If the release has potential to travel offsite, further emergency procedures should be considered. Also, there may be localised depletion of oxygen after an ignition and this should be taken into account if personnel are trapped in wreckage.

Vapour dispersion modelling can help to assess potential consequences (i.e. hazard distances and vapour/air concentrations) associated with such releases.

2.6.5 Blast effects/missiles

In some cases, events such as BLEVE or pressure vessel burst will result in fragments of plant and equipment being projected with obvious danger to people and structures. The consequences of this are more difficult to assess. However, documented BLEVE events and incident experience have shown that fragments can be projected over several kilometres, and some consequence models now include ways of assessing this potential.

2.7 FIRE AND EXPLOSION MODELLING

2.7.1 General

In an area where flammable liquids and gases are processed, handled or stored it is often possible to predict the physical effects of fires and explosions to assess the threat to personnel and to consider whether incident escalation is possible.

Recent advances in fire, explosion and gas dispersion modelling techniques enable fire protection engineers to determine with some confidence the potential effects of accidental releases of flammable fluid through the use of sophisticated computer programs or simulations. However, fire and explosion modelling alone cannot act as a substitute for an overall FEHM approach, in which incident experience, fire engineering and process awareness all play a significant part.

Fire and explosion modelling can be used to:

— Quantify the physical effects associated with fire and explosion such as heat radiation, explosion overpressure and flame shape or length. These calculations can be used to assess whether personnel and fire responders will be placed at risk in the immediate or surrounding environment.
— Determine the response of plant and equipment to heat radiation and blast loadings and estimate the likelihood of incident escalation due to factors such as the erosion or failure of vessels and piping/equipment by flame or heat radiation.
— Determine the response of buildings to heat radiation and blast loadings, and estimate what the consequences may be for the occupants, if either they remain in the building or attempt to escape.

— Highlight the need for fire protection or mitigation measures such as PFP or water spray for cooling purposes. Additionally, analyses can be used to underline the requirement for additional fire-fighting resources.

Results of modelling can be included in scenario-specific ERPs to provide guidance for technicians and fire responders in the early stages of an incident. Information such as heat radiation or overpressure contours can be superimposed on installation plot plans to assist incident response.

2.7.2 Types of model

2.7.2.1 Pool fire

For the purposes of assessing risk to personnel, plant and equipment it is most often the heat radiation component that is modelled although the amount and toxicity of smoke can also be addressed. Most models express levels of heat radiation in terms of kW/m^2, representing these as contours in the final output. Also, the degree of flame tilt and drag due to wind effects can be shown, since this can bring the fire closer to downwind objects and engulf them. A typical pool fire model output might appear as shown in Figure 2.1, with the results of an analysis being used in an ERP, shown opposite. In this example, the contours produced by a pool fire model have been superimposed on a storage tank in order to represent the levels of heat radiation and their distances, from a full surface fire. (It is worth noting that this type of analysis or 'firemap' could equally be used to show heat radiation emanating from pool fires beneath vessels and other process equipment).

2.7.2.2 Jet fire

From a modelling perspective factors such as flame length and fire duration should be addressed, since they determine the degree of flame impingement, subsequent heat transfer and therefore escalation potential. Jet flames tend to be extremely erosive due to their significant momentum, and so modelling jet fire behaviour can assess the likelihood of PFP damage. A typical jet fire model gives similar contours to the pool fire model, enabling risk to personnel and equipment to be considered. Recently, more sophisticated computational fluid dynamics (CFD) models have evolved allowing more in-depth calculations of flame temperature in specific regions, and detailed breakdowns of convective and radiative heat transfer.

A typical jet fire analysis also requires modelling of fuel release rates. These should be found by using a separate 'source' model, which may be part of the fire-modelling package. Release rates invariably have a bearing on fire duration and flame length, and should be estimated from credible scenarios, e.g. as a result of small-bore pipe work, pump seal ruptures and larger equipment failures. Also, it is possible to model jet fires (and subsequent pool fires if liquid 'rains' out of the plume) whilst taking into account a plant's blowdown strategy.

2.7.2.3 Gas dispersion

It is also possible to estimate the likely size, composition and flammability characteristics of accidental gas releases by modelling release rates. This should be carried out if the gas release may threaten large areas of process plant and personnel due to the risk of a VCE. Gas dispersion models are especially

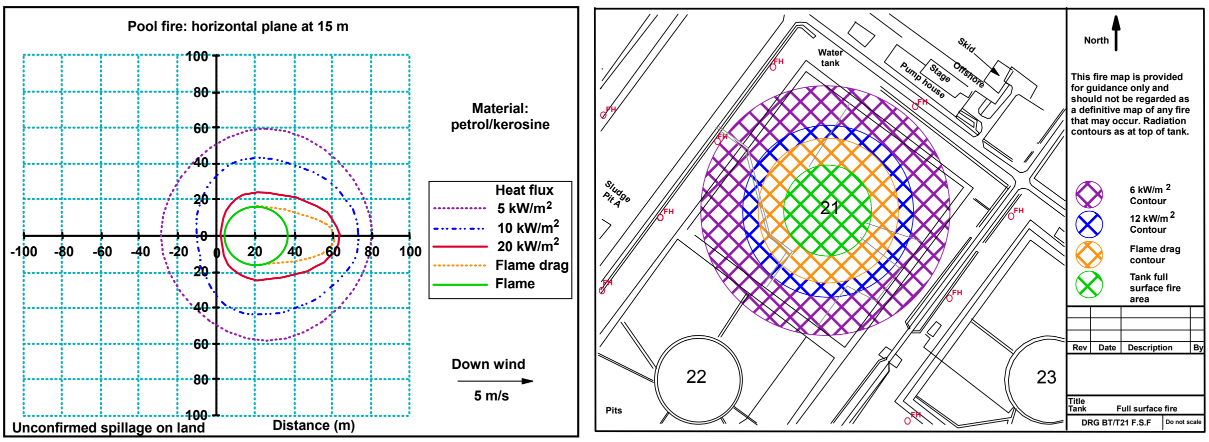

Figure 2.1: Typical pool fire analysis and fire-map aspect of scenario-specific ERP

useful when specifying and planning the location of flammable or toxic gas detection, since it is possible to determine potential gas concentrations at specific locations, and hence select and position detectors able to respond at a point well before the LFL or toxic threshold. Also, this type of model can be used to determine the extents of the flammable range, whether or not gas will accumulate at low points if heavier than air, or indeed whether pockets of potentially explosive gas/air mixtures might exist at a particular point. Modelling can therefore help to define a significant gas hazard in terms of risk to personnel and assets. From a fire response perspective, the results can be used to track gas movement and provide guidance relating to the deployment of water curtains and other barriers to gas dispersion. More sophisticated models may even be able to portray the degree of mixing within congested areas and allow these results to be fed into further explosion severity analyses.

2.7.2.4 Explosion models

Regardless of model type, the approach is usually to calculate or specify maximum potential explosion overpressures upon the ignition of gas/air (in some cases fine droplet/air) mixtures. The results can be fed into the design of blast-resistant buildings in petroleum refineries, or to study the effect of plant design modifications in reducing explosion overpressures (See CIA *Guidance for the location and design of occupied buildings on chemical manufacturing sites*). The technique can also be used with very good effect for emergency response purposes and can aid the production of ERPs by indicating evacuation requirements.

Historically, explosion models such as the TNO multi-energy model have been used to determine potential hazard consequences. However, this method is not always appropriate for all VCEs and new approaches such as congestion assessment, exceedance and other CFD-based models are typically used.

3

FEHM PROCEDURE

3.1 INTRODUCTION

The concept of risk-based FEHM was introduced in Section 1. It recognises the input to fire risk reduction from a wide range of issues and enables selection of cost-effective site-specific strategies that are directly relevant to real needs.

The FEHM technique involves a scenario-based evaluation of credible incidents, an assessment of their potential consequences and quantification and implementation of the resources required to respond to them. (It should be realised, however, that not all possible scenarios may be foreseen, nor may excessive analysis be desirable).

As noted in section 1.7, meeting legislation alone is insufficient because this is primarily aimed at life safety and protecting the environment. In addition, incident consequences to other risk drivers should be assessed.

This section expands on the key steps in the FEHM procedure and outlines typical risk reduction options. Finally, guidance is given on selecting appropriate FEHM policies and implementing them.

3.2 FIRE SCENARIO ANALYSIS

This forms the first step of any risk-based FEHM approach. Its purpose should be to identify fire scenarios, and assess them in terms of incident probability and consequences to build a picture of the overall risks at an installation. Depending on these risks, appropriate and justified FEHM strategies aimed at reducing risk can be selected and implemented as part of an overall FEHM policy.

The aim should be to recognise and select credible fire scenarios on a site-specific basis. The scenarios that should be considered are outlined in Section 2, and include pool fires, jet fires, BLEVEs, VCEs, and flash fires.

The first step should be to identify hazardous substances and processes along with potential sources of ignition. Scenarios should then be described and potential consequences outlined.

As part of this, various scenario analysis tools may be used to evaluate incident probability and consequences. These can include:

— HAZAN/HAZID/HAZOP;
— QRA;
— event trees;
— fault trees;
— estimated maximum loss;
— risk matrices;
— industry databases;
— incident experience;
— fire and explosion modelling.

Use of these techniques can help to focus on the probability of potential loss of containment events and sources of ignition, as well as indicating the likely consequences of an incident in terms of asset loss, personnel safety, business interruption etc. Risk matrices and QRA techniques are particularly useful tools in assigning 'numerical' values of risk that can be compared against risk criteria.

The types of generic fire scenarios that can occur at various installations are well understood and are described in 3.2.2.

3.2.1 Identification of major fire scenarios, hazards and hazard characteristics

Typical fire and explosion scenarios are discussed in section 2.5.

In addition to fire scenarios associated with plant/storage areas, other fire hazards and events such as cellulosic fires and electrical fires should be identified for probability and consequences. External fire sources that are not immediately obvious should also be considered. These may include those initiated by events such as tanker fires, collisions, vegetation fires, etc.

Each identified hazardous event might result in a range of possible scenarios. Usually, scenarios should be selected that represent the most significant consequences to personnel, production and the environment. The most appropriate way is to carry out a risk analysis aimed at identifying these, which also takes incident probability and consequences into account. Following this, it should be easier to select credible design events meriting risk reduction options and further, define the role of fire prevention and protection systems in reducing risk.

In most cases, it will be impractical to consider every possible scenario and a balance should be struck between addressing larger, less frequent scenarios that could cause more damaging consequences and smaller, potentially more frequent events that could lead to escalation or significant localised damage.

An example of a smaller, more frequent event might be fire resulting from an ignited pump seal release or a localised fire in an electrical cabinet – both of which may have significant consequences in terms of production continuity.

An example of a larger, less frequent event may be a full surface tank fire or large bund fire causing extensive damage with high consequences.

Consequently, recent risk-based legislation will often be satisfied if a range of credible scenarios is addressed as well as a smaller selection of larger, less credible but nevertheless potentially high consequence events.

In selecting and evaluating scenarios, consideration should be given to the following factors:

- installation design features;
- human factors (e.g. human error);
- failure modes;
- probability of failure/release;
- locations of releases/potential release points;
- fuel characteristics (density, flash point, composition, ignition temperature, heat output etc.);
- release characteristics (e.g. pressure, temperature etc.);
- degree of isolation/quantity of isolated inventory;
- release size;
- probability of ignition;
- ignition location;
- mitigation measures;
- potential consequences (life safety, environment, production).

A useful way of selecting scenarios is to draw up a list of installations or plant areas and examine possible generic fire or explosion events (e.g. pool fires) for probability and consequences. In other words, the question should be asked, "how probable is this scenario, and what consequences will it have?" A range of scenario analysis tools is available for this purpose (see 3.2), but to assist, a list of typical scenarios for various installations and areas is given in 3.2.2.

As well as the initial effects of fire or explosion, consideration should be given to whether and how escalation can occur and if this can affect personnel, adjacent plant and the environment. Escalation might also render fixed fire-fighting installations ineffective, and this should be addressed as part of the scenario analysis.

Escalation analysis can be carried out by using event and/or fault tree methods, HAZOP, etc. Such scenario analysis tools are useful in identifying potential escalation routes and failures, which might result in a particular level of risk. By using such techniques, additional risk reduction options can be identified to reduce either probability or consequences.

Industry databases and incident experience can also be used to estimate the probability of escalation from given fire or explosion scenarios.

3.2.2 Typical scenarios for various installations/ areas

Scenario analysis tools (see 3.2) should be used to define potential fire and/or explosion events.

It should be remembered that any fire incident is possible; however, whether it is credible or not is a decision that should be made based on incident probability and through examination of potential consequences.

Incident probabilities and consequences vary depending on the nature of the event or installation, and each scenario should be assessed on an individual basis.

For major petroleum fires to occur there would need to be a loss of containment (i.e. a release or spill) and a source of ignition. Process parameters such as temperature and pressure as well as the size and nature of any release will determine the type of fire or explosion event anticipated.

The following sub-sections set out installations/ areas that should be assessed.

3.2.2.1 Process areas

In many process areas, flammable fluids are typically at elevated temperatures and pressures. Releases may be in the form of liquid sprays, or vapour jets depending on these and other factors such as hole size, substance composition, release location and point of ignition. Also, releases from atmospheric plant could result in product accumulation under vessels and other plant. Scenario analysis should identify what type of event could be expected.

Some examples of typical generic fire/explosion events for process areas include:

— flammable or toxic product releases (liquid or gaseous phase);
— VCE, e.g. as a result of delayed ignition of flammable vapour;
— pool fires, e.g. because of an ignited flammable liquid spill;
— spray fires, e.g. from a pressurised flammable liquid release;
— jet fires, e.g. ignition of a pressurised vapour release.

Remote product pumps and manifolds are also potential sites for the above, and should be included in any analysis. In all cases, consequence modelling can assist in estimating the size and composition of releases as well as their consequences (e.g. flame lengths, pool size and flammable regions).

3.2.2.2 Atmospheric storage tanks

The types of scenario for atmospheric storage tanks are well understood. The type of event depends to a large degree on tank construction, safety features, product volatility and potential for loss of containment. Typical fire scenarios that should be considered include, for particular tank types:

— vent fires (fixed roof tanks or internal floating roof tanks);
— vapour space explosion (fixed roof tanks);
— contained and uncontained spill fires;
— rim seal fires (open-top floating roof tanks);
— pontoon explosion (open-top floating roof tanks);
— spill-on-roof fires (open-top floating roof tanks);
— full surface fires (fixed, internal and open-top floating roof tanks).

These events are also discussed in section 2.5.

Incident probabilities and escalation routes for these events are well-documented in industry databases such as RPI *LASTFIRE*. (In most cases, large events such as full surface fires result from an initiating fire such as a spill-on-roof fire or vapour space explosion).

As well as bulk storage areas (tank farms) there may be external areas for petroleum storage in intermediate bulk containers (IBCs). For guidance on safe storage, reference should be made to HSE *The storage of flammable liquids in containers* or equivalent.

3.2.2.3 Pressurised storage tanks

The types of scenarios associated with spheres or bullets containing pressurised LPG that should be considered include:

— combined jet/pool fire;
— vent fire, e.g. from ignition of LPG released from a pressure relief valve (PRV);
— jet fire, e.g. resulting from ignition of a release from valves or pipework;
— BLEVE.

In some cases, a pool fire will result from an initial jet fire if the tank is depressurised (due to product burn-off or emergency shutdown (ESD)). The most likely sites for jet fires would normally be from associated pipework or valves. BLEVE is a potentially high consequence event that should not be overlooked (see section *2.3.3.3*).

3.2.2.4 Road tanker vehicle and rail tank wagon loading areas

Road tanker vehicle and rail tank wagon loading areas often handle a wide variety of flammable substances ranging from LPGs and hydrogen to bitumens, as well as process intermediates and other refined products. Product transfers through loading and unloading arms or hoses are potentially hazardous operations. Most fire events occur through ignition of accidental product loss of containment due to breakout of hoses and couplings, etc.

In such cases, a pool fire could occur if the spill is ignited. Also, liquefied gases or other very volatile products may ignite close to the source of release and cause a flash fire or jet fire.

BLEVE should also be considered as a possibility if a prolonged pool or jet fire is likely close to, or under road tanker vehicles and rail wagon tanks containing liquefied gases and other high-energy products.

3.2.2.5 Jetties

As well as spill fires resulting from accidental releases of product from loading or unloading arms, ship fire incidents should also be considered, since they may threaten jetties. A VCE is also a possibility in areas of confinement or semi-confinement, particularly where large releases of liquefied gases are considered as a potential scenario.

In addition, flash fires and/or spill fires can result at jetty 'roots' around product pipelines, especially if there is potential for loss of containment around motorised valves.

3.2.2.6 Electrical/switchgear facilities and substations

Petroleum installations invariably include critical switchgear, electrical installations, substations/ transformers and associated cabling. Some of these may utilise oil-filled equipment and the risk of pool fires should be examined. For electrical installations, fires can originate from faulty equipment. Initially, fires may smoulder and go unnoticed if appropriate fire detection is not installed.

Fires can also occur within computing facilities, motor control centres (MCCs) and other critical enclosures. They can originate from the equipment themselves, mechanical media, or auxiliary equipment such as air conditioning units or cooling systems. Such fires may only cause localised damage but could have an effect on production continuity and data integrity.

3.2.2.7 Turbine enclosures

Turbine enclosures may utilise flammable substances such as oil, hydraulic fluids and fuel gas. They generally consist of the following areas and potential fire scenarios:

— control compartment – electrical fires;
— auxiliary compartment – liquid jet, gas jet and electrical fires;
— turbine compartment – liquid jet, gas jet and electrical fires, short duration gas explosion;
— generator – deep-seated electrical fires.

Each of these potential fire incidents should be reviewed as part of a risk analysis.

3.2.2.8 Buildings

Support buildings and offices are also potential fire locations and credible fire scenarios should be addressed. Fires including cellulosic (i.e. ordinarily combustible materials) as well as flammable liquids and gases should be examined. Some examples of potential fire locations can include:

— control rooms;
— laboratories;
— warehouses/ storage areas;
— workshops;
— pump houses;
— generator enclosures;
— administration buildings;
— accommodation.

Where appropriate, factors such as the fire load, presence of flammable gases and liquids and hazardous processes such as hot work, should be taken into account to determine fire scenarios.

Fires in storage areas containing bulk storage of flammable liquids in IBCs should also be considered. Tests have demonstrated that when ignited (e.g. by oil-soaked rags or paper under IBC valves) containers can melt dramatically in a matter of seconds and pool fires can spread over a large area. Similarly, idle pallet storage in these areas can represent a significant fire hazard.

3.2.3 Design/credible scenario selection

Credible scenarios that are selected from risk assessments as meriting further risk reduction options because of their probability or consequences can be termed 'design events'. This is illustrated in Figure 3.1 where design events can consist of one or more prevention, control and mitigation measures for identified fire hazards and scenarios.

As part of this process the role of prevention, control and mitigation measures, including those of fire prevention and protection systems should be identified. For further guidance, see section 8.9.3. For example, the role of a gaseous fire protection system might be to control or extinguish a deep-seated electrical fire within an enclosure.

The selection of appropriate design events varies between installations but the following factors should be considered:

— Whether to include risk reduction for less frequent, catastrophic events.
— Whether risk reduction is appropriate.
— What ESD time should be used.
— Whether the fire/explosion characteristics merit risk reduction.
— What other emergency response measures can be implemented.

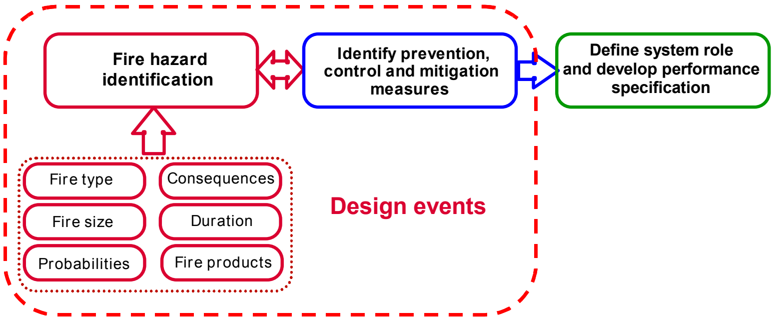

Figure 3.1: Design/credible scenario selection

In some cases, CBA should be applied to determine whether to design and implement risk reduction options. For example, it might be shown that the annual statistical costs associated with an incident far exceed the amortised costs of implementing a particular risk reduction option. This is explained further in 3.3.

A particularly effective way of selecting appropriate design events is to use a risk matrix approach in which potential scenarios are superimposed on a grid. Both incident probability/frequency and consequences can be assigned numerical values to obtain an overall risk 'score'. Risk reduction measures can then be considered for incidents above a certain threshold and incident strategies can be developed.

An example of a risk matrix (used in the exploration and production sector) is shown in Figure 3.2. Such a matrix can be easily adapted for use at petroleum refineries and bulk storage installations.

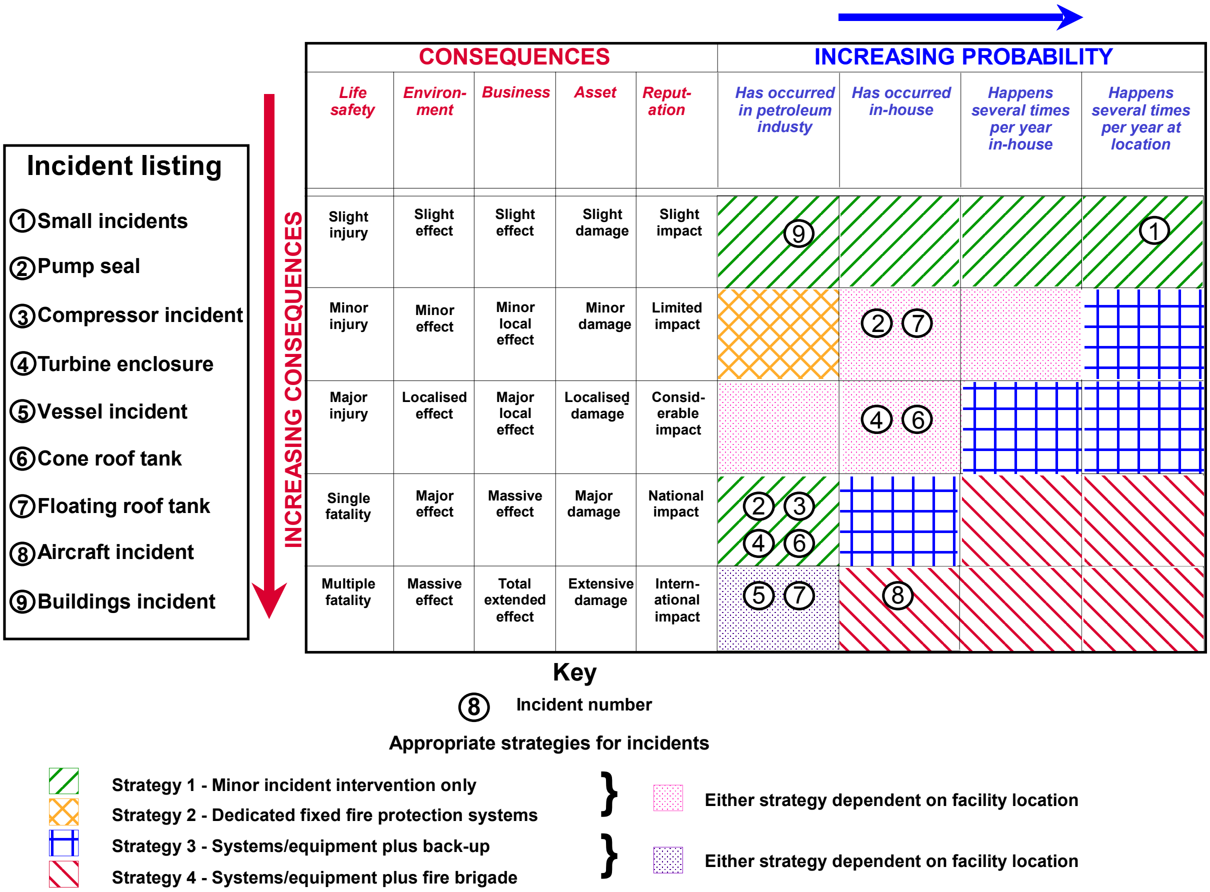

Figure 3.2: Scenario risk matrix

In Figure 3.2, credible scenarios are identified and appropriate strategies are matched to incident risk. Thus, high-risk events might merit fire-fighting systems and possibly fire brigade intervention. Events that are considered lower risk (top left of the matrix) might benefit from minor intervention only (e.g. using portable fire-fighting equipment).

Decisions on which risk reduction measures are to be implemented should therefore be based on the actual risk. Having made the decisions, publications (codes of practice, design standards, specifications, guidance, etc.) on fire protection system design can be used to give guidance on implementation.

Also, once appropriate risk reduction measures have been identified (see 3.3) good fire engineering judgement and practices should be applied for design and implementation. As part of this, a framework of FSIA should be adopted (see 3.5.2).

3.2.4 Fire and explosion modelling

Typical approaches to fire and explosion modelling are described in section 2.7.

It should be noted that modelling can only give an approximate indication of the likely consequences of a particular fire or explosion scenario. It should never be used to 'predict' the effects of an incident with certainty. Although modelling techniques are now very advanced, interpretation requires great skill and care. Consequently, the results should be used as 'guidance' to assist in developing appropriate response strategies (i.e. as a tool to help decide policies, rather than to decide them alone).

3.3 RISK REDUCTION OPTIONS

Fire and explosion risk reduction can be achieved in many ways:

- elimination or substitution of fire and explosion hazards;
- fire and explosion prevention measures;
- fire and flammable gas detection;
- emergency shutdown;
- PFP;
- active fire protection systems;
- salvage.

This is illustrated in Figure 3.3.

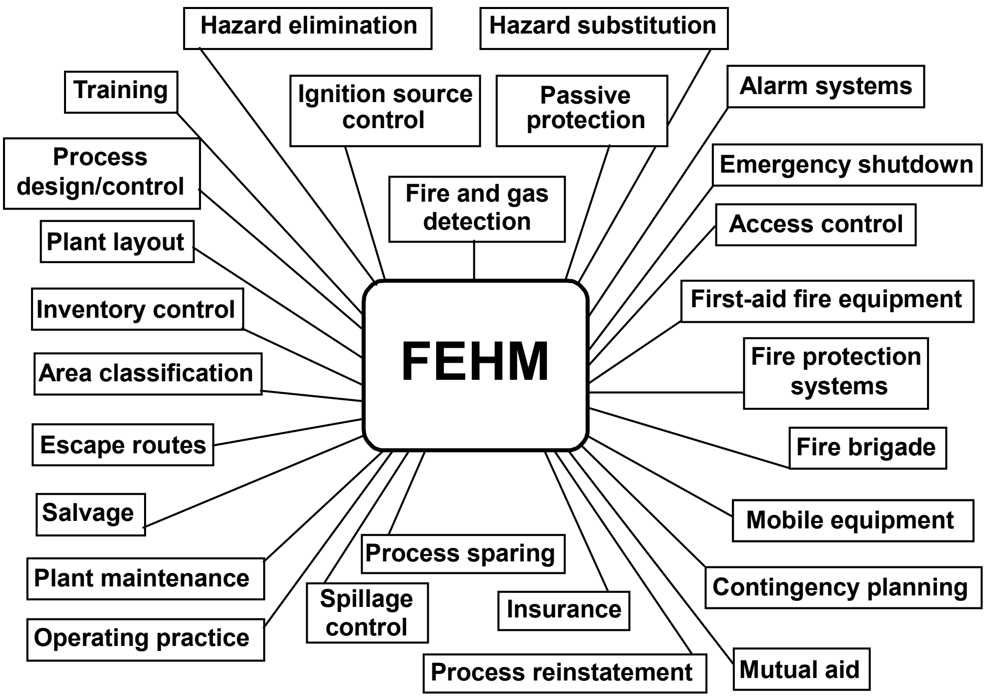

Figure 3.3: FEHM risk reduction options

The approach should be to consider risk reduction options in the following order of importance:

— fire prevention;
— fire and flammable gas detection;
— active fire protection and PFP measures;
— fire response requirements.

Regardless of the method(s) of risk reduction employed, it is vital to assess each in terms of its contribution to overall FEHM.

Guidance is given on the most common risk reduction options in this publication. To locate the appropriate section, see Table 3.1. However, for clarity the following general measures should be addressed:

— inventory control;
— site layout to minimise fire consequences;
— flammable and combustible product control and containment;
— safe working practices and procedures including ignition source control;
— fire and flammable gas detection measures;
— alarm systems and communications;
— escape and evacuation arrangements;
— fire control and extinguishment (fixed, semi-fixed or mobile systems);
— emergency procedures and plans;
— pre-fire planning;
— fire response training.

Alternative prevention, protection and mitigation measures should be evaluated. The most appropriate way of achieving this is to adopt a scenario worksheet approach in which scenarios are identified, current risk reduction measures are outlined and potential risk reduction measures are evaluated for appropriateness and effectiveness. As part of this, necessary resources (i.e. prevention, protection and fire response measures) should be listed.

Table 3.1: Risk reduction options guidance

Risk reduction option	Section
Fire prevention measures	
— Control of flammable substances	4.2
— Atmospheric monitoring	4.3
— Control of sources of ignition	4.4
— Permit-to-work systems	4.5
— Maintenance practices	4.6
— Housekeeping	4.7
— Site layout	4.8
— Buildings fire precautions	4.9
Flammable gas detection	5.2.1
Fire detection	5.2.2
Passive fire protection – Options, applications and design issues	6.2
Active fire protection	6.3
Extinguishing media	6.4
— Water	6.4.2
— Foam	6.4.3
— Dry powder (dry chemical)	6.4.4
— Gaseous agents	6.4.5
— Fixed systems – Options, applications and design issues	6.5
— Water spray systems	6.5.2
— Fixed monitors	6.5.3
— Sprinkler systems	6.5.4
— Water mist systems	6.5.5
— Foam systems	6.5.6
— Dry powder (dry chemical) systems	6.5.7
— Gaseous systems	6.5.8
Fire equipment	7.6
— Portable and mobile fire-fighting equipment	7.6.1

Any identified FEHM shortfalls should also be identified, and risk reduction measures considered to correct these.

Risk reduction measures should aim to reduce either probability or consequences, or both:

Risk = probability x consequences

Reduced probability or consequences → reduced risk

CBA is one way of justifying a particular risk reduction option (or options) in line with ALARP-type principles. See HSE *Reducing risks, protecting people*. A risk reduction measure is cost beneficial if the cost of the following quantitative relationship applies:

$$\{(C_{without} \times \gamma_{without}) - (C_{with} \times \gamma_{with})\} \times Pr_{control} > \text{Cost of implementation}$$

where:

- $C_{without}$ is expected cost of incident without option in place;
- C_{with} is expected cost of incident with option in place;
- $\gamma_{without}$ is expected statistical frequency of the initiating event if option is not implemented;
- γ_{with} is expected statistical frequency of the initiating event if option is implemented;
- $Pr_{control}$ is probability that option will perform as required.

3.4 FEHM POLICY

As every installation operates in its own particular environment, the optimum, cost-effective incident consequence reduction strategy/policy should be developed taking into account local conditions, the installation's criticality and an incident's potential effect on life safety, the environment, assets, continued operations and company reputation.

Previously, fire protection practices used in major hazards industries have been very prescriptive in approach and were not based on the real needs of a particular installation. However, due to major incident experience, legislators/regulators, such as NFPA (USA) and HSE, require goal-setting performance-based standards within a safety report. Consequently, requirements for cost effective fire protection resources should be assessed and justified based on credible major incident scenarios.

Essentially, if both parties adopt risk-based approaches to FEHM then there should be no conflict. Policies based on meeting legislation alone are not necessarily appropriate or sufficient.

As noted in section 1.7, a number of drivers should be taken into account when developing appropriate FEHM policies. These include life safety and the environment, as well as asset loss, business interruption and reputation.

Most companies adopt a policy somewhere in between providing 'total protection' policy and adopting a 'burndown' policy; see Figure 3.4.

Thus, the overall aim should be to establish, in an auditable way, a formal, site-specific justified and cost effective fire and explosion damage mitigation policy appropriate to the criticality and overall needs of the installation.

The most appropriate way to achieve this is to use fire and explosion scenario analysis. Following this, appropriate and justified risk reduction measures can be adopted and implemented.

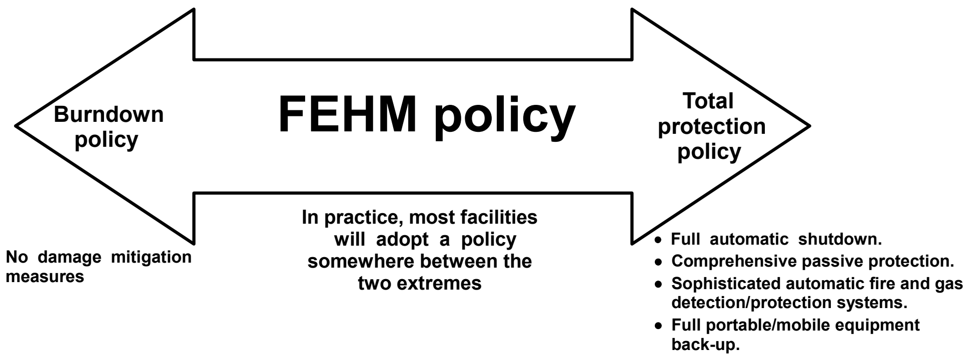

Figure 3.4: FEHM policy options

Of course, many publications (codes of practice, design standards, specifications, guidance, etc.) are available and these should be used where appropriate to assist in implementing risk reduction options appropriate to the FEHM policy.

In many cases, protection over and above the requirements of these documents may be required. If this is the case, all assumptions and design philosophies should be stated.

Once a policy has been decided and appropriate risk reduction measures (see 3.3) have been implemented, the policy should be maintained through relevant practices and procedures, system testing and maintenance, preplanning etc. For more guidance, see Section 8.

3.5 IMPLEMENTATION

To effectively implement FEHM policy as part of a SHEMS, the following issues should be addressed:

- practices and procedures;
- FSIA:
  - inspection and testing of fire systems;
- emergency response preplanning:
  - fire response training;
  - fire response exercises;
- competency development;
- monitoring.

3.5.1 Practices and procedures

This refers to various aspects of FEHM such as:

- continuing hazard identification, assessment and control;
- incident and near-miss reporting;
- safe operating procedures and working practices;
- safety induction;
- control of sources of ignition;
- PTW systems;
- protective clothing;
- pre-planned maintenance (PPM).

Guidance on some of these issues is given in Section 4.

3.5.2 Fire systems integrity assurance

FSIA is a structured approach aimed at ensuring the implementation of test, inspection and maintenance procedures for fire systems. For guidance, see section 8.9.3.

3.5.3 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 should be quickly identified. When defining schedules and procedures, the reliability of system components and the levels of risk reduction that the system is designed to provide should be considered. 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 demonstrates that the functional performance can be achieved.

If appropriate schedules and procedures are unable to be drawn up, then guidance should be sought from manufacturers' recommendations and recognised publications (codes of practice, design standards, specifications, guidance, etc.) (see annex I.3). For guidance on inspection and maintenance of fire equipment, see section 7.6.3.

3.5.4 Fire response preplanning

The only way that fire incidents can be handled safely and effectively is to ensure a formalised and justified strategy that everybody involved understands is in place, 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. Even if the FEHM policy is burndown, an appropriate ERP should be developed to formalise it.

Strategic incident preplans should be developed addressing non-fire response issues such as production continuity, media reporting, human resources and other aspects of incident management. For further guidance, see section 8.3.

The implementation of risk-based legislation (e.g. under the Seveso II Directive) specifically requires duty holders to demonstrate emergency preparedness and to develop, maintain and exercise pre-fire plans for major incidents. These should serve as training aids for fire responders, enabling desktop and practical exercise response performance to be measured. For further guidance, see section 8.7.

Pre-fire plans should be supported by scenario-specific ERPs (see section 8.8) that provide instant written instructions, guidance and helpful information for operators and fire-fighters to assist them at the critical early stage of a major incident 'on the ground'. In addition, they should provide sufficient potential hazard information to enable informed decisions to be taken regarding the safety of personnel responding to the incident. As part of this, regular exercises and responder competencies should be implemented. For further guidance, see section 8.9.1.

Preplanning is only of value if the equipment that is going to be used in the fire response is well-maintained and the ERPs are exercised regularly to check that they are workable and that those involved are competent and aware of their role in a real incident.

3.5.5 Competency development

As well as fire responder competencies, personnel involved with the upkeep of fire and other safety systems as well as plant maintenance should undergo regular review and assessment. This should be aimed at ensuring that personnel have the necessary skills to work safely and contribute to continuing safety. For further guidance, see section 8.6.

3.5.6 Monitoring

Monitoring processes should be implemented as part of a management of change approach to ensure that:

- Incidents and near misses are recorded and reviewed.
- Fire systems maintenance practices and testing procedures are reviewed for effectiveness.
- Personnel training and competencies are kept up-to-date.
- Fire risk assessments are periodically recorded and reviewed.
- Risk reduction measures are reviewed for continuing effectiveness.
- Practices and procedures are updated or revised where necessary.
- Fire response training is regularly reviewed.
- Safety education and training are effectively implemented and updated.
- Safe working practices are followed.

4

FIRE PREVENTION

4.1 INTRODUCTION

This section describes several means of hazard avoidance that aim to prevent unplanned releases and avoid their ignition.

Fire prevention can be considered as the first step in effective FEHM; it includes many aspects of installation design, operation, inspection and maintenance aimed at avoiding fire and explosion by preventing accidental releases and avoiding ignition.

Duty holders should in the first instance minimise the probability of fire or explosion before considering other risk reduction options such as fire and flammable gas detection and passive or active fire protection systems.

This can be achieved with the following preventative measures:

— control of flammable substances (and other combustible materials);
— atmospheric monitoring (e.g. flammable gas detection);
— control of sources of ignition (e.g. through hazardous area classification);
— controlling hazardous work (e.g. PTW systems);
— using well-designed maintenance schedules and procedures;
— good housekeeping to minimise fire hazards;
— effective site layout to minimise fire risks and escalation potential;
— buildings fire risk assessment and fire prevention.

4.2 CONTROL OF FLAMMABLE SUBSTANCES

4.2.1 General principles

The petroleum industry handles a wide range of products derived from crude oil that are processed in downstream units; they range from LPGs and hydrogen to bitumens, as well as process intermediates and other refined products. If released at storage or processing conditions these streams behave differently, forming gases, sprays or pools of liquid. They may freeze or spontaneously ignite and the vapours may rise or form dense, low-lying clouds. Additionally, releases may be acutely toxic if they contain hydrogen sulphide.

Duty holders should be familiar with the properties of the substances they handle. In addition, they should know immediately of losses of containment so that they can activate the appropriate ERP.

4.2.2 Liquid releases

Many potential releases (e.g. from leaking valves or pipe joints) can be eliminated by good operational and maintenance practices; however, small liquid leaks and discharges can sometimes occur during normal plant operation (e.g. from manual and continuous analyser sampling). Wherever possible, releases should be contained at source and either returned to the plant or to a closed system. Liquid leaks should be collected and removed safely. Secondary containment can be used to prevent petroleum liquid carry-over to other areas, or to direct larger spills to a safe area, and prevent fire spread in the event of ignition.

4.2.3 Flammable atmospheres

Flammable atmospheres are often present at petroleum refineries or bulk storage installations. Small quantities of vapour may exist during routine operations, in the vicinity of loading and unloading operations, or released from vents (e.g. as a result of the normal, daily 'breathing cycle' of a tank).

Prevention measures should be implemented where applicable to minimise vapour releases to atmosphere. These may include:

— inerting;
— vapour recovery;
— closed system design and/or avoiding open system design;
— prompt maintenance;
— venting.

In many cases, environmental requirements should minimise emissions; for example, by using primary and secondary seals in the rim seal areas of floating roof tanks.

Flammable atmospheres can also arise as a result of accidental spills, loss of containment resulting from failure of vessels or pipework, operator error, or simply because flammable concentrations of vapour are expected to occur in certain areas from time to time.

Flammable atmospheres can also be formed within a nominally empty tank due to residual product adhering to the tank walls and the roof underside. Vapours emitted present a fire and/or explosion risk, particularly during filling or tank cleaning operations.

4.2.4 Isolation/depressurisation

The amount of fuel involved in a release can be minimised by plant isolation and depressurisation. This should reduce the probability of a large fire and should also reduce fire duration and consequences in the event of ignition.

Vessels and equipment containing large inventories of flammable substances should be equipped with isolation valves that are accessible in emergency conditions. Valves to relief systems should normally be locked open. However, due to radiation from fires, it may not always be possible to operate valves manually and automatic 'fire safe' isolation valves should be provided, or otherwise the valve(s) should be situated outside any potential fire area.

Remote operation for larger valves should be given consideration, especially if access during an emergency would be hazardous. Remotely operated valves used for isolation of flammable substances and the associated power supply lines should be fitted with PFP if they are in the potential fire zone near to the protected equipment. The valves should be routinely tested, on-line if practicable, or as part of shut down and start-up procedures, and their use should be included or simulated in emergency exercises (see HSE *Emergency isolation of process plant in the chemical industry*).

Draining and depressurising valves should be provided for clearing material from a system when normal process lines cannot be used. They should be routed to a recovery system or flare rather than to atmosphere or ground.

4.2.5 Flammable gas/vapour dispersion

The aim of gas dispersion is to reduce the concentration of any flammable gas to below the LFL as quickly as possible and within the shortest distance from the leak. This can be achieved by using fixed water sprays, monitors or fan spray nozzles positioned to aid the dispersion of gas into the atmosphere and divert it away from fixed sources of ignition in plant areas.

If provided for gas dispersion, fixed sprays and monitors should be located where experience has shown there is the greatest probability of serious releases. For deployment techniques, see section *7.2.1.3* and section *7.6.1.9*, respectively.

NB: Adequate collection, drainage and oil/water separator facilities should be provided for water used for gas dispersion purposes. Also, gas releases may be accompanied by flammable liquid and this too should be managed.

4.3 ATMOSPHERIC MONITORING

Installations processing flammable gases or liquids where there is a possibility of a loss of containment producing a flammable atmosphere, may require flammable gas detectors to give advance warning of a developing hazard. This is especially applicable to installations that have a small operational staff and where large sections are virtually unstaffed or staffed only during daytime working hours.

A scenario-based review of potential gas release incidents should be carried out, preferably with the use of dispersion modelling. Appropriate flammable gas detectors may be selected to detect foreseeable releases. The purpose of flammable gas detection should be to give enough warning of potentially hazardous gas concentrations in plant and building areas. Detection should be set to alarm at a point well before the LFL is reached – typically < 20% LFL. Flammable gas detectors can be used to perform executive actions such as plant shutdown, isolation or damper activation to prevent ingress of flammable atmospheres into buildings.

When selecting flammable gas detectors, units should be chosen that are stable and reliable in the particular environment of the plant. Most flammable gas detectors include 'reference sensors' that are able to recognise potentially spurious alarm sources such as fog, dust, humidity, etc.

4.4 CONTROL OF SOURCES OF IGNITION

4.4.1 General

Control of sources of ignition refers to the practices and procedures necessary that aim to prevent accidental ignition of petroleum and its products.

Potential sources of ignition include:

— naked flames;
— welding and cutting equipment;
— smoking;
— friction and sparks generated by equipment and/or vehicles;
— thermite sparks;
— electrical lighting;
— electrical equipment not suitably certified for use in a hazardous area;
— hot surfaces;
— radio equipment/ mobile telephones;
— static electricity;
— incandescent particles;
— pyrophoric scale/deposits (e.g. in crude oil/ bitumen tanks);
— flares;
— external sources.

One or more of the above sources can ignite combustible solids, flammable liquids and flammable atmospheres.

To control ignition risks, the following precautions should be adopted:

— Controlling hot work and grinding through PTW procedures (see 4.5).
— Declaring hazardous areas (see IP *Area classification code for installations handling flammable fluids*).
— Prohibiting smoking, except in designated 'safe' areas.
— Vehicular restrictions, where practicable.
— Prohibiting non-certified electrical, electronic and mechanical equipment.
— Wearing of anti-static PPE (e.g. clothing and footwear).
— Following anti-static procedures when loading/unloading.

The above controls are usually only necessary within ignition source control areas. However, when applied across an installation they can help to reinforce good FEHM as part of a SHEMS or overall safety culture. Control of sources of ignition should be reinforced regularly with the help of signage, and for visitors and contractors incorporated within a site induction process.

4.4.2 Static electricity

Static electricity is generated when relative movement results in charge separation and accumulation on different parts of plant or liquid surfaces. If the plant is not earthed or if the liquid has a low electrical conductivity the charges may accumulate more quickly than they can dissipate and cause an electrical discharge to adjacent equipment in the form of a spark. With sufficient energy this could ignite a flammable atmosphere, depending on the ignition energy of the gas or vapour concerned.

Static electricity is undoubtedly a major source of ignition, particularly during tanker loading/unloading, product transfer and gauging operations. For static electricity to cause fire or explosion, four conditions need to be met:

— A means of static generation.
— A means of accumulating charge and maintaining a potential difference.
— A spark with sufficient energy.
— A spark in a flammable atmosphere.

Operations and process conditions susceptible to static electricity generation in the petroleum industry include:

— High velocity and turbulent mixing e.g. in pipelines, at the discharge of jets from nozzles, tank mixing, etc.
— Filtration, particularly through micropore elements, with a large surface area exposed to fluid flow.
— Liquid droplets or foam falling through a vapour, e.g. spray or mist formation in vapour spaces.
— Splash filling of tanks or tankers.
— Application of fire-fighting foam to an exposed fuel.
— Settling of water droplets through petroleum

liquids, e.g. in tankage.
— Bubbling of gas or air through petroleum liquids.
— Water jetting in tank cleaning.
— Movements of belts and sheets of material over pulleys and rollers.
— Movement of vehicles, fans, persons etc.
— Movement or transport of powders.
— Release of steam to the atmosphere.

Anti-static precautions can include:

— Earthing and bonding.
— Using anti-static additives.
— Reducing flow velocities.
— Avoiding splash filling.
— Restricting tank sampling.
— Wearing anti-static PPE, e.g. clothing and footwear, which should be regularly tested.

All persons involved in process, maintenance or fire-fighting operations should have a basic understanding of static electricity as it affects their own work. For further guidance, see IP *Guidelines for the control of hazards arising from static electricity*.

4.4.3 Lightning

In recent years, a number of proprietary lightning protection systems have become available. However, there are no internationally recognised publications (codes of practice, design standards, specifications, guidance, etc.) clearly defining design parameters and efficiency of such systems for use at petroleum installations.

Standards such as NFPA 780 and others, which deal with the installation of lightning protection systems, generally make no specific attempt to define applicability of proprietary systems, other than recognising that tanks should be suitably grounded. These precautions may be necessary to conduct away the current of direct lightning strikes, and to avoid the build-up and potential that can cause sparks to ground.

4.5 PERMIT-TO-WORK SYSTEMS

Legislation and good practice require duty holders to ensure safe working practices are carried out during maintenance, repair and hazardous operations.

The probability of fire incidents can be increased when personnel (including staff, contractors and delivery drivers) have little knowledge of the hazards associated with petroleum products, and if correct safety procedures are not carried out. For this reason, personnel should be competent in the correct use of PTW systems through regular training and refresher training.

PTWs should ensure that:

— All hazards are identified. (Personnel should be trained to recognise the physical properties and fire-related hazards of flammable substances, and to ensure that the activity to be carried out does not introduce any new hazards to the area without appropriate precautions being taken.)
— Correct precautions and safety equipment, including appropriate PPE, are used.
— Clear and adequate instructions are given to all personnel relating to the work/equipment concerned.
— Conflicts between interacting operations are avoided and there is clear authorisation and communication regarding potentially hazardous tasks.

Permits should typically cover:

— Personnel entry into special areas.
— Testing, maintenance or repair work on plant and equipment including equipment disjointing, electrical isolation, etc.
— Personnel entry into confined spaces (e.g. tanks, vessels, sewers, excavations, etc.).
— Vehicle entry into plant or storage areas.
— Introduction into plant or storage areas of naked flames or other sources of ignition (e.g. use of burning, welding, brazing, grinding, grit blasting, pneumatic drilling and non-certified electrical and battery powered tools and equipment).
— Excavation work.
— Use of particularly hazardous substances (e.g. radiation sources).
— Precautions associated with inert gas for fire protection.
— Installation and operation of non-standard, temporary, process equipment or bypassing of equipment.

Further guidance can be found in HSE *Guidance on permit-to-work systems*.

4.6 MAINTENANCE PRACTICES

4.6.1 General

Many maintenance practices can be potentially hazardous and require fire prevention to be considered by management and operators prior to, during and following the work. Such maintenance activities should be subject to a PTW system (see 4.5).

For example, breaking containment can lead to releases of flammable gases or liquids, whilst sparks are often generated during hot work practices such as grinding or welding, increasing the chance of ignition.

Other maintenance practices, particularly on safety and fire protection equipment, require systems to be temporarily disabled. This could increase the probability of fire occurring or potential consequences should a fire develop. Such maintenance activities should also be subject to a PTW system (see 4.5).

Before maintenance work can be carried out, personnel should plan thoroughly. Process knowledge, approvals from operations personnel and hazard awareness should be in place. Safety and Fire Officers should be consulted during the planning phase of a major turnaround.

At the design stage, plant areas should be laid out to enable safe access and working. Special areas or buildings for maintenance work should be provided. These areas should be a suitable distance away from possible sources of hazard arising from the plant.

Materials and supplies should be safely stacked and stored. Personnel issuing and checking them should ensure they are kept in their proper location. Where mixed goods are stored, combustible materials should be alternated with non-combustible items (other than oxidising agents) where practicable, in order to prevent extensive fire spread. Also, tools, accessories and equipment should be safely stored in cabinets, racks or suitable containers. Work areas and work benches should be kept clear and clean.

Handling of waste should be given special consideration. Waste and rubbish containers should be provided in appropriate locations, and emptied regularly. Clean rags and waste should be stored in metal containers. Oily rags should be placed in self-closing or covered metal containers and emptied at the end of every shift. Combustible material should be properly disposed of and stored in appropriate containers. Plant areas and out of the way places should be kept clean, well lit and free from waste material.

Flammable liquids in small quantities should be kept in dedicated containers (e.g. made of materials that are impact resistant and compatible with the fluid), and kept in a suitable fire resisting cabinet. Larger quantities should be stored in purpose-built stores, labelled as hazardous, in a safe area away from buildings.

4.6.2 Hot work

Hot work is any activity which may involve, or have the potential to generate sufficient heat, sparks or flame to cause a fire. Hot work includes welding, flame cutting, soldering, brazing, grinding and using disc cutters and other similar equipment.

Before such work commences, suitable fire extinguishers should be available (see sections *7.6.1.1-7.6.1.5*). Operators should be competent to use them, and in hazardous areas, standby fire-fighting personnel should be considered. Adequate precautions should be taken to prevent flame, sparks or hot metal from starting fires in adjacent materials, at lower levels or the surrounding area in open plant. For example, the area could be wetted and drains covered, or vents protected where vapours could escape to the atmosphere. The atmosphere should be regularly monitored to check the safety of the operation. Where necessary, the requirement for such checks should be written into the permit.

4.6.3 Electrical equipment used for maintenance

Portable electrical equipment such as power tools, lighting and test equipment, associated cables, plugs, sockets etc., and temporary installations for maintenance purposes, should conform to the requirements of IP *Electrical safety code*. Their use should be subject to PTW procedures and examination by a competent person. Equipment not meeting these requirements should be used only under hot work PTW procedures.

Particular care should be paid to the condition of equipment, cables, connections etc. to minimise the risk to personnel and the possibility of fire.

Portable pneumatic or hydraulic powered tools, though generally considered safe from the viewpoint of power supply, may produce sparks due to their application. They should therefore be subject to hot work PTW procedures when used in hazardous areas.

4.6.4 Hand tools

The use of 'non-sparking' tools is not recommended in petroleum installations; such tools are misnamed because they can sometimes produce sparks on impact. As they are made of relatively soft metal, particles of harder spark producing materials can become embedded. They also have a low mechanical strength.

When tools or equipment are used in a hazardous area, then hot work PTW procedures should be followed. Consideration should also be given to covering the ground or surface below the work to prevent sparks due to possible impact. The equipment and the area should be wetted to prevent and quench sparks.

4.6.5 Chemical cleaning

Chemical cleaning is used when mechanical means are either unsatisfactory or impracticable. The substances used may be inhibited acids, alkalis or proprietary products formulated for a particular cleaning operation. Many solvents may be flammable liquids. A temperature approaching the boiling point of water may be necessary in some cases.

Chemical cleaning can lead to the evolution of flammable and/or toxic gases or vapours, for example when removing scale-containing sulphides. Appropriate precautions should be taken for the safe disposal of such gases, not only from the equipment being cleaned but also from any temporary surge tank and pipework. Operators should also wear appropriate PPE. Drains are required on each piece of equipment and at all high and low points on associated pipework in the loop.

4.6.6 High pressure water

High pressure water jetting is commonly used for cleaning purposes. In addition to the dangers of water impact there is a risk of electrostatic charges being developed which are potentially dangerous in the presence of flammable mists that can be generated by water jetting. See 4.4.2.

4.7 HOUSEKEEPING

Good housekeeping should include the following precautions:

— Maintaining indoor and outdoor plant areas in an orderly condition free from fire and other hazards.
— Minimising combustible materials and wastes.
— Storing flammable liquids and flammable/ combustible waste in closed, non combustible containers.
— Safely disposing of flammable and combustible wastes at frequent intervals.
— Segregating empty and full or part full flammable liquid or gas containers.
— Storing flammable liquids and gases outdoors in dedicated areas.

Plant areas should be kept in a clean and tidy condition. Releases of petroleum, its products and other process fluids should be prevented where practicable. ERPs including spill control measures should be in place to activate assistance in the event of a significant release posing a fire (or consequential environmental risk). Particular attention should be paid where leakages saturate insulation on hot or traced line systems or tanks, since spontaneous ignition can occur. Minor, low hazard leaks of substances such as waxes, oils, bitumens, etc. should be collected in drip trays and the cause should be remedied as soon as possible.

Access-ways and roads should be kept free from obstruction and maintenance materials should be removed promptly after completion of work. Items forming a temporary obstruction should be clearly marked as a hazard and brought to the attention of process supervisors and operators. Close attention should be paid to the condition of cladding and PFP materials on process vessels, columns and tanks. In some cases, loose cladding may allow ingress of water, causing hidden corrosion and weakening of the structure. Where necessary, it should be repaired promptly to avoid the risk of it becoming detached and creating a hazard.

Regular and systematic inspections should be made to ensure that safe, clean and orderly conditions are maintained. PTW systems should therefore address tidying-up and safe disposal etc.

Vegetation likely to constitute a fire risk should be cut short within 6 m of any storage building containing flammable or combustible materials. Cuttings should be removed to a safe place.

Sawdust or other combustible materials should not be used for soaking up spills of flammable liquids. Dry sand or absorbent inert mineral material should be used or otherwise proprietary spill kits suitable for the purpose.

4.8 SITE LAYOUT

4.8.1 General

The layout and general design of a petroleum refinery or bulk storage installation should be optimised with respect to safety, operational efficiency and environmental protection.

National regulations (e.g. COMAH) and local regulations including petroleum-licensing conditions, building regulations and local bylaws, may have specific layout requirements and should be consulted at the design phase of an installation. For example, the preparation and submission of a pre-construction safety report can be a requirement under Seveso II-type legislation. Discussions should be held at an early stage with all authorities responsible for these and any other requirements. Formal approval should be obtained before construction work commences.

Some petroleum companies have in-house standards for site layout and minimum separation distances may be specified. These may be based on experience and can in many cases be used as a starting point for layout purposes. However, for optimisation purposes, there should be additional considerations.

Under a goal setting (i.e. risk-based) legislative framework, detailed layout studies and fire protection analyses should be carried out. Their purpose may be to optimise installation layout, whilst considering necessary FEHM measures. For example, fire protection such as water spray systems might be considered (depending on potential fire exposure and emergency response, etc.) if land use needs to be optimised and storage tanks or plant are to be situated close to each other. For a typical study, the following should be considered:

— Credible fire scenarios at the installation (e.g. pool fire, pressurised gas jet or liquid spray fire, etc.).
— Fire probability and consequences (e.g. potential for asset damage).
— Potential fire exposures, including personnel and buildings and implications for life safety (e.g. is the flame from the fire likely to impinge on adjacent equipment, vessels etc. or will nearby items and personnel be exposed to high radiant heat levels?).
— Potential risk reduction options or mitigation measures (e.g. fixed water spray systems or foam systems), including the extent of spacing/separation required between items or areas of plant.

Generally, spacing between tanks and other items of plant can be relaxed with a higher degree of fire protection. For example, if PFP (i.e. a fire wall) is provided between two critical product pumps, then greater separation may not be required.

In some cases, appropriate fire detection backed up by a rapid fire response (whether by fixed fire-fighting systems or by manual means) can allow relaxation.

In all cases, criticality of plant and equipment and implications of loss for asset damage, business interruption and reputation should be considered, as well as those for life safety.

For areas where personnel are normally present (e.g. loading and unloading areas) there may be considerations for access and emergency egress. Also, appropriate areas should be set aside to allow safe vehicle movement, and features such as crash barriers should be installed to prevent collision with plant and structures.

In heavily built-up areas, a risk assessment should be carried out to determine both personnel and societal risks (see section 1.7.2) arising from potential fire or gas release events. The use of fire and explosion modelling and other scenario analysis tools such as event tree analysis can assist in this purpose.

For buildings and other occupied structures, potential for external fire spread should be assessed. Fire could start and spread because of exposure to fires within plant areas or it could propagate due to fire spread from adjacent or adjoining buildings. Generally, a 'clear' area should be provided around buildings where possible to minimise fire spread.

4.8.2 Boundaries

Installations should be surrounded by a suitable security fence or wall of minimum height of 2 m. Where petroleum installations are situated within a fenced or controlled area, such as dock or harbour premises, the requirements for fencing may be relaxed by agreement with the local controlling authority.

4.8.3 Storage tank layout/secondary containment

Installations intended for the handling of only Class II(1) or Class III(1) petroleum products present a lower level of risk than those handling Class I, Class II(2) or Class III(2). However, safe separation distances of storage and handling installations from boundaries should still be observed for these products having regard to the installation's location and the nature of its surroundings.

Normally, good tank design and operations good practice should prevent large product releases. Catastrophic tank failure is one possibility, but is usually considered a low probability event. Although considerable research has been aimed at the subject of bund overtopping, good bund design and minimising potential for large releases in the first instance should significantly reduce the probability of such an event. Tank inspection practices aimed at identifying potential corrosion points well before a leak could develop should be implemented as part of a site pre-planned inspection and maintenance programme.

Above-ground tanks should be provided with a form of secondary containment, which will serve to contain any releases that may occur. Bunds or walls may be constructed from earth, concrete, masonry or steel, or a combination of these. They should be substantially impervious to liquid and capable of withstanding the hydrostatic pressures to which they may be subjected. The floor of the bund area should be substantially impervious to petroleum and its products in order to safeguard groundwater quality. Environmental regulations and water protection standards should be observed in the design of compounds, drainage systems and impounding systems.

Intermediate walls of up to half the height of the main walls, but normally not more than height 0,5 m may be provided within a bund area to control losses of containment and avoid the spread of substance to the vicinity of other tanks sharing the same bund. Such walls should divide the tankage into groups of a convenient size.

When planning tank bunds and bund walls, the bund should be capable of holding a volume equal to 110% of the maximum capacity of the tank.

As an alternative to these designs lower walls may be employed in conjunction with systems to direct the lost product to an impounding basin at a convenient, safe location.

The maximum total capacities of tanks within a single compound should be:

(1) Single tanks, all classes, including crude oil	No restriction
(2) Two or more floating roof tanks	120 000 m^3
(3) Two or more fixed roof tanks	60 000 m^3
(4) Crude oil tanks	Not more than two tanks of greater individual capacity than 60 000 m^3

The data for (2), (3) and (4) may be exceeded provided that an assessment indicates no significantly increased risk of environmental impact or to people. Such assessment may take account of developments in floating roof seal technology and practice and should consider the design of appropriate fire protection and extinguishment measures.

For guidance on storage tank separation distances in relation to fire risk reduction options (including bunding), see annex C.2 and Table C.1.

4.8.4 Process plant layout

Process areas should include access-ways for fire-fighting, as well as routine inspection and maintenance. Some guidance on process plant layout includes:

- Access-ways should be arranged in a rectangular grid pattern, so that fire-fighting can take place from two opposite sides.
- To limit fire spread, low walls or kerbs should be provided and each should be connected to a drainage system (but not any storm water system). These can assist foam blanketing and limit fire spread caused by low flash point products floating and burning on the surface of the water (carry-over). However, during fire-fighting, it should be recognised that the drainage capacity of kerbed areas may be exceeded and flooding may occur under full fire-fighting water application rates.
- Fixed water spray or foam systems should be considered for high-risk equipment where fire-fighting access is poor or if items are vulnerable to fire exposure. PFP should also be considered.

4.8.5 Fire-fighting access

Pre-fire plans (see section 8.7) should identify emergency vehicle access points, including means of gaining entry where unattended or remotely-operated secure entry systems exist. Roads and crossings, as well as overhead pipe rack clearances, should allow emergency vehicles easy access to all areas of the site. Main roads should also be suitably surfaced and drained. Speed bumps, which could limit response times, should not be provided on emergency routes.

Roads or access over firm ground should be provided to allow fire appliances to approach within reasonable operating distance of the hazard. Access should be kept free of obstruction. In certain circumstances, railway lines may impede access for fire appliances. Each case should be considered separately, but for initial guidance, access should be provided within 20 m to 45 m of the hazard. Water supplies should be available at these places.

A subsidiary road should be provided in large installations for general access and fire-fighting purposes around the perimeter. This road may be sited within the safety distance specified for the spacing of tanks from the boundary and should have access to the public road system at two points at least. Secondary access to the site should normally remain secure or locked and with well-defined arrangements for opening in emergencies. Connecting roads should normally be arranged to permit approach from two directions to all major fire hazards onsite.

Roadways should be provided with passing spaces for fire vehicle access if they do not permit two lanes of traffic. Recommended widths for two-directional traffic and for single directional traffic should not normally be less than 6 m and 4 m respectively. Cul-de-sacs should be avoided, but, if necessary, should be provided with adequate turning areas. Road junctions and curves should be constructed with sufficiently large turning circles to ensure easy vehicle manoeuvring. It may be necessary to provide one or more vehicle turning points and to cater for emergency vehicles, such as by providing hard standings at strategic locations.

Each large storage area of flammable substances or major process plant unit should be accessible from at least two sides. If access is only possible from two sides, these should, wherever possible, be the longest opposite sides.

The design of the road layout should be influenced by plant complexity and the type(s) of fire appliances likely to be employed in fire-fighting. Road widths, gate widths, clearance heights, turning circles and axle loadings for the various types of vehicles likely to be called to the hazard should be considered. These could include vehicles other than fire-fighting appliances such as heavy bulk foam and/or carbon dioxide (CO_2) carriers.

One or more hard standings should be provided beside each open water source to enable fire-fighting appliances to be positioned at strategic points, where this is necessary to prevent blocking roadways. A waiting area should be allocated near each main entrance to the site as a rendezvous point for emergency vehicles where this is warranted by the size or nature of the installation.

These aspects should be considered in consultation with the local government Fire and Rescue Service (FRS).

4.8.6 Drainage systems

Due to their flammability and classification as dangerous to the aquatic environment, sewerage companies and environmental agencies generally do not allow entry of petroleum and its products into drainage systems and natural watercourses under their respective control. In addition, fire-fighting water is likely to be highly polluting, posing a threat to watercourses, groundwater and sewage treatment facilities. Therefore, the capacity of site drainage systems should be carefully evaluated and the management of fire-fighting water should be included in ERPs (see 8.8).

Adequate drainage for storm water should be available and special provisions such as pumps, run-off areas, etc., may be necessary for the disposal of water used in fire-fighting operations. Increasingly, there are controls on the release of fire-fighting foam due to concerns over the toxicity of fluorochemicals used, and some environment agencies may require catchment and specialist disposal of foam run-off.

To avoid flooding during fire-fighting, the drainage system should be designed to cope with the fire-fighting water available to that area, including cooling water. Generally, this would comprise at least 90% of the flow, assuming some 10% evaporates in the fire.

Area drainage or alternative disposal systems for the large volumes of water that may be used should be adequate to avoid flooding, which can introduce other hazards. Consideration may be given to installing recycling facilities for oil-free water. The system should be designed to prevent carryover of petroleum, its products and other pollutants into the sea, rivers, or other environmentally sensitive areas. Contingency plans should be discussed with the relevant environment agency.

Consideration should also be given to the possible danger from the mixing of incompatible effluents. Flammable vapours can arise if hot fluids, e.g. steam condensate, mix with petroleum and its products in drainage systems. Also, flammable substances may be carried offsite by drains and precautions should be taken to prevent this possibility.

4.8.7 Fire protection and other safety critical equipment

Fire protection and other safety critical equipment should be located in safe and non-hazardous areas. Consequence modelling should be carried out to determine placement of such items as they may constitute sources of ignition. Consideration should also be given to locating such equipment so as to enable access at all times during incidents. In addition, such equipment should be capable of withstanding the effects of fire and explosion if its use is required during emergency conditions. For example, fire pumps should be located at a safe distance away from any possible fire consequences.

4.9 BUILDINGS FIRE PRECAUTIONS

National and local regulations may require fire risk assessments to be performed for occupied, as well as some unoccupied buildings at petroleum installations. In addition, some building regulations (e.g. in England and Wales – TSO *Building Regulations Approved Document B – Fire safety)* specify minimum requirements for fire prevention and protection in newly constructed buildings. Where applicable, these building regulations should be met. For existing buildings, fire risk assessments should be performed to identify the extent of fire risk and used to implement additional fire precautions and protection where appropriate.

See CIA *Guidance for the location and design of occupied buildings on chemical manufacturing sites* for buildings fire safety considerations at petroleum installations.

Fire risk in buildings can be assessed and appropriate FEHM measures implemented by performing a fire risk assessment. A typical assessment should consider for a building:

- Its nature and use.
- The type of construction, including its internal features.
- Its size and layout.
- Its contents, including equipment, furniture and furnishings.
- The presence of combustible materials or flammable substances.
- Identification of all internal and external fire hazards.
- Potential sources of ignition, both internal and external.
- Its occupants, including whether they are typically staff, contractors or visitors and their ability to respond in the event of a fire emergency.
- Means of escape.
- Existing fire prevention and protection measures.

For each building, the following steps should be taken:

- Identify all fire hazards, including combustible materials and flammable substances, potential sources of ignition and structural features contributing to fire risk.
- Identify personnel at risk.
- Eliminate, control or avoid fire hazards.
- Assess existing FEHM measures and improve if needed.
- Record the assessment.
- Prepare an ERP.
- Review the assessment periodically.

See annex C.7 for typical fire detection/protection measures for various building types at petroleum refineries and bulk storage installations.

5

FIRE AND FLAMMABLE GAS DETECTION

5.1 INTRODUCTION

Depending on the criticality of the installation and emphasis on life safety, automatic fire and flammable gas detection systems can be used to give early warning of a fire event and allow immediate investigation and/or fire response. This section sets out the various types, recent developments, application to various facilities/ areas and design issues.

The capability to detect fire early is especially applicable to installations that have a small operational staff and early warning is paramount to a rapid fire response. Appropriate fire detection systems can be employed within operational areas, support facilities and buildings. Detection systems can also be linked to active fire protection systems, thus providing executive actions.

Releases of flammable gases from process units pose an immediate threat to operations personnel and plant, and accidental discharges should be detected as early as possible to avoid the possibility of confined or partially confined VCEs.

5.2 PRINCIPLES OF FIRE AND FLAMMABLE GAS DETECTION – OPTIONS, APPLICATIONS AND DESIGN ISSUES

5.2.1 Flammable gas detection

For areas where the risk arises solely from a leak of flammable gas or vapour, appropriate flammable gas detection should be employed.

5.2.1.1 Point detection

Point detectors measure gas concentration in a flammable gas/air atmosphere at a specific location. To detect flammable gas they should be situated in an area close to potential sources of release for maximum response.

5.2.1.2 Open-path detection

Open-path infrared (IR) detectors are useful for monitoring large open areas for gas releases. In effect, they act as a series of point detectors placed end-to-end. Experience has shown that they are most effective over distances of about 60-100 m but may be used over greater distances in some cases.

Open-path detectors may be considered for use as perimeter monitoring devices around installations; see Figure 5.1. The purpose of perimeter monitoring might be to track the movement of a flammable gas/air cloud either around or offsite. Ideally, open-path detectors should be supplemented with the use of point detection situated close to potential sources of releases. In this way, sources can be pinpointed and the cloud movement assessed to assist mitigation or deployment of gas cloud control actions.

5.2.1.3 Catalytic gas detection

Point catalytic detectors typically comprise an electrically heated platinum wire coil coated in a catalyst, sometimes called a pellistor bead. This sensor responds to a flammable gas/air mixture by heating and altering the resistance of the platinum coil. The amount of heating (and therefore change in resistance) is proportional to the amount of combustible gas present and a reading can be displayed on a meter.

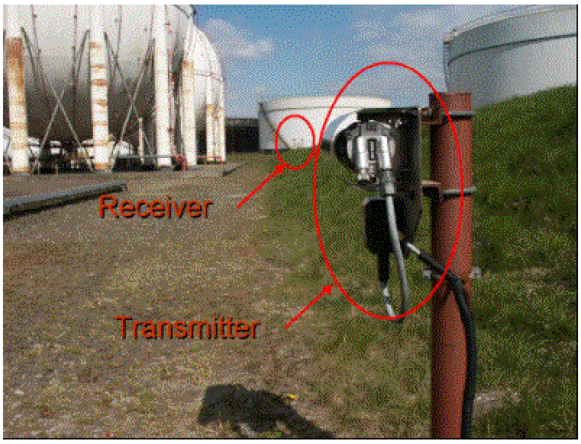

Figure 5.1: Open-path flammable gas detection used as perimeter monitoring

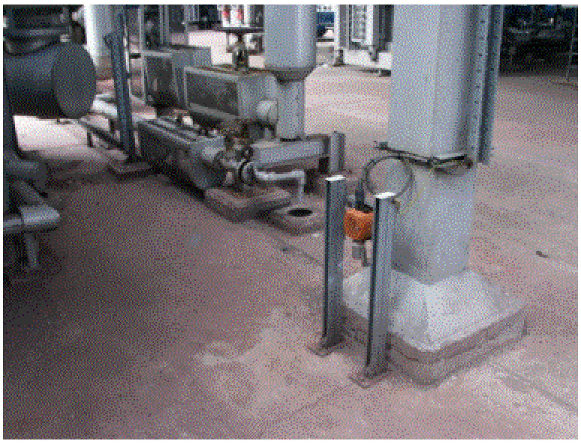

Figure 5.2: Catalytic flammable gas detection in process area

Point catalytic detectors should be located near to potential points of gas release; see Figures 5.2-5.3. Response can be delayed if the released gas has to travel to the sensor to operate the detector.

Catalytic devices have been used very effectively for a number of years, but there are recognised problems with such detectors, mainly due to the pellistor sensor becoming poisoned and losing sensitivity over a period of time. Poisoning can be caused by a wide variety of substances normally present in petroleum refineries and bulk storage installations – one such substance is silicone grease. When specifying detectors, those with poison-resistant sensors should be selected. It is also worth noting that they require oxygen (air) to operate and thus will not respond in oxygen-deficient atmospheres.

It is also possible that excessively high background gas concentrations outside the UFL can cause poisoning. Other problems with catalytic detectors may include the sintered disc through which gas/air passes being blocked with particulates, such as oils, fine dust, salt, grit, corrosion or even water. Approved splash guards should be installed to prevent clogging in areas where hoses are used frequently.

Catalytic detectors typically require more frequent attention than the newer IR absorption types of flammable gas detection. As a minimum, detectors should be inspected, maintained and calibrated twice a year; however, at some LPG/LNG installations, frequency of inspection should be increased depending on criticality.

5.2.1.4 Infrared gas detection

IR detectors work on the principle that gases absorb infrared energy at certain wavelengths.

Figure 5.3: Catalytic flammable gas detection in LPG storage area

Advances in IR technology have meant that both point and open-path type detectors are available.

Point IR devices typically consist of a sealed detection tube containing an IR transmitter and receiver. The amount of flammable gas present in the atmosphere is proportional to the amount of IR absorbed by the 'cloud' inside the unit. Again, the detector should be placed close to potential sources of release for maximum response, necessitating a scenario-based assessment of potential gas release incidents.

Point IR detectors generally require less frequent calibration, are immune to poisoning and although relatively expensive, can be very cost effective in the long term due to reduced maintenance. Experience has shown that they are sensitive, reliable detectors with good resistance against spurious alarms if designed, installed and maintained correctly.

On the other hand, an open-path detector measures the attenuation of IR by a gas cloud in the midst of a beam between a transmitter and receiver over a large area.

Double pass detectors require a retro reflector allowing relay of the IR beam back to the receiver component of the transmitter/receiver unit. Single pass units can also be used, consisting of separate transmitter/receiver units. Both types of device can scan a large distance, or path length. Typical coverage distances may be in the order of up to 300 m, although in practice these may be limited to <100 m to ensure accuracy and reduce spurious alarms.

In effect, the beam measures the total amount of gas present along the beam, as if a row of point detectors were placed end-to-end. In this way, the significance of a gas release hazard can be estimated. This feature enables open-path detectors to be used effectively as perimeter monitoring devices to track the size and direction of releases, although it is common to provide point detection in order to back up such systems and identify specific release points. Open-path IR detectors usually make a second reading at a reference wavelength, not absorbed by petroleum and its products, so that differences in signal-to-noise ratio can be interpreted as environmental effects.

Whatever device is used, components should be mounted to a rigid structure, free from vibration to minimise disruption to the beam and to allow accurate alignment. The potential for ambient environmental influences on flammable gas detection including dust, humidity and solar radiation should also be assessed and appropriate units immune to these should be selected.

5.2.1.5 Acoustic detection

Recently, acoustic units have become available that are able to detect the characteristic sound of high-pressure gas releases and/or jet fires. Typically, they operate by detecting frequencies outside the normal range of human hearing.

These units should be considered for the detection of gas releases only and should be carefully specified to provide the quickest response and immunity to unwanted alarms (e.g. as a result of steam emission).

Whilst other proven types of flammable gas detection may be more appropriate as outlined below, acoustic detection is another option that should be considered.

5.2.1.6 Applicability

Suitable flammable gas detection should be provided where scenario-based analysis has identified potential gas releases in installations and the need for early detection of accidental loss of containment. Guidance on fire detection applications – including appropriate types – for typical installations/areas is given in Annex C.

The optimum configuration of detectors will depend to some extent on the manufacturer. However, the following should be considered:

— Point detection should be placed close to potential sources of release and take into account vapour density. For example, near LPG tanks (or other tanks containing heavier than air gases) the detectors should be placed close to ground with suitable clearance, according to the manufacturer's guidance.
— Due to the possibility of poisoning, catalytic detectors should be regularly maintained and calibrated in accordance with the manufacturer's guidance as a minimum.
— Detectors should allow sufficient warning of a release. Typically, detectors should be set to alarm at a maximum of 20% LFL, although in certain critical circumstances, sensitivity may be increased.
— Point catalytic detectors may not respond, or may become poisoned, if subjected to high velocity instantaneous releases of liquefied gas. For this reason, detectors should not be sited too close to potential sources of release. Alternatively, IR detection may be used, as it offers greater resistance to high gas concentrations.
— A narrow plume of gas may drift away from a point gas detector if placed too close to the source of release, or it may miss the detector completely if dispersion occurs in another direction due to changes in wind direction. For this reason, there should be careful thought as to the potential size of a release, and likely plume direction for siting purposes.
— Consideration should be given, e.g. around a liquefied gas storage area, to supplementing point detection with perimeter monitoring in the form of open-path detection. Consideration should be given to providing both types of detector so that potential sources of release can be pinpointed or tracked by point detection, and the open-path component can give a reading of average concentration over a specific area. This type of configuration can allow estimation of the potential for a significant gas hazard arising at an installation or otherwise drifting offsite.

5.2.1.7 General design guidance

Most standards relating to flammable gas detection only give an overview of operating principles and key design criteria. The most appropriate way of evaluating whether flammable gas detection is required and specifying/designing a system is to perform a scenario-based review of potentially significant gas release hazards and develop performance based design criteria. Installations should be designed taking into account the characteristics of potential gas releases. Most vapours at petroleum refineries or bulk storage installations are heavier than air, even when hot; yet, some gases containing a high proportion of methane or hydrogen may be lighter than air and will rise if released. LNG, however, is so cold that it is denser than ambient air and on escape may persist at ground level. It will initially be visible due to condensation of atmospheric water. Also, heavier vapours will tend to accumulate in low-lying areas (e.g. sumps). Gas dispersion modelling can assist in identifying and optimising detector location.

Whilst specific design guidance relating to individual components and capabilities can be found in relevant standards, any flammable gas detection design philosophy and subsequent implementation should be developed based on site-specific reviews.

Reference should be made to standards such as BS EN 61779-1 and BS EN 50073 for flammable gas detection design and application.

5.2.2 Fire detection

5.2.2.1 General

In recent years, developments in fire detection systems utilising more reliable and appropriate technologies have been made such that there is now a greater choice. Selecting a detector for a given application should be based on a sound knowledge of the principles and standards involved.

In typical petroleum refineries and bulk storage installations, a range of detectors may be used. The most appropriate way to establish detector suitability is to conduct a scenario-based survey of the area concerned. The key consideration for a fire detection system should be to match the type of detector and its response time to the type of fire and combustion products that are likely to develop during an incident.

Fire detectors can be chosen to detect one or more of the following combustion phenomena:

— heat;
— smoke;
— ultraviolet (UV) or IR radiation (flame detection);
— incipient combustion gases e.g. carbon monoxide (CO).

To select a successful detector it should be known what kind of fire is likely to develop, taking into account the properties and characteristics of hazardous substances in the detection area.

Generally, flammable gases, vapours, mists and low flash point liquids burn fiercely with immediate generation of heat. The most appropriate types of detector for fires involving them are heat, flame or optical units, although acoustic detectors may also be used in some cases. Ultimately, the choice of detector should take into account the particular combustion characteristics of the fuel.

Many solid materials can smoulder for a period before developing into flaming combustion. During this period, smoke is formed without very much heat; however, some solid materials can exhibit rapid flaming combustion. Again, the choice of detector should depend on the combustion characteristics and fire phenomena generated by the burning material.

Detailed descriptions of detector operating principles and applicability can be found in international fire detection standards such as NFPA 72, BS EN 54 and BS 5839. Guidance on fire detection applications – including appropriate types – for typical installations/areas such as buildings, is given in Annex C.

The following sections provide guidance on some of the most common detection options.

5.2.2.2 Heat detection

Heat detectors respond to temperature increases associated with developing fires. Detectors can be classified as either 'fixed temperature', 'rate-of-rise' or 'rate-compensated' type. They are usually point detectors placed in a specific location (e.g. above a generator) and will respond to a fire in close proximity. A further type of linear heat detection (LHD) is also useful for specific applications such as detection of rim seal fires in open top floating roof tanks.

Heat detectors should be used where a scenario-based survey of installation/building locations has identified areas where fires are likely to develop heat in their early stages rather than large quantities of smoke. Potential applications are close to equipment skids where flammable liquids may be released.

Heat detectors are not generally suitable for protection of life as their response is much slower than smoke detection. Their use should be restricted to defined areas where smoke detection is problematic or alternative detection cannot be used.

Heat detectors should not be used in buildings, in escape routes or areas (e.g. electrical cabinets) where the use of smoke detection would give a much more rapid response to smouldering fires or those likely to produce reasonable amounts of smoke. Also, they should not normally be used in outdoor areas where heat from the fire is likely to dissipate rapidly.

Conventional sprinkler heads or fusible plugs should be considered as heat detectors and may be installed in locations where automatic fire protection should be provided. They function by maintaining pipework under pressure, usually using air, and when one or more of the heads bursts, a fall in pressure actuates an alarm and operates any executive actions such as an extinguishment release system. However, sprinkler heads are relatively insensitive as point heat detectors and this should be taken into account when planning their positioning and arrangement.

The following two kinds of installation may be considered:

— Close arrangement around specific high-risk equipment: heads are located close to and just above points where releases and fires may be expected, e.g., above pumps, valve systems, vents. See Figure 5.4
— General surveillance: heads are arranged in an array covering the required area. To ensure that fire will be detected before significant fire damage is suffered by structures and plant, heads should not be spaced too far apart; a spacing of not more than 2,5 m is normally appropriate.

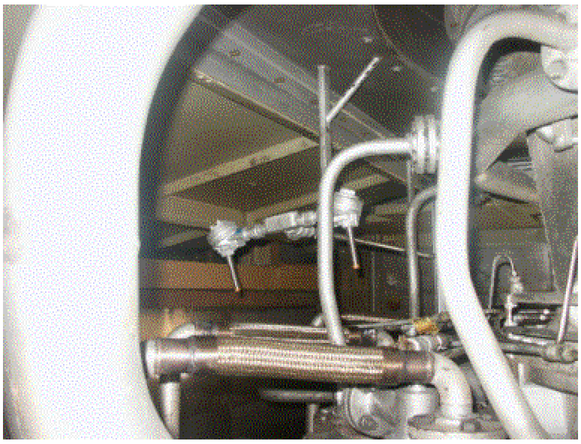

Figure 5.4: Heat detection in enclosure

5.2.2.3 Linear heat detection

LHD is now an accepted way of achieving a cost-effective detection strategy for a wide range of applications, such as the protection of open-top floating roof storage tanks, pumps, pipe racks, cableways and service tunnels. There are a number of different types of detector available:

— Electrical – a shorting wire contact operating at fixed temperatures ('digital'), or an 'analogue' type measuring a change in resistance upon the application of heat, which is also self-resetting, but may have a length limitation. This type of cable is especially suitable for the protection of petroleum storage tanks, where alarm zoning is not normally required. See Figure 5.5. A range of cable types may be available, offering standard, chemical, or increased mechanical resistance.

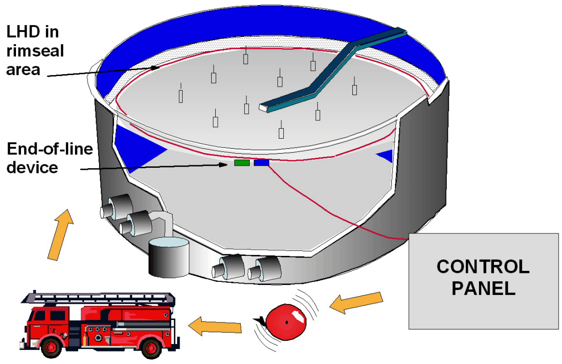

Figure 5.5: LHD for open top floating roof tank

— Pneumatic – a fusible plastic tube containing an inert gas such as nitrogen is depressurised when broken by fire. This type of LHD requires a pressure/electrical control interface and may have a length limitation or be susceptible to physical damage or UV deterioration. Nevertheless, this type of detection may be suitable for protecting indoor cableways or pump sets, and is relatively inexpensive. See Figure 5.6.

Figure 5.6: Pneumatic LHD in LPG storage area

— Optical – relies on internal changes in the properties of light transmitted down its length when subjected to fire. Key applications for optical detection are service tunnels where an indication of the position of the fire may be required; the cable may be split into zones and sophisticated control and indicating equipment can be incorporated. Generally, this type of detection is not widely employed at petroleum refineries and bulk storage installations and is relatively unproven but may be of use in specific circumstances.

LHD should be placed near to, or just above equipment, where experience indicates that fires can start. For specific applications, see Annex C. Generally, the basic digital electrical type has been found to be the most reliable and straightforward type providing the system is designed and maintained properly.

5.2.2.4 Smoke detection

Smoke detectors are widely used to detect smouldering or flaming fires capable of generating appreciable amounts of smoke and are classified as point or volumetric types. Point detectors can be ionisation or optical (photo-electric) types. Volumetric smoke detectors include ‘beam’ type detectors or 'incipient' units.

Point smoke detectors are often referred to as 'conventional' detectors and should typically be used in indoor plant areas or buildings because smoke is rapidly dispersed in the open air. Typical applications should include detection in control rooms, offices, equipment cabinets and enclosed plant areas.

Generally, ionisation detectors are more suitable for detecting fires in fuels that are likely to flame more rapidly on combustion whilst still producing appreciable smoke. They tend to detect 'invisible' smoke having smaller particles more rapidly, as opposed to lighter 'visible' smoke produced when a fuel smoulders. However, for practical purposes, although optical smoke detectors are more responsive to smouldering fires, response times for the two types of detector are similar. In some cases, a mixture of ionisation and optical detectors may be appropriate for the earliest possible alarm.

For guidance on detailed location and applicability issues, see NFPA 72, BS EN 54, BS 5839 or equivalent standards.

5.2.2.5 Incipient fire gas detection

Typically, these devices are variations on conventional smoke detectors that are able to detect concentrations of combustion gases produced by a fire in its incipient (early) stages. The most common detectable gases are CO and CO_2, although other toxic combustion products such as hydrogen chloride (HCl) may be detected.

This type of detector should not be employed in isolation. It may be considered for specific instances to back-up 'conventional' smoke and heat detection. Particular care should be taken if specifying such devices, because not every fire will generate the aforementioned fire gases resulting from combustion.

5.2.2.6 Combination detectors ('multi-sensors')

To reduce incidences of unwanted alarms, a number of manufacturers now offer 'combined' or 'intelligent' conventional smoke and heat detectors. Typical devices are optimised to sense whether fire phenomena such as smoke, heat and incipient fire gases such as CO are present in sufficient quantities or the right proportions. The detectors thus make an 'intelligent' decision over whether they are 'seeing' a fire, rather than some other false alarm source (e.g. dust). Many devices can be optimised to take into account the expected nature of potential fires (i.e. whether a slow, smouldering fire will result, or if the fire will exhibit rapid growth with flaming) and respond accordingly. In tests, and in use, these devices drastically reduce the incidence of 'nuisance' alarms due to smoking and vehicle fumes.

These detectors are usually termed 'multi-sensors' and can be considered for use in areas where problems with 'conventional' smoke or heat detection are encountered, such as frequent unwanted alarms.

When considering and selecting multi-sensors, fire sensitivities and response times should be assessed in line with a relevant standard such as BS EN 54.

5.2.2.7 Incipient fire smoke detection

Incipient smoke detection or 'aspirating' detection is now seen as an effective way of providing protection in support facilities such as computer suites or other areas containing sensitive electronic equipment. This type of detection operates by sampling air through an array of detection pipework, which is then drawn back to a central or local detection unit for analysis. Typical units can detect very low smoke concentrations and contain algorithms able to distinguish between smoke particles and other possible causes of false alarm such as dust or fine particles in the air ('particle rejection').

This type of system can 'buy time' and allow an initial investigation at a set pre-alarm level. Fire response can be taken manually, or by means of some other executive action. As part of an extinguishant release strategy, the system may be able to delay release of inert gas until an initial investigation is made when the fire is still very small and at a stage when hand-held extinguishers can be used. Such systems can also be considered as part of a halon phase-out strategy, often removing the need for a fixed fire protection system.

Incipient detection can overcome site-related problems of smoke stratification and difficult access for maintenance. In the case of computer suites, pipework can also be routed so that detection is provided for individual cabinets, allowing internal fires to be detected when still at the pre-smouldering stage. Ducting and floor/ceiling voids can be protected as well as the room void, as part of a multi-zone system.

There are a number of key considerations to take into account at the design stage and throughout the system's lifetime to ensure continued effectiveness. These include ensuring that sampling points are positioned away from strong airflows (e.g. air conditioning ducts), and that key system performance criteria such as transport time, sensitivity and hole balance are all met for the intended application. Key performance criteria such as response time, sensitivity and alarm functions should be specified in detail at the design stage and measured by testing the system regularly.

Standards such as BS 6266 specify ways of testing incipient detection; typically, they include methods of generating 'hot' smoke using standard 'hot wire tests'. When performed correctly, they can allow easy, effective testing of these types of system.

In most cases, this type of detection should be used alongside 'conventional' smoke detection (typically a mixture of ionisation and optical devices) for specific risks such as electronic data processing suites. Guidance on application and design can be found in standards such as BS 5839 and BFPSA *Code of practice for category one aspirating detection systems.*

5.2.2.8 Flame detection

The use of flame detectors to detect flammable liquid fires is increasingly common. Flame detectors are essentially optical devices and operate by a variety of means, each having its own limitations.

(i) Single wavelength flame detectors

Single wavelength flame detectors usually operate on either IR or UV principles, and are widely applied for the detection of a range of petroleum fuels. They can be considered for use in indoor or outdoor plant areas where the main risks are flammable liquid or liquid spray fires.

Where the possibility of high-pressure gas fires exists, the use of flame detectors may not be appropriate, because these types of fire exhibit little or no low frequency flickering, which is sometimes required by the sensor components.

Typically, IR flame detectors are configured to only detect burning fuels emitting appreciable amounts of CO_2. Consequently, fuels that do not contain carbon - such as hydrogen, sulphur or burning metals - will not be detected. To detect fires involving these fuels, detectors using UV principles should be considered.

Most UV detectors operate by measuring small bursts of current caused by the absorption of UV radiation given off by the fire, and compare these against set values. Since virtually every fuel emits UV radiation when under fire conditions, difficult to detect fires involving the above fuels can be detected.

Materials such as smoke and vapours present in the detection area should also be capable of absorbing UV radiation. Some vapours (usually hazardous) exhibit significant absorption characteristics, and might restrict UV detection if present in large concentrations. Others, including the lighter alkanes such as methane, propane and butane, do not. Consequently, an initial survey to determine detector suitability should be carried out. It is also possible that some spurious sources such as sunlight, hot surfaces, welding and rotating machinery will cause false alarms, but most models incorporate means of distinguishing between these and real fire sources, such as 'flame flicker discrimination'.

Flame detectors are essentially optical devices, and airborne contaminants such as smoke, dirt, grease and oils can potentially 'blind' them; units should be chosen that have means of continuously monitoring optical integrity, and routine cleaning of optical surfaces should be carried out.

(ii) Combined UV/IR flame detectors

Combined UV/IR detectors can represent an effective solution for detection in areas where a mixture of fuels is present. Current UV/IR technology produces very sensitive, yet stable detectors.

Limitations of such devices are usually a combination of their respective technologies but the process of ageing, or contaminants on the detector window may still affect them; hence there should be effective maintenance. Vapours should not usually present an absorption problem in the case of the IR component, except for a small range of substances containing triple molecular bonds such as acetylene (ethyne) or nitriles.

Combined UV/IR devices are able to respond to a wide range of potential fire scenarios involving many different materials. Also, more sophisticated IR flame detectors are now available to combat incidences of false alarm and response failure. A new generation of 'triple wavelength' ('IR3') devices able to detect three separate wavelengths present in the IR spectrum of a burning fuel should be considered. Such devices may enable previously 'unseen' fuel types to be detected and may represent a cost-effective alternative to the provision of separate IR and UV devices or other combined units.

Ultimately, the key to choosing the most applicable flame detector is a good understanding of detector architecture and special features, an understanding of the fuels involved and potential fire sizes, and the effects of spurious environmental sources on operation. Where false alarms are seen to be a continued problem, there are other forms of optical detection that may be appropriate.

5.2.2.9 Optical (video linked) detection systems

Until recently, causes of unwanted alarms from optical flame detectors have been poorly understood. The remoteness of some sites can make communication of problems with detection difficult. In some cases it has been reported that false alarms have been caused by sunlight, or even by personnel wearing brightly coloured coveralls! A more common cause of false alarms can be flare stacks, since some detectors can respond to reflections in water or on metal surfaces. This problem has recently been overcome with optical detectors incorporating 'flame imaging technology'. Such systems typically include three basic components – the camera/detector, control panel and visual display. The camera/detection unit contains the camera and computing facilities to determine whether or not the unit is 'seeing' a fire, and is programmed with a range of algorithms to determine whether the phenomena within its field of view are fires or not. If a fire is detected, the view of the camera is automatically displayed at the control point.

Units are available that can sense characteristic smoke patterns, and are thus very sensitive smoke detectors whilst some units work by detecting flames over relatively large distances.

Some false alarm problems have been reported with such devices, but in most instances these have been overcome through operational experience, and it is often a matter of re-programming the unit with updated algorithms to ignore previously unseen spurious sources. Experience of using this type of device is that the main benefit is being able to see a 'live' image of the area of alarm, providing unambiguous information about the detection of fires.

This type of system can be considered for use in covering relatively large plant areas with scope for inclusion in existing closed circuit television (CCTV)/security systems, since many now feature image recognition and processing software able to detect flames and/or smoke. However, they should not preclude other forms of detection strategically placed around plant areas and buildings.

5.2.3 General design guidance

The fire or flammable gas detection system should be designed taking into account all relevant factors relating to the FEHM strategy for an installation and following a scenario-based review of potential fire incidents.

Detailed fire detection design guidance can be found in BS EN 54, BS 5839, NFPA 72 or equivalent national standards.

For protection of specific areas such as electronic data processing (EDP) installations and computer suites, additional guidance is available in BS EN 6266, NFPA 75 or equivalent national standards.

Fire detection systems should be designed, installed and maintained in accordance with the framework for FSIA (see section 8.9.3).

5.3 CONTROL SYSTEM EXECUTIVE ACTIONS

Automatic fire detection can be configured to initiate executive actions such as extinguishant release, damper closure, shutdown or isolation.

Where there is no immediate fire-fighting response, extinguishing systems linked to fire detection systems may be considered for particularly hazardous, remote or unstaffed installations such as offsite pumping stations.

Cross-linked zones employing similar or different detector types (i.e. monitoring different fire phenomena) should be considered. The separate zones of the two detection systems may be superimposed with the detectors of each zone alternated. Separate alarms may be given locally from each system, but usually, automatic protection equipment operation or remote alarm sounding will require the operation of detectors in each system. An alternative scheme is to store the alarm from the first detector and either to re-examine the circuit after a given time interval to see if the alarm is sustained, or to wait for a second detector to operate, before transmitting the main alarm. In the case of flame detectors, those in each zone may cover a potential fire area from opposite sides. This has the advantage that both zones are not likely to detect flames produced outside the area to be supervised. Where smoke may obscure the flames, detectors should be sited so that not all the linked detectors are downwind of the fire.

5.4 FIRE/GAS ALARM AND WARNING SYSTEMS

Fire and flammable gas detection systems should be considered for each indoor or outdoor plant location following a scenario-based review of potential fire or gas incidents. Fire and flammable gas detection systems may be critical at particularly hazardous remote or unstaffed sites such as offsite pumping stations where there is no immediate fire-fighting response.

The need for, and exact types of system employed should depend on a number of factors including installation criticality, potential for asset loss, life safety and other human factors such as staffing arrangements. Guidance on system suitability/applicability can be obtained from publications (e.g. codes of practice, relevant fire detection standards, etc.) or from the authority having jurisdiction (e.g. FRS).

Alarm and fault signals should be transmitted to a staffed location where personnel have the competence and authority to act on alarm information. Both audible and visual forms of annunciation should be distinguishable from other installation alarms (e.g. process, level alarms, etc.). Where an occupational fire brigade is provided, signals should be repeated to the fire station control room.

Detailed guidance on system architecture, monitoring and annunciation can be found in relevant international fire detection standards such as NFPA 72, BS EN 54 or BS 5839. Products and components certified by an approved test/certification body should be used.

Systems should be tested regularly in accordance with the manufacturer's instructions and within a framework of FSIA (see section 8.9.3).

6

FIRE PROTECTION

6.1 INTRODUCTION

This section describes passive and active fire protection measures, which are intended to reduce the consequences of fire. Options, applications and design issues are reviewed for passive fire protection materials in limiting temperature rise and preventing excessive heat absorption. The capabilities of active fire protection media are reviewed for controlling a fire, extinguishing a fire, or preventing ignition during an emergency. In addition, media application is reviewed, whether using fixed or semi-fixed systems and portable/mobile fire response equipment.

The objective of fire protection is to protect equipment and structures from damaging fire consequences such as radiant heat as well as convective and conducted heat through prolonged fire exposure and direct flame impingement. Some potential consequences of fire exposure include:

— Increase in the temperature of steel to the point where its strength is impaired; structural steel engulfed in flames may weaken and collapse.
— Increase in the temperature of petroleum and its products or other process intermediates in tanks, lines and vessels to levels at which vapour emissions increase, ignite and potentially cause fire escalation.
— In the case of LPG, onset of BLEVE conditions where potentially large quantities of boiling flammable product are released following vessel failure and ignited. Whilst LPG storage is the major BLEVE scenario, it can also occur to a pressure vessel containing a large quantity of volatile petroleum product.
— Increase in the pressure in confined or semi-confined spaces to a level where the pressure exceeds the strength of the steel (possibly reduced by a temperature increase) or of seal systems, resulting in failure with a consequent rapid release of flammable product.

6.1.1 Passive and active fire protection

Protection measures can be provided by both passive and active means. For the purposes of this publication, fire and flammable gas detection is considered as a separate type of fire protection measure. See Section 5.

PFP refers to the application of materials which are designed to limit temperature and prevent excessive heat absorption, to items of process plant, structures or vessels (or within buildings). In some in-house petroleum company standards the term is also used for other FEHM measures, such as increased plant separation; however, this is not generally accepted.

Active protection involves the application of fire extinguishing or other protective media to surfaces either on fire, or exposed to heat or potential ignition during an emergency. Common media can include foam, powders, gases, and coolants (which are normally water mists, sprays or deluge).

The protection may be applied to extinguish the fire or to protect equipment in the vicinity from the damaging effects of the fire and to reduce the risk of escalation of the incident. For example, a fixed water-spray system might be provided to protect a tank from potential radiant heat exposure from an adjacent tank fire.

6.2 PASSIVE FIRE PROTECTION – OPTIONS, APPLICATIONS AND DESIGN ISSUES

6.2.1 General

PFP should be considered as an overall system, the aim of which is to provide a degree of fire resistance to fire exposed structures, vessels, pipework and equipment.

Historically, PFP has been used to protect process plant; typically, this was referred to as fireproofing, although the term PFP is now preferred. PFP comprises a variety of heat-resisting materials, coatings, structures, blocks, tubes, sleeves, blankets and covers used to provide fire resistance in buildings and within process/storage areas.

PFP is often applied to critical items that might create additional risk (e.g. BLEVE) if exposed to high levels of thermal radiation flux.

Within buildings PFP should be used to prevent spread of smoke, flame or heat by the provision of such measures as fire doors, fire-rated wall construction and floor/ceiling void compartmentation. National building regulations and approved fire engineering publications (e.g. codes of practice, design standards, specifications, guidance, etc.) should be used to determine the requirements.

For plant areas, consideration should be given to the fire resistance of structures supporting vessels, the vessels themselves and associated equipment and pipework. If the vessel or its supporting structure might be exposed to external fires, adequate fire protection should be provided. Critical valves or process control equipment including cabling may also require PFP.

PFP should be used to perform one or more of the following functions:

- Contain a fire within a compartment or space in a building.
- Delay fire effects impacting on means of escape.
- Delay heat transfer to stored or processed flammable liquids and gases.
- Delay the collapse of load-bearing structures or members.
- Delay the failure of steel used for holding flammable liquids or gases.
- Assure the closure of critical isolation valves or ESD valves under fire conditions.
- Delay ignition of cables or control wiring.

Passive protection can be provided to protect against direct flame impingement/engulfment or exposure to radiant heat, smoke and heat stopping, and also blast/overpressure protection.

The types of PFP materials available include:

- Cementicious materials – these are usually sprayed or trowel applied but may also be cast to preformed shapes or sections. PFP performance relies on a combination of two effects – insulation and dehydration causing cooling.
- Lightweight concrete (vermiculite) – such materials are effective and do not spall in fires involving petroleum and its products. However, some have a high porosity and will absorb liquids if unprotected, leading to lower impact resistance, reduced adhesion to steel and potential corrosion. A mesh retaining system should be used for petroleum fire protection systems to provide good protection against pool fires or flame engulfment and jet fires.
- Concrete masonry – this is not commonly used because of high installation costs and extensive maintenance requirements. Assemblies are prone to cracking and admitting moisture with serious corrosion and spalling problems.
- Magnesium oxychloride plaster – this is not typically used for PFP in petroleum areas.
- Fibrous materials – these are flexible, allowing them to be used for relatively complex shaped items. Compared to spray coatings they can be more easily removed for inspection of the protected equipment.
- Composite materials – these tend to be lightweight and easily adapted for protection of complex structure and shapes. The flexible types available are relatively easy to install and remove for inspection.
- Preformed blocks, panels, sleeves etc. – these are normally for internal use only to provide sealing and/or protection of penetrations and critical equipment.
- Preformed firewalls – these consist of specialist combinations that can resist the effects of fires and overpressures arising from petroleum and its products. Fire and blast protected enclosures, or box units, are also available for protection of critical ESD valves and/or their actuators.
- Intumescent coatings – these are most often used as spray coatings but also available as paints and varnishes, prefabricated panels, mastics for sealing penetrations, and in strip form for sealing gaps such as those between doors and door frames.

6.2.2 Applications and design issues

The need for PFP should be determined with the help of a scenario-based risk assessment of potential fire events. Thus, a potential pool fire incident might identify the need for passively protecting an exposed vessel and associated equipment. Common applications for PFP in outdoor plant areas include the protection of liquefied gas vessels, supporting structures, critical items of equipment and other process vessels. Some petroleum companies may have in-house standards for the design and application of PFP, and these should be taken into account.

PFP should be selected by carefully reviewing design event fire and explosion events. Careful specification of fire resistance ratings and, if necessary, overpressure requirements are necessary to ensure fit-for-purpose PFP systems. Whilst a formal fire assessment may identify no flame impingement on a structure or vessel, there may still be a requirement to apply PFP due to high levels of radiant heat. Techniques such as fire modelling can assist in assessing this.

Structural steelwork on process plant should be given special consideration for passive protection if its collapse in a fire would escalate the fire's severity. Where the design of the vessel supports makes it difficult to ensure adequate protection against fire by water spray (e.g. for the legs of Horton spheres) PFP should be provided.

PFP should also be considered for protection of critical actuators, electrical or instrument cable systems, since damage to these items can lead to ESD or control problems during an emergency.

The type of fire expected should be considered carefully. In the case of a pool fire, any flame impinging on vessels and/or equipment would not normally cause erosion of the PFP, other than deterioration due to prolonged exposure and heat input. However, in a jet fire a high-velocity flame will normally be sustained for as long as burning fuel is emitted at high pressure. By their nature, jet fires tend to be very erosive, and it follows that the PFP could deteriorate if jet fire resistance is not adequately specified. For this reason, PFP should be certified as having jet fire resistance if the design objective is to protect equipment and vessels against this type of fire.

Various jet fire resistance test methods are available; see HSE *Jet fire resistance test of passive fire protection materials.* If jet fire protection is to be provided, the size of the jet fire used during the fire test conditions (and thereby as the basis for an approval certificate) should represent the expected or credible jet fire size impacting on the structure or vessel to be protected.

It should be noted that effectiveness of PFP systems is very installation dependent. Approvals testing should be carried out to a recognised standard that uses a standard hydrocarbon time-temperature curve and the method of installation should not differ from that subjected to the test. The PFP should be regarded as a 'system', in which the quality of installation is as important a factor as the physical properties and fire resistance of the material.

For buildings PFP, hydrocarbon resistance may not be required and testing/approvals in line with a recognised cellulosic fire test should be specified (e.g. BS 476).

Regardless of the type of PFP used, the following practical availability and reliability factors should be considered:

— It should provide its functional role by limiting the temperature of the protected structure or vessel to that specified over the potential time for the design fire event.
— It should not fail rapidly or catastrophically during the design fire event.
— It should remain in place under the design fire event conditions.
— It should not present additional hazards to fire responders or personnel such as toxic by-products or spalling etc.
— It should not lose any integrity over the design lifespan whilst *in situ*. It should remain intact, in place, for the expected duration of the fire and not be compromised by unauthorised actions during maintenance activities.
— It should not hinder periodic examination/testing and maintenance of the structural integrity of the protected structure or vessel.
— Its application method should be subject to a recognised approvals test and it should be applied by an approved contractor. Any alterations or repair to the PFP should meet the standard of the original approvals testing for the 'system'.

For more guidance, see HSE *Passive fire protection* and HSE *Availability and properties of passive and active fire protection systems*.

Guidance on PFP for specific installations/areas is given in Annex C.

6.3 ACTIVE FIRE PROTECTION

6.3.1 General

Active fire protection systems are designed to achieve one or more of the following objectives:

— Cooling fire engulfed plant and equipment.
— Cooling plant and equipment exposed to thermal radiation.
— Fire control and/or extinguishment.
— Prevention of fire escalation.
— Prevention of ignition (e.g. through application of foam to an unignited spill).

Common media include water, foam, dry powder (dry chemical) and gaseous agents. They may be applied to extinguish the fire or to protect the equipment in the vicinity from the damaging effects of thermal radiation, conduction and convection and to reduce the risk of incident escalation.

Under certain circumstances, foam may be used to reduce the probability of ignition (e.g. in the case of a sunken roof in an open top floating roof tank where petroleum product is exposed). However, this application requires special consideration and techniques. See annex D.9.

6.4 EXTINGUISHING MEDIA

6.4.1 General

The most common fire-fighting agents applied at large petroleum fire incidents are water and foam. Powders and gases are also used at petroleum refineries and bulk storage installations, although their use tends to be restricted for small scale or local application to confined fires and those in enclosed or semi-enclosed spaces.

6.4.2 Water

Water is the most widely available and effective medium for extinguishing and controlling Class A fires (see *7.6.1.2*). It also acts as a cooling medium to protect equipment from the damaging effects of flame impingement or high levels of thermal radiation and convection. Also, it can be used selectively as an extinguishing agent on some higher flash point fuels. However, water is not generally effective as an extinguishing medium for flammable liquid fires, for which foam is preferred. Water also cannot be used on live electrical equipment. For such applications, electrically non-conductive media including CO_2 and powders should be used, although for smaller incidents extinguishers using foam spray or water spray approved for use (with limitations) on electrical equipment are available.

Water's advantages include its high thermal capacity and latent heat of vaporisation, non-toxicity and low cost. Its main disadvantage is freezing in cold weather. Its high effectiveness in cooling makes it valuable for the protection of buildings, plant and storage vessels exposed to heat radiation from a fire. Water may be applied either manually via portable and mobile equipment, or by means of a fixed installation.

Water-based systems are detailed in 6.5.2-6.5.5, and corresponding application rates for specific situations are given in annex D.2-D.5.

An adequate and reliable supply of water for all purposes should be available. This supply should be sufficient to ensure that normal process requirements are met and that sufficient additional water is available for fire-fighting and fire protection purposes. Wastage of resources and creating excessive fire-fighting water (which may be dangerous to the environment) should be avoided.

In practice, fixed fire systems and application equipment should usually determine how much water should be provided and the necessary supply pressure. However, the most appropriate way of determining water requirements for fire-fighting should be through consideration of credible design events.

Water availability should match the requirements for the largest design event envisaged at the installation, taking into account that needed for portable, as well as fixed application equipment.

Further guidance, including an example calculation of water requirements, is provided in annex D.6.

6.4.3 Foam

Foam is one of the most important extinguishing media for Class B fires (see *7.6.1.2*); however, it is not effective on pressurised liquid (spray) fires or running liquid fires. Unfortunately, poor understanding, specification and testing often lead to ineffective system performance.

To assist in foam selection, specification and system design, guidance is provided in the following sections for the most common foam types and systems used at petroleum installations. Foam application rates are addressed in annex D.7-D.9. Further guidance is available in the standard most commonly applied internationally, NFPA 11.

6.4.3.1 Foam production

The principal reason for foam's effectiveness on burning petroleum substances is that it provides a tough fire and heat resistant, vapour-suppressing blanket that floats on the fuel surface, cutting off the fuel from the flame; this prevents evolution of flammable vapours. In addition, foam provides a cooling action on the fuel, which reduces its tendency to emit flammable vapour and cools any objects in the fire area.

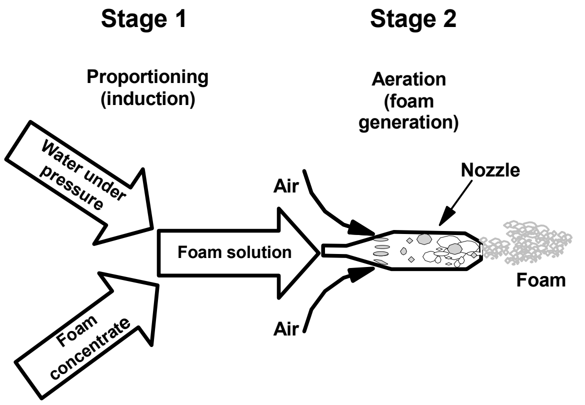

Figure 6.1: Stages in foam production

There are two stages to foam production; see Figure 6.1. In the first stage, foam concentrate is introduced – at the correct percentage – into a water supply to produce foam solution (water plus foam concentrate). The water can be provided by fire trucks, via dedicated water storage and pump equipment or from a hydrant system; the volumes and pressures required depend upon the type and size of the hazard, but for large atmospheric storage tank fires can be very large. This first step is termed 'proportioning' and ultimately, it is the rate of foam solution application that determines the efficiency of extinguishment. If a sufficiently high rate of foam solution application is not achieved, then the fire will not be extinguished. Application rates are described in units of $l/min./m^2$. The critical application rate is the minimum rate at which foam solution extinguishes a given fire. Typically, for a liquid fire involving petroleum and its products, this is in the order of $1 – 2\ l/min/m^2$.

Published application rates in internationally recognised standards attempt to strike a balance between ensuring fast, secure extinguishment and minimising wastage of resources. Annex D.7-D.9 provides typical application rates based on current standards and incident experience. Where appropriate, key considerations are also given in Annex C for typical petroleum installations/areas.

In the second stage of foam production, expanded foam is produced by mixing air with the foam solution. Air is usually introduced into the foam solution by means of a venturi effect in a foam nozzle; although some types of foam can be used through non-aspirating equipment such as water spray nozzles where air is not deliberately introduced into the solution. In practice, most non-aspirating discharge devices do give some levels of foam expansion due to the nozzle design or travel through the air.

There is a conflict of requirements to some extent in that unaspirated foam is generally recognised as not having such good vapour suppression qualities as fully aspirated foams; yet it can be projected further and tends to flow more readily across a fuel surface. Therefore, a balance has to be achieved.

Different nozzles give different foam characteristics hence the foam concentrate/nozzle combination should be tested in practice to ascertain actual performance.

6.4.3.2 Foam properties

Ideally, foam should combine several different properties, each of which is described below. However, even though many developments have taken place, there is still no single foam that truly represents the best and most cost-effective solution to every possible situation. The foam user should consider the particular application, decide the key foam properties and then select the best foam for the task.

It should be remembered that producing good quality foam depends on the proportioning system accuracy and the foam generating equipment as well as the foam concentrate. However, if the wrong concentrate is chosen, poor quality foam will be achieved whatever equipment is used in the system.

In order to achieve effective extinguishment there are eight qualities that foam should exhibit:

— Cohesion – foam bubbles should cling together and form a tough cohesive blanket that does not split and allow pockets of uncovered fuel.
— Vapour suppression – the foam should be capable of suppressing flammable vapours and prevent them percolating through the bubbles to burn on the foam surface.
— Stability/water retention – the foam should have the ability to retain water in order to continue to perform its cooling function as long as possible. The method of assessing this is to measure the 25% drainage time (or quarter life/quarter drainage time) of the foam (see *6.4.3.3*).
— Flowability/flame knockdown – in order to knock down the flame front and control a fire as quickly as possible, the foam should flow rapidly across the fuel surface and around any obstructions in the hazard.
— Heat resistance – the foam should be able to resist the destructive effects of heat radiated from any remaining fire or from hot objects. To some extent, this property is related to water retaining ability, but this, in itself, is insufficient. Special additives give good quality foams additional heat resisting capability.
— Sealing capability – the foam should have the

ability to seal against any obstruction in the fire; otherwise, vapours will rise in the gap created and continue to burn.

— Burn-back resistance – the foam should have the ability to resist burning back after the majority of the fire has been extinguished. Testing for this property should be part of a critical fire test for foam. When the fire has been extinguished in such a test it is normal practice to re-ignite a small area and then see how long the foam layer remains to assess its burn-back resistance.
— Fuel tolerance – it is good practice to apply foam as gently as possible and minimise fuel pick-up within the foam. However, this is not always possible. Any foam, if totally saturated with fuel, will burn, but some foam types have the ability to resist fuel pick-up better than others. Such foams are said to be oleophobic and the bubbles actually try to 'push out' any fuel within their structure.

6.4.3.3 Foam quality

To achieve the properties described in *6.4.3.2*, foam should be of good quality. This term usually refers to two distinct foam characteristics: expansion and drainage time. Standards such as NFPA 11 give guidance on the values of these parameters that should be achieved on certain risks.

Expansion and drainage time can easily be measured and compared against manufacturers' typical values. However, 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 should also be recognised that values given for expansion and drainage time usually relate to a particular foam/equipment combination.

(i) Expansion

Foam expansion is the ratio of volume of foam produced to the volume of foam solution used to produce it. It is, therefore, a measure of the foam solution's ability to produce a quantity of expanded foam. Its value depends on the foam-making device and the method of measurement. It can also be affected by operating pressures, temperature and quality of water.

This property can be measured by collecting a fixed volume of foam in a standard container such as that specified in NFPA 11. The weight of foam collected is then translated into a volume of foam solution. (Normally it is assumed that 1 ml of foam solution has a mass of 1 g.) The volume of foam is then divided by the volume of foam solution used to make the foam, as shown in the expression below:

$$\text{Expansion} = \frac{\text{Volume of foam}}{\text{Volume of foam solution}}$$

Low expansion foam (expansions up to 20:1) is the most widely used type for fighting flammable liquid fires. Medium expansion foam (20-200:1) is most commonly used for bund fire protection and extinguishment but may be used in some cases for pool fires; there are several types of portable equipment and fixed systems designed to apply this type of foam. High expansion foam (200-1 000:1) is most effective in indoor spaces where it can be used to submerge a combustible solid or flammable liquid fire and exclude the air needed for combustion. Because it has relatively low water content per unit volume, it does not have a great cooling effect on solid surfaces and so the extinguishment process depends mostly on smothering the fire. High expansion foam is most valuable in total flooding of spaces where it is inadvisable for personnel to go during fire-fighting operations. In some cases, it can be used to provide local application to risks where it is not feasible to flood the entire volume.

(ii) Drainage time

Drainage time is a measure of the rate at which water drains from foam. A high drainage time demonstrates a foam's ability to maintain its heat-resisting and stability properties.

Drainage time is usually expressed as 25% drainage time (or quarter life/quarter drainage time). This is the time taken for 25% of the original water content to drain from the foam. It is a property that can be influenced by the same factors as expansion.

6.4.3.4 Foam types

At the time of publication, there was an increasing interest in the environmental impact of foam, which could lead to controls on their use and application. Users should ensure that their foam concentrates meet environmental discharge requirements. It may be necessary to contain foam solution onsite; for disposal, it may be classified as waste, which in the UK is subject to the requirements of The Hazardous Waste (England and Wales) Regulations, or The Special Waste Regulations, as amended, in Scotland.

(i) Fluoroprotein

Fluoroprotein (FP) foams are produced from a protein base to which special fluorochemicals are added. The good stability and heat resistance associated with a protein base are still achieved, but also some other very useful properties are provided:

- Fuel tolerance so that FP foams can be used with less gentle application methods. In particular, FP foams can be used for sub-surface injection systems.
- Greater compatibility with dry chemicals.
- Lower shear stress in the finished foam allowing it to flow more quickly across the fuel surface and hence give faster knockdown and extinguishment.

FP foams can achieve expansion ratios of up to approximately 40:1 but are normally used for fire-fighting up to 10:1.

(ii) Aqueous film forming foam

Aqueous film forming foam (AFFF) was developed specifically for crash fire situations where fast fire knockdown is vital to maximise chances of personnel rescue.

AFFFs comprise fluorocarbon surfactants and synthetic foaming agents that give the foam solution surface tension characteristics such that a thin vapour sealing film is produced on a petroleum liquid surface. This film spreads rapidly over the surface resulting in fast flame knockdown. The effectiveness and durability of the aqueous film is directly influenced by the surface tension of the product. AFFFs are more effective on fuels with higher surface tension coefficients such as kerosine, diesel oils and jet fuels than they are on fuels with low surface tension coefficients such as hexane.

AFFFs are formulated to drain foam solution quickly from the foam bubble to produce optimum film formation for rapid fire knockdown. To achieve this, long-term sealability and burn-back resistance are sacrificed to some degree.

Because of the extremely low surface tension of AFFF solution, these foams may be of some use as a wetting agent in Class A (solid fuel) materials (see *7.6.1.2*) where deeper penetration of water is needed.

Some AFFF products contain perfluorooctane sulfonates (PFOS); there are emerging legislative and regulatory moves to restrict their use due to their inherent environmental hazards.

(iii) Film forming fluoroprotein foam

In order to combine the good stability and heat resistance of protein base foam and the fast knockdown of a film forming one, some manufacturers have developed a film forming fluoroprotein foam (FFFP) type. The result is usually foam that exhibits good all round properties but may not achieve quite the same knockdown as an AFFF or quite the same burn-back resistance as a FP. This is understandable because for fast knockdown, rapidly draining fluid foam is better; whereas, for burn-back resistance, slow draining stable foam is better. Thus, requiring these two features tends to require opposite properties.

(iv) Multi-purpose/ alcohol resistant foam

Polar solvents and water miscible fuels such as alcohols and ketones are destructive to standard foams used for petroleum and its products because they extract the water contained in them and rapidly destroy the foam blanket. These fuels require a special type of multi-purpose (MP) concentrate often known as alcohol resistant (AR).

The early types of AR foams were based on standard protein foam and suffered from severe limitations such as the amount of time that they could be stored in premix and the fact that they required very gentle application onto the fuel surface. They were not very efficient on liquid fires involving petroleum and its products.

MP foams have replaced AR foams. Some have a synthetic AFFF base and others have a FFFP base. Both types can be used, with the right application techniques, on petroleum and its products, and polar solvent fires. Generally, but not exclusively, they contain special polymeric additives that remain in the foam until it comes into contact with the water soluble fuel. As the fuel extracts the water in the foam bubbles a tough polymeric membrane preventing further destruction of the foam blanket on top of it is formed on the fuel surface. This effect does not occur on petroleum liquids but instead the foam behaves as a conventional AFFF or FFFP with additional stability and burn-back resistance caused by the polymer additives. Hence, modern MP foams can provide an effective agent for both types of flammable liquid.

The MP foams currently available are suitable for use in sub-surface injection systems for petroleum and its products but not for water-soluble liquids.

Earlier types of MP foams were designed for 3% use on petroleum and its products and 6% on polar solvents (i.e. they differed from most conventional foams in that they were used at different concentrations according to the fuel type). There are now grades available for use at 3% on both substance types.

Application rate of foam solution for MP concentrates depends on the identity of the fuel being extinguished.

When purchasing foam concentrate for water miscible fuels, the manufacturer should be consulted regarding the correct application rate to be used for the pertinent fuels prior to determining quantity requirements.

(v) Synthetic detergent foam

Synthetic detergent foam (SD or Syndet) concentrates are based on a mixture of synthetic foaming agents with additional stabilisers. They are very versatile in that they can be used to produce low, medium or high expansion foams. For this reason they are often referred to as high expansion foam concentrates. In addition, they can provide a certain amount of wetting action for Class A solid combustible material fires (see *7.6.1.2*).

The foams produced from them have good fluidity, will flow around obstructions and achieve rapid knockdown. However, they have low stability and relatively rapid drainage times and so provide little radiant heat resistance and tend to dissipate fairly quickly. Therefore, SD foams exhibit very little burn-back resistance and their fuel surface sealing capabilities are limited.

For these reasons SD foams have found very little application in the petroleum industry. However, for general purpose FRS use they can be of value because of their versatility.

6.4.3.5 Foam selection

At most installations there will be a range of hazards and potential fire scenarios. In some cases, users should seek independent specialist advice regarding the foam type to be used, especially where mutual aid schemes are in place and foam and supporting equipment compatibility is necessary. (There are undoubtedly benefits in standardising foam concentrate type as well as equipment in such instances.)

Ideally, only one type of foam concentrate should be kept onsite to avoid the possibility of cross-contamination and to simplify foam application.

Whilst many different foam types are available, users should choose the appropriate concentrate by reviewing the foam properties most relevant to their applications, site-specific considerations such as fuel types, potential scenarios, ambient conditions and environmental concerns, as well as, of course, price.

For example, a tank fire application requires foam with excellent heat resistance and burn-back resistance, whilst in other situations fast knockdown capability might be preferable. Table 6.1 illustrates the properties attainable from good quality foam from each generic type of foam concentrate for fighting flammable liquid fires. However, other factors such as cost effectiveness, standardisation onsite, storage conditions and corrosion should be considered prior to selecting the agent.

6.4.3.6 Foam specification and storage issues

For many installations handling petroleum and its products, storage tank application will be one of the most critical hazards. In order to minimise risk to fire-fighters and reduce fire losses, the foam concentrate should be specified, maintained and used correctly. Its application – particularly to large storage tank fires – demands effective, efficient performance in both extinguishing a fire and preventing re-ignition. Often such fires burn for several hours before the resources to extinguish them are deployed. This means that the foam concentrate has to be capable of withstanding the effects of heat build-up in the fuel and the tank walls and be able to form an effective seal against the hot tank wall, thus preventing further vapour emission and possible reignition.

Unfortunately, too often a fire performance test is not included as part of a procurement specification or one that is not relevant to the situation is selected. This issue is highlighted in OGP *Fire systems integrity assurance*.

Correct specification, stock management and storage are critical to ensuring continuing foam performance but they are often not given sufficient consideration onsite.

When procuring foam stocks, a recognised fire test should be specified that is relevant to the application. For example, when evaluating foam for storage tank application, RPI *LASTFIRE: Foam fire test specification for storage tank fires* should be used. For other applications a test such as UL 162 can be specified. Aviation-type test requirements designed to evaluate foam for rapid rescue situations are not used as the exclusive specification for foam procurement. Fire testing should be carried out at batch acceptance and at regular intervals thereafter to ensure that the foam will perform as intended.

A detailed procurement specification should also demand measurement of various physical properties on the batch. These, whilst not having a direct relevance to fire performance, can be used to assess any changes in the concentrate due to degradation, contamination or dilution. Samples should be retained by the user and the manufacturer to act as reference points to facilitate identification of the cause of any degradation.

Table 6.1: Comparison of foam properties

Property	Foam type					
	P	**FP**	**AFFF**	**SD**	**FFFP**	**MP/AR**
Cohesion	****	***	**	**	***	***
Vapour suppression	****	****	**	**	***	****
Stability/ water retention	****	***	**	**	***	***
Flowability/ flame knockdown	*	**	****	***	***	***
Heat resistance	****	****	**	*	***	***
Sealing capability	***	****	**	*	***	****
Burn-back resistance	****	****	**	*	***	****
Fuel tolerance – petroleum and its products	*	***	***	*	***	***
Fuel tolerance – polar solvents	0	0	0	0	0	***

Key:
Performance:
**** Excellent *** Good ** Reasonable * Poor 0 Insufficient

Foam types:
P – Protein foam (obsolete) FP – Fluoroprotein
AFFF – Aqueous film forming SD – Synthetic detergent
FFFP – Film forming fluoroprotein MP – Multi-purpose

Notes
1 Apart from protein foam (now obsolete) and SD foams (which exhibit very little burn-back resistance, and have found very little application in the petroleum industry), all other types indicated above are widely used for petroleum installation fire-fighting.

Good storage and regular inspection of concentrate are essential for ensuring performance is maintained. Some basic principles are:

- Where possible and deployment logistics allow, concentrate should be kept in original containers.
- Concentrate should not be transferred to recycled drums that have been used for other liquids.
- Concentrate should be stored within manufacturer's temperature limits.
- Storage should avoid direct sunlight impinging onto containers or storage vessels.
- The air/liquid interface should be minimised by filling to expansion dome or using sealer oil.
- Storage tank materials should be compatible with concentrate.
- Tank linings or coatings should be avoided. (High-density UV stabilised polyethylene is a proven material for storage tanks.)
- Clear labelling of tanks should be provided to minimise the possibility of contamination from other materials.
- Foam concentrate stock should be segregated from other materials.
- Prior to adding new batches to existing bulk storage, the condition of existing bulk storage should be assessed.
- Foam concentrate properties should be tested regularly (at least annually) for degradation.
- Any bulk storage tank should be thoroughly cleaned if concentrate is all used prior to refilling.
- Bulk concentrate should not be kept in a single tank. Having two tanks allows the use of a main tank until fully utilised, followed by a reserve tank. This means that concentrate is used in sequence and tanks can be thoroughly cleaned and inspected.

- Concentrates of different generic types should not be mixed.
- Concentrates from different manufacturers for long-term bulk storage should not be mixed.
- Concentrates having different proportioning rates should not be mixed.

6.4.4 Dry powder (dry chemical)

Various chemicals in powder form are used in a wide range of portable fire extinguishers and fixed suppression systems.

Powders generally are extremely effective in flame knockdown, as they act whilst in the form of an airborne suspension. However, when the agent has settled out of suspension, its flame knockdown capability is reduced. Powders are particularly useful against running flammable liquid fires, which can result from ignition of a release or pipe fracture. (Foam cannot readily extinguish these types of fire.) Powder can, in some cases, be used in conjunction with other media such as water sprays, certain foams and gaseous agents although compatibility should be confirmed before doing so. Dry powder application requires special application techniques and users should be experienced, since factors such as poor visibility can hinder use.

6.4.4.1 Powder types

(i) BC powder

Sodium and potassium bicarbonates and similar salts are particularly effective for the extinction of flammable liquid fires.

(ii) ABC powder

Ammonium phosphate and some other salts are capable of extinguishing liquid and solid fires, and can extinguish glowing embers.

(iii) Foam compatible powders

Some powders are incompatible with foam, as the chemicals used tend to break down the bubble structure. Consequently, other powders have been developed that are compatible with foam. Their advantage applies particularly to cases where the larger types of dry chemical equipment are located and where it is probable that additional fire-fighting will be undertaken by means of large quantities of foam.

6.4.4.2 Application

Powders are of particular value in dealing with fires involving flammable liquids, carbonaceous substances, electrical equipment, gases and metals. However, some types of powder are more effective than others for different applications.

Powder gives very rapid control of fire, although on initial application there may be a momentary increase in radiation from the fire. Wind effects may also be an issue, as the powder may be carried away from the fire when used outdoors. Powder may also be affected by humid conditions. In some cases, if stored for a long time, powder may settle and become compacted. It should be recognised that powder does not provide as effective vapour suppression and post-fire security as foam; re-ignition is therefore a possible hazard. Supplementary application of foam should therefore be considered.

Clean-up of powder residues from equipment will usually be necessary; for this reason, it is not generally recommended for use on sensitive electronic equipment.

6.4.5 Gaseous agents

6.4.5.1 Types of gaseous agent

A number of gaseous agents are available for fire-fighting use. With the recognition of the contribution of halons to the breakdown of the Earth's ozone layer and regulatory restrictions on its use, several alternative gaseous agents have been developed. The wide choice of agents means that comprehensive performance criteria should be developed both for agents and systems using them.

Gaseous agents are divided into three distinct types – CO_2, 'chemical' halon replacements and other proprietary inert gases.

Regardless of agent used, it should be of the correct quality. Guidance on quality requirements for different gases is given in BFPSA *Code of practice for gaseous fire fighting systems* and NFPA 2001.

(i) CO_2

CO_2 effectively dilutes the atmosphere to a point where the oxygen content will no longer support combustion. In doing so, it may create an oxygen deficient atmosphere hazardous to personnel; this may especially be the case when a large volume discharge drifts and settles in an adjacent low-lying area, pit or trench.

CO_2 produces little cooling effect. Glowing combustion may continue and the fire may re-ignite once the extinguishing gas has dispersed

(ii) 'Chemical' halon replacements

Chemical agents typically function by terminating the chemical reactions that maintain combustion. The use of chemical agents as halon replacements has gained popularity recently and many systems are installed. However, at the time of publication, there are concerns regarding their environmental acceptability and potential future legislation restricting their use.

(iii) Other gaseous agents

These are mainly mixtures of inert gases and typically include trade names such as Argonite (50% argon, 50% nitrogen) and Inergen (40% argon, 52% nitrogen, 8% CO_2). Some agents are promoted by manufacturers as being non-toxic and non-asphyxiant to personnel.

6.5 FIXED SYSTEMS – OPTIONS, APPLICATIONS AND DESIGN ISSUES

6.5.1 General

This section outlines the main fixed fire protection options, potential applications and common design issues. Typical requirements and applicable standards for fixed fire systems in specific installations/areas – storage tanks, process areas, liquefied gas facilities, marine facilities and buildings – are given in Annex C. Portable and mobile fire-fighting equipment are addressed in section 7.6.1.

The need for fixed fire protection systems will depend on identified scenarios, potential consequences and other factors such as fire response availability. In all cases, a scenario-based approach should be used, backed-up where necessary by a CBA. This approach can allow the potential benefits in risk reduction gained from different system types, options and configurations to be compared against the cost of implementation.

Fire-fighting equipment is only called into action when a problem has occurred. Therefore, it should be designed, manufactured, inspected and maintained to the best possible standards so that when it is needed it can be brought rapidly into effective operation. The best method of doing this is to design in accordance with recognised publications (codes of practice, design standards, specifications, guidance, etc.) and use materials that have been approved by a reputable testing authority. Personnel who will be expected to use, inspect or maintain the system should be fully trained and competent in these aspects.

6.5.2 Water spray systems

The principal objectives of water deluge/spray systems are:

— cooling fire-engulfed plant and equipment;
— cooling plant and equipment exposed to thermal radiation.

Whichever of these objectives the system is intended to meet should be clearly defined before a design is attempted or the system is installed, as application rates differ depending on the objective.

The first priority should be to decide whether a water deluge/spray system is needed. Typically, this will require consideration of the local legislative position as well as fully appraising the risk. The most appropriate method is to carry out a scenario-based evaluation of credible fire incidents. For example, a single small tank, where options exist for rapid deployment of portable fire-fighting equipment may not necessitate use of such a fixed system. However, a large tank within a bund with minimal separation and significant fire exposure potential might benefit from fixed water-cooling.

One method of determining whether fixed water-cooling might be required is to make use of validated fire consequence modelling software packages to determine the extent of radiant heat flux on a given tank or part of an installation. Generally, fixed water-cooling should be considered if the exposed tank, vessel or plant is likely to be exposed to a radiant heat flux in excess of 32 kW/m^2 (see section 2.6.2).

Where exposures are likely to be subjected to less than this amount – typically 8 kW/m^2 and above – fixed water-cooling may be considered, but may not always be necessary. Generally, cooling will be required at some stage but this may be provided by mobile means (e.g. with the use of portable water monitors – portable and mobile fire response issues are outlined in section 7.6.1).

Cooling water requirements should be based on the amount needed for the total vessel or structure surface areas (see annex D.5 for typical water application rates).

Note that, in sizing relief valves, no credit for reduced heat input should be taken for water spray cooling even though this will probably limit the heat input to the vessel.

For tanks, only that section of the tank surface exposed to the potential risk needs to be protected by cooling. This is particularly applicable to large storage tanks where some heat absorption can be tolerated. Note that for spheres and horizontal cylinders the lower half of the surface of the vessel should be sprayed. Reduced nozzle spacing may be required for this portion of the vessel.

When designing water spray systems special attention should be paid to drainage. Drains should be suitably sized to handle the maximum design rate of water spray and be equipped with flame traps and oil/water separators.

Consideration should be given to system drain points, testing facilities and flushing facilities, particularly when brackish or salt water is used. For general design criteria refer to NFPA 15.

The requirement for water deluge/spray should also be considered in relation to the protection given by PFP measures.

6.5.3 Fixed monitors

Fixed monitors may be used as an alternative to fixed water spray systems for providing cooling water to exposed tanks, vessels and equipment.

Fixed monitors should be provided with adjustable, constant-flow, fog-to-straight-stream nozzles so that process equipment is suitably covered but will not be damaged by a solid stream at shorter ranges. Care should be taken not to direct water jets onto hot operating process equipment since thermal shock could lead to relaxation of joints or fracture of the equipment. The use of fine sprays is recommended in this situation.

A heavy fog may be projected into the process area if needed for exposure protection of equipment or personnel.

Fixed monitors should be located within range of the equipment to be protected. In the case of storage tank farms, they should be located outside bund areas. If, due to obstructions, monitors are required closer to the equipment, cooling for the monitor should be considered. Manually operated monitors should be located in an area that is not likely to receive more than 6,3 kW/m^2 (see section 2.6.2) which is considered as the limit for fire responders to perform brief alignment tasks, if wearing appropriate PPE. This also applies to actuation points and remote control units, which should be located outside of the fire hazard area.

Various types of monitors are available for use with foam or water, and remote controlled, electric or water-powered oscillating units are commercially available. Whichever type is used, range should be assessed in the most demanding flow and wind conditions.

6.5.4 Sprinkler systems

Sprinkler systems should be considered for storage areas and warehouses holding ordinarily combustible (cellulosic) materials. For manufacturing or filling areas involving flammable liquids or flammable liquid storage, use of automatic sprinkler systems requires careful consideration of the system design, type of materials involved, and drainage provisions. Where low flash point flammable liquids are stored, foam sprinkler systems are preferred, since water-only sprinklers are largely ineffective against these risks and may actually spread the fire to other areas.

The design of sprinkler systems will vary with the hazards and size of the installation. The type, size and number of sprinklers that will operate in a fire, the water discharge rate and duration of discharge are linked to the hazard classification. Thus, the size of the water supply source and supply mains will vary accordingly.

For sprinkler systems protecting indoor storage of barrels, pallets and non-pressurised containers, pipework should be designed to avoid impact damage during movement and stacking operations.

Sprinkler systems should be designed, installed and maintained in accordance with NFPA 13, BS EN 12845 or other recognised standard.

6.5.5 Water mist systems

Water mist systems have evolved from existing sprinkler and water washing systems technology. They produce very fine water droplets – most fewer than 400 μm in diameter and only small amounts of water are used. They are a viable alternative to gaseous systems for protecting certain areas, although in most cases application is limited to some turbine enclosures and other smaller, enclosed compartments.

Single fluid (i.e. water only) and dual-fluid (water plus inert gas) high and low pressure systems are available for local and volume application.

The advantages of water mist are that only small amounts of water are required, and the water does not dissipate through enclosures like a gaseous agent. Cooling, wetting of combustibles and a degree of oxygen exclusion are all given on activation.

Systems should be highly engineered to provide a high level of protection – there are many variables in the design that have an effect on the effectiveness of the system; these include nozzle spacing, positioning, ventilation, hazard geometry and fire size. In addition, some dual fluid systems actually rely on additional inerting of the atmosphere by the inert gas carrier. Care should be taken when specifying and designing these components. In most cases, where water mist systems are to be used a full trial design should be established and tested to ensure the system will work in practice.

For guidance on the design, installation and maintenance of water mist systems, see NFPA 750.

6.5.6 Foam systems

Critical performance criteria relevant to foam systems include:

- system response time (i.e. time taken to produce effective foam);
- application method (e.g. via foam sprinkler/spray nozzles or fixed foam pourer, and whether 'gentle' or 'forceful' application);
- foam quality (expansion, drainage time and proportioning rate concentration);
- application rate;
- foam coverage;
- duration of discharge;
- foam type.

6.5.6.1 Foam sprinkler/spray systems

Correctly designed foam sprinkler/spray systems provide effective protection for both indoor and outdoor risks where flammable liquids may be released in relatively large quantities. Typical risks that may be protected are road tanker vehicle and rail wagon tank loading gantries, horizontal storage tanks, pump rooms, flammable liquid warehouses and process units.

They can provide an even distribution of foam giving fast flame knockdown and fire control coupled with secure and safe extinguishment. In addition, they can provide a valuable cooling effect to structures within the fire area or exposure protection from heat radiation from adjacent fire areas.

Foam sprinkler or spray systems should therefore be considered for loading/unloading bays, pump slabs and warehouses of strategic importance in which Class I and II products are handled.

Systems can be initiated either automatically (e.g. by flame detection) or manually depending on the layout of plant and access for fire-fighting services. Most foam systems apply foam through foam-water sprinkler/spray heads positioned above the potential fire hazard. For outdoor risks the effect of wind should be taken into account. It is common practice in circumstances where this can be a problem to cover an additional area each side of the actual risk. For example, if loading gantry dimensions were 10 m x 10 m, the area covered may be increased to 13 m x 13 m. The actual allowance in any situation will depend upon the particular circumstances such as prevailing wind directions and the degree of exposure to strong winds. Obstructions to foam distribution should also be accounted for. It may be necessary to provide additional nozzles to compensate for this. A wide range of nozzles having directional capability and different angles of discharge is available for such circumstances.

Discharge nozzles should be tested with the foam concentrate being used. This is particularly true for polar solvent risks where minimum application rates vary according to the foam concentrate used and the product being protected. (In such cases, test data, preferably from an independent source, should be used to decide final application rates.)

A good quality foam concentrate/nozzle combination will produce foam that, after 10 min. foam solution discharge (or once foam concentrate supplies have run out), will withstand 20 min. water discharge from the same nozzles and still provide an acceptable degree of burn-back resistance and vapour suppression.

Essentially, there are two types of system:

(i) Open head foam/water deluge spray

In this type of system, every nozzle discharges simultaneously. This system is most suitable for loading gantries, pump rooms, etc.

The nozzles used can be non-aspirating or aspirating. Aspirating type will generally produce better foam quality. When non-aspirating heads are used, a film forming foam type should be used.

Various nozzles with different discharge patterns for mounting at elevated or ground level are available for this type of risk.

(ii) Closed head foam sprinkler

This is a conventional sprinkler system using closed, non-aspirating heads. Heat from a fire will cause individual heads to discharge. Proportioning accuracy over the very wide range of possible flows can cause a problem and it is normal practice to choose a proportioner type that will tend to give a rich concentration of foam solution as opposed to a weak one at low flow levels where only a few heads discharge.

The introduction of a film forming foam into a sprinkler system provides a wetting action by reducing the surface tension of the water and enabling it to penetrate further and more quickly into Class A materials (see *7.6.1.2*). Tests have shown that fires can be extinguished more rapidly using a film forming foam in such circumstances, thereby ensuring that water damage is kept to a minimum. When a warehouse is protected by a sprinkler system, the introduction of foam concentrate into the system is often used when the risk in the warehouse involves flammable liquids.

Design should be in accordance with NFPA 11, NFPA 16 and/or BS 5306-6. Generally, a fixed foam system should be designed to provide foam solution over the full surface area to be protected at the typical application rates given in annex D.7 and Table D.2.

6.5.6.2 Foam systems for storage tanks

Many tanks in service 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 such as foam/water monitors. 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.

The type of protection system specified will depend on the construction of the tank and the properties of the product stored. In the event that a system is considered justified, the standard typically applied is NFPA 11. See also the RPI *LASTFIRE* project deliverables, which features a comprehensive review of tank related foam system applications.

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 should also be remembered that all fixed systems should have supplementary foam back-up. Requirements are outlined in Section 7.

(i) Fixed foam pourers for bunds

Fixed foam pourers are sometimes used for protection of bunded areas. The discharge devices are fixed to the bund wall at equally spaced intervals so that the foam discharges into the bund itself.

Typically, application rates should be at least 4 l/min./m^2. For foam destructive fuels (e.g. polar solvents), the foam concentrate manufacturer's recommendations should be followed.

(ii) Fixed foam pourer systems for fixed roof tanks

Fixed foam pourers are often used as the primary protection method for fixed roof tanks. See Figure 6.2. 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 or plastic seal that breaks under pressure from foam entering the device.

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

- foam generator – this may be mounted very close to the discharge device or remotely from it;
- vapour seal box;
- 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.

The major disadvantages of foam pourers for tank protection are: 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 to operate than the alternative protection methods for fixed roof tanks.

Where an internal floating roof is present within a fixed roof tank, fixed foam pourers are the preferred protection method. In such cases, foam solution application rates are the same as for standard fixed roof tanks and are based on the entire surface area of the tank, unless the internal roof construction is one of the types normally associated with open top floating roof tanks.

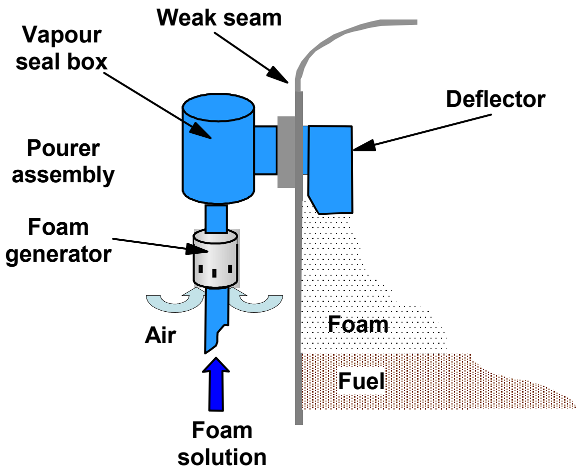

Figure 6.2: Fixed foam pourer system for fixed roof tanks

(iii) Subsurface protection of fixed roof tanks

With subsurface 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-suppressing blanket over the entire surface. See Figure 6.3. Circulation of the fuel caused by the travel of foam through it helps to cool the fuel surface. 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 more popular as the primary protection method for tanks storing petroleum and its products. There is currently no foam suitable for use in such systems with water-soluble substances.

Special consideration should be given to high viscosity fuels, as subsurface injection may not be suitable.

With some products 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 100 °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 product 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 should be provided that are designed to produce suitable quality foam against the backpressure caused by the product head in the tank and any friction losses between the foam generator and foam discharge point inside the tank. Such high back-pressure generators typically can produce foam against 25-40% backpressure. Normally a minimum inlet pressure at the generator of 7 bar is required.

In order to minimise product pick-up and foam breakdown the foam discharge velocity into the tank should be limited in subsurface. This factor, along with the need to calculate and minimise backpressure, mean that the pipework sizing and routing can be more critical than with other pourer systems.

In order to provide a positive seal against the product leaking back down the foam system pipework, a bursting disc should be positioned 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 have been incorporated into the system layout. Such test outlets should be of a size sufficient to simulate actual flow conditions and foam generation.

(iv) Semi-subsurface protection of fixed roof tanks

In an attempt to overcome the disadvantages of subsurface systems for fixed 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 foam is applied gently to the product surface. See Figure 6.4. This, in theory, allows use on water-soluble products.

To some extent this equipment was made obsolete by the use of foams that can be used in a true subsurface system. However, true subsurface systems cannot be used on water-soluble products, so semi-subsurface techniques might be a solution in such cases. (This point should be borne in mind now that more and more foam destructive additives are being added to petroleum products such as unleaded petrol.)

The equipment used for semi-subsurface technique consists of a container, either mounted in the product itself or just outside the tank shell near its base, with a hose of length equal to the tank height. 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 major disadvantage of the system is that it is complicated compared to other types. It is also relatively difficult to maintain and check and the unattached end of the hose can disrupt the foam blanket as it moves around due to the reaction force of the discharging foam. Consequently, it is not a preferred option.

(v) Foam top 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.

In fact, this type of tank has a relatively good safety record and some petroleum 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 hose line can be connected here and by walking around the walkway, a fire-fighter can direct foam into the seal area.

Such methods are not considered good practice and should be considered as a last resort for localised rim seal fires only. The optimum solution is to provide a fixed foam pourer system; see Figure 6.5. It comprises a number of pourers positioned strategically around the top of the tank discharging foam into the seal area. A foam dam is fixed on the tank roof to contain the foam in the seal area.

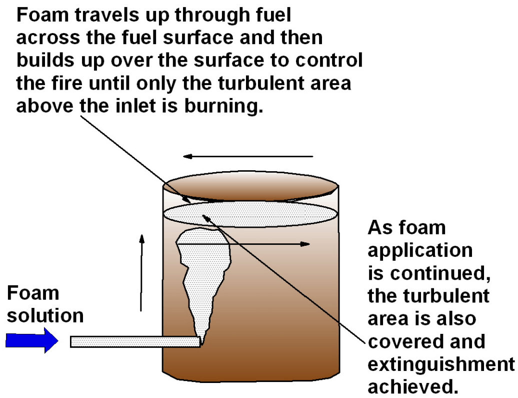

Figure 6.3: Subsurface foam system for fixed roof tanks

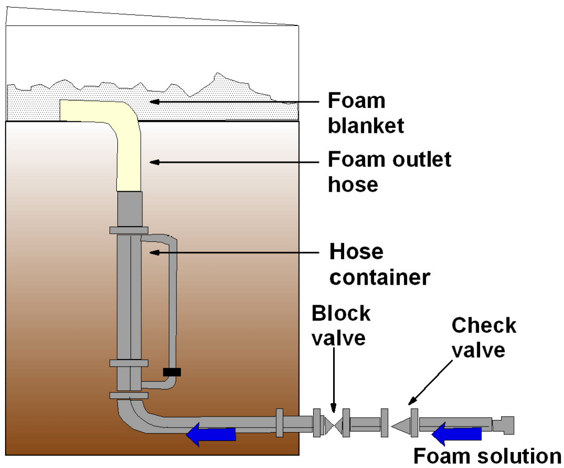

Figure 6.4: Semi-subsurface foam system for fixed roof tanks

Pourer systems have the following advantages:

— Relatively simple installation.
— No moving parts on tank roof.
— Maintenance of pourers is straightforward and safe to carry out provided the tank has a walkway.
— 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. In theory, this is more effective but in practice gives rise to

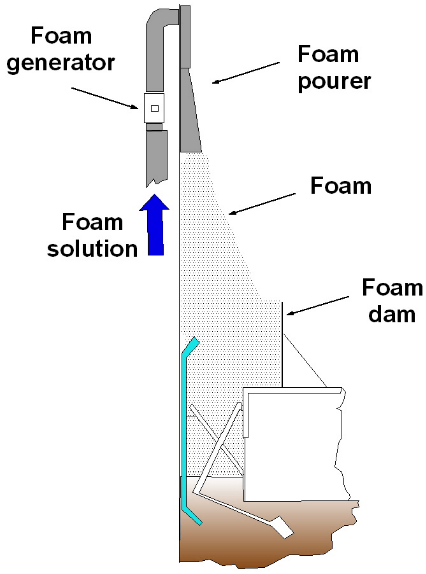

Figure 6.5: Foam pourer for open top floating roof tanks

additional maintenance issues. Therefore, foam pourers are normally considered as the preferred choice.

(vi) Catenary system protection of open top floating roof tanks

In order to overcome the potential disadvantages of the top foam pourer system for open top floating roof tanks, some manufacturers have 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 may not be a foam dam and discharge may be above or below a secondary seal. See Figure 6.6.

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

— Routine maintenance has to be carried out on the floating roof.
— Air inlets to the foam maker are on the roof and so may draw in fumes or combustion products.
— The flexible hose is very prone to damage from the environment or the rolling ladder or other fixtures trapping it.

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

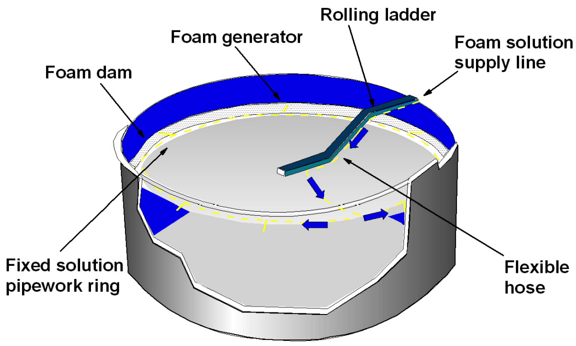

Figure 6.6: Catenary system for open top floating roof tanks

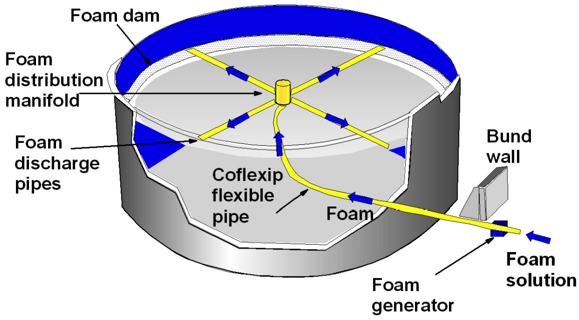

Figure 6.7: Coflexip system for open top floating roof tanks

(vii) Coflexip system protection of open top floating roof tanks

In the Coflexip system, a special flexible pipe of the type used for roof drains on a floating roof tank is installed inside the tank.

Depending upon the total flow rates required and hydraulic calculations 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). See Figure 6.7.

This system therefore overcomes the potential disadvantages of top pourer and catenary systems; however, a critical part of the system is actually inside the tank and therefore cannot easily be inspected, maintained and repaired.

Acceptance of this type of system therefore depends on the reliability of the flexible pipe and the joints connecting it to the distribution pipework.

6.5.7 Dry powder (dry chemical) systems

A range of fixed dry powder (dry chemical) systems are available including:

— fixed total flooding systems;
— fixed local application systems;
— monitors;
— hosereels.

The main issues are selection of an appropriate powder (some are more effective than others at extinguishing flammable liquids, for instance), application method and, for fixed systems, pipework design. Discharge devices such as nozzles, monitors etc. should be compatible with the powder used, positioned correctly and provide the correct flow rate to control and extinguish the fire. Weight and composition of the powder and propellant type are also key factors in system design. Specialist guidance and component/agent approvals should be sought when considering dry powder systems.

In the case of total flooding systems, pipework should be designed so that the design concentration is achieved within 30 s. The possibility of particulates and residues affecting flow should also be borne in mind and pipework should be designed accordingly.

Guidance on dry powder system design can be found in NFPA 17.

6.5.8 Gaseous systems

Fixed gaseous extinguishing systems use extinguishing media such as CO_2, various 'chemical' halon replacements and other inert gases. Halon systems are being phased out due to international restrictions prohibiting their use for fire-fighting application.

'Total flooding' systems are commonly used in enclosed areas, mainly to contain electrical fires such as those in computer suites, control rooms and switch rooms but they are also used in turbine enclosures. See Figure 6.8. 'Local application' systems are used for specific hazards. See Figure 6.9.

Local application systems have also been used to provide protection to the rim seal area of floating roof tanks. However, experience has shown that these types of system provide only limited discharge time and do not significantly cool the fire. (A more suitable system is a fixed rim seal foam pourer system.)

Careful consideration should be given and, where necessary, expert advice sought on the design and installation of such systems for enclosed areas, particularly with respect to personal safety.

It should be recognised that whilst some other gaseous agents are marketed as 'personnel safe', exposure should be limited (particularly for 'chemical' halon replacements) and international standards usually offer guidance on these aspects. For example, CO_2 is toxic and an asphyxiant and therefore hazardous to personnel – adverse health effects can be felt at concentrations as low as 4% in air.

Entry into confined spaces protected by gaseous systems should be strictly controlled by a PTW system. Provision should also be made to positively isolate the protection system whilst maintenance work is carried out in the area covered by the system and to reinstate the system once work is completed.

Some design considerations include:

— design concentration;
— application rates and retention time;
— requirement for extended discharge;
— nozzle placement;
— detection, actuation and control;
— ventilation;
— life safety issues – interlocks and positive isolation;
— post-discharge response procedures.

Design concentration, application rate and retention time are key design criteria. The concentration required will depend on the product and fire type. It may be necessary to develop specific performance criteria for some applications. Normally, a safety factor over the minimum design concentration should be applied.

Comprehensive guidance can be found in BS 5306-4 or NFPA 12 for gaseous systems using CO_2, and BS ISO 14520 or NFPA 2001 for agents other than CO_2.

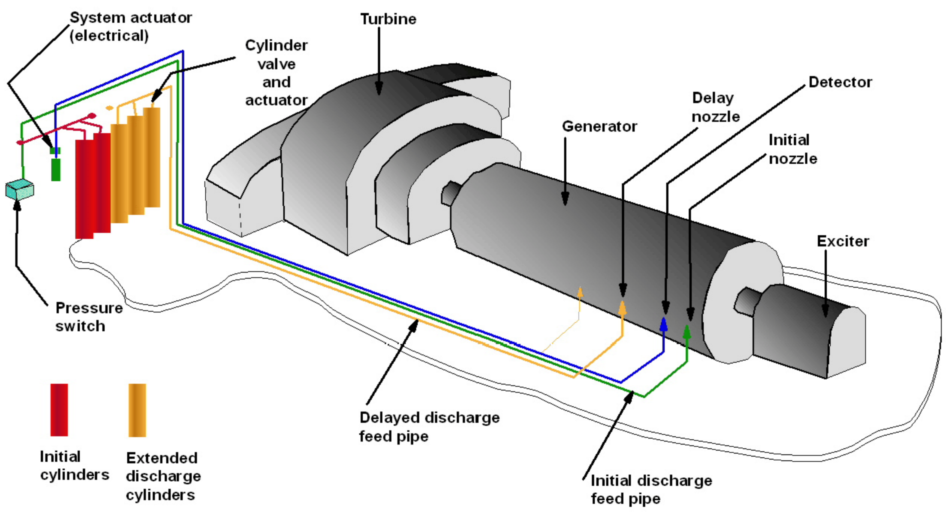

Figure 6.8: Total flooding gaseous system schematic

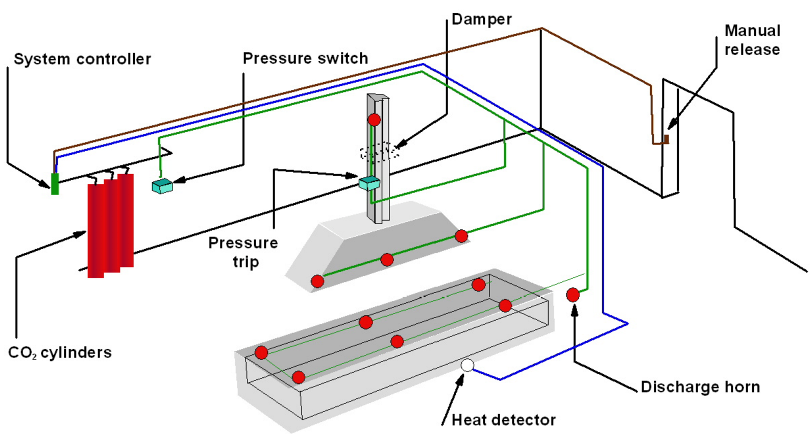

Figure 6.9: Example schematic of a CO_2 local application gaseous system

7

RESPONSE STRATEGIES AND OPTIONS

7.1 INTRODUCTION

This section provides incident response strategies for various fire and explosion scenarios identified in section 2.5; it includes options for mobile and portable fire response, including the specification, use and maintenance of fire-fighting equipment ranging from fire monitors to responder personal protective equipment (PPE).

Fire incident response is only one aspect of FEHM; this section is based on the premise that other FEHM measures – such as fire prevention, fire and flammable gas detection and fire protection – are in place.

The guidance in this section reflects incident experience and good practice in fire response. It can be used as a basis for developing site-specific fire response strategies accompanied by ERPs.

7.2 INCIDENT RESPONSE STRATEGIES

7.2.1 Unignited gas release

7.2.1.1 LPG or LNG liquid release

For LPG releases, the use of medium or high expansion foam application is not fully proven as an effective control or extinguishing agent although there is anecdotal evidence of a small number of limited successes. When foam is applied, this may initially result in a higher rate of evaporation of the LPG before any control is achieved. However, in at least one instance, the weather conditions were sub-zero, resulting in the foam forming an ice sheet over the liquid LPG.

Good practice for LPG and LNG is to use fixed and/or portable water monitors or water curtain/fan spray nozzles to contain or direct the liberated gas and prevent it from reaching a source of ignition. Where downwind or downhill gas migration is toward an area that has no source of ignition, the opportunity should be taken to set up water screens or curtains upwind if sources of ignition are present in this direction, in case of wind direction changes. It should not be assumed that wind direction and speed will be constant during any incident. It should be assumed that a gas cloud will ignite and therefore any intervention, after proper initial and continuing risk assessment, should consider setting-up water curtains to contain or disperse the gas to below its LFL. In most cases, such deployment should be supported by hose line teams using water curtains to protect the deployment teams. Such work needs careful pre-planning and exercising.

The full response strategy depends on the size and nature of the release, and the wind direction, but it should consider the following tactics:

- Halting all work and summoning emergency services.
- Halting, switching-off and abandoning vehicles and machinery in the affected area or onsite.
- Evacuating all non-essential personnel.
- Isolating the source of liquid release, if possible, safe and practical to do so.
- Assessing as early as possible the gas cloud extent and areas that may be affected either downwind or on all 'sides' of the cloud.

- Identifying as early as possible potential sources of ignition the gas may reach and necessary actions including:
  - Switching-off heaters and furnaces, extinguishing naked lights, and isolating electrical systems only if this is possible in a safe time frame before any gas migrates to the equipment. (It should be noted that heaters and furnaces, once shut off, can still retain high temperatures that can autoignite the gas.)
  - Halting traffic on rail lines or nearby public roads.
  - Preventing access by pedestrians/passers-by.
- Alerting any neighbouring (e.g. 'domino') sites or public areas to gas hazard and actuating any offsite ERPs to evacuate people and halt traffic, etc.
- Closing roads, as required.
- Implementing emergency response from upwind direction.
- Activating arrangements for meeting oncoming external response groups at a safe distance from the affected area to advise gas location.
- Being aware of plant drainage systems, storm water drainage and other low level drainage or piping, conduit, ducting or cable sleeve routes through which gas may migrate to remote locations.
- Being aware of buildings and enclosures where gas may accumulate and then ignite, causing an explosion.
- Using water in the form of water screens/curtains/spray that may check, contain or minimise gas migration.
- Avoiding direction of water streams/jets into the liquid release as this will increase the rate of gas evolution. (Also, jets may cause electrostatic discharge which may ignite gas/vapours.)
- Using portable flammable gas detection equipment to monitor gas cloud extent.
- Using water streams to agitate/aid gas dispersion at or near to the source of release. (This would only be practical if the release was not of significant size or scale and the spray streams were placed close together at the source to create turbulence.)
- Using foam for vapour suppression if LNG is involved.
- Avoiding use of foam if LPG liquid release is involved (as this is unproven).
- Avoiding entering the liquid/gas hazard area under any circumstances.
- Expecting gas ignition at any time, even if there does not appear to be any obvious source of ignition.
- Being aware that if a large gas cloud does ignite in a congested area, a VCE may occur with resultant overpressures and blast debris consequences.

7.2.1.2 Gas or vapour release

The response strategy is similar to LPG or LNG liquid release (see *7.2.1.1*), but the gas release will typically be under pressure and will clearly depend on release size and direction of gas migration through wind direction.

The overall strategy should consider the following tactics:

- Halting all work and summoning emergency services.
- Halting, switching-off and abandoning vehicles and machinery in the affected area or onsite.
- Evacuating all non-essential personnel.
- Isolating the source of liquid release, if possible, safe and practical to do so.
- Assessing as early as possible the gas cloud extent and areas that may be affected either downwind or on all 'sides' of the cloud.
- Identifying as early as possible potential sources of ignition the gas may reach and necessary actions including:
  - Switching-off heaters and furnaces, extinguishing naked lights, and isolating electrical systems only if this is possible in a safe time frame before any gas migrates to the equipment. (It should be noted that heaters and furnaces, once shut off, can still retain high temperatures that can autoignite the gas.)
  - Halting traffic on rail lines or nearby public roads.
  - Preventing access by pedestrians/passers-by.
- Alerting any neighbouring or public areas to gas hazard;
- Alerting any neighbouring (e.g. 'domino') sites or public areas to gas hazard and actuating any offsite ERPs to evacuate people and halt traffic, etc.
- Closing roads, as required.
- Implementing emergency response from upwind direction.
- Activating arrangements for meeting oncoming external response groups at a safe distance from the affected area to advise gas location.
- Being aware of plant drainage systems, storm water drainage and other low level drainage or piping, conduit, ducting or cable sleeve routes through which gas may migrate to remote locations.
- Being aware of buildings and enclosures where gas may accumulate and then ignite, causing an explosion.
- Using water in the form of water screens/curtains/spray that may check, contain or minimise gas migration.
- Using portable flammable gas detection equipment to monitor gas cloud extent.
- Use of water streams to assist gas dispersion at or

near to the source of release. (This would only be practical if the release was not of significant size or scale.)
— Using water streams to agitate/aid gas dispersion at or near to the source of release. (This would only be practical if the release was not of significant size or scale.)
— Being cautious when using water streams/jets for gas dispersal as static electricity may cause ignition.
— Avoiding entering the gas hazard area under any circumstances.
— Expecting gas ignition at any time, even if there does not appear to be any source of ignition.
— Being aware that if a large gas cloud does ignite in a congested area, a VCE may result with resultant overpressures and blast debris consequences.

7.2.1.3 Gas or vapour dispersion with water-spray
Response strategies that may include gas dispersion using water spray should consider several safety factors:

— Approaching the source of release from upwind direction.
— Fire responders wearing full fire-resistant PPE including SCBA.
— Using wheeled or portable water monitors (without permanent staffing).
— Facilitating manual handling of water monitors.
— Using hand-held hose lines with water curtain streams to protect fire responders approaching to set up water monitors.
— Being cautious when using water streams/jets for gas dispersal as static electricity may cause ignition.
— Safely re-accessing the water monitors if there is a change of conditions (e.g. wind, release volume increase etc.).
— Using portable flammable gas detection equipment to monitor gas cloud extent.
— Providing relief crews for fire responders as they may only be able to work for a limited time.

Total confidence should not be placed in any water spray dispersion of a gas release. Monitoring of the area in the vicinity of the release outside the water spray area should to be continuous to check if the tactic is effective. If the water supply has to be provided by fire vehicles, these should be located upwind and preferably at a distance of >100 m from the identified source of release. Wind direction and speed should be monitored critical during such operations.

The best method of water application for dispersal is to set monitor nozzles to a wide angle spray and gradually build up water pressure, whilst trimming the water spray to a semi-fog or semi-solid stream pattern that will create turbulence to assist in the rapid dispersal of the gas to below its LFL.

7.2.1.4 Foam blanketing for vapour suppression
A foam blanketing response strategy may be used where vapours from flammable liquids are released and where the liquid release is either constant or vapour migration may be a major hazard. The objective should be to apply foam onto the liquid to reduce vapour and thus reduce the distance to LFL.

Response strategies that may include foam blanketing should consider several safety factors:

— Selecting low, medium expansion or high expansion foam concentrate and application equipment according to the liquid.
— Approaching the source of release from upwind direction.
— Using hand-held hose lines with branches to cover those approaching to set-up foam pourers or monitors.
— Using hand-held hose lines with water curtain streams to protect fire responders approaching to set-up foam bund pourers or foam monitors.
— Fire responders wearing full fire-resistant PPE.
— Facilitating manual handling of foam bund pourers or foam monitors.
— Directing foam application devices to apply foam ahead of any liquid in a rolling application to minimise static electricity generation and consequent ignition.
— Avoiding foam stream application directly into the liquid.
— Safely re-accessing the foam bund pourers or foam monitors if there is a need to re-position.
— Using portable vapour or flammable gas detection equipment to monitor migration.

The applied foam blanket will need regular 'topping-up' to maintain vapour suppression. Once portable equipment is in position and functioning correctly, fire responders should retire to a safe distance from the general hazard area to observe foam application.

The environmental impact of foam application should be considered and therefore this strategy should be reviewed in advance to ensure that such an impact is either eliminated or reduced. There is an increasing environmental requirement to contain fire-fighting water and foam applied for incident control (see section 1.7.3).

7.2.2 Flammable liquid pool fire

Where a major liquid release has occurred with subsequent ignition, and where there may be a need to urgently limit the fire hazard this creates in terms of flame impingement or radiant heat, the strategies for dealing with such a liquid pool fire should include:

- Halting all work and summoning emergency services.
- Evacuating all non-essential personnel.
- Assessing flame impingement or radiant heat impact on affected plant, columns, equipment, spheres, tanks, vessels, drums, etc.
- Alerting any neighbouring or public areas to potential escalation hazard.
- Alerting any neighbouring (e.g. 'domino') sites or public areas to potential escalation hazard and actuating any offsite ERPs to evacuate people and halt traffic, etc.
- Actuating any fixed water spray or deluge system for affected and adjacent plant, columns, equipment, spheres, tanks, vessels, drums, etc.
- Using water jets, sprays, screens or curtains to protect radiant heat exposed plant, columns, equipment, spheres, tanks, vessels, drums, etc.
- Using foam to reduce the flame and fire size and radiant heat and possibly to extinguish the fire, resulting in an unignited liquid pool.
- Being aware of flame impingement hazards and fire escalation mechanisms (e.g. BLEVE).
- Considering water stream application onto flame impinged areas of plant, columns, equipment, spheres, tanks, vessels, drums, etc. if risk assessment concludes this can be achieved in a safe time and will not expose fire responders to escalation dangers.

7.2.2.1 Use of water for exposure protection during a flammable liquid pool fire

Water may be used for exposure protection where a flammable liquid pool fire is impinging on petroleum-containing plant, columns, equipment, spheres, tanks, vessels, drums, etc. to reduce heat input to such equipment and therefore to maintain equipment integrity. The objective is to apply water onto affected surfaces until either burn-out of the liquid fuel or foam application extinguishes it. Pool fire response strategies that include water application for exposure protection should consider several safety factors:

- Applying water from portable or fixed monitors in accordance with annex D.2 and annex D.5 onto affected steelwork of flame impinged petroleum-containing plant, columns, equipment, spheres, tanks, vessels, drums, etc.
- Fire responders wearing full fire-resistant PPE.
- Using wheeled or portable water monitors (without permanent staffing).
- Facilitating manual handling of water monitors.
- Using hand-held hose lines with water curtain streams to protect fire responders approaching to set up water monitors.
- Being aware of potential delays in setting-up or applying water, fire escalation potential and the possible need to fully evacuate fire responders.
- Being aware that prolonged water application may result in localised drainage problems or flooding that may undermine hardstanding.
- Being aware that prolonged water application may also result in flotation of the flammable liquid pool fire to other areas of installation (product carry over).

If there is ever any doubt over the extent of flame impingement on petroleum-containing plant, columns, equipment, spheres, tanks, vessels, drums, etc., consideration must be given to full evacuation of the area unless water can be directed to the affected plant in a timely manner. There are no clear time warnings where flame impingement has occurred on plant, columns, equipment, spheres, tanks, vessels, drums, etc. If fire responders confirm flame impingement an immediate concern should be to apply cooling water onto the impinged or heat affected area. If this cannot be done within the first minutes of the fire starting, evacuation must be given priority, especially where no local fire-fighting water for cooling can be applied, for whatever reason, until the arrival of the FRS.

One method of assessing the need for cooling is to play a stream of water onto suspected heat affected plant, columns, equipment, spheres, tanks, vessels, drums, etc. and observe the response. If the water vaporises (steams), then further cooling is clearly required; however, if no steam is produced, cooling is not required at that time, but further checks may be necessary.

7.2.3 Gas/liquid release, flash fire and jet fire

Where a gas or liquid release has occurred and the gas or vapour migrates some distance and is ignited, there will be a flash fire that burns back rapidly, though sometimes not instantly, to the source of release. Due to the nature of a flash fire, plant, columns, equipment, spheres, tanks, vessels, drums, etc. in its path will be exposed to high heat levels and flame impingement for only a few seconds, although sensitive electrical equipment and instrumentation may be damaged in the event. Escalation from a flash fire is therefore unlikely.

This flash fire condition is one reason why fire responders and others must not enter a gas cloud. There have been cases where fire responders have done so in the belief that the 'middle' of the cloud was too rich to burn, only to discover that when the cloud edge ignited, they did not have time to escape from the resultant flash fire.

Where the gas release occurs from a pressure source, the flash fire may burn back, leaving a gas or liquid jet fire that may or may not impinge on adjacent equipment.

Of all the fire events that are encountered by responders, jet fires have the potential to cause rapid escalation through total failure of a vessel or drum, with subsequent BLEVE consequences, depending on the pressures and liquids involved.

This response strategy may be used where a jet fire exists and is impinging on a vessel or drum etc. to reduce the heat input to such equipment and therefore to maintain equipment integrity. The objective will be to apply water on to flame or heat affected exposures until either isolation or burn out of the jet fire.

Response strategies should consider several safety factors:

- Applying water stream onto the area of jet flame impingement of affected equipment.
- Fire responders wearing full fire-resistant PPE.
- Isolating the source of release – extinguishing jet fires without isolation will result in continued gas/vapour flow and a flammable atmosphere can quickly develop.
- Using wheeled or portable water monitors (without permanent staffing).
- Facilitating manual handling of water monitors.
- Being aware of potential delays in setting-up or applying water, fire escalation potential and the possible need to fully evacuate fire responders.
- Not attempting to extinguish the jet fire by using dry powder or water application.
- Being aware that prolonged water application may result in localised drainage problems or flooding that may undermine hardstanding.

Under certain conditions, it may be possible to 'bend' a minor to moderate gas jet fire or to deflect it away from a sphere or vessel. This tactic has had some success but only on relatively low-pressure jet fires. It employs several water streams that are set to a pattern between semi-fog and straight jet. The aim is to hit a large area of the flame near the impingement area and direct it away. It is stressed that this tactic involves fire responders approaching close to the fire area using mobile equipment. Therefore, if this is considered as a strategy, the water application must be deployed early on in the incident. Under no circumstances should any such attempt be made where flame impingement has been continuing for more than 15-20 minutes.

In every case, the following should be established as early as possible: the identity of the inventory; the fill level of the vessel or drum; time of fire starting; and if possible, the status of the inventory. This will aid risk assessment and lead to incident decisions being made on sound information.

If fire responders confirm flame impingement, an immediate concern should be to apply cooling water onto the affected area. If this cannot be done within the first minutes of the fire starting, evacuation must be given priority, especially where no cooling water can be applied, for whatever reason, until the arrival of the FRS.

7.2.4 Unconfined/semi-confined vapour cloud explosions

The hazard of VCEs, both in unconfined or semi-confined mode, should be recognised and assessed in pre-incident scenario analysis and ERPs.

Semi-confined VCEs may be possible where flammable gas or vapour releases in the order of 5 tonne and above form either instantly or in a few seconds within and around process plant and equipment that may be defined as a congested area. The gas/vapour-in-air mix will be such that on ignition, the cloud may burn slowly but as the flame front meets obstructions, it increases speed and continues to increase as it encounters more obstacles in congested areas. The rapidly moving flame causes a pressure wave to build up in milliseconds, which creates an overpressure capable of severe damage depending on the congestion and the installations involved. This 'explosion' in a congested area can lead to secondary gas/liquid releases and/or fire event. The overpressure decays over distance but fire responders, when responding to any large flammable gas or vapour cloud building up in a plant congested area must consider, as a matter of urgency, immediate evacuation to a safe distance in case of a VCE.

Apart from the congestion factor, the relative proportions of the air/fuel mixture (stoichiometry) will govern the efficiency of the explosion. If the mix is perfect or close to it, very high overpressures can result when combined with large areas of plant congestion.

It is not possible to combat a VCE once a large cloud builds up in a plant. The safest course of action is to evacuate.

7.2.5 Fireball/boiling liquid expanding vapour explosion

Normally, if flame impingement is below the liquid level, the liquid boiling off helps to keep the steel cool. If the flame impinges above the liquid level, the temperature of the steel rises to failure point and tears open, releasing the contents in a mass of combined burning vapour and boiling liquid that expands to produce more vapours to feed the resultant fireball.

Thermal radiation levels from the resulting rising fireball are sufficiently high to result in fatalities or serious burn injuries to people nearby. Damage to plant and equipment can occur due to overpressures from the explosion aspect.

Although most of the recorded cases of BLEVE involve LPGs, it can be created from other flammable liquids under pressure in containers. However, it should be noted that LNG or refrigerated LPG storage tanks or atmospheric flammable liquid storage tanks will not normally develop a BLEVE condition due to their construction and lack of pressure. However, failure of an LNG tank or a refrigerated LPG tank shell may result in a very large and rapid burning liquid pool fire cascading from the failed shell area to cover the full bund and possibly overflow it.

7.3 OCCUPATIONAL FIRE BRIGADES

7.3.1 Overview

Historically, at least from the 1950s, the need for petroleum companies to have an onsite full-time or part-time (auxiliary) petroleum fire brigade or ERT was driven by insurance companies. Post-World War II memories of fire damage also drove many companies to establish their own occupational fire brigade with a view to a rapid response by knowledgeable and capable fire responders.

Insurance companies recognised that financial and production losses could be minimised if a well-trained, competent, rapid response was available. The need for a full-time occupational fire brigade was greater if the local government FRS stations were distant from the site, with subsequent response delays. Gradually, this resulted in a full-time petroleum fire brigade at major installations. This practice continued until the 1980s and 1990s, until their benefits were reviewed against their costs with rationalisation of business operations.

Around the same time, although occupational fire brigades were previously viewed as a necessity by insurance companies, it became apparent that the largest financial losses were actually resulting from catastrophic incidents that occupational fire brigades could do little to prevent or reduce their consequences. Such instantaneous disasters (VCE, pressure burst explosion etc.) occurred from either total failure of vessels or columns, or an explosion without warning. These factors have meant that insurance companies do not normally insist on a full-time occupational fire brigade at petroleum installations.

In the 1990s, due to CBA reviews and staffing rationalisation studies, many petroleum companies reduced their onsite fire service capability, in some cases completely, with reliance placed on only the FRS, or in other cases by use of auxiliary fire team members. These auxiliaries were either shift working plant operators or shift maintenance personnel who had a secondary job function as an ERT member.

7.3.2 Options for site fire response

7.3.2.1 Full-time occupational fire brigade
(i) General

A full-time occupational fire brigade may be considered where the FRS is remote from the site in terms of response time or if the site is large and complex and there is a need for an immediate response by personnel fully familiar with fire and other emergency hazards that may be encountered.

Whilst there are many successful full-time occupational fire brigades, it is not typically good practice to provide one for a petroleum installation from an economic viewpoint unless there is:

— Lengthy FRS response times to the site or areas of the site (e.g. for large sites).
— Justification from the requirements for credible scenarios (e.g. for complex sites with numerous fire and other emergency hazards requiring rapid response by competent personnel).
— Low operations staffing that limit or prevent an operations-based ERT.
— Adequate workload for their personnel on a rotating shift basis.
— Justification in terms of risk to assets and business interruption since more and more FRSs will not put their personnel at risk to save property or business interests.

This is a pragmatic view since most companies cannot have a large body of personnel onsite waiting for an incident that may not happen for some time, if at all.

However, petroleum companies recognise that depending on the site, its assets and continued production criticality, some form of rapid fire response may be desirable. This, in combination with good plant design practices, effective process safety controls, fire and flammable gas detection, competent operators, and safe working practices can mean that incidents are minimised in terms of frequency and size.

Petroleum companies do not normally have an explicit legislative requirement to provide an occupational fire brigade. However, they are usually legally required through emergency planning to protect their workforce, the public and the environment from harm. See section 8.2.

It should be stressed that in the petroleum industry, it is usually fire prevention, detection and mitigation measures that are considered as the first 'lines of defence'; fire response exists as a further mitigation measure when the other measures have failed or need supplementing. For example, the primary site safety objective might be not to have an accidental release of flammable product (or toxic substance). If, however, a release occurs a secondary objective will be ignition prevention. If it does ignite, fire detection would operate and various mitigation measures including fire response may be the last line of defence to limit escalation and damage.

It is also worthwhile recognising that for fires in process areas, industrial fire responders do not always extinguish the fire event alone. Often, operations personnel will assist in isolating inventories, depressurising vessels, drums or equipment and making safe the remaining plant, thus making it easier for the fire responders to control or extinguish any residual, depressurised fire. This differs from FRS fire-fighting whose tactics are to bring large scale fires downward to easier managed fire sizes and then go on to extinguish the fire itself. The two types of fire brigade therefore operate, or at least should operate, on different strategic lines.

Taking the above into account, and given the normally low frequency of incidents in the petroleum industry, the principal justification for a site full-time occupational fire brigade is not to respond to emergency incidents – although that is clearly a function of their role. Major incidents should be very infrequent on a well-designed and operated petroleum installation.

One method of developing a full-time occupational fire brigade is to identify and establish their functions to ensure that there are clear needs that justify its existence. Typical functions of a full-time occupational fire brigade are described below; the list contains examples only, and should not be considered exhaustive. Sites should develop a pertinent listing according to site-specific requirements.

(ii) Functions of a full-time occupational fire brigade

— To assure the availability, reliability and performance of all portable fire equipment located throughout the installation.

  This work is a key requirement if personnel are to utilise first-aid fire-fighting equipment on discovering a fire. Such fires are far more frequent than major fires and with the availability and guaranteed operability of onsite fire equipment, small fires should be successfully controlled or extinguished before the arrival of the occupational fire brigade thus preventing small incidents from escalating to major incidents.

— To assure the safe working operation, availability, reliability and performance of SCBA sets, airline sets and any other breathing apparatus (BA) sets and cylinders located throughout the site.

  The life safety/protection factor of BA is critical in hazardous operating areas. Personnel, in some emergencies, require ready-to-wear BA that must be guaranteed safe and operating correctly.

— To assure the instant readiness, availability, reliability and performance of all fire vehicles and trailers/mobile vehicles on a 24-hour basis.

  Fire vehicles are designed to provide a fully mobile and flexible response to those fire incidents that go beyond the incipient stage. They should be available to respond, from a cold standing condition, at any moment on a 24-hour basis. Inspections and vehicle tests should be regularly performed.

— To assure the availability, reliability and performance of fire equipment, fire systems and rescue equipment on-board fire vehicles on a 24-hour basis.

  Like fire vehicles, the on-board systems and equipment should be guaranteed to work when required. Inspections and vehicle tests should be regularly performed.

— To assure the availability, reliability and performance of all fixed fire systems including foam systems and water systems.

  Whilst more than one department may have responsibility for the electronics and mechanics of fire detection and fire-fighting systems, the occupational fire brigade should be responsible for coordination and witnessing of fixed fire systems' availability and readiness.

— To assure the maintenance of the required levels of fixed and portable fire related equipment spares, extinguishing agent quantities, BA spares and rescue equipment spares.

— To assure the availability, reliability and performance of the site fire-fighting water pumps and fire mains distribution on a 24-hour basis.

The occupational fire brigade should have control of the fire-fighting water system to ensure that an adequate quantity of fire-fighting water is available instantly and is assured in terms of pressure and flow at each fire hazard area onsite.

— To perform fire prevention/protection inspections throughout the installation and train operating units, line departments and personnel on correct fire safety procedures and initial fire actions.

Site operating personnel cannot be expected to understand the requirements of fire prevention and protection. Even with fire safety training, they require periodic fire protection advice.

— To conduct onsite fire safety education classes for employees not connected with production/storage operations.

Although the operating units are the critical assets, the support infrastructure personnel require knowledge of basic fire safety procedures in order to enhance life safety.

— To liaise, discuss and advise on site-wide fire protection requirements for new projects, revamps and/or upgrades in company installations.

This is over and above any technical fire protection engineering input from any external organisation or projects department.

— To participate in daily/weekly fire training sessions using fire vehicles and equipment and daily fire theory sessions.

Unlike operations personnel, fire-fighters may have to face situations and circumstances which cannot be easily predicted and which require a combination of fire-fighting and/or rescue tactics with, in some situations, improvisation. Since each fire or emergency situation is usually different from the previous, fire-fighters have to maintain and where possible extend their level of knowledge in order to meet fire-ground conditions and perform effectively. This should be done by daily training sessions.

— To participate in a daily physical exercise programme in order to maintain the required job fitness level.

This exercise requirement is unique in any operating company environment. Fire-fighters, by the nature of their job assignment, require a minimum fitness standard to allow them to perform manual tasks in sometimes harsh conditions. Daily exercise sessions are fundamental to maintaining this fitness level.

— To provide a trained auxiliary fire brigade (or operations support fire brigade) capable of supporting the emergency actions of the occupational fire brigade.

This requires the organising, administration and training of auxiliary fire responders on a regular basis to provide a trained ERT to act as back-up to the full-time occupational fire brigade.

— To establish, update and maintain pre-fire plans, ERPs and procedures for each operating and support installation.

This work enables fire responders to become familiar with the hazards and risks associated with installations and provide a pre-plan of actions that should be used to combat emergencies there, thus improving fire control capability.

— To perform, on a routine and regular basis, simulated fire exercises for all credible fire scenarios including major incidents to determine the adequacy of ERPs and pre-fire plans in cooperation with FRS and operations departments and to evaluate responses to those exercises.

This is an important aspect of incident control and should assist in maintaining a state of readiness and capability at the site.

— To develop, create and maintain the company Major Incident Control Centre and any back-up facility. This facility could act as the site major incident support room for future major incidents. The back-up facility may be offsite.

— To liaise with national regulatory organisations and FRS on all FEHM issues and ensure company compliance with all relevant national fire safety legislation.

— To check, test and maintain communication links to and from the fire station or stations and to and from mobile fire vehicles.

— To maintain administration and inspection/testing records associated with aforementioned functions.

— To maintain a status report on the facilities, roads, and operations of the site which may affect fire response times or fire protection.

— To assist in fire safety stand-by duties during hazardous working conditions in operating installations.

— To respond and perform rescue, fire-fighting duties and special services within the site and, if requested, to offsite facilities in public areas.

— To respond and perform special services including environmental controls such as spillage clean-up.

— To participate in live or desktop emergency response exercises with FRSs and other emergency agencies.

Once the functions are defined and agreed, the responsibilities for the occupational fire brigade can be developed. From these responsibilities, job descriptions can be created and then, finally, the competencies for the positions can be developed with the final addition of the ERPs and scenarios adding to the detail of the competencies. This ensures an auditable trail and justification.

7.3.2.2 Auxiliary fire brigade

The use of auxiliary fire responders can offer an effective full-time fire response option for petroleum companies but there are normally restrictions on personnel numbers that can respond from operations so that others, e.g. maintenance, should be considered. Even at sites where a full-time occupational fire brigade is in place, auxiliary fire brigade members may be used to support the full-time response. This offers an economic means of meeting human resource requirements for the foreseeable major incidents at a site.

In addition, if the auxiliary members are selected from onsite personnel (e.g. from process plants) there will be readily available knowledge of the plants and processes involved, something of which site full-time occupational fire brigade responders may not have full awareness. This can lead to more rapid incident control.

Wherever auxiliary fire responders are selected from, they should be:

— Shift workers.
— Instantly available for response (no permissions required).
— Available for regular fire and emergency training.
— Physically and medically fit.

For large sites, it is not always practical to have a 100% auxiliary fire brigade due to the workload involved in maintaining the response capability and the overall site fire-fighting equipment and systems in readiness at all times. The numbers of extinguishers, SCBA sets, fire hydrants, fire hose, etc., requiring inspection, testing and availability assurance can place excessive demands on auxiliary members with limited time each shift.

7.3.2.3 Combination full-time/auxiliary fire brigade

A combination full-time and auxiliary occupational fire brigade can be the most effective method of providing large numbers of trained fire responders for worst-case incidents, provided the auxiliaries are readily available and well trained. The strategy for such a response would focus on an initial deployment by the full time responders (for cooling or for SCBA rescue work, etc.) whilst the auxiliaries arrive to support them in a reasonable time frame (typically, within 5-10 min. from the call).

For auxiliaries, consideration should be given to:

— Holding their turnout gear (see *7.6.2.1*) near their working area.
— Travel distance and transport to potential incidents locations.

The option of requiring auxiliaries to move to the fire station to collect their turnout gear and then travel to the incident may not always be the most time efficient means of supporting the full-time occupational fire brigade members and should therefore only be used if there are insurmountable difficulties.

7.4 ORGANISATION OF OCCUPATIONAL FIRE BRIGADES

There are no clear rules or standards for the organisation of an occupational fire brigade. Typically, the structure and ranks within it will broadly follow that of the FRSs and, indeed, many of its staff tend to be ex-FRS personnel, whether full- or part-time.

7.5 COMPETENCY STANDARDS FOR SITE FIRE RESPONDERS

Guidance for the organisation and certification of personnel is provided in standards such as NFPA 600 and IPDS *National occupational standards*. The minimum competencies for such brigades should be defined bearing in mind factors such as the site's size, nature of operations, response systems and equipment.

There are various company competence standards used for a variety of disciplines. An example of one set of competencies for a fire team (part-time) is provided in annex E.2.

7.6 FIRE EQUIPMENT

7.6.1 Portable and mobile fire-fighting equipment

7.6.1.1 Fire extinguishers

A site-specific review should be performed to establish the types, locations, numbers and sizes of fire extinguishers. Standards such as BS EN 3 can assist in this purpose, but often too few (or too many) extinguishers can be located in a hazard area.

Portable fire extinguishers are available for a variety of fire types and conditions. National and international standards typically rate them for a range of limited fire sizes that will be either in the form of burning cellulosic solids (three-dimensional) or burning flammable liquids (two-dimensional).

Portable extinguishers are intended to provide a first-aid fire-fighting capability for dealing with small (incipient) fire events. For larger fires, where more extinguishing medium is required, wheeled extinguishers should be used. The extinguishers provided for specific areas in a petroleum installation should be of a type suitable for use in fighting a fire of the kind most likely to occur in the location. It should be noted that the use of hand-held extinguishers is unlikely to be successful for pool fires of diameter >3-4 m.

Similar types of extinguishers in a petroleum installation should operate in a standard manner. All personnel should be made familiar with their siting, use, operation and colour coding. Formal training should include extinguisher use.

Extinguishers should be constructed and comply with a current standard for colour coding such as given in BS EN 3 or other recognised standard.

7.6.1.2 Fire classes

Fire classes defined by the European classification system (derived from BS EN 2) are:

- Class A - Carbonaceous solid materials (wood, plastics, paper, etc.)
- Class B - Flammable (or combustible) liquids
- Class C - Flammable gases or vapours
- Class D - Metals (magnesium, sodium, etc.)
- Class E - Electrical equipment
- Class F - Cooking oils

More guidance is given in Annex F on these, including other classification systems.

7.6.1.3 Extinguisher types

It should be noted that in providing portable fire extinguishers, the more types available, the more potential there will be for using the wrong type on particular fires. Although it may be necessary to have different types for use on various fire hazards in petroleum installations, there are advantages in keeping the number of types to a minimum.

(i) Dry powder (dry chemical)

There are different types of dry powder available. B types are for use mainly on flammable liquid fires and have a simple bicarbonate base; whereas BC types using a sodium bicarbonate base can be used for liquids and gases. ABC and ABCD types are also available as multi-purpose powders, typically using mono-ammonium phosphates as a base although other additives are necessary for the metal fire-fighting aspect. Such extinguishers may be used for hazards such as diesel fire hazard areas or liquid product pumps and equipment.

Dry powder can also be used to deal with fires involving live electrical equipment, but it should be remembered that powder will leave a residue that may damage electrical components.

The advantage of using dry powder extinguishers for flammable liquid fires is its large extinguishing power over a given area compared to a foam or CO_2 extinguisher. Also, units can be installed outdoors due to relative resistance to freezing temperatures.

Unfortunately, dry powder provides relatively little cooling effect when applied to flammable liquids or to hot surfaces. During application, flames may be obscured. If application is halted, flame 'flashback' can occur. Dry powders are also not generally compatible with foam, and may affect their stability if applied simultaneously.

Typical sizes of fillings for the extinguishers are 6 kg, 9 kg and 12 kg, each with different ratings for fire sizes. When selecting size, consideration should be given to weight and movement in restricted areas.

(ii) Carbon dioxide

CO_2 stored as a liquid under CO_2 vapour pressure in extinguishers is most effective on fires involving live electrical equipment. It should be effective against small flammable liquid fires in enclosed spaces, rooms or enclosures but will not be effective in open-air conditions where there is any appreciable wind speed.

The advantage of using CO_2 for fires involving electrical equipment is that it is a non- conductor and does not leave any residue that damages sensitive electrical equipment. The disadvantages are that it is affected by winds, is an asphyxiant in confined or enclosed spaces and can cause ice burns on prolonged discharge due to the low CO_2 temperatures involved.

Typical sizes of fillings are 2 kg and 5 kg.

(iii) Foam

Foam extinguisher types are available for different flammable liquid hazards and are mainly a Class B extinguisher. The most common types are:

— foam jet pre-mix;
— foam spray pre-mix.

Foam jet pre-mix foam extinguishers typically use a low expansion FP base foam concentrate mixed with water, the nozzle aerating the foam/water solution near the exit.

The foam spray pre-mix extinguisher typically uses an AFFF foam concentrate and water mix but the nozzle will be designed to allow a fine spray of foam that can be used for Classes A and B and can also be used in areas where there may be a risk of spraying foam onto electrical equipment found in offices. This does not mean that it is completely safe to use on electrical equipment, especially high voltage equipment, for which CO_2 should be used. (Certain foam spray extinguishers are 'approved' for use in the environs of electrical equipment if they meet the requirements of the dielectric test of BS EN 3-7. When used in close proximity to electrical risks, they tend to reduce the danger of conduction along the discharge stream. However, it should be realised that they will not reduce the risk of conduction (and therefore electric shock) via wetted surfaces such as floors.)

The advantage of using foam for flammable liquid fires is that it smothers/blankets the flammable liquid surface and also cools any hot metal, whereas dry powder offers no post-ignition protection. The disadvantage of foam is that it does not have the same rapid fire knockdown capability of dry powder and that it can freeze at temperatures < 0 °C.

Typical capacities are 6 l and 9 l.

(iv) Water

Water extinguishers should be used only on Class A fires, i.e. with 'cellulosic' type combustibles. Under no circumstances should they be placed in an area where the predominant hazard is flammable liquids or electrical equipment.

The advantage of using water is that it cools, reducing carbonaceous materials to below their ignition temperature. The disadvantage is that water cannot be used on fires involving electrical equipment and that it can freeze in sub zero climates.

Typical capacity is 9 l.

7.6.1.4 Extinguisher operation

Regardless of which particular extinguishing medium is selected for the identified fire hazards, extinguishers should be as simple to operate as possible. The fewer actions to actuate the extinguisher, and the more obvious the actuation means, the better for users.

There are basically two types of operation: CO_2 or nitrogen cartridge type and stored pressure type. In the first type, a pin will have to be removed and then the cartridge actuated before use. With the second type, actuation is usually by pin removal and squeezing.

7.6.1.5 Wheeled fire extinguishers

Larger sized wheeled extinguishers are mainly for use with dry powder, CO_2 and foam. Where larger quantities of water are required, a hose reel is more effective (see *7.6.1.7*).

An assessment of the available personnel to use such extinguishers should be made to ensure they can, in fact, be deployed under emergency conditions.

Typical filling sizes are:

dry powder	-	50-100 kg;
foam	-	40-150 l;
CO_2	-	20-50 kg.

7.6.1.6 Steam lances

Steam application by a lance may be used in certain cases for smothering certain fire types, such as flange fires or other relatively small sized fire events. Steam can also be used within vessels as a snuffing agent but not where there is likely to be a dangerous reaction with the substances involved in the fire. In addition, it should not be injected into unvented vessels.

Steam lances should be used with care and under controlled conditions. Operators and fire responders should be well practised in their use and protected against scalding and burning. Dry steam should be used by the provision of effective trapping coupled with a good supply system.

Steam applied at a pressure of about 7 barg is effective in the control of fire involving leakages of petroleum and its products and hydrogen from flanges or joints, or sulphur in sulphur plants. It may also be used to disperse small clouds of flammable vapour that have not ignited.

Steam lances should be earthed to minimise the possibility of electrostatic discharge.

7.6.1.7 Hose reels

Hose reels should typically be used where there may be an identified requirement for relatively large quantities of water. They offer continuous, uninterrupted, water supply for fire-fighting small to medium Class A fires, typically in office buildings, workshops, ship cabins and compartments, etc.

Different operations are available for hose reels in that they can be either actuated by a manual valve or by an automatic valve that activates when the reel is unwound. Personnel training is essential in the use of such equipment.

Hose reel hose sizes vary from 20-40 mm diameter with hose nozzles typically ranging between 50-400 l/min.

Hose reels can be used in place of normal fire hose because they offer a quick deployment option and one-person operation.

7.6.1.8 Fire hose and branches/nozzles

(i) Fire hose

Fire hose sizes range from 45 mm and 65/70 mm diameter and length 15-22 m. Various natural and synthetic mixed materials make up fire hose but regardless of the type selected, the hose should be flexible and strong. For restricted area fire-fighting, such as that found on tank walkways or process structures, 45 mm diameter hose provides easier manoeuvrability than larger sizes. For other areas, it may be necessary to use 70 mm sizes to apply maximum water or foam to a fire area. Regardless of the sizes being considered, the immediate personnel availability should be considered to ensure the hose can be deployed if an emergency occurs.

(ii) Branches/nozzles

Hand-held water or foam projecting stream discharge devices are known as branches (UK) or nozzles (Europe/USA). Regardless of their provision and location, if such devices are to be used effectively they should have stream controls, both in shut-off and stream pattern (from jet to wide angle fog/spray). Water discharge can have the advantage of reducing radiation from the fire and also drag cool air past the operator.

For water branches, typical flowrates are from 250-600 l/min. although some nozzles can be up to 1 000 l/min. Foam branches will typically be from 200-1 000 l/min. but due to the lesser jet reaction, can be easier to handle than water branches of high throughput.

For marine terminals and berths, an international ship-shore connection should normally be provided, through which water could be supplied to a tanker's fire main if required for shipboard fire-fighting. For more guidance, see ICS/OCIMF/IAPH *International safety guide for oil tankers and terminals (ISGOTT)*.

7.6.1.9 Monitors

(i) Water monitors

Water monitors may be fixed or portable/mobile. For petroleum installations there are advantages in having both fixed and portable units, with the fixed ones for immediate actuation whereas the portable units are used for flexible response, e.g. cooling difficult access areas etc. Portable or mobile monitors should have a base that provides stability on ground surfaces. The monitor should preferably be capable of deployment and actuation by one person. It is advantageous to have fire hose either pre-connected or flaked ready for rapid connection and use with a mobile monitor, to save time in deployment.

Portable and mobile water monitors have various throughputs; some have a fixed flowrate whereas others have a variable flowrate. For either type, typical ranges are 1 800-4 500 l/min. Variable flow types can be adjusted at the nozzle and offer the capability to reduce flow for limited or reduced fire-fighting water supply or due to fire-fighting water flooding concerns where drainage capacities are limited.

Monitors should be able to project water streams to distant tank or jetty cooling targets. It should be ensured that the listed ranges of monitor streams can be achieved in reality and at the pressures of the petroleum installation's fire-fighting water system.

Monitors should have a means of rotating the nozzle and elevating/depressing it. It should be possible to retain the selected position to allow the monitor to be used unstaffed.

When considering size and numbers of water monitors, it should be ensured that site fire-fighting water supply can provide the flow rate and pressure demands during credible scenarios, e.g. to project water streams to distant tank or jetty targets. In addition, it should be ensured that adequate personnel numbers will be available to deploy the equipment.

(ii) Foam monitors

Foam monitors may be fixed or portable. For portable units, bases are similar to water monitors and like them, there are different flowrates available.

The type of foam monitor also depends on the type of foam to be used and whether it is capable of aspiration or not. Non-aspirating foam monitors can provide a greater range than aspirating; this factor should be considered when evaluating tank fire risks. They can also be used in variable flow mode. Aspirating foam monitors are fixed flow rate types.

A wide variety of foam monitor flowrates are available, from 2 500-80 000 l/min., the latter being intended for use only for large diameter tank fires.

Provision of foam monitors also requires a stock of foam concentrate that should be calculated for a given duration and by the number of monitors that may be used. This reinforces the use of scenario worksheet analysis to ensure adequate foam supplies are provided. See annex G.2.

7.6.2 Responder personal protective equipment

7.6.2.1 Selection of personal protective equipment
Responder PPE should meet an ISO, EN, NFPA or equivalent standard. See annex I.3.

PPE should be viewed as a 'system' in terms of wearer total protection, rather than separate items that can be mixed to suit individual budgets. The level of responder intervention and exposure will determine the levels of PPE required. For instance, at the lower exposure end, if the responder actions are simply to actuate a fire system switch and check evacuation status, then the PPE selection may be for only normal installation coveralls (which should ideally be inherently fire resistant). However, where responder actions require manual deployment of monitors, use of BA, etc., there will be a need for 'turnout gear', which should typically comprise:

— fire helmet with visor;
— fire coat;
— fire trousers;
— fire boots;
— fire gloves;
— SCBA.

The use of fire resistant materials for such PPE is critical for responder protection (see *7.6.2.2*). In addition, responder normal workwear should comprise fire resistant coveralls to ensure maximum protection is provided under fire-exposed conditions. This becomes particularly important when responders are working nearby to a gas release (knowingly or otherwise), where there is potential for a flash fire event.

7.6.2.2 Fire retardant treatments versus inherently fire resistant
Materials that are inherently fire resistant, such as meta-aramid (e.g. Nomex) fibres, offer continuous fire resistance for responders. This resistance can be provided in coveralls, two piece protection suits or turnout gear.

Materials such as cotton that have been treated with fire retardant chemicals offer some fire protection capability but when subjected to heat or flame, often result in the mass release of these chemicals, thus making the garment unfit for further service. In addition, the regular cleaning of fire retardant treated clothing will result in leaching of the protective chemicals. This being the case, the preference should be for inherently fire resistant clothing rather than fire retardant treated clothing.

Special clothing and equipment may be necessary for dealing with specific site hazards in an emergency (e.g. acids and hydrogen fluoride). These will typically be what are commonly referred to as 'gas suits' or 'acid suits', which are worn over turnout gear including SCBA. These types of PPE are highly specialised such that employers should risk assess them in consultation with the personnel who would wear them. Issues such as airline connections for principal air supply and SCBA, as well as offtake air connections should be determined. Vision, comfort, safety and size of such PPE are factors that should be carefully reviewed.

7.6.2.3 Breathing apparatus
SCBA should be available for fire-fighting and rescue. Arrangements should be made for a supply of cylinders sufficient for the scale and duration of credible incidents. BA at an incident should be strictly controlled and the advice of the FRS obtained on aspects such as correct use, etc. Thorough training of personnel and maintenance of equipment is essential and should be to the HO *Breathing apparatus* or national equivalent. A medical examination (by a qualified doctor) should be a prerequisite for using SCBA. The servicing of SCBA should also be to the requirements of HO *Breathing apparatus* or national equivalent. Records of servicing should be kept for a minimum of five years.

In the UK for servicing, see BS EN 137.

There are three main types of BA: canister type that uses a filter to scrub the inhaled air; oxygen sets that can regenerate or reuse exhaled oxygen; and compressed air SCBA sets that rely on a single or double compressed air cylinder.

SCBA should be used in preference to the canister type, due to the latter not being able to protect against oxygen deficiency caused by enclosed fires. Thus canister types are not recommended.

Oxygen regeneration sets, which offer prolonged (>1 hr.) breathing duration may be considered for deep entry or difficult rescue conditions but are not normally applicable to petroleum installations.

Although there are standards for the use of BA, there is seldom any guidance on the number, type and duration of such sets for emergency response. There is, however, a requirement that if BA is to be used, there always be a minimum of two persons in a team and two persons in a back-up team.

Recent developments in the materials and engineering of such equipment has led to compressed air cylinder capacities of 9 l, instead of the standard 6 l. SCBA sets and cylinders can now provide one hour duration and this is an important feature for sites where a prolonged toxic release may occur.

7.6.3 Inspection and maintenance

All fire protection equipment should work instantly and faultlessly when needed. This requirement can be achieved only if there is a comprehensive and reliable system of inspection, maintenance and appropriate testing.

It is almost always a condition of insurance that fire-fighting equipment is installed and inspected at regular intervals. Insurance fire surveyors may inspect premises at regular intervals. Notwithstanding insurance and legal requirements, all equipment should be regularly inspected and maintained by a competent person.

Details of fire protection maintenance are outside the scope of this publication. Maintenance will vary with the type of equipment used and with the environment in which it is kept. Maintenance schedules should be drawn up covering all items of equipment.

Reference should be made to specific standards for system design and maintenance. For further guidance on FSIA, see section 8.9.3.

A register of all fire protection equipment should be kept as one aspect of an equipment management system; the dates and the nature of all inspections and maintenance operations should be recorded in it.

8

MAINTAINING FEHM POLICY

8.1 INTRODUCTION

This section sets out the requirements for maintaining an effective FEHM policy, in particular through emergency planning from high-level incident preplans through to scenario-specific ERPs. In addition, it covers personnel competency development, emergency plan testing and details the concept of FSIA with regard to fire and flammable gas detection and fire protection systems.

8.2 ORGANISATION OF EMERGENCY PROCEDURES

For UK sites subject to the COMAH regulations, both onsite and offsite emergency plans should be prepared. They should cover emergency incidents and also include aspects such as pollution control, since fire-fighting activities may otherwise result in uncontrolled discharge of pollutants, whether petroleum and its products or fire-fighting media, into watercourses.

Typically, site management should prepare emergency plans to deal with a range of credible scenarios. The plans should be reviewed in conjunction with the police, FRS, medical and other emergency services, as well as local governments who may make supplementary plans and arrangements for incidents affecting offsite areas. They might address fire, explosion, loss of containment (e.g. gas release), spills or other major emergencies and their consequences. The plans should include procedures for the mobilisation of all resources that may be required.

Plans should be made for incidents where:

(a) The effect is confined within the site boundary and the occurrence can be controlled without external assistance.
(b) The effect is confined within the site boundary but external assistance will be required.
(c) The effect may extend beyond the site boundary.
(d) The occurrence is outside the site boundary.

External authorities should be brought into the early stages of planning as they will have a major role to play in (b), (c) and (d). The FRS should have necessary information regarding the site facilities, e.g. mains water pressure, stocks and types of foam available, fire equipment, etc. In addition, mutual aid arrangements with other industrial facilities may also be commissioned, as required. Cooperative exercises should be held with the FRS whether there is an occupational fire brigade or not.

Plans should be reviewed periodically, at least annually and when any significant additions or changes to plant and/or personnel are made. Experience gained in site exercises should be incorporated in the plans.

8.3 INCIDENT PREPLANNING

A comprehensive incident preplan should be developed for all locations storing or handling petroleum and its products; it should take account of the guidance on fire protection and precautions described in this publication. The incident preplan should be supported by a series of pre-fire plans (see 8.7). These in turn should be supported by scenario-specific ERPs (see 8.8).

Factors that should be considered when formulating the incident preplan include:

- The nature and quantity of substances processed and stored.
- The proximity of other process plant, storage vessels, neighbouring major hazards sites with 'domino' potential, works and public buildings and vegetation.
- Accessibility to the site for fire-fighting appliances.
- Escape routes for personnel and the public.
- Site security.
- Emergency power supplies.
- Timing considerations.
- Liaison with local government, FRS, medical services, watercourse regulators (in the UK - EA, SEPA and EHSNI), local industry and the media.
- Meteorological and topographical conditions such as wind, precipitation, relief etc.

The incident preplan should include liaison with the FRSs to establish the pre-determined attendance (PDA) in normal response and in worst-case response. For severe toxic releases, the PDA should be greatly reduced to lower the potential impact on the FRS approaching the installation.

The approach to fire-fighting may be different in each major fire area depending on the type of operation. Different areas containing process units, bulk storage, and buildings may employ different techniques of fire-fighting given the different hazards and risks. However, resources for control, containment, and fire-fighting on the site should be provided for the largest demand on each individual resource or fire-fighting agent in any major fire area.

8.4 RECOGNITION OF HAZARDS

The preparation of an incident preplan should commence by identifying the risks, making a reasonable assessment of the possible consequences and their effect, and bringing these to the attention of the external authorities in a way which will enable them to understand the size and scope of the problems they may be faced with. In making this assessment, the consequences of major damage to essential services, e.g. electrical power supply, communication systems, water supplies, etc. should be considered along with what needs to be done to overcome these consequences including the possible need to provide alternative supplies.

A large-scale incident may not only disrupt the normal means of access to the site but, in addition, may impose restrictions on the normal way of life in the area surrounding the site, at least for the duration of the incident.

It should be recognised that terrorism is a possible incident initiator; incident preplans should address potential hazards, security issues and contingencies for dealing with such incidents.

8.5 CONTROL OF INCIDENTS

Various separate control functions should be defined and co-ordinated, e.g. police, fire, medical services and site management. Within the management structure of larger sites, various responsibilities and duties also should be clearly defined. In the event of an incident, an experienced, senior person from the site should be designated as the person responsible for liaison with external services. The police and site management will have the administrative control and, where there is a fatality, the police may have additional responsibilities. The FRS and medical services are primarily concerned with physical activity onsite. If the incident is a fire, the senior fire officer will have control. The designated site liaison manager should closely liaise with them.

A forward control point, sited according to the circumstances, will be required by the operational units. A suitably equipped vehicle or mobile trailer unit commonly serves this purpose.

Additionally, if the incident is large enough to warrant it, a rear (or main) control point will also be required, sited in a safe place, where senior site management, local government representatives and others may be present. Their function would be to control the wider effects of the incident on the remainder of the premises and beyond, give technical advice to the operational units and to deal with media enquiries, casualty status enquiries, next of kin, etc. Individual responsibilities should be defined in the incident preplan. Plant drawings, a site plot plan, a large scale Ordnance Survey map of the area, technical information and personnel lists (addresses and telephone numbers) should be available.

On a large site comprising several major hazard installations, an alternative location for the co-ordination centre should be available if there is any possibility of the building becoming sufficiently damaged or rendered unavailable for some other reason in a major incident.

A high standard of communications is necessary between the two control points and with external authorities.

In addition, it is common for large petroleum sites to be divided between several duty holders. Clearly, any arrangements for emergency planning should be well-known and understood through good inter-company coordination.

8.6 TRAINING OF PERSONNEL

The key personnel involved in an incident preplan should be trained and practise it in conjunction with appropriate local government personnel. Up to a certain level of emergency this should be by practical exercise onsite but training for a major emergency should be carried out at least annually and should be in the form of a table-top exercise using realistic data related to the site.

All personnel should be given clear instructions as to their responsibilities during an emergency. These should include first-aid, fire-fighting and organisation of evacuation and marshalling at defined locations.

Under regulations such as COMAH, there is a requirement for sites to carry out one major exercise every three years, which covers the on- and offsite ERPs. For smaller petroleum sites not subject to such regulations, proportionate fire response exercises should be performed at regular intervals to ensure onsite personnel and the FRS maintain a robust fire incident response capability.

8.7 PRE-FIRE PLANS

Regulations such as COMAH require planning for credible major incidents and also for these pre-fire plans to be exercised. Pre-fire plans should address:

— Actuating site alarm systems.
— Using fire-fighting agents.
— Using fire-fighting equipment.
— Emergency procedures for shutting-down process plant.
— Emergency evacuation procedures and assembly points in safe locations and procedures for the establishing and staffing of a fire control centre.
— Training of personnel.
— Cleaning-up the environment.

Whilst there are many styles or formats of such plans, it is advantageous to have regulator involvement in their format and content.

The most appropriate way to provide pre-fire plans at a petroleum installation is to develop scenario-specific ERPs.

8.8 SCENARIO-SPECIFIC EMERGENCY RESPONSE PLANS

Although a petroleum installation should have a site-wide incident preplan and pre-fire plans for higher-level control of credible scenarios, a series of generic and specific incident ERPs should be prepared for use by incident responders. They should cover, as a minimum, all the credible scenarios identified in any safety report. In addition, further ERPs should be prepared for some lesser fire events. The ERPs should be:

— Based on potential credible scenarios.
— Site-specific and therefore relevant to the installation's systems and equipment.
— Fit-for-purpose.
— Easy to use.
— Helpful to the end users.

ERPs should consist of only one or two pages and preferably a single front page of text intended as guidance and instruction for incident responders; an example is provided in Annex G. On the reverse of the text page, an effects map can be provided. This should indicate the potential jet or pool fire flame impingement area, radiant heat hazard areas or other affected area where adjacent or nearby plant, tanks, vessels and associated equipment could be affected by the incident. Unignited gas releases contours should also be indicated on the effects maps to indicate the potential worst case incident severity.

The purpose of ERPs is to provide instant written instructions, guidance and helpful information for personnel to assist them at the critical early stage of a major incident, and, to provide sufficient potential hazard information to enable informed decisions on the safety of personnel responding to the incident.

ERPs are intended to provide guidance on the actions and resources required to deal with the incident during its first 20-30 minutes. Once this early stage has passed, a stable response should have been established and if the incident duration may be prolonged, a continuing strategy for dealing with this should be developed by those managing the incident. The ERPs should combine operator and fire responder actions so that a coordinated approach is adopted for incident management.

The plans may consist of a three-tiered response with:

1. Installation operators as the first response.
2. Installation emergency responders as the second response.
3. FRS or fire tugs (in the case of jetty incidents) etc. as the third response.

The ERP effects are produced from fire, gas dispersion and explosion consequence-modelling programmes. See section 2.7.

Effects maps can only ever be indicative of the potential gas, fire or explosion area that may be, or may become, involved during a major incident. Nevertheless, they create an appreciation of potential incidents for all responders.

The ERPs should be developed from detailed analysis of credible major incidents. This is usually done in the form of scenario worksheets that set out the incident consequences, prevention measures, mitigation measures and response measures. The scenario worksheets themselves should not be viewed as ERPs, but as a basis for ERPs and as an auditable trail for ERP development. An example of a scenario worksheet is given in annex G.2

The worksheets should also allow an agreed fire or incident control strategy and a set of tactics to be established, most of which is then transferred to the ERP. In this way, a fully auditable trail is created for future reference.

An example of an ERP, as used at several petroleum sites, is provided in annex G.2.

Copies of ERPs should typically be distributed to:

— operations personnel;
— onsite fire responders and onsite security personnel (if applicable);
— onsite incident management personnel (e.g. as part of the incident preplan);
— local FRSs.

The exact format and distribution will vary from site-to-site, but it has been found advantageous to provide operations personnel with bound copies of ERPs for reference purposes and onsite fire responders with larger format, weatherproof versions that are normally used as the active ERPs during an incident. (Ultimately, all personnel who are expected to use the ERP should be provided with copies; however, only one copy may be marked-up and passed between responder groups during an incident).

8.9 MAINTAINING INCIDENT RESPONSE

8.9.1 Training and emergency response plans

In addition to their use during an incident, ERPs can also provide an effective means of measuring the 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, etc. The provision of effects maps enhances responder collective vision of the fire or gas cloud area, which better focuses the exercise when compared to imaginary areas.

The ERPs should consider staffing and capability of the local FRS. They should highlight as much information as possible on the incident hazards and other concerns should be highlighted for units who may attend an onsite incident. The local government FRS should be involved in exercising the plans. Whilst it is not practical to expect them to attend every exercise given other demands on their time, the aim should be to hold at least one major exercise per year with their units to ensure familiarisation. An annual desktop exercise should also be considered with FRS officers attending if possible.

Simulated incidents can be carried out to test the ERPs. Observers should use the ERPs to check the actions performed by operators at a plant control room as well as in the installation general area (and any ships alongside, in the case of jetty incidents). The actions of fire responders at the simulated incident scene should 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 incidents on the particular installation.

Also, software packages are now available that are able to simulate developing scenarios with animation and these should not be overlooked as an aid to incident response planning.

For sites with occupied buildings, other than local control rooms, etc., fire wardens should be assigned to be responsible for evacuation and muster head counts, reporting on building fire equipment, fire exit or other fire safety shortfalls within their floor or section of a building. The number of fire wardens will depend on the size, number of floors and complexity of a building.

8.9.2 Dynamic risk assessment

Dynamic risk assessment is the continuous process of identifying hazards, assessing risks, taking action to eliminate or reduce risk, and monitoring and reviewing these in the rapidly changing circumstances of an incident. This process should be adopted by senior fire responders and crews who will participate in an incident. There are five key principles:

— Evaluate the incident, responder tasks and persons/items at risk.
— Select response procedures and ensure competency.
— Assess response procedures and evaluate whether the risks are proportional to the benefits.
— Introduce additional risk reduction measures e.g. SCBA, PPE, Safety Officers, etc.
— Re-assess response procedures and additional risk reduction measures.

More detailed guidance can be found in national health and safety or fire services publications such as HO *Dynamic management of risk at operational incidents* or equivalent local publication.

8.9.3 Fire systems integrity assurance

Operating experience has often shown that fire detection and protection systems are not always designed or specified in sufficient 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.

Generally, risk reduction measures including fire systems do not provide a direct contribution to production and revenue. Consequently, they are sometimes not given the inspection or maintenance priorities that they deserve and 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 a continuing basis, are therefore essential, especially when the system is intended as a risk management measure for personnel safety.

In any event it is impracticable to give fire systems a full performance test onsite 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 risk-based approach to the provision of fire systems, a structured approach to FSIA should be implemented by:

- Reviewing potential fire incidents as part of risk assessment.
- Setting performance standards to clearly define what measurable criteria the risk reduction measure or fire system should meet.
- Developing component specifications suitable to meet the performance criteria.
- Developing relevant test, inspection and maintenance procedures through which continuing performance can be assured.
- Implementing and keeping records of the test, inspection and maintenance programme.

For further guidance, see OGP *Fire systems integrity assurance.*

ANNEX A

RELEVANT UK AND EUROPEAN LEGISLATION

A.1 NATURE OF LEGISLATION

Recent fire safety legislation in the UK, Europe and many other parts of the world has generally moved away from prescriptive requirements that specify precise fire safety measures. A more risk-based approach has been adopted which recognises foreseeable incident scenario frequencies as a means to identify options for risk reduction measures.

This risk-based legislation, as opposed to prescription, is supported by publications such as Approved codes of practice (ACoPs) and guidance, for example, HSC *Storage of dangerous substances* and HSE *The storage of flammable liquids in tanks*, respectively.

The choice of safety system measures to be put in place is therefore the decision of the duty holder provided they can demonstrate to the regulator that the measures are adequate and appropriate in terms of reducing risk to safety and the environment and that they are implemented and maintained correctly.

This annex sets out for petroleum refineries and bulk storage installations, the requirements of pertinent UK legislation, and where appropriate, the European legislation which it implements.

A.2 SEVESO II DIRECTIVE AND COMAH REGULATIONS

The Seveso II Directive, as amended, places a duty on duty holders to ensure major hazards have been addressed and all practicable steps have been taken to limit the probability and consequences of major accident hazards.

Implementation of major accident hazard legislation throughout Europe in response to the Seveso II Directive follows a broadly similar approach throughout Member States. For example, it is implemented in the UK as the COMAH Regulations, except for land-use planning. Their main aim is to prevent and mitigate the effects of those major accidents involving dangerous substances such as those commonly found at petroleum refineries and bulk storage installations. It should be noted that the COMAH Regulations treat risks to the environment as seriously as those to people.

The COMAH Regulations require demonstration of the means to achieve safe operation, through hazard identification, risk assessment and the organisational and engineering measures taken at an installation to reduce risks of major accidents including those involving fires. For larger sites, this is documented in a safety report.

In the first instance, duty holders should determine if the regulations apply by assessing quantities of dangerous substances present, or likely to be present, and comparing against thresholds set out in Regulation 3 and Schedule 1. If enough dangerous substances are present over the lower threshold then 'lower-tier' duties apply and if there are enough to exceed the higher threshold then 'top-tier' duties apply. The scope of COMAH requires not only fire, but explosion, toxicity and environmental impacts to be taken into account.

The key duties for lower-tier site duty holders are:

— Notify basic details to the CA.
— Take all measures necessary to prevent major accidents and limit their consequences to people and the environment.
— Prepare a major accident prevention policy (MAPP).

Accident prevention should be based on the principle of reducing risk to ALARP for human risks and using the best available technology not entailing excessive cost (BATNEEC) for environmental risks. The ideal should always be, wherever possible, to avoid a hazard altogether.

The MAPP should usually be a short and simple document setting down what is to be achieved but it should also include a summary and further references to the SHEMS that will be used to put the policy into action. The detail should be contained in other documentation relating to the site e.g. plant operating procedures, training records, job descriptions, audit reports, to which the MAPP can refer.

The MAPP should also address issues relating to the SHEMS, such as:

— Organisation and personnel.
— Identification and evaluation of major hazards.
— Operational control.
— Planning for emergencies.
— Monitoring, audit and review.

Top-tier duty holders usually have to comply with the above except that they may not have to prepare a separate MAPP; their safety reports (see below) have to include the information that would in any case be provided in a MAPP.

A safety report is a document prepared by a top-tier site duty holder and provides information to demonstrate to the CA that all measures necessary for the prevention and mitigation of major accidents have been taken. It should include:

— A policy on how to prevent and mitigate major accidents.
— An SHEMS for implementing that policy.
— An effective method for identifying any major accidents that might occur.
— Measures (such as safe plant operating procedures) to prevent and mitigate major accidents.
— Information on the safety precautions built into the plant and equipment when it was designed and constructed.
— Details of measures (such as fire-fighting) to limit the consequences of any major accident that might occur.
— Information about the ERP for the site, which is also used by the local government in drawing up an offsite ERP.

In addition, top tier duty holders should:

— Keep the safety report up-to-date.
— Prepare and test onsite ERPs.
— Supply information to local government for offsite emergency planning purposes.
— Provide the public with relevant details of the dangerous substances, the possible major accidents and their consequences, and what to do in the event of a major accident.

The COMAH Regulations are supported by complementary regulations (see A.3) and publications including ACoPs and guidance (see Annex I.3).

A.3 COMPLEMENTARY REGULATIONS

In addition to major accident hazard legislation there is complementary legislation that addresses relevant supporting issues, albeit where the potential impact is less. The following apply in the UK, but are representative of similar provisions throughout Europe.

(i) ATEX Directives, Chemical Agents Directive and DSEAR

The ATEX Directives introduce specific legal requirements aimed at specifying the necessary properties of electrical and non-electrical equipment for use in flammable atmospheres, and protecting personnel from the potential dangers of flammable atmospheres, respectively.

ATEX 100a (ATEX Equipment Directive) (94/9/EC) (Approximation of the Laws of Member States concerning Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres) is implemented in the UK by The Equipment and Protective Systems for use in Potentially Explosive Atmospheres Regulations. Such equipment should be assessed against the essential health and safety requirements (EHSR) of the Directive and CE marked if it conforms. This may require assessment by a notified body for certain categories of equipment. The marking also comprises other information as may be required by the European Communities directives applying to a particular product.

ATEX 137 (ATEX Workplace Directive) (99/92/EC) (Directive on the Minimum Requirements for Improving the Health and Safety of Workers Potentially at Risk from Explosive Atmospheres), and the safety aspects of Council Directive 98/24/EC of 7 April 1998 on the Protection of the Health and Safety of Workers from the Risks related to Chemical Agents at Work (Chemical Agents Directive) are implemented in the UK by DSEAR. This outlines minimum requirements for improving the safety of personnel at risk from flammable atmospheres. Any changes to workplaces and any new installations should comply with the requirements, including training, PTW systems, classification of flammable atmospheres, mitigation of flammable atmospheres, explosion protection and safety aspects of SHEMSs.

Detailed information regarding the implementation of the ATEX Directives throughout Europe is available from the EC ATEX guidelines website.

DSEAR sets out minimum requirements for the protection of workers from fire and explosion risks arising from dangerous substances (as defined in the regulations), and potentially explosive atmospheres arising from work with them. DSEAR applies at all petroleum installations, including those not subject to the COMAH Regulations. The main requirements of DSEAR are to:

— Risk assess work activities involving dangerous substances.
— Provide technical and organisational measures to eliminate or reduce as far as is reasonably practicable the identified risks.
— Provide equipment and procedures to deal with accidents and emergencies.
— Provide information and training to employees.
— Classify places where flammable atmospheres may occur into zones, and mark the zones where necessary.

DSEAR has removed the need for licensing under the Petroleum (Consolidation) Act at most bulk storage installations.

For up-to-date information on implementation, the relevant CA should be consulted. In the UK, information is available from HSE *ATEX and DSEAR frequently asked questions* website. The following ACoPs also provide relevant guidance:

— HSC *Dangerous substances and explosive atmospheres*.
— HSC *Design of plant, equipment and workplaces*.
— HSC *Storage of dangerous substances*.
— HSC *Control and mitigation measures*.
— HSC *Safe maintenance, repair and cleaning procedures*.

(ii) The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations

Carriage of dangerous goods by road or rail is regulated internationally by the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) and Regulations covering the International Carriage of Dangerous Goods by Rail (RID). In the UK, they are implemented by The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations.

Their purpose is to protect consignees or carriers as well as those who might become involved in an incident (such as members of the emergency services and public). They place duties upon everyone involved in the carriage of dangerous goods, to ensure that they know what they have to do to minimise the risk of incidents and guarantee an effective response.

(iii) The Fire Precautions (Workplace) Regulations

In the UK, The Fire Precautions (Workplace) Regulations implement relevant aspects of Council Directive 89/391/EEC of 12 June 1989 on the Introduction of Measures to Encourage Improvements in the Safety and Health of Workers at Work (Framework Directive). The Fire Precautions (Workplace) Regulations and similar European regulations apply largely to buildings which form part of a petroleum refinery or bulk storage installation.

Under such regulations, duty holders should ensure the safety of personnel in case of fire; where necessary, workplaces should be equipped with appropriate fire detection and alarm, emergency routes and exits, emergency lighting and signage, fire-fighting equipment and relevant ERPs.

Typical workplace fire precautions regulations are goal-based rather than prescriptive. This means that fire safety objectives such as means of escape are specified, but implementation may be in a manner which best suits the duty holder's needs. Advice, with examples of how compliance can be achieved, may be found in national building regulations and design standards but if employers wish to achieve compliance by other means, it is open to them to do so (e.g. as part of a fire engineered approach). This contrasts with certification under previous legislation (e.g. the Fire Precautions Act) where the fire authority prescribes exactly what needs to be done and the occupier should comply with its requirements.

Note that the UK legislative framework for industrial fire safety is being amended. The Regulatory Reform (Fire Safety) Order (RRO) has revoked The Fire Precautions (Workplace) Regulations in England and Wales, similarly in Scotland by the Fire (Scotland) Act. See A.3 (ix).

(iv) The Fire Certificates (Special Premises) Regulations

The Fire Certificates (Special Premises) Regulations apply to a range of premises which hold certain specified quantities of substances, e.g. ≥4 000 tonnes or more of highly flammable liquids, or ≥100 tonnes of LPG. Where these regulations apply an application for a Fire Certificate should be made to the local area office of the HSE.

Note that the UK legislative framework for industrial fire safety is being amended. The RRO and Fire (Scotland) Act have revoked The Fire Certificates (Special Premises) Regulations in England and Wales, and Scotland, respectively. See A.3 (ix).

(v) The Notification of Installations Handling Hazardous Substances Regulations

The Notification of Installations Handling Hazardous Substances (NIHHS) (Amendment) Regulations apply to premises with specified quantities of particular substances, and require such sites to be notified to the HSE.

(vi) The Dangerous Substances in Harbour Areas Regulations

The Dangerous Substances in Harbour Areas Regulations control the carriage, handling and storage of dangerous substances in harbours and harbour areas.

(vii) Management of Health and Safety at Work Regulations

The Management of Health and Safety at Work Regulations expand upon the general duties within the Health and Safety at Work etc. Act and require employers to manage health and safety. They require risk assessments to be carried out for all work activities for the purpose of deciding what measures are necessary for safety.

(viii) Confined Spaces Regulations

If a risk assessment identifies risks of serious injury/adverse health from work in confined spaces, such as a lack of oxygen, or the presence of toxic gases, fumes or vapours, and ingress of liquids or solids, The Confined Spaces Regulations may apply. They require:

— Avoiding entry to confined spaces (e.g. by doing the work from outside).
— If entry to a confined space is unavoidable, following safe systems of work.
— Putting in place adequate emergency arrangements before the work starts.

(ix) The Regulatory Reform (Fire Safety) Order/Fire (Scotland) Act

The RRO and Fire (Scotland) Act provide a new legislative framework for fire safety in workplaces in England and Wales, and Scotland respectively. They revoke The Fire Precautions (Workplace) Regulations and The Fire Precautions (Special Premises) Regulations, and repeal other legislation.

The Order and Act introduce: a general duty to ensure, so fas as is reasonably practicable, the safety of employees; a general duty in relation to relevant non-employees to take such fire precautions as may reasonably be required in the circumstances to ensure that premises are safe; and a duty to carry out a suitable and sufficient risk assessment. Fire certificates are no longer required.

They impose a number of specific duties in relation to the fire precautions to be taken and provide for enforcement. This will be by local fire and rescue authority; however process fire safety will be enforced by HSE (see A.4).

The Order and Act implement some aspects of the Chemical Agents Directive and the ATEX Workplace Directive with respect to dangerous substances. In doing so, they set out requirements to be considered in risk assessments where dangerous substances are present, and to their mitigation by inventory reduction, prevention of loss of containment, managing sources of ignition, etc.

In general, they emphasise the need to prevent fires and reduce risk. A responsible person should carry out a risk assessment to: identify fire hazards; identify people at risk; evaluate risks and remove and reduce risks; record, plan and train; and review risks.

A.4 LICENSING AND ENFORCEMENT

Regulations are normally enforced by a CA. Safety and health regulations are enforced at UK petroleum refinery and bulk storage installations by HSE. Under COMAH, the CA also comprises the relevant environment agency, i.e. EA, SEPA or EHSNI.

Licensing and enforcement for petroleum legislation may also fall to the local fire and civil defence authority or regional government. In many cases, responsibilities fall to the local harbour authority in a harbour area and to the CA at sites subject to hazardous installations regulations.

The licensing procedure usually includes an assessment of a site by the licensing authority or CA to decide whether or not to grant or renew a licence and what conditions to attach to it. Site occupiers should therefore discuss with the licensing authority the proposed arrangements for keeping or handling petroleum products before bringing them onto the site.

Enforcement of fire safety under the RRO and Fire (Scotland) Act is the responsibility of the local fire and rescue authority; however, process fire safety is enforced by HSE at sites subject to the COMAH Regulations.

ANNEX B

FIRE-RELATED HAZARDS OF PETROLEUM AND ITS PRODUCTS

B.1 INTRODUCTION

This annex provides physical properties and the IP classification of petroleum and its products; these should be used when assessing their fire-related hazards.

B.2 BOILING POINTS (OR RANGES), FLASH POINTS AND IGNITION TEMPERATURES OF PETROLEUM PRODUCTS

Table B.1 provides boiling points (or ranges), flash points and ignition temperatures of petroleum products.

Table B.1: Boiling points (or ranges), flash points and ignition temperatures of petroleum products

Substance	Boiling point (or range) (°C)	Flash point (closed cup) (°C) (Note 1)	Ignition temperature (°C) (Note 2)
Methane	−161,5	N/A	537
Ethane	−88,6	N/A	510
Propane	−42,1	N/A	466
Butane	−0,5	N/A	430
2-methylpropane (isobutane)	−11,8	N/A	Note 4
Pentane	361	< -40	309
Hexane	687	−22	247
Ethylene	−103,7	N/A	542
Propylene	−47,7	N/A	Note 4
1-Butene	−6,3	N/A	Note 4
2-Butene	4	N/A	Note 4
Benzene	801	−11	580
Toluene	110,6	4	552
Hydrogen	−252	N/A	580
Kerosine (Note 3)	150 - 300	38-50	254
Naphtha (Note 3)	100 - 177	−2 - +10	Note 4
Petrol (Note 3)	37 - 200	<−40	257
Gas oil (Note 3)	260 - 370	>56	338
Atmospheric residue (fuel oil) (Note 3)	>350	>66	Note 4

Notes

1 See Section 2.2 regarding limitations of using flash points. For substances whose flash point is identified 'N/A', flash point is not applicable as substance exists in gaseous state under ambient conditions.
2 The data for ignition temperature should be regarded as approximate only, since they depend on the characteristics of the test method used. See Section 2.2.
3 As they are mixtures, these petroleum products boil over a wide boiling range. In addition, the range data are typical; actual values vary with manufacturer and specification.
4 Data not available.

B.3 IP CLASSIFICATION OF PETROLEUM AND ITS PRODUCTS

Table B.2 provides the IP classification of petroleum and its products by flash point.

Table B.2: IP classification of petroleum and its products

Class	Description	Substance
0	Liquefied petroleum gases (LPG)	LPGs, ethylene, propylenes
I	Liquids that have flash points below 21 °C	Petrol Stabilised crude oil Avtage wide cut jet fuel (JP4; Jet B) Benzene Toluene Naphtha Methanol
II(1) (Note 2)	Liquids that have flash points from 21 °C up to and including 55 °C, handled below flash point	Avtur/Jet A/Turbofuel Kerosine (a) premium grade, (b) regular
II(2) (Note 2)	Liquids that have flash points from 21 °C up to and including 55 °C, handled at or above flash point	Cutback bitumens (Note 4)
III(1) (Note 2)	Liquids that have flash points above 55 °C up to and including 100 °C, handled below flash point	Gas oil/distillate heating oil Automotive diesel
III(2) (Note 2)	Liquids that have flash points above 55 °C up to and including 100 °C, handled at or above flash point	Cutback bitumens (Note 4)
Unclassified (Note 3)	Liquids that have flash points above 100 °C	Atmosphere residues Heavy fuel oils Bitumens other than cutback grades

Notes

1 See section 2.2 regarding guidance on limitations of using flash points. Data based on closed cup flash points, except for LPG.
2 Class II and Class III petroleum and its products are subdivided in accordance with the circumstances in which they are handled.
3 Unclassified petroleum products should be considered as Class III(2) when handled at or above their flash points.
4 Depends on diluent. Bitumens using kerosine as diluent are typically Class III(2), whereas those using naphtha as diluent are typically Class II(2) or possibly Class I.

B.4 FLAMMABLE LIMITS OF PETROLEUM PRODUCTS

Table B.3 gives flammable limits in air of some petroleum products under ambient conditions.

Table B.3: Flammable limits of petroleum products

Substance	Physical state at ambient temperature	Flammable limits (% vol/vol)	
		Lower	Upper
Methane	Gas	5,0	15,0
Ethane	Gas	3,0	12,5
Propane	Gas	2,1	9,5
Butane	Gas	1,6	8,5
Pentane	Liquid	1,5	7,8
Hexane	Liquid	1,1	7,5
Heptane	Liquid	1,05	6,7
Hydrogen (Note 1)	Gas	4,0	75,0
Petrol	Liquid	1,4	7,6
Naphtha	Liquid	1,1	5,9
Kerosine	Liquid	0,7	5,0

Notes
1 Hydrogen is a special case owing to its wide flammability range.
2 Flammable limits can widen significantly when substances are at elevated temperature or pressure.
3 Main data source: NFPA *Fire protection guide to hazardous materials*.
4 See section 2.2 regarding the definition of flammable limits.

ANNEX C

TYPICAL INSTALLATIONS/AREAS – FIRE AND EXPLOSION HAZARD MANAGEMENT (DETECTION AND PROTECTION)

C.1 INTRODUCTION

This annex provides guidance on the most common fire and flammable gas detection and fire protection risk reduction measures for various installations/areas. Similar guidance could be developed for other installations/areas such as road tanker vehicle and rail wagon tank loading and unloading facilities, and road tanker vehicle parking areas. The lists are not intended to be prescriptive; rather, they indicate the risk reduction measures that should be considered for implementation depending on the results of a risk assessment.

In all cases, comprehensive design guidance on the listed risk reduction measures can be found in publications such as ACoPs and design standards; see Annex I.3.

C.2 STORAGE TANKS

The most comprehensive guidance for storage tank FEHM includes RPI *LASTFIRE* and design standards such as API RP 2021. Risk reduction measures to be considered by tank type are set out in the following sections.

(i) All tanks

- Bund walls.
- Drains for bunded areas.
- Earthing/bonding for tanks.
- Bund wall penetration sealing or transit piece seals.
- Fire-fighting water mains and fire hydrants.

(ii) Fixed roof tanks

- Tanks identified as critical may require heat detection at vents for early response.
- Fixed water spray systems for tank roof and tank shell if risk assessment warrants protection against tank-to-tank escalation or bund fire protection.
- Fixed or semi-fixed foam systems for low flash point product tanks if risk assessment warrants protection.
- Fixed monitors for cooling tanks, in place of water spray systems, may be considered where tanks are of small diameter and can be protected by such monitors.
- Wheeled large capacity dry powder and/or foam extinguishers where tanks are of relatively small height and diameter and where the range of dry powder stream or foam stream will reach all bunded areas.
- Portable, hand-held dry powder and/or foam extinguishers for minor spillage fires in bunds.

(iii) Internal floating roof tanks

- Fixed or semi-fixed foam system if risk assessment warrants protection.

- Fixed or portable monitors for cooling tanks may be considered where tanks are of small diameter and can be protected by such monitors.
- Wheeled large capacity dry powder and/or foam extinguishers where tanks are of relatively small height and diameter and where the range of dry powder stream or foam stream will reach all bunded areas.
- Portable, hand-held dry powder and/or foam extinguishers for minor spillage fires in bunds.

(iv) Open top floating roof tanks

- Secondary rim seals.
- Fire retardant rim seal materials.
- Foam dam and semi-fixed or fixed foam system with top pourers.
- Auxiliary foam hose line outlets at the tank top walkway.
- LHD in the rim seal area.
- Fixed water spray system for tank shell if risk assessment warrants protection against tank-to-tank escalation or bund fire protection.
- Fixed monitors for cooling tanks, in place of water spray systems, may be considered where tanks are of small diameter and can be protected by such monitors.
- Wheeled large capacity dry powder and/or foam extinguishers where tanks are of relatively small height and diameter and where the range of dry powder stream or foam stream will reach all bunded areas.
- Portable, hand-held dry powder and/or foam extinguishers for minor spillage fires in bunds.

(v) Typical spacing for storage tanks

The minimum spacings given in Table C.1 are applicable to the storage of petroleum and its products in Classes I, II(2) and III(2) in above-ground tanks. They should be used in conjunction with an appropriate level of fire protection. Spacings may be varied depending on local site conditions/tank criticality or providing fire protection is selected accordingly, based on risk assessment.

Petroleum and its products in Class II and Class III stored at bulk storage installations such as depots may be regarded as Class II(1) and Class III(1) respectively in temperate climates since they will be below their flash points at ambient temperatures. The spacing of tanks should be governed by constructional, maintenance and operational convenience only. However, where Class I products are also present, tanks for Class II products should be spaced from tanks storing Class I product at the distances for fixed roof tanks shown in Table C.1.

At petroleum refineries, products or product component stocks may at times be held at temperatures higher than their flash points. In this case, Class II substances will be classified as Class II(2) and spacings should be in accordance with Table C.1.

C.3 PROCESS AREAS

(i) Process areas – General

Some of the most common risk reduction options and considerations for process areas include:

- Point flammable gas detectors at pumps and compressors to detect accidental flammable releases.
- Acoustic gas detection may be provided for very high-pressure gas/vapour detection at potential release points.
- Open-path gas detection may be provided on one or more sides of a process plant if risk assessment requires early alert to a gas cloud moving off plant or to an identified source of ignition (perimeter monitoring).
- Point gas detection and point smoke detection at HVAC air inlets for local control rooms on or adjacent to process areas.
- Toxic gas detection for identified hazards (H_2S, CO, etc.).
- Flame detection or LHD at pumps transferring low flash point or above ignition temperature products, if justified.
- PFP on steel structures supporting vessels, drums and petroleum-containing equipment – typically PFP up to 8 m high.
- PFP on petroleum-containing vessels or drums etc. if risk assessment identifies high or rapid escalation risk.
- Low height walls as spillage retention for vessel inventory, which may initially overwhelm the installation drainage.
- Grade level island design to ensure spillages run from under/around vessel to installation drainage and eventual containment.
- Fire-fighting water mains and fire hydrants.
- Fixed monitors for cooling may be considered where staffing is low or the response and deployment of portable monitors or hose lines may be greater than identified vessel, equipment or structure failure times.
- Portable or wheeled water monitors if operations staffing is adequate to deploy in short time or fire responders will respond in a short time.
- Wheeled large capacity dry powder and/or foam extinguishers where risk assessments identify potential flammable liquid spills beyond the capability of conventional hand-held extinguishers.
- Portable, hand-held dry powder and/or foam extinguishers for minor spillage fires.

Table C.1: Location and spacing for above-ground tanks for storage of petroleum and its products in Classes I, II(2) and III(2)

Tank type	Factor	Minimum spacing
Fixed roof, above ground, including those with internal floating roofs; horizontal cylindrical tanks	1. Within group of small tanks (i.e. tanks 10 m diameter or less, height 14 m or less); aggregate capacity 8 000 m^3 or less.	Determined solely by construction/ maintenance/operational convenience.
	2. Between groups of small tanks (i.e. tanks 10 m diameter or less, height 14 m or less); aggregate capacity 8 000 m^3 or less.	Minimum 15 m, or as determined by fire consequence modelling.
	3. Between a group of small tanks and any tank outside the group.	Not less than 10 m, or as determined by fire consequence modelling.
	4. Between tanks not being part of a group of small tanks.	Half the diameter of the larger tank or the diameter of the smaller tank, whichever is less, or as determined by fire consequence modelling.
	5. Between a tank and any filling point, filling shed or building not containing a fixed source of ignition.	15 m, or as determined by fire consequence modelling but not less than 6 m.
	6. Between a tank and outer boundary or installation, any designated non-hazardous area, or any fixed source of ignition at ground level.	15 m, or as determined by fire consequence modelling.
	Note 1: For tanks greater that 18 m in height it may be necessary to consider whether the distances above should be increased to take account of the height of the tank.	Note 2: Fixed roof tanks fitted with internal floating roofs may be considered as fixed roof tanks for the purpose of tank location and spacing.
Floating roof	1. Within a group of small tanks.	Determined solely by construction/maintenance/operational convenience.
	2. Between two floating roof tanks.	10 m for tanks up to and including 45 m diameter. 15 m for tanks over 45 m diameter, or as determined by fire consequence modelling. The size of the larger tank should govern the spacing. For crude oil, not less than 10 m but a minimum spacing of 0,3 D should be considered, with no upper limit.
	3. Between a floating roof tank and a fixed roof tank.	Half the diameter of the larger tank or the diameter of the smaller tank, whichever is less, or as determined by fire consequence modelling but not less than 10 m.
	4. Between a floating roof tank and any filling point, filling shed or a building not containing a possible source of ignition.	15 m, or as determined by fire consequence modelling but not less than 6 m.
	5. Between a floating roof tank and outer boundary of installation, any designated non-hazardous area or any fixed source of ignition at ground level.	15 m, or as determined by fire consequence modelling.
	Note 3: For tanks greater that 18 m in height it may be necessary to consider whether the distances above should be increased to take account of the height of the tank.	Note 4: Floating roof tanks fitted with external geodesic domes extending over the entire roof area may be considered as fixed roof tanks for the purpose of tank location and spacing.

Note: The spacings should be used in conjunction with an appropriate level of fire protection. Spacings may be varied depending on local site conditions/tank criticality or providing fire protection is selected accordingly, based on risk assessment.

C.4 LPG STORAGE INSTALLATIONS

The location and type of LPG storage installations should govern the levels of FEHM measures and provisions. If scenarios have potential offsite impact, additional measures should be considered. Below are typical measures for pressurised LPG spheres and vessels, but these may not be suitable for every installation:

— Sloping ground away from sphere or vessel to a drainage system or catchment pit.
— Drain system water seals to minimise gas or flame migration.
— Low height bund walls as spillage retention.
— Point flammable gas detectors at pumps, compressors.
— Open-path gas detection may be provided on one or more sides of an LPG vessel storage area if risk assessment requires early alert to a gas cloud moving off plant or to an identified source of ignition.
— Point gas detection at HVAC air inlets for local control rooms on or adjacent to LPG storage areas.
— Manual call point fire alarm system.
— Flame detection may be considered for LPG pumps and for coverage of potential leak/fire points under vessels and spheres in case of early or instantaneous ignition of a gas release.
— PFP of sphere legs and vessel saddles.
— PFP on sphere or vessel shell depending on risk assessment, criticality and offsite escalation impact.
— Fixed water spray system for spheres or vessel shell.
— Fire-fighting water mains and fire hydrants.
— Fixed monitors for additional cooling to support the water spray system.
— Portable or wheeled water monitors if operations staffing is adequate to deploy in short time or fire responders will respond in a short time.

C.5 LNG INSTALLATIONS

Some of the most common risk reduction options and considerations for LNG installations include:

— Sloping ground away from storage tanks to a catchment pit for limited size spill containment.
— Point flammable gas detectors at pumps using gas detection appropriate to LNG, i.e. calibration for methane, located according to gas density characteristics.
— Open-path gas detection may be provided on one or more sides of an LNG process/transfer area if risk assessment requires early alert to a gas cloud moving off plant or to an identified source of ignition.
— Point gas detection at HVAC air inlets for local control rooms on or adjacent to LNG storage areas.
— Flame detection may be considered for LNG pumps in case of early or instantaneous ignition of a gas release.
— PFP on tank shell depending on risk assessment, criticality and offsite escalation impact.
— Fixed water spray system for storage tanks, road tanker vehicle and rail wagon tank loading gantries and any other identified potential fire exposure hazards.
— Fixed dry powder system may be considered for road tanker vehicle and rail wagon tank loading gantries.
— Fire-fighting water mains and fire hydrants.
— Fixed monitors for additional cooling to support water spray systems.
— Fixed water monitors for ship/jetty manifold area at jetties.
— High-expansion foam systems for tank bunds may be considered.
— High-expansion foam system for spill retention catchment pits.
— Portable or wheeled water monitors if operations staffing is adequate to deploy in short time or fire responders will respond in a short time.
— Wheeled large capacity dry powder extinguishers.
— Portable, hand-held dry powder extinguishers for minor spillage fires.

C.6 MARINE FACILITIES

Some of the most common risk reduction options and considerations for marine installations include:

— Point flammable gas detectors at LPG or low flash point flammable liquid pumps to detect accidental flammable releases.
— Point gas detection at HVAC air inlets for local control rooms if gas export/import operations.
— Flame detection may be considered for critical pumphouses.
— Fire-fighting water mains and fire hydrants.
— International ship/shore connection.
— Port authority fire tug or other fire tug availability, if possible.
— Fixed water monitors for ship/jetty manifold area at jetties if gas export/import; fixed water/foam monitors if flammable liquids export/import or if combination of flammable liquids/gases export/import.
— Portable or wheeled water monitors at strategic locations.
— Wheeled large capacity dry powder and foam

extinguishers.
- Portable, hand-held dry powder extinguishers for minor spillage fires.

C.7 BUILDINGS

(i) Local/central control rooms in process areas

Some of the most common risk reduction options and considerations for local/central control rooms in process areas include:

- Blast and external fire protection if risk assessment warrants such protection.
- Fire protection/fire resistant construction and internal linings in accordance with fire regulations.
- Point gas and smoke detection at HVAC air inlets with executive actions for damper closures, etc.
- Manual call point fire alarm system.
- Internal point smoke detection (depending on size of control room).
- Means of escape, emergency exits, emergency lighting in accordance with fire regulations.
- Portable, hand-held dry powder, water, and CO_2 extinguishers.
- Water sprinkler system or a gaseous system may be provided depending on criticality assessment.

(ii) Electrical switchgear rooms/sub-stations

Some of the most common risk reduction options and considerations for electrical switchgear rooms/sub-stations include:

- Blast and external fire protection if criticality warrants such protection.
- Point gas detection at HVAC air inlets with executive actions for damper closures etc.
- Manual call point fire alarm system.
- Incipient or point smoke detection.
- Means of escape, emergency exits, emergency lighting in accordance with fire regulations.
- Portable, hand-held dry powder or CO_2 extinguishers.
- A gaseous system may be provided depending on criticality assessment.

(iii) Computer/IT facilities

Some of the most common risk reduction options and considerations for computer/IT facilities include:

- Manual call point fire alarm system.
- Fire protection/fire resistant construction and internal linings in accordance with fire regulations.
- Incipient smoke detection.
- Means of escape, emergency exits, emergency lighting in accordance with fire regulations.
- Portable CO_2 extinguishers.
- A gaseous system or water mist system may be provided depending on criticality assessment.

(iv) Warehouses

Depending on the construction and identity and criticality of stored substances, a water sprinkler system may be necessary. For warehouses storing packaged flammable liquids for transport or export, a foam sprinkler system may be required depending on quantities and warehouse design. Water or foam may or may not be effective depending upon a variety of factors e.g. wetability of contents, storage arrangements, type of containers, etc. Regardless of system type, it should be carefully designed taking into account the relevant hazard classification, which in itself is dependent on the nature of the stored goods.

If sprinkler systems are used, consideration should also be given to the effects of fire-fighting water run-off.

Some of the other most common risk reduction options and considerations for warehouses include:

- Smoke detection if warehouse is of relatively low height – high roof structures may mean some time before smoke detection alarms.
- Manual call point fire alarm system.
- Internal office fire protection/fire resistant construction and internal linings in accordance with fire regulations.
- Means of escape, emergency exits, emergency lighting in accordance with fire regulations.
- Fire-fighting water mains and fire hydrants.
- Internal hose reels.
- Portable, hand-held dry powder, water or CO_2 extinguishers.

(v) Laboratories/workshops

Some of the most common risk reduction options and considerations for laboratories/workshops include:

- Fire protection/fire resistant construction and internal linings in accordance with fire regulations.
- Electrical equipment rated for use in hazardous areas, if appropriate.
- Limited quantities (typically 50 l) of flammable liquids held in laboratories.
- Flammable liquids to be in fire-resisting cabinet.

- Segregation of reactive substances.
- Gas and liquid line supplies from outside to have emergency isolation valves operable from outside.
- Manual call point fire alarm system.
- Internal point smoke detection (away from any fume hoods etc.).
- Means of escape, emergency exits, emergency lighting (classified according to hazardous area use, if appropriate) in accordance with fire regulations.
- Portable, hand-held dry powder, foam spray or CO_2 extinguishers.
- Water sprinkler system or a gaseous system may be provided depending on criticality assessment.

(vi) Administration buildings

Administration buildings should generally be provided with fire precautions and fire protection in accordance with local fire regulations, e.g. in the UK, The Fire Precautions (Workplace) Regulations. Note that the UK legislative framework for industrial fire safety is being amended. The RRO and Fire (Scotland) Act have revoked The Fire Precautions (Workplace) Regulations in England and Wales, and Scotland, respectively.

ANNEX D

TYPICAL APPLICATION RATES

D.1 INTRODUCTION

This annex provides guidance on typical fire-fighting media application rates for various equipment types and fire scenarios; however, they may require adjustment if equipment spacing is minimal, or according to the results of scenario-based risk assessment. Most of this annex focuses on water and foam as they are the fire-fighting media commonly applied to large petroleum fires for extinguishment and/or cooling. Some guidance is provided for use of powders and gases as extinguishing agents for smaller scale fires and those in enclosed or semi-enclosed spaces.

Water is used in fire-fighting at petroleum installations to control fire and act as a cooling medium to protect equipment from the damaging effects of flame impingement or high levels of thermal radiation and convection. It can be used selectively as an extinguishing agent, normally applied as a fine spray. However, water may not be effective as an extinguishing medium for fires involving flammable liquids.

Foam may be used as an extinguishing agent, and also for fire protection by suppressing vapours. Applied as a blanket, it can also protect surfaces such as the roofs of floating roof tanks from radiation, reduce the risk of ignition of pools of petroleum or its products, and extinguish fires by excluding air.

D.2 WATER BASED SYSTEMS

The application rates given in this section should provide a satisfactory level of protection in most circumstances. Some duty holders may choose to increase the application rates for process plant, tanks or equipment that have a high asset value or where loss would have a significant effect in terms of business interruption.

Requirements for cooling heat-affected plant, tanks and equipment can be determined by techniques such as fire modelling (see section 2.7).

(i) Process areas

Table D.1 provides typical design fire-fighting water application rates for cooling petroleum refinery process areas.

(ii) Cooling uninsulated equipment enveloped in flame

Minimum recommended water spray application rates for cooling specific items of equipment at petroleum installations are given in Table D.1. The application rates given relate to the area of equipment exposed to radiation from the fire. The rates apply to pool fires. It is generally not realistic to increase application rates sufficiently to mitigate the effects of direct jet flame impingement.

(iii) Equipment exposed to radiant heat

The radiated heat received by an object in the vicinity of a fire varies inversely with the square of the separation distance. Equipment close to a fire will require much more water for cooling. The actual water requirements will depend on the level of radiated heat, the absorbance of the irradiated surface, and the effect of any wind on the flame pattern as well as the separation distance of equipment from the fire.

Generally, applying water to equipment not immediately involved in the fire may divert resources from other more critical tasks. This should be continually assessed during the emergency and tactics should be changed where necessary to optimise available resources. The rates shown below are for guidance only. If the applied water does not evaporate from the surface it is supposed to be protecting, the surface may not be hot enough to warrant protection. If resources are limited and under strain at the time, concentration on other, more critical areas should then be considered.

Cooling may be required if the equipment is likely to be exposed to heat fluxes in excess of 8-12 kW/m^2. Usually, the most appropriate way of determining the need for cooling will be to carry out fire modelling calculations as part of the fire scenario analysis to identify exposures (see section 3.2).

Once a need for cooling has been identified, the minimum application rates given in Table D.1 should be used.

D.3 CONTROL OF BURNING

In some cases, water only may be used to control a fire until extinguishment is possible. Although not usually fully effective at extinguishing flammable liquid fires, the water may slow fire development and spread as well as providing valuable cooling to exposed equipment. Although it is not possible to specify application rates for all fire types (since these will depend on the petroleum product type, fire size and presence of obstacles as well as application equipment), the minimum application rate range given in Table D.1 should be used.

Table D.1: Minimum application rates for water based systems

	Application rate (l/min./m^2)
Process areas (Application rates based on ground area)	
Process unit blocks	4
High density - stacked equipment	6-8
Cooling uninsulated equipment enveloped in flame	
Process vessels, equipment, structural steel, pipe racks, fin-fan coolers etc.	10
Pumps handling flammable liquids in isolated areas [Note 1]	10
Pumps handling flammable liquids adjacent to cable runs, fin-fans, pressure equipment, pipe racks etc. [Note 2]	20
Compressors handling flammable gases	10
Electrical and instrument cable trays, transformers, switchgear etc.	10
Cooling equipment exposed to radiant heat	
Miscellaneous process equipment	2
Fixed [Note 3] and floating roof [Note 4] tanks containing Classes I, II and III liquids	2
Pressurised tanks (general)	10
LPG tanks	10
Buildings such as warehouses, offices and laboratories	2
Control of burning	
Water spray for control of fire (application rate depends on product type)	10-20

Notes

1 Per square metre of horizontal area extending 0,6 m from the pump and driver's periphery
2 Total water application rate based on application equipment and run time
3 Consider roof and shell of fixed roof tanks
4 See D.5 for considerations on cooling tanks. Water spray should not be applied to the roof

D.4 EXTINGUISHMENT USING WATER ONLY

The application rate of spray water for extinguishment will depend on the circumstances of the fire and no precise guidance can be given. If necessary, trials with actual application equipment should be conducted to establish required application rates. Actual application rates will depend on factors such as nozzle type, spacing and location, water pressure and flowrate etc. As noted in D.3, water is not generally an effective extinguishing material for fires involving Class I petroleum and its products.

D.5 STORAGE TANKS

(i) Considerations regarding the use of cooling water for tanks on fire

The need for cooling a fire-affected tank shell above the product level has been much debated. 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.

Tank shells are 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 spill or overflow. Therefore, cooling water should not be applied to the tank on fire.

However, it should be remembered that if extinguishment is to be attempted, tank shell folds may trap pockets of burning product that the foam blanket cannot flow over. This may cause some difficulty in achieving complete extinguishment. In addition, 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 towards the end of an incident 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 installations may no longer be required, thus reducing total water flow demand.

(ii) Cooling adjacent tanks

Cooling of heat-exposed tanks can be achieved through the use of fixed or semi-fixed water spray systems, or by mobile means. Table D.1 provides a summary of minimum application rates.

For adjacent tank cooling, the required water flow depends on the distance from the fire, wind direction, the area exposed to radiation, the type of tank (e.g. fixed or floating roof) and the intensity of the fire. The need for fixed water-cooling can, if necessary, be assessed by using appropriate fire modelling techniques, or otherwise at the time of an incident if no fixed protection is provided.

Various publications provide guidance on water cooling requirements for exposed tanks but a practical fire ground 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 clearly be made if in doubt about prolonged exposure to radiant heat.

To avoid unnecessary wastage of water and the potential problems of bund flooding or oil/water separator overflow, if the water applied does not steam off, its application should be stopped and tried again at regular intervals.

Overall, the final decision as to whether or not to apply cooling water should be the responsibility of the person in charge of fire attack, and should be based on the prevailing conditions.

Lessons learned from incidents include many cases where water has been over-applied for cooling adjacent tanks, leading to bund flooding, carry-over of product to other areas and excessive discharge of contaminated water offsite, as well as a shortage of water for more critical use.

For tank fire design events, radiant heat should be calculated. Any exposures receiving more than 32 kW/m^2 should be provided with fixed cooling water systems. Any exposures receiving 8-32 kW/m^2 may require cooling, but this can be provided by mobile/portable means providing that it can be deployed in a reasonable time.

A water application rate of 2 l/min./m^2 is normally sufficient; this removes 43 kW/m^2 thermal radiation at 50% efficiency, 30 kW/m^2 at 35%, or 69 kW/m^2 at 80% respectively. At many sites this may be the maximum practical rate determined by supply and drainage considerations. Rates higher than 2 l/min./m^2 do not provide a proportionate increase in protection.

Box D.1: Example calculations sheet

Note: Data are nominal only and should not be used for design purposes

1. Spillage fire foam quantity:

Spillage area	= 50 m^2	
Foam application rate (e.g. 3% FP foam)	= 6,5 l/min./m^2	
Total application rate	= 325 l/min.	
Run time	= 15 min.	
Total foam concentrate	= 325 x 0,03 x 15	= 146,25 l
Water requirement for foam application	= 325 x 15	= 4 875 l (~5 m^3)

2. Foam systems:

Tank area	= 346 m^2	
Foam application rate (NFPA 11)	= 4,1 l/min./m^2	
Total application rate	= 346 x 4,1	= 1 420 l/min.
System run time (NFPA 11)	= 55 min.	
Foam concentrate quantity	= 1 420 x 0,03 x 55	= 2 343 l
Foam solution quantity (water)	= 1 420 x 0,97 x 55	= 75,8 m^3 (~76 m^3)

3. Water for cooling four adjacent tanks, based on typical tank dimensions of 20 m diameter x 10 m height and a minimum application rate of 2 l/min./m^2 over 50% of the height:

Each segment shell area	$= \frac{\pi}{4} \times 20 \times 10$	= 157 m^2
Each segment roof area	$= \frac{\pi \times 20^2}{4 \times 4}$	= 78,5m^2
Cooling on shell/segment	= 0,5 x 157 x 2	= 157 l/min.
Cooling on roof segment	= 78,5 x 2	= 157 l/min.
Total cooling/segment	= 314 l/min.	
Total for four segments	= 1 256 l/min.	
Run time	= 2 hr.	
Total quantity	= 1 256 x 120 = 150 720 l (~ 151 m^3)	

Total quantities:

Maximum water flow for foam solution (Bund spill extinguished first)	= 1 420 l/min.
Total quantity of water for foam solution	= 76 m^3
Foam concentrate	= 2 343 l
Maximum water flow for cooling	= 1 256 l/min.
Total quantity of water for cooling	= 150,72 m^3 (~ 151 m^3)

Therefore, calculation of required resources results in the following quantities required onsite:

Foam systems:

Foam concentrate	= 2 350 l
Foam solution (water) flow	= 1 420 l/min.
Foam solution quantity	= 78,1 m^3 (includes approximately 76 m^3 water)

Water cooling:

Water cooling flow	= 1 256 l/min.
Water cooling quantity	= 151 m^3

D.6 WATER SUPPLY

Fire-fighting water and foam solution requirements for credible fire scenarios should be determined. Calculation of the required resources to manage fires to a given strategy is best achieved through the use of 'calculation sheets' detailing overall water demands for those scenarios. An example calculation sheet is given in Box D.1; this should not be used for design purposes but indicates the calculation process only.

During an incident water supply requirements may vary greatly as cooling water is turned on or off as required, or as foam is applied to the fire. (Generally, cooling water should be minimised to reduce the possibility of bund filling, etc.) Generally, the water flow requirement should be based on the maximum that might be required at any moment taking into account the application rates needed to deal with credible and/or worst case fire scenarios.

In many cases, it will be the actual application equipment, system run time etc. that govern the required water flowrates, as well as incident experience.

Having assessed the overall water flow requirements it should be ensured that this water is available. It is not sufficient to simply specify a total water flow capability of the main fire pumps. Assessments of water requirements should be made on an area-by-area basis from fire scenario evaluations. Hydraulic analysis of the fire water system should then be used to assess whether or not these requirements can be met. In critical situations, hydraulic calculation results should be checked by site tests.

Scenario evaluation should be used to calculate total water quantity, but a minimum of two hours' supply should be considered based on the potential use of water or foam in a design event fire. However, in practice this figure may vary depending on incident strategy, system run times, etc.

Consideration should be given to contingency arrangements in the event of the site supply being exhausted before the fire is under control. Water containment and its recycling are options which might also be considered.

D.7 FOAM APPLICATION RATES

Foam is the most widely used extinguishing medium for large petroleum fires. It can be applied over horizontal or near-horizontal surfaces subjected to thermal radiation during a fire, to the rim seal area of a floating roof tank, by sub-surface injection in suitably equipped fixed roof tanks, or over a pool of petroleum. A foam blanket protects surfaces from thermal radiation, reduces the risk of ignition and will extinguish a fire if properly applied.

Generally, there will be a minimum application rate below which foam application will not be effective. The critical application rate is the minimum rate at which foam solution extinguishes a given fire. Typically, for a petroleum liquid fire, this is in the order of 1-2 l/min./m^2. However, some foam destructive products (e.g. MTBE, MEK and acetone) require much higher application rates. Figure D.1 illustrates these principles.

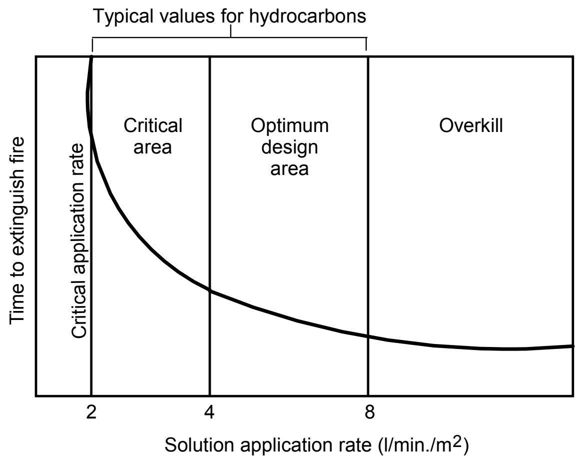

Figure D.1: Efficacy of foam application

Actual application rates should be much higher than this to provide a safety margin and faster extinguishment. However, if the application rate is further increased, a point is reached when no noticeable improvement is made in extinguishing time such that the additional application rate is effectively wasted. Published application rates in internationally recognised standards therefore attempt to strike a balance between ensuring fast, secure extinguishment and minimising wastage of resources.

As far as application method is concerned, it is generally desirable to apply foam as gently as possible to the product surface and so minimise product pick-up or disruption of any foam blanket; however, this is not always possible from a practical viewpoint. A range of application devices are available ranging from those that only cause the foam to flow from them gently without any residual kinetic energy to those that produce a foam jet that is projected a considerable distance.

D.8 POOL FIRE FOAM APPLICATION

For pool fires in process areas the minimum application rates given in Table D.2 should be used. For foam destructive products (e.g. polar solvents), guidance on minimum application rates should be sought from foam manufacturers.

Table D.2: Minimum foam solution application rates

	Application rate ($l/min./m^2$)
Pool fires	
Petroleum and its products – liquids	4
Foam destructive products	6,5 (Note 1)
Tank bund fires	
Petroleum and its products – liquids	4
Foam destructive products	6,5 (Note 1)
Fixed roof tanks and internal floating roof tanks (Note 2)	
Petroleum and its products – liquids	4
Foam destructive products	6,5 (Note 1)
Open top floating roof tank rim seal fires	
Foam pourer protection	12,2
Catenary system (Note 3)	20,4
Coflexip system (Note 3)	20,4
Coflexip system (Note 4)	12,2
Full surface fires – monitor application (Note 5)	
Petroleum and its products – liquids	10,4
Foam destructive products (Note 6)	> 10,4

Notes
1 Guidance on minimum application rates for foam destructive products should be sought from foam manufacturers
2 Using fixed foam pourers or subsurface systems
3 Application under rim seal
4 Topside application
5 This should achieve a minimum application rate of 6,5 $l/min./m^2$ foam solution onto the fire surface
6 Rates should be greater than the minimum application rate of 10,4 $l/min./m^2$ and specialist advice should be sought

When applying foam for the purposes of ignition prevention, the information in D.9 (vi) should be considered.

D.9 TANK FIRE FOAM APPLICATION

This section describes typical strategies and minimum application rates that should be used to tackle rim seal fires, roof spill fires, bund fires and full surface fires in petroleum storage tanks. For further guidance, see prEN 13565-2 and NFPA 11.

(i) Bund fires

For bund fires, the strategy should 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 hose lines without cooling may be appropriate.

If a foam attack will take some time to organise, cooling water streams should normally be directed onto exposed piping, valves or any tank shell above the tank product liquid level.

For large bund fires, or where a tank has lost containment of all its contents into the bund and fire occurs, the strategy should be to split the fire into manageable areas or segments. This principle can apply to both fixed systems and portable equipment. It is often necessary because a large fire area can make it impracticable to tackle the complete bund at one time. Also, there may be limitations to foam flow over a large surface area. Portable foam monitors or portable foam bund pourers may be used for fire-fighting under these conditions and moved as control is gained in one area.

Fixed foam protection may also be considered for common bunded areas surrounding multiple tanks with poor access for fire-fighting. Recommended minimum application rates are given in Table D.2.

For foam destructive products (e.g. polar solvents), guidance on minimum application rates should be sought from foam manufacturers.

(ii) Open top floating roof tank rim seal fires

The main fire risk for open top floating roof tanks is the seal area between the tank shell and the floating roof. The most appropriate risk reduction option is to use fixed or semi-fixed foam systems. There are three basic methods of applying foam to the rim seal area, as identified in section *6.5.6.2*. Minimum foam application rates for these systems are given in Table D.2.

(iii) Foam application to 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, cooling of the 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 should 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 should be considered. The obvious hazard 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 should 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.

(iv) Fixed roof tanks and internal floating roof tanks

Fixed foam pourers are often used as the primary protection method for cone roof tanks. Subsurface or semi-subsurface systems may also be used.

Internal floating roof tanks may also use fixed foam pourer systems, or in some cases subsurface systems.

Minimum foam application rates for these systems are given in Table D.2.

For foam destructive products (e.g. polar solvents), foam manufacturers' recommendations should also be sought on minimum application rates.

(v) Foam application rates for full surface fires – Monitor application

Table D.2 provides minimum application rates for full surface fires when using monitor application. A minimum application rate of 6,5 l/min./m^2 of foam solution onto the fire surface should be used for full surface tank fires when using portable foam monitors for 'over the top' application. This figure 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 should be compensated by a higher application rate. The rate currently in use by several major oil company fire departments is 10,4 l/min./m^2 for fires involving petroleum and its products. (This figure is usually higher for water-soluble products.) This equates to approximately 60% more than the minimum rate to ensure that the minimum rate of 6,5 l actually settles on the product 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 more than the 60% may be required. However, a higher application rate will mean that a greater quantity of foam concentrate and foam monitors is required.

Once the surface area of the tank is known and the total foam solution application rate is calculated, foam monitors should be selected that meet the total minimum application rate, as shown in the following example:

80 m diameter tank	≡ 5 028 m^2
Foam application rate	= 10,4 l/min./m^2
Total foam application rate	= 52 291 l/min. (foam solution)
Typical monitors to be used	= 13 000 l/min. each
Number of monitors required	= 5

In practice, it will be the type(s) and capacities of application equipment such as foam monitors that will determine the required total application rate of foam solution, and consequently foam concentrate and water supplies. Thus, in the above example, the calculated flowrate was 52 291 l/min. but actual flow rate would be higher (perhaps 60 000 l/min.) corresponding to actual monitors available at the incident.

The figure of 10,4 l/min./m^2 coincides with actual large diameter tank incidents that have been successfully extinguished and should be used as a minimum until fire tests or incident experience prove otherwise.

Providing such a large foam solution flow rate (as well as any supplementary cooling that might be required at an incident) can present logistical concerns insofar as needing large throughput monitors, foam concentrate supplies, etc. However, incident experience shows that if this method of extinguishment is attempted, the increased application rate of 10,4 l/min./m^2 is necessary so that a minimum of 6,5 l/min./m^2 is actually delivered to the fuel surface.

(vi) Foam application to prevent ignition or re-ignition

Foam can also be used under some circumstances to prevent ignition of flammable liquids by blanketing spills and suppressing flammable vapours. However, foam generation and its subsequent discharge from a nozzle can produce an electrostatic charge that can potentially ignite the fuel. Also, when applied to a product surface the foam will tend to break down into foam solution and fall through the product as droplets of water. It is thought that this mechanism can have the potential to generate a charge sufficient to cause ignition.

These phenomena are thought only to be a problem with non-conductive products such as refined spirits and then only when there is a product spill of an appreciable depth (> 0,5m).

In order to minimise the risk of ignition in this way, the most appropriate strategy for an incident such as a sunken roof in a tank containing non-conductive product is not to apply a foam blanket unless there is an immediate risk to safety due to vapour spread or there is a definite potential source of ignition (e.g. a lightning storm or generation of such a large vapour cloud that it could reach a source of ignition such as vehicles on public roads, heaters, flares, etc.). In such circumstances, resources required to foam the surface should be deployed and put on standby so that application can be carried out immediately if required.

If foam application is required to an unignited surface, it should not be applied directly into the product but should be run down the tank wall onto the product surface.

There is very little proven guidance available regarding the amount of foam required to supplement a foam blanket and prevent re-ignition following an incident. This will clearly depend on the site-specific conditions and time taken to pump out or reclaim unburnt product. However, it is considered that the minimum quantity of at least 50% of that required to extinguish the fire should be available for this purpose. Replenishment of all foam concentrate to minimum required stock levels should be available within 24 hr. of usage.

D.10 GASEOUS SYSTEMS

For gaseous systems, the minimum application rate is actually based on the quantity of gaseous agent needed and the maximum allowable time to achieve design concentration. Usually the requirements differ for 'total flooding' or 'local application' systems.

For example, NFPA 12 specifies that the design concentration should be achieved within 1 min. from start of discharge for surface fires and 7 min. for deep-seated fires for total flooding installations.

To a large extent, the application rate will depend on individual nozzle characteristics such as the design discharge rate, but also the nozzle location and projection distance. Other factors influencing application rate will be the product, area to be protected, the presence of obstacles within an enclosure and enclosure integrity.

Systems should be engineered on an individual basis and performance criteria such as design concentration, the time taken to achieve the design concentration and retention time should be specified.

For detailed design and performance criteria, see NFPA 12 and NFPA 2001.

D.11 INCIDENT EXPERIENCE

Only competent people should interpret guidance on application rates; in addition, they should be fully aware of their application, and have knowledge of actual fire incidents and resource deployment options.

(i) Tank fires

For major tank fires involving petroleum products, there are three main options:

- Controlled burn.
- System application of foam.
- Monitor application of foam.

All three strategies have been used successfully at different locations around the world. The final decision on the most appropriate strategy will depend on site-specific issues including the perceived risk, availability of water supplies and availability of trained responders. Clearly the site strategy should be reviewed and accepted by the local regulatory authority and appropriate incident preplans for both duty holders and responders should be developed.

One major problem at tank fires in the past has been the unnecessary over-application of water to exposed tanks and to tanks on fire. The experience-based consensus is that provided the tank on fire is designed to API Std. 650 or equivalent (e.g. BS EN 14015), it should not be cooled except, perhaps, to help foam seal against the hot tank shell in the final stages of a fire. The tank shell above the contents will gradually curve inwards in a fire and not jeopardise the tank shell integrity. Some cooling may be required eventually to assist any foam seal against the tank wall.

The maximum recommended thermal radiation exposure level for unprotected tanks (i.e. having no active fire protection or PFP) should be 8 k W/m^2 or 32 kW/m^2 for protected tanks (see section 2.6.2). This, with the availability of validated radiant flux calculation programs, allows a more rigorous analysis of fire-fighting water requirements.

Incident experience has demonstrated that monitor application of foam can be a successful way of extinguishing large tank fires providing the response is well planned, the required resources are available and foam logistics (see section D.11*(iv)*) are carefully considered. In practice, actual application rates for the largest successfully extinguished tank fires have been in excess of the minimum application rates specified in publications. Consequently the minimum application rate should be 10,4 $l/min./m^2$ (see section D.9*(v)*); however, this may need to be increased to achieve extinguishment.

Regarding incident duration, petroleum and its products on fire in a tank, will typically burn down at a rate of approximately 2-4 mm/min. Incident duration has been reduced in some cases by pumping out the fuel from the base of the tank into spare tanks a safe distance away. Note however, the proviso regarding boilover in section D.11*(ii)*).

(ii) Boilover

The phenomenon of boilover in crude oil storage tanks remains of major interest and opinions are divided over the effects of fire-fighting strategies on its probability and consequences.

The boilover mechanism is described more fully in section *2.5.5.7*. Essentially, the height of the boilover and the lateral spread depends on the characteristics of the crude, the amounts of water crude in the tank as well as ambient conditions. Some boilover events will be more severe than others. However, from a fire-fighting perspective it should be assumed that once a crude tank full surface fire develops, a boilover will always occur unless the fire is extinguished.

What is less clear is the effect of application of large amounts of water and/or foam to the tank and whether this can actually speed up the boilover mechanism or result in more severe consequences. The effect of fire-fighting media application on boilover probability and consequences is not fully understood, although work is being carried out internationally to establish this.

In addition, work is being carried out internationally to establish the exact mechanisms present for boilover to occur, and whether indeed boilover is inevitable. Also, opinions are divided as to whether boilover can occur in certain other denser products such as fuel oil.

Regarding fire-fighting strategies, it should be noted that pumping out of product is one option that could reduce the consequences of a boilover (since less product would be present to boil over) but it is generally accepted that doing so would probably reduce the time taken for boilover to actually occur. It has also been suggested that hot zone formation (if this is indeed the dominant boilover mechanism) could be tracked using available equipment such as thermographic cameras, thermocouples etc. to predict time to boilover. However, work is still continuing to establish practical fire ground techniques useful in predicting boilover time and consequences.

(iii) Bund fires and process area fires

Bund and process area fires have been successfully extinguished using both fixed systems and mobile means. With regard to foam application, standards such as NFPA 11 recognise that portable monitors, foam hose streams or both have been adequate in fighting spillage fires. There is also a suggestion that in order to obtain maximum flexibility due to the uncertainty of location and the extent of a possible spillage in process areas and tank farms, portable or trailer mounted monitors are more practical than fixed foam systems in covering the area involved. However, there are logistical issues to address and in some cases a fixed or semi-fixed system may be appropriate depending on staffing, training and availability, etc.

It should also be recognised that large throughput monitors may not be the most appropriate choice for fighting process area fires. In particular, large volumes of water or foam delivered at high pressure might make an incident worse by rupturing pipework, damaging equipment or causing product 'carry over'. In many cases, mobile foam trolleys or wheeled extinguishers may be the most suitable equipment for fighting relatively small spillage fires.

As always, incidents should be reviewed by risk assessment, as part of an FEHM approach, and equipment should be matched to the scenario for suitability, application rate and system run-time.

(iv) Foam logistics

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

The use of 25 l 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 4 500 l/min., which at 3% proportioning rate would require 135 l/min. or more than five drums each minute.

Although many occupational fire brigades favour 200 l drums for supply, these will clearly last for less than 1,5 minutes assuming a 4 500 l/min. monitor is in use. With monitor flowrates above 4 500 l/min., the 200 l drums are consumed rapidly. These drums are therefore of no benefit if large throughput foam monitors of 30 000-60 000 l/min. are to be used.

One option may be to use large capacity IBCs of 1 000 litres or more, which can be transported using flatbed trucks or fork-lift vehicles to each fire vehicle (or monitor) and delivered to the spot within foam suction hose reach. Having two or more within suction hose reach will clearly 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 10 000-15 000 l 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 onsite within a very short period of the incident start.

(v) Environmental issues

The environmental protection consequences of a controlled burn policy for tank fires are, essentially, smoke production. Some limited data on the toxic effects of smoke from petroleum products are available. It is recognised that the environmental effects of controlled burn may be preferable to the potential effects of over-application of water and/or foam and the potential for run-off to offsite areas caused by this in some circumstances.

Another environmental issue for tank fire-fighting is that of fluorosurfactants in foam. At the time of writing all proven foam concentrates that are effective contain fluorosurfactants. There is continuing work in this area but no firm conclusions regarding acceptable policies have been developed at the time of writing of this publication.

For process area fires, the consequences of controlled burn may be more severe, depending on escalation potential. There will, in many cases, be a requirement to fight the fire, and fire-fighting water runoff and limiting its consequences will be a major consideration.

(vi) Fire and rescue services response issues

FRSs have water tenders as the main response units to incidents. There may be special foam carrying or other vehicles where the need has been identified. These may include emergency tenders for rescue or large scale BA incidents, foam tenders (which are not recognised as petroleum industry foam tenders but will carry limited quantities of foam concentrate, hydraulic platforms or aerial ladders, command and control vehicles, etc.).

Water tenders will typically feature a water tank of 2 250 l and a fire-fighting water pump in the order of 2 250 l/min. There may be some units that can pump 4 500 l/min., depending on the brigade, its area of response and the facilities within.

The type and number of foam monitors carried by FRSs is very limited. Water tenders will typically carry one or two foam branches of 225 l/min. or 450 l/min. capacity, together with an inductor. Some brigades may have one or two larger capacity foam monitors but will not usually hold the numbers and capacity of foam monitors necessary for larger incidents such as tank fires.

Taking these factors into account, it is considered that the unofficial role of FRSs during major fire incidents is to respond and provide trained and disciplined personnel for hose deployment, water and foam monitor deployment and foam supply.

There is therefore a clear need to ensure that a competent industry response team will mobilise the major resources required and provide the guidance and expertise to FRSs to deal with the incident, if necessary.

ANNEX E

EMERGENCY RESPONSE TEAM MEMBER – EXAMPLE COMPETENCY PROFILE

E.1 INTRODUCTION

This annex provides an example ERT member competency profile based on four units: operations; maintenance; procedures; and skills.

E.2 COMPETENCY MAPPING PROFILE FOR ERT MEMBER

Unit 1 Operations
Elements
1.1 Inspect and test fire vehicles
1.2 Inspect and test fire station communications
1.3 Exercise emergency response
1.4 Fire prevention

For details, see Table E.1.

Unit 2 Maintenance
Elements
2.1 Inspect and test site portable/mobile fire equipment
2.2 Inspect and test site fixed fire systems
2.3 Inspect and test site fire hydrants

For details, see Table E.2.

Unit 3 Procedures
Elements
3.1 Execute assigned duties
3.2 Working safely

For details, see Table E.3.

Unit 4 Skills
Elements
4.1 Respond to emergencies
4.2 Fixed systems/fire tender work in incident area
4.3 Carry out fire-fighting or incident control operations
4.4 Rescue personnel
4.5 Reinstate resources
4.6 Training and instruction

For details, see Table E.4.

Table E.1: Unit 1 Operations

Element	Performance criteria	Range	Equipment usage	Knowledge
1.1 Inspect and test fire vehicles	1. Vehicles ready for start-up.	Vehicle fuel, oils, water, battery levels.		Vehicle chassis/drive unit layout, fuel, water, oil capacities.
	2. Vehicles ready for driving.	Lights, indicators, wipers/washers, horn, sirens, tyres condition, defects.	Vehicle cabin switches, tyre pressures.	
	3. Vehicles roadworthy and safe.	Acceleration, braking, steering, gear changing, engine condition, defects.	Fire tenders.	Speed limits, safe driving requirements.
	4. Fire and emergency equipment on-board vehicles.	Equipment quantities, extinguishing agents, equipment fastenings.		Vehicle equipment and agents quantity standard.
	5. Vehicles' SCBA ready for use.	SCBA sets general condition, air and pressure readings, warning alarm, spare cylinder air and pressure readings.	SCBA cylinder valves.	SCBA set minimum contents and pressure, warning alarm settings, harness/backplate safe condition.
1.2 Inspect and test fire station communications	1. Station communications hardware functioning clearly.	Station communications hardware.	Radios, telephones, fire and gas alarms.	Communication methods, styles, call signs and procedures.
1.3 Exercise emergency response	1. Participation in theory and practical training sessions according to training programme.	Training according to training programme/schedule.	Portable/mobile fire-fighting equipment, rescue equipment, fire vehicle pumps and systems.	Daily training programme, training session aims and objectives.
	2. Appropriate actions taken and equipment selected and used for ERP drills and exercises.	Response procedures	ERPs, fixed fire systems, portable/mobile equipment, vehicle pumps and systems.	Actions required from ERPs.
1.4 Fire prevention	1. Monitor buildings means of escape and take appropriate action for deficiencies.	Emergency exits, emergency lighting, means of escape routes, fire enclosures, fire doors, door self-closers.	Building structure hardware, fire doors, door fire stops/seals, self-closures and final exit doors.	Effects of heat, smoke and poor visibility, means of escape regulations for buildings.
	2. Test building fire alarms according to schedule.	Smoke detection, manual alarm call points, building fire alarms.	Fire alarm call points, fire alarm panels, smoke generator.	Fire alarm testing procedures, use of manual fire alarm call points for tests, use of smoke detection for tests, use of smoke generator.
	3. Monitor building evacuation during drills and take appropriate actions for deficiencies.	Evacuation routes, fire warden reporting, assembly points, head counts.	Evacuation checklists, assembly checklists.	

Element	Performance criteria	Range	Equipment usage	Knowledge
1.4 Fire prevention continued	4. Monitor site facilities for housekeeping and take appropriate actions for deficiencies.	Clean and tidy facilities, safe storage of combustible and flammable substances, drip trays, ignition controls.	Fire prevention checklists.	Safe working procedures and practices, safe storage of flammable and combustible substances, sources of ignition and controls.

Table E.2: Unit 2 Maintenance

Element	Performance criteria	Range	Equipment usage	Knowledge
2.1 Inspect and test site portable/mobile fire equipment	Check equipment condition in accordance with manufacturers' instructions and procedures.	All portable and mobile fire and rescue equipment onsite.	Extinguishers, portable water/foam monitors, branches, foam inductors, fire hose, ancillary fire equipment, rescue equipment.	Equipment locations, manufacturers' recommended inspection procedures and methods, inspection frequency, recording procedures.
	Top-up, recharge, refill equipment in accordance with manufacturers' instructions and procedures.	Portable and mobile fire equipment.	Extinguisher gas cartridges, dry chemical, water, SCBA cylinders, foam drums, foam tanks, water tanks.	Required capacities, loads and levels of fire and rescue equipment, recording procedures.
	Service and clean equipment in accordance with manufacturers' instructions and procedures and take appropriate actions for deficiencies.	Portable and mobile fire equipment.	Extinguishers, portable water/foam monitors, branches, foam inductors, fire hose, ancillary fire equipment, rescue equipment.	Manufacturers' recommended servicing procedures and methods, recording procedures.
	Test, operate, run equipment in accordance with procedures and take appropriate actions for deficiencies.	Fire vehicles, vehicle fire and foam pumps, fire-fighting and rescue equipment.	Vehicle foam and water pumps, monitors, branches, foam inductors, fire hose, SCBA sets, ropes, harnesses, rescue equipment, stretchers, ancillary equipment.	Manufacturers' recommended testing and operating procedures and methods, recording procedures.
2.2 Inspect and test site fixed fire systems	Check equipment condition in accordance with manufacturers' instructions and procedures.	All fixed fire systems onsite.	Fixed fire and water monitors, foam/water hose reels, water deluge systems and rim seal foam system.	Manufacturers' recommended inspection procedures/methods, frequency, recording procedures.

Element	Performance criteria	Range	Equipment usage	Knowledge
2.2 Inspect and test site fixed fire system continued	Top-up, recharge, refill equipment in accordance with manufacturers' instructions and procedures.	Foam systems.	Rim seal foam system, foam drums at fixed monitors, foam tanks at foam hose reels.	Required capacities/levels, recording procedures.
	Service and clean equipment in accordance with manufacturers' instructions and procedures and take appropriate actions for deficiencies.	Fixed fire/water monitors.	Fixed fire and water monitors, foam/water hose reels, water deluge systems, rim seal foam system, foam drums at fixed monitors, foam tanks at foam hose reels.	Manufacturers' recommended servicing procedures and methods, recording procedures.
	Test, operate, run equipment in accordance with procedures and take appropriate actions for deficiencies.	Fixed equipment and systems. Foam/water monitors, fixed deluge systems, foam/water hose reels and rim seal foam systems.	Foam/water monitors, fixed deluge systems, foam/water hose reels and rim seal foam systems.	Manufacturers' recommended testing and operating procedures and methods, recording procedures.
2.3 Inspect and test site fire hydrants	Check condition in accordance with site or manufacturers' procedures.	All fire hydrants and isolation valves onsite.	Fire hydrant discharge outlets and their valves.	Manufacturers' or site recommended inspection procedures/methods, frequency, recording procedures.
	Service and clean equipment in accordance with site or manufacturers' procedures and take appropriate actions for deficiencies.	All fire hydrants and isolation valves onsite.	Fire hydrant discharge outlets and their valves.	Manufacturers' or site recommended servicing procedures and methods, recording procedures.
	Operate/flush hydrants in accordance with site procedures and take actions for deficiencies.	All fire hydrants and isolation valves onsite.	Fire hydrant discharge outlets and their valves.	Manufacturers' or site recommended testing and operating procedures and methods, recording procedures.

Table E.3: Unit 3 Procedures

Element	Performance Criteria	Range	Equipment usage	Knowledge
3.1 Execute assigned duties	1. Discharge daily routine duties.	ERT role, responsibilities, functions and duties.	Required vehicles and equipment according to test schedule.	ERT organisation, role within operations, routine duties, schedules, programmes.
3.2 Working safely	2. How to work safely.	Safety, health and environmental working methods, operations and practices.	Required equipment and tools according to work carried out.	Site safety procedures, use of PTWs, use of PPE for routine and emergency work.

Table E.4: Unit 4 Skills

Element	Performance criteria	Range	Equipment usage	Knowledge
4.1 Respond to emergencies	1. Alarms responded to in accordance with site procedures.	Site alarms, communications, evacuation routes, access roads.	Alarm response routines, role of ERT member, site emergency incident plan and evacuation plan.	Alarm response routines, role of ERT member, site emergency incident plan and evacuation plan.
	2. Identification of hazards and hazardous areas.	Crude oil, condensate and associated gas. LPG, refined products.	Site ERPs.	Site ERPs, fire chemistry, fire behaviour characteristics of crude oil, condensate and associated gas, wind direction and approach roads.
	3. Identification of potential or actual means of escalation.	Fire, explosion.	Site ERPs.	Site ERPs, BLEVE causes and effects, boilover causes and effects.
	4. Turnout gear worn in accordance with procedures.	Fire clothing, boots, helmet, gloves.	Use and limitations of turnout gear.	Use and limitations of turnout gear.
	5. SCBA worn if required.	BA.	Fitting, adjusting, wearing and controlling BA.	Fitting, adjusting, wearing and controlling BA.
	6. SCBA entry control procedures completed in accordance with procedures	SCBA entry control board, pre-entry checks.	Pre-entry checks, tally system and entry control procedures.	Pre-entry checks, tally system and entry control procedures.
4.2 Fixed systems and fire tender work in incident area	1. Fixed water/foam monitors or fixed deluge used to optimum effect to fight fire.	Fixed fire systems, monitors, hose reels.	Operating fixed water/foam monitors, making foam via monitors, operating deluge systems.	Monitor water/foam throughput, water deluge controls and locations. Selection of appropriate stream patterns.
	2. Fire hydrants used for fire tender water supply.	Fire-fighting water system capacity, water pressure, source.	Connecting to fire hydrants, fire tender pumps suction.	Site fire pumps' capacities, mains sizes, friction loss, head/pressure, mains isolation valves.
	3. Fire tenders used to supply foam or water or both for fire-fighting.	Fire vehicles' on-board systems, extinguishing agent capacities.	Fire tender water and foam pumps' pressure and flow control, foam proportioning system, dry chemical system.	Power take off (PTO) engagement, centrifugal and gear pump operating principles, pressure relief equipment and methods.
	4. Effectiveness of fixed fire systems monitored and corrective actions taken to optimise fire control.	Water and foam streams, water deluge coverage.	Operating fixed water/foam monitors, making foam via monitors, operating deluge systems.	Determining water cooling efficiency and/or foam blanket efficiency. Limitations of fire-fighting foams.

Element	Performance criteria	Range	Equipment usage	Knowledge
4.3 Carry out fire-fighting or incident control operations	1. Appropriate portable and mobile fire-fighting equipment used according to the incident type and location.	Hoses, water and foam branches, stream patterns, dry chemical, water and CO_2 extinguisher ranges.	Running out hoses, adding hose lengths, removing hose lengths, replacing hose lengths, branch connections, foam/water branch streams/patterns control, producing foam via foam inductors and foam branch, operating extinguishers.	Use and limitations of portable equipment, types of foam concentrate, foam proportioning methods, water and foam application techniques and equipment usage. Use and limitations of water, dry chemical and CO_2 extinguishers.
	2. Effectiveness of portable and mobile equipment water/ foam streams monitored and corrective actions taken to optimise fire or emergency incident control.	Water and foam streams, foam application, foam blanketing.	Foam/water branch streams and patterns control.	Determining water cooling efficiency and/or foam blanket efficiency. Limitations of fire-fighting foams.
	3. Escape routes and exits maintained for duration of incident.	Fire-fighter personnel safe emergency routes away from incident area.		Choosing safe evacuation and escape routes under emergency conditions.
4.4 Rescue personnel	1. Missing personnel confirmed by appropriate people.	Evacuation plan and procedures.		Evacuation plan and procedures.
	2. Missing personnel are found using appropriate search methods and procedures.	Search and rescue procedures.	SCBA, entry control equipment.	Search techniques and methods.
	3. Trapped personnel are extricated or released as a matter of urgency.	Rescue equipment, stretchers.		Considerations to be taken into account when extricating personnel. Choosing appropriate equipment, knots and ropes. Selecting appropriate first-aid treatment for casualties.
	4. Casualties are prioritised and treated in an appropriate manner in accordance with procedures.	Airway breathing and circulation, resuscitation, establish breathing, cardiac massage, stop bleeding, correct positioning, reassurance and comfort.	Body harness, quadpod and winch system, stretcher, karabiners, rescue ropes with loops rescue ropes for general-purpose work.	

Element	Performance criteria	Range	Equipment usage	Knowledge
4.4 Rescue personnel continued	5. Casualties removed to safe location using appropriate equipment and handling methods and procedures.	Casualty movement, casualty handling.	Stretchers.	Casualty condition considerations when handling/moving.
4.5 Reinstate resources	1. Response equipment serviced and cleaned.	Fixed systems and equipment, portable and mobile equipment.	Fixed systems, monitors, hose reels, valves and actuation devices, portable fire-fighting equipment, fire tenders.	Cleaning materials and methods, foam flushing procedures, foam drums refilling/replacement methods and procedures.
	2. Resources, stocks, agents replenished.	Response equipment, extinguishing agents, fuel, breathing air.	Replacement foam concentrate, dry powder, water, CO_2 agents, SCBA air cylinders, fire hose, rescue equipment, fire vehicle fuels and lubricants.	Required stock and agents levels, types and capacities of extinguishers, fire vehicle equipment levels, and fuel and lubricant levels.
4.6 Training and instruction	1. Fire training facility in safe condition and ready for use.	Free from tripping hazards, product spill, hydrants in order, hose extinguishers, branches ready.	Checking fuels, valves, PPE, extinguishers, hose reels, monitors for training use.	Fuel control, safe storage of flammables, hardware requirements.
	2. Delivery of training on raising alarm and use of first-aid fire-fighting equipment for company employees.	Emergency reporting, chemistry of fire, classification of extinguishers, use of extinguishers and hose reels on live fires.	Instruction on running out hoses, adding hose lengths, removing hose lengths, replacing hose lengths, branch connections, foam/water branch streams and patterns control, producing foam via foam inductors and foam branch, operating extinguishers.	Use of instruction techniques, use of audio and visual equipment, training session aims and objectives.

ANNEX F

CLASSIFICATION OF FIRES

F.1 INTRODUCTION

This annex details the European basis of classifying fires based on BS EN 2. Annex F.7 reviews the NFPA system.

F.2 CLASS A – FIRES INVOLVING SOLID MATERIALS

Class A fires are those involving solid materials, usually of an organic nature, in which combustion normally takes place with the formation of glowing embers.

The most effective extinguishing medium for most of these fires is water, in the form of a jet or a spray; this is effective in extinguishing glowing material. Powders or foam may also be used in appropriate circumstances, for example where access is difficult, but these media may be less effective in extinguishing glowing material in preventing re-ignition. Halons are being phased out for environmental reasons. CO_2 is not recommended for Class A fires.

F.3 CLASS B – FIRES INVOLVING LIQUIDS OR LIQUEFIABLE SOLIDS

Selection of an effective extinguishing medium for Class B fires involving liquids or liquefiable solids depends on whether the burning substance is miscible with water or not. Suitable extinguishing media include foam, powder, CO_2 and water spray. Medium or high expansion foams may be used on both types of liquids, but MP (i.e. AR) foam is necessary if foam is to be used on a miscible or semi-miscible liquid. Water sprays can be used for extinguishing fires of non-miscible liquids with a flash point above 66 °C, or fires of miscible liquids of any flash point.

Note: Fires involving liquids or molten solids are particularly prone to frothing if water is present. This gives rise to froth-over or boilover which can be particularly hazardous to fire-fighters.

F.4 CLASS C – FIRES INVOLVING GASES

The most effective method of extinguishing Class C fires involving gases is to cut off the supply. If the flames are extinguished, but the gas continues to flow, there is a possibility of the build-up of a large volume of gas-air mixture, which could cause a serious explosion if ignited.

Burning gas jets may be deflected and their effects mitigated by the appropriate use of water jets.

F.5 CLASS D – FIRES INVOLVING METALS

Class D fires are those involving burning metals such as magnesium, titanium, sodium, potassium, calcium and uranium. One example is a fire in a packed column at a petroleum refinery. The usual extinguishing agents are ineffective and may be dangerous to use. Special materials and techniques are necessary, and prior planning is essential.

F.6 CLASS E – FIRES INVOLVING ELECTRICAL EQUIPMENT

Class E fires are those involving electrical equipment. The use of water and foam media can result in electric shock from the electrical equipment. This is due to water or aqueous foam solution being conductive and allowing current to either pass up the discharge stream to the operator, or via wetted surfaces such as the floor as the operator passes over them. Suitable CO_2, 'clean agent' (gaseous) or specialist powder extinguishers should be used instead, since the risk of electric shock is reduced.

Recently, some water-based extinguishers have been 'approved' for use near electrical equipment. Such extinguishers should meet the requirements of a dielectric test such as that given in BS EN 3-7. However, they should not be used directly on electrical hazards.

The first action to be performed when confronted by a fire involving electrical equipment is to isolate the electrical supply to the affected item, and any others that could be affected.

F.7 CLASS F – FIRES INVOLVING COOKING OILS

The Class F designation is relatively new, and encompasses fires involving cooking fats or oils. One area of application is in kitchen areas. Cooking oil fires, because of their low ignition temperatures are difficult to extinguish. Water based extinguishers are not effective for cooking oil fires, as they do not cool sufficiently or may even cause burning oil to be ejected as water expands to steam at the base of the oil layer, putting the operator at risk. Dedicated Class F extinguishers should be used for these fires.

Good housekeeping, including regular cleaning of cooking equipment and ducting to remove deposits, can reduce the probability of such fires. Also, fire consequences can be minimised by the provision and use of approved fire blankets.

F.8 OTHER CLASSIFICATION SCHEMES

Certain countries have adopted a different classification scheme. For example, the following is based on the NFPA (USA) approach:

- Class A: Fires in ordinary combustible materials, such as wood, cloth, paper, rubber, and many plastics.
- Class B: Fires in flammable liquids, combustible liquids, petroleum greases, tars, oils, oil-based paints, solvents, lacquers, alcohols, and flammable gases.
- Class C: Fires that involve energised electrical equipment where the electrical nonconductivity of the extinguishing media is of importance. (When electrical equipment is de-energised, fire extinguishers for Class A or Class B fires can be used safely.)
- Class D: Fires in combustible metals, such as magnesium, titanium, zirconium, sodium, lithium, and potassium.
- Class K: Fires in cooking appliances that involve combustible cooking media (vegetable or animal oils and fats).

ANNEX G

EXAMPLE SITE-SPECIFIC EMERGENCY RESPONSE PLAN

G.1 INTRODUCTION

This annex provides an example site-specific ERP. Forming two back-to-back pages, it comprises a text aspect with several phases of response (see Table G.1) and an example fire map, which includes effects contours (see Figure G.1). An example scenario worksheet is provided (see Box G.1), which includes equipment and resources in support of the ERP. In addition, some benchmark radiant heat levels and their effects are provided.

G.2 EXPLANATORY NOTES TO TEXT ASPECT OF SITE-SPECIFIC ERP

The ERP is divided into key sections, or panels, as shown in Table G.1.

(i) 'Strategy' heading
The 'Strategy' heading should be a broad series of statements intended as guidance on what actions should be taken during the first 15-20 min. to either minimise or control the consequences from an incident.

The strategy is taken from the incident scenario worksheets, which are also used to determine for the incident numbers of fire vehicles and other mobile equipment, fire-fighting water flows, fire systems applications, water and foam monitors, hose, foam concentrate and staffing, etc.

It should be recognised that it will not always be possible or desirable to list every action necessary for successful control or elimination of any incident. Therefore, the responders, using dynamic risk assessment (see section 8.9.2), may determine at any time that a change in strategy or tactics is required due to changing conditions or circumstances.

(ii) 'Immediately' heading
The 'Immediately' heading is intended for the immediate personnel to carry out initial procedures identified in the emergency procedures such as personnel alerting, evacuation and assessment related tasks, together with the equipment and resources required unless these are obvious.

(iii) '2nd response' heading
The '2nd response' heading is intended primarily for an occupational fire brigade (if any), although further operator actions may also be listed. The text here should usually set out the tactics/actions for minimising escalation potential or controlling or extinguishing the incident, together with the minimum equipment and resources necessary to do so.

(iv) '3rd response' heading
A '3rd response' heading may also be included; this is intended primarily for the FRS or other 3rd party response group. 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.

Recognising that escalation can occur or may occur very early into the incident, the ERPs should make reference to other plans that may be used when or if this happens. Responders should be reminded in the ERP of the existence of such plans, thus ensuring a rapid and early provision of such documents.

(v) 'Ongoing potential hazards' heading

The 'Ongoing potential hazards' heading may be 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, explosion potential, escalation hazards, gas migration hazards, etc.

(vi) 'Other issues' heading

The 'Other issues' heading contains information on any other identified issues such as offsite considerations, incident control cautions, resource issues or other incident-specific concerns which have been noted during the course of the incident scenario evaluation work. This assists responders by prompting early consideration or an early decision without having to wait for, or seek, information.

(vii) 'Equipment and resources' headings

A scenario analysis of credible major incidents should be carried out for the petroleum installation. This analysis should include the likely resources required to deal with the incident in terms of fire vehicles, fire hose, staffing, water and foam monitors, foam concentrate quantities, etc. Resources stated on ERPs should be the minimum required and should be agreed with responders. This analysis may lead to identification of equipment or resource shortfalls not previously noted.

A typical scenario worksheet is shown in Figure G.2 and indicates the levels of analysis that may be used in developing the ERPs.

Table G.1: Example text aspect of site-specific ERP

Emergency response plan for	Description of the type of fire or emergency anticipated			
Strategy	The fire control (fire-fighting) strategy which states the overall objectives to prevent escalation and bring the incident under control			
Immediately	**Actions**	**Equipment**	**Resources**	**Comments**
Usually control room or site personnel who will alert, shutdown and evacuate etc.	Logical step-by-step actions which are required according to the fire type and location. Typically, alarm, evacuation, isolation, shut down, informing etc.	What equipment required to carry out the actions. Valves or devices to isolate.	Any specific resources not previously mentioned or personnel who will need to react immediately.	As required.
1st response	**Actions**	**Equipment**	**Resources**	**Comments**
May be site personnel who will use portable fire equipment or fixed fire systems. If no personnel available for this, the 1st response would be occupational fire brigade.	Logical step-by-step actions necessary to isolate the fuel, or carry out initial fire control actions.	Valves or devices to isolate. Fixed fire systems installed onsite. Portable fire equipment for initial control. Any water or foam monitors required.	Any foam concentrate required. The anticipated water demand for the fire. Fire hose/nozzles required. The number of hose will be based on the hydrant locations and fire vehicles used. The fire vehicles from the FRS and their personnel.	As required.
2nd response	**Actions**	**Equipment**	**Resources**	**Comments**
Usually the supporting fire group or FRS. Site personnel may be required to do other tasks at this stage.	Logical step-by-step actions necessary to control and extinguish the fire.	Fixed fire systems installed onsite. Any water /foam monitors required.	Any foam concentrate required. The anticipated water demand for the fire. The fire vehicles from the FRS and their personnel.	Foam applied at pertinent application rate etc.
Ongoing potential hazards Any known hazards that will be present because of the anticipated fire either from flame impingement or radiated or conducted heat. Also consider any explosion possibility.				
Other issues Any other issues, e.g. personnel safety, gas releases, public exposure etc.				

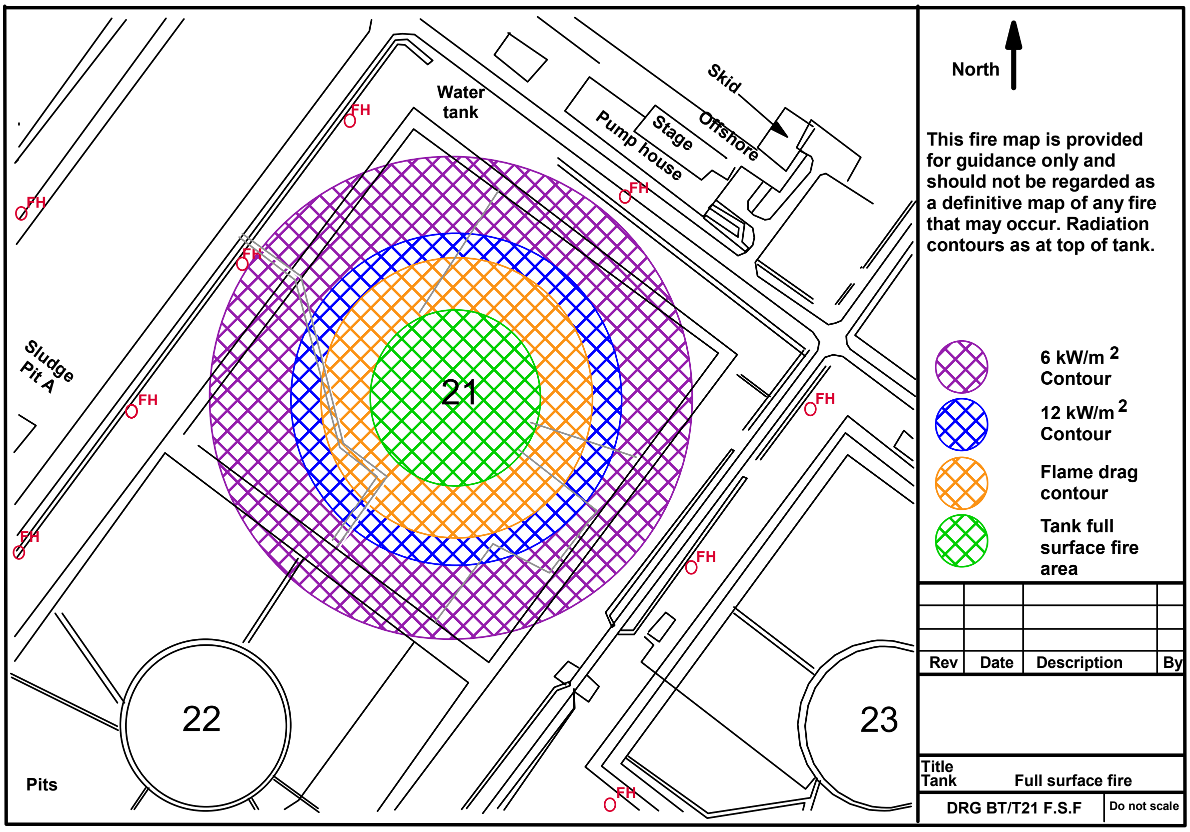

Figure G.1: Example fire map aspect of site-specific ERP

Scenario Worksheet 1

SCENARIO

CONSEQUENCES

Immediate
Life safety
Environment
Business interruption
Asset loss
Escalation time estimates
Post escalation
Life safety
Environment
Business interruption/deferment
Reputation

EXISTING FEHM

Detection
Process control
Mitigation
Containment
Drainage
Passive protection
Active protection
Fixed systems

FIRE FIGHTING STRATEGY

FIRE FIGHTING TACTICS

Scenario Worksheet 2

RESOURCES FOR STRATEGY

Non-response group resources

Detection
Process
Fire and gas
Alarm system
Response group
Passive protection
Active protection
Firewater flow (fixed systems)
Drainage
Containment

Fire response group resources

Procedures
Vehicles
Staffing
Hose
Monitors
Special equipment
Extinguishing agent
Firewater flow (portable equipment)
Total firewater flow
Total water quantity

Figure G.2: Example scenario worksheets

G.3 EFFECTS MAPS

Various effects contours may be used in effects maps but the most widely used and informative are:

— Pool fire or jet fire extent, whereby the radiant heat would be in the initial order of 200-300 kW/m^2.
— Radiant heat contour emanating from the jet/pool area down to 12 kW/m^2.
— Radiant heat contour of 6,3 kW/m^2 lessening from the edge of the 12 kW/m^2 contour down to 6,3 kW/m^2.
— BLEVE/fireball extent where the fireball area is in the order of 200-300 kW/m^2.
— Gas cloud extent to LFL/UFL.

It should be recognised that radiant heat levels and extent may be affected by wind as well as obstructions. Also, flames may drag or be deflected towards ground level downwind of the fire. Clearly, any effects map should include this possibility, but the actual effects can only be assessed at the time of an incident. For this reason, effects maps should be used as guidance only.

G.4 RADIANT HEAT EXAMPLES

The following indicates radiant heat levels and their effects:

1-1,5 kW/m^2	=	Sunburn
6-3 kW/m^2	=	Personnel injury (burns) if normal clothing worn and fast escape not possible.
8-12 kW/m^2	=	For example, escalation through ignition of other product surfaces if long exposure times without protection.
200-300 kW/m^2	=	Within the flame of a pool or jet fire. Steel structures can fail within several minutes if there is no cooling or other protection.

It may be necessary to use proprietary fire consequences modelling software programmes to assist with this aspect of the ERPs.

ANNEX H

GLOSSARY OF TERMS AND ABBREVIATIONS

H.1 INTRODUCTION

For the purpose of this publication, the interpretations for terms in H.2 and abbreviations in H.3 apply, irrespective of the meaning they may have in other connections.

H.2 GLOSSARY OF TERMS

active fire protection: fire protection systems designed to control or extinguish fires, to provide cooling to heat affected plant (and prevent fire escalation), or to prevent ignition by applying fire-fighting media such as water, foam, dry powder (dry chemical) or gaseous agents. See *passive fire protection* and *fire-fighting media*.

application rate [foam]: the rate at which foam solution is applied to a fire, expressed as litres per minute, per square metre (l/min./m^2). See *foam solution*.

application rate [water]: the rate at which water is applied for the purposes of exposure protection (cooling), expressed as litres per minute, per square metre of exposed area (l/min./m^2).

area classification: the notional division of an installation into hazardous areas and non-hazardous areas, and the subdivision of hazardous areas into zones. See *hazardous area* and *non-hazardous area*.

as low as reasonably practicable (ALARP): a level of risk which is tolerable compared to cost, effort and time needed to further reduce it. CBA may be used in ALARP decision making: See *risk* and *cost-benefit analysis (CBA)*.

atmosphere explosiv: See *explosive atmospheres directives*.

atmospheric monitoring: the use of portable or fixed flammable gas detection equipment to give advance warning of a developing flammable or toxic hazard. See *gas detector*.

autoignition temperature: see *ignition temperature*.

boilover: a major fire scenario that can occur within a prolonged fire in tanks containing crude oil or certain fuel oils. The consequences include a major spreading of the fire with fall-out of burning liquid over the surrounding area.

breathing apparatus (BA): PPE that ensures that the wearer has a continuously available supply of uncontaminated air through a face mask, helmet or mouthpiece. BA comprises canister, oxygen and SCBA types. See *personal protective equipment (PPE)* and *self-contained breathing apparatus (SCBA)*.

bund: secondary containment in the form of a compound around the primary containment, which includes a bund wall, embankment, or barrier. See *secondary containment*, *primary containment* and *bund wall*.

bund wall: a wall of appropriate height and size forming part of a bund, constructed of suitable materials and designed to retain fire-fighting media or petroleum and its products that have lost containment from primary containment. See *bund* and *fire-fighting media*.

catalytic gas detector: flammable gas detection using a sensor that responds to a potentially flammable atmosphere by heating up and altering the resistance of a platinum coil. See *gas detector* and *flammable atmosphere*.

catenary foam system: a foam system for open-top floating roof petroleum storage tanks in which foam is applied through a ring of pipework on the tank roof. At equal intervals around the ring there are foam makers discharging foam into the rim seal area. See *foam*.

classification of fires: system of assigning fires to classes based on properties such as the type of fuel (e.g. by its physical and chemical properties) or the type of item that warrants protection (e.g. electrical equipment). The system can be used to select fire-fighting media. See *fire-fighting media*.

classification of petroleum: system of IP classification of petroleum and its products into Classes 0, I, II(1), II(2), III(1), III(2) and Unclassified based upon their flash points. See *IP* and *flash point*.

Coflexip foam system: a foam system for open-top floating roof petroleum storage tanks in which foam is applied through a 'spider' network of pipes to the rim seal area. The foam first travels through a special flexible pipe of the type used for roof drains, situated inside the tank. See *foam*.

cold work: the carrying out of any task, or the use of any tool or equipment that will not produce a source of ignition in a flammable atmosphere. It includes the use of tools for erection, dismantling and cleaning, which are not liable to produce sparks, and operations such as drilling, tapping and cutting carried out in such a way as to limit the heat produced and keep the temperature of the tools and work below the level at which ignition of a flammable atmosphere could occur (typically 100 °C). See *source of ignition*, *flammable atmosphere* and *hot work*.

combustible: a substance not falling into the flammable classification as such, but capable of self-sustained burning in air, once ignited. See *flammable*.

competency development: ensuring personnel have the necessary skills to work safely and contribute to continuing safety.

competent authority (CA): body or bodies responsible for enforcing health, safety and environmental legislation. See *environment agencies* and *Health and Safety Executive (HSE)*.

concentration: the percentage of foam concentrate contained in a foam solution. For example, a 3% foam concentrate is mixed in the ratio of 3 parts foam concentrate and 97 parts water to make foam solution. See *foam concentrate* and *foam solution*.

control of sources of ignition: practices and procedures necessary in order to prevent accidental ignition of petroleum and its products. See *source of ignition*.

cost-benefit analysis (CBA), process of determining the cost of a control against the risk reduction benefits that it provides. CBA may be used in ALARP decision making. See *as low as reasonably practicable (ALARP)*.

credible scenario: scenarios that represent the most significant consequences to personnel, business and the environment. See *fire scenario analysis* and *design event*.

critical application rate: the minimum application rate at which foam solution extinguishes a given fire. See *application rate [foam]* and *foam solution.*

design event: credible scenarios that are selected from risk assessments as meriting further risk reduction measures/options because of their probability or consequences. See *credible scenario* and *risk reduction measures/option*.

drainage time: a measure of foam quality, which is the rate at which water drains from foam. A high drainage time demonstrates foam's ability to maintain its heat-resisting and stability properties. See *foam quality* and *foam*.

dry powder (dry chemical): a fire-fighting medium which inhibits the combustion process. See *fire-fighting media*.

earthing: the provision of a safe path of electrical current to ground, in order to protect structures, plant and equipment from the effects of stray electrical currents and electrostatic discharge. See *static electricity*.

emergency response plan (ERP): a pre-fire plan designed to assist operators and fire responders in the early stages of a petroleum fire incident by listing actions, resources required and continuing potential hazard information. See *pre-fire plan* and *hazard*.

emergency response team (ERT): an occupational fire brigade employed or contracted to implement fire safety ERPs and to take initial action to protect property using fire-fighting equipment. Its service capability is less than a petroleum fire brigade. See *occupational fire brigade*, *emergency response plan (ERP)* and *petroleum fire brigade*.

emergency shutdown (ESD) time: time taken to shut down/depressurise fire affected plant.

environment agencies: government sponsored bodies responsible for enforcing environmental protection regulations in the UK at most installations subject to the requirements of this publication. They comprise the Environment Agency (EA) in England and Wales (http://www.environment-agency.gov.uk), the Scottish Environment Protection Agency (SEPA) in Scotland (http://www.sepa.org.uk) and the Northern Ireland Environment and Heritage Service (EHSNI) in Northern Ireland (http://www.ehsni.gov.uk). See *competent authority (CA)*.

expansion ratio: a measure of foam quality which is the ratio of final foam volume to original foam solution volume. See *foam quality*, *foam* and *foam solution*.

explosive atmospheres directives: ATEX 100a (ATEX Equipment Directive) (94/9/EC) Approximation of the Laws of Member States concerning Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres and ATEX 137 (ATEX Workplace Directive) (99/92/EC) Minimum Requirements for Improving the Health and Safety of Workers Potentially at Risk from Explosive Atmospheres.

exposure protection: protection of plant, equipment and personnel against the damaging effects of thermal flux. See *thermal flux*.

FEHM policy: a site-specific, optimum, cost-effective incident consequence reduction strategy which takes into account local conditions, the installation's criticality and an incident's potential effect on life safety, the environment, asset value, continued operations and company reputation. See *fire and explosion hazard management (FEHM)*.

fire alarm: visual and/or audible alarm of a fire or developing fire when sensed by fire detection equipment, either locally, or at a remote staffed location. See *fire detection*.

fire and explosion hazard management (FEHM): an auditable, integrated approach to risk reduction by the provision of prevention and consequence reduction measures appropriate to the levels of risk. See *FEHM policy*.

[local government] Fire and Rescue Service (FRS): a fire response group funded by a statutory fire authority under the auspices of local government. See *occupational fire brigade*.

fire detection: equipment used to warn of a fire by sensing fire phenomena such as heat, smoke, flame radiation or incipient combustion gases. Fire detection can give a local, remote or site-wide fire alarm. See *heat detection*, *incipient detection* and *smoke detection*.

fire-fighting media: Agents such as water, foam, dry powder (dry chemical) and inert gases used to prevent, control or extinguish fires. See *foam*, *dry powder (dry chemical)* and *gaseous agent*.

fire resistant treated [PPE]: materials used in certain types of PPE that offer fire resistance through modification of their normal physical properties, usually by the application of special chemicals and/or treatments designed to resist fire. See *personal protective equipment (PPE)* and *inherently fire resistant [PPE]*.

fire safe valve: a valve for petroleum service that will withstand a fire and provide a degree of isolation that is acceptable under specified fire conditions. See *isolation*.

fire scenario analysis: the process of identifying credible fire scenarios (in terms of incident probability and consequences) at an installation. See *credible scenario*.

fire systems integrity assurance (FSIA): a structured approach aimed at ensuring the implementation of test, inspection and maintenance procedures for fire systems.

fixed system: a fire protection system designed to work with minimal or no personnel intervention. See *semi-fixed system*.

flame detection: fire detection designed to sense fires by sensing infrared (IR), ultraviolet (UV) or a combination of UV/IR radiation emitted by fires, and generate a fire alarm. See *fire detection* and *fire alarm*.

flammable (synonymous with inflammable): a combustible substance (solid, liquid, gas or vapour), which is easily ignited in air. The term non-flammable refers to substances that are not easily ignited but does not necessarily indicate that they are non-combustible. See *combustible*.

flammable atmosphere: a mixture of flammable gas or vapour with air in such proportion that, without any further addition of gas or air, it will burn when ignited.

flammable gas detector: see *gas detector*.

flammable gas dispersion: reducing the concentration of any flammable gas to below the LFL as quickly as possible and within the shortest distance from the release source. See *flammable*, *lower flammable limit (LFL)* and *release*.

flammable limits: the limits of combustibility of flammable vapours when mixed with air. See *lower flammable limit (LFL)* and *upper flammable limit (UFL)*.

flash point: the lowest temperature, corrected to a barometric pressure of 101,3 kPa, at which the application of a source of ignition in a prescribed manner causes the vapour of a test portion to ignite and the flame propagates across the surface of the test sample under the specified test conditions. See *source of ignition*.

foam: a fire-fighting medium made by mixing air and foam solution using suitably designed equipment; it can be aspirated or non-aspirated. It flows freely over a burning flammable liquid surface and forms a tough fire and heat resistant, vapour-suppressing blanket that floats on the product surface thus cutting off the product from the flame. See *fire-fighting media* and *foam solution*.

foam concentrate: concentrated liquid as received from the supplier used to make foam solution. See *foam solution*.

foam pourer: a discharge device designed to apply foam gently onto a flammable liquid (e.g. in the case of a fixed foam system for rim seal foam application on a petroleum storage tank). See *foam*.

foam quality: foam parameters such as expansion ratio and drainage time which, when measured, indicate foam's properties such as flowability and heat resistance. See *expansion ratio* and *drainage time.*

foam solution: a mixture of water and foam concentrate in the correct proportions (e.g. 3 parts foam concentrate to 97 parts water). See *foam concentrate* and *foam*.

foam sprinkler/spray system: a conventional sprinkler system supplemented with foam for the protection of flammable liquid installations, such as road tanker vehicle and rail wagon tank loading gantries, horizontal product storage tanks, pump rooms, flammable liquid warehouses and process units. See *sprinkler system*.

gas detector (synonymous with flammable gas detector): an instrument, fixed or portable, designed to detect and measure the presence and concentration of flammable gas/vapour/mist/spray in an area. Note that other types of gas detector exist (e.g. to measure the oxygen content or the presence of specific toxic substances (e.g. H_2S)). See *flammable*, *catalytic gas detector*, *infrared (IR) gas detector*, *open-path gas detector*, *perimeter monitoring* and *point gas detector*.

gaseous agent: CO_2, chemical halon replacements and other proprietary inert gases used for extinguishing fires (e.g. in areas such as turbine enclosures). They work either by reducing oxygen concentration to a point below which combustion cannot be supported, by terminating combustion reactions, or a by combination of both mechanisms.

gaseous system: a fixed fire protection system using a gaseous agent. See *gaseous agent*.

halogenated alkane: see *halon*.

halon (synonymous with halogenated alkane): a group of chemical compounds based on alkanes where one or more hydrogen atoms have been replaced by halogen atoms. They have been used as fire-fighting media but have detrimental effects on the environment, such as ozone depletion. See *fire-fighting media*.

hazard: the potential for human injury or adverse health, damage to property, business interruption or environmental impact. See *risk*.

hazardous area: a three-dimensional space in which a flammable atmosphere is or may be expected to be present at such a frequency that special precautions are required with potential sources of ignition within it, such as electrical and non-electrical apparatus or hot work. Note, in this context the term does not refer to the possibility of that atmosphere also being toxic, oxygen deficient or radioactive. A hazardous area may be part of a wider ignition source control area. See *flammable atmosphere*, *source of ignition*, *hot work*, *hazardous area*, *toxicity* and *ignition source control area*.

Health and Safety Executive (HSE): government sponsored body responsible for implementing health and safety regulations in the UK at most installations subject to the requirements of this publication. http://www.hse.gov.uk. See *competent authority (CA)*.

heat detection: fire detection designed to respond to temperature increases associated with developing fires and generate a fire alarm. See *fire detection* and *linear heat detection (LHD)*.

hot work: the carrying out of any task, or the use of any tool or equipment that might produce a source of ignition in a flammable atmosphere. This typically includes welding, the use of any flame or electric arc, any equipment likely to cause heat, flame or spark, such as drilling, caulking, chipping, riveting, grinding, and any other such heat-producing operation unless it is carried out in such a way as to keep the temperature below the level at which ignition of a flammable atmosphere could occur (typically 100 °C). See *source of ignition*, *flammable atmosphere* and *cold work*.

ignition source: see *source of ignition*.

ignition source control area: a general area that may contain several hazardous areas and some non-hazardous areas in which hot work is controlled by a PTW. See *hazardous area*, *non-hazardous area, hot work* and *permit-to-work (PTW)*.

ignition temperature (synonymous with spontaneous ignition temperature and autoignition temperature): the temperature at which a petroleum substance will burn without application of a source of ignition. See *petroleum substance* and *source of ignition*.

impounding basin: a form of secondary containment where lost product is temporarily collected at a convenient, safe location. See *secondary containment*.

incandescence: self-heating. See *pyrophoric scale*.

incident preplan: a high-level plan setting out emergency preparedness arrangements for major fire incidents. It is supported by a series of pre-fire plans. See *pre-fire plan*.

incipient detection: Fire detection designed to give the earliest possible warning of a fire and generate a fire alarm, by sensing minute quantities of smoke or combustion gases such as CO and CO_2 in the early stages of a fire. See *fire detection*, *fire alarm* and *smoke detection*.

individual risk: risk to personnel. See *risk* and *societal risk*.

inflammable: see *flammable*.

infrared (IR) gas detector: Flammable gas detector designed to work on the principle that gases absorb infrared energy at certain wavelengths. See *gas detector*.

inherently fire resistant [PPE]: materials used in certain types of PPE that offer fire resistance without modification of their normal physical properties. See *personal protective equipment (PPE)* and *fire resistant treated [PPE]*.

interceptor: see *oil/water separator*.

intermediate bulk container (IBC): usually a high-density cross-linked polyethylene container, with typical volume 1 000 l, used for storage of liquids, including flammable liquids and fire-fighting foam. They usually have a valve or tap at the base.

IP: formerly The Institute of Petroleum; the successor body being the Energy Institute. The term is used for numbered publications, e.g. IP 34, and for classifying petroleum and its products. See *classification of petroleum*.

isolation: means to reduce the amount of fuel involved in a loss of containment, such as by plant isolation or depressurisation. This will reduce the probability of a large fire but will also reduce fire duration and consequences in the event of ignition. See *loss of containment*.

jet fire: a stable jet of flame produced on ignition of a high velocity loss of containment, usually pressurised gas or flammable liquid spray. See *loss of containment*.

l/min./m^2: units of litres per minute, per square metre are typically used for water and foam application rates. See *application rate [water]* and *application rate [foam]*.

large atmospheric storage tank fires (LASTFIRE) project: a joint petroleum industry project examining the fire risks associated with large diameter atmospheric petroleum storage tanks.

linear heat detection (LHD): electrical, pneumatic or optical heat detection cabling designed to initiate a fire alarm when sensing heat from fires. See *heat detection* and *fire alarm*.

liquefied natural gas (LNG): liquid form of natural gas, consisting primarily of methane, with low concentrations of other hydrocarbons and water, CO_2, nitrogen, oxygen and sulphur.

liquefied petroleum gas (LPG): light hydrocarbons, which at normal atmospheric temperature and pressure exist as gases, but which are readily liquefied by the application of moderate pressure. They may be stored and handled as liquids under pressure at ambient temperature or as refrigerated liquids at substantially atmospheric pressure. The term LPG includes commercial butane, commercial propane and their mixtures.

loss of containment (synonymous with release): loss of product, usually in the form of a gas, liquid, mist or spray, from a process vessel, pipework, storage, bund, etc. See *bund*.

lower explosive limit (LEL): see *lower flammable limit (LFL)*.

lower flammable limit (LFL) (synonymous with lower explosive limit (LEL).): the lowest concentration of flammable gas or vapour in air at atmospheric pressure capable of being ignited, expressed as percentage by volume. The term LFL is preferred to LEL. See *flammable*, *flammable limits* and *upper flammable limit (UFL)*.

major accident prevention policy (MAPP): documentation, usually required by a CA under the COMAH Regulations to demonstrate hazard identification, operational controls, emergency planning and other organisational arrangements such as monitoring and assessment are in place at certain smaller petroleum installations. At larger installations, a safety report may be needed. See *competent authority (CA)* and *safety report*.

mobile fire-fighting equipment: fire-fighting equipment generally larger than portable fire-fighting equipment but which is nevertheless designed for effective deployment by small numbers of fire responders at a fire incident. It typically includes mobile foam units or medium sized monitors. See *portable fire-fighting equipment* and *monitor*.

monitor: a portable, mobile or fixed cannon designed to project water, foam, or both, for fire protection purposes. See *portable fire-fighting equipment, mobile fire-fighting equipment*, *fixed system* and *foam*.

non-hazardous area: a three-dimensional space in which a flammable atmosphere is not expected to be present so that special precautions are not required with potential sources of ignition within it, such as electrical and non-electrical apparatus or hot work. Note, in this context the term does not refer to the possibility of that atmosphere also being toxic, oxygen deficient or radioactive. A non-hazardous area may be part of a wider ignition source control area. See *flammable atmosphere*, *source of ignition*, *hot work*, *hazardous area*, *toxicity* and *ignition source control area*.

occupational fire brigade: a fire response group, which unlike the FRS is not funded by a statutory fire authority. It exists to save life and protect property from fire or other emergency in locations owned, managed or occupied by the sponsor. It may be employed by the sponsor or contracted from an external competent organisation. It may operate as a full- or part-time (auxiliary) petroleum fire brigade or a more limited service ERT. See *Fire and Rescue Service (FRS)*, *petroleum fire brigade* and *emergency response team (ERT)*.

oil/water separator (synonymous with interceptor): an installation to remove oil from oily water effluent.

open-path gas detector: gas detector designed to indicate a potentially flammable atmosphere by monitoring large open areas for flammable gases. See *gas detector, flammable atmosphere* and *point gas detector*.

passive fire protection (PFP): fire protection systems designed to reduce vulnerability to fire and heat by treating process plant, structures or vessels (or within buildings) with materials that limit temperature and prevent excessive heat absorption. See *active fire protection*.

perfluorooctane sulfonates (PFOS): substances used in some AFFFs whose usage may be restricted by emerging legislative and regulatory moves.

perimeter monitoring: open-path gas detectors used, for example, around a liquefied gas storage area, to supplement point detection. See *gas detector*, *open-path gas detector* and *point gas detector*.

permit-to-work (PTW): a document (whether paper or electronic) issued by an authorised person or persons permitting specific work to be carried out in a defined area during a stated period of time, provided that specified safety precautions are taken.

personal protective equipment (PPE): clothing, head protection, footwear, etc. designed to offer protection against toxicity, fire and other potential hazards, provided, where required by a task risk assessment, to employees by employers to prevent or reduce exposure. See *inherently fire resistant [PPE]*, *fire resistant treated [PPE]* and *turnout gear*.

petroleum class: see *classification of petroleum*.

petroleum fire brigade: an occupational fire brigade with specialist petroleum fire-fighting capability. Its service capability is more than an ERT. See *occupational fire brigade and emergency response team (ERT)*.

petroleum substance: a substance extracted with, or derived from, crude oil, e.g. by refining.

point gas detector: flammable gas detector designed to indicate a potentially flammable atmosphere at a specific plant location. See *gas detector*, *flammable atmosphere* and *open-path gas detector*.

pool fire: a fire involving flammable liquid with very little or no initial momentum, usually a result of an ignited loss of containment of petroleum, which is either contained or lies in a static pool.

portable fire-fighting equipment: fire-fighting equipment designed for simple, effective operation by one or two persons such as a fire extinguisher, portable monitor, foam hose line etc. See *mobile fire-fighting equipment* and *monitor*.

pre-fire plan: plans for fire response developed for credible scenarios in support of a high-level incident preplan. They are supported by ERPs. See *credible scenario*, *incident preplan* and *emergency response plan (ERP)*.

preplanning: the process of demonstrating emergency preparedness by developing, maintaining and exercising incident preplans for major fire incidents. See *incident preplan*.

primary containment: equipment and facilities having direct contact with petroleum and its products (e.g. tanks and pipework), and their operation and management to prevent loss of containment. See *loss of containment* and *secondary containment*.

pyrophoric scale, deposits or material: usually finely divided ferrous sulphide formed inside a tank, pipeline or equipment, in the presence of mercaptans or hydrogen sulphide, but oxygen-depleted. It is capable of incandescence when its temperature or the surrounding oxygen concentration is increased. See *incandescence*.

qualitative risk assessment: methods of qualifying risk. A variety of scenario analysis tools are available including HAZAN, HAZID, HAZOP, and fire scenario analysis. See *risk* and *fire scenario analysis*.

quantified risk assessment (QRA): numerical methods of quantifying risk. See *risk*.

release: see *loss of containment*.

risk: the likelihood (product of incident frequency (or probability) and consequences) of human injury or adverse health, damage to property, business interruption or environmental impact from a hazard. See *hazard*, *individual risk*, *societal risk* and *as low as reasonably practicable (ALARP)*.

risk reduction measure/option: methods of reducing fire risk such as fire prevention measures, fire and heat detection, passive and active fire protection systems and incident response. Cost-effective risk reduction options can be selected depending on the results of a fire scenario analysis and a CBA. See *risk*, *fire detection*, *heat detection*, *passive fire protection (PFP)*, *active fire protection*, *fire scenario analysis* and *cost-benefit analysis (CBA)*.

safety report: documentation, usually required by a CA to demonstrate compliance with, and implementation of FEHM policy and other safety related requirements (e.g. under the COMAH Regulations) at larger petroleum installations. At smaller installations, a MAPP may suffice. See *competent authority (CA)*, *fire and explosion hazard management (FEHM), COMAH* and *major accident prevention policy (MAPP)*.

scenario analysis tools: methods such as QRA, HAZOP, fault tree analysis etc. that can be used to assist in fire scenario analysis. See *quantified risk assessment (QRA)* and *fire scenario analysis*.

scenario worksheet: documentation used as part of fire scenario analysis to qualify risk, existing and potential fire risk reduction measures and incident response. They are usually supplemented by calculation sheets for determination of FEHM resources and can form an auditable trail for inclusion in a safety report. See *fire scenario analysis*, *risk*, *risk reduction measures*, *fire and explosion hazard management (FEHM)* and *safety report*.

secondary containment: measures used to contain petroleum and its products in primary containment (e.g. tank high level alarms) and contingency provisions for losses of containment from primary containment. The latter may be in the form of a bund and bund walls, lagoon, diversionary walls or ditches to direct flow to a dispersion or impounding basin, or a drip tray. Secondary containment measures should also contain fire-fighting media applied during an emergency. See *loss of* *containment*, *primary containment*, *bund*, *bund walls*, *impounding basin* and *fire-fighting media*.

self-contained breathing apparatus (SCBA): BA that relies on air supplied by a single or double compressed air cylinder. It is the preferred type of BA for fire-fighting and rescue. See *breathing apparatus (BA)*.

semi-fixed system: a fixed fire protection system that requires some personnel intervention (e.g. the connection of foam lines to a foam inlet connection on a petroleum storage tank foam system) in order to function correctly. See *fixed system*.

semi-subsurface foam system: a foam system for storage tanks in which foam is injected into the tank from the base through a special hose. It is usually used for tanks containing water soluble products. See *foam*.

Seveso II Directive: European Communities Council Directive 96/82/EC on the Control of Major-Accident Hazards Involving Dangerous Substances, as amended.

site layout: the optimum layout and general design of a petroleum refinery or bulk storage installation with respect to fire safety, operational efficiency and environmental protection.

smoke detection: fire detection designed to warn of smouldering or flaming fires capable of generating smoke in their incipient or developing stages, and generate a fire alarm. See *fire detection*, *incipient detection* and *fire alarm*.

societal risk: risks to population groups as a whole. See *risk* and *individual risk*.

source of ignition (synonymous with ignition source): accessible source of heat or energy, electrical or non-electrical, capable of igniting a flammable atmosphere. See *flammable atmosphere* and *hot work*.

spontaneous ignition temperature: see *ignition temperature*.

sprinkler system: fixed multiple nozzle spray systems to enable water to be applied, for either cooling purposes or fire containment. They may be fitted with automatic activation systems. See *foam sprinkler/spray system*.

static electricity: the build-up of an electrical difference of potential or charge, through friction of dissimilar materials. See *earthing*.

subsurface foam system: a foam system for storage tanks in which foam is injected into the tank from the base. The foam travels upwards through the product to form a vapour-suppressing blanket over the entire surface. See *foam*.

thermal flux: the level of heat (thermal) radiation given off by a fire. Thermal radiation has the potential to cause damage to plant and equipment or injury to personnel.

toxicity: the capacity of substances to induce adverse health on reaching a susceptible site or sites on or within the body. Acute toxicity refers to effects occurring within a short period of time following exposure, whereas chronic toxicity refers to effects occurring after prolonged or repeated exposures.

turnout gear: fire responder PPE comprising:
— fire helmet with visor;
— fire coat;
— fire trousers;
— fire boots;
— fire gloves;
— SCBA.

See *personal protective equipment (PPE)*, *self-contained breathing apparatus (SCBA)*, *fire resistant treated [PPE]* and *inherently fire resistant [PPE]*.

unignited gas release: a loss of containment of petroleum or a petroleum product in the gaseous state which is close to, or has formed a flammable atmosphere, but has not ignited and has the potential to cause a VCE. See *loss of containment*, *flammable atmosphere* and *vapour cloud explosion (VCE)*.

upper flammable limit (UFL) (synonymous with upper explosive limit (UEL)): the highest concentration of flammable gas or vapour in air at atmospheric pressure capable of being ignited, expressed as percentage by volume. The term UFL is preferred to UEL. See *flammable*, *flammable limits* and *lower flammable limit (LFL)*.

vapour cloud explosion (VCE): an explosion resulting from the ignition of an unconfined or partially confined vapour cloud within its flammable limits. See *flammable limits*.

water mist system: a fire protection system producing very fine water droplets – most fewer than 400 μm diameter. It controls and extinguishes fires by wetting combustible materials, cooling, and to a certain extent, excluding oxygen. Minimal amounts of water are used in this type of system, but it should be highly engineered to be effective.

water spray system: a fire protection system consisting of fixed nozzles (designed to discharge water over plant or equipment) for the purposes of cooling against thermal flux*,* or, in some cases, for fire control. See *thermal flux*.

H.3 ABBREVIATIONS

ADR	European Agreement concerning the International Carriage of Dangerous Goods by Road.
AFFF	aqueous film forming foam.
AIT	autoignition temperature.
ALARP	as low as reasonably practicable.
AR [foam]	alcohol resistant [foam].
ATEX	explosive atmospheres [directives] (atmosphere explosiv).
BA	breathing apparatus.
BATNEEC	best available technology not exceeding excessive costs.
BLEVE	boiling liquid expanding vapour explosion.
CA	competent authority.
CBA	cost benefit analysis.
CCTV	closed circuit television.
CFD	computational fluid dynamics.
CO	carbon monoxide.
CO_2	carbon dioxide.
COMAH [Regulations]	Control of Major Accident Hazards [Regulations].
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations.
EA	Environment Agency.
EDP	electronic data processing.
EHSNI	Northern Ireland Environment and Heritage Service.
EHSR	essential health and safety requirements.
EN	European norm.
ERP	emergency response plan.
ERT	emergency response team.
ESD	emergency shutdown.
FEHM	fire and explosion hazard management.
FFFP [foam]	film forming fluoroprotein [foam].
FP [foam]	fluoroprotein [foam].
FRS	Fire and Rescue Service.
FSIA	fire systems integrity assurance.
HAZAN	hazard analysis study.
HAZID	hazard identification study.
HAZOP	hazard and operability study.
HSE	Health and Safety Executive.
HVAC	heating, ventilation and air conditioning.
IBC	intermediate bulk container.
IR	infrared.
ISGOTT	International safety guide for oil tankers and terminals.
JOIFF	Joint Oil and Industry Fire Forum.
l/min.	litres per minute.
l/min./m^2	litres per minute, per square metre.
LASTFIRE [project]	large atmospheric storage tank fires [project].
LFL	lower flammable limit.
LHD	linear heat detection.
LNG	liquefied natural gas.
LPG	liquefied petroleum gas.
MAPP	major accident prevention policy.
MCC	motor control centre.
MP [foam]	multi-purpose [foam].
NOS	national occupation standards.
PDA	pre-determined attendance.
PFOS	perfluorooctane sulfonates.
PFP	passive fire protection.
PPE	personal protective equipment.
PPM	pre-planned maintenance.
PRV	pressure relief valve.
PTO	power take off.
PTW	permit-to-work.
QRA	quantified risk assessment.
RID	Regulations covering the International Carriage of Dangerous Goods by Rail.
RRO	Regulatory Reform (Fire Safety) Order.
SCBA	self-contained breathing apparatus.
SD [foam]	synthetic detergent [foam]. See *Syndet*.
SEPA	Scottish Environment Protection Agency.
SHEMS	safety, health and environment management system.
Syndet [foam]	synthetic detergent [foam]. See *SD*.
UFL	upper flammable limit.
UV	ultraviolet.
VCE	vapour cloud explosion.

ANNEX I

REFERENCES, BIBLIOGRAPHY AND FURTHER INFORMATION

I.1 INTRODUCTION

The information provided in this annex is divided into: references to publications that are referred to in IP 19; bibliographies that provide listings of further publications not specifically referred to in IP 19; and other information sources such as Internet sites. All were current at the time of its writing. Users should consult the pertinent organisations for details of the latest versions of publications. To assist, contact details are provided.

Generally, in terms of the provision of risk reduction measures, once it is decided to implement a certain measure, a great deal of information is available; some is general in nature, whereas others address specific FEHM issues. To assist users, key publishers of FEHM publications are summarised in I.2.

Regulators may recognise some publications as providing a benchmark of good practice, which if complied with can contribute to the demonstration of regulatory compliance.

I.2 KEY PUBLISHERS OF FEHM PUBLICATIONS

The most relevant, internationally recognised FEHM publications (e.g. codes of practice, design standards, specifications, guidance, etc.) pertinent to this publication are published by the following European-based organisations:

- Chemical Industries Association (CIA);
- Engineering Equipment and Materials Users Association (EEMUA);
- Environment agencies (EA/SEPA/EHSNI);
- Fire Protection Association (FPA);
- Health and Safety Commission (HSC)/Health and Safety Executive (HSE) (published by HSE Books);
- Home Office (HO);
- International Association of Oil and Gas Producers (OGP);
- IP (published by Energy Institute (EI));
- RPI *LASTFIRE*.

The following non-European-based organisations are internationally recognised and offer a wealth of publications on FEHM issues:

- API;
- ASME;
- National Fire Protection Association (NFPA).

In addition, many national standards organisations such as the British Standards Institution (BSI) and the International Standards Organisation (ISO) publish specific standards and specifications.

In the UK, the HSE publishes ACoPs and guidance to advise duty holders on health and safety issues in support of pertinent regulations.

Lists of the most useful publications from these and other organisations are given in I.3.

I.3 CODES OF PRACTICE, DESIGN STANDARDS, SPECIFICATIONS, GUIDANCE, ETC.

I.3.1 European

British Fire Protection Systems Association (BFPSA)
http://www.bfpsa.org.uk

References
- Code of practice for category one aspirating detection systems
- Code of practice for gaseous fire fighting systems

British Standards Institution (BSI)
http://www.bsi-global.com

References
- BS 476: Fire tests on building materials and structures (in several parts)
- BS 5306: Fire extinguishing installations and equipment on premises
  - Part 4: Specification for carbon dioxide systems
  - Part 6: Foam systems (in two parts)
- BS 5839: Fire detection and alarm systems for buildings
  - Part 1: Code of practice for system design, installation, commissioning and maintenance
- BS 6266: Code of practice for fire protection of electronic equipment installations
- BS EN 2: Classification of fires
- BS EN 3: Portable fire extinguishers (in several parts)
  - Part 7: Characteristics, performance requirements and test methods
- BS EN 54: Fire detection and fire alarm systems (in several parts)
- BS EN 137: Specification for respiratory protective devices: self-contained open-circuit compressed air breathing apparatus
- BS EN 12845: Fixed firefighting systems. Automatic sprinkler systems. Design, installation and maintenance
- BS EN 14015: Specification for the design and manufacture of site built, vertical, cylindrical, flat-bottomed, above ground, welded, steel tanks for the storage of liquids at ambient temperature and above
- BS EN 50073: Guide for selection, installation, use and maintenance of apparatus for the detection and measurement of combustible gases or oxygen
- BS EN 61779: Electrical apparatus for the detection and measurement of flammable gases
  - Part 1: General requirements and test methods
- BS ISO 14520: Gaseous fire-extinguishing systems (in several parts)
- prEN 13565-2: Fixed firefighting systems. Foam systems

Bibliography
- BS 2000: Methods of test for petroleum and its products (in several parts)
- BS 2050: Specification for electrical resistance of conducting and antistatic products made from flexible polymeric material
- BS 2594: Specification for carbon steel welded horizontal cylindrical storage tanks
- BS 3492: Specification for road and rail tanker hose assemblies for petroleum products, including aviation products
- BS 5041: Fire hydrant systems equipment
  - Part 1: Specification for landing valves for wet risers
  - Part 2: Specification for landing valves for dry risers
  - Part 3: Specification for inlet breachings for dry riser inlets
  - Part 4: Specification for boxes landing valves for dry risers
  - Part 5: Specification for boxes for foam inlets and dry riser inlets
- BS 5306: Fire extinguishing installations and equipment on premises
  - Part 0: Guide for the selection of installed systems and other fire equipment
  - Part 1: Hydrant systems, hose reels and foam inlets
  - Part 2: Specification for sprinkler systems
  - Part 3: Code of practice for the inspection and maintenance of portable fire extinguishers
  - Part 8: Selection and installation of portable fire extinguishers
- BS 5499: Graphical symbols and signs. Safety signs, including fire safety signs. Specification for geometric shapes, colours and layout
- BS 5970: Code of practice for thermal insulation of pipework and equipment (in the temperature range −100 °C to +870 °C)
- BS 6150: Code of practice for painting of buildings
- BS 7430: Code of practice for earthing
- BS 7777: Flat-bottomed, vertical, cylindrical storage tanks for low temperature service (in several parts)
- BS 7944: Type 1 heavy duty fire blankets and type 2 heavy-duty heat protective blankets
- BS EN 340: Protective clothing. General requirements

- BS EN 420: General requirements for gloves
- BS EN 469: Requirements and test methods for protective clothing for firefighting. Protective clothing for firefighters. Performance requirements for protective clothing for firefighting
- BS EN 531: Protective clothing for workers exposed to heat
- BS EN 659: Protective gloves for firefighters
- BS EN 1869: Fire blankets
- BS EN 12266: Industrial valves. Testing of valves. Pressure tests, test procedures and acceptance criteria (in two parts)
- BS EN 12416: Fixed fire fighting systems. Powder systems.
  - Part 2: Design, construction and maintenance
- BS EN 14605: Protective clothing against liquid chemicals. Performance requirements for clothing with liquid-tight (type 3) or spray-tight (type 4) connections, including items providing protection to parts of the body only (types PB [3] and PB [4])
- BS EN 50015: Electrical apparatus for potentially explosive atmospheres. Oil immersion 'o'
- BS EN 50017: Electrical apparatus for potentially explosive atmospheres. Powder filling 'q'
- BS EN 50020: Electrical apparatus for potentially explosive atmospheres. Intrinsic safety 'i'
- BS EN 60079: Electrical apparatus for potentially explosive atmospheres
  - Part 1: Flameproof enclosure 'd'
- BS EN ISO 4126: Safety devices for protection against excessive pressure
  - Part 1: Safety valves
- BS EN ISO 12944: Paints and varnishes. Corrosion protection of steel structures by protective paint systems (in several parts)
- BS EN ISO 20344: Personal protective equipment. Test methods for footwear
- BS EN ISO 20345: Personal protective equipment. Safety footwear
- PD CLC/TR 50404: Electrostatics. Code of practice for the avoidance of hazards due to static electricity

Chemical Industries Association (CIA)
http://www.cia.org.uk

References
- Guidance for the location and design of occupied buildings on chemical manufacturing sites

Bibliography
- Risk – Its assessment, control and management
- Warehouse fire safety – Guidance on chemical warehouse fire safety: Key questions for managers concerned with the protection of warehouses against fire

CIRIA/Environment Agency (CIRIA/EA)
http://www.environment-agency.gov.uk

Bibliography
- Concrete bunds for oil storage tanks
- Masonry bunds for oil storage tanks

Engineering Equipment and Materials Users Association (EEMUA)
http://www.eemua.co.uk

Bibliography
- 147: Recommendations for the design and construction of refrigerated liquefied gas storage tanks
- 155: Standard test method for comparative performance of flammable gas detectors against poisoning
- 159: Users' guide to the maintenance and inspection of above ground vertical cylindrical steel storage tanks
- 180: Guide for designers and users on frangible roof joints for fixed roof storage tanks
- 181: A guide to risk based assessments of *in-situ* large EX 'e' and EX 'N' machines
- 186: A practitioner's handbook - Electrical installation and maintenance in potentially explosive atmospheres
- 190: Guide for the design, construction and use of mounded horizontal cylindrical vessels for pressurised storage of LPG at ambient temperatures
- 191: Alarm systems – A guide to design, management and procurement
- 193: Recommendations for the training, development and competency assessment of inspection personnel

Environment agencies (EA/SEPA/EHSNI)
http://www.environment-agency.gov.uk

Pollution prevention guidance notes:
http://www.environment-agency.gov.uk/ppg

Bibliography
- PPG 02: Above-ground oil storage
- PPG 03: The use and design of oil separators
- PPG 18: Managing fire water and major spillages
- PPG 27: Installation, decommissioning and removal of underground storage tanks

Environment Agency (EA)
http://www.environment-agency.gov.uk

References
— Environmental impact of controlled burns, EA Technical report SP2-081-TS-E-E

European Communities (EC)
http://europa.eu.int/index-en.htm

Directives:

References
— Approximation of the Laws of Member States concerning Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres 94/9/EC (ATEX Equipment Directive) OJ L 100, 19.4.1994
— Council Directive 89/391/EEC of 12 June 1989 on the Introduction of Measures to Encourage Improvements in the Safety and Health of Workers at Work (Framework Directive) OJ L 183, 29.6.1989, pp 1–8
— Council Directive 98/24/EC of 7 April 1998 on the Protection of the Health and Safety of Workers from the Risks related to Chemical Agents at Work (Chemical Agents Directive) OJ L 131, 5.5.1998, pp 11–23
— Directive 2003/105/EC of the European Parliament and of the Council of 16 December 2003 amending Council Directive 96/82/EC on the Control of Major-Accident Hazards involving Dangerous Substances OJ L 345, 31.12.2003, pp 97–105
— Directive on the Minimum Requirements for Improving the Health and Safety of Workers Potentially at Risk from Explosive Atmospheres 99/92/EC (ATEX Workplace Directive) OJ L 23, 57, 28.1.2001
— European Communities Council Directive 96/82/EC on the Control of Major-Accident Hazards Involving Dangerous Substances (Seveso II Directive) OJ L 10, 14.1.1997, pp. 13–33

Internet sites:

References
— ATEX guidelines
http://europa.eu.int/comm/enterprise/atex/guide

Fire Protection Association (FPA)
http://www.thefpa.co.uk

Bibliography
The FPA offers a wide selection of publications, guidance and design standards relating to fire protection in buildings and the process industries

Health and Safety Commission (HSC) (published by HSE Books)
http://www.hsebooks.com

Legal (Approved codes of practice):

References
— L134: Design of plant, equipment and workplaces. Dangerous Substances and Explosive Atmospheres Regulations 2002. Approved code of practice and guidance
— L135: Storage of dangerous substances. Dangerous Substances and Explosive Atmospheres Regulations 2002. Approved code of practice and guidance
— L136: Control and mitigation measures. Dangerous Substances and Explosive Atmospheres Regulations 2002. Approved code of practice and guidance
— L137: Safe maintenance, repair and cleaning procedures. Dangerous Substances and Explosive Atmospheres Regulations 2002. Approved code of practice and guidance
— L138: Dangerous Substances and Explosive Atmospheres. Dangerous Substances and Explosive Atmospheres Regulations 2002. Approved code of practice and guidance

Bibliography
— L5: Control of Substances Hazardous to Health: The Control of Substances Hazardous to Health Regulations 2002. Approved codes of practice and guidance
— L111: A Guide to the Control of Major Accident Hazards Regulations 1999 (as amended). Guidance on regulations

Health and Safety Executive (published by HSE Books)
http://www.hsebooks.com

Guidance:

References
— HSG 51: The storage of flammable liquids in containers
— HSG 176: Storage of flammable liquids in tanks
— HSG 250: Guidance on permit-to-work systems: A guide for the petroleum, chemical and allied industries

Bibliography
— HSG 65: Successful health and safety management

— HSG 71: Chemical warehousing – The storage of packaged dangerous substances
— HSG 140: Safe use and handling of flammable liquids
— HSG 158: Flame arresters – Preventing the spread of fires and explosions in equipment that contains flammable gases and vapours
— HSG 178: The spraying of flammable liquids
— HSG 186: The bulk transfer of dangerous liquids and gases between ship and shore
— HSG 190: Preparing safety reports: Control of Major Accidents Hazards Regulations 1999
— HSG 191: Emergency planning for major accidents
— HSG 228: CHIP for everyone

Internet sites:

References
— ATEX and DSEAR frequently asked questions http://www.hse.gov.uk/electricity/atex/index.htm

Miscellaneous:

References
— CHIS 2: Emergency isolation of process plant in the chemical industry
— Reducing risks, protecting people

Bibliography
— INDG 136: COSHH: A brief guide to the regulations
— INDG 254: Chemical reaction hazards and the risk of thermal runaway

Regulations:

Bibliography
— HS(R)27: A guide to Dangerous Substances in Harbour Areas Regulations 1987
— HS(R)29: Notification and Marking of Sites. The Dangerous Substances (Notification and Marking of Sites) Regulations 1990: Guidance on regulations

Research reports:

References
— OTI 92 606: Passive fire protection: Performance requirements and test methods
— OTI 92 607: Availability and properties of passive and active fire protection systems
— OTI 95 634: Jet fire resistance test of passive fire protection materials
— RR025: Application of QRA in operational safety issues

Bibliography
— CRR 137/1997: Efficacy of water spray protection against jet fires impinging on LPG storage tanks

Home Office (HO) (published by Her Majesty's Stationery Office)
http://www.opsi.gov.uk

Bibliography
— Code of practice for fire precautions in factories, offices, shops and railway premises not required to have a fire certificate (exempted premises)
— Fire Prevention Note 1/70
— Guide to fire precautions in existing places of work that require a fire certificate
— Guide to The Fire Precautions Act 1971: Factories, offices, shops and railway premises: fire safety at work
— Manual of firemanship. A survey of the science of fire-fighting. Book 2 Fire service equipment

Home Office (HO) (published by The Stationery Office)
http://www.tso.co.uk

References
— Dynamic management of risk at operational incidents
— Breathing apparatus: Command and control procedures. Technical Bulletin 1/97

Bibliography
— Manual of firemanship. A survey of the science of fire-fighting. Book 6 Breathing apparatus and resuscitation
— Manual of firemanship. A survey of the science of fire-fighting. Book 7 Hydraulics, pumps and pump operation
— Petroleum (Consolidation) Act 1928 model code of principles of construction and licensing conditions. Part 2 For distributing depots and major installation

Integrated Personal Development System (IPDS)
http://www.ipds.co.uk

References
— National occupational standards

IP (published by Energy Institute)
http://www.energyinst.org.uk

Model codes of safe practice in the petroleum industry:

References
— Part 1: Electrical safety code
— Part 15: Area classification code for installations handling flammable fluids
— Part 21: Guidelines for the control of hazards arising from static electricity

Bibliography
— Part 2: Design, construction and operation of petroleum distribution installations
— Part 9: Liquefied petroleum gas. Vol.1 Large bulk pressure storage and refrigerated LPG

Other publications:

References
— Guidelines for the design and protection of pressure systems to withstand severe fires

Standards for testing and sampling:

References

— IP 34: Determination of flash point – Pensky-Martens closed cup method. (Technically identical to BS 2000/34, BS EN ISO 2719.)
— IP 170: Determination of flash point – Abel closed cup method. (Technically identical to BS 2000/170, BS EN ISO 13736)

RPI *LASTFIRE*
http://www.resprotint.co.uk/LASTFIRE%20Project.htm

References
The large atmospheric storage tank fires (LASTFIRE) project is a joint petroleum industry initiative to review the risks associated with large atmospheric storage tank fires. Over 20 major international petroleum companies have been involved. The LASTFIRE project has, from a comprehensive and independent review of the risks associated with large storage tanks and associated risk reduction options, provided a methodology by which duty holders can select appropriate and justified measures to reduce fire related risk to ALARP for storage installations. The project co-ordinators, Resource Protection International (RPI) can offer the following project deliverables:
1. Incident frequency survey report
2. Risk reduction options review
3. Fire-fighting foam review
4. Risk workbook
5. Lightning study
6. Foam fire test specification for storage tank fires

Items 1-4 above are included in the main RPI *LASTFIRE* Report, and a number of other deliverables are available.

Office of Public Sector Information (OPSI)
http://www.opsi.gov.uk

References
— Fire Precautions Act 1971
— Fire (Scotland) Act 2005 (2005 asp5)
— Health and Safety at Work etc. Act 1974
— Petroleum (Consolidation) Act 1928
— The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2004 (SI 2004/568)
— The Confined Spaces Regulations 1997 (SI 1997/1713)
— The Control of Major Accident Hazard Regulations 1999 (SI 1999/743)
— The Control of Major Accident Hazards (Amendment) Regulations 2005 (SI 2005/1088)
— The Dangerous Substances and Explosive Atmospheres Regulations 2002 (SI 2002/2776)
— The Dangerous Substances in Harbour Areas Regulations 1987 (SI 1996/37)
— The Equipment and Protective Systems for use in Potentially Explosive Atmospheres Regulations 1996 (SI 1996/192)
— The Equipment and Protective Systems for use in Potentially Explosive Atmospheres (Amendment) Regulations 2001 (SI 2001/3766)
— The Fire Certificates (Special Premises) Regulations 1976 (SI 1976/2003)
— The Fire Precautions (Workplace) (Amendment) Regulations 1999 (SI 1999/1877)
— The Fire Precautions (Workplace) Regulations (SI 1997/1840)
— The Hazardous Waste (England and Wales) Regulations 2005 (SI 2005/831)
— The Management of Health and Safety at Work Regulations 1999 (SI 1999/3242)
— The Notification of Installations Handling Hazardous Substances (Amendment) Regulations 2002 (SI 2002/2979)
— The Regulatory Reform (Fire Safety) Order 2005/SI 2005/1541)
— The Special Waste Regulations 1996 (SI 1996/972)
— The Special Waste Amendment (Scotland) Regulations 2004 (SSI 2004/204)

The Stationery Office (TSO)
http://www.tso.co.uk

References
— Building Regulations Approved Document B – Fire safety

Underwriters Laboratories International (UK) Ltd (UL)
http://www.ul.com

References
— UL 162: Standard for safety foam equipment and liquid concentrates

United Nations Economic Commission for Europe (UNECE)
http://www.unece.org

References
— European Agreement concerning the International Carriage of Dangerous Goods by Road 2003 (ADR)
— Regulations covering the International Carriage of Dangerous Goods by Rail 2003 (RID)

I.3.2 Non-European

API
http://www.api.org

Publications:

Bibliography
— Pub 2021: Guide for fighting fires in and around petroleum storage tanks
— Pub 2026: Safe access/egress involving floating roofs of storage tanks in petroleum service
— Pub 2030: Application of water spray systems for fire protection in the petroleum industry
— Pub 2201: Procedures for welding or hot tapping on equipment in service
— Pub 2214: Spark ignition properties of hand tools
— Pub 2216: Ignition risk of hydrocarbon vapours by hot surfaces in the open air
— Pub 2218: Fireproofing practices in petroleum and petrochemical processing plants
— Pub 2510A: Fire protection considerations for the design and operation of liquefied petroleum gas (LPG) storage facilities

Recommended practices:

References
— RP 2021: Management of atmospheric storage tank fires

Bibliography
— RP 520: Sizing, selection and installation of pressure relieving devices in refineries
  – Part 1 sizing and selection
— RP 521: Guide for pressure relieving and depressurising systems
— RP 752: Management of hazards associated with location of process plant buildings
— RP 2001: Fire protection in refineries
— RP 2003: Protection against ignitions arising out of static, lightning and stray currents
— RP 2009: Safe welding, cutting and hot work practices in the petroleum and petrochemical industries
— RP 2027: Ignition hazards involved in abrasive blasting of atmospheric storage tanks in hydrocarbon service
— RP 2028: Flame arrestors in piping systems
— RP 2210: Flame arrestors for vents of tanks storing petroleum products

Standards:

References
— 650: Welded steel tanks for oil storage

ASME
http://www.asme.org

Bibliography
— Fire and explosions – Recent advances in modelling and analysis
— Management of fire and explosion
— Materials and design against fire
— Fire induced stresses in tanks containing liquefied gas. ASME Pressure Vessels and Piping conference, June 1974

International Chamber of Shipping/ Oil Companies International Marine Forum/ International Association of Ports and Harbours (ICS/OCIMF/IAPH) (published by Witherbys)
http://www.witherbys.com

References
— International safety guide for oil tankers and terminals (ISGOTT)

International Association of Oil and Gas Producers (OGP)
http://www.ogp.org.uk

References
— Fire systems integrity assurance (Publication 304)

National Fire Protection Association (NFPA)
http://www.nfpa.org

References
- Fire protection guide to hazardous materials
- NFPA 11: Low-, medium-, and high-expansion foam systems
- NFPA 12: Carbon dioxide extinguishing systems
- NFPA 13: Installation of sprinkler systems
- NFPA 15: Water spray fixed systems for fire protection
- NFPA 16: Installation of foam-water sprinkler and foam-water spray systems
- NFPA 17: Standard for dry chemical extinguishing systems
- NFPA 72: National fire alarm code®
- NFPA 75: Standard for the protection of electronic computer/data processing equipment
- NFPA 497: Classification of flammable liquids, gases or vapours and of hazardous (classified) locations for electrical installation in chemical process areas
- NFPA 600: Standard on industrial fire brigades
- NFPA 750: Water mist fire protection systems
- NFPA 780: Standard for the installation of lightning protection systems
- NFPA 1971: Standard on protective ensemble for structural fire fighting
- NFPA 2001: Clean agent fire extinguishing systems

Bibliography
- NFPA 10: Portable fire extinguishers
- NFPA 14: Installation of standpipe and hose systems
- NFPA 20: Installation of stationary pumps for fire protection
- NFPA 24: Installation of private fire service mains and their appurtenances
- NFPA 30: Flammable and combustible liquid code
- NFPA 45: Fire protection for laboratories using chemicals
- NFPA 58: Liquefied petroleum gas code

I.4 INDUSTRY ORGANISATIONS

Association for Specialist Fire Protection (ASFP)
Association House, 235 Ash Road, Aldershot, Hampshire, GU12 4DD, UK
t: +44 (0) 1252 321322
f: +44 (0) 1252 333901
e: info@associationhouse.org.uk
w: http://www.asfp.org.uk

British Fire Protection Systems Association (BFPSA)
Neville House, 55 Eden St., Kingston upon Thames, Surrey, KT1 1BW, UK
t: 020 8549 5855
f: 020 8547 1564
e: bfpsa@abft.org.uk
w: http://www.bfpsa.org.uk

British Safety Industry Federation (BSIF)
93 Bowen Court, St Asaph Business Park, Glascoed Road, St Asaph, Clwyd, LL17 0JE, UK
t: +44 (0) 1745 585600
f: +44 (0)1745 585800
e: b.s.i.f@virgin.net
w: http://www.bsif.co.uk

Chemical Industries Association (CIA)
Kings Buildings, Smith Square, London, SW1P 3JJ, UK
t: +44 (0) 20 7963 6738
f: +44 (0) 20 7834 8586
e: enquiries@cia.org.uk
w: http://www.cia.org.uk

Engineering Equipment and Materials Users Association (EEMUA)
10-12 Lovat Lane, London, EC3R 8DN, UK
t: +44 (0) 20 7621 0011.
f: +44 (0) 20 7621 0022.
e: info@eemua.org
w: http://www.eemua.org

Energy Institute (EI)
61 New Cavendish Street, London W1G 7AR, UK
t: +44 (0) 20 7467 7100
f: +44 (0) 20 7255 1472
e: info@energyinst.org.uk
w: http://www.energyinst.org.uk

European Process Safety Centre (EPSC)
165-189 Railway Terrace, Rugby, Warwickshire, CV21 3HQ, UK
t: +44 (0) 1788 534409
f: +44 (0) 1788 551542
e: lallford-epsc@icheme.org.uk
w: http://www.epsc.org

Fire Extinguishing Trades Association (FETA)
Neville House, 55 Eden St., Kingston upon Thames, Surrey, KT1 1BW, UK
t: +44 (0) 8549 8839
f: +44 (0) 8547 1564
e: feta@abft.org.uk
w: http://www.feta.org.uk

Fire Industry Confederation (FIC)
Neville House, 55 Eden Street, Kingston-upon-Thames, Surrey, KT1 1BW, UK
t: +44 (0) 20 8549 8839
f: +44 (0) 8547 1564
e: Fic@abft.org.uk
w: http://www.the-fic.org.uk

Institution of Chemical Engineers (IChemE)
Davis Building, 165-189 Railway Terrace, Rugby, Warwickshire, CV21 3HQ, UK
t: +44 (0) 1788 578214
f: +44 (0) 1788 560833
e: icheme@icheme.org
w: http://www.icheme.org.uk

Institution of Engineering and Technology (IET)
Savoy Place, London WC2R 0BL, UK
t: +44 (0) 20 7240 1871
f: +44 (0) 20 7240 7735
e: postmaster@theiet.org.uk
w: http://www.theiet.org

Institution of Fire Engineers (IFE)
London Road, Moreton in Marsh, Gloucestershire, GL56 0RH, UK
t: +44 (0) 1608 812 580
f: +44 (0) 1608 812 581
e: info@ife.org.uk
w: http://www.ife.org.uk

Institution of Mechanical Engineers (IMechE)
1 Birdcage Walk, London SW1H 9JJ, UK
t: +44 (0) 207 222 7899
f: +44 (0) 207 222 4557
e: enquiries@imeche.org.uk
w: http://www.imech.org.uk

LASTFIRE Group
Project Coordinators, Resource Protection International, Lloyd Berkeley Place, Pebble Lane, Aylesbury, Buckinghamshire, HP20 2JH, UK
t: +44 (0) 1296 399311
f: +44 (0) 1296 395669
e: ramsden@resprotint.co.uk
w: http://www.resprotint.co.uk

LP Gas Association (LPGA)
Pavilion 16, Headlands Business Park, Salisbury Road, Ringwood, Hampshire BH24 3PB, UK
e: mail@lpga.co.uk
w: http://www.lpga.co.uk

Oil Companies International Marine Forum (OCIMF)
27 Queen Anne's Gate, London, SW1H 9BU, UK
t: +44 (0) 20 7654 1200
f: +44 (0) 20 7654 1205
e: enquiries@ocimf.com
w: http://www.ocimf.com

Society of International Gas Tankers and Terminal Operators (SIGTTO)
17 St. Helens Place, London, EC3A 6DG, UK
t: +44 (0) 20 7628 1124
f: +44 (0) 20 7628 3163
e: secretariat@sigtto.org
w: http://www.sigtto.org

UK Petroleum Industry Association Limited (UKPIA)
9 Kingsway, London, WC2B 6XH, UK
t: +44 (0) 20 7240 0289
f: +44 (0) 20 7379 3102
e: info@ukpia.com
w: http://www.ukpia.com

I.5 OTHER SAFETY ORGANISATIONS

Chemical Hazards Communication Society (CHCS)
P.O. Box 222, Lymington, Hampshire, SO42 7GY, UK
t: +44 (0) 7000 790 337
f: +44 (0) 7000 790 338
e: CHCS@CHCS.org.uk
w: http://www.chcs.org.uk

European Fire and Safety Group (EFSG)
Secretariat c/o VdS (Ms Gabriele Späth), Amsterdamerstrasse 174, D-50735 Köln, Germany
t: + 49 221 7766 375
f: + 49 221 7766 377
e: info@efsg.org
w: http://www.efsg.org

Fire Protection Association (FPA)
London Road, Moreton in Marsh, Gloucestershire, GL56 0RH, UK
t: +44 (0) 1608 812 500
f: +44 (0) 1608 812 501
e: fpa@thefpa.co.uk
w: http://www.thefpa.co.uk

Fire Safety Engineering Group (FSEG)
University of Greenwich, 30 Park Row, Greenwich, London, SE10 9LS, UK
t: +44 (0) 20 8331 8730
f: +44 (0) 20 8331 8925
e: e.r.galea@greenwich.ac.uk
w: http://fseg.gre.ac.uk

Health and Safety Executive (HSE)
Rose Court, 2 Southwark Bridge, London, SE1 9HS, UK
t: +44 (0) 20 7717 6000 or +44 (0) 845 345 0055
f: +44 (0) 20 7717 6717

Redgrave Court, Merton Road, Bootle, Merseyside, L20 7HS, UK
t: +44 (0) 151 951 4000 or +44 (0) 845 345 0055
f: +44 (0) 151 922 5394
e: hse.infoline@natbrit.com
w: http://www.hse.gov.uk

International Maritime Organisation (IMO)
4 Albert Embankment, London, SE1 7SR, UK
t: + 44 (0) 20 7735 7611
f: +44 (0)20 7587 3210
w: http://www.imo.org

Institution of Occupational Safety and Health (IOSH)
The Grange, Highfield Drive, Wigston, Leicestershire, LE18 1NN, UK
t: +44 (0) 116 257 3100
f: +44 (0) 116 257 3101
e: enquiries@iosh.co.uk
w: http://www.iosh.co.uk

Institute of Risk Management (IRM)
Lloyds Avenue House, 6 Lloyds Avenue, London, EC3N 3AX, UK
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f: +44 (0) 20 7709 0716
e: office@theirm.org
w: http://www.theirm.org

International Institute of Risk and Safety Management (IIRSM)
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w: http://www.iirsm.org

Joint Oil and Industry Fire Forum (JOIFF)
JOIFF Secretariat, Fulcrum Consultants, GD House, Tallaght Business Park, Dublin 24, Ireland
t: + 353 (0)1 4137300
f: +353 (0)1 4137301
e: info@gdgroup.ie
w: http://www.joiff.com

I.6 STANDARDS AND APPROVALS ORGANISATIONS

British Standards Institution (BSI)
389 Chiswick High Road, London, W4 4AL, UK
t: +44 (0)20 8996 9000
f: +44 (0)20 8996 7001
e: cservices@bsi-global.com
w: http://www.bsi-global.com

Building Research Establishment (BRE)
Garston, Watford, Hertfordshire, WD25 9XX, UK
t: +44 (0) 1923 664000
f: +44 (0) 1923 664010
e: enquiries@bre.co.uk
w: http://www.bre.co.uk

Comité Européen de Normalisation (CEN)
European Committee for Standardisation, 36 rue de Stassart, B-1050 Brussels, Belgium
t: + 32 2 5500811
f: + 32 2 5500819
e: infodesk@cenorm.be
w: http://www.cenorm.be

Comité Européen de Normalisation Electrotechnique (CENELEC)
European Committee for Electrotechnical Standardisation, 35 rue de Stassart, B-1050 Brussels, Belgium
t: + 32 2 5196871
f: + 32 2 5196919
e: info@cenelec.org
w: http://www.cenelec.org

Det Norske Veritas (DNV)
Palace House, 3 Cathedral Street, London, SE1 9DE, UK
t: +44 (0) 20 7716 6518
f: +44 (0) 20 7716 6739
e: certificationuk@dnv.com
w: http://www.dnv.co.uk/certification/

Factory Mutual (FM)
FM Insurance Company Limited, 52 Leadenhall Street, London, EC3A 2BJ, UK
t: +44 (0) 20 7480 4000
f: +44 (0) 20 7488 2555
w: http://www.fmglobal.com

International Organisation for Standardisation (ISO)
1, rue de Varembé, Case postale 56, CH-1211 Geneva 20, Switzerland
t: +41 22 7490111
f: +41 22 7333430
w: http://www.iso.org

Loss Prevention Certification Board (LPCB)
BRE Certification Ltd., Garston, Watford, Hertfordshire, WD25 9XX, UK
t: +44 (0)1923 664100
f: +44 (0)1923 664603
e: enquiries@brecertification.co.uk
w: http://www.bre.co.uk, http://www.brecertification.co.uk

UL International (UK) Ltd (UL)
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f: +44 (0) 1483 302 230
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w: http://www.ul.com/uk

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